BOOK ABSTRACTS

International Workshop on Radiation Imaging Detectors
3 - 7 July 2016
Barcelona, Spain.
Local Organizing Committee

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IFAE

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IMB-CNM

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Bernd Schmitt, PSI, Switzerland
Val O´Shea, University of Glasgow, United Kingdom
The International Workshops on Radiation Imaging Detectors are held yearly and provide an international forum for discussing current research and developments in the area of position sensitive detectors for radiation imaging, including semiconductor, gas and scintillator-based detectors. Topics include processing and characterization of detector materials, hybridization and interconnect technologies, design of counting or integrating electronics, readout and data acquisition systems, and applications in various scientific and industrial fields. The workshop will have plenary sessions with invited and contributed papers presented orally and in poster sessions. The invited talks will be chosen to review recent advances in different areas covered in the workshop.
Scientific Programme

Monday, 4 July

8:00-9:15
Registration

9:15-9:30
Welcome Talk

9:30-9:50
Resistive Micromegas for the Muon Spectrometer Upgrade of the ATLAS Experiment
Alan Peyaud, ATLAS Muon Collaboration

9:50-10:10
Imaging in (high pressure) MicroMegas based TPC detectors
Gloria Luzón, Universidad de Zaragoza

10:10-10:30
Development of a high rate TPC – GEM foil quality assurance for the ALICE TPC upgrade
Markus Ball, Helmholtz Institut für Strahlen- und Kernphysik (HISKP)

Coffee Break

11:00-11:20
The Liquid Hole-Multiplier: a novel local dual-phase element for noble-liquid TPCs
Lior Arazi, Department of Particle Physics and Astrophysics, Weizmann Institute of Science

11:20-11:40
Towards spark-proof gaseous-pixel detectors for precise particle tracking
Stergios Tsigaridas, Delft University of Technology, Delft, The Netherlands

11:40-12:00
Application of GEM-based detectors in full-field XRF imaging
Władysław Dabrowski, AGH University of Science and Technology, Faculty of Physics and Applied Computer Science, Krakow, Poland

12:00-12:30
Single photons, single plasmons, single molecules
Niek F. van Hulst, ICFO-the Institute of Photonic Sciences

12:30-12:50
2D (Graphene)-Quantum dot Hybrid photodetector technology for CMOS compatible high performance photodetectors from the UV to Short-wave Infrared
Frank Koppens, ICFO-the Institute of Photonic Sciences

Lunch Break

14:10-14:40
Micro-Pattern Gas Detector Technologies for Physics Projects at the Energy, Intensity and Cosmic Frontiers
Maxim Titov, CEA Saclay, Irfu

14:40-15:00
The GAP-TPC
Biagio Rossi, Princeton Univeristy

15:00-15:20
Prototype of core-shell diode array for high performance particle detectors & imaging sensors
Guobin Jia, Leibniz Institute of Photonic Technology

15:20-15:40
The Tynode: a new vacuum electron multiplier for ultra fast pixelised particle detectors
Harry van der Graaf, the MEMBrane group
15:40-16:00
**Light-Trap: A SiPM Upgrade for VHE Astronomy and Beyond**
John E. Ward, IFAE-BIST

**Coffee Break + Poster**

17:30-17:50
**Characterisation of HV-CMOS sensors for the ATLAS upgrade**
Dima Maneuski, University of Glasgow

17:50-18:10
**CdZnTe position-sensitive drift gamma-ray detectors**
Aleksey Bolotnikov, Brookhaven National Laboratory

18:10-18:30
**Silicon pixel-detector R&D for CLIC**
Magdalena Munker, CERN

18:30-18:50
**The LHCb VELO Upgrade**
Pablo Vazquez, IGFAE / Universidade de Santiago de Compostela

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**Scientific Programme**

**Tuesday, 5 July**

9:00-9:20
**Development and Performance Evaluation of a High-Resolution APD-Based Pixelated Detector FrontEnd for Pre-Clinical PET Imaging**
Mélanie Bergeron, Université de Sherbrooke, Sherbrooke, Québec, Canada

9:20-9:40
**PRaVDA: Fully solid-state proton CT and dosimetry system for Proton Therapy**
Nigel Allinson, University of Lincoln, UK

9:40-10:00
**Asymmetric masks for large field-of-view and high-energy X-ray phase contrast imaging**
Marco Endrizzi, Department of Medical Physics and Biomedical Engineering, University College London, Gower Street, London WC1E 6BT, UK

10:00-10:20
**First results of the INSIDE in-beam PET scanner for the on-line monitoring of hadrotherapy treatments**
Maria Antonietta Piliero, University of Pisa, Pisa, Italy and INFN sez. Pisa, Pisa, Italy

**Coffee Break**

10:40-11:10
**CZT Sensors for Computed Tomography**
Kris Iniewski, Redlen Technologies

11:10-11:40
**Position-sensitive superconductor detectors**
Masahiko Kurakado, Techno-X Co., Ltd.

11:40-12:00
**Proton energy and scattering radiographs to improve proton treatment planning: A Monte-Carlo study**
Aleksandra Biegun, KVI-Center for Advanced Radiation Technology (KVI-CART), University of Groningen, The Netherlands
A sub-millimeter resolution detector module for small-animal PET applications
Ilaria Sacco, University of Heidelberg, Institute of Computer Science

Experimentally enhanced model-based deconvolution of propagation-based phase-contrast data
Martin Pichotka, IEAP, Czech Technical University of Prague

Lunch Break

X-ray breast imaging: radiation detector requirements and clinical performance
Andrew Smith, Hologic, Inc.

Biological Image Detection and Processing: from Retina to Brain
Alan Litke, Santa Cruz Institute for Particle Physics

The Timepix chip 10 years of applications
Xavier Llopard, CERN

Protein nano-crystallography using optimized quantum area direct electron detectors like the Medipix and EIGER families
Eric van Genderen, Paul Scherrer Institute – LBR, Switzerland

Development and characterization of high-resolution neutron pixel detectors based on Timepix read-out chips
Frantisek Krejci, Institute of Experimental and Applied Physics

Coffee Break + Poster session

Germanium “hexa” sensor with Medipix3RX read-out chip
Milija Sarajlic, Deutsches Elekronen-Synchrotron (DESY)

Exploring Transmission Kikuchi Diffraction using a Timepix detector
Stefano Vespucchi, Department of Physics, SUPA, University of Strathclyde

Study of dynamical processes by fast X-ray 4D CT utilizing fast CdTe semiconductor detector Timepix with AdvaPIX readout
Daniel Vavrik, Insitute of Experimental and Applied Physics, CTU in Prague

Per-pixel Energy Calibration of Photon-counting Detectors
Ali Atharifard, Department of Radiology, University of Otago, Christchurch, New Zealand

Meeting – Local Organising
Scientific Programme

Wednesday, 6 July

9:00-9:20
Miniaturized X-ray telescope for VZLUSAT-1 nanosatellite with Timepix detector
Tomas Baca, Faculty of Electrical Engineering, Czech Technical University in Prague

9:20-9:40
Measurement of particle directions in low earth orbit with a Timepix
Stefan Gohl, Institute of Experimental and Applied Physics, Czech Technical University in Prague

9:40-10:00
Summary of Medipix Technology’s 3-Years in Space and Plans for Future Developments
Lawrence Pinsky, University of Houston, Houston, TX, USA

10:00-10:20
Measurements of Ultra Fast Single Photon Counting Chip with Energy Window and 75 μm Pixel Pitch for X-Ray Imaging and Synchrotron Applications
Pawel Grybos, AGH University of Science and Technology, Krakow

Coffee Break + Poster

11:50-12:10
Radiation-hard silicon photonic modulators for detector instrumentation
Piotr Skwierawski Karlsruhe, Institute of Technology

12:10-12:30
Micro-bump connection technology for 3D stacked imaging detectors
Makoto Motoyoshi, Tohoku-MicroTec Co., Ltd

12:30-12:50
Initial results from new 3D neutron detectors
Roberto Mendicino, University of Trento and TIFPA INFN

Lunch Break

14:00-14:30
Interposer-an enabling technology for fan-out hybrid pixel modules
Thomas Fritzsch, Fraunhofer IZM

14:30-15:00
The Data Deluge at Synchrotrons: Big Cameras, Big Data
Steve Aplin, DESY

15:00-15:20
Realization of Monolithic Multichannel SiPM Detectors.
Florian Wiest, KETEK GmbH

15:20-15:40
Characterization and Optimization of a Novel Direct Hit Electron Detector for Fast Imaging Applications
Ibrahim Dourki, Max Planck Institute for the Structure and Dynamics of Matter, CFEL

15:40-16:00
Test beam results of a Depleted Monolithic Active Pixel Sensor (DMAPS) prototype
Theresa Obermann, Physikalisches Institut

16:00-16:20
Simultaneous x-ray transmission and fluorescence imaging
Christopher Hall, Australian Synchrotron
X-Ray Imaging at 4.5 MHz with GaAs:Cr Sensors
Matthew Veale, STFC Rutherford Appleton Laboratory

20:00 – 23:30
Conference Dinner

Scientific Programme

Thursday, 7 July

9:00-9:20
Comparison of CdTe, GaAs and CdZnTe Assemblies with PILATUS and IBEX ASICs
Michael Rissi, DECTRIS Ltd.

9:40-10:00
Towards Gotthard-II: Development of A Silicon Micro-Strip Detector for the European XFEL
Jiaguo Zhang, Paul Scherrer Institut (PSI)

10:00-10:20
EIGER high frame rate large area photon counting detector systems
Erik Frojdh, Paul Scherrer Institut

Coffee Break

10:50-11:20
ALBA light source: present status and perspectives
Salvador Ferrer, ALBA light source

11:20-11:40
First experimental results on active-edge silicon sensors for XFEL
Lucio Pancheri, Università di Trento and TIFPA-INFN, Italy

11:40-12:00
JUNGFRAU: a gain switching pixel detector for SwissFEL
Sophie Redford, PSI

12:00-12:20
The Development of the DSSC Detector for the European XFEL: toward the Prototype Camera
Matteo Porro, European X-Ray Free-Electron Laser Facility GmbH

12:00-13:00
FAREWELL TALK

13:00-17:00
ALBA VISIT
Steve Aplin
The Data Deluge at Synchrotrons: Big Cameras, Big Data.

Salvador Ferrer
ALBA light source: present status and perspectives

Thomas Fritzsch
Kai Zoschke
Markus Wöhrmann
Klaus-Dieter Lang
Interposer – an enabling technology for fan-out hybrid pixel modules

Kris Iniewski
CZT Sensors for Computed Tomography

Masahiko Kurakado
Kazuo Taniguchi
Position-sensitive superconductor detectors

Alan Litke
Biological Image Detection and Processing: from Retina to Brain

Andrew Smith
X-ray breast imaging: radiation detector requirements and clinical performance

Maxim Titov
Micro-Pattern Gas Detector Technologies for Physics Projects at the Energy, Intensity and Cosmic Frontiers

Niek F. Van Huls
Single photons, single plasmons, single molecules
The Data Deluge at Synchrotrons: 
Big Cameras, Big Data

Steve Aplin¹

1) DESY

The latest generation of pixel detectors currently being deployed at synchrotron and X-ray free electron laser facilities are capable of generating data rates well in excess of 1 Gigabyte per second and with frames rates exceeding 1 kHz. This will increase by a factor of 10 in the near future. Such data rates coupled with the fact that data reduction and online data rejection are not widely utilised in the field, create a significant challenge in terms of data handling.

The traditional approach to data acquisition at synchrotrons has been based around writing a single frame per file directly to a local, or network attached, file system. This approach was rejected a priori by free electron laser facilities, which have implemented dedicated DAQ systems. But now the single frame per file approach is also pushing the limits of what is possible even at synchrotrons.

The intrinsic nature of beam-line utilisation, where competing scientific groups may be present at the beam-line concurrently, also presents the need for strong data access control, authentication, and authorisation. With what is potentially Petabytes of data, this requires a far closer collaboration between beam-line scientists, experiment control groups, and central IT infrastructure than ever before.

The presentation will focus on giving an overview of what is happening after the data leaves the detector. This will be illustrated using the recent upgrade of the computing infrastructure at PETRA III, discussing some of the technical solutions implemented to cope with the massive increase in data, such as messaging software used to distribute the data, file systems and formats used to store it, and access points which finally allow users to get their data home.
1) ALBA light source

Alba is a 3rd generation light source with eight operational Beamlines, one in construction and another one approved. The first Beamlines were commissioned in 2012 and are dedicated to life sciences, condensed matter physics and chemistry. The phase 1 comprised 7 beamlines devoted to Magnetic dichroism (XMCD, XMLD), magnetic scattering (SXRS), Photoemission Electron Microscopy (PEEM), Near Ambient Pressure Photoemission (NAPP), X-ray Absortion, Machromolecular chrystallography, Non Christalyne Diffraction, Transmission X-Ray Microscopy, Powder Diffraction, etc. The phase 2 included an infrared beamline in operation since mid-2016 and an angular resolved photoemission beamline in construction.

The critical success factors of the experiments are given by the end station and sample environment, the beam optics, the synchronization capabilities, the data acquisition and the detectors. Maximizing these factors is the condition to be on the cutting-edge of synchrotron light.

This talk will present the characteristics of the facility with particular examples and scientific results of the recent experiments.
Hybrid pixel detector modules are the main building blocks of silicon particle tracking detectors in high energy physics experiments as well as in x-ray cameras for research and development using synchrotron radiation. In most of the application the pixel pitch is the same for the electronic readout chips and the pixelated solid-state sensor. With this approach larger sensor tiles have to be connected to multiple readout chips. The idea presented here offers a more flexible hybrid module concept. Using a silicon interposer with copper-filled through silicon vias (TSVs) the high density pixel pitch of the electronic readout ASIC can be redistributed to a flexible sensor pixel pitch adapted to the requirements of the application. This fan-out hybrid pixel module approach opens a wide range for the use of different sensor configurations and materials.

The state of the art of the interposer technology in industrial application will be described in this presentation, i.e. for new FPGA and high end GPU concepts. Starting from the concept of fan-out hybrid pixel module the individual process steps of interposer manufacturing up to the interconnection technology will be described in detail. These are the routing of the high density pitch on readout ASIC side using frontend feature size and technology, the formation of through silicon via and applicable interconnection technologies for both sides of the interposer.

Glass comes into focus as an interposer material due to its good electrical isolation characteristic. New results of technological process development and material characterization of glass interposers will be presented. The development of these devices is driven by the reduction of interposer thickness and the reduction of through glass via (TGV) diameter and pitch. To summarize the presentation an overview of interposer processed at Fraunhofer IZM for several applications will be shown.
Recent advances in THM growth and device fabrication that require additional processing steps has enabled to dramatically improve hole transport properties and reduce polarization effects. As a result high flux operation of CZT sensors at rates of 200 Mcps/mm2 is now possible and has enabled multiple medical imaging OEMs to start building prototype CT scanners.

In order to prepare for high volume commercial production we are moving from individual tile processing to whole wafer processing using silicon methodologies, such as waxless processing, cassette based / touchless wafer handling. We have been developing parametric level screening at the wafer stage to ensure high wafer quality before detector fabrication in order to maximize production yields. These process improvements enable us, and other CZT manufacturers who pursue similar developments, to provide high volume production for photon counting applications in an economically feasible manner.

CZT sensors are capable of delivering both high count rates and high-resolution spectroscopic performance, although it is challenging to achieve both of these attributes simultaneously. The talk discusses material challenges, detector design trade-offs and ASIC architectures required to build cost-effective CZT based detection systems. Photon counting ASICs are essential part of the integrated module platforms as charge-sensitive electronics needs to deal with charge-sharing and pile-up effects.

Technological development and innovation in CT imaging proceeds at a rapid pace. New CZT sensor technologies for spectral multi-energy image acquisition are being developed partially driven in the demands of the field of cardiac radiology for better quality images of tiny moving structures as well as a push towards using CT for novel tissue characterization. Whole heart coverage, rapidly acquired motionless images with lower contrast volumes at very low doses is becoming a reality.
Superconducting tunnel junction (STJ) detectors and superconducting transition edge sensors (TESs) are representative superconductor detectors that have much higher energy resolutions than those of semiconductor detectors. STJ detectors are thin (e.g., 0.2-μm) and are therefore suitable for the detection of low-energy X-rays. The signals of STJ detectors are more than 100 times faster than those of TESs. In contrast, TESs are micro-calorimeters that measure the radiation energy by the change in temperature. Therefore, signals are slow and typically several hundred μs. Thus, attainable count rates for X-rays are usually lower than a few hundred cps. However, TESs possess excellent energy resolutions. For instance, it is 1.8 eV for 5.9-keV X-rays. STJ detectors and TESs are thin-film detectors that are fabricated using lithography and can be easily arrayed. An array of STJs or TESs can be utilized as a pixel detector. Superconducting series-junction (SSJ) detectors consist of many STJs and a single-crystal substrate as an absorber for radiations (Fig.1). SSJ detectors are position sensitive (Fig.2). They have low energy resolutions compared to that of STJ detectors or TESs. However, their resolutions are higher than those of semiconductor detectors (Fig.3). In addition, their detection efficiencies and possible count rates are relatively high.

In this presentation, we will give an overview of STJ detectors, TES and SSJ detectors.

**Fig.1** Structure of an SSJ detector

**Fig.2** Two-dimensional imaging. \( V_A, V_B, V_C \) and \( V_D \) are signal heights from each series-junction.

**Fig.3** Pulse-height spectrum of Mn Kα and Kβ X rays measured with an SSJ detector.
The back of the eye is lined by an extraordinary dynamic image detector, the retina. This living neural network is able to extract vital information about the external visual world, and transmit this information in a timely manner to the brain. The brain, in turn, processes the retinal data and generates visual perception and behavior.

In this talk, after a brief introduction to retinal architecture, I will describe how we measure the functional properties of the retina, show what we have learned about its functional organization, and discuss studies aimed at guiding the design of retinal prosthetic devices. I will next describe the methods we employ to study visual processing in the brain. Along the way, I will illustrate how the technology we use for the retinal and brain studies was inspired by, and is linked to, the development of radiation imaging detectors for experiments in high energy physics.
This talk will cover the imaging requirements for state-of-the-art x-ray breast imaging systems. There will be a strong focus on practicality and the clinical needs. We will cover the requirements for 2D digital mammography, digital breast tomosynthesis, dual-energy imaging, and breast biopsy.

The advantages and disadvantages of direct conversion (such as a-Selenium) and indirect conversion (such as CsI) detectors will be discussed. Similarly, we will cover charge integrating and photon counting detectors. The talk will cover spatial resolution, temporal requirements, and noise properties for high performance breast imaging. We will also review x-ray sources and their implications for the radiation detectors. We will also briefly cover gamma ray breast imaging systems.

A review of commercially available and proposed imaging systems will be discussed.
Micro-Pattern Gas Detector Technologies for Physics Projects at the Energy, Intensity and Cosmic Frontiers

Maxim Titov

1) CEA Saclay, Irfu

“Micro-Pattern Gas Detector Technologies for Physics Projects at the Energy, Intensity and Cosmic Frontiers” and Overview of the RD51 Collaboration Activities

Improvements in detector technology often come from capitalizing on industrial progress. Advances are made with new insights; recent industrial developments in photo-lithography, microelectronics and printed circuits technique have opened the road for the production of micro-structured gaseous amplification devices: Microstrip Gas Chamber (MSGC), Gas Electron Multiplier (GEM) and Micro-mesh gaseous structure (Micromegas), followed by the thick-GEM (THGEM), resistive GEM (RETGEM), Micro-Pixel Gas Chamber (μ-PIC), and an integrated readout of gaseous detectors using solid-state pixel chips (InGrid). By using a pitch size of a few hundred micrometers, MPGD systems now offer operational stability, protection against discharges, radiation hardness, high-rate capability (> 1MHz/mm2), excellent spatial resolution (~30 μm), and a time resolution down to a few-hundred pico-second range.

During the past five years, there have been major developments of Micromegas and GEMs for ATLAS, CMS and ALICE upgrades at the LHC, as well as THGEMs for the COMPASS RICH upgrade at CERN. Today, the choice of the MPGD technology fulfills the most stringent constraints imposed by future facilities: from the Facility for Antiproton and Ion Research (FAIR) and the Electron-Ion Collider (EIC), to the electron-positron Linear Colliders (ILC/CLIC), and proton-proton Future Circular Collider (FCC). MPGDs have also found numerous applications in other fields of fundamental and applied research; they are being used or considered for X-ray imaging and neutron scattering science, neutrino-nucleus scattering experiments, dark matter and astrophysics experiments, including operation at cryogenic temperatures, plasma diagnostics at tokamaks, material sciences, radioactive-waste monitoring and security applications, medical physics, portal imaging and hadron therapy.

The interest in the novel MPGD concepts has led to the establishment of the RD51 collaboration at CERN in 2008. The aims are to facilitate technological development of advanced MPGDs, software, and associated electronic-readout systems, for applications in basic and applied research. Originally created for the five-year term, the RD51 was prolonged for another five years beyond 2013. Many of the MPGD technologies we know today were introduced before RD51 was founded. But with more techniques becoming available (or affordable), new detection concepts are still being introduced and existing ones are substantially improved. This talk will highlight recent MPGD technology advances, review RD51 collaboration activities, and address numerous MPGD applications at the Energy, Intensity and Cosmic Frontiers.
-Niek F. Van Huls-

1) ICFO—Institut de Ciencies Fotoniques, Barcelona Inst. of Science & Technology, 2) ICREA - Institució Catalana de Recerca i Estudis Avançats

Detecting single photons from single nano-objects it now routine to address individual molecules, quantum-dots, proteins, single plasmonic antennas, etc... Here I will focus on the control of interactions with single quantum emitters both in space and time, specifically using optical nano-antennas and ultrafast coherent control concepts, all at the single photon limit.

For spatial control, single photon emitters are brought in the near field of optical resonant antennas for nanoscale excitation and enhancement of the emission into multipolar radiation patterns, with full command of symmetry, multipole parity, rates and polarization. With state-of-the-art antenna fabrication the excitation can be confined to 10 nm scale, while the emission can be enhanced up to 1000 times, reaching towards strong coupling in the weak cavity limit.

For temporal control, phase shaped fs pulses are exploited to drive single quantum systems and resonant antennas to dynamically control both their fs response and nanoscale fields. As examples we tackle vibrational response and Rabi-oscillations in individual molecules at ambient conditions; and closed loop control of two-photon excitation of single quantum dots.

Finally, as an application of the spatio-temporal control, I will address the role of quantum effects in photosynthesis. Surprisingly within individual antenna complexes (LH2) of a purple bacterium it is observed that ultrafast quantum coherent energy transfer occurs under physiological conditions. Quantum coherences between electronically coupled energy eigen-states persist at least 400 fs, and distinct, time-varying energy transfer pathways can be identified in each complex. Interestingly the single molecule approach allows tracking coherent phase jumps between different pathways, which suggest that long-lived quantum coherence renders energy transfer robust in the presence of disorder.

In conclusion I hope to apprise the IWORID2016 audience as to the potential of nano-femto tools
Resistive Micromegas for the Muon Spectrometer Upgrade of the ATLAS Experiment

Alan Peyaud

1) ATLAS Muon Collaboration

Large size resistive Micromegas detectors will be employed for the first time for the Muon Spectrometer upgrade of the ATLAS experiment. The current innermost stations of the muon endcap system, the Small Wheel, will be upgraded in 2019 to retain the good precision tracking and trigger capabilities in the high background environment expected with the upcoming luminosity increase of the LHC.

The “New Small Wheel” will be equipped with eight layers of Micromegas (MM) detectors arranged in multilayers of two quadruplets, for a total of about 1200 m². All quadruplets will have surface areas between 2 and 3 m². The MM system will provide both trigger and tracking capabilities.

In order to achieve a 15% transverse momentum resolution for 1 TeV muons, a challenging mechanical precision is required in the construction for each plane of the assembled modules, with an alignment of the readout elements (the strips) at the level of 30 μm along the precision coordinate and 80 μm perpendicular to the plane. Each MM plane must achieve a spatial resolution better than 100 μm independent of the track incidence angle and operate in an inhomogeneous magnetic field (B < 0.3 T), with a rate capability up to ~15 kHz/cm².

In the recent years, the achievement of the required performance has been demonstrated with dedicated test-beams performed on small (10×10 cm²) and medium size (1×0.5 m²) resistive MMs.

In Spring 2016 the first three (out of four different types) full size prototypes (modules-0) will be completed and will undergo a thorough validation phase.

After a brief review of the performance studies of small prototypes, demonstrating the excellent characteristics of the detectors, the Modules-0 construction procedures will be reviewed along with the results of the validation tests obtained with X-rays, cosmic tracks and with high-energy particle beams at CERN.
The T-REX project of the group of the University of Zaragoza includes a number of R&D and prototyping activities to explore the applicability of gaseous Time Projection Chambers (TPCs) with Micromesh Gas Structures (Micromegas) in rare event searches where the pattern recognition of the signal is crucial for background discrimination.

In CAST experiment (CERN Axion Solar Telescope) a background level as low as \(0.8 \times 10^{-6} \text{ counts keV}^{-1} \text{ cm}^{-2} \text{ s}^{-1}\) was achieved. Prototyping and simulations promise a \(10^5\) better signal-to-noise ratio than CAST for the future IAXO (International Axion Observatory) using x-ray telescopes. A new strategy is also explored in the search of WIMPS based in high gas pressure: the TREX-DM experiment, a low energy threshold detector with a good electron/neutron discrimination.

In both cases, Axion and WIMP searches, the image of the expected signal is quite simple: a “one cluster” deposition coming from the magnet bore in the case of axions and, if possible, with a “tadpole” form in the case of WIMPs.

It is in the case of double beta decay where “imaging” and “pattern recognition” plays a major role. Results obtained in Xe + trimethylamine (TMA) mixtures reduces electron diffusion improving the quality of the topological pattern, with a positive impact on the discrimination capability, as show in TREX-MM prototype. Microbulk Micromegas are able to image the DBD ionization signature with high quality while, at the same time, measuring its energy deposition with a resolution of at least a \(~3\%\ FWHM@Q_{\beta\beta}\) and even better (up to \(~3\%\ FWHM\)) as extrapolated from low energy events. That makes Micromegas-read HPXe TPC a very competitive technique for the next generation DBD experiments (as PANDAX).

Last results of the TREX project detectors and software will be presented.
Markus Ball

1) Helmholtz Institut für Strahlen- und Kernphysik (HISKp)

The ALICE (A Large Ion Collider Experiment at CERN) collaboration plans an upgrade of the detector system during the second long shutdown of the LHC. After this period the interaction rate of the collider will be increased to 50 kHz for Pb-Pb collisions. This demands operation of the Time Projection Chamber (TPC) in an ungated continuous mode. A conventional gating grid can not be used to prevent ions drifting back into the drift volume. Micro Pattern Gaseous Detectors (MPGD) such as GEMs and Micromegas have demonstrated to operate at high rates and offer a suppression of ions. A four GEM amplification system has been chosen to replace the Multi Wire Proportional Chambers of the ALICE TPC. To keep distortions due to space-charge at a tolerable level, an ion yield of 10 to 20 back drifting ions per incoming electron is required. However, the need for low ion backflow should not compromise the detector performance and the stability of the system.

The capability to operate the system at large scales has been studied extensively. Test beams have been carried out to demonstrate the large scale performance of Inner Readout Chamber (IROC) equipped with a quadruple GEM system. Also an quadruple GEM Outer Readout Chamber (OROC) was assembled and successfully operated, being the largest detector of this type. The upgrade of all readout chambers with a quadruple GEM system has started in 2016. To ensure the stability of operation for all readout chambers during construction, commissioning and final operation in the TPC the quality of the GEM foils must be maintained at all times. A quality assurance scheme has been established that includes a large set of quality assurance measures to ensure that the quality of GEM foils and ROC performance is always preserved during the production and assembly process. The QA flow and how it is embedded in the general work flow of the TPC upgrade production will be presented.
The Liquid Hole-Multiplier: a novel local dual-phase element for noble-liquid TPCs

Lior Arazi¹, Eran Erdal¹, Michael Rappaport¹, Sergei Shchemelinin¹, David Vartsy¹, Amos Breskin¹

1) Department of Particle Physics and Astrophysics, Weizmann Institute of Science

Large-volume noble-liquid time projection chambers are a leading tool in rare-event searches and neutrino-physics experiments. However, scaling up existing designs to the multi-ton regime calls for new innovative detector solutions.

We propose a new concept, the bubble-assisted Liquid Hole-Multiplier (LHM) – a “local dual-phase” detection element, designed for the detection of both ionization electrons and primary scintillation photons induced by particle interactions within the noble liquid. The LHM comprises a perforated micro-pattern electrode (e.g. Thick Gas Electron Multiplier – THGEM, or Gas Electron Multiplier – GEM) immersed in the liquid, with a bubble of the noble gas supported underneath. Ionization electrons and scintillation-induced photoelectrons extracted from a cesium iodide (CsI) photocathode drift through the electrode’s holes and induce electroluminescence (EL) in the bubble, with up to several hundred EL photons emitted per drifting electron. Accurate imaging of the EL patterns, resulting in precise reconstruction of the event topology, can be performed with small-pixel photon detectors, e.g. SiPMs or Gaseous Photomultipliers – GPMs.

We will present the principle of the new concept, as well as measurements of ionization electrons and VUV scintillation photons using CsI-coated THGEM and GEM-based LHM prototypes in liquid xenon (LXe). The mechanism, stable over months of operation, yields energy resolutions surpassing those of current dual-phase LXe TPCs, with a time resolution on the nanosecond scale for events comprising a few hundred photoelectrons. In addition, we will present our parallel work on the development on cryogenic GPMs. Potential applications are discussed within the framework of dark matter searches, neutrino physics experiments and neutron and gamma radiography.
Towards spark-proof gaseous-pixel detectors for precise particle tracking

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Our group is active in the development of micro-pattern gaseous-pixel detectors. We use micromegas-like amplification structures on top of pixelated readout-chips of the Medipix family. As a prevention against discharges a protection layer is deposited on the chip. Supporting pillars of approximately 50 μm height hold a grid above the chip, defining the amplification region. A cathode plane above the grid defines the drift region. The structure is built into a chamber filled with a gas mixture. With this technology we are able to reconstruct 3D track segments thanks to the time-to-digital converter (TDC) in each pixel which enables the recording of the drift time.

Using a small scale prototype of the Timepix3 chip, we have created the most precise gaseous detector to date for measuring the position of individual ionisation electrons. The existing Timepix3 chip, with its faster front-end and the high resolution TDC (1.6 ns) per pixel, improves the performance. Furthermore, the simultaneous measurement of the time-of-arrival (ToA) and charge via time-over-threshold (ToT) allows corrections to timewalk effects, improving further the resolution. However, the spark protection layer needs further improvement to make reliable detectors.

I will report on recent results obtained from lab-measurements and test-beams, including a new set-up dedicated to spark-protection studies.
Application of GEM-based detectors in full-field XRF imaging

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X-ray fluorescence spectroscopy (XRF) is one of popular techniques of non-destructive elemental analysis, which is used in cultural heritage investigations. It can be applied to investigations of provenance of historical objects as well as to studies of art techniques.

Macro-XRF imaging is realised usually by scanning an object with a narrow focused X-ray excitation beam and measuring characteristic fluorescence radiation using a high energy resolution detector, usually a silicon drift detector. Such a technique is suitable for imaging flat surfaces but it is very time consuming because the spatial resolution is basically determined by the spot size of the beam. Another approach is the full-field XRF, which is based on simultaneous irradiation and imaging of large area of an object. The image of the investigated area is projected by a pinhole camera on a position-sensitive and energy dispersive detector. The infinite depth of field of the pinhole camera allows one, in principle, investigation of non-flat surfaces.

One of possible detectors to be employed in such an application is a GEM based detector with 2 dimensional readout. In the paper we will report on development of an imaging system equipped with a standard 3-stage GEM detector of 10×10 cm² and readout electronics based on dedicated ASICs. With a demonstrator system we have obtained 2-D spatial resolution of the order of 100 mm and energy resolution at a level of 20% FWHM for 5.9 keV. This energy resolution is not satisfactory for very detailed elemental analysis but it is perfectly adequate for performing fast screening of large area objects. In the paper test results will be reported and possible further improvements will be discussed.

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The GAP-TPC

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The Geiger-mode Avalanche Photodiode Time Projection Chamber (GAP-TPC) is an innovative prototype detector for directional direct dark matter search. The GAP-TPC, based on the concept of the widely developed noble liquid TPCs, will have unprecedented performance in terms of: residual radioactivity of the photosensors, energy and spatial resolution and light/charge collection efficiency. The use of cryogenic SiPMs instead of the PMTs will allow for having a full optical coverage (4π) and thus maximizing the light collection. The SiPMs granularity will also be very beneficial in reaching sub-cm spatial resolution for surface background rejection. The conceptual design of the GAP-TPC will be presented together with preliminary results obtained in operating large-size SiPM arrays and their relative cryogenic readout electronics.
There is an urgent need for a detector technology that offers high sensitivity, broad spectral response (from UV to mid-IR), low cost and CMOS integrability. We will present our recently discovered technology platform for photodetectors enabled by graphene's high mobility and atomically thin profile and the tailored and high absorption of colloidal quantum dots. Following up to our original report [1], where we demonstrated a new hybrid phototransistor architecture covering both UV-Vis and SWIR (short wave infrared) with exceptionally high gain on the order of 107 and normalized detectivity in the range of 1013 Jones, we will show some recent results in which the passive sensitizing layer of QDs is transformed into an electrically active QD photodiode. In doing so we report a 4-orders of magnitude improvement in gain-bandwidth product over our first report achieving at the same time responsivity of 106 A/W, electrical bandwidth on the order of kHz and quantum efficiency of up to 75% [2].

In the second part of the talk we will present results from hybrid 2D-QD photodetectors in which the 2D transistor channel is implemented with a semiconducting 2D transition metal dichalcogenide MoS2 layer [3]. By modulating the transistor we can reach very low dark currents and responsivities on the order of 105 A/W [4].

In the last part of our talk we will briefly present some recent prototypes based on this technology in the field of image sensing and wearable and IOT applications.

References:
Improvements in detector technology often come from capitalizing on industrial progress. Advances are made with new insights; recent industrial developments in photo-lithography, microelectronics and printed circuits technique have opened the road for the production of micro-structured gaseous amplification devices: Microstrip Gas Chamber (MSGC), Gas Electron Multiplier (GEM) and Micro-mesh gaseous structure (Micromegas), followed by the thick-GEM (THGEM), resistive GEM (RETGEM), Micro-Pixel Gas Chamber (μ-PIC), and an integrated readout of gaseous detectors using solid-state pixel chips (InGrid). By using a pitch size of a few hundred micrometers, MPGD systems now offer operational stability, protection against discharges, radiation hardness, high-rate capability (> 1MHz/mm²), excellent spatial resolution (~30 μm), and a time resolution down to a few-hundred pico-second range.

During the past five years, there have been major developments of Micromegas and GEMs for ATLAS, CMS and ALICE upgrades at the LHC, as well as THGEMs for the COMPASS RICH upgrade at CERN. Today, the choice of the MPGD technology fulfills the most stringent constraints imposed by future facilities: from the Facility for Antiproton and Ion Research (FAIR) and the Electron-Ion Collider (EIC), to the electron-positron Linear Colliders (ILC/CLIC), and proton-proton Future Circular Collider (FCC). MPGDs have also found numerous applications in other fields of fundamental and applied research; they are being used or considered for X-ray imaging and neutron scattering science, neutrino-nucleus scattering experiments, dark matter and astrophysics experiments, including operation at cryogenic temperatures, plasma diagnostics at tokamaks, material sciences, radioactive-waste monitoring and security applications, medical physics, portal imaging and hadron therapy.

The interest in the novel MPGD concepts has led to the establishment of the RD51 collaboration at CERN in 2008. The aims are to facilitate technological development of advanced MPGDs, software, and associated electronic-readout systems, for applications in basic and applied research. Originally created for the five-year term, the RD51 was prolonged for another five years beyond 2013. Many of the MPGD technologies we know today were introduced before RD51 was founded. But with more techniques becoming available (or affordable), new detection concepts are still being introduced and existing ones are substantially improved. This talk will highlight recent MPGD technology advances, review RD51 collaboration activities, and address numerous MPGD applications at the Energy, Intensity and Cosmic Frontiers.
Prototype of core-shell diode array for high performance particle detectors & imaging sensors

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First prototype of core-shell diode array1 was fabricated by using state-of-the-art micro- & nanotechnology2 as shown in the Fig. 1a, 1b, and cross-sectional SEM image in Fig. 1c, and the functionality to be used as particle detector has been tested by electron beam induced current (EBIC) at various accelerating energies. This core-shell diode structure avoids the performance limitations in respect to low radiation hardness, poor spatial resolution, low sensitivity, high power consumption and slow signal response of the conventional silicon drift detectors (SDDs), and will perform far beyond state-of-the-art. This novel detector will provide solutions for various fundamental research fields currently limited by instrumentation such as high energy physics (HEP)3,4, astronomy and x-ray based protein crystallography.

The core-shell diode array is expected to have the following properties simultaneously:

- Ultrahigh radiation hardness beyond state-of-the-art
- High spatial resolution
- High sensitivity
- Low power consumption (working even without reverse bias and cooling of detector might be omitted)
- Fast signal response (for measurements at high count rate)

We target to fabricate electrically isolated core-shell diode array like that demonstrated in the cross-sectional and 3D sketches in Fig. 2a and 2b, respectively. This structure could be realized by state-of-the-art deep reactive ion etching technologies, during which the sidewalls are protected and the etching occurs only at the bottom. This electrically isolated core-shell diode array can be used as novel high performance radiation detector & imaging sensor, and is highly promising for high luminosity HEP experiments and many other fundamental research fields in astrophysics, life science such as protein crystallography & medical diagnostic and for the x-ray based structural and compositional analyze of materials.

References:

2. G. Jia et al., Photonics and Nanostructures-Fundamentals and Applications 19, 64 (2016).
The Tynode: a new vacuum electron multiplier for ultra fast pixelised particle detectors

Harry van der Graaf

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By placing, in vacuum, a stack of transmission dynodes (tynodes) on top of a CMOS pixel chip, a single free electron detector could be made with outstanding performance in terms of spatial and time resolution. The essential object is the tynode: an ultra thin membrane, which emits, at the impact of an energetic electron on one side, a multiple of electrons at the other side. The electron yields of tynodes have been calculated by means of GEANT-4 Monte Carlo simulations, applying special low-energy extensions. The results are in line with another simulation based on a continuous charge-diffusion model.

By means of MEMS technology, tynodes and test samples have been realised. The secondary electron yield of several samples have been measured in three different stations. Finally, several possibilities to improve the yield are presented.
Ground-based gamma-ray astronomy in the Very High Energy (VHE, $E>100$ GeV) regime has fast become one of the most interesting and productive sub-fields of astrophysics today. Utilizing the Imaging Atmospheric Cherenkov Technique (IACT) to reconstruct the energy and direction of incoming gamma-ray photons from the universe, several source-classes have been revealed by previous and current generations of IACT telescopes (e.g. Whipple, MAGIC, HESS and VERITAS). The next generation pointing IACT experiment, the Cherenkov Telescope Array (CTA), will provide increased sensitivity across a wider energy range and with better angular resolution.

With the development of CTA, the future of IACT pointing arrays is being directed towards more and more telescopes (and hence cameras), and therefore the need to develop low-cost pixels with acceptable light-collection efficiency is clear. One of the primary paths to the above goal is to replace Photomultiplier Tubes (PMTs) with Silicon-PMs (SiPMs) as the pixels in IACT cameras. However SiPMs are not yet mature enough to replace PMTs for several reasons: sensitivity to unwanted longer wave-lengths while lacking sensitivity at short wavelengths, small physical area, high cost and electronic noise.

Here we propose a novel method to build relatively low-cost SiPM-based pixels utilising a disk of wavelength-shifting material, which overcomes some of these drawbacks by collecting light over a larger area than standard SiPMs and improving sensitivity to shorter wavelengths while reducing background. We aim to optimise the design of such pixels, integrating them into an actual 7-pixel cluster which will be inserted into a MAGIC camera and tested during real observations.

Results of simulations, lab measurements and the current status of the cluster design and development will be presented.
Characterisation of HV-CMOS sensors for the ATLAS upgrade

Dima Maneuski

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The planned HL-LHC (High Luminosity Large Hadron Collider) upgrade in 2025 is being designed to maximise the physics potential through a sizable increase in luminosity. With the increase in expected radiation damage, readout rates and granularity, a complete re-design of the current ATLAS Inner Detector (ID) is being developed as the Inner Tracker (ITk).

High voltage CMOS Monolithic Active Pixel Sensors produced on commercially available fabrication processes are being studied as an alternative to conventional silicon tracker technologies for the ITk. HV CMOS technology can potentially offer lower material budget, increased granularity and cheaper front-end interconnection.

In this presentation, a summary of the recent results of characterising HV-CMOS sensors for particle physics will be given, covering variety of laboratory characterisation techniques (synchrotron, X-rays, lasers, Sr90) and particle test beams. It’s been demonstrated that even though the levels of noise are increased thought different CMOS vendors after the irradiations, there is an increase in depletion region leading to higher than expected charge collection. The response of HV-CMOS sensors before and after irradiation and measurements investigating the charge collection will be presented.
High-energy resolution position-sensitive CdZnTe (CZT) drift detectors offer unique capabilities for imaging gamma rays and correcting the response non-uniformities caused by crystal defects. The long electron lifetime in today’s CZT crystals allows for making CZT drift detectors with much greater thicknesses than those for any other existing detectors. We will present data on detectors up to 50-mm long. Recently, we proposed to develop an array of position-sensitive CZT drift detectors for imaging and spectroscopy of gamma-ray sources. Here, we will present the results from testing of the first prototypes of such arrays. The array prototypes employ 6x6x20 mm³ and 7x7x20 mm³ CZT crystals encapsulated into polyester shells with 4-5 mm-wide charge-sensing pads placed new the anode. The pad signals provide X-Y position information, which allow for more accurate corrections of the charge losses caused by crystal defects. The basic array (module) consists of a number of detectors grouped into 2x2 sub-arrays, each having a common cathode made by connecting together the cathodes of the individual detectors. The cathode signals provide position information along Z coordinate. Each module is coupled with its front-end ASIC chip, which captures signals from 36 anodes and 9 cathodes. As we will describe in the talk, this feature can significantly improve the performance of detectors fabricated from typical CZT material and, thus, extend their acceptance boundaries, leading to an increase in the yield and an expected decrease in cost.
Magdalena Munker

1) CERN

The silicon vertex and tracking detectors at the CLIC multi-TeV linear e+e- collider must have excellent spatial resolution, full geometrical coverage extending to low polar angles, extremely low mass, low occupancy facilitated by time-tagging, and sufficient heat removal from sensors and readout. These considerations, together with the precision physics needs and beam structure of CLIC, push the technological requirements to the limits. A detector concept based on hybrid pixel technology is under development for the CLIC vertex detector, profiting from synergy with detectors developed for imaging applications. Timepix and Timepix3 readout ASICs are used as technology platforms for the evaluation of ultra-thin (50-300 micron) slim-edge and active-edge sensors. The CLICpix chip was derived from the Medipix/Timepix architecture as a small-pitch (25 micron) readout ASIC implemented in 65 nm CMOS technology. It comprises fast time stamping (~10 ns) and can be operated in pulsed powering mode, to reduce the average power consumption to a level compatible with cooling through forced air flow (<50 mW/cm2). Charge interpolation between neighbouring pixels results in a single-point resolution of a few micron. Prototype assemblies of CLICpix ASICs bump bonded to planar sensors or capacitively coupled to active HV-CMOS sensors have been tested successfully with radioactive sources and in particle beams. For the outer tracking region, both hybrid concepts and fully integrated CMOS sensors are under consideration. Seamless tiling of sensors in large areas requires the use of Through-Silicon-Via (TSV) technology. A TSV process was therefore developed for Medipix3 and thinned (50 microns) Timepix3 ASICs, in collaboration with Medipix and external partners. This talk gives an overview of the R&D program for silicon detectors at CLIC.
The LHCb VELO Upgrade

Pablo Vazquez\textsuperscript{1}

1) CERN

The upgrade of the LHCb experiment, scheduled for LHC Run-3, will transform the experiment to a trigger-less system reading out the full detector at 40 MHz event rate. The Vertex Locator (VELO) is the silicon vertex detector surrounding the interaction region. The strip detector currently installed will be replaced with a hybrid pixel system equipped with electronics capable of reading out at 40 MHz, designed to accumulate an integrated luminosity of $50 \text{ fb}^{-1}$ and beyond.

The upgraded detector comprises silicon pixel sensors with $55 \times 55 \text{ \mu m}$ pitch, read out by the VeloPix ASIC, from the Timepix/Medipix family. The sensors will approach to within 5.1 mm from the LHC beams, resulting in a radiation tolerance requirement of up to $8 \times 10^{15} \text{ n}_{\text{eq}} / \text{ cm}^2$ over the full lifetime of the upgrade. The proximity also results in high data rates, with the hottest region having pixel hit rates of 900 Mhits/s. The total data rate of the upgraded VELO is more than 3 Tbit/s for the upgraded VELO.

The VELO Upgrade module is a double sided construction, with two hybrid pixel assemblies and their PCB circuits mounted on either side of the central backbone; a 400 um thick silicon plate incorporating cooling microchannels for the circulation of evaporative CO\textsubscript{2}. Microchannel cooling brings many advantages: very efficient heat transfer with almost no temperature gradients across the module, no CTE mismatch with silicon components, and low material contribution. However the thermal stability has to be carefully controlled due to the large temperature gradients and the limited mechanical envelope for the module. A new design using borosilicate glass has been implemented to match the CTE while insulating the relevant module parts.

The ASIC readout is data driven and zero suppressed, and the implementation of the super pixel concept (4x2 pixel grouping) further optimises the bandwidth and available space. The timewalk is minimised to reduce the number of out-of-time hits in the 25 ns LHC datataking conditions. Because of the severe radiation environment the ASIC is equipped with SEU protection and is designed to cope with sensor leakage currents. In order to meet the huge data output rate requirement while keeping the power consumption within the budget a dedicated 5.12 Gbit/s output serialiser, the GWT (Gigabit Wireline Transmitter), has been developed. The high data rates require development of low-mass, high-speed, flexible electrical serial links bringing the data out of the vacuum where electrical-to-optical conversion is performed.

As part of the research and design process, a dedicated Timepix3 telescope has been constructed for use in test beam facilities. capable of reconstructing tracks with high rate and precision. Tracks measured with the telescope have excellent temporal (~1 ns) and spatial resolution (~2 um), and the telescope has been operated with a rate of tracks written to disk up to 5 MHz - limited so far only by available beam conditions. Sensors for the VELO upgrade have been produced with a variety of designs, including both $n$-type and $p$-type, various guard ring designs and thicknesses, and from two vendors, and irradiated to full fluence before evaluation in the telescope.

This paper will present the status of the VELO Upgrade module design, as well as latest results from the electronics and readout developments. The results from irradiated sensors in lab and beamtests will be shown.
Spatial resolution, image quality and count rate performance can all be optimized in imaging systems using pixelated sensor arrays and independent channel readout. In preclinical PET imaging, the pixel needs to be downsized to ~1.2 mm or less in order to achieve an image definition in mice that is comparable to that currently obtained in humans. This represents a daunting challenge arising from the scintillation crystal arrays, the pixelated photodetector readout, and processing system that must be implemented to achieve the one-to-one readout scheme in a compact configuration.

These challenges were addressed by designing a free-standing detector front-end consisting of four 4×8 arrays of Lu1.9Y0.1SiO5 (LYSO) scintillator crystals, each matched to 4×8 monolithic arrays of reach-through avalanche photodiodes (APD) interfaced through an interposer to two custom-designed 64-channel, mixed-signal, application-specific integrated circuits (ASICs). The interposer consists of a ceramic APD-carrier surface-mount to a PCB daughter board carrying the flip-chip ASICs on the backside.

The scintillation light is piped within each pixel using epoxy-bonded 3M ESR reflective film on sides and a diffuse reflector opposite to the readout face. The blue-enhanced APD achieved 55% quantum efficiency at the LYSO peak emission of 420 nm. The APD pixel leakage current and noise were limited to 2±1 nA and < 0.5 pA/Hz½, respectively, by trading off some area of side pixels with a guard ring. The APD signal is processed by the custom-designed ASIC implementing a real-time, dual-threshold, time-over-threshold (ToT) scheme to enable low power and low area occupancy analog-to-digital data conversion.

A module-to-module (128×128 pairs) coincidence time resolution below 4 ns was measured and the energy resolution was 24±2% after correction for the non-linear ToT response. This 128-channel front-end detector module will serve as the building block to develop the next generation PET scanners achieving sub-mm spatial resolution for small to medium-size animal imaging.

This paper will present the status of the VELO Upgrade module design, as well as latest results from the electronics and readout developments. The results from irradiated sensors in lab and beamtests will be shown.
The rapid rise in the application of proton beams in the radiotherapeutic treatment of cancer has highlighted the need for imaging, both planar and CT, using the same particles to treat and to image. PRaVDA (Proton Radiotherapy Verifications and Dosimetry Applications) is a unique instrument capable of delivering several imaging modalities, both for planning and on-treatment monitoring, and accurate dosimetry.

Two sets of double proton trackers, before and after the patient, consist of multiple silicon strip sensors; while the (optional) residual energy range discriminator (or range telescope) can be implemented in multiple crossed layers of strips, radiation-hard fast CMOS imagers, or a mixture of both. Both the strips, and associated ASICs, and large-area CMOS were custom designed to meet the specific needs of the proton therapy environment. Strips operate at over 100 MHz, while the 5 x 10 cm CMOS operate at 1k frame/s. It is current state of development, PRaVDA can record the trajectories of over 25M proton/s.

This presentation will cover the overall design of the system, including the DAQ, but with a particular emphasis of the performance of the sensors.

The overall aim of PRaVDA is to provide multi-mode proton CT of clinical quality.

Figure shows reconstructed images of Pacman-shaped beam passing through four proton trackers (29 MeV).
Asymmetric masks for large field-of-view and high-energy X-ray phase contrast imaging

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We report on a large field of view, laboratory-based X-ray phase-contrast imaging [1] (XPCI) setup. The method is based upon the asymmetric mask design [2] that enables the retrieval of the absorption, refraction and ultra-small-angle scattering properties of the sample without the need to move any component of the imaging system. This can be thought of as a periodic repetition of a group of three (or more) apertures arranged in such a way that each laminar beam, defined by the apertures, produces a different illumination level when analyzed with a standard periodic set of apertures. The sample is scanned through the imaging system, also removing possible aliasing problems that might arise from partial sample illumination when using the edge illumination (EI) [3] technique. This approach preserves the incoherence and achromatic properties of EI, removes the problems related to aliasing and it naturally adapts to those situations in clinical, industrial and security imaging where the image is acquired by scanning the sample relative to the imaging system. These concepts were implemented for a large field-of-view set of masks (20 cm x 1.5 cm and 15 cm x 1.2 cm), designed to work with a tungsten anode X-ray source operated at 80-100 kVp. Details on the system design and the retrieval algorithm will be presented and discussed along with the preliminary experimental results.

Hadrontherapy monitoring by means of PET systems has been carried out since 1997 and it is one of the in-vivo non invasive monitoring techniques employed clinically. It can be performed off-line, in-room and in-beam. The in-beam modality is the least affected by the biological wash-out and patient repositioning.

On the other hand, the large radiation background produced during the irradiation (mainly prompt gammas and neutrons) can worsen the measurement of the 3D spatial distribution of the $\beta^+$ emitter isotopes. Therefore the in-beam PET monitoring is either performed after irradiation, as for example in cyclotron based facilities, or during the inter-spill pauses at the synchrotron based facilities. As a result, a fraction of PET data (as for example the in-spill data) is discarded.

In this work we present the performance of the in-beam PET scanner developed within the INSIDE project. The INSIDE PET scanner is made of two planar heads, 10 cm wide (transaxially) x 25 cm long (axially), composed of pixellated LFS crystals coupled to Hamamatsu MPPCs. Custom designed FE and DAQ systems allow an on-line reconstruction of PET images from separated in-spill and inter-spill data sets.

The INSIDE PET scanner has been recently installed at the CNAO hadrontherapy facility and the first experimental measurements have been carried out.

PET data were acquired during the irradiation of PMMA phantoms with monoenergetic proton beams. A sub-millimetric precision was achieved in the measurement of the activity fall-off. The difference in the activity fall-off between two different beam energies was in agreement within 1 mm with the expected proton range difference calculated from the NIST data.

PET images of a treatment proton therapy plan delivered to an anthropomorphic phantom were also successfully reconstructed.
CZT Sensors for Computed Tomography

Kris Iniewski¹

1) Redlen Technologies

Recent advances in THM growth and device fabrication that require additional processing steps has enabled to dramatically improve hole transport properties and reduce polarization effects. As a result high flux operation of CZT sensors at rates of 200 Mcps/mm² is now possible and has enabled multiple medical imaging OEMs to start building prototype CT scanners.

In order to prepare for high volume commercial production we are moving from individual tile processing to whole wafer processing using silicon methodologies, such as waxless processing, cassette based / touchless wafer handling. We have been developing parametric level screening at the wafer stage to ensure high wafer quality before detector fabrication in order to maximize production yields. These process improvements enable us, and other CZT manufacturers who pursue similar developments, to provide high volume production for photon counting applications in an economically feasible manner.

CZT sensors are capable of delivering both high count rates and high-resolution spectroscopic performance, although it is challenging to achieve both of these attributes simultaneously. The talk discusses material challenges, detector design trade-offs and ASIC architectures required to build cost-effective CZT based detection systems. Photon counting ASICs are essential part of the integrated module platforms as charge-sensitive electronics needs to deal with charge-sharing and pile-up effects.

Technological development and innovation in CT imaging proceeds at a rapid pace. New CZT sensor technologies for spectral multi-energy image acquisition are being developed partially driven in the demands of the field of cardiac radiology for better quality images of tiny moving structures as well as a push towards using CT for novel tissue characterization. Whole heart coverage, rapidly acquired motionless images with lower contrast volumes at very low doses is becoming a reality.
Masahiko Kurakado¹, Kazuo Taniguchi¹

1) Techno-X Co., Ltd.

Superconducting tunnel junction (STJ) detectors and superconducting transition edge sensors (TESs) are representative superconductor detectors that have much higher energy resolutions than those of semiconductor detectors. STJ detectors are thin (e.g., 0.2-μm) and are therefore suitable for the detection of low-energy X-rays. The signals of STJ detectors are more than 100 times faster than those of TESs. In contrast, TESs are micro-calorimeters that measure the radiation energy by the change in temperature. Therefore, signals are slow and typically several hundred μs. Thus, attainable count rates for X-rays are usually lower than a few hundred cps. However, TESs possess excellent energy resolutions. For instance, it is 1.8 eV for 5.9-keV X-rays. STJ detectors and TESs are thin-film detectors that are fabricated using lithography and can be easily arrayed. An array of STJs or TESs can be utilized as a pixel detector. Superconducting series-junction (SSJ) detectors consist of many STJs and a single-crystal substrate as an absorber for radiations (Fig.1). SSJ detectors are position sensitive (Fig.2). They have low energy resolutions compared to that of STJ detectors or TESs. However, their resolutions are higher than those of semiconductor detectors (Fig.3). In addition, their detection efficiencies and possible count rates are relatively high.

In this presentation, we will give an overview of STJ detectors, TES and SSJ detectors.
Proton radiography imaging technique has a large potential to improve the accuracy of proton energy losses (proton stopping powers, PSPs) in various tissues in patients undergoing proton therapy. The uncertainty of PSPs, currently obtained from translation of X-ray Computed Tomography (CT) images, needs to be minimized from 3-5% or higher \[1-5\] to less than 1%, which is crucial to make an accurate treatment plan with a proton beam.

With the Geant4 Monte Carlo toolkit we simulated a proton radiography detection system (as we have used in actual experiments) with two position sensitive detectors, and a residual energy detector. A complex phantom filled with 11, partly tissue-equivalent, materials (figure a) is placed between the two position detectors. We irradiated the phantom with various proton beam energies relevant in clinics (70-250 MeV) and study energy loss and scattering angle radiographs. Protons passing through different materials in the phantom lose energy. The energy loss calculated as a difference between the proton beam energy and proton residual energy recorded in the energy detector is used to create a radiography image of the phantom. The multiple Coulomb scattering of a proton traversing different materials causes blurring of the radiography image. To improve the image quality and identify each material in the phantom, we select protons with small scattering angles. Applying a scattering angle cut of 8.7 mrad (figure b, dark blue line) results in better determination of the energy loss of the phantom materials.

A good quality of the proton radiography image, in which different materials can be recognized accurately, and in combination with X-ray CT will lead to more accurate relative stopping powers predictions.

![Proton radiography image](image-url)

**Proton energy and scattering radiographs to improve proton treatment planning: A Monte-Carlo study**

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In small-animal PET imaging, lesions are in the order of only few mm and the detector spatial resolution has a large contribution on the final image quality.

We present a γ-ray detection module optimized for very high resolution PET, able to resolve arrays of scintillators with sub-millimeter pitch.

The detector is composed of a single ceramic substrate (LTCC): it hosts four bump-bonded PETA5 ASICs on the bottom side and an array of SiPMs on the top surface (fabricated in HD-RGB technology by FBK).

Each chip has 36 channels, leading to 144 readout channels on a sensitive area of about 3×3 cm². The module is MR-compatible.

The thermal decoupling of the readout electronics from the photon sensors is obtained with an efficient internal liquid channel, integrated within the ceramic substrate.

Two modules have been designed, based on different SiPM topologies:

- Light spreader-based: an array of 12×12 SiPMs, with an overall pitch of 2.5 mm², is coupled with a scintillators array using a 1 mm glass plate. The light from one crystal is spread over a group of SiPMs, which are readout in parallel using PETA5 internal neighbor logic
- Interpolating SiPM-based: ISiPMs are intrinsic position-sensitive sensors. The photon diodes in the array are connected to one of the four available outputs, so that the center of gravity of any cluster of detected photons can be reconstructed using a proper weight function of the four signal amplitudes. An array of ISiPMs, each 5×7.5 mm², is directly coupled with the scintillating crystals.

Both modules can clearly resolve LYSO arrays with a pitch of only 0.833 mm (see Fig1).

The detector can be adjusted for clinical PET, where has already shown ToF resolution of about 200 ps CRT at FWHM.
In recent years phase-contrast has become a much investigated modality in radiographic imaging. The radiographic setups employed in phase-contrast imaging are typically rather costly and complex, e.g. high performance Talbot-Laue interferometers operated at synchrotron light sources. In-line phase-contrast imaging states the most pedestrian approach towards phase-contrast enhancement. Utilizing small angle deflection within the imaged sample and the entailed interference of the deflected and un-deflected beam during spatial propagation, in-line phase-contrast imaging only requires a well collimated X-ray source with a high contrast & high resolution detector. Employing high magnification the above conditions are intrinsically fulfilled in cone-beam micro-tomography. As opposed of 2D imaging, where contrast enhancement is generally considered beneficial, in tomographic modalities the in-line phase-contrast effect can be quite a nuisance since it renders the inverse problem posed by tomographic reconstruction inconsistent, thus causing reconstruction artefacts.

We present an experimentally enhanced model-based approach to disentangle absorption and in-line phase-contrast. The approach employs comparison of transmission data to a system model computed iteratively on-line. By comparison of the forward model to absorption data acquired in continuous rotation strong local deviations of the data residual are successively identified as likely candidates for in-line phase-contrast. By inducing minimal vibrations (few mrad) to the sample around the peaks of such deviations the transmission signal can be decomposed into a constant absorptive fraction and an oscillating signal caused by phase-contrast which again allows to generate separate maps for absorption and phase-contrast. The contributions of phase-contrast and the corresponding artefacts are subsequently removed from the tomographic dataset. In principle, if a 3D handling of the sample is available, this method also allows to track discontinuities throughout the volume and therefore states a powerful tool in 3D defectoscopy.
This talk will cover the imaging requirements for state-of-the-art x-ray breast imaging systems. There will be a strong focus on practicality and the clinical needs. We will cover the requirements for 2D digital mammography, digital breast tomosynthesis, dual-energy imaging, and breast biopsy.

The advantages and disadvantages of direct conversion (such as a-Selenium) and indirect conversion (such as CsI) detectors will be discussed. Similarly, we will cover charge integrating and photon counting detectors. The talk will cover spatial resolution, temporal requirements, and noise properties for high performance breast imaging. We will also review x-ray sources and their implications for the radiation detectors. We will also briefly cover gamma ray breast imaging systems.

A review of commercially available and proposed imaging systems will be discussed.
The back of the eye is lined by an extraordinary dynamic image detector, the retina. This living neural network is able to extract vital information about the external visual world, and transmit this information in a timely manner to the brain. The brain, in turn, processes the retinal data and generates visual perception and behavior.

In this talk, after a brief introduction to retinal architecture, I will describe how we measure the functional properties of the retina, show what we have learned about its functional organization, and discuss studies aimed at guiding the design of retinal prosthetic devices. I will next describe the methods we employ to study visual processing in the brain. Along the way, I will illustrate how the technology we use for the retinal and brain studies was inspired by, and is linked to, the development of radiation imaging detectors for experiments in high energy physics.
The Timepix chip – 10 years of applications

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The Timepix chip is composed of a matrix of 256 x 256 square pixels at a pitch of 55μm. It can be programmed on a pixel-by-pixel basis to record particle arrival time, Time-over Threshold (ToT) or particle counts. This has made it a very versatile device and it has been used in the readout of various segmented semiconductor detectors, micro channel plates and different kinds of gas gain grid (GEM, InGrid etc). The chip has been used in a large variety of applications including classroom experiments, space science, space dosimetry, X-ray diffraction and spectroscopy, neutron imaging and finally back to High Energy Physics. This paper will attempt to summarize 10 years of experience with the Timepix chip and cover many of the applications highlighting, where possible, its unique contribution to a given field.
In recent years new detectors became available for imaging in Electron Microscopy e.g. FEI Falcon and Gatan K2, the DE-series. These detectors gave a huge boost to imaging of tissues, cells and protein complexes. Recently these detectors, together with advances in image processing and computing power, made it possible to break the 2.5 Ångstrom resolution barrier in imaging of single bio-molecular complexes (Bartesaghi, Nature 2015: the ‘resolution revolution’ (Kühlbrandt, Nature 2014). These detectors have some drawbacks when it comes to diffraction studies: they are not very radiation hard and have a low dynamic range. These characteristics make it almost impossible to perform a good very low dose diffraction experiment, and one was still dependent on CCD cameras which are characterized by electronic noise, dark currents and noise coming from other sources than electrons (like the huge X-ray background that is present in any EM).

We have recently demonstrated that quantum area electron detectors like the Medipix have a similar impact when switching to diffraction mode [van Genderen, 2016]. We have solved the crystal structures of organic compounds from nano-crystals using electron diffraction with as low a dose as 0.013e-/Å²s. This enabled us to collect sufficient data for structure solution from a single nano-crystal even at room temperature.

I will discuss our recent progress on electron nano-crystallography, how these types of detectors will tear down the boundaries of electron diffraction of organic materials, why we think that diffraction will overcome the resolution problems that single particle faces and what role specialized diffraction cameras play in this process.

van Genderen et al. 
van Genderen et al. 
Nederlof, I., van Genderen, et al. 
Development and characterization of high-resolution neutron pixel detectors based on Timepix read-out chips

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Recent advances in semiconductor technology allow for the construction of hybrid planar pixelated detectors enabling position-sensitive detection of single quanta with high sensitivity, energy discrimination, noiseless digital integration (counting), high frame rate and virtually unlimited dynamic range. All these properties can be utilized also for neutrons by adaptation of the sensor with a suitable isotope, such as 6Li and 10B, converting thermal and cold neutrons into energetic light ions. The adopted devices then typically provides spatial resolution at the level comparable to the pixel pitch (~55 mm for Timepix) and sensitive area of about few cm².

In this contribution we describe further progress in neutron imaging performance based on the development of the Timepix-based large area imaging detector consisting of a matrix of sensitive detector tiles. Each tile - a single Timepix assembly equipped with an edgeless silicon sensor forms the final device without image-disrupting gaps or insensitive areas (4 × 5 tiles with the total sensitive area of 71 × 57 mm² comprising 1.3 M pixels). Further presented technological development is devoted to modular fast read-out single-chip neutron devices which can be operated effectively in the even-by-event mode enabling position sensitive detection with resolution better than 5 mm.

The measurements characterizing detectors performance were carried out in combination with high-quality neutron beamlines such as the cold neutron imaging instrument ICON at PSI, the high-flux instrument Neutrograph at ILL and the newly built thermal neutron imaging beamline at the Research Centre Rez near Prague. At all these facilities, high-resolution high-contrast neutron radiography with the newly developed detector have been successfully applied for imaging of objects that were earlier with hybrid pixel technology difficult to image, for example, various composite materials, objects of cultural heritage, larger paleontological samples etc.
Here we report about new and enlarged Germanium pixelated sensors for the Medipix3RX read-out chip. The size of the sensor is 45 mm x 30 mm with 768 x 512 pixels. The size of the pixels is 55 um x 55 um. The pixel matrix of a single Medipix3RX chip is 256 x 256 pixels. Here we have a Germanium sensor made in the shape of 3 x 2 Medipix3RX read-out chips.

Germanium sensors have an advantage in respect to Silicon sensor because their quantum efficiency is much higher for photon energies above 20 keV. We target the application of Ge sensors for photon energies between 20 keV and 50 keV. Advantage of Ge is that it can be produced in a wafer size of up to 100mm with excellent uniformity. One disadvantage of Ge is that it cannot be used at room temperature. Theoretical considerations show that satisfactory results could be produced already at -80 C. In our set-up we can cool a Ge detector down to -105 C before operation. This is enough to make imaging and estimate the quality of the detector performance.

The germanium sensor was fabricated by Canberra Company in France. It was bump bonded to the Medipix3RX ASICs by Fraunhofer IZM institute in Berlin, Germany and at DESY we are testing the sensor performance.

In the summer of 2015 we did a preliminary testing in the climate chamber at a temperature of around -40 C in order to estimate the quality of bump bonds. It was shown that more than 99% of all pixels are bonded correctly. Now, we prepare the experiment with the new vacuum chamber and cooling system in order to make imaging with the Ge hexa sensor. These results will be presented at the conference.
Electron backscatter diffraction (EBSD) is a well-established scanning electron microscope (SEM) -based technique [1]. It allows the non-destructive mapping of the crystal structure, texture, crystal phase and strain with a spatial resolution of tens of nanometers. Conventionally this is performed by placing an electron sensitive screen, typically consisting of a phosphor screen combined with a charge coupled device (CCD) camera, in front of a specimen, usually tilted 70° to the normal of the exciting electron beam. Recently, a number of authors have shown that a significant increase in spatial resolution is achievable when Kikuchi diffraction patterns are acquired in transmission geometry; that is when diffraction patterns are generated by electrons transmitted through an electron-transparent specimen. The resolution of this technique, called transmission Kikuchi diffraction (TKD), has been demonstrated to be better than 10 nm [2,3]. We have recently demonstrated the advantages of a direct electron detector, Timepix [4], for the acquisition of standard EBSD patterns [5]. In this talk we will discuss the advantages of Timepix to perform TKD. Particularly relevant for TKD, is its very compact size, which allows much more flexibility in the positioning of the detector in the SEM chamber. We will furthermore show recent results using Timepix as a virtual forward scatter detector, and will illustrate the information derivable on producing images through processing of data acquired from different areas of the detector. We will show results from samples ranging from gold nanoparticles to nitride semiconductor nanorods.

Nowadays X-ray computed tomography (CT) techniques employing synchrotron radiation source allow studying rapid processes such as foam forming, metal crystallization, bubbles nucleation etc. Related 4D tomography refers to the possibility to perform series of time-lapse 3D topographies, providing information about the material microstructure evolution, where CT data are acquired within one second or faster. It leads to requirement of the intensive X-ray source and fast detector with appropriate efficiency. By another words, lower intensity of the X-ray source requires higher detection efficiency and vice versa.

In this contribution we show that the fast 4D CT is possible to be performed even in laboratory conditions. The experiment was done with sparkling water in plastic syringe (dissolving C vitamin), carried out at the Centre of Excelence Telč. The microfocus X-ray tube operated at 60 kV potential with power 50 W on the target was used as X-ray source. Semiconductor imaging detector Timepix with 1 mm thick CdTe sensor and fast parallel read-out interface AdvaPIX allowing frame rate of up to 1700 fps was employed. The object rotation was carried out using air-bearing rotational stage with maximal speed of 1 revolution per second. The projection data were taken in continuous “on the fly” regime not stopping the rotational stage between exposures to reduce the dead time. Finally 30,000 projections images with 3.4 ms exposure each were taken during two minutes while object was rotated 120 times. Each single data set for CT reconstruction consists of projections over 180 degrees.

CT reconstructions were done using iterative algorithm OSEM (12). In the final time dependent reconstruction it is nicely visible that evolution of bubbles is quite dramatic at the beginning of the experiment and that their movement is influenced by the centrifugal acceleration.
Per-pixel Energy Calibration of Photon-counting Detectors

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We present an algorithm for per-pixel energy calibration of Medipix3RX detectors used in MARS spectral computed tomography (CT). Quality of a spectral CT system is influenced by the accuracy of the detector’s energy calibration. Global energy calibration maps a given threshold to the average energy response of all pixels of the detector. Per-pixel energy calibration quantifies the energy response of individual pixels relative to this average response. Additional information provided by per-pixel calibration can be utilized to improve spectral reconstruction.

Variations arising from CMOS manufacturing process and also in properties of the sensor mean that different pixels respond differently to photons with the same energy. This leads to a dispersion of energy response to a global threshold across the detector pixels [1]. Therefore, an offset exists between the true energy response of the pixels and the average energy response (Figure 1). When unaccounted for, this error challenges spectral imaging by degrading the energy resolution and contributes to blurring of the energy information [2].

The algorithm given here uses a global energy calibration to operate a threshold scan over five consecutive threshold levels, centred at the pre-selected target threshold. This procedure is repeated for the other energies. A set of offsets calculated at different target energies determines the energy threshold difference between the global energy calibration and true energy response of a pixel across the energy spectrum. We use linear regression to produce a separate calibration map for every pixel. These energy maps have slightly different slope and offset from each other and from the global energy map.

This algorithm was validated using a MARS scanner with an equalized Medipix3RX chip flip-bonded to 2 mm thick CdTe semiconductor crystal at a pitch of 110 μm. Results revealed that our algorithm improved FWHM of the energy response of the pixels by 30%.
Miniaturized X-ray telescope for VZLUSAT-1 nanosatellite with Timepix detector

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We present the application of a Timepix detector on the VZLUSAT-1 nanosatellite. Timepix is a compact pixel detector (256x256 square pixels, 55x55 μm each) sensitive to hard X-ray radiation. It is suitable for detecting extraterrestrial X-rays due to its low noise characteristics, which enables measuring without special cooling. This project aims to verify the practicality of the detector in conjunction with 1-D lobster-eye optics to observe celestial sources between 5 and 20 keV. A modified USB interface (made by IEAP at CTU in Prague) is used for low-level control of the Timepix. An additional 8-bit Atmel microcontroller is dedicated for commanding the detector and to processes the data on-board the satellite. We present software methods for onboard post-processing of captured images, which are suitable for implementation under the constraints of the low-powered embedded hardware. Several measuring modes are prepared for different scenarios including single picture exposure, solar UV-light triggered exposure, and long-term all sky monitoring. The work has been done within Medipix2 collaboration. The satellite is planned for launch during the summer of 2016 as a part of the QB-50 project with an end of life expectancy in 2018.
Measurement of particle directions in low earth orbit with a Timepix

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In low earth orbit (LEO) in space electronic equipment on board satellites and space crews are exposed to high ionizing radiation levels. To reduce radiation damage and the exposure of astronauts, to improve shielding and to assess dose levels, it is valuable to know the composition of the radiation fields and particle directions. The presented measurements are carried out with the Space Application of Timepix Radiation Monitor (SATRAM). There, a Timepix detector (300 μm thick silicon sensor, pixel pitch 55 μm, 256 x 256 pixels) is attached to the Proba-V, an earth observing satellite of the European Space Agency (ESA). The Timepix detector’s capability was used to determine the directions of energetic charged charged particles. Data are continuously taken at an altitude of 820 km on a sun-synchronous orbit. The particles pitch angles with respect to the sensor layer were measured and converted to an Earth Centred Earth Fixed (ECEF) coordinate system. The simulated angular response functions of the detector – taking the systematics of the reconstruction algorithm and the pixilation into account – were used for the unfolding of the measured angular distributions.
NASA has evaluated 7 Timepix-based radiation imaging detectors from the CERN-based Medipix2 collaboration on the International Space Station (ISS), collecting more than 3-years of data, as well on the December, 2014 EFT-1 mission testing the new Orion Multi-Purpose Crew Vehicle. These data along with data collected at ground-based accelerator facilities including the NASA Space Radiation Lab (NSRL) at Brookhaven in the US, as well as at the HIMAC facility at the National Institute for Radiological Sciences in Japan, have allowed the development of software analysis techniques sufficient to provide a stand-alone accurate assessment of the space radiation environment for dosimetric purposes. Recent comparisons of the performance of the Timepix with both n-on-p and p-on-n Si sensors will be presented.

The further evolution of the Timepix technology by the Medipix3 collaboration in the form of the Timepix3 chip, which employs a continuous data-driven readout scheme, is being evaluated for possible use in future space research applications. Initial performance evaluations at accelerators will be reported.

The Medipix2 Collaboration is also in the process of designing an updated version of the Timepix chip, called the Timepix2, which will continue the frame-based readout scheme of the current Timepix chip, but add simultaneous charge encoding using the Time-Over-Threshold (TOT) and first-hit Time-of-Arrival (TOA) encoding. Current plans are to replace the Timepix by the Timepix2 with minimal reconfiguration of the supporting electronics.

Longer-term plans include participation in the currently forming Medipix4 collaboration. A summary of these prospects will also be included.
Single photon counting pixel detectors becomes increasingly popular in various 2-D X-ray imaging techniques and scientific experiments mainly in solid state physics, material science and medicine [1]. This paper presents architecture and measurement results of UFXC32k chip designed in CMOS 130 nm process. The chip consists of about 50 million transistors and has an area of 9.64 mm x 20.15 mm. The core of the IC is the matrix of 128 x 256 pixels of 75 μm pitch. Each pixel contains a CSA, a shaper with tuneable gain, two discriminators with correction circuits and two 14-bit ripple counters operating in normal mode (with energy window), long counter mode (one 28-bit counter) and zero-dead time mode (up to 50 kfps). Gain, noise and high count rate performance were verified with X-ray radiation (Roentgen lamp and synchrotron radiation). The measured ENC is equal to 123 el. rms and each pixel dissipates 26 μW at room temperature. An effective offset spread calculated to the input is only 9 el. rms with the gain spread of 2 %. The count rate per pixel depends of the effective CSA feedback resistance and in the ultra fast mode dead time in the front-end electronics can be set as low as 85 ns (paralyzable model). The chip performance was also characterized vs. temperature dependence.


This work is supported by the National Center for Research and Development, Poland PBS1/A3/12/2012 in the years 2012-2016.

Fig. 1. Rhinoceros beetle – photo and radiograms taken with UFXC32k chip bump-bonded to Si detector.
An optical data transmission system based on wavelength division multiplexing (WDM) has the potential to increase the data readout bandwidth of current and future imaging detectors substantially. We propose a multi-wavelength-channel transmitter developed on a silicon photonics platform consisting of monolithically integrated modulators and optical (de-)multiplexers. The first demonstrator currently under development aims for a data rate of 160 Gbit/s per optical fiber, scalable to 5 Tbit/s and beyond.

A crucial component is the electro-optic modulator to encode sensor data onto an optical carrier. We present the results of both simulation and measurement of the impact of radiation on silicon Mach-Zehnder modulators based on pn-junctions.

The modulators were exposed to ionizing X-ray radiation to a total dose of 1.0 MGy, which is sufficient for most detectors at FAIR, XFEL or even at HL-LHC. All devices show significant performance degradation in modulation efficiency, but were still functional at the end of the experiment. The degradation strongly depends on the chosen working point of the modulators.

Simulations have been performed focusing on carrier accumulations at the interface layer between silicon and silicon dioxide, which is the main damage mechanism in metal-oxide-semiconductor structures. The charged layer restricts the expansion of the space-charge region, which is essential for the operation of photonic pn-modulators.

The above results represent a first important step in providing an optical high-speed WDM transmission system even in harsh radiation environments.
A 3D-IC (Three Dimensional Integrated Circuit) is an effective solution for reducing the manufacturing costs of advanced 2D LSI while ensuring equivalent device performance and functionalities. This technology allows for a new device architecture of stacked detectors/sensor devices with a small dead sensor area and facilitates hyper-parallel data processing. This structure with micro-bump connections enables considerable improvement of the time–space resolution for detectors and array sensors. This paper presents experimental results for a prototype pixel detector with 3.0-μm gold cone bumps fabricated by NpD (nanoparticle deposition) and that with gold cylindrical bumps fabricated by a low-incident-angle deposition method. The as-deposited cone bumps consist of gold nanoparticles and are easier to deform compared to the plated gold bumps. Consequently, the collapsibility of the gold cone bumps allows for low-stress bonding, resulting in a compliant and reliable junction without damaging the device surface. The bump size is determined by photoresist patterning, and the bump connection does not greatly protrude during junction formation, in contrast with melting-type bump connections. In addition, the shrinkage ratio of the volume is larger than that of the surface area. Thus, the bump resistance of an easily oxidized metal with a diameter of few microns is affected by the bonding atmosphere. On the other hand, gold is an oxidation-resistive material; therefore, bonding with gold cone microbumps does not adversely affect the electrical characteristics. The resistances per bump of the stacked Si-base pixel detector and stacked CdTe/Si-LSI X-ray sensor are both approximately 0.25 Ω.
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We designed, simulated and fabricated new sensors with MEMS based high aspect-ratio trenches (3D) to be filled with $^{10}$B neutron converter with a predicted efficiency of about 20% (to be compared with 4% of traditional planar deposition on the sensor’s surface) and reduced fabrication complexity compared to our previous prototypes [1] and to sensors proposed by other groups [2][3]. The wafer layout includes pixel detectors compatible with MEDIPiX read-out chip and diodes to allow bump-bonding-free tests. Several device layouts were designed, differing by the geometrical options adopted for trenches allowing for several application possibilities.

A fabrication batch was recently completed at Fondazione Bruno Kessler (FBK) in Trento, Italy on 6” substrates showing excellent first results from electrical measurements. Tests on wafers indicated full depletion voltages between 80 and 100V (depending on the sensor’s geometry) and leakage currents as low as ~5 nA/cm². Breakdown voltages exceeded 500 V with total capacitances of about 45 pF/cm². Furthermore preliminary functional tests with an $^{241}$Am α-source have shown full charge collection efficiency. Both electrical and functional test results are in good agreement with TCAD simulations, thus validating the design approach and the quality of the fabrication process.

At the conference we will report on the device design and technology, as well as on selected results from the electrical and functional characterization.

References
Hybrid pixel detector modules are the main building blocks of silicon particle tracking detectors in high energy physics experiments as well as in x-ray cameras for research and development using synchrotron radiation. In most of the application the pixel pitch is the same for the electronic readout chips and the pixelated solid-state sensor. With this approach larger sensor tiles have to be connected to multiple readout chips. The idea presented here offers a more flexible hybrid module concept. Using a silicon interposer with copper-filled through silicon vias (TSVs) the high density pixel pitch of the electronic readout ASIC can be redistributed to a flexible sensor pixel pitch adapted to the requirements of the application. This fan-out hybrid pixel module approach opens a wide range for the use of different sensor configurations and materials.

The state of the art of the interposer technology in industrial application will be described in this presentation, i.e. for new FPGA and high end GPU concepts. Starting from the concept of fan-out hybrid pixel module the individual process steps of interposer manufacturing up to the interconnection technology will be described in detail. These are the routing of the high density pitch on readout ASIC side using frontend feature size and technology, the formation of through silicon via and applicable interconnection technologies for both sides of the interposer.

Glass comes into focus as an interposer material due to its good electrical isolation characteristic. New results of technological process development and material characterization of glass interposers will be presented. The development of these devices is driven by the reduction of interposer thickness and the reduction of through glass via (TGV) diameter and pitch. To summarize the presentation an overview of interposer processed at Fraunhofer IZM for several applications will be shown.
The Data Deluge at Synchrotrons: Big Cameras, Big Data.

Steve Aplin

1) DESY

The latest generation of pixel detectors currently being deployed at synchrotron and X-ray free electron laser facilities are capable of generating data rates well in excess of 1 Gigabyte per second and with frames rates exceeding 1 kHz. This will increase by a factor of 10 in the near future. Such data rates coupled with the fact that data reduction and online data rejection are not widely utilised in the field, create a significant challenge in terms of data handling.

The traditional approach to data acquisition at synchrotrons has been based around writing a single frame per file directly to a local, or network attached, file system. This approach was rejected a priori by free electron laser facilities, which have implemented dedicated DAQ systems. But now the single frame per file approach is also pushing the limits of what is possible even at synchrotrons.

The intrinsic nature of beam-line utilisation, where competing scientific groups may be present at the beam-line concurrently, also presents the need for strong data access control, authentication, and authorisation. With what is potentially Petabytes of data, this requires a far closer collaboration between beam-line scientists, experiment control groups, and central IT infrastructure than ever before.

The presentation will focus on giving an overview of what is happening after the data leaves the detector. This will be illustrated using the recent upgrade of the computing infrastructure at PETRA III, discussing some of the technical solutions implemented to cope with the massive increase in data, such as messaging software used to distribute the data, file systems and formats used to store it, and access points which finally allow users to get their data home.
Various applications require densely packed multichannel photo sensor modules with single photon resolution. This allows to achieve a high precision in position tracking or coincidence measurement. Compared to bulky PMTs, Silicon Photomultipliers (SiPM) are like CMOS sensors most suitable for the realization of miniaturized, monolithic integrated multichannel arrays due to silicon planar technology.

The manifold possibilities of customized SiPM sensor design are illustrated on the basis of two detector prototypes with very different requirements, disclosing the ambitious packaging technology demands for high density channel integration.

For the application in high energy physics, the performance of a 128-channel SiPM detector module prototype with a single channel active area of 252 μm x 1620 μm for the LHCB Upgrade scintillating fiber Tracker at CERN was developed. The main request here is a very high photon detection efficiency in the blue-green range combined with an extremely low optical cross talk. Based on KETEK’s metal trench technology, a cross talk probability below 2% and a peak PDE at 420nm above 40% is realized.

Regarding the field of nuclear imaging applications, a tillable monolithic 64-channel SiPM chip with a size of 4.1 mm x 4.1 mm for small animal PET is demonstrated. The main challenge for this application is a very high blue light sensitivity combined with a sufficient dynamic range for a quite small active single channel area of 400 μm x 400 μm. This competitive requirement could be achieved on the basis of a 20μm-pitch micro cell with a very high fill factor of approximately 65%.
Performing low-noise electron diffraction experiments and exploring the fast dynamics of biological macromolecules in real space and real time with low electron dose require advanced ultrabright electron sources and high performance 2D detectors. Direct-electron-hit silicon detectors with high detective quantum efficiency (DQE) are a promising candidate to perform fast imaging experiments with high signal-to-noise ratio (SNR) and are thus becoming increasingly attractive. Therefore, we develop a novel direct-electron-hit silicon detector allowing high DQE and fast readout speed using DEPFET (DEpleted P-channel Field Effect Transistor) technology. This advanced detector will operate in a single shot mode at frame rates up to 80 kHz and will be devoted to carry out real time and real space imaging experiments such as capturing the molecular dynamics in biological samples. Due to its excellent noise performance and internal amplification, the DEPFET is able to detect small signals. This together with its low power consumption allows building very thin detector without extra material for cooling and mechanical support which leads to reduced multiple scattering and charge sharing in the sensitive layer. While this improves the spatial resolution, noise signal produced by backscattered electrons can degrade the detector performance. To characterize and optimize the performance of the detector, Monte Carlo simulation models are implemented. We optimized the detector design reducing largely backscattered electrons from the detector substrate and the surrounding housing, offering thus an excellent SNR and the capability to detect single primary electrons with high probability. This novel detector design shows good imaging performance in terms of improved spatial resolution, with modulation transfer functions (MTFs) very close to the MTF of the detector without housing and substrate. Based on the detector simulation models, the detector is now in the production process.
Test beam results of a Depleted Monolithic Active Pixel Sensor (DMAPS) prototype

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The DMAPS concept is a new monolithic pixel detector concept which integrates the front-end circuitry and the sensor on the same silicon substrate which can be fully depleted. The realization of prototypes of the DMAPS concept relies on the availability of multiple well CMOS processes and high resistive substrates. The CMOS foundry ESPROS photonics offers both and was chosen for prototyping. We have developed two prototypes, EPCB01 and EPCB02, in their 150 nm process on a high resistive n-type wafer of 50μm thickness. The prototypes have 352 square pixels of 40 μm pitch and small n-well charge collection node with very low capacitance (n+-implantation size: 5 μm by 5 μm) and about 150 transistors per pixel (CSA and discriminator plus a small digital part).

Measurements of the charge collection efficiency after neutron irradiation up to 5E14 neq were carried out in the lab and in a beam experiment using the AIDA telescope for reference. Due to the low leakage current of all sensors it was possible to operate them at room temperature. In addition the capacitances of two sensor designs with different diameters of the n+-implantation for contacting the charge collection node, 1.8 μm and 10 μm, were measured with a charge pump circuitry integrated on the chip.
Simultaneous x-ray transmission and fluorescence imaging

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X-ray imaging exploits the differences in the complex x-ray refractive index of materials to obtain spatial information on electron density changes. This technique has been used for over 100 years and is a popular in many areas of research. The use of x-ray fluorescence from materials for imaging has taken a little longer to emerge, but is now a mainstream imaging technique for materials analysis, especially on synchrotron storage ring sources. If these two techniques are combined and information obtained simultaneously on electron density and elemental concentration, it would add greatly to the characterisation of the object.

At the Imaging and Medical Beamline at the Australian Synchrotron we have been exploring methods of using coded illuminating beams during x-ray computed tomography. This is done in such a way that has little or no effect on the quality of the x-ray CT but the fluorescence emission from regions within the object is encoded. Emission encoding needs to be made such that it provides a means of decoding a map of fluorophore within the object. Data is presented which demonstrates the reconstruction of low resolution iodine fluorescence maps of a plastic phantom, from data collected on a single point detector during a CT scan. The future direction of this work aims to use a manifestation of compressive sensing to improve the accuracy of the reconstruction.
X-Ray Imaging at 4.5 MHz with GaAs:Cr Sensors

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2) Diamond Light Source
3) Tomsk State University

The STFC Rutherford Appleton Laboratory (UK) and Tomsk State University (Russia) have been working to develop and characterise detector systems based on chromium-compensated gallium arsenide (GaAs:Cr) semiconductor material for high rate X-ray imaging. Previous work has demonstrated the excellent uniformity of the material and its resistance to damage induced by high fluxes of X-rays. In this paper, recent results from experiments at the Diamond Light Source Synchrotron will demonstrate X-ray imaging with GaAs:Cr sensors at 4.5MHz.

STFC are currently developing a MHz frame rate X-ray camera, the Large Pixel Detector (LPD), for the European XFEL. The final detector will have 1 million pixels and allows analogue storage of 512 images at 4.5MHz in the detector front end. The current generation of the LPD detectors are being produced using 500\,\mu m thick silicon with a pixel pitch of 500mm. While these sensors produce excellent results, the detection efficiency above 12keV rapidly falls to <50\% requiring the use of tungsten shields to prevent significant radiation dose being absorbed in the ASIC. GaAs:Cr is >80\% efficient at energies <40keV leading to a greater number of X-rays being stopped, removes the need for tungsten shielding and extends the working energy range of the system.

Prototype LPD GaAs:Cr sensors with 16x32 pixels on a pitch of 250\,\mu m by 400\,\mu m were fabricated by Tomsk and flip-chip-bonded directly to the LPD ASIC at STFC using a silver-loaded epoxy and gold stud technique. Two 500\,\mu m thick GaAs:Cr tiles were mounted in an LPD super-module along with 2 regular Si sensors for comparison. The performance of these detectors were characterised at the Diamond Light Source on the B16 beam line operating in hybrid mode. Sensors were irradiated with monochromatic X-rays with energies 12-20keV delivered in a single hybrid pulse with a flux of \~1x10^8 photons s\textsuperscript{-1} mm\textsuperscript{-2}.
CdZnTe, CdTe and GaAs sensors bump bonded to DECTRIS’s readout ASICs PILATUS and IBEX are compared in terms of quantum efficiency, energy resolution, imaging properties like modulation transfer function (MTF) and line spread function (LSF) and count rate capabilities.

The quantum efficiency (QE) as a function of the energy for a monochromatic x-ray beam and a threshold at half the incoming x-ray energy shows distinctive differences between GaAs and CdTe/CdZnTe sensors. Due to the higher average atomic number of CdTe/CdZnTe, their quantum efficiency at energies above 40keV is higher. Because of the self fluorescence x-rays within the sensor material, the QE differs further at low energies between 10.3keV (k-edge of Ga) and 20keV, where the QE of GaAs is reduced and between 26.7keV (k-edge of Cd) and 40keV, where the QE of CdTe is reduced due to self-fluorescence x-rays in the sensor. The energy resolution of CdTe/CdZnTe and GaAs is similar between 15keV and 25keV. Between 26.7keV and 40keV, GaAs has a better resolution due to the self-fluorescence in the CdTe sensor resulting in a distorted measured x-ray spectrum. Above 40keV, the energy resolution of both materials is comparable.

For polychromatic x-ray beams the imaging properties were determined, including line spread function (LSF), the modulation transfer function (MTF) and the relative detective quantum efficiency (DQE). It was found that the LSF and MTF are very close to the theoretical limit expected from the corresponding pixel size, important for high spatial resolution imaging applications.

Furthermore, the rate capability of the sensors will be investigated. The novel IBEX ASICs allows to measure incoming photon fluxes up to $10^9$ counts/s/mm², making it an interesting readout ASIC to characterize sensors in the high rate regime.
Status of the AGIPD detector for the European XFEL

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AGIPD (adaptive gain integrating pixel detector) is a detector system for the European XFEL (XFEL.EU), which is currently being constructed in Hamburg, Germany.

The XFEL.EU will operate with bunch trains at a repetition rate of 10Hz. Each train consists of 2700 bunches with a temporal separation of 220ns corresponding to a rate of 4.5MHz. Each photon pulse has a duration of < 100fs (rms) and contains up to 1012 photons in an energy range between 0.25 and 25keV. In order to cope with the large dynamic range, the first stage of each bump-bonded AGIPD ASIC is a charge sensitive preamplifier with three different gain settings that are dynamically switched during the charge integration. Dynamic gain switching allows single photon resolution in the high gain stage and can cover a dynamic range of 10⁴x12.4keV photons in the low gain stage. The burst structure of the bunch trains forces to have an intermediate in-pixel storage of the signals.

The full scale chip, AGIPD1.0, has 352 in-pixel storage cells inside the pixel area of 200x200μm².

This contribution will report on the main results of the characterization of AGIPD1.0 that lasted 2 years showing the main performance of the chip. During this long characterization period several flaws were spotted in this chip and this suggested, even if the actual chip is working and usable, to resubmit a new version of the actual chip (AGIPD1.1) to fix the problems and make the final detector more easily usable and less demanding in terms of calibration.

AGIPD1.1 was received back at the end of March 2016 and is actually under test. First measurement results on the new chip will also be shown as well as a general update of the status of the AGIPD detector.
Towards Gotthard-II: Development of A Silicon Micro-Strip Detector for the European XFEL

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The next generation light source, the European X-ray Free-Electron Laser (XFEL.EU), is currently being constructed in the Hamburg region and will be available for user operation in 2017. It will deliver extrashort, high intense X-ray pulses with a separation of 220 ns. The unique X-ray beam poses the following challenges to detectors used at the XFEL.EU: A dynamic range of 0, 1, ..., 10⁴ 12.4 keV photons, a frame rate of 4.5 MHz, and last but not least radiation damage up to 1 GGY for 3 years of operation.

Gotthard-II is a 1-D micro-strip detector specifically developed for the XFEL.EU. It will be used not only as a spectrometer meeting all requirements mentioned above but also as a beam diagnostic tool with additional logic to generate veto signal for the other 2-D detectors in imaging experiments, like AGIPD and LPD. Gotthard-II makes use of silicon micro-strip sensor with a pitch of either 50 μm or 25 μm and with 1280 channels in total wire-bonded to ASIC chips with build-in ADCs and memories for a continuous readout of frames and hit information generated by each X-ray pulse.

The performance of existing prototypes has been investigated extensively. In this work, the results regarding to noise, dynamic range and strip-to-strip coupling by means of infrared laser and X-rays will be shown and its influence on the design of Gotthard-II discussed. The arichitecture of the final ASIC will be presented.
The photon counting detector EIGER, which was developed at the Paul Scherrer Institut (PSI), is now being commissioned at several beam-lines of the Swiss Light Source. With a fully parallel design the detector aims to give the same performance regardless of the number of modules in a system. This includes the 23 kHz frame rate in 4 bit mode as well as online rate correction and summing of frames in the FPGA to extend the dynamic range from the ASICs 12 bits to 32 bits.

An EIGER detector is made up of several modules, where one module consists of 8 ASICS each with 256x256 square pixels at a 75um pitch.

For each 4 ASICS there is a dedicated readout board with one 10Gb link for data transfer. A key feature which enables the high frame rates and gives the possibility of online summing of frames without significant loss in efficiency is the dead time free readout mode. In this mode the detector can remain active while the previous frame is being read out, reducing the dead time between frames to 10us.

This paper outlines the detector system from the ASIC to the data backend focusing on the 9M pixel detector which is being produced for the cSAXS beamline at SLS. We present results on threshold trimming and calibration on module the level using both X-ray fluorescence and monochromatic radiation. In addition the count rate performance and the online count rate correction is characterized.
1) ALBA light source

Alba is a 3rd generation light source with eight operational Beamlines, one in construction and another one approved. The first Beamlines were commissioned in 2012 and are dedicated to life sciences, condensed matter physics and chemistry. The phase 1 comprised 7 beamlines devoted to Magnetic dichroism (XMCD, XMLD), magnetic scattering (SXRS), Photoemission Electron Microscopy (PEEM), Near Ambient Pressure Photoemission (NAPP), X-ray Absortion, Machromolecular chystallography, Non Christalyne Diffracion, Transmission X-Ray Microscopy, Powder Diffraction, etc. The phase 2 included an infrared beamline in operation since mid-2016 and an angular resolved photoemission beamline in construction.

The critical success factors of the experiments are given by the end station and sample environment, the beam optics, the synchronization capabilities, the data acquisition and the detectors. Maximizing these factors is the condition to be on the cutting-edge of synchrotron light.

This talk will present the characteristics of the facility with particular examples and scientific results of the recent experiments.
First experimental results on active-edge silicon sensors for XFEL

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Synchrotron and X-ray Free Electron Laser (XFEL) spectroscopy applications require tiled large-area detectors with high spatial resolution, to collect the radiation patterns generated by X-ray diffraction. Standard thick detectors include large border regions to avoid edge breakdown at the high bias voltage typically needed in these applications. These inactive regions are especially important in the presence of a high oxide charge density induced by radiation damage, at radiation doses that could reach levels as high as 1GGy using future XFEL sources. Active and slim-edge pixelated sensors offer the possibility to minimize these dead areas and thus to improve the quality of the acquired X-ray patterns.

In this work we present the first experimental characterization results of a pilot fabrication run developed in the framework of INFN project PixFEL. Active and slim-edge p-on-n sensors were fabricated on n-type high-resistivity silicon with 450um thickness, bonded to a support wafer. Both diodes and pixelated sensors with a pitch of 110um were included in the design. The sensor edges were defined through deep trenches, fabricated with Deep Reactive Ion Etching technique and doped to be electrically active. Optimized guard ring structures were included to enable the application of a large bias voltage, necessary both for fast and efficient charge collection and for a maximum spatial resolution at high signal levels. The edge structures were designed to stand a large voltage also after accumulating 1GGy ionizing radiation dose.

A preliminary electrical characterization campaign has been conducted on the produced sensors. A breakdown voltage exceeding 500V was measured on diodes with 4 guard rings and an edge region of 155um, matching the design values. Functional measurements of charge collection efficiency and speed are under way and radiation damage tests are planned for the next summer.
JUNGFRAU: a gain switching pixel detector for SwissFEL

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JUNGFRAU (adJUstiNg Gain detector FoR the Aramis User station) is a two-dimensional hybrid pixel detector under development for photon science applications at free electron laser and synchrotron facilities. In particular, JUNGFRAU detectors will equip the Aramis end-station of SwissFEL, an X-ray free electron laser currently under construction at the Paul Scherrer Institut in Villigen, Switzerland.

JUNGFRAU has been designed specifically to meet the challenges of photon science at XFELs, including high frame rates, single photon sensitivity in combination with a large dynamic range, vacuum compatibility and tilable modules. This has resulted in the realisation of a charge integrating detector with three dynamically adjusting gains, low noise of 55 ENC, readout speeds in excess of 2 kHz, single photon sensitivity down to 2 keV (with a SNR of 10) and a dynamic range covering four orders of magnitude at 12 keV.

Each JUNGFRAU module consists of eight chips of 256 x 256 pixels, each 75 x 75 μm² in size. The chips are arranged in 2 x 4 formation and bump-bonded to a single silicon wafer 320 μm thick, resulting in an active area of approximately 4 x 8 cm² per module. Multi-module vacuum compatible systems comprising up to 16 Mpx (32 modules) will be used at SwissFEL to perform experiments in, for example, serial nanocrystallography and time-resolved X-ray diffraction.

The design of the JUNGFRAU system for SwissFEL will be introduced, together with results from early prototypes and a characterisation of the first final JUNGFRAU modules. In order to translate from a measured charge to a number of photons, each pixel must be individually calibrated. Plans and first results of this process will be shown. Noise measurements, pixel uniformity, peak finding and clustering techniques will also be presented.
The Development of the DSSC Detector for the European XFEL: toward the Prototype Camera

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Among the developments for the European XFEL, the DSSC will be the only 2D large-area high-speed detector able to achieve single photon resolution even in the low energy range down to 0.25 keV. The camera is based on Si-sensors and is composed of 1024×1024 pixels for an active area of 210×210 mm². 256 ASICs provide full parallel readout, comprising analog filtering, 8-bit digitization and data storage. The challenge of having high-dynamic range and single photon detection simultaneously requires a non-linear system front-end. The first mega-pixel camera for the day-zero of the European XFEL operation will be equipped with linear MiniSDD pixel arrays and the dynamic range compression has to be provided by the ASIC front-end. The DEPFET pixels foreseen for the advanced version of the camera provide signal compression at the sensor level. All the electronics components are available and tested and the assembly of the first prototype cameras based both on DEPFETs and MiniSDDs has started. We will give an overview of the DSSC system with its main components from the sensor to the DAQ electronics together with the latest experimental results. Operating the system at 1 MHz, a noise down to 18 el. rms. and of 50 el. rms has been achieved with the DEPFET and with the mini-SDD sensor respectively. The DEPFET and the Mini-SDD solutions will be compared by the theoretical point of view and on the basis of experimental results. First imaging capability of the system prototype at 4.5 MHz with available sensors and the full-format readout ASIC will be given for the first time. Eventually we will show the status of the fabrication of non-linear DEPFET pixels produced for the first time in an industrial CMOS foundry. They will be used for the advanced version of the megapixel camera.
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Fast X-ray imaging using 30 keV and above X-ray photons is highly desirable for studies of dynamic material evolution and discovery of new materials. The state-of-the-art single-line-of-sight X-ray camera technology, which is mostly based on silicon sensors and silicon application specific integrated circuits (ASICs), cannot meet the requirements because the atomic number of silicon is only 14 (“Low - Z”), and the highest speed achieved so far is less than 10 MHz frame-rate in X-ray Free Electron Laser (XFEL) environment. Fast readout chips with an equivalent frame rate above 100 MHz do exist through on-board data storage. Therefore, it is possible to construct "4H" X-ray cameras for high-energy XFELs. "4H" stands for High-Z (Z>30) sensor, high resolution (less than 300 micron pitch), high-speed (above 100 MHz), and high energy (above 30 keV in photon energy). We discuss progress and plans to realize such a technology.
New gamma detector module based on new model micro-pixel avalanche photodiode

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This paper presents the results of the ionizing radiation detector module, developed based on the new model of micro pixel avalanche photodiode (MAPD) type MAPD-3NK0. The samples were made in cooperation with the Zecotek Photonics and had the following parameters: a sensitive area- 3.7mm * 3.7mm, the density of pixels - 10000 pixels/mm², the photon detection efficiency- 40% (450-550nm) and operation voltage- 91V. Beta particle and gamma ray detection performance of MAPD with different single scintillation crystal materials such as NaI, LFS, p-terphenyl and phoswich detector (LFS+p-terphenyl) was investigated.

New gamma ray detector module demonstrated very well linear behavior of detected signal amplitudes as a function of the gamma ray energy (26.3keV-1.33MeV). Minimum detectable energy for gamma ray was 26.3keV. The count ratio of beta particle and gamma ray from Cs-137 (with p-terphenyl) was about 37%. For signal readout from the detector, a special readout electronics was constructed of electronic components such as a DC-DC converter, an amplifier, a comparator, a shaper and an analog-to-digital converter.
The feasibility study of multi-wavelength detectable dosimeter containing lead oxide in medical X-ray device for diagnosis and therapy

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There has been a need to develop a multifunctional medical device that can perform radiologic diagnosis and treatment at the same time. Nonetheless, separate technology is used in clinical practice due to the difference in energy between diagnosis and treatment. Such measuring technology may induce measurement errors during quality assurance, ultimately increasing the uncertainty of treatment. Therefore, it is essential to develop multi-wavelength detecting technology. This study aims to evaluate the feasibility of developing a multi-wavelength detectable dosimeter using lead oxide (PbO).

In order to resolve the low sensitivity of PbO, a 200 μm thick dosimeter was manufactured using a screen-printing method that allows metallization of a thick film. In addition, radiography (at 100 keV) and a LINAC (at 15 MV) were used as the multi-wavelength source. The performance of the dosimeter was evaluated relative to the ideals for reproducibility, linearity and sensitivity. To evaluate the feasibility of clinical application, HVL was analyzed for diagnosis and PDD was analyzed for treatment. For an objective examination, our dosimeter was compared with commercial silicone diodes and chambers.

The reproducibility tests showed a CV similar to Si diodes for radiography, and the STD was 0.23% higher for LINAC. The linearity test showed a R-Sq identical to Si diodes for radiography and LINAC. The sensitivity was 0.004 mAs⁻¹ lower for radiography and 0.025 MU⁻¹ lower for LINAC. Finally, in the evaluation of clinical feasibility, there was a 5.5% error compared with the chamber for radiography, and for LINAC there was 0.2% error at the state of build-up and 4.67% at 10cm depth. Such results not only demonstrate the multi-wavelength detection characteristics of the PbO dosimeter, but also prove the feasibility of application in the clinical field.
In this paper we propose the application of a new detector based on a triple Gas Electron Multiplier (GEM) with a front-end electronics formed by four medipix chips having an active area of about 30 x 30 mm$^2$ and a pixel size of 55 mm x 55 mm and. This detector has a high dynamic range because of the intrinsic gain due to the GEM foils, so it can work in a range of X-ray fluence of 6 orders of magnitude, arriving to the detection of a single photon. In addition medipix electronics allows working in Time over Threshold (ToT) mode, in which each pixel register digital counts proportional to the charge released in the gas. This is useful for time integrated imaging of fast X-ray burst (scales from nanosecond to femtosecond), where photon counting is not possible. This detector, in ToT mode, has been tested and characterized at the laser facility ECPLIPSE, at the Bordeaux University. This is a Nd:YLF laser, wavelength 810 nm and pulse duration 40 fs, with a corresponding energy of 170 mJ (power about 510$^{12}$ W) and a focal spot of about 10 mm (power density about 510$^{18}$ W/cm$^2$). This laser has been fired on many different targets (Fe, Ni, Cu, Ti, Ag, plastic). Thanks to calibrations performed previously at the NIXT laboratory of ENEA-Frascati, we estimated that for the experiments at ECLIPSE the real spatial resolution at the working gain was about 21-23 pixels (macro-pixel). The fluences measured at ECLIPSE revealed about 20-25 photons per macro-pixel for copper target (15-20 for iron) at center of the image, and 2-3 photons at edge.
Active sandwich-like multilayer detectors have been developed, and their potential for motion-artifact-free dual-energy x-ray imaging at a “single exposure” has been demonstrated in the material decomposition context. For the detection of relatively higher energy x-ray photons at the “rear” detector layer, compared to the “front” detector layer, a thicker scintillator would be preferable. Since the sandwich detector uses the x-ray beam transmittance through the front layer, direct x-ray interaction within photodiode in the front layer is unavoidable, and which would increase noise in the front detector images. To obtain a better contrast performance, an additional filter layer can be placed between the two detector layers. In contrast, the filter layer can adversely increase noise in images obtained from the rear detector layer by reducing the number of x-ray photons reaching it. For successful and reliable operation of the sandwich detectors, therefore, optimal detector design, in terms of scintillator thickness and filter material/thickness for example, is important, and it is challenging. A theoretical model, which can describe the signal-to-noise performance of the sandwich detector as functions of various design parameters, has been developed by using a linear cascaded-systems theory. The direct x-ray interaction noise is considered as spatially non-correlated. From the cascaded-systems analysis on the sandwich detectors, the direct x-ray interaction increases noise in the high spatial frequencies where the number of secondary quanta lessens. The intermediate filter layer enhances the contribution of additive electronic noise in the overall noise performance of the rear detector layer. The detailed cascaded-systems signal-to-noise analysis on the x-ray sandwich detectors will be presented in comparisons with the measured noise-power spectra and detective quantum efficiencies.

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Micromesh selection for the ATLAS New Small Wheel Micromegas

Fabien kuger

1) ATLAS Muon Collaboration (name of presenter will be sent later)

With New Small Wheel Upgrade scheduled for the next long LHC shutdown the innermost end-cap regions of the ATLAS Muon system will be equipped with eight layers of Micromegas detectors. The single quadruplet modules will be up to 2.5m long and 2.2m wide.

A key component of a Micromegas are fine conductive meshes, dividing the gas volume into a drift and an amplification region.

The selection of the correct mesh is an important design objective, affecting various detector aspects. Among others the electrical field configuration, electron losses during mesh transition and gas flow within the detectors have been studied. Mechanical stability requirements and production process related constrains have been investigated in close collaboration with industrial partners.
A scintillation detector (NaI(Tl) and LaBr3(Ce)) and an HPGe have been used for verifying U-235 enrichment of an UO2 pellets or powder and an UF6 cylinder during nuclear safeguards inspection. A NaI(Tl) detector has low energy resolution so that its application is limited in measuring exact nuclear material accountancy. An HPGe is bulky because it employs a liquid nitrogen cooling method. The liquid cooling system of an HPGe detector makes verification activities of UF6 cylinder enrichment inconvenient and inefficient. To replace the existing NaI(Tl) and HPGe gamma-ray detectors, we developed a CZT detector array by combining several large-volume CZT semiconductor detectors. Performance testing of our CZT array-based uranium enrichment measurement system was conducted using various nuclear materials (UO2 pellets and powder, UF6 cylinder). For low-enriched UO2 pellets or powder, the discrepancy between a facility’s declared and our measured enrichment was less than about 2.0 percentage under 300 seconds measurement time. In contrast, IAEA IMCN(IMCA+NaI) was about 3.5 percentage in discrepancy. For a UF6 cylinder, there was large difference in the declared and measured value. The large discrepancy arose from the scattered radiation caused by the shielding structure for the CZT-detector array. Therefore, we re-designed the CZT-detector array including its shielding to correctly measure uranium enrichment in UF6 cylinders. Currently, the modified CZT array-based detection system is under construction. Experimental results from a targeted UF6 cylinder enrichment measurement will be discussed in a workshop and compared with the HPGe. In conclusion, experimental results will show whether the existing NaI(Tl) and HPGe can be replaced with our Quad-CZT array based gamma-ray spectrometer.
Impulse response of sandwich detector for single-shot dual-energy x-ray imaging

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An x-ray radiographic system consisting of two detectors in tandem, or a sandwich detector, can produce dual-energy image at a single-shot exposure. Subtraction of two images obtained from the two detectors can produce a shaped dual-energy image when two images are characterized by different spatial-resolution properties, and which can be achieved by using the front and rear detectors with different thickness phosphors. This unique characteristic of the sandwich detector may be attractive to some imaging applications that require mid or high spatial spectral information in images rather than low spectral information. Therefore, it is important to investigate the impulse response of sandwich detectors in the spatial frequency domain. In this study, we measure the modulation-transfer function (MTF) of sandwich detectors. We assume that the weighted logarithmic subtraction is included in the sandwich detector system as an intrinsic procedure. The MTF is evaluated from the images obtained for an edge-knife phantom. The edge profiles are extracted from the edge images, and the edge-spread functions (ESFs) are determined by least-squares regression analysis using an in-house fit function. Weighted logarithmic subtraction is then applied to the ESFs obtained from the front and rear detectors. The subtracted ESF is subsequently differentiated to give rise to the corresponding LSF. By performing fast Fourier transformation to the LSF, we obtain the MTF curve. From the preliminary results, we obtain a band-pass filter character of MTF. This result implies that the sandwich detector loses the contrast-transfer performance for large-area objects whereas it relatively gains that for object details. The MTF results of sandwich detectors with various designs (phosphors, intermediate filters, and weighting factors) will be shown in detail.

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Monte Carlo analysis of megavoltage x-ray interaction-induced signal and noise in detectors for container inspection

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Related to homeland security and contraband control, x-ray scanning system may increase the effectiveness and efficiency of cargo screening at the port. While high quality x-ray images, with which one identifies abnormal objects visually and quantitatively, are demanded, the images normally suffer from poor quality due to low photoelectric but high Compton-scatter events of megavoltage x-ray photons. Annihilation-photon escapes, as a result of pair production, from the detector will further degrade the image quality. We investigate fundamental megavoltage x-ray interactions in the container-inspection detector system by using a Monte Carlo (MC) technique. For a pencil-like megavoltage x-ray beam onto a linear scintillation crystal and photodiode array, we record all energy-absorption events in 3D coordinates. The energy-absorption events include partial-energy absorption at local position, at which the Compton scattering occurs, and its correlated energy absorption at remote positions due to reabsorption of scattered photons. Similarly, partial energy-absorption events due to the reabsorption and escape of fluorescence and annihilation photons are also recorded. Based on those tallies, we investigate the spatial distributions of signal and noise and their crosstalk between detector channels. The MC simulations also provides the absorbed energy distribution from which the energy moments can be determined. We define quantum efficiency, Swank noise factor, and detective quantum efficiency in terms of energy moments, and investigate them as functions of various detector geometries. Detained methods used in this study and their results will be shown. This work will suggest fundamental limits of the signal-to-noise performance due to megavoltage x-ray interactions in the container-inspection detector system.

This work was a part of the project titled ‘Research on Fundamental Core Technology for Ubiquitous Shipping and Logistics,’ funded by the Ministry of Oceans and Fisheries, Korea.
Anneal induced transforms of deep traps in n-type and p-type CZ Si 6.6 MeV electron irradiated with fluences of (1-5)×10\(^{16}\) e/cm\(^2\) have been studied. The Schottky diodes were fabricated by Au sputtering and ohmic contact sintering on wafer sample after each anneal procedure to perform DLTS measurements. The isochronal anneals for 24 hours were applied using nitrogen gas ambient at 80°C, 180°C and 280°C temperatures. The deep level spectra were examined by combining the capacitance and current deep level transient spectroscopy using optical injection techniques, to identify modifications of radiation defects. The DLTS spectroscopy has been combined with measurements of the temperature dependent carrier trapping lifetime (TDTL) recorded on the same samples using a contact-less technique of the microwave-probed photoconductivity. The suppression of the rather deep carrier emission centres after heat treatment has been revealed. The reduction of deep acceptor concentration after anneals at elevated temperatures is accompanied by increase of the shallow acceptor concentrations, assigned to the formation of shallow vacancy related traps that compensate the dopants. The activation energies extracted for the predominant TDTL and DLTS spectral peaks are in good agreement. The radiation induced defects ascribed to vacancy-oxygen, vacancy-phosphorus, interstitial Si-oxygen complexes and to multi-vacancies have been identified. It has been demonstrated that TDTL technique is an effective and contact-less tool to examine the re-distribution of the excess carrier capture and thermal emission flows among several radiation defects.
Gallium nitride (GaN) is a promising material for fabrication of the radiation tolerant particle detectors those are operational in both electrical and optical signalling regimes. However, polarization effects considerably affect signals of detectors made of CVD and MOCVD grown material. To suppress polarization effects, the GaN structures of sandwich and mesa type have been fabricated using epi-layers of different crystalline orientations. Also, various unintentionally doped and semi-insulating GaN materials provided by different vendors were involved into these investigations. The capacitor and junction type sensors were fabricated by combining laser ablation, metal sputtering and sintering techniques. The laser lift-off technique was employed to get self-standing layers in production of the capacitor type sensors. The mesa type GaN junction structures were employed in this study. The current-voltage, capacitance-voltage, pulsed photo-ionization, microwave probed photoconductivity, and transient current profiling techniques have been combined to evaluate characteristics of the pristine and reactor neutron irradiated materials and sensors. These characteristics will be presented and discussed.
Quantum dot (QD) is extensively studied in various areas such as light emitting devices, solar cells, and photodetectors due to its varying electrical properties by controlling its size. In this study, we have investigated the characteristics of an indirect-type X-ray organic detector coupled with CsI(Tl) scintillator. As shown in Fig. 1, the active layer of the detectors was fabricated using the blend of the conjugated polymer poly(3-hexylthiophene) (P3HT) and the fullerene derivative phenyl-C60-butyric acid methyl ester (PCBM) containing cadmium selenide (CdSe) QD. Visible photons generated due to the incident X-ray in the scintillator were absorbed in QD-blended active layer. The excitons were generated in the active layer, and then the charges dissociated from the excitons were collected by respective electrodes. Fig. 2 shows the variations of absorption spectrum resulting from the QD blending conditions. Three different sizes of CdSe-QDs were tested. The active layer containing QDs indicates relatively higher absorbance than the active layer without QDs. It means that QDs possibly act as visible-light-harvester to enhance the detector performance.

In order to understand the inherent properties of the organic detector without the scintillator, the current-voltage curves were measured using a solar simulator with AM 1.5 G filters. As shown in Fig. 3, the intrinsic solar efficiency was improved from 2.103 % to 2.513 % by adding QDs. The performance of the X-ray detector coupling with the scintillator was evaluated by measuring collected charge density (CCD), dark current density (DCD), and sensitivity with X-ray generator. The sensitivity was also improved from 188.628 to 220.081 nC/mR·cm² at the bias of -0.6 V. Presently, we are currently working on the process condition of the active layer to improve the sensitivity.
Characterization and simulation of fast neutron detectors based on surface-barrier VPE GaAs structures with a polyethylene converter

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Surface-barrier structures based on thin (≤ 50 μm) high-purity VPE (Vapor-Phase Epitaxy) GaAs epilayers were proposed as a sensor for fast neutron detection by the recoil proton method [1]. This has allowed to reduce the detection threshold of recoil protons and improve the signal-to-gamma-background ratio as well as increase the operating temperature and radiation stability in comparison with silicon.

The current work is a continuation of this research and reports the results of characterization and simulation of fast neutron VPE GaAs detectors with an increased area (80 mm²). The detectors are intended for neutron yield measurements from various targets in accelerator physics experiments.

The recoil-proton surface-barrier sensor was fabricated on HP GaAs epilayers with the layer thickness of 45 μm implementing the process flow presented in [1].

The neutron detection efficiency measured using a 241Am-Be source was 1.30 · 10⁻³ puls./neutr for the PE converter thickness of 670 μm. The signal-to-gamma-background ratio was at the level of 50. Simulation of the detector characteristics in GEANT4 toolkit has showed a good agreement with the experimental data and allowed to estimate the maximum theoretical detection efficiency of the detector which is determined by the PE converter – 1.37 · 10⁻³ puls./neutr. (Fig 1). The difference between measured and simulated values of detection efficiency is due to the fact that events with energies below 0.5 MeV were not taken into account during the experimental measurements.

Future works will be aimed at optimization of the sensor design in order to reduce the sensitivity to gamma-ray background and to reduce the registration threshold of the recoil protons.

Fig. 1 – Comparison of experimental and simulation results: a) measured and simulated spectra of recoil protons; b) comparison between simulated converter efficiency and measured GaAs detector efficiency
Gd2O3:Eu scintillator modeling using GEANT4 Monte Carlo simulation code

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The components of detector systems have become sophisticated and complicated in light of an improvement in the performance of scintillator-based radiation detectors. Therefore, an optimized design of the detector system based on the operating environment and purpose is required. Recently, Monte Carlo methods have been used to optimize the design and modeling of radiation detectors. However, most Monte Carlo codes have fixed optical characteristics, and the effect of the signal readout devices is not considered because of the limitations of a geometry function. It has been reported that the modeling of a comprehensive radiation detector system is feasible using the GEometry ANd Tracking 4 (GEANT4) simulation code for the optical physics modeling. In this study, we modeled a Gd2O3:Eu scintillator using the GEANT4 simulation code. To obtain the measurement data, the Gd2O3:Eu scintillator was synthesized using solution combustion methods. X-ray diffraction (XRD) was used to analyze the crystal structures of the synthesized scintillator, and the photoluminescence (PL) characteristics of the synthesized scintillator were evaluated by measuring the PL spectrum and decay time. We imported the measured data into the GEANT4 code because GEANT4 cannot simulate a fluorescence phenomenon. The imported data were used as a distribution function for optical photon generation based on the deposited energy in the scintillator. A strong emission peak consistent with the measured data was observed at 611 nm, and the overall trends of the spectrum agreed with the measured data (Figure 1). This result is significant because the measured characteristics of the scintillator are equally implemented in the simulation, indicating a valuable improvement in the modeling of scintillator-based radiation detectors.
Energy resolving photon-counting technique enables spectral CT systems and spectral cameras for food quality inspection, baggage control at airports, and multi-color medical imaging. Based on the excellent results of dual energy CT, the interest for multi-energy discrimination detectors is visible with several energy resolving photon counting readout ASICs.

For pixelated solid-state detectors, the charge sharing among neighbor pixels represents an intrinsic energy resolution limitation. Nevertheless, the readout ASIC is able to locate the center of the charge cloud and assign all collected energy of the photon into the central pixel, so the spectral energy information is maintained.

The Energy Resolving In Line Camera (ERICA) ASIC is a photon counting with energy resolving for in-line scanners using X-Rays photons up to 200 keV for food quality inspection and security. The data is read at 1kHz rate to allow Time Delay Integration (TDI) image processing. Beside this, the ASIC has Half-Full Buffer flag to avoid saturated image in case of high flux.

The ERICA ASIC is composed of an 8x20 pixel array with a pixel pitch of 330 μm, multiple 11-bit voltage DACs for reference generation, a 10-bit temperature sensor, a chip ID, and a digital controller. The pixel’s block diagram is shown in Figure 1.

The gain of the pre-amplifier is set to define a dynamic range of 800 mV for 200 keV energy deposited in CdTe detectors. With 5-bit programmable bias, the active feedback resistor can adjust the width of the preamplifier’s pulse from 200ns to 10μs standing up to 40nA detector leakage current. To allow high photon detection rate, an automatic reset circuit with adjustable delay has been implemented in the feedback resistor. The complete analog and digital processing, including charge sharing compensation, takes less than 1 μs.
The paper describes a preamplifier, elaborated to process the signals of silicon X-ray detectors. The preamplifier was optimized for operation with detectors, having capacitances of 100 fF and leakage current no more than 10 pA.

The preamplifier has a gain equal to 33 mV/fC, ENC at T=27°C equal to 8.6 e (simulation results) at using a shaper of the 6th order with a time constant of 8 us. The power consumption of preamplifier is 0.5 mW. The preamplifier has been built as a cascode circuit with an n-channel built-in CMOS input transistor. The feedback circuit contains a 30fF capacitor and a transistor, operating in a switched mode. The feedback capacitor discharges, when the gate of this transistor is supplied by a positive pulse. This reset pulse is generated by a Shmitt trigger. The latter’s input is fed by the CSA output signal. When this signal exceeds the preset upper threshold, the trigger generates a positive step, whereas at the same signal falling below the preset lower threshold the trigger generates a negative step, thus shaping a logic signal for CSA reset.

The output voltage swing of preamplifier equals 1.9 V. At a leakage current of detector equal to 10 pA the need of reset arises every 13.5 ms. The preamplifier output is connected to a shaper of the 6-th order, having variable time constants.

The preamplifier has been manufactured by the CMOS 0.35 um technology of AMS (Austria) via Europractice and currently is under the measurements.
Microtomography with photon counting detectors: Improving the quality of tomographic reconstruction by voxel-space oversampling

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High resolution X-ray tomography providing non-destructive sample investigation with micrometer resolution has become a popular imaging tool in many fields of science. With recent development of WidePIX technology enabling construction of large area detector arrays, dimensions of photon counting detectors Timepix have become fully competitive to conventional X-ray cameras used for high resolution applications.

The most common X-ray cameras used in commercially available micro-CT systems utilize scintillating sensor layer in combination with CCD read-out electronics. Such detectors provide extreme pixel granularity with pixel pitch often below 10 μm. However point spread function (PSF) of such cameras is rather proportional to scintillator thickness than pixel size. Since the scintillator thickness is higher than pixel size the PSF at full width half maximum (FWHM) typically covers a cluster of pixels. On the other hand photon counting detectors Timepix are characterized by 55 μm pixel pitch but steep PSF with FWHM below pixel dimensions. The spatial resolution achievable using photon counting detectors is therefore comparable to the latest CCDs.

During the tomographic reconstruction the voxel size is typically determined as a ratio between pixel size and image magnification. As a result of wide PSF of CCD detectors, voxel resolution of reconstructed CT slices is usually much higher than the real spatial resolution. In the same case the spatial resolution provided by Timepix device is equivalent to voxel size. In this contribution we demonstrate that sharp PSF of photon counting detectors enables to oversample the voxel space. Decreasing voxel dimensions improves detail detectability and overall quality of obtained by means of increased uniformity and noise reduction. Using proposed approach micro-tomography using large area Timepix detector provides tomographic reconstructions of comparable spatial and voxel resolution as state-of-the-art conventional X-ray imaging cameras.
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A low-noise analog readout channel optimized for operation with the Silicon Drift Detectors (SDDs) with a built-in JFET is presented. The energy resolution of the detector itself is 132 eV (FWHM) at MnKα, -20 °C, 10 kcps and a shaping time of 1 μs. The detector capacitance is about 100 fF. Thus, the requirement to the readout electronics was at least 12 e of ENC.

The designed readout channel contains a charge sensitive amplifier (CSA), 6th order shaper and reset trigger. The CSA optimized for operation with SDDs by PNDetector GmbH. The CSA operates both in self-reset and pulse-reset modes using the reset diode, built in the SDD detector. The shaper is a 6th order semi-Gaussian filter with switchable discrete shaping times. The shaper includes 3 stages. Each of them are the 2nd order filters (multiple feedback filters and the Sallen-Key filter). The readout channel provides the Equivalent Noise Charge (ENC) of 12e- and an input dynamic range of 30 keV. The channel was prototyped in the AMS 350 nm CMOS process as a miniASIC via Europractice in late 2015.

The test PCB with the bonded caseless ASIC sample has been designed. For the analog readout channel tests there was used the detector module SDD-10-130-PTW LTplus-ic (PNDetector GmbH) with the following parameters: SDD sensitive area 10 mm², SDD thickness - 450 μm, housing TO-8, built-in Peltier cooler and thermal sensor.

The measured energy resolution of this module with the designed readout channel is 200 eV (FWHM) at Fe-55, -16 °C, 1 kcps and a shaping time of 8 μs. The readout self noise of 163 eV was measured as well. The power consumption is 7 mW/channel.
The Voxel Imaging PET (VIP) project presents a new approach for the design of nuclear medicine imaging devices by using highly segmented pixel CdTe sensors. CdTe detectors can achieve an energy resolution of 1% FWHM at 511 keV and can be easily segmented into submillimeter sized voxels for optimal spatial resolution. These features help in rejecting a large part of the scattered events from the PET coincidence sample in order to obtain higher quality images.

Another contribution to the background are random events, i.e., hits caused by two independent gammas without a common origin, with a rate proportional to the square of the injected dose. Given that 60% of 511 keV photons undergo Compton scattering in CdTe (i.e. 84% of all coincidence events have at least one Compton scattering gamma), we present a simulation study on the possibility to use the Compton scattering information of at least one of the coincident gammas within the detector to reject random coincidences.

The idea uses the fact that if a gamma undergoes Compton scattering in the detector, it will cause two hits in the pixel detectors. The first hit corresponds to the Compton scattering process and from the deposited energy the Compton scattering angle can be calculated (ignoring the Doppler effect). The second hit corresponds to the photoelectric absorption of the remaining energy of the gamma. By measuring both hit locations of the scattering gamma and the hit location of the coincident gamma we can construct the geometric angle, under the assumption that both gammas come from the same origin. Using the difference between the Compton scattering angle and the geometric angle, random events can be rejected.

\[ E_{1S} \]
\[ X_{1S} \]
\[ \theta \]
\[ X_{1A} \]

With true coincidences, the Compton scattering angle (from \( E_{1S} \)) and the geometric angle (from \( x_2, x_{1S} \) and \( x_{1A} \)) are equal. With random coincidences, they are different.

\[ X_2 \]
\[ \text{real gamma paths} \]
\[ \text{fictitious gamma paths} \]
Positron emission tomography (PET) is widely used for oncology and neuroimaging. Meanwhile, photomultiplier tube (PMT) has been widely used for a PET detector, but many research groups have shown that SiPM is a very competitive candidate for the next generation PET system. However, to replace PMTs with SiPMs, a huge number of sensor pixels are required because the dimension of one SiPM is much smaller than one PMT. As a result, a technique for selecting valid signals and decoding channel position is needed.

In this work, an ASIC was developed to solve the problems stated above in PET systems. In the ASIC, the amplified pulse was split into two signals, and each signal was fed into two comparators each with different reference levels. Then the valid signals from each comparator were combined by the digital logic block. The trimmed signals from the digital logic block contain information of incident radiations. The energy and position information of a detected radiation can be derived from the output of the D flip-flop in the logic block by using time over threshold (ToT). The timing information could be measured from a delayed rising edge of the combined signal. The delayed signal is the combination of an output from the comparator with low level reference and an output of the D flip-flop in the logic block.

Using this ASIC design, we can improve the performance of PET in many ways. First, the ASIC has only digital outputs; therefore, a correction circuit for analog signal distortion is not necessary. Secondly, by using the ASIC the valid signals are intrinsically selected, reducing the burden of DAQ and the position of SiPMs where valid signals were generated. Moreover, these advantages of this ASIC development are not only limited to PET systems, but are beneficial to many other radiation imaging systems.
Fast signal processing in the readout front-end electronics implemented in CMOS 40 nm technology

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The important limit in the Single Photon Counting (SPC) mode based X-ray detection systems is the maximum input pulses count rate performance, what in modern applications is at a level of several Mcps/pixel. From this point of view the integrating mode based systems offer better performance, but nowadays more and more attention is paid on the SPC based systems. Thanks to the use of nanometer CMOS technologies the input signal can be processed in a short time, what make them suitable to design the readout front-end electronics operating in the SPC mode. The price for the shorter pulse processing time, what means higher count rate, is an increase in the noise level. The authors present the considerations about the design of the fast readout front-end electronics implemented in the CMOS 40 nm technology with the emphasis on the relationship between the dead time, noise performance and power dissipation of the processing channel. The results of schematic and post-layout simulations with randomly generated input pulses in a time domain according to the Poisson distribution are presented and analyzed. Dead time below 20 ns is possible keeping the ENC ≈ 100 el. rms for Cdet = 160 ff. The prototype ASIC was implemented in 40 nm CMOS technology with pixel pitch of 100 μm and was sent to fabrication in March, 2016. The front-end electronics analog part architecture details will be presented during the conference.

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PETIROC2 based readout electronics optimization for Gamma Cameras and PET detectors

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Developing frontend electronics to improve charge detection and timing resolution is one of the main tasks to improve performance in new multimodal imaging systems that merge information of Magnetic Resonance Imaging and Gamma Camera or PET tomographs.

The aim of this work is to study the behavior and to optimize the performance of an ASIC for PET and Gamma Camera applications based on SiPMs detectors. PETIROC2 is an ASIC developed by Weeroc to obtain accurate charge and time coincidence resolutions. It has 32 analog input channels that are treated independently. Each channel is divided into two signals, one for time stamping using a TDC and one for charge measurement. In this work, PETIROC2 is evaluated with different SiPM array configurations attached to different crystal scintillators structures and with different environmental conditions.

The experimental setup in this research is focused on PET applications. It is composed by two LYSO based detectors. Scintillators are attached to a 4x4 SiPM array, 16 input channels per detector, 32 channels on the whole system. All the experiments are conducted using an 1mm 22Na source.

Data acquisition is done by means of the PETIROC2 evaluation board provided by Weeroc. This board has a PETIROC2 ASIC attached to an FPGA. The FPGA configures the ASIC and reads the acquired data. A control PC collects the acquired data through the USB that is attached to the FPGA. The PC is in charge of the coincidence analysis. Considering that a 511keV detected event triggers different ASIC channels, the PC has also the task of combining charge information and timestamp from several channels to obtain one timestamp, one charge value and the detectors impact position associated to the 511keV event.

The results of this paper allow us to optimize and to improve the readout electronics of our Medical Image system.
Performance study of a PET scanner based on monolithic scintillators for different DoI-dependent methods

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Aim of the work

In this work we present the performance study of a brain dedicated PET, developed within the MindView collaboration, which has the purpose to develop an advanced PET/MR brain scanner to better diagnose schizophrenia and other pathologies. The use of monolithic scintillators, allows us to test different Depth-of-Interaction (DoI) dependent approaches to analyze the behavior of the tomographic spatial resolution, especially towards the Field of View edge. Both experimental and simulation measurements are presented.

Materials & Methods

The experimental measurements were performed on a 50x50x20mm³ LYSO crystal coupled to a photodetection system based on a 12x12 SiPM array, with row and column charge projection readout. This setup represents a single PET module and allowed us to tune the methods.

The simulated scanner geometry is composed by one ring (332mm in diameter) of 20 detector modules. The system defines an axial (transaxial) FOV of about 50mm (240mm). The simulations, based on both GATE and Geant4 software, followed a NEMA standard protocol allowing to assess scanner performance.

The capabilities of three different imaging methods have been evaluated through tomographic reconstruction performed via Filtered-Back-Projection. The first approach is based on a center-of -gravity algorithm without DoI information. The other methods are instead based on a novel method providing discrete (second method) or continuous (third one) DoI information.

Results

The results with both discrete and continuous DoI information shown a strong improvement of the spatial resolution (radial and tangential). Average spatial resolutions (radial and tangential) of the point spread function below 2mm are observed in the FOV center, degrading only to about 4mm at the edges.

Conclusions

This work, through simulations, shows how DoI-dependent methods allow an improvement of the PET scanner performance. Experimental tests with the currently assembled PET ring are expected to run soon.
A programmable, multichannel Power Supply for SiPMs with temperature compensation loop and Ethernet interface

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The SiPM power supply uses output voltage and temperature sensor feedback: a high-resolution ADC digitizes both the output voltage and an analog signal proportional to the SiPM temperature, the appropriate change in the bias voltage is computed in a micro-controller and this correction is applied via a high resolution DAC to the control input of a DC/DC module that produces the output voltage. This method allows to reduce gain variations from typically 30% to only 0.5% in a 10 °C range.

The power supply is housed in a 3U-height aluminium box. A 2.4” touch screen on the front panel provides local access to the configuration and monitoring functions using a graphical interface. The unit has an ethernet interface on its rear side to provide remote operation and integration in slow control systems using the encrypted and secure SSH protocol. A Labview application with SSH interface has been designed to operate the power supply from a remote computer.

The power supply has good characteristics, such as 90 V output range with 1 mV resolution, typical 4 mVpp ripple and noise and programmable rise and fall voltage ramps. Commercial power supplies from well known manufacturers can show far better specifications though can also result in an over featured and over costly solution for typical applications.

The source is currently in use at the 1800-channel SiPM tracking plane array for the NEW detector at the Laboratorio Subteráneo de Canfranc (NEXT experiment).
Each front-end readout ASIC for the High-Energy Physics experiments requires robust and effective hit data streaming and control mechanism. A new STS/MUCH-XYTER2 full-size prototype chip for the Silicon Tracking System and Muon Chamber detectors at the Compressed Baryonic Matter experiment at Facility for Antiproton and Ion Research (FAIR, Germany) is a 128-channel time and amplitude measuring solution for silicon microstrip tracker and gas detectors and is supposed to operate at 250 kHit/s/channel hit rate, each producing 27 bits of information (5-bit amplitude, 14-bit timestamp, position and diagnostics data). The back-end implements fast channel read-out, timestamp-wise hit sorting and data streaming via scalable interface implementing a dedicated protocol (STS-HCTSP) for chip control and hit transfer with data bandwidth from 9.7 MHit/s up to 47 MHit/s. It also includes multiple options for link diagnostics, failure detection and throttling features. The back-end is designed to operate with the data acquisition architecture based on the modified CERN GBTx transceivers. This paper presents the details of the back-end and interface implementation in the UMC 180 nm CMOS process.

Fig. A) Simplified back-end diagram. B) Detailed back-end circuit structure.
Front-end of the STS/MUCH-XYTER2, full-size prototype ASIC for CBM experiment

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Each front-end readout ASIC for the High-Energy Physics experiments requires robust and effective hit data streaming and control mechanism. A new STS/MUCH-XYTER2 full-size prototype chip for the Silicon Tracking System and Muon Chamber detectors at the Compressed Baryonic Matter experiment at Facility for Antiproton and Ion Research (FAIR, Germany) is a 128-channel time and amplitude measuring solution for silicon microstrip tracker and gas detectors and is supposed to operate at 250 kHit/s/channel hit rate, each producing 27 bits of information (5-bit amplitude, 14-bit timestamp, position and diagnostics data). The back-end implements fast channel read-out, timestamp-wise hit sorting and data streaming via scalable interface implementing a dedicated protocol (STS-HCTSP) for chip control and hit transfer with data bandwidth from 9.7 MHit/s up to 47 MHit/s. It also includes multiple options for link diagnostics, failure detection and throttling features. The back-end is designed to operate with the data acquisition architecture based on the modified CERN GBTx transceivers. This paper presents the details of the back-end and interface implementation in the UMC 180 nm CMOS process.

Fig. A) Simplified back-end diagram. B) Detailed back-end circuit structure.
Silicon Drift Detectors (SDDs) are mainly used for x-ray fluorescence analysis and energy dispersive spectroscopy (EDS). Reliable operations of SDDs require hermetically tight housings with integrated, highly transparent x-ray windows. Vacuum encapsulation allows for efficient detector cooling but the resulting pressure load of 1 bar weighs on the x-ray windows, which is a mechanical burden for the window material.

Standard transmission windows are made out of beryllium due to its high x-ray transparency and mechanical strength. Beryllium windows do not require a support structure. However, their thickness of at least 8 μm absorbs low energy x-rays below 1 keV. Therefore, light element detection in EDS applications is not possible with Be transmission windows. As beryllium is toxic, its production requires extensive precautions and broken windows contaminate the surroundings.

Low energy transmission windows need to be extremely thin, which seems contradictory to the high mechanical stability. Polymer windows are commonly chosen as low energy windows and achieve an acceptable x-ray transmission for radiation in the energy range below 1 keV by using low Z elements and a reduced window thickness. However, the low temperature tolerance of polymer windows impedes vacuum encapsulation and thus limits the detector performance. The low stability of the polymer films requires a support grid and leads to a fill factor below 80 %.

As a replacement for both, Be and polymer windows, Graphenic carbon windows have been designed and fabricated by KETEK. They show a superior transmission compared to conventional windows and allow for vacuum encapsulated detector modules. The high mechanical resilience of Graphenic carbon is demonstrated by pressure cycle tests, yielding over 10 million cycles without damage. Qualification test results of the Graphenic carbon windows are presented. Long term stability and reliability data of the new windows are shown.
Surface treatment of CdTe/CdZnTe radiation detectors is an important technological operation critically influencing the detector performance and has been studied thoroughly in the last years. Mechanical polishing, chemical etching and passivation are routinely employed for this purpose. One of the not largely investigated issues is the time deterioration of the detector, normally assigned to oxide layer formation on the detector surface. The dynamics and properties of CdZnTe surface oxide layers, created by passivation with KOH and NH4F/H2O2 solutions, were studied by optical ellipsometry and XPS. Studied samples were chemo–mechanically polished on a silk pad using a 3% bromine–ethylenglycol solution for 60 seconds. Afterwards they were chemically etched by immersion into a standard 3% bromine–methanol (Br–MeOH) solution for 60 seconds and passivated by immersion into the corresponding chemicals. XPS and ellipsometry of the samples was measured in dependence of time within one month after the treatment. The ellipsometric data were confronted with a new theoretical model of the sample structure, consisting of the substrate, an effective–medium–approximation layer (composed of substrate and CdTe oxide) and a surface roughness layer. Thickness and growth rate of the surface oxide layers differed in each of the passivation methods. Leakage currents, which influence the final spectral resolution of the detector, were measured simultaneously with ellipsometry. Results of optical and electrical measurements were compared and correlated. NH4F/H2O2 passivation showed to be a method with most desirable properties of the surface oxide layer.
Development of a clear sub-millimeter small animal PET scanner by reducing the influence of the non-collinearity effect

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Small animal PET plays a major role in studying molecular processes in vivo. However, the spatial resolution of small animal PET is limited by physical effects like positron range, photon non-collinearity, or object scattering.

The aim of this project was to minimize the influence of the non-collinearity effect by reducing the distance between the coincidence detectors leading to an improved spatial resolution.

We used a multi-wire proportional chamber-based high-resolution PET scanner (quadHIDAC) offering a spatial resolution of 1 mm FWHM [1].

By removing two opposite detector banks of the 4-detector-setup, the inner distance between the two remaining detector plates could be reduced from 180 mm to 40 mm.

For the measurement of the intrinsic spatial resolution, a molecular sieve (0.5 nm pore size, 2 mm diameter) was split into small pieces of 0.2 mm diameter and soaked with FDG. This bare point source (no surrounding positron annihilating material) was attached to a plasticine cone mounted on the tip of a thin glass capillary and positioned in the center of the scanner.

A list-mode acquisition was performed over 60 min and images were reconstructed (0.2 mm voxel size) using FBP (ramp filter, Nyquist cutoff frequency). The FWHM in the radial, tangential, and axial directions were calculated by fitting a gaussian function to the reconstructed data and calculating the profile FWHM.

The prototype high-resolution PET scanner showed improved spatial resolution in radial (0.9 mm FWHM), tangential (0.9 mm FWHM), and axial (0.8 mm FWHM) direction, respectively offering clear sub-millimeter imaging. We could demonstrate that blurring effects due to photon non-collinearity can be reduced by minimizing the detector distance.

Charge Transport and Spectroscopy of GaAs:Cr

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We present a study of the charge transport properties and spectroscopic performance of Chromium-doped Gallium Arsenide (GaAs:Cr) and assess its suitability for X-ray imaging applications. Semi-insulating GaAs material has been investigated for detector applications over many years [1,2]. In this work we study 500 μm thick GaAs grown using the Liquid Encapsulated Czochralski (LEC) method that has been compensated with chromium to produce high resistivity single crystals suitable for spectroscopic imaging devices [3]. Current-voltage measurements show a typical material resistivity of 2.5x10⁹ Ω cm at room temperature. We have carried out X-ray and gamma ray spectroscopy using the HEXITEC spectroscopic pixel detector [4] which has demonstrated energy resolution values of 2.8–3.3 keV per pixel (Fig. 1). Mobility-lifetime product values for electrons of ~5x10⁻⁵ cm²/V have been obtained. Optical Time of Flight (TOF) measurements of electron and hole drift velocity have been carried out from room temperature down to -50°C. These data show a linear relationship between drift velocity and applied voltage (Fig. 2) with a room temperature electron mobility value of >400 cm²/Vs. By studying the trend of electron and hole mobility at low temperatures we can identify the key conduction processes in this compensated material.

References:

Semiinsulating (CdZn)Te is very promising material for the preparation of room temperature X-ray and gamma-ray detectors due to their optimal energy band-gap, high density and good transport properties. The wide spreading of such detectors is still limited by many factors. One of the main problems of preparation of high performance (CdZn)Te detectors is the formation of long-term stable ohmic contacts. Contact preparation is a complex of methods including surface treatment, metallization and surface passivation. Each step of the contact preparation must be optimized to eliminate final surface leakage current. Electroless deposition technique using aqueous solution of chlorides is widely used for the detector metallization. In this work the mechanical and electrical properties of gold contacts electrolessly deposited from the aqueous or alcoholic solution of AuCl3 are compared. After standard surface treatment using Al2O3 polishing and Br-methanol etching guard-ring structure of gold electrodes is used for I-V characteristic and spectroscopic measurement. Guard-ring electrode enclosing one of the detector electrodes was on the same potential resulting in the elimination of the surface leakage current between detector electrodes. Finely alpha and gamma spectroscopy is used for characterization of the charge collection efficiency of the detectors (CCE) with both types of metallization. It was found that gold contacts prepared by alcoholic based deposition have much higher surface adhesion and near ohmic I-V characteristics. Detectors prepared with those contacts have slightly better CCE.
X-Ray Imaging With a Large Area Gas Electron Multiplier Operating in Pure Krypton

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A non-standard Gas Electron Multiplier, made from a 100 micron thick kapton foil (2-fold thicker than standard GEM's) was developed and operated in a double GEM configuration in Ar:CO₂. Gains above 10⁴ and energy resolutions of 21% (5.9 keV) were recorded over the 10×10 cm² area of the detector [1]-[3].

The high gains and immunity of the detector to damage caused by discharges allowed to incorporate the double GEM cascade in an imaging system, using a 2D resistive line readout (using only 4 electronic channels). 10×10 cm² images were obtained, having achieved a resolution of 1.7 mm. The position resolution is dominated by the SNR up to photon energies of 15 keV and above that by the range of the photo-electron emitted by the argon atom. This range has a direct influence on the position resolution and keeps increasing with the energy of the incoming photon [3].

In this work we study the performance of the 100 micron GEM in pure Krypton and Krypton based mixtures. Krypton is a good candidate for x-ray imaging applications as it presents the lowest intrinsic position resolution of the noble gases, for energies in the range from 16 to 35 keV. For low energies, where the position resolution of our system is dominated by the SNR, its behaviour is similar to the one of argon [4]. The operation of an x-ray imaging system made from a double GEM cascade detector operating in Krypton based mixtures should therefore present superior performances, particularly for energies above 16 keV.

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Polyhedral multi-radiation counters for quantitative measurement of radioactive sources

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Generally, well-shaped counters such as gamma counter and dose calibrator are used for quantitative measurements of radioactive sources in radiopharmaceuticals study and clinical use. Well-shaped counters have a limited space in which a radioactive material sample may be placed, so the sample has to be measured in a small container having a predetermined shape, such as a vial. We studied novel radiation counter which have wide detection area by placing several independent small detectors on the multipositioned 4π direction from the radioactive source. We designed polyhedral-shaped multi-radiation counter that consist several small detectors at the corner of polyhedral frame. The inner space of polyhedral-shaped counter was expected to be low measurement error space like the sample measurement region of well-shaped counter. To investigate the distribution of measurement error in the polyhedral-shaped counter’s inside, we calculated the incident radiation on detector surface using solid angle changes in the case of cube. And we made a 25×25×25 cm³ cube-shaped counter. The counter consist Hamamatsu Si PIN diode with amplifier board, and 8-channel cortex-M3 micro controller. We measured the count rates using liquid F-18(180 mCi) contained in the vial at 21 different position. The measuring area was the circle of 15 cm diameter on the center of cube(calculated deviation is about >3%). The errors were calculated by comparing the count rate at the center and the other positions. The mean of errors showed a very low value as 1.17%. In this study, we verified that the polyhedral-shaped counter has a possibility to measure quantitative RI sources in wide space. Although we used PIN-diode which has low detection efficiency for gamma ray, if high efficiency detectors such as scintillation detector are used, polyhedral-shaped counter is expected to be applied to various radiation measuring devices and region monitoring system.
Particle detectors based on high purity epitaxial 4H-SiC reveal promising properties in detection of various type of ionizing radiation. In this work we have focused on detection of thermal neutrons generated by 239Pu-Be isotopic neutron source. A high quality liquid phase epitaxial layer of 4H-SiC was used as a detection region. The thickness of the layer was 70 mm and the diameter of circular Au/Ni Schottky contact was 4.5 mm. Around the Schottky contact two guard rings were created. The reverse current-voltage measurement shows the breakdown voltage higher than 500 V. Measured current density of 10 nA/cm² at -100 V was obtained. Further, the detector structure was examined as a detector of 5.5 MeV alpha particle generated by 241Am radioisotope. The detector showed 100 % of charge collection efficiency at a voltage of -100 V. Monoenergetic protons of energies from 300 keV up to 2 MeV were also used for detector energy calibration and a good linearity was acquired.

The 6LiF conversion layer was applied on the detector Schottky contact. The products of reaction between 6Li and thermal neutron are an alpha particle (2.05 MeV) and triton (2.73 MeV) which are emitted in opposite directions and hence only one particle can reach the detector active volume at the same time. In our experiment we used two different thicknesses of conversion layer (6 and 15 mg/cm²). Measured detected spectra show two parts corresponding to alpha particles detection in lower energy channels and 3H in higher energy channels. We have also performed simulations of thermal neutron detection using MCNPX (Monte Carlo N-particle eXtended) code. The detection efficiency was optimized and the detector response to thermal neutrons was calculated with respect to the 6LiF layer thickness and is found to be in good agreement with experiment (Figure).
Characterisation of hybrid pixel detector for time-resolved pump-probe diffraction experiments at Synchrotron SOLEIL

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The experimental set-up for time-resolved studies of ultrafast dynamics at Synchrotron SOLEIL is based on a general pump-probe scheme that has been developed and implemented on the CRISTAL hard X-ray diffraction beamline. The sample is excited with very short laser pulses of ~40 fs duration (the pump), and induced changes in sample’s atomic structure are studied by measuring, with a precisely controlled delay, a diffraction pattern from a single pulse of synchrotron radiation (the probe) with a 2-D pixel detector. We propose an improvement to the classical scheme, by parallel probing the sample’s response at two different delays after excitation. The first one to study induced dynamics, while the second one being a reference measurement at sample’s equilibrium that permits detection of drifts in the experimental conditions (e.g. beam misalignment, sample degradation). In view of achieving this, a detector with a very fast readout time, a very high dynamic and linearity range was tested. The UFXC32k is a single photon counting readout circuit with the following main features: small pixels of 75 μm pitch, two thresholds and two 14-bit counters. The chip is arranged in a matrix of 128 × 256 pixels and can be read out in few tens of μs when operated in 2 bits mode. In this work we present the first characterisation of the single chip UFXC32k detector with a silicon sensor for time resolved studies. The tests were carried out on the METROLOGY beamline of Synchrotron SOLEIL. We demonstrate an excellent temporal resolution of the detector and its ability to record in parallel images with a delay shorter than 100 μs. Moreover, the detector allows photons pile-up detection thanks to its double threshold feature, which is also presented.

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Simulation of charge sharing compensation algorithms with experimental verification

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In pixel hybrid detectors with decreasing pixel size the charge sharing effect, which occurs when photon hits the detector in the area between two or four pixels, becomes more significant. If the charge generated in the detector is collected by more than 1 pixel, the photon energy and the event position may be improperly detected by the system. Therefore, the charge sharing compensation algorithms need to be implemented to improve system performance. Firstly, such algorithms must be verified on the simulation level. Our model was implemented to verify in particular the C8P1 algorithm performance used in CHASE Jr. chip, however, due to modular implementation it is designed to be easily adjusted to further tests of modified versions of charge sharing compensation algorithms. Our simulations cover the issues that were identified during C8P1 algorithm test, such as:

- sensitivity to channel gain dispersion,
- timing properties of comparators,
- noise issues and calibration.

The goal was to implement the simulations optimizing both the simulation’s accuracy and simulation’s time taking also into consideration the model flexibility, so that it can be quickly adapted for future use. We propose the solution that enables automatic validation of the system behavior at the higher level of abstraction, namely behavioral models implemented in cadence environment that allow for faster algorithm implementation and verification. The readout channel of the chip is represented using parameterized behavioral blocks of different functionality, such as, charge sensitive amplifier, shapers, discriminators, comparators. The interpixel connections are taken into account, so this approach enables top-down design and parameter optimization of the chip regarding the performance of the charge sharing compensation algorithms.

The simulation approach will be described in details and the simulation results will be presented together with experimental data obtained during synchrotron measurements for the CHASE Jr. with C8P1 algorithm implemented.
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The performance of silicon based detectors for x-ray applications is limited in high energy range. Their quantum efficiency (QE) of typical detectors systems decays to about 1% at 100 keV. A challenging alternative for high energy applications is the combination of silicon detection system with a downstream scintillator transforming the transmitted photons into photoelectrons and fluorescence photons of lower energy which can be detected with high efficiency in the silicon. Here we report on application of a low noise fully depleted pnCCD detector with 128 x 128 pixel of 75μm pixel size with a 700μm thick CsI(Tl) scintillator in the range from below 1 keV to 100 keV. In the indirect detection mode, i.e. detection of X-rays converted in the scintillator, the measured energy resolution was about 9% to 13% at 100keV, depending on the depth of interaction in the scintillator. The position resolution of the whole system can reach a value of about 30μm using a columnar CsI(Tl) scintillator. The parameters of the whole system are tested using radioactive sources and hard x-rays of a laboratory source accompanied by modeling of the detector response. The excellent performance of the detection system is demonstrated at the example of a Laue diffraction experiment taken from a GaAs single crystal using white synchrotron radiation between 30 to 100keV provided by EDDI beamline of BESSY II synchrotron.
Dual energy cone-beam CT can distinguish two materials with different atomic compositions. The principle of dual energy cone-beam CT based on modulation layer is that higher energy spectrum can be acquired at blocked x-ray window. To evaluate the possibility of modulation layer based dual energy cone-beam CT, we analyzed x-ray spectrum for various thicknesses of modulation layers by Monte Carlo simulation. And we developed contrast phantom with 3D printer and inserted iodine plug with various densities to analysis of image quality. As the result of comparing, the mean energy of energy spectrum for 80 kVp are well matched with that of simulation. The mean energy of energy spectrum for 80 and 120 kVp were increased as 1.67 and 1.52 times by 2.0 mm modulation layer, respectively. The image contrast was improved in iodine plugs. We realized that the virtual dual energy x-ray source can be generated by modulation layer effectively.
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In homeland security and environment protect need detectors that can detect and locate the nuclear devices and orphan radioactive sources. The Rotating Modulation Collimator (RMC) is a quick and simple imaging system with low cost, which makes it a reasonable selection for locating and potentially tracking nuclear material and radiation sources wherever they might be located. An advantage of the RMC is to image radiation sources with using a single non-position sensitive detector to record a one-dimensional time dependent map of a three-dimensional source scene through two or more masks made out of high Z material which have slits that run the length of the masks. In the research, we applied new design of masks, using two hemisphere masks rotated together. For this design, the field-of-view of the RMC is the range of angles expanded and increased the counts of radiation reaching the detector, hopefully.

In this research, two hemisphere masks sets used were constructed and simulated for the modulation profiles by the MCNP code system. In the simulation, we assumed a non-position sensitive monolithic CZT detector to record the modulation profiles. The gamma ray events of interest were determined at each rotational angle by the use of the pulse height distribution (F8) tally in MCNP. Obtained modulation profiles were then investigated to reconstruct the image for the gamma-ray source distribution. We evaluate the imaging performance of the extended concept of RMC technique.
ExcaliburRX: Development and characterization of a small-pixel photon counting area detector

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1) Diamond Light Source
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ExcaliburRX is a large area photon counting detector based on the Medipix3RX read out chip. It is the upgrade of the Excalibur detector, which was based on the first version of the Medipix3 ASICs. The main differences of the Medipix3RX ASIC with respect to previous Medipix3 versions are: a new front-end architecture for the CSM, new threshold trimming circuitry, improvement to both the continuous read-write mode and of its radiation hardness, and the increase to four operational gain modes. The ExcaliburRX detector consists of three monolithic silicon sensors with 16 Medipix3RX chips flip chip bonded to each sensor. Each sensor has a format of 2048 x 512 pixels with a pixel size of 55 um x 55 um giving a sensitive area equal to 113 mm x 28.2 mm. The read-out architecture is fully parallel with 6 acquisition channels reading 8 chips each. The parallel read-out architecture enables to achieve a frame rate of 100 Hz when the data are streamed to the data acquisition servers (6 in total, 2 per module) and of 2 kHz when the data are stored in the RAM of the data acquisition boards. The detector development together with results from its characterization will be presented. Currently, the detector is deployed for ptychography experiments performed in the coherent diffractive imaging branch (I13) at Diamond Light Source.
Improving Rotating Modulation Collimator Imaging Algorithm for Locating Mid-Range Point Sources

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Objective: To improve the quality of the RMC images, we propose a new image reconstruction algorithm based on adaptive regularization technique.

Background: Detecting stray radiation sources poses important issues for national security and international nuclear safety. The Rotating Modulation Collimator (RMC) is among the most promising techniques in remote source detection. In a RMC, a pair of masks located in front of a detector pass or block photons. As the masks rotate, the number of photons recorded at the detector create a modulated pattern. An image reconstruction algorithm processes this one-dimensional signal to visualize the location of the radiation sources. Recently, Kowash proposed an algorithm based on the maximum-likelihood method to locate mid-range sources. However, the RMC images from his algorithm suffer from undesirable artifacts when sources are weak.

Method: To solve this problem, we propose an improved image reconstruction algorithm using a regularization method. In the algorithm, we maximize a penalized likelihood by imposing an adaptive weight to each pixel. The weight is set inversely proportional to the source activity estimate of the pixel. The proposed algorithm increases the sparsity in the reconstructed RMC images; thus, reducing the artifacts. To demonstrate the proposed algorithm, we performed Monte-Carlo experiments. From the RMC system model, we generated RMC modulation patterns for a point source. Our algorithm is used to reconstruct the RMC images and to visualize the direction of the radiation sources. The result images are compared with the algorithm proposed by Kowash. We also computed the SNR and PSNR of the reconstructed images.

Conclusion: Our algorithm successfully reduces the artifacts and improves the quality of the RMC images. The improvement is clearly visible in the result images (see attached image). The quantitative analysis on the SNR and PSNR also proves better performance of our algorithm.

Fig. 1 A circle represents a source located at (25,25,500)cm and rectangles represent the estimates from the image reconstruction algorithms. Left: The result from the algorithm proposed by Kowash shows artifacts (grey rectangles). Middle: Our algorithm using regularization technique reduces the artifacts from the image. Right: Our algorithm greatly improves PSNR over a wide range of source activities.
Improving image reconstruction algorithm for Rotating Modulation Collimator using a variance stabilization transform

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Objective: We propose an improved RMC image reconstruction algorithm using variance stabilization transforms.

Background: It is important to detect orphan sources for national security and nuclear activity detection. One of the promising techniques for detecting remote radiation sources is based on the Rotating Modulation Collimator (RMC). It consists of a detector and two masks that selectively pass photons to the detector. As the masks rotate, the RMC records the number of detected photons over time. Thus, an image reconstruction algorithm is essential to visualize the location of the radiation sources from the one-dimensional RMC signal. A conventional RMC image reconstruction is utilizing the maximum likelihood expectation maximization algorithm as proposed by Kowash. He modeled the RMC signal with a Poisson distribution. However, his algorithm produces undesirable artifacts when source activities are weak due to the data-dependence on the Poisson noise variance.

Materials and Method: In this paper, we propose an improved algorithm using a variance-stabilizing transformation. The transformation eliminates data-variance-dependence by converting a Poisson distribution to a Gaussian distribution. Then we newly define a likelihood function from the Gaussian model and derive an improved reconstruction algorithm on the transformed RMC modulation profile. We performed Monte-Carlo simulations on the data generated from the RMC system model. The simulated modulation profile is converted by a variance-stabilizing transform. Then the proposed image reconstruction algorithm is used to visualize the radiation sources. The result image is compared with the original algorithm by Kowash. For various source activities and locations, we computed the SNR and PSNR of the two algorithms.

Conclusion: In the reconstructed images, our algorithm shows reduced artifacts than the original algorithm. The improvements are clearer for weak radiation sources (see attached image). Furthermore, our algorithm shows better performance on PSNR and SNR.

Fig. 1 A circle represents a source located at (25,25,500)cm and rectangles represent the estimates from the image reconstruction algorithms. **Left:** The result from the conventional algorithm shows artifacts (grey rectangles). **Middle:** Our algorithm using variance stabilization reduces the artifacts from the image. **Right:** The PSNR over a wide range of source activities shows better performance of our algorithm, particularly for weak sources.
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Optical coherence tomography is a promising medical imaging approach which enables noninvasively, high-resolution cross-sectional imaging of the biological specimens [1]. Fourier domain Optical Coherence Tomography (FD-OCT) including spectral domain (SD-) and swept source OCT (SS-OCT) has attracted considerable attention due to its dramatically enhanced sensitivity and higher imaging speed compared over the conventional time-domain implementation [2]. In OCT, endoscopic probes have been employed to observe usefully inside of hollow cavity or the surface of inner organs of a human body for more accurate diagnosis or surgery in a minimally invasive approach. Advances in miniaturized endoscopic probe for OCT has increased the accessibility to deep legions of inner organs substantially which are typically inaccessible by other medical imaging tools. Fiber can play an critical role of an OCT probe in itself without any additional focusing optics. In addition, the side view imaging can be also realized by an angled end of a conventional single-mode fiber (SMF). Due to its inherent compactness, it’s very useful in the applications where micro thin probe is highly required for minimal invasion.

In this study, the concept purpose is to demonstrate the potential of OCT applicable to the cochlear surgery as an intraoperative navigation tool when the round window approach are performed to insert the electrode array into a human cochlear duct. The surgeon can reach up to the proper region near the basal turn safely with the patient-dependent structural information. Hence, we can critically minimize the damage and side-effects during a surgery through the above mentioned ‘soft surgery technique’ [3,4]. We demonstrated successfully the proof–concept for in vivo intraoperative guidance and presurgical planning as acquiring the images of the cochlea lumen of the human cadaveric temporal bone.
While there has been recent research on high energy radiation dosimeters of a direct conversion type, it is still in early stages of development. In this study, we sorted out useable photoconductive materials and evaluated fundamental properties that should be prepared for the high energy radiation dosimeter. To evaluate the photoconductive material, we selected the materials with high atomic number (Z) and density (g/cm³) and fabricated prototype dosimeter unit cells using selected materials (HgI₂, HgI₂ with Oxide, PbO, PbI₂, HgO) using particle-in-Binder method. Then, we measured the high energy response, dose rate dependence, linearity and reproducibility as fundamental property using the linear accelerator (LINAC, Clinac iX, Varian Medical system, USA) at 4MV and 10MV external photon beam. As a result, we couldn’t obtain the standard values in PbO, PbI₂ and HgO dosimeter unit cell, however, the HgI₂ and HgI₂ with Oxide dosimeter unit cell was satisfied with the standard value from International Atomic Energy Agency (IAEA) and American Association of Physicists in Medical (AAPM). In the case of the HgI₂ dosimeter unit cell, its sensitivity was higher than that of monitoring chamber installed in the LINAC at 10MV photon beam. The reproducibility of the HgI₂ and HgI₂ with Oxide dosimeter unit cell was 0.45% and 0.6% at 4MV and 0.95% and 0.48% at 10MV, which is comparable to ~ 0.5% of the value recommended from IAEA. Therefore, in this study, we could sort out the useable photoconductive material and it was demonstrated that the HgI₂ and HgI₂ with Oxide have the standard properties for the high energy radiation dosimeter.
Investigation of CMOS pixel sensor with 0.18 um CMOS technology for high-precision tracking detector

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The Circular Electron Positron Collider (CEPC) proposed by the Chinese high energy physics community is aiming to measure Higgs particles and their interactions precisely. The tracking detector including Silicon Inner Tracker (SIT) and Forward Tracking Disks (FTD) has driven stringent requirements on sensor technologies in term of spatial resolution, power consumption and readout speed. CMOS Pixel Sensors (CPS) is a promising candidate to approach these requirements which has been well equipped in high energy experiments such as STAR pixel detector. However, in order to equip the CEPC tracking detector it remains challenge of keeping high collection efficiency with large pixel pitch.

This paper presents the preliminary studies on the sensor optimization for tracking detector to achieve high collection efficiency while keeping necessary spatial resolution. This is mainly determined by Q/C and results in relative signal-to-noise ratio. Detailed studies have been performed on the charge collection using a 0.18 μm CMOS imager sensor process. This process allows higher resistivity epitaxial layer, leading to significant improvements on charge collection and therefore improving radiation tolerance. Together with the simulation results, we have designed the first exploratory prototype for sensor optimization. The prototype includes 9 different pixel arrays, which vary in terms of pixel pitch, diode size and geometry. Besides, in order to improve charge collection efficiency with large pixel pitch, the layout of the pixel is drawn with staggered diodes. The total area of the prototype amounts to 2 x 7.88 mm\textsuperscript{2}.

This paper will describe the details of the sensor optimization and the circuit implementation of the prototype. Also the preliminary laboratory experimental results will be shown, complemented with an outlook on further design improvements.
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PET scanners with limited angle tomography make difficult to reach high quality reconstructed images when accurate timing resolution is not considered. This is the case, for instance, of dedicated cardiac or prostate PET systems, where detector modules might be small and with partial coverage. Thus, a PET imager with missing angular information produces non-uniformities and artifacts in the reconstructed image across the field of view. If Time-of-Flight (TOF) information is available, one could afford loosing part of this information reducing the artifacts on the final reconstructed image.

Detectors based on SiPM technology have demonstrated that, in order to obtain a very accurate time resolution, it is required to independently process each SiPM element so that the time information related to the rise time of the signal is preserved. Application Specific Integrated Circuits (ASICs) is one of the most suitable solutions to carry out this work when SiPM arrays are used due to the amount of channels that needs to be processed.

In this work we study the performance of two coincidence detectors based on the commercial TOF- PET ASIC from Petsys, coupled to a SiPM array and a LYSO crystal array (2 mm pitch) in order to validate their use for TOF-PET applications. First results show a submilimetric spatial resolution (Fig. 1 top) and coincidence resolving time below 400 ps for pixelated crystal arrays (Fig. 1 bottom-left). Several parameters with strong influence on the CRT such as temperature (Fig. 1 bottom-right) or discriminator threshold will be also evaluated. In addition to crystal arrays, tests with monolithic crystals have been started with promising results. Here, the scintillation light is shared among several SiPM channels and we will evaluate timing performance with different surface treatments. Moreover, these crystals allows one to also determine the photon impact Depth of Interaction.

Figure 1. Top: Spatial resolution with 2 mm scintillator pixel size and 8x8 SiPM arrays. Bottom: Coincidence timing performance dependency according bias voltage and temperature.
Performance improvement of a pixellated CdZnTe detector by using a gamma-ray tracking based on pulse rise-time

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Room temperature semiconductor detectors, in particular Cadmium Zinc Telluride (CZT) detectors, are widely used in X-ray and gamma-ray spectroscopy. The use of CZT detectors has helped to increase both efficiency and effectiveness of detector performance in many applications, such as nuclear medical imaging and industrial imaging systems. Since the inefficient charge collection within the detector especially for holes degrades the detector performance [1], various methods have been suggested to diminish the effects caused by the hole trapping and to improve the energy resolution of CZT detectors. Especially for a pixellated CZT detector as a component of the gamma-ray imaging device, such as a Compton camera, multiple scattering of gamma rays in the CZT material results in poor image resolution and image sensitivity.

In this work we carried out the gamma-ray tracking to improve the energy resolution and determine the interaction positions in a 16-pixellated CZT detector manufactured by eV Products. Two-pixel events were selected for the gamma-ray tracking from the Monte Carlo simulation studies using a GEANT4 simulation toolkit [2]. In order to determine the interaction depth in the detector, we used the correlation function between the pulse rise-times and the depths in the analysis. The algorithm for identifying valid multiple gamma-ray scattering sequences was developed in this work. Pulse shapes were digitally recorded with a 64-channel 62.5 MS/s digitizer (v1740B) manufactured by CAEN. By using data obtained for gamma rays emitted from a 22Na standard source, we were able to conduct depth sensing and determining gamma-ray sequences.


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Spectrometric properties of semi-insulating GaAs detectors irradiated by 5 MeV electrons at different dose rates

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In our previous research [1], we have investigated the influence of 5 MeV electron irradiation on selected spectrometric properties of semi-insulating (SI) GaAs detectors. Each detector group was irradiated by a different dose rate (20, 40 and 80 kGy/h). The charge collection efficiency, the detection efficiency and the relative energy resolution were studied with respect to applied accumulative dose in the range from 1 kGy up to 24 kGy. In this paper, we have proceeded with our study up to an accumulative dose of 120 kGy at the same dose rates during irradiation.

The electron irradiation has negatively affected the detector CCE (Charge Collection Efficiency). Un-irradiated detectors exhibited the CCE of 79 % at maximum operating reverse bias voltage of 300 V and 73% at 200 V. With increasing applied dose, the CCE was systematically decreasing, following the trend observed in [1]. Moreover, the higher doses affected also the detector operating voltage. After a dose of 120 kGy, the detectors could not reach operating voltage higher than 200 V. Thus, the maximum CCE after irradiation by a dose of 120 kGy was 51% at 200 V.

Energy resolution was also affected by electron irradiation. Its global degradation was observed in the range of doses from 24 up to 120 kGy, where an increase from 19 % up to 39 % at 200 V reverse bias was noticed.

On the other hand, a global increase of detection efficiency with dose, by about 30% at 120 kGy, was observed with all samples. We did not observe any significant influence of chosen dose rates applied during irradiation on investigated spectrometric properties of detectors.

REFERENCES

Semi-insulating GaAs based detector of fast neutrons produced by D-T nuclear reaction

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In our previous research [1], we have optimized the bulk semi-insulating (SI) GaAs detectors for fast-neutron detection. Their active area of 7.4 mm² was created by a multi-pixel structure of Schottky contact, which was coated by a HDPE (High Density PolyEthylene) conversion layer, where neutrons transfer their kinetic energy to hydrogen atoms through elastic scattering. Detectors were tested at a 239Pu-Be source of fast neutrons with continuous spectrum of neutrons up to 12 MeV and with their mean energy of about 4 MeV.

In this paper, we have examined SI GaAs detectors at a different type of neutron source to study their detection properties. The detectors were exposed to mono-energetic neutrons with kinetic energy of 16.8 MeV generated by deuterium – tritium nuclear reaction. The MCNPX (Monte Carlo N-particle eXtended) code has been used to support the analysis of the experiment. First, the influence of HDPE layer thickness on the relative detection efficiency of fast neutrons was studied. The theoretical optimum thickness of the conversion layer was determined to 1.9 mm using the MCNPX code. The HDPE conversion layers of various thicknesses, in the range from 50 μm to 3200 μm, were glued on the top Schottky contact of SI GaAs detector in the experiment. The experimental data showed very good agreement with results from simulation. The MCNPX code was used also to model the detector response to used fast neutrons concerning the effect of various thicknesses of the HDPE conversion layer. Finally, the effect of active detector thickness modified by detector reverse bias on detection efficiency was studied.

REFERENCES
A developed method for the formation of indium bumps commonly used in medipix/timepix detectors with a diameter of 30 μm is demonstrated. The method is based on electroplating of indium by using indium sulfamate plating bath. Deposition of indium by electroplating saves the amount of used indium compared with evaporation, which is of importance, since the cost of indium has increased during the recent years. An aluminum layer of 300 nm provides a common contact during electroplating. The advantage using aluminum is that it can be etched selectively not eroding the formed indium bumps. The under bump metallization consist of 30 nm titanium and 200 nm of nickel. Often a thin gold layer is deposited on top of the Nickel to prevent oxidation. It is not used here since it can cause a brittle interface and affect the plasticity of the indium. Instead an oxide etching step is included prior the electroplating to remove the formed oxide on the nickel layer. The bonding process is demonstrated with bumps growth on one surface and the second surface with evaporated 30 nm Ti, 200 nm Ni and 300 nm In. The pitch of the bumps is 220 μm and is arranged in a 64 by 64 pattern compatible with the medipix family read out chip [1]. The thermo-compression conditions are varied to achieve optimal electrical connection and bonding yield. The bonding is observed electrically by measuring the connection in each row and optical by using a boron silicate patterned window as top layer device. The figure displays the electroplated bumps after resist removal, before annealing to form spheres.

One of the most important properties of any photoconductor used in radiation detectors is electron-hole pair creation energy $W$. Improving $W$ is important to increase sensitivity of any direct conversion detector with a photoconductive layer as the x-ray-to-charge-transducer. This also applies to amorphous selenium (a-Se) the material of choice for direct conversion mammography detectors. It was shown that $W$ in a-Se does not follow the so-called Klein rule for semiconductors and is dependent on electric field. Previous attempts to measure $W$ in plain a-Se layers were unsuccessful due to the technical complications with a-Se stable operation at electric fields higher than 30 V/μm.

Using avalanche, a-Se structure with pixel electrodes we investigate $W$ in a-Se in a wide range of electric fields and show its saturation at 9 eV in the vicinity of the avalanche multiplication threshold. In addition we measured $W$ in a wide range of temperatures (193K - 330 K) and showed that it decreases with increasing temperature. This saturation as well as overall temperature and field dependences do not support the conventional columnar recombination model [1], which is based on Langevin recombination mechanism within the column created by charge carriers along the track of the primary photoelectron. To explain our results, we modified the theory of columnar recombination, taking into account that at the highest electric fields, the recombination rate becomes limited by the time of the recombination event rather than by the time needed for electron and hole to meet in space, and the concept of Langevin recombination inside the column fails. Our results suggest a fundamental limit of a-Se x-ray sensitivity and expand our knowledge on recombination in amorphous x-ray-to-charge transducers [2].

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Feasibility Study of Graphene based Radiation Detector for the Improvement Sensitivity using the Phosphor Electrostatic Potential Layer in X-ray Imaging

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Digital radiography is a technology that produces images by processing the electrical signals generated by X-rays. High sensitivity and contrast are critical to achieving the early detection of minute lesions. So studies are being conducted on the graphene-based radiation detector with the aim to improve the sensitivity.

The graphene-based radiation detector measures the surface resistance variation that is sensitive to the electric field variation. It is composed of the semiconductor layer for absorbing radiation, the electrostatic potential layer for maintaining the electric field, the graphene layer that is sensitive to the resistance variation caused by electric field. In this study, the author intended to evaluate the graphene based detector structure that is used Particle In Binder type phosphor which presents dielectric strength as an electrostatic potential layer. 200 μm Hgl2 was used to prepare the semiconductor layer and 10 μm Gd2O2S:Tb prepared in PIB type was used for the electrostatic potential layer. Additionally, graphene was used to form the electric field and Dirac Point was confirmed at 312 V to 350 V through I-V test. When 6.5 mR/cm2 X-ray was radiated, the electric charge of 2.9 nC to 3.3 nC was generated, confirming the voltage variation of 1.1V and the consequential resistance variation of 0.7 kΩ to 1.0 kΩ. In addition, the thickness phosphor layer was optimized by considering the resistance variation caused by the visible light generated from the phosphor and the input voltage according to the breakdown voltage for maintaining the electrostatic potential. The prepared phosphor was adjusted from 5 μm to 25 μm to measure the signal acquisition time. And the optimal result was obtained at 10 μm.
Development of Helical Computed Tomography Oriented Linear Detector Array for High-Energy X-ray Non-Destructive Testing System

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Ever since the first utilization of x-ray imaging, remarkable progress has made us inspect almost everything interested. Among x-ray imaging modalities, computed tomography (CT) has outstanding merits compared to conventional radiography. The necessity of high-energy helical CT has been increasing for objects which have complex structure. According to the opinion of Ammunition Support Command under Republic of Korea Army, the primary requirement of missile inspection was to identify subtle density differences enclosed within high density structure. To meet the market demand on the high-energy CT system, especially in the defense industry, we proposed the optimal design of linear detector array prototype which consisted of cadmium tungstate (CWO) scintillator and PIN photodiode. Considering typical density and thickness of exterior structure of missile, we designed linear detector array for 6MeV x-ray operation. In order to optimize CWO dimension, energy deposition simulation using Monte Carlo N-Particle code was conducted. Key factor was the depth size of scintillator, which is the length of x-ray incident path. We found that there were a certain level of saturation in energy deposition to the scintillator; therefore, it is possible to approach the optimal depth of scintillator considering the cost that is proportional to its volume. PIN diode was fabricated on the wafers with thinner thickness, less resistivity, and less capacitance to achieve low noise, and less dark current. Elaborate guard rings were introduced to guarantee high performance against leakage current through diverse routes. To obtain uniform pixel pitch between PIN diode arrays, the boundary pixels of arrays had 40 narrower width to compensate for sawing scribe margin. The whole detector modules should be shielded properly against high-energy radiation damage. The integrated prototype linear detector array modules will be fabricated and tested to verify our degree of technology completion.
Differently from x-ray radiology based on absorption properties of tissues, x-ray phase contrast (PhC) arises from front wave modulation and associates changes of the propagation direction of x-rays traversing the object. Due to the vast difference in the cross sections PhC yields higher contrast than conventional x-ray radiology, but intermediate steps to transform PhC into measurable intensity modulations are required. For the implementation free space propagation PhC is the simplest technique since it does not require any particular optics, however it relies on a highly coherent source. At the clinical beamline of the Italian synchrotron ELETTRA, free space propagation has been used to carry out mammography on patients.

Owing to an analyzer crystal, an angular filter with a bandwidth in the microradian regime placed between the sample and the detector, in Analyzer-Based Imaging (ABI) the angular change of the radiant wave field propagation direction is transformed into intensity modulations on the detector. Employing appropriate algorithms, absorption, refraction and dark field images are extracted providing complementary information. Regarding its implementation, ABI is demanding for its x-ray optics that requires high stability and microradian resolution. In return, this method possesses an extremely high sensitivity among the PhC techniques.

In this work we have tested the feasibility of ABI in a preclinical set-up implementing the system in the clinical beamline. The ABI set-up was installed between the patient position and movement support and a commercial large area CCD. The overall performance of the system, which is suitable for patient examinations, will be discussed. First high quality images of test objects and breast tissues specimens will be presented and compared to images acquired at a conventional mammography unit. Moreover, detector requirements such as efficiency, dynamic range, noise floor and long-term stability, which are particularly crucial for this kind of application, will be discussed.
The radiation damage effects in silicon segmented detectors caused by X-rays have become recently an important research topic driven mainly by development of new detectors for applications at the European X-ray Free Electron Laser (E-XFEL). However, radiation damage in silicon strip and silicon pixel detectors is observed not only after extreme doses up to 1 GGy expected at E-XFEL, but also at doses in the range of tens of Gy, to which the detectors in laboratory instruments like X-ray diffractometers or X ray spectrometers are exposed.

We will present the study of radiation damage effects in a custom developed silicon strip detector used in laboratory diffractometers equipped with X-ray tubes. Our investigation shows that significant degradation of the detector performance occurs at low doses well below 200Gy, which can be easily reached during normal operation of laboratory instruments. Degradation of the detector energy resolution can be explained by increasing leakage current and increasing interstrip capacitance of the sensor. Another observed effect caused by accumulation of charge trapped in the surface oxide layer is change of charge division between adjacent strips, which indicates clearly for changes of the electric field profile in the interstrip regions. In addition, we have observed significant unexpected anomalies in the annealing process.

The experimental results will be presented and qualitative models of radiation damage effects in silicon strip detector caused by soft X-rays will be discussed.
Material properties and multi-functionality of metal foams can be improved by coating the base open-cell metal foam with a nanocrystalline layer of other metal, e.g. nickel. Resulting material is a hybrid foam with unique material properties benefiting from higher plateau stress and profound strain-rate dependence. To describe the deformation behaviour of such a novel material time-lapse X-ray microtomography was used for mechanical characterization of Ni/Al hybrid foam. The samples were prepared by electrodeposition of Ni layer of variable thickness on aluminium open-cell foam. To understand the influence of the coating layer on the resulting material’s effective properties, we compared compressive response of the base uncoated foam to response of the material with coating thickness 50 and 75 microns. Digital volumetric correlation was applied to obtain volumetric strain fields of the deforming microstructure. The samples were gradually loaded up to complete failure to capture the collapse of the cellular structure and to describe the densification of the material.

Compressive mechanical tests were analysed using X-ray radiography and tomography. A custom design experimental device which enables for X-ray tomography during loading was used for compression of the specimens in prescribed deformation states. Planar X-ray images were taken during the loading phases and X-ray tomography was performed at the end of each loading phase. The samples were irradiated using XWT-240-SE reflection type X-ray tube and images were taken using the XRD1622 large area GOS scintillator flat panel detector with active area 410x410mm and resolution 2048x2048 pixels. Digital volume correlation was used to identify the displacement and strain fields evolution during the compressive loading from the tomographical reconstructions of each deformation state.

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A Gas Proportional Scintillation Counter with Krypton Filling

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Gaseous detectors are particularly appropriate for x-ray spectrometry. While solid-state detectors have energy-resolutions ~150 eV @ 6 keV, ionisation-counters may reach values of ~800 eV. In addition, modern hole-type structure detectors for charge-amplification present even worse resolutions. Yet, gaseous detectors have advantages over solid-state competitors: room-temperature operation, large detection-areas, low-cost 2D-imaging capabilities.

GPSCs are gas-filled x-ray detectors where charge-signals of x-ray interaction inside the active volume is amplified through secondary-scintillation processes, in opposition to avalanche-amplification processes. Electrons from radiation interactions with the gas are guided towards a region where the electric field promotes signal amplification. The electric field allows excitation but not ionisation of gas atoms; electroluminescence resulting from de-excitation is proportional to primary electron number. Statistical fluctuations in electroluminescence are lower than in ionisation processes and even lower than in primary-charge production allowing energy resolutions ~450 eV @ 6 keV. Though, optimal operation requires cleaner gas and higher biasing voltages.

Their application was restricted mostly due to the use of fragile, bulky and power consuming PMTs for scintillation-readout. Large-area avalanche photodiodes and SiPMs are suitable alternatives to PMTs. These photosensors allow large-area, yet compact, low power-consuming and cost-effective readouts with 2D-imaging capabilities. One can have competitive GPSCs for spectrometry applications, where large detection areas / imaging capabilities are important.

Xenon and argon are used in rare event detection (WIMP dark matter and neutrinoless double-beta decay). Krypton has a radioactive isotope, but is cheaper having the highest absorption cross-section for 13 - 34 keV x-rays, advantageous for specific applications.

A Kr-filled GPSC with a large-area avalanche photodiode as photosensor is presented. Electroluminescence, energy-resolution performance and x-ray spectrometry capabilities are assessed.
Accumulating Type High-Frame-Rate Camera and Application to Pulsed Neutron Bragg-Edge Transmission Imaging

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ABSTRACT

An accumulating type high-frame-rate camera for pulsed neutron transmission spectroscopic radiography has been developed and applied for Bragg-edges transmission imaging at an electron linac compact pulsed neutron source in Hokkaido University.

IMAGING SYSTEM

As shown in fig.1 the imaging system consists of a neutron image intensifier, a high-frame-rate camera, a frame accumulator and a personal computer for image data recording. The high-speed CMOS camera can take images of 320 x 240 pixels with 100kfps, 512 x 512 pixels with 30kfps or 960 x 960 pixels with 10kfps. The resolution is 12 bit. When the repetition rate of the linac is 50 Hz and the camera is operated with the speed of 100kfps, successive 2,000 frames are accumulated repeatedly over every from 16 to 4096 linac triggers. Accumulated from 16 to 24 bit data are transferred to PC memory by high speed data link and next accumulation starts to achieve seamless data taking.

BRAGG-EDGES TRANSMISSION IMAGING

An experiment has been made to deduce the texture and microstructure information of a test sample, a Japanese kitchen knife at Hokkaido University neutron source (HUNS). The linac electron energy was 34MeV, the pulse width was 3 μs, the pulse repetition rate was 50 Hz, and the beam current was 33 μA. The neutron flight path length from the source to the detector was 5.676 m. The measuring time was 15 hours. The high-frame-rate camera was operated with the mode of 512 x 512 pixel and 30 kfps, that is, the time resolution was 33.3 μs. Figure 3 is the result of analysis by the RITS (Rietveld Imaging of Transmission Spectra) code. The pixel size is 0.54 mm. The alpha-iron (the BCC phase) zone and the austenite stainless steel (the FCC phase) zone could be separately analyzed. The crystalline phase analysis has been successfully made.
In-pixel ADCs for use in hybrid pixel detectors for spectroscopic applications

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Recent years showed increased effort of many groups (e.g. Medipix, PIXIE, PIX45) towards development of various circuit and design solutions for Single Photon Counting systems, allowing for reconstruction of the entire charge generated in the detector volume by a single photon. Having the information about the total amount of deposited charge, one has an opportunity to reliably measure its amplitude. This would allow to gather the information not only about the number of impinging photons, but also about their energy, e.g. for spectroscopy purposes. However, factors specific to X-ray imaging systems, such as large number of readout channels per single ROIC and stochastic nature of incoming photons, call for conversion of each event into the digital domain as soon as possible, independently in each channel. This approach requires a very low-area and low-power analog-to-digital converter, which could be implemented in every readout channel of the integrated circuit.

This work presents an in-depth analysis and comparison of various ADC architectures, based on the current state-of-art, in terms of their applicability in single photon counting systems. Also, the design and measurement results of a flash analog-to-digital converter, dedicated for in-pixel application in hybrid pixel detector ROICs with pixel size of 100 μm × 100 μm, manufactured in 40 nm CMOS technology are presented and compared. The considerations define the required conversion rate (with respect to the radiation intensity) and adequate resolution range and are focused mostly on how the chosen converter’s architecture affects its area occupancy and power consumption. Also other architecture-specific aspects, such as the necessity of a dedicated conversion clock or a reference voltage buffers are taken into account.
Charge sharing among neighboring pixels pauses serious limitation to photon counting sensors in general and to those that have multi-energy levels in particular. Semiconductor detectors with high Z, such CdTe, are favored for high energy photons, suffers from limited e-h mobility and this increases the charge clouds spread, and hence increases the probability of charge sharing among neighboring pixels. Moreover, the use of thick detector is favored to increase the detection efficiency of energetic photons and at the same time detector with small pixel size is favour for achieving better image spatial resolution. However as the ratio of the pixel size to the detector thickness decreases, the impact of charge sharing increases.

Reducing the impact of the charge sharing in photon counting devices is paramount for multi-energy sensor. Medipix3 chip includes an algorithm to reduce the impact by charge sharing by summing the charge in the neighbor pixels. However it performs best on 2x2 pixels array where each pixel size is 110um x 110um. The C8P1 algorithm also sums up charges among neighboring pixels but it can handle 3x3 pixels array. Both designs are complex and limited at the level of circuit design and performance.

We present a simple algorithm that can detect the pixel with the maximum deposited energy, which we call the master pixel, without the need to measure its energy and to compare it to the energies in neighboring pixels. After the identification of the master pixel, the summation of the charges in the surrounding signals is added to that of the master pixel. In principle, the algorithm can handle any array of pixels, nxn, that are engaged in charge sharing of the same photon.
Eu-doped SrI2 scintillator has an excellent light output of over 50,000 photons/MeV, and good energy resolution of less than ~4% at 662 keV (FWHM), and intrinsic background from radio isotope in the scintillator is negligible. Thus, this material can be used in a radiation spectrometer like a food monitor under low doses of ionizing radiation. On the other hand, this crystal is expensive, because it is difficult to grow the crystal due to strong hygroscopic nature. Thus, we have developed a phoswich-type detector with Eu:SrI2 and Tl:NaI, because Tl:NaI has low cost. Although Tl:NaI has worse energy light output (~40,000 photons/MeV) and energy resolutions (~7% at 662 keV, FWHM), in the MeV region (over 1 MeV), the FWHM energy resolution of Tl:NaI can be achieved less than 5%.

Eu:SrI2 and Tl:NaI with a diameter of 8 mm were cut, polished and assembled to the phoswich-type detector, and this phoswich-type one was sealed with a hermetic package due to hygroscopic nature. Here, Eu:SrI2 was gamma-rays source side, and Tl:NaI was a photo-detector side (glass window side). The detector was irradiated with gamma rays from a gamma-ray source. The FWHM energy resolutions of Eu:SrI2 and Tl:NaI were approximately 4.6% and 7.5% at 662 keV using a photo multiplier (Hamamatsu, R7600U-200). Moreover, we optimized some read-out parameters such as shaping time. In this presentation, we show the above scintillation properties.
Simultaneous application of SDD and CZT detectors in combined X-ray fluorescence and gamma spectrometer

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X-ray fluorescence spectrometer (XRF) with silicon drift detector (SD) and gamma spectrometer using cadmium-zinc-telluride (CZT) detector was simultaneously applied to determine the activity of the radioactive isotopes and concentration of inactive elementary composition of waste materials. The component of the XRF spectrometer i.e. the SD detector and a mini X-ray tube are mounted on a vertically moving console and the sample is fixed on x-y stage moving into horizontal directions. Due to the significant difference of the sensitive energy ranges of these two types of energy-dispersive detectors they can be applied simultaneously performing both measurements on the same sample. The XRF device has been constructed in confocal measuring arrangement, with diameter approximately 2 mm of the focal spot. An optical alignment system was developed for selection of the measuring spot on the sample surface that system is based on two laser module and a web camera. Analytical capability, i.e. limit of detection, and lateral resolution of the confocal XRF spectrometer were determined. Adapted theoretical calculation model for determination of the concentration of the inactive elements in the sample was developed on the basis of the fundamental parameter method (FPM). In order to evaluate and quantify the gamma spectra a new reverse Monte Carlo conception was designed and tested with application of the MCNP-6 validated code for simulation of gamma spectra.
The use of PET imaging using radioisotope (RI) tracer is a widespread method for detecting tumors and diagnosing Alzheimer’s in its early stages. To conduct a quantitative diagnosis, accurate estimation of tracer’s RI concentration in blood is required. Current treatment extracts blood from the patient and then measures the concentration using a curie-meter, which can be a burden for the patients. In this study, we have developed a small high-resolution PET system for measuring blood RI concentration in a non-invasive way.

In this study, the developed PET detector consists of Silicon photomultipliers (SiPM) array individually coupled with Ce:Gd3(Ga, Al)5O12 (Ce:GAGG) scintillators. Ce:GAGG scintillator has attention in various fields of nuclear medicine and experimental physics because of high density (6.63g/cm3), fast decay time (88ns) and high light output (around 48000ph/MeV).

The detector consists of 1.6mm×1.6mm Ce:GAGG scintillators positioned in a 12×12 array. Also a 1.6mm×1.6mm SiPM is arranged on a 12×12 channel, both working as individual readout systems. The gap and pitch of each pixel are 300μm and 1.9mm, respectively. Signal from the SiPM array are first sent to 3 pieces of newly developed 48 channel current-comparing type time-over-threshold ASIC for individual readout of pixels, converted to digital signal, then sent to the data acquisition circuit.

The PET system developed has been evaluated with spatial resolution, sensitivity and count rate performance using 22Na point source. The resolution of 0.98mm(FWHM) was measured in the first experiment. Imaging capability of this system including image uniformity and recovery coefficient were measured using NEMA NU-4 phantom injected with 18FDG. Finally, timing response to changes in RI concentration was also measured using 5mm diameter syringe injected with several concentrations of 18FDG.
A Patterned Pixel Array for Multiple K-edge Imaging

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According to the rapid development of photon counting X-ray detectors in the last two decades, photon counting detectors have been receiving more and more attention as next generation of X-ray image detectors due to its low noise operation and energy separation capability. More energy bins in a pixel provide multiple K-edge images and better material decomposition. However, more energy bins require more area of pixel. Pixel size is limited due to maximum counting rate. Therefore, the number of energy bins in each pixel is limited. In this research, we proposed patterned pixel array that improves material decomposition capability of 2D photon counting detectors without more comparators and counters in a pixel. Each pixel has a common threshold to represents the number of incident photons regardless of the energy of incident photons and a specific threshold according to its pixel type to separate incident photon energy. Although each pixel has only two comparators and counters, five energy bins are obtained by interpolation with its neighbor pixels. In order to evaluate the proposed method, Monte Carlo simulation (MCNP6) was performed. The Monte Carlo simulation results with two energy bins in each pixel show five images from five energy bins instead of two images without additional circuit blocks. The spatial resolution is not decreased by interpolation since every pixel has common threshold at a comparator. Detailed simulation results will be presented at the conference.
Feasibility study of SOI-CMOS imaging sensors based on linear-mode Si APDs

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We have been developing a new type of soft X-ray imaging spectroscopy sensor which is fabricated using a 0.2μm fully depleted Silicon-On-Insulator Complementary-Metal–Oxide–Semiconductor (SOI CMOS) process and based on a Avalanche Photo Diode (APD) called SOI-APD detector (SOIAPD).

The SOIAPD is comprised of a this top Si layer, where CMOS circuit is build, and a thick high-resistivity substrate. These two Si layers are separated by a thin Buried Oxide (BOX) layer. APD structure is fabricated in the substrate and it can be fully depleted. As a result of this structure, SOIAPD has many advantages in comparison with bulk CMOS sensors such as sensor and readout circuit can be integrated in a small pixel, operation in wide temperature range, hi-speed and low-power consumption. The APD structure is introduced to detect soft X-ray which generate small charge only. We use linear-mode avalanche region to measure the energy of the X-ray instead of Geiger-mode avalanche.

In this presentation, we report test results of several test element group (TEG) fabricated in a prototype SOIAPD chip. The structure of the APD pixel is studied by using a Technology Computer-Aided Design (TCAD) tools. A typical pixel size is 26μm square, and both a single and 10 by 10 array pixels are implemented. We have measured the light response to inspect the gain and timing performance. We observed avalanche gain of 1~10 by illuminating with LED infrared light of which dominant wavelength is 960nm.
PERCIVAL (“Pixelated Energy Resolving CMOS Imager, Versatile And Large”) is being developed by DESY, RAL, Elettra, DLS and PAL to address the challenges of high brilliance Light Sources such as new generation Synchrotron and Free Electron Lasers. Typical requirements of these sources are high frame rates, large dynamic range, single-photon counting capability with low probability of false positives, high Quantum Efficiency (QE), and (multi)-mega-pixels.

PERCIVAL is a monolithic active pixel sensor (MAPS), based on CMOS technology. It is originally designed for the soft X-ray regime and, therefore, it will be back-thinned to access its primary energy range of 250 eV to 1 keV.

This work will report on the latest experimental results on Charge Collection Efficiency (CCE) estimated for multiple back-side-illuminated (BSI) test chips (160 x 210 pixels) during two different campaigns at P04 beam-line at Petra III and SX700 beam-line at BESSY/PTB spanning the full primary energy range as well as characterising the performance for photon energies below 250 eV.
Ultra deep submicron CMOS technologies provide enhanced radiation tolerance and possibility to integrate complex electronics in a small area, which makes them attractive for fabrication of pixel front-end chips. Presented work concerns the development of a charge injection circuit using 65 nm CMOS technology. The target application of this circuit is calibration of the pixel front-end chip that is being developed by the RD53 collaboration at CERN. Two prototype chips have been designed and submitted. The first chip contains a 12-bit voltage DAC and the second implements the DAC in a charge injection circuit. The charge injection circuit consists of the following blocks: 12-bit voltage DAC, switch and analogue buffers. In addition, the second chip contains a charge sensitive amplifier and a bank of capacitors representing capacitive load of large pixel array that has been integrated for testing of the charge injection circuit. Design of both chips, as well as circuit simulations, laboratory measurements and studies of radiation tolerance will be presented.
Tissue sensitive imaging and tomography without contrast agents for small animals with Timepix based detectors

Eliska Trojanova\textsuperscript{1}, Ludwig Dubois\textsuperscript{2}, Jan Jakubek\textsuperscript{1}, Alain Le Pape\textsuperscript{3}, Lotte Schyns\textsuperscript{2}, Daniel Turecek\textsuperscript{1}, Josef Uher\textsuperscript{1}, Frank Verhaegen\textsuperscript{2}

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The advantages of energy sensitive photon counting pixel detectors in the field of small animal imaging were already demonstrated. Those are namely: high spatial resolution, good imaging contrast and energy sensitivity. It was shown that the energy sensitive tomography of mouse performed with Medipix3 detector can distinguish even several contrast agents simultaneously.

We show in this contribution that the tissue sensitive radiography and tomography can be performed even without contrast agents. The differences between soft tissue types such as kidney, muscles, fat, liver, brain, spleen were identified. The Timepix based detector WidePIX 2x5 with 300 $\mu$m thick silicon sensors was used for most of measurements. These good results led to further optimizations of the detector technology. The first point was optimization of the low sensitivity of silicon replacing it with 1 mm thick CdTe sensor that allowed reaching of 100% detection efficiency. The high efficiency of CdTe sensors also allows reduction of the exposure time (event down to milliseconds) especially with a high speed Advapix interface. The second optimization is related to the shape of imager’s sensitive area for tomographic measurements. Therefore ADVACAM company has developed the first photon counting detector with curved surface (section of cylinder) optimized for tomography of small objects such as small animals. The detector resolution is 1.3 megapixels (4x5 Timepix tiles) and its curvature radius is 15 cm.
A comprehensive model of Penning energy transfers in Ar-CO2 mixtures

Ozkan Sahin

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During avalanche formations in Ar-CO2 mixtures, besides direct ionizations (Ar+, CO2+), excited argon atoms (Ar*) are generated. A fraction of the excess energy stored in Ar* levels can be used to ionize neutral CO2 molecules and argon atoms. These excitation-induced ionizations considerably decrease statistical fluctuations; hence, the energy resolution of gaseous detectors can be improved [1]. Additional ionizations are formed in various energy transfer mechanisms known as Penning transfers [2]. Some of the energy transfers depend on mixture pressure and fraction of CO2 with different scaling factors; others are independent of the gas medium. Probabilities of the additional ionizations in Ar-CO2 mixtures were derived from the simulation of experimental gas gain curves and a pioneer parameterization of transfer mechanisms was discussed in [3,4].

In this work, a comprehensive model was introduced to investigate the energy transfers. The published transfer probabilities were fitted with a combined fit function working over several mixture pressures and CO2 fractions. Fit parameters of the model were used to identify the contribution of each transfer process take place in avalanche growth in Ar-CO2 mixtures. The presented results have particular importance in characterization studies of micro-pattern gaseous detectors like GEM and MICROMEGAS.

Tissue sensitive imaging and tomography without contrast agents for small animals with Timepix based detectors

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DEVELOPMENT OF A PHASE-SENSITIVE CT SYSTEM FOR BREAST IMAGING WITH SYNCHROTRON RADIATION

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Introduction

In the present communication the SYRMA-CT project will be presented. The project aims to set-up the first clinical trial of phase-sensitive breast CT with synchrotron radiation (SR). In order to combine high image quality and low delivered dose, a number of innovative elements are merged: a CdTe single photon counting detector, state-of-the-art CT reconstruction algorithms, phase retrieval pre-processing.

Materials and Methods

A large area CdTe single photon counting detector (PIXIRAD-8) is used. The active area is 250 x20 mm², the pixel pitch is 60 μm, pixels are arranged on a honeycomb matrix. Each pixel incorporates a hexagonal electrode connected to a charge amplifier, which feeds two discriminators, and two 15 bit counters. Each counter can be written while the other is read. Using this feature and setting up both discriminators at the same level is possible to realize the so called Dead Time Free (DTF) modality where no events are lost over the time. The projections are acquired, in propagation-based phase-contrast imaging (PPCI) conditions, during the continuous rotation of the patient support. Phase-retrieval algorithms are applied, exploiting the edge-enhancement of the PPCI. Due to the peculiar irradiation modality ad-hoc Monte Carlo simulations and experimental measurements were performed for the dose evaluations.

Results

CT data sets of large objects (up to 12 cm diameter) have been acquired in DTF mode at the frame rate of 10 f/s. Images of surgical samples included in large test objects were acquired in clinical compatible dose conditions (Mean Glandular Dose ~20 or 5 mGy) and small voxel size of (120mm)³.

Conclusion

Image quality and dose assessment indicate that the clinical study is feasible. Clinical trial at the SR facility will allow the evaluation of the PPCI breast CT in optimal conditions and will give indication for the translation to the hospital of phase-sensitive techniques.
Comparison of hit allocation algorithms of unambiguous registering of hits when charge sharing is present in pixel detectors

Piotr Otfinowski¹, Piotr Maj¹, Grzegorz Deptuch¹, Farah Fahim², James Hoff²

¹) AGH University of Science and Technology ²) Fermi National Accelerator Laboratory

Charge sharing is the fractional collection of the charge cloud generated in a detector by two or more adjacent pixels. It may lead to excessive registrations of hits or to inefficiencies of registrations of hits comparing to numbers of impinging photons depending on how thresholds are set in a typical pixel detector. The problems are particularly exposed for fine pixel sizes and/or for thick detectors. Presence of charge sharing is one of the limiting factors that discourages decreasing sizes of pixels in X-ray radiation imaging systems.

Currently, there exist a few different approaches tackling with the charge sharing problem (e.g. Medipix3, PIX45). The general idea is, first, to reconstruct the entire signal from four adjacent pixels and, secondly, to allocate the hit to a single pixel. This paper focuses on the latter part of the process, i.e. on a comparison of how different hit allocation algorithms affect the spatial accuracy and false registration vs. missed hit probability.

For that purpose, a pixel detector readout IC simulation model was prepared, consisting of a front-end amplifier, signal reconstruction hub, discriminators and other blocks. The model includes ingredients, such as quantified noise, proportions of charge sharing, dispersions of gain and discriminator/comparator. Different hit allocation algorithms were simulated, including standard counting (no full signal reconstruction) and the C8P1 algorithm. Also, a novel approach, based on detection of patterns, with significantly limited analog signal processing, was proposed and characterized.

Each algorithm was tested considering three specific cases regarding hit position in a pixel: center hit, edge hit and corner hit. Also, simulations with random hit position and realistic radius of a diffusing charge cloud were performed to assess the performance in a typical applications. The algorithms were characterized comparing false/missed hit probability and hit allocation spatial accuracy.

![C8P1 algorithm diagram](image)
Towards using large and thick monolithic scintillators with high DOI performance

Andrea Gonzalez\textsuperscript{1}, Antonio Gonzalez\textsuperscript{1}, Jose Maria Benlloch\textsuperscript{1}, Albert Aguilar\textsuperscript{1}, Pablo Conde\textsuperscript{1}, Amadeo Iborra\textsuperscript{1}, Liczandro Hernandez\textsuperscript{1}, Koldo Vidal\textsuperscript{1}, Filomeno Sanchez\textsuperscript{1}, Matteo Galasso\textsuperscript{2}, Andrea Fabbri\textsuperscript{2}, Gilles Lerondel\textsuperscript{3}, Loïc Le Cunff\textsuperscript{3}

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Both whole body and organ-dedicated PET systems typically require a high detection efficiency imposing the use of thick scintillators, normally done with crystal arrays. When depth of interaction (DOI) information is required, this type of crystals significantly increase the material cost. An alternative we are proposing in this work is the use of thick and large monolithic LYSO crystals returning accurate 3D photon impact coordinates, both planar and DOI.

We have tested two surface treatments for a 50x50x20 mm\textsuperscript{3} LYSO block with lateral walls black painted and the exit face coupled to the photosensor (12x12 SiPM array) polished. The entrance face was (i) black painted, (ii) coupled to different corner-cube retroreflector (RR) layers, with cubes sizes of 1 and 6 mm.

The best detector performance is observed when using the RR with the smallest corner-cubes and coupled to the LYSO block by means of optical grease. An almost constant energy resolution of about 15\% has been determined for all DOI layers. When compared to the black painted case, the largest energy improvement is observed for the entrance layer (10\% relative) since more photons are retroreflected. Our readout electronics permit to decode the 511 keV photon DOI, with about 5.0 mm FWHM for the RR and 5.6 mm FWHM for the black paint.

The best result concerning the detector spatial resolution was also found when the small cubes were used. The detector spatial resolution was evaluated at four DOI layers, from the crystal entrance to the photosensor, we determined 2.0, 1.9, 1.7 and 1.3 mm, respectively. These values are about 14\% better than those obtained with the 6 mm cubes, and as more as 20\% better than the black case.

Further works including a correlation method to reduce the background noise are currently being investigated and will also be presented.
Investigation of n-in-p planar pixel modules for the ATLAS upgrade

Natascha Savic, Julien Beyer¹, Anna Macchiolo¹, Richard Nisius¹, Stefano Terzo¹

1) Max-Planck Institute for Physics

Facing the LHC upgrade towards the High Luminosity (HL-LHC), planned to start around 2025-2026, the ATLAS experiment will undergo a major upgrade of the Tracking Detector. A higher luminosity will imply higher irradiation levels and hence will demand higher radiation hardness from the detectors. The n-in-p silicon technology is a promising candidate to instrument the new pixel system, also with respect to its cost-effectiveness because it only requires a single side processing in contrast to the n-in-n pixel technology presently employed in the LHC experiments. In addition, thin sensors were found to ensure radiation hardness at high fluences. The sensor technology will be discussed and a complete overview of the results on the characterization of not irradiated and irradiated n-in-p planar pixel modules will be presented. The focus will be on n-in-p planar pixel sensors with an active thickness of 100 and 150 um recently produced at ADVACAM. To maximize the active area of the sensors, slim and active edges were implemented. The performance of these modules has been investigated at beam tests and the results on edge efficiency will be shown. Finally, the first characterization of pixel sensors with 50x50 and 25x100 um² cell size, as foreseen for the HL-LHC, will be presented.
3D sensors for the HL-LHC

David Vazquez 1

1) IFAE-Barcelona

3D silicon detectors, with cylindrical electrodes that penetrate the sensor bulk perpendicular to the surface, have recently undergone a rapid development from R&D, to industrialization, to their first operation in a high-energy-physics experiment. Since June 2015, the ATLAS Insertable B-Layer is taking collision data with 3D pixel sensors. At the same time, 3D devices have been installed in February 2016 as part of the ATLAS Forward Proton detector. The next challenge for tracking detectors is the high-luminosity LHC (HL-LHC) tracker upgrades, where fluences of up to 1.4E16 neq/cm² are expected for the innermost layer. The 3D technology is a promising candidate for the innermost pixel layers given its excellent radiation hardness at low operational voltages and power dissipation as well as moderate temperatures. This paper will give an overview on the recent developments of the HL-LHC generation of 3D sensors.
Laura Moliner¹, Jorge Alamo², Daan Hellingman³, Carlos Correcher², Antonio Gonzalez¹, José María Benlloch¹

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We present the performance characteristics of the MAMMOCARE PET prototype based on an adaptation of the NU 2-2007 and NU 4-2008 NEMA standards. MAMMOCARE is a project under the European Commission’s 7th Framework programme which developed a breast biopsy system guided by dedicated breast PET (dbPET) images. The PET system is formed by two rings with twelve detector modules each. The transaxial FOV is 170 mm and the axial FOV is 94 mm. The system can separate the detectors up to 60mm in transaxial direction to allow the biopsy needle entrance, modifying the transaxial FOV in the center. The images are reconstructed using the LMOS reconstruction algorithm with the TOR backprojector, 1 iteration and 16 subsets. The voxel and pixel sizes are (1 × 1 × 1) mm³ and (1.6 × 1.6) mm² respectively. The radial resolution measured is 1.62mm in the center of the FOV and 3.45mm at 50mm of the center in the radial direction using the closed configuration. In the open configuration the resolution reaches 1.85mm and 3.65 mm at center and at 50mm off-center. The adapted recovery coefficients (ARC) are measured for six hot inserts inside of a cylindrical phantom with a warm background. The ratio between hot and background regions is 10. The ARC values for the closed configuration are 0.32, 0.77 and 0.96 for the inserts with a diameter of 4.5mm, 8.3mm and 25mm, respectively. This values decrease to 0.16mm, 0.52mm and 0.77mm for the open configuration. The sensitivity measured using an energy window of 250keV-750keV is 3.6% and 2.5% for the closed and open configurations respectively. The NEC peak is 34kcps@27MBq and 33kcps@39MBq for closed and open configurations. The performance characteristics measured with the open ring configuration decreases with respect the open configuration, however the values remain comparable to other dbPETs.
First Inverse LGAD Fabrication at IMB-CNM (CSIC)

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The first Inverse Low Gain Avalanche Detector (iLGAD) detectors have been fabricated at IMB-CNM (CSIC). iLGAD devices have an APD-like structure in the back-side contact while the segmented front surface is created with an ohmic contact. iLGAD are P-on-P position-sensitive-detectors, with low signal amplification and a uniform electric field all along the device area that guarantees the same signal amplification wherever a particle passes through the sensitive bulk.

In this work we present the electrical and technological simulations performed using Silvaco and Sentaurus TCAD tools. Simulation is become very important in order to find the optimal doping profiles of these new detectors and to study the voltage capability, the electrical performance, as well as, the timing performance of iLGAD.

We will also report the first electrical characteristics and the charge collection studies performed in our laboratory. Applications of iLGAD range from tracking and timing applications like primary interaction vertex to medical imaging.
The report presents the results of experimental studies of the electrophysical characteristics of the GaAs: Cr (HR GaAs) material in the form of 4 inch wafers as well as the characteristics of the pad X-ray sensors on its base.

Resistivity mapping of 4 inch HR GaAs wafers was carried out by means of contactless method and controlled by Hall measurements. It was shown that the resistivity distribution in HR GaAs material essentially depends on the distribution of the shallow impurity in the n-GaAs wafers. The minimum value of the HR GaAs wafer resistivity is not less than $5 \times 10^8 \text{Ohm} \times \text{cm}$.

IV characteristics and charge collection efficiency of 500 um thick pad sensors were investigated. It is found that within operating voltage range the IV characteristics have close to linear dependence on bias voltage. Estimation of $(\mu t)n$ leads to value of about $7 \times 10^{-5} \text{cm}^2 / \text{V} \times \text{s}$.

It is shown that 4 inch HR GaAs wafers are promising candidate for producing of pixel sensor with large size of active area.

The investigation was financially supported with RF grant # 14.587.21.0003 (RFMEFI58714X0003).
A combined surface and bulk TCAD damage model for the analysis of radiation detectors operating at HL-LHC fluences

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In this work we present the application of a new TCAD modeling scheme to simulate the effects of radiation damage on silicon radiation detectors at the very high fluence levels expected at High Luminosity LHC (up to $2 \times 10^{16}$ 1MeV n/cm²).

In particular, we propose a combined approach for the analysis of the surface effects (oxide charge build-up and interfacetraps states) as well as bulk effects (deep level traps or recombination centers and dopant “removal”).

We actually rely on experimentally measured parameters of deep-level states as well as oxide charge and interface trap state density. The goal is the definition of a model as much comprehensive as possible, while avoiding fitting parameters to preserve the generality of the approach.

The model has been validated through comparison with literature data for bulk damage effects (due to both neutron and proton irradiations up to $2.2 \times 10^{16}$ n/cm²), while dedicated irradiation and measurement campaigns have been carried out to study the surface effects. In particular measurements after X-ray irradiations within the 50 krad-10 Mrad range have been used to extract the oxide charge build-up and donor interface trap densities.

Among others, two significant parameters have been selected as reference for the model validation. In particular the isolation between sensing nodes (e.g. the interstrip resistance) (Fig. 1) and the charge collection efficiency as a function of the fluence (Fig. 2).

The good agreements between experimental measurements and simulation findings foster the suitability of the TCAD modeling approach as a predictive tool for investigating the radiation detector behavior at different fluences and operating conditions. This would allow the optimization of innovative 3D and planar silicon detectors for future HL-LHC High Energy Physics experiments.

This work is supported by the H2020 project AIDA-2020, GA no. 654168.
Production and Quality Control of Micromegas Anode PCBs for the ATLAS NSW Upgrade

Fabian Kuger

1) ATLAS Muon Collaboration

For the 2019-20 New Small Wheel upgrade of the ATLAS detector, Micromegas detectors for a total active area of 1200 m² will be built. On this large scale industrialization of anode boards production is an essential precondition for detector construction. Design and construction methods of these boards have been optimized towards mass production. In parallel quality control procedures have been developed and established.

The first pre-series of large size Micromegas anode boards has been produced in industries during 2015 and demonstrates the feasibility of the project. Full scale production is currently launching and will last 16 months.

The design and quality control methods of the anode boards are presented together with the results of the quality control procedure on the first pre-series.
A Fully 3-D Integrated Detector For X-ray Correlation Spectroscopy

D. Peter Siddons¹, Abdul Rumaiz¹, Anthony Kuczewski¹, Joseph Mead¹, Grzegorz Deptuch², Farah Fahim², Alpana Shenai², Gabriella Carini³, Robert Bradford⁴, Alec Sandy⁴, Suresh Narayanan⁴, Eric Dufresne⁴, John Wlezeorick⁴, Pawel Grybos⁵, Piotr Maj⁵, Robert Szczygiel⁵, Piotr Kmon⁵, Mark Sutton⁶

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We have developed a new detector, designed from the ground up to facilitate X-ray Correlation Spectroscopy (XCS) experiments. The device uses state-of-the-art silicon technology [1] to allow continuous, zero dead-time measurements with microsecond resolution. The detector only delivers non-zero data, greatly reducing the communications overhead typical of conventional frame-oriented detectors such as CCDs. The talk will describe how this is achieved and show some preliminary data taken at APS. We will also indicate our plans for future developments along these lines.

Evaluation of Minimum Detectable Activity for Radiation Monitoring System in Water

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Water is one of the most important resources for mankind. People drink water every day and typically cannot survive without it for longer than ten days. Therefore, it is necessary to prevent drinking water supply sources from contamination. In particular, radioactive materials in drinking water, which can be generated from any incidents at neighboring nuclear facilities or from nuclear weapons and cause internal and external exposure, have to be monitored consistently. In the present study, we evaluated the minimum detectable activity (MDA) in water to develop the underwater radiation monitoring system.

To determine the type of radiation detector for the system, BGO, CsI(Tl), LaBr₃(Ce) and NaI(Tl) cylindrical detectors (2 inch in diameter and 2 inch in length) were compared in water for different radionuclides using Monte Carlo simulations in terms of the energy resolution and the cost-benefit ratio based on the detection efficiency. In general, the detection efficiency comes first for selecting the type of detector, but in this case, many detectors will be placed in water to monitor radioactive materials in a wide area, and thus the cost should also be considered. Radioactive nuclides were ¹³¹I (364 keV) and ¹³⁷Cs (662 keV) which are only produced by nuclear fission. Based on the results of the simulations, an NaI(Tl) detector was contained with multi-channel analyzer (MCA) in a waterproof device. Finally, a waterproof detector system was then used to count the background radiation in freshwater to experimentally determine the MDA values as a function of energy. The MDA values will become the criteria to make a decision regarding the presence of radioactive materials in water while operating the radiation monitoring system.
In the recent years, the method of single photon counting X-ray micro-CT is being actively developed and applied in various fields. Results of our studies carried out using the micro-CT scanner MARS equipped with GaAs:Cr Medipix-based camera are presented. The procedure of mechanical alignment of the scanner is described, including direct and indirect measurements of the spatial resolution. The software chain for data processing and reconstruction has been developed and reported. We demonstrate the possibility to apply the scanner for research in geology and medicine and provide demo images of geological samples (chrome spinellids, titanium magnetite ore) and medical samples (atherosclerotic plaque, abdominal aortic aneurysm). The first results of multi-energy scans using GaAs:Cr-based camera are shown.
The interest in use of resistive gallium arsenide compensated by chromium (GaAs:Cr) for photon detection steadily grows thanks to its numerous advantages over silicon. At the same time, prospects of this material as a sensor for pixel detectors in the nuclear and high energy physics are much less studied.

We report the results of characterization of the Timepix detectors hybridized with the GaAs:Cr sensors of different thickness using synchrotron radiation and various charged particles, including protons, alphas and heavy ions. The energy and spatial resolution has been determined. Interesting features of GaAs:Cr specific to the detector response to the extremely dense energy deposit by heavy ions have been observed for the first time. Performance of Timepix detector with GaAs:Cr is studied for different temperatures. Long-term stability of the detector has been evaluated based on a one year long measurements. Possible limitations of GaAs:Cr as a sensor for high flux X-ray imaging are discussed.
The semiconducting crystal lithium indium diselenide, $\text{LiInSe}_2$, has recently been shown to be an efficient solid state thermal neutron detection media in both charge collection (semiconducting) and photon generation (scintillation) modes. The 24% atomic density of Li yields a thermal neutron mean free path of only 920 $\mu$m. Both pixelated semiconducting imagers and scintillation plates have been tested for efficiency, spatial resolution and spatial efficiency variation. As a semiconductor imager, resolution of approximately, $\frac{1}{2}$ the pixel pitch has been achieved, although nontrivial variation in the neutron response from each pixel was observed. For the imager tested, pixels were 550 $\mu$m and the observed resolution against a Gd resolution mask was 300 microns. As a scintillator, the intrinsic spatial resolution was 30-60 microns with an anti-reflective backing. Further, it was observed that the spatial resolution was independent of crystal thickness such that higher detection efficiencies can be achieved without degradation of spatial resolution. Absorption measurements indicate that the Li concentration is uniform throughout the samples and its absorption efficiency as a function of thickness follows general nuclear theory, indicating that the variation in apparent brightness is likely due to a combination of particle escape, light transport, and activation of the scintillation mechanisms. The presence of $^{115}\text{In}$ and its long-lived $^{116}\text{In}$ activation product did not result in ghosting (memory of past neutron exposure), demonstrating potential for using LiSe for imaging transient systems.
Previous works on chromium compensated gallium arsenide (GaAs:Cr) have shown high efficiency, good spatial and energy resolution, which is obviously connected with the high quality of material itself. The purpose of this research was to aggravate the diffusion process by increasing the annealing temperature and to observe whether there will be any degradation of material characteristics. The investigation of three 3-inch GaAs:Cr wafers with different annealing temperature of chromium was carried out. Resistivity and mobility-lifetime measurements were made using pad sensors made of these wafers. The I-V curves were built to estimate the resistivity across the wafer. Furthermore charge collection efficiency (CCE) measurements were carried out in order to estimate the $\mu\tau$ product of GaAs:Cr.

The resistivity mapping has showed a variation of resistivity across the wafer in the range from 1.25 10^9 to 5.5 10^8 Ohm cm. Although the third wafer showed quite good uniformity, the resistance didn't reached values higher than 3.5 10^8 Ohm cm. In spite of harsh diffusion conditions all the materials showed quite good CCE (about 90%) and $\mu\tau$ more than 5 10^{-5} cm^2/V. Also a strong dependency between the resistivity and mobility-lifetime product was found only for one wafer. So the uniformity of $\mu\tau$ product across the wafer can be stated independently of resistivity. More detailed information and discussion of experimental results is presented in the article.

The investigation was financially supported with RF grant # 14.587.21.0003 (RFMEFI58714X0003).
Synchrotron beam test of a photon counting pixel prototype based on Double-SOI technology

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Synchrotron beam measurement results with CPIXETEG3b, the first counting type Silicon-On-Insulator (SOI) pixel sensor prototype without crosstalk issue [1], are reported. The prototype includes a 64×64 pixel matrix with 50 um pitch size. Each pixel consists an N-in-P charge collection diode, a charge sensitive preamplifier, a shaper, a discriminator which thresholds could be adjusted by an in-pixel 4-bit DAC, and a 6-bit counter.

The study was performed in the beam line 14A at KEK Photon Factory (KEK-PF). Homogeneous response of the prototype, including charging-sharing effects between pixels were studied. 16 keV and 8 keV monochromatic X-ray with 10 um radius spot were used for charge sharing study, and a flat-field was added for homogenous response investigation. The influence of basic detector parameters on charge sharing between pixels and on the overall detector homogeneity has been investigated. Figure 1 illustrates the charge sharing results between the pixels by scanning the detector across the beam in steps of 5 um along one column; the counts in each pixel position as well as the sum of all pixels are plotted as a function of the beam position.

Figure 1: Scan with a 16 keV beam. The threshold has been set to 2600 e- (left plot), 1400 e- (right). For 1400 e- (< 1/2 of total charge) the effect of charge sharing is attenuated.

Improvement of image homogeneity by adjusting the threshold of each pixel individually was demonstrated; the pixel thresholds dispersion reduced from around 130 e- to 27 e-. A measurement of the point spread function and quantum efficiency (QE) evaluation are also presented.

References:
The European X-ray Free Electron Laser (XFEL.EU) will provide every 0.1 s a train of 2700 coherent X-ray ultrashort-pulses at 4.5 MHz to six scientific instruments. The DEPFET Sensor with Signal Compression (DSSC) detector has been developed to meet the requirements set by the XFEL.EU soft X-ray (0.5keV–6keV) instruments. The DSSC imager is a 1 mega-pixel camera able to store up to 800 single-pulse images per train.

The ASIC read-out electronics provide a pixel-wise amplification and filtering, an up-to 9 bit ADC and digital memory. The electronics has a double front-end to allow to use either the DEPFET sensors or the Mini-SDD sensors. In the first case the signal compression is a characteristic of the sensor; in the second case the compression is generated at the first amplification stage. The goal of signal compression is to meet the requirement of single-photon detection capability and wide dynamic range.

The so-called DSSC Ladder camera is the basic unit of the DSSC. It is the single unit of sixteen identical-units composing the DSSC-megapixel camera. Therefore, from the electronic point-of-view, a single DSSC Ladder contains all representative components of the full-size system and allows testing the full electronic chain. Each DSSC Ladder has a focal plane equipped with 64k pixels.

Due to the requirements of soft-X-rays beamlines, the detector will be operated under high vacuum conditions. A vacuum vessel (FENICE) designed to operate the DSSC Ladder in vacuum has been commissioned. There, the ladder can be operated at the planned operating temperature.

The DSSC Ladder camera is the first DSSC demonstrator usable for scientific experiments at the beamlines. We present the first results obtained under real operating conditions.
New developments and optimizations of high-spatial resolution detectors for synchrotron imaging

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Single crystal thin-film scintillators are key components of state of the art detectors for micrometer and submicrometer spatial resolution imaging. The scintillator converts X-rays in a visible image which is magnified and projected by microscope optics on a camera. At low X-ray energy the spatial resolution is mainly limited by light diffraction, out-of-focus light or the camera pixel size. However, above 20 keV the scintillator response is crucial for high-spatial resolution imaging. Additionally, other properties of the overall system ultimately depend on the choice of the scintillating material. For example the decay time and the afterglow affect the speed, the crystal optical quality can limit the exploitable dynamic range, and the scintillator absorption and light yield limit the overall efficiency.

In our group we use liquid phase epitaxy to develop and produce thin scintillating films, and we characterize their luminescence properties as well as their imaging performances when implemented in a high-spatial resolution detector, to give scientists the choice to optimize the configuration with respect to the experiment they are performing.

A summary of the last results will be presented, including the development and the characterization of new, high density and high-effective Z oxide materials. The advancements in numerical simulations to estimate the overall detector response as a function of the detector configuration and X-ray energy, as well as the study of different effects that may affect the spatial resolution, like the scintillator birefringence or the substrate fluorescence, will also be presented.
X-ray imaging is a powerful tool in diagnosis and research. A wide range of applications demand micrometer spatial resolution especially in material and biological science. Furthermore, enhanced material separation possibilities are given by dual-energy-CT, a promising field of current research. The combination of both into a dual-energy micro-CT setup, appears to have an enormous application potential, especially if the setup can be used with a laboratory microfocus X-ray tube.

In this work a dual-layer, dual-color, single-crystal scintillator detector prototype was designed and constructed to achieve a dual-energy CT setup with micrometer spatial resolution. Therefore, the dual-layer, dual-color scintillator was coupled via microscope optics and a dichroic mirror to two CCD cameras. The used white X-ray beam was generated with a laboratory microfocus X-ray tube.

A resolution of 12μm with a material separation in the energy map at an X-ray tube peak energy of 160keV could be proven. The setup design shows great potential for the usage with stained biological samples as well as for material science demanding high X-ray energies.
Geometry based correction methods for Timepix based large area detectors

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X-ray micro radiography with hybrid pixel detectors provide versatile tool for the object inspection in various fields of science. It has proven itself especially suitable for the samples with low intrinsic attenuation contrast (e.g. soft tissue in biology, plastics in material sciences, thin paint layers in cultural heritage, etc.). The limited size of single detector (2 cm2) was recently overcame by the construction of large area detectors Widepix assembled of Timepix chips equipped with edgeless silicon sensors. Largest device consists of 100 chips and provide fully sensitive area of 14.3 × 14.3 cm2 without any physical gaps between sensors. The resolution of this device is 2560 × 2560 pixels (6.5 Mpix).

The unique modular detector layout requires special processing of acquired data to avoid occurring image distortions. It is necessary to use several geometric compensations after standard corrections methods typical for this type of pixel detectors (i.e. flat-field, signal-to-thickness calibration). The proposed geometric compensations cover both concept features and particular detector assembly process of large area detectors based on Timepix assemblies. The former deals with larger border pixels in individual edgeless sensors and their behaviour while the latter grapple with shifts, tilts and steps between detector rows. The real position of all pixels is defined in Cartesian coordinate system and together with non-binary reliability mask it is used for the final image interpolation.

The results of geometric corrections for test wire phantoms and paleo-botanic materials will be presented in this contribution.
Their inherent radiation tolerance makes 3D sensors appealing for the future “Phase 2” upgrades at the High-Luminosity LHC (HL-LHC), in particular for the innermost pixel detector layers. However, in order to cope with the challenging requirements of HL-LHC experiments, several improvements are required, such as: increased pixel granularity (e.g., 50×50 or 25×100 μm² pixel size), extreme radiation hardness (up to 2×10¹⁶ neq.cm⁻² fluence), thinner active region (~100 μm), 3D electrodes having narrower width (~5 μm) and reduced spacing (~30 μm), and very slim edges (~50 μm). To this purpose, in the INFN–FBK “Phase 2” R&D program, we started the development of a new generation of 3D sensors [1]. The first batch was fabricated at FBK on Si-Si Direct Wafer Bonded 6” substrates. Initial results from tests performed on wafer highlighted remarkably good electrical characteristics: low leakage current (< 1 pA/column), intrinsic breakdown voltage of more than 150 V, capacitance of about 50 fF/column. All these values are in good agreement with TCAD simulation predictions, thus assessing the validity of the design approach. Several types of pixel sensors, compatible with both existing (e.g., ATLAS FEI4 and CMS PSI46) and future (e.g., RD53) read-out chips, were electrically tested with an automatic probe station making use of a temporary metal layer that shorts rows of pixels together. By doing so, besides selecting functioning devices before bump-bonding and estimating the process yield, it is possible to obtain a statistically significant distribution of relevant electrical quantities, thus gaining insight into the impact of process-induced defects.

At the conference, we will review the most important design and technological aspects, and report on selected results from the characterization of sensors and test structures.

FPGA-based GEM detector signal acquisition for SXR spectroscopy system

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The presented work is related to the Gas Electron Multiplier (GEM) detector soft X-ray spectroscopy system for tokamak applications. The used GEM detector is one-dimensional with 128 channel readout structure. The channels are connected to the radiation-hard electronics with configurable analog stage and fast ADCs, supporting speeds of 125 MSPS for each channel. The digitalized data is then sent directly to the FPGAs using fast serial links. The preprocessing algorithms are implemented in the FPGAs, with the buffering made in the on-board 2Gb DDR3 memory chips. After algorithmic stage, the data is sent to the Intel Xeon based PC for further postprocessing using PCI-Express link Gen 2. For connections of multiple FPGAs, PCI-Express switch 8-to-1 was designed. The whole system can support up to 2048 analog channels. The scope of the work is an implementation of the GEM detector raw signal recorder in the FPGAs. Since the system will be working in very challenging environment (neutron radiation, intense electromagnetic fields), the registered signals from the GEM detector can be corrupted. In case of the very intense hot plasma radiation (e.g. laser generated plasma), the registered signals can overlap. Therefore, it is valuable to register the raw signals from the GEM detector with high statistics during soft X-ray radiation. The signal analysis will have direct impact on the implementation of photon energy computation algorithms. As the result, the system is providing energy spectra and topological distribution of soft X-ray radiation. Extended software was developed in order to perform complex system startup and monitoring of hardware units. The implemented algorithms are evolution of the first preliminary design. Using two one-dimensional GEM detectors array it will be possible to perform tomographic reconstruction of plasma impurities radiation in SXR region.
Their inherent radiation tolerance makes 3D sensors appealing for the future “Phase 2” upgrades at the High-Luminosity LHC (HL-LHC), in particular for the innermost pixel detector layers. However, in order to cope with the challenging requirements of HL-LHC experiments, several improvements are required, such as: increased pixel granularity (e.g., 50×50 or 25×100 μm$^2$ pixel size), extreme radiation hardness (up to 2×10$^{16}$ neq.cm$^{-2}$ fluence), thinner active region (~100 μm), 3D electrodes having narrower width (~5 μm) and reduced spacing (~30 μm), and very slim edges (~50 μm). To this purpose, in the INFN-FBK “Phase 2” R&D program, we started the development of a new generation of 3D sensors [1]. The first batch was fabricated at FBK on Si–Si Direct Wafer Bonded 6” substrates. Initial results from tests performed on wafer highlighted remarkably good electrical characteristics: low leakage current (< 1 pA/column), intrinsic breakdown voltage of more than 150 V, capacitance of about 50 fF/column. All these values are in good agreement with TCAD simulation predictions, thus assessing the validity of the design approach. Several types of pixel sensors, compatible with both existing (e.g., ATLAS FEI4 and CMS PSI46) and future (e.g., RD53) read-out chips, were electrically tested with an automatic probe station making use of a temporary metal layer that shorts rows of pixels together. By doing so, besides selecting functioning devices before bump-bonding and estimating the process yield, it is possible to obtain a statistically significant distribution of relevant electrical quantities, thus gaining insight into the impact of process-induced defects.

At the conference, we will review the most important design and technological aspects, and report on selected results from the characterization of sensors and test structures.

Oblique fluorescence in a MARS scanner with a CZT-Medipix3RX

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The latest version of the MARS small bore scanner makes use of the Medipix3RX ASIC, bonded to a CdTe or CZT semi-conductor layer, to count x-ray photons and create a spectroscopic CT data set. The MARS imaging chain uses the energy-resolved 2D transmission images to construct quantitative 3D spectral and material images. To ensure that high quality and accurate images are obtained it is important that the energy response of the detector is well calibrated. A common methodology for doing energy calibration is by using x-ray fluorescence (XRF), due to its effective monochromatic nature. Oblique (off-axis) XRF can be measured in situ in the MARS small bore scanner. A monoatomic foil is placed in front of the x-ray source and off-axis XRF is measured. A key issue is identifying near optimal measurement positions that maximize the XRF signal while minimizing transmitted and scattered x-rays from the primary beam.

This work shows the development of a theoretical model that is able to identify where in the detector plane XRF is maximum. We present: (1) a theoretical model that calculates the XRF photon distribution across the MARS scanner detector plane produced from illuminated foils attached to the scanner’s filter bar; (2) preliminary experimental measurements of the XRF distribution outside of the main beam taken with a Medipix3RX detector; and (3) a comparison between the model and experiment. The main motivation behind creating this model is to identify the region in the detector plane, outside of the main beam, where XRF is at a maximum. This provides the optimum detector location for creating an off-axis monochromatic XRF source for use in the per-pixel energy calibration of the CZT-Medipix3RX detector in the MARS scanner.
Micropattern Gaseous Detectors (MPGD) based on Thick-COBRA (THCOBRA) structures had already shown its potential for X-ray projection imaging. This type of detectors allows for single photon counting with energy and position detection capability and has some important features such as the possibility of electronic noise rejection; fair energy resolution; high count rate capability and absence of dead areas. THCOBRA allows for two charge amplification stages in a single structure, leading to high gains and good signal to noise ratio. Two resistive lines, orthogonal to each other, deposited by serigraphy, allow the determination of the interaction position and the energy of each photon that interacts with the detector volume. [1]

In this work, a 10×10 cm² THCOBRA based detector [2] was operating in a continuous gas flow mode in an Ar/CH₄ (95/5) atmosphere. To improve the signal to noise ratio a charge pre-amplification stage based on a THGEM structure, was used.

This study aims to assess the THCOBRA performance characteristics for X-ray transmission imaging, namely: charge gain; energy resolution; image uniformity and Signal to Noise Ratio (SNR) of the image; spatial resolution and the Modulation Transfer Function (MTF); Noise Power Spectrum (NPS); Detective Quantum Efficiency (DQE). The evaluation methods follow the International Electrotechnical Commission (IEC) standards.

The obtained results will be presented, discussed and also compared with results from some detectors currently used in X-ray imaging. Future work will be discussed in order to improve its characteristics and image quality in general.

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10 um-thick Four-quadrant Transmissive Silicon Photodiodes for Beam Position Monitor Application: Electrical Characterization and Gamma Irradiation Effects

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Silicon photodiodes are very useful devices as X-ray beam monitors in synchrotron radiation beamlines1. In order to be used in transmissive mode and given the absorption properties of silicon, the devices must be thinner than 10 mm to achieve X-ray transmission higher than 90% for photon energies above 10 keV. In a previous study2, ALBA and IMB-CNM-CSIC reported first results of 10x10 mm2 single photodiode prototypes fabricated on thin silicon layers for beam intensity monitoring purposes. This work presents four-quadrant photodiodes designed primarily to be used as beam position monitors of synchrotron beams, although this type of segmented devices is also of potential interest for astronomy and space applications such as solar tracking systems3. Radiation hardness of the involved technologies is a major concern for high-energy physics and space applications.

The devices have been produced on both ultrathin and bulk silicon substrates with different design parameters along with auxiliary technology test structures (single diodes and MOS capacitors). An extensive electrical characterization has been carried out on non-irradiated and gamma-irradiated devices up to doses of 100 Mrad by using both current-voltage (I-V) and capacitance-voltage (C-V) techniques. Special attention has been put into the study of charge build-up in diode interquadrant isolation, as well as its impact on interquadrant resistance. The devices have been characterized with an 8 keV laboratory X-ray source at 108 ph/s (Figure 1) and in a synchrotron beamline with 1012 ph/s with energies from 6 to 20 keV. Sensitivity, spatial resolution and uniformity depending on different space gap between quadrants of the devices have been evaluated.

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Diamond is a material with outstanding physical properties that foster its use for radiation detection applications, in particular in difficult operating environment. By conjugating the properties of diamond substrates and the capabilities of CMOS electronics, it is possible to devise innovative devices for particle detection.

Within this framework, the application of Technology Computer Aided Design (TCAD) simulation tools is highly envisaged; however, diamond is a “novel” material in electronic applications and it is not included in the material library of commercial TCAD software tools.

In this work, we propose the development and the application of numerical models to simulate the electrical characteristics of poly-crystalline diamond conceived for diamond and Silicon-on-Diamond (SoD) sensors for particle detection. The model is based on the introduction of an articulated, yet physically based, picture of deep-level defects acting as recombination centers and/or trap states. While a definite picture of the poly-crystalline diamond bandgap is still debated, the effect of the main parameters (e.g. trap densities and capture cross-sections) can be deeply investigated thanks to the simulated approach.

The charge collection efficiency has been selected as reference for the model validation. In particular, the measured collection properties of the material provided by different vendors and with different electrode configurations when stimulated with a beta particle have been compared with simulations.

The good agreement between experimental measurements and simulation findings, keeping the trap density only as main fitting parameter, assesses the suitability of the TCAD modeling approach as a predictive tool for the design and optimization of diamond radiation detectors.

This work is supported by the Italian INFN CSN5 3D-SOD project.

Figure: Charge collection Efficiency (CCE) of a simple diamond device as a function of the bias voltage: comparison between experimental measurements and simulation findings.
A Depth-of-Interaction encoding method for SPECT monolithic scintillation detector

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Introduction

The Depth of Interaction (DoI) discrimination of gamma-photons within scintillation crystals allows to improve imaging performance in PET scanners as well as in SPECT devices equipped with non-parallel collimators (i.e. pinhole ones).

The authors experimentally proved the efficiency of a DoI-encoding technique in case of a 20mm-thick monolithic crystal PET module[1].

For thinner crystals DoI determination still remains a challenging goal.

To this aim, in this work the authors have experimentally evaluated the DoI-encoding method on a 6mm-thick monolithic crystal.

Materials and Methods

The measurement was performed on a 51x51x6 mm³ LaBr₃(Ce) scintillation crystal coupled to a Hamamatsu H9500 MultiAnode PMT with 256 independent readout channels.

A 45 degree-slanted beam irradiation from a 0.4mm collimated ⁹⁹mTc source was used, with the purpose to obtain a direct correlation between the planar position and the DoI.

The proposed method is based on the shape of scintillation light distribution[1].

Results

Despite the low crystal thickness, the proposed DoI-encoding technique allows to discriminate scintillation events occurring at two crystal layers, each one about 3mm thick. This result is supported from both imaging and spectroscopic evidences: different images and pulse-height spectra of the slanted beam can be obtained for each layer.

Conclusions

The proposed DoI-encoding technique ensures a DoI discrimination with a resolution of about 3mm, despite the small crystal thickness. Respect to other methods reported in literature, the proposed one is particularly engaging since it allows high DoI resolution without complex software procedures (e.g. fit or MLEM) or additional hardware equipment (e.g. phoswich detector or double-sided readout).

References

X-ray sensitivity of small organic molecule and lead oxide mixture layers deposited using thermal melting technique

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Recently the spin-coating technique was employed to deposit X-ray sensitive layers of polymer mixture with high atomic number nanoparticles. Here, we demonstrate thermal melting method for deposition of X-ray absorptive thick layers. For investigations of X-ray photocurrent the thermally melted layers of various content of N,N,N′,N′-Tetra(p-tolyl) benzidine (TPTB) and Lead Oxide (PbO) powder have been formed between two ITO-glass and Al-glass substrates. An introduction of PbO particles into organic melt led to higher conductivity and sensitivity to X-rays. Under X-ray flux of $3.5 \times 10^9$ s$^{-1}$cm$^{-2}$ the estimated values of photocurrent were up to 120 nA/cm$^2$ and increased up to 10 times compared to the dark current.
Coded aperture imaging transcends planar imaging with conventional collimators in efficiency and field of view size. We present results from measurements and simulations using one or more spatially extended gamma sources with uniform and normally distributed activity. These results prove that the method can be used for intraoperative imaging of radio-traced sentinel nodes and thyroid remnants. The study was performed using a setup which consists of two masks of the Modified Uniformly Redundant Array rank 19 type in front of two CdTe gamma cameras with active area 4.4×4.4 cm² each. The mask element size is less than 2mm and the CdTe detector pixel pitch is 350um. The energy detectable range is from 15 keV to 200 keV, with 3-4 keV FWHM energy resolution. Triangulation is exploited to give all the spatial coordinates of the radioactive spots localized in the system field of view. Two extended sources with Gaussian distributed activity (σ=1cm) placed at 15cm from the system and with 3cm distance between them can be resolved and localized with better than 5% accuracy.
Anastasiya Khromova¹, Peter Göttlicher², Igor Shevyakov², Joshua Supra², Qingqing Xia², Manfred Zimmer², Jens Viefhaus², Frank Scholz², Jörg Seltmann², Cornelia B. Wunderer², Jonathan Correa², Helmut Hirsemann², Sabine Lange², Alessandro Marras², Magdalena Niemann², Sergej Smoljanin², Maximilian Tennert², Heinz Grafsma², Salim Reza², Nicola Tartoni³, Ulrik K Pedersen³, Hazem Yousef³, Ralf Menk¹, Luigi Stebel¹, Giuseppe Cautero¹, Dario Giuressi¹, Giovanni Pinaroli¹, April D. Jewell⁴, Todd J. Jones⁴, Michael E. Hoenk⁴, Shouleh Nikzad⁴, Seungyu Rah⁵, HyoJung Hyun⁵, KyungSook Kim⁵, Renato Turchetta⁶, Iain Sedgwick⁶, Dipayan Das⁶, Nicola Guerrini⁶, Ben Marsh⁶, Tim Nicholls⁶, Stephan Klumpp²

The PERCIVAL (Pixelated Energy Resolving CMOS Imager, Versatile And Large) soft X-ray 2D imaging detector is based on stitched, wafer-scale sensors possessing a thick epilayer, which together with back-thinning and back-side illumination yields elevated quantum efficiency in the photon energy range of 125eV-1000eV. A 2Mpixel detector version (P2M) comprising 1408x1484 pixels with a pixel pitch of 27μm is currently being fabricated and will be available in a front-side illuminated version in late 2016. Since connection pads are restricted to two sides of the sensor, up to 4 sensors can be assembled together in order to achieve larger detection areas. Main application fields of PERCIVAL are foreseen in photon science with FELs and synchrotron radiation: this requires high dynamic range (up to 10^5[ph]@250eV) paired with single photon sensitivity at moderate frame rates (10-120Hz). These figures imply the availability of dynamic gain switching on a pixel-by-pixel basis and a highly parallel, low noise analog and digital readout, which is intrinsically on-chip in the PERCIVAL sensor layout.

Different aspects of the detector performance have been assessed using prototype sensors with different pixel and ADC flavors. This presentation reports on the results of recent measurements that have been carried out with a bench-top system using continuous light sources and at synchrotron radiation and FEL beamlines with mono-energetic photons in the 125-1000eV range. For the target frame rates (10-120Hz) an average noise floor of 14e- has been determined in the highest gain, indicating the ability of detecting single photons with energies above 250eV. Owing to the successfully implemented adaptive gain switching, the integrated charge level exceeds 3.5*10^6e-. For all gains the noise floor remains below the Poisson limit also in high-flux conditions. The recent updates on the structure of P2M detector head will be highlighted as well.
A low cost fluorescence lifetime measurement system based on SPAD detectors and FPGA processing

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This work presents a low cost fluorescence life time measurement system, aimed at carrying out fast diagnostic tests through label detection in a portable system so it can be used in a medical consultation, within a short time span. The system uses Time Correlated Single Photon Counting (TCSPC), measuring the arrival time of individual photons and building an histogram of those times, showing the fluorescence decay of the label which is characteristic of each fluorescent substance. The system is implemented using a Xilinx FPGA which controls the experiment and includes a Time to Digital Converter (TDC) to perform measurements with a resolution in the order of tenths of picoseconds. A laser diode and the driving electronics to generate short pulses as well as a HV-CMOS implemented Single Photon Avalanche Diode (SPAD) as a high gain sensor are the other elements. The system is entirely configurable so it can easily be adapted to the target label molecule and measurement needs. The histogram is constructed within the FPGA and can then be read as convenient. Various performance parameters are also shown, as well as experimental measures of a quantum dot fluorescence decay as a proof of concept. In the conference those measurements will be presented and discussed.
Fast Pixelated Sensors For Radiation Detection And Imaging Based On Quantum Confined Structures In III/V Semiconductors

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In order to improve the characterization of the delivered beams in many types of photon sources, innovative beam profilers based on III/V semiconductor materials (InGaAs/InAlAs) have been deeply investigated. Owing to a tunable and direct band gap these devices allow radiation detection in a wide spectral range. In order to increase the sensitivity of the device in low energy/low intensity radiation detection, charge amplification on the sensor level is implemented. This is achieved by growing In0.75Ga0.25As/In0.75Al0.25As quantum wells (QW) hosting two-dimensional electronic gases (2DEG) through molecular beam epitaxy (MBE).

Internal charge amplification mechanism can be achieved for very low applied voltages, while the high carrier mobility allows the design of very fast photon detectors with sub-nanosecond response times. Several small size pixelated devices have been deeply investigated as PhBPM, and now this technology has been preliminarily exploited to fabricate prototype beam profilers with a striped geometry (50 um wide stripes).

Tests were carried out both with conventional X-ray tubes and at the Elettra synchrotron facility. The results testify how these profi
There is a great interest in utilization of non-crystalline photoconductors for direct conversion medical X-ray imaging detectors. Currently, the only direct conversion detectors, available on the market, are amorphous selenium (a-Se) based. Unfortunately, a-Se is a low Z (atomic number) material and suffers from low X-ray stopping power. This limits the application of direct conversion detectors to high dose and low X-ray energy procedures (mammography). For low dose and high energy imaging (fluoroscopy), a-Se must be replaced by high Z material. Potential candidates are: polycrystalline layers of HgI2, PbI2, TlBr, CdZnTe and PbO. Poly-PbO holds a special place in this list: like a-Se, it was previously successfully utilized in optical imaging (Plumbicons pick up tubes) that suggests its appropriate photoconductive properties. Further advantage of PbO over other candidates is the absence of heavy absorption edges up to 88 keV, which inherently offers the higher spatial resolution. In 2005 Simon et al showed a prototype of a PbO-based flat-panel X-ray detector characterized by very high spatial resolution and charge yield sufficient for low dose imaging. However, at that time, poly-PbO layers exhibited the residual signal after the end of X-ray exposure, called lag. Reported signal lag restricts application of PbO to static imaging only and obscures full potential of PbO for medical imaging.

We have developed a practical approach that allows to combat the signal lag. The objective is achieved by advancing the deposition technology and provides a novel type of amorphous lead oxide (a-PbO). The results on temporal response of novel a-PbO samples were found to compare favorably to published results on poly-PbO and a-Se films. Our advances in PbO technology offer a-PbO films, suitable for real time X-ray imaging.
We report the effect that positron range has over Positron Emission Tomography studies through Line Spread Function (LSF) measurements. Thin nylon capillary tubes were filled with 18F, 13N or 68Ga (Emax of 634, 1198 and 1899 keV, respectively) and placed along the axis of symmetry of tissue-equivalent cylindrical phantoms (lung inhale and exhale, adipose, solid water, trabecular and cortical bone). PET scans were performed with a microPET Focus 120 small-animal PET scanner using 2D FBP image reconstruction. The LSFs were analyzed using radial profiles and the full-width at half- (FWHM), tenth- (FWTM) and twentieth- (FWTwM) extracted. The 18F profiles are very similar for all materials with tails extending no more than 8 mm from the source. Tails extend over longer radial distances when higher energy positron sources (13N and 68Ga) are used, being more important when traversing less dense media. Spatial resolution degradation increases with positron energy and with decreasing tissue density in a complex way. The smallest FWHM (1.9 mm) corresponded to 18F, while the largest (2.8 mm) occurred for 68Ga, both in cortical-bone. For the profile tails, the smallest FWTwM (4.7 mm) corresponded to 18F in cortical-bone, while the largest (13 mm) occurred for 68Ga in lung-inhale.

Analytical fits to the LSFs were obtained using double Gaussian functions: a narrow Gaussian associated with the scanner resolution and a wide Gaussian with a strong dependence with material density and positron energy. The LSFs were used to obtain the Point Spread Functions (PSF), which were incorporated into an iterative deconvolution process to correct for partial volume. The results show a drastic improvement in the spatial resolution of the corrected LSFs, with FWHMs within [1.01, 2.59] mm and FWTwMs within [2.10, 5.38] mm for all material-radionuclide combinations.
Spatial resolution effects of positron-range in tissue-equivalent materials

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We report the effect that positron range has over Positron Emission Tomography studies through Line Spread Function (LSF) measurements. Thin nylon capillary tubes were filled with ¹⁸F, ¹³N or ⁶⁸Ga (Emax of 634, 1198 and 1899 keV, respectively) and placed along the axis of symmetry of tissue-equivalent cylindrical phantoms (lung inhale and exhale, adipose, solid water, trabecular and cortical bone). PET scans were performed with a microPET Focus 120 small-animal PET scanner using 2D FBP image reconstruction. The LSFs were analyzed using radial profiles and the full-width at half- (FWHM), tenth- (FWTM) and twentieth- (FWTwM) extracted. The ¹⁸F profiles are very similar for all materials with tails extending no more than 8 mm from the source. Tails extend over longer radial distances when higher energy positron sources (¹³N and ⁶⁸Ga) are used, being more important when traversing less dense media. Spatial resolution degradation increases with positron energy and with decreasing tissue density in a complex way. The smallest FWHM (1.9 mm) corresponded to ¹⁸F, while the largest (2.8 mm) occurred for ⁶⁸Ga, both in cortical-bone. For the profile tails, the smallest FWTwM (4.7 mm) corresponded to ¹⁸F in cortical-bone, while the largest (13 mm) occurred for ⁶⁸Ga in lung-inhale.

Analytical fits to the LSFs were obtained using double Gaussian functions: a narrow Gaussian associated with the scanner resolution and a wide Gaussian with a strong dependence with material density and positron energy. The LSFs were used to obtain the Point Spread Functions (PSF), which were incorporated into an iterative deconvolution process to correct for partial volume. The results show a drastic improvement in the spatial resolution of the corrected LSFs, with FWHMs within [1.01, 2.59] mm and FWTwMs within [2.10, 5.38] mm for all material-radionuclide combinations.
Improvement and Evaluation of an SOI Pixel Detector with an Event-driven Readout Mode for an X-ray Astronomy

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We have been developing monolithic active pixel detectors, named “XRPIX” based on the silicon-on-insulator (SOI) pixel technology, for future X-ray astronomical satellite missions. Our objective is to replace X-ray Charge Coupled Devices (CCD), which are now standard detectors in the field. The XRPIX series offers good time resolution (~1 μs), fast readout time (~10 μs), and a wide energy range (0.5–40 keV) in addition to having imaging and spectroscopic capability comparable to CCDs. XRPIX contains a comparator circuit in each pixel for hit trigger (timing) and two-dimensional hit-pattern (position) outputs. Therefore, signals are read out only from selected pixels. X-ray readout by this function is called “event-driven readout”.

In our previous studies, we improved the X-ray spectral performance by introducing in-pixel charge-sensitive amplifier circuit in the frame readout mode, which an analog signal from all pixels periodically. We achieved an energy resolution of 320 eV (FWHM) for 5.9 keV X-rays with which Mn-Kα and -Kβ lines are resolved for the first time in the XRPIX series. Furthermore, we successfully demonstrated X-ray detection by the event-driven readout. On the other hand, we found some problems in the operation of a circuit. These investigations progressed as the results of many evaluation tests. Thus, we designed a new prototype in which we modified the circuit and structure. We have also enhanced the function of the peripheral circuit. In this presentation, we report on the development and evaluation results of the new device.
Natascha Raab¹, Jolanta Sztuk-Dambietz¹, Kai-Erik Ballak¹, Thomas Dietze¹, Marko Ekmedžić¹, Steffen Hauf¹, Friederike Januschek¹, Alexander Kaukher¹, Markus Kuster¹, Philipp Lang¹, Astrid Münich¹, Rüdiger Schmitt¹, Monica Turcato¹

1) European XFEL GmbH, Albert-Einstein-Ring 19, Hamburg, Germany

The European X-ray Free Electron Laser (XFEL.EU) will provide unprecedented peak brilliance and ultra-short pulses in an energy range of 0.25 to 25 keV. The timing structure is unique with a burst of 2700 pulses of 100 fs length at a temporal distance of 220 ns followed by a 99.4 ms gap.

To make use of these capabilities a great variety of detectors are being developed for use at XFEL.EU, including 2D X-ray cameras with repetition rates up to 4.5 MHz, driven by the timing structure of the XFEL, dynamic ranges up to $10^5$ photons/px/pulse, different operating conditions and a vast range of sensor and pixel sizes.

In order to characterize and calibrate this variety of detectors and for testing of detector prototypes, the XFEL.EU detector group has been working on building up an X-ray test laboratory dedicated to provide X-ray photons with characteristics that are as similar to the future beam line conditions at the XFEL.EU as is possible with laboratory sources.

To achieve this, the approach is to use different sources and test setups that complement each other.

A total of four test environments provide the infrastructure for detector tests and calibration: two portable setups that utilize low power X-ray sources and radioactive isotopes, a test environment where a commercial high power X-ray generator is in use and a pulsed electron source which will provide pulses as short as 25 ns in XFEL.EU burst mode combined with target anodes of different materials.

The status of the test environments, three of which are already in use while one is in commissioning phase, will be presented as well as first results from performance tests and characterization of the sources.
Basic design of a multi-wire proportional counter using Garfield++ for ILSF

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3) Iranian Light Source Facility (ILSF), Institute for Research in Fundamental Sciences (IPM), Tehran, Iran.

Synchrotron as one of the main γ-ray sources has always been an important role to study the structure of material. In recent years, Iranian Light Source Facility (ILSF) as a new 3GeV synchrotron radiation in Middle East is being designed. Since the first generation of the synchrotron facilities, gas detectors are widely used as probe tools in radiation experiments. Position sensitive gas detector based on the Multi-Wire Proportional Counter (MWPC) as an important member of the collection of imaging devices is available for x-ray scattering measurement.

In this paper, design and simulation of two-dimensional MWPC are well described. The geometry of the designed MWPC contains detector active area as well as wire and strip characterizations are optimized using Garfield++ code. The active area of prototype counter is considered to be 10cm×10cm. To make a good spatial resolution, the optimized values of strip width and pitch are obtained to be 1.5 and 0.5 mm, respectively.

In order to investigate detector effective gain, other parameters in association with the detector structure such as gas filled, pressure and temperature as well as voltage are also investigated.

The designed detector is now ready for fabrication as a prototype at ILSF.
Development of a Sub-Millimeter Resolution Gamma-ray Detector for Variable Pinhole SPECT

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1) Department of Bio-convergence Engineering, Korea University
2) School of Biomedical Engineering, Korea University
3) Department of IT Convergence, Korea University
4) Research Institute of Global Health Technology, Korea University

The major advantages of a novel SPECT system with a Variable Pinhole (VP) collimator are high sensitivity and spatial resolution for the specific Region of Interest (ROI). The acceptance angle of the pinhole and the distance between collimator and detector need to be optimized to the ROI for each rotation angle. Due to the novel SPECT concept, there are needs for the gamma-ray detector of this system, that are submillimeter level intrinsic resolution, compact size, large detection area. The goal of this study is to develop a compact gamma-ray detector with sub-mm resolution and large detection area for VP SPECT system.

We applied CsI(Tl) scintillator (Pixel 0.7×0.7×5 mm³). The array consists of 51×51 pixels and the size of whole scintillator array is 45.7×45.7 mm². The detection area composed of 2×2 array of four MPPC modules, which has a small dead space at the edge of the sensor, so the dimension of effective detection area was 52×52 mm². We designed a printed circuit board for the placement of modules array. The analog readout circuit chain of the prototype system is composed of the 16×16 symmetric charge division circuit, the charge-sensitive preamplifier, a gain amplifier, and baseline adjustment. The flood map image is acquired by Co-57. The prototype detector consists of MPPC connection and positioning circuit (Top), signal processing and ADC driver circuit(Side), and basement circuit(Bottom). The positioning method is the row/column weighted sum. The FPGA based data acquisition board is used.

We developed a light weight, sub-millimeter resolution (0.9mm), and large area (45.7×45.7 mm²) gamma-ray detector for VP SPECT system. We achieved 0.46mm and 0.54mm FWHMs for X and Y axis with Co-57 (122keV) by developing positioning, analog signal processing, and ADC driver circuit.
In the present work we focus on detection of interference patterns on X-ray radiograms caused by low-contrast microstructures. Currently phase-contrast techniques in mammography aim to improve the image quality for distinction of breast composition which is limited with conventional absorption techniques. Experimental studies based on X-ray phase-contrast imaging carried out using polychromatic X-ray sources are mostly based on Laue diffraction interferometers and Bragg reflections featuring crystals or gratings. However, implementation of such setups in a clinical environment is rather complex. A more robust and easily implemented method to obtain phase-contrast information is the in-line holography technique. This method only differs from conventional radiography in the gap object-to-detector in order to allow sufficient distance for the refracted rays to diverge from the undeviated ones. This approach provides a broad usage in table-top laboratory set-ups as well as in clinical mammography since it solely requires a sufficient degree of lateral coherence given by the focal-spot size and source-to-object distance together with high spatial resolution of the detector, such as the Medipix and Timepix detectors, and long propagation paths. For this work we employed in the current experiment were edgeless high resolution single-tile 1.4x1.4cm² Timepix detectors equipped with 300µm-Si sensors as well as a tiled Widepix detector with 5x10 single chips. Each of these devices has a pixel pitch of 55µm. Using a table-top setup featuring a standard Tungsten microfocus X-ray source with a nominal spot-size of 5µm, a systematic optimization of the geometry, energy parameters, and detectors was undertaken to obtain phase-contrast on tissue-equivalent samples under mammographic conditions. The results of these optimizations will be presented including phase-contrast radiograms of a custom-made mammographic phantom.
Shunsuke Kurosawa, Shohei Kodama, Takahiko Horiai, Akihiro Yamaji, Yuji Ohashi, Kei Kamada, Yuui Yokota, Akira Yoshikawa

1) Tohoku Univ.

Pure Cs2HfCl6 is novel scintillator and Burger et al. reported that it has a good energy resolution (FWHM) of less than 4% at 662 keV, and an emission wavelength of around 400 nm using a photo-multiplier tube (PMT). Additionally, this scintillation material has high effective atomic number of approximately 58, while other chloride scintillators such as LaCl3 have less than 55.

Since this material has a long decay time of over 3 $\mu$s, a Silicon Photomultipliers (Si-PM), Multi-Pixel Photon Counter (MPPC), is expected to be used for the detection of scintillation photons; even it has large light output, saturation can be suppressed. Here, the MPPC and Si-avalanche photodiode (APD) have compact size and large quantum efficiency than PMT. Thus, we grew a pure Cs2HfCl6 crystal grown by the Bridgman technique, and investigate the light output or other scintillation properties with a MPPC (Hamamatsu, S13360-6025CS) and . Moreover, other Hf-based chloride scintillators such as Na-doped Cs2HfCl6 crystal were also prepared by the same way.

Using the MPPC, energy resolution of pure Cs2HfCl6 was estimated to be 5.5 % (662 keV, FWHM), and its light output was ~40,000 photons/MeV. In this paper, we show the energy resolutions for the Hf-based chloride scintillators, and compare their properties between the MPPC, APD and PMT.
The hybrid particle counting pixel detectors of Medipix family are well known. In this contribution we present new USB 3.0 based interface AdvaPIX for these detectors. The AdvaPIX interface is designed with maximal emphasis to flexibility. It is successor of FitPIX interface developed in IEAP CTU in Prague. Its modular architecture supports all Medipix/Timepix chips and all their different readout modes: Medipix2, Timepix (serial and parallel), Medipix3 and Timepix3. The high bandwidth of USB 3.0 permits readout of 1700 full frames per second with Timepix or 5 channel data acquisition from Timepix3 at frequency of 320 MHz.

The AdvaPIX interface is compatible also with large area pixel detectors WidePIX assembled of many Timepix chips with edgeless sensors. In this configuration the interface supports simultaneous read-out of up to 8 serials streams.

The control and data acquisition is integrated in multiplatform PiXet software (MS Windows, Apple OS, Linux). Several examples illustrating properties of the USB 3.0 read-out will be shown to auditorium: Fast X-ray radiography, 4D tomography (tomography of time dependent process) or fully spectral radiography with Timepix/Timepix3 in ToT mode.
Applications of fast USB 3.0 based Timepix and Timepix3 readout AdvaPIX for fast X-ray radiography and fully spectral imaging

Jan Jakubek¹, Pavel Soukup¹, Eliska Trojanova¹, Daniel Turecek¹

1) ADVACAM s.r.o., Prague, Czech Republic

The newly developed fast USB 3.0 interface AdvaPIX for hybrid particle counting pixel detectors of Medipix family significantly extents application field of Medipix technology. The AdvaPIX interface is compact, fast, plug-and-play and easy to use since all modern computers are equipped with one or more USB 3.0 ports. Preparing the experimental or measurement setup with AdvaPIX is then very simple and quick. The first implementation of AdvaPIX interface contains single Timepix detector reaching maximal speed of 1700 full frames per second. Several such units can be placed next to each other aligning detectors in 2D forming larger area for imaging applications and/or stacking them in 3D for particle tracking. There are many possible configurations of such detector system: Quad (4 chips, 512x512 pixels), row (4 chips 1024x256 pixels), stack (4 chips in layers, 256 x 256 x 4 pixels) etc.

In this contribution we present several measurements performed by the AdvaPIX with Timepix and Timepix3 detectors. The first application is a fast X-ray radiography of dynamic processes: the radiography of mouse heart beat will be shown demonstrating that even at 1000 frames per second the CdTe Timepix device can reach radiographic contrast capable to visualize changes in blood content (pulsing) in lungs and heart ventricles. The second application is fast X-ray tomography. It will be shown that full tomographic measurement can be performed in a fraction of second even for object composed of light materials. The last application is fully spectroscopic X-ray imaging with Timepix and Timepix3 detectors operated in the ToT mode (Time-over-Threshold). It will be shown that the AdvaPIX’s readout speed is already sufficient to perform such spectroscopic measurement at nearly full intensity of radiographic setups equipped with nanofocus X-ray tubes.
Front end electronics of double SOI X-ray imaging sensors

Toshinobu Miyoshi¹, Yasuo Arai¹, Yowichi Fujita¹, Kazuhiko Hara², Yoichi Ikegami¹, Kazuya Tauchi¹, Toru Tsuboyama¹, Miho Yamada¹, Shun Ono¹, Ryutaro Nishimura³, Ryutaro Hamasaki³, Ikuo Kurachi¹

1) High Energy Accelerator Research Organization (KEK)
2) Univ. of Tsukuba
3) SOKENDAI

We have developed monolithic pixel sensors using silicon-on-insulator (SOI) technology. The SOI consists of a sensor substrate and an electric circuit at the thin silicon (SOI) layer with an insulator (buried oxide, BOX) between the silicons. Since the sensor and the circuit are close in each other, there are some interference effects such as the back gate effect and crosstalk between sensor and circuit. Holes are accumulated at the BOX after high dose irradiation, which causes the change of transistor properties. As one of solutions in various problems, we utilized a double SOI wafer which includes two SOI layers. Top SOI layer is used as an electric circuit and bottom SOI layer (the middle silicon layer) is used as a shield layer against the back gate effect and a crosstalk between sensors and circuit. The potential control at the middle SOI layer helps to compensate with charge accumulation at the BOX. We designed integration-type pixel sensors with charge sensitive preamplifier within 16 microns of the pixel size as shown in figure 1. We can select feedback capacitors to switch the gain. The sensor was processed on single and double SOI wafers. The sensors were irradiated with radiation sources, monochromatic X-rays at KEK Photon Factory, and X-rays from X-ray tube generators. We measured X-ray spectra using americium and iron sources, and extracted the sensor gain of single and double SOI sensors. In the single SOI sensor, the sensor gain was small due to parasitic capacitances. In the double SOI sensor, the sensor gain was consistent with the results of SPICE simulation, because of the suppression of crosstalk between sensor and circuit. We also demonstrated X-ray imaging using both sensors. In the presentation, up-to-date results will be shown.
A generalized quantitative interpretation of multi-energy dark-field contrast for highly concentrated microsphere suspensions

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In X-ray grating interferometry, dark-field contrast arises due to partial extinction of the detected interference fringes. This is also called visibility reduction and is attributed to ultra-small-angle scattering from unresolved structures in the imaged object. In recent years, analytical quantitative frameworks of dark-field have been developed for highly diluted monodisperse microsphere suspensions with maximum 6% volume fraction. These frameworks assume that scattering particles are separated by large enough distances, which make any interparticle scattering interference negligible. On the other hand, to potentially extract quantitative dark-field information from dense biological or material science samples, it is necessary to study both the theoretical and experimental dependence of dark-field for highly concentrated systems (volume fraction much higher than 6%). In this paper, we start from the small-angle scattering intensity equation and, by linking Fourier and real space, we perform an analytical and experimental quantitative validation of dark-field contrast for a range of suspensions with volume fractions reaching 40%. By taking into account interparticle scattering interference in the form of an adhesive hard sphere structure factor and without introducing any additional fitting parameters, we successfully predict the experimental values measured at the Swiss Light Source TOMCAT beamline. Finally, we apply this theoretical framework to an experiment probing a range of system correlation lengths by acquiring dark-field images at different energies. This method has the potential to be applied in single-measurement-mode using an X-ray tube polychromatic setup and a single-photon-counting energy-resolving detector.
Front end electronics of double SOI X-ray imaging sensors

Toshinobu Miyoshi¹, Yasuo Arai¹, Yowichi Fujita¹, Kazuhiko Hara², Yoichi Ikegami¹, Kazuya Tauchi¹, Toru Tsuboyama¹, Miho Yamada¹, Shun Ono¹, Ryutaro Nishimura³, Ryutaro Hamasaki³, Ikuo Kurachi¹

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We have developed monolithic pixel sensors using silicon-on-insulator (SOI) technology. The SOI consists of a sensor substrate and an electric circuit at the thin silicon (SOI) layer with an insulator (buried oxide, BOX) between the silicons. Since the sensor and the circuit are close in each other, there are some interference effects such as the back gate effect and crosstalk between sensor and circuit. Holes are accumulated at the BOX after high dose irradiation, which causes the change of transistor properties. As one of solutions in various problems, we utilized a double SOI wafer which includes two SOI layers. Top SOI layer is used as an electric circuit and bottom SOI layer (the middle silicon layer) is used as a shield layer against the back gate effect and a crosstalk between sensors and circuit. The potential control at the middle SOI layer helps to compensate with charge accumulation at the BOX. We designed integration-type pixel sensors with charge sensitive preamplifier within 16 microns of the pixel size as shown in figure 1. We can select feedback capacitors to switch the gain. The sensor was processed on single and double SOI wafers. The sensors were irradiated with radiation sources, monochromatic X-rays at KEK Photon Factory, and X-rays from X-ray tube generators. We measured X-ray spectra using americium and iron sources, and extracted the sensor gain of single and double SOI sensors. In the single SOI sensor, the sensor gain was small due to parasitic capacitances. In the double SOI sensor, the sensor gain was consistent with the results of SPICE simulation, because of the suppression of crosstalk between sensor and circuit. We also demonstrated X-ray imaging using both sensors. In the presentation, up-to-date results will be shown.
A binary multichannel front-end architecture for position-sensitive detector, providing fully parallel signal processing, is a good solution for high intensity radiation application. The mixed-signal PRIMA-chip was designed and optimized for a microstrip silicon detector (pitch 200μm and thickness 320μm) which has to detect protons with energy up to 250MeV and acquisition rate up to 1 MHz, for application in proton imaging field [1,2]. The chip includes 32-front-end channels with a charge preamplifier, a shaper and a comparator. To adjust the comparator thresholds, each channel includes a 8-bit DAC, programmed using an I2C-like interface. The PRIMA-chip was designed to reach the best compromise between noise and counting rate performance. It was fabricated using the AMS 0.35μm standard CMOS process and its performances were tested coupling it to the silicon microstrip detectors used in the tracker assembled for the pCT (proton Computed Tomography) apparatus described in [1,2]. The chip performances (gain, noise and power) meet the project requirements. The chip architecture will be described. Simulations and experimental results of the chip will be shown and discussed. Moreover, results of first tests performed with an x-y plan of the tracker, assembled with 8 detectors and 48 chips, with a 60MeV proton beam, will be shown.
Comparison of the position linearity response for recently developed monolithic scintillators: CRY018 and CRY019 for dual isotope gamma ray imaging applications

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1) Morphogenesis and tissue Engineering, Doctorate School of Biology and Molecular Medicine - SAIMLAL Department, Sapienza University of Rome, Italy
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Aim

The growing interest for new scintillation crystals with outstanding performances (i.e. resolution and efficiency) has suggested the study of recently discovered scintillators: CRY018 and CRY019. The crystals under investigation are monolithic (allowing to obtain better performances in respect to the pixelated ones) and show enhanced characteristics both for gamma ray spectrometry and for Nuclear Medicine applications such as the dual isotope imaging. Moreover, the non-hygroscopic nature and the absence of afterglow make these scintillators even more attractive for the potential improvement in a wide range of applications.

Methods

CRY018 and CRY019 have round shape and white painted surfaces (instead of the absorbent treated crystal dedicated for imaging). Both scintillators have been tested with a standard PMT (considered as the gold standard for spectrometric applications) and with a position sensitive PMT equipped with a SBA photocathode (guaranteeing a higher quantum efficiency). In this way, the position linearity as a function of the energy and the dual isotope imaging performances have been evaluated.

Results

The scintillation crystals show a great Energy Resolution in the energy range involved in Nuclear Medicine, allowing the discrimination between very close energy values. This result has been highlighted and confirmed by the comparison with a LaBr₃:Ce. In spite of the reduction of position linearity for continuous crystals (strongly affected by compression effects due to internal reflections), the implementation of an optimized algorithm guarantees the alignment of the crystals, ensuring their suitability of being powerful imaging systems.

Conclusion

The imaging from radioisotopes with different photon emissions (i.e. ¹¹¹In, ²⁰¹Tl, ⁷⁵Se) is a useful and often performed technique for cerebral and cardiac imaging but also for many others applications as the preoperative localization of parathyroid tumors. So, an accurate discrimination of the different contribution in the overall spectrum can increase considerably the diagnostic potential.
A Highly-Integrated Germanium Multi-element Detector For Energy-dispersive Diffraction.

D Peter Siddons¹, Abdul Rumaiz¹, Anthony Kuczewski¹, Joseph Mead¹, Gianluigi De Geronimo¹, Antonino Miceli³, John Wiezeorick³, Thomas Krings², Jonathan Baldwin³, Russell Woods³

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2) Forschungszentrum Jülich GmbH
3) Argonne National Laboratory, Argonne, Illinois, USA

Based on a monolithic multi-element germanium detector technology developed at Juelich and on integrated circuits developed at BNL, we have constructed a 64-channel detector with full spectroscopic readout from each element. This system shows good energy resolution (~400eV @ 60keV). Readout is performed by a compact unit based on the ZynQ FPGA / processor system-on-chip. We will present data produced by this system, and will discuss the upgrades to this system which are underway, including an expansion to a 384-channel system.
The world-wide shortage of 3He gas has triggered research on novel approaches for thermal and cold neutron detection such as the development of scintillation based detectors to be used in small angle neutron scattering (SANS) experiments. In order to improve the neutron count rates by simplifying the detector readout algorithms and simultaneously increase the detectors space resolution, in SANS instruments requiring detectors with active areas up to 1 m² pixelated scintillator detectors could be the new way to proceed. Here, each detector “pixel” would have the size directly matching the required space resolution. An interesting candidate for the photodetector part in these detectors could be an array of silicon photomultipliers (SiPM), either analog or digital. It would yield the possibility of single photon counting, low power consumption, an acceptable space resolution, neutron counting rates much higher than those achieved by current 3He based detectors, and the complete insensitivity to magnetic fields up to several Tesla.

The main risk defined so far their radiation hardness considering thermal or cold neutron irradiation. We investigated the dark signal and breakdown voltage performances of three SiPM technologies, two analog ones and one based on digital counting of avalanche events, both with and without a scintillator material covering the following photodetector arrays: SensL Series C 12x12 ArrayC-30035-144P, Hamamatsu 8 × 8 MPPC array S12642-0808PB-50, and Philips DPC3200-44-22 module. We irradiated the photodetector arrays under test with cold neutrons (ln = 5 Å) at the KWS-1 instrument of the Heinz Maier Leibnitz Zentrum in Garching, Germany, up to a dose of 6 × 10¹² n·cm⁻². The SiPM detectors were at all times fully operational, and the measurements were performed in-situ. In this work we present the results of the breakdown voltage, dark signal, and gain factor characterization of those SiPM arrays before and after the irradiation.
A discriminator with sub-10 ps time resolution for ToF in medical imaging

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A front end application specific integrated circuit (ASIC) for the readout of common cathode Silicon Photo-Multipliers arrays is presented with the following features: less than 10 ps RMS of timing resolution, wide dynamic range, high speed, multi-channel, low input impedance current amplifier, low power (∼10mW per channel), common cathode connection, directly coupled input with common mode voltage control and separated timing and charge signal output.

The low jitter current mode processing together with a configurable differential current mode logic (CML) output provides a timing signal suitable for Time of Flight (ToF) measurements. This low jitter allows coincidence time resolution (CTR) measurements close to 100 ps using 2x2x5 mm³ LYSO crystals. Each channel delivers a digital output of a Time over Threshold (ToT) type with a pulse width proportional to peak current (charge) input.

The current mode input stage features a novel double feedback; a low speed feedback loop keeps input node voltage constant while a higher speed feedback loop keeps input impedance low. Dedicated circuitry allows SiPM high over-voltage operation, thus maximizing photon detection efficiency (PDE) and timing resolution. Design was submitted in a 0.35 μm HBT BiCMOS technology and tested using different SiPM crystals.

A new prototype is being developed using a 0.18 μm CMOS technology with which four times less power consumption and better timing resolution is under design.
GUALI, imaging and mapping radioactive contamination

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Imaging of radioactive sources becomes of special interest in decommissioning nuclear facilities, since many materials become contaminated during the power plant operation, a radioactive waste classification is necessary for efficient and safely dismantle the facility. Thus, the more precise the radioactive sources spatial distribution either in walls, containers and drums is known, the better the dismantling strategy could be defined. Furthermore, many important parameters as dismantling resources, budget and operators radioactive exposure could be minimized with a more detailed knowledge of the radioactive scenario.

To improve the dismantling strategy, we are developing GUALI (Gamma Unit Advanced Location Imaging) in collaboration with ENRESA (Empresa Nacional de Residuos Radiactivos, S.A): a compact and portable gamma-ray imaging system which will allow users to map radioactive sources in contaminated environments.

GUALI portable system is capable of obtain high resolution real-time gamma imaging of the main radioisotopes present on the contaminated materials, identifying the radioisotopes and its activities. With this new device, operating personnel will be able to rapidly locate, identify and measure radioactive waste and therefore perform a more accurate classification according both to the radioisotope activity and distribution.

GUALI development and first in-field radioactive waste classification measurements are shown as well as the improvement obtained in comparison with current conventional techniques. Project overview, current status and future steps and evolution are described.
The effect of low-temperature annealing on a CdZnTe detector

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It is known that low temperature annealing at below 200°C decreases the leakage current in a CdTe and CdZnTe (CZT) detector. However, only CZT detectors which have electrodes made by electroless method and low temperature annealing in the air showed diminished leakage current after annealing. With the aid of an in-situ annealing monitoring system, we measured the leakage current of a CZT detector while carrying out low-temperature annealing. A decrease in the leakage current resulted from the presence of thin insulating Te oxide layers, TeO₂ and CdTeO₃, instead of CZT/electrode interface enhancement by diffusion of Au. Other measurement results of Auger electron spectroscopy, micro TEM analysis, and pulse height spectrum were in good agreement with our new interpretation of the low temperature annealing effects of CZT.
Simulation Results for PLATO: A Prototype Hybrid X-Ray Photon Counting Detector with a Low Energy Threshold for Fusion Plasma Diagnostics

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PLATO is a prototype hybrid X-ray photon counting detector that has been designed to meet the specifications for plasma diagnostics for the WEST tokamak platform (Tungsten (W) Environment in Steady-state Tokamak) in southern France, with potential perspectives for ITER. The objective is to detect X-ray fluorescence photons emitted by a tokamak plasma at energies as low as 3 keV. Therefore, PLATO represents a customized solution that fulfills high sensitivity, low dispersion and high photon counting rate. The PLATO prototype matrix is composed of 16 x 16 pixels with a 70 μm pixel pitch. Each pixel contains a charge sensitive amplifier, two discriminators and two 12-bit counters/shift registers. New techniques have been used in analog sensitive blocks to minimize noise coupling through supply rails and substrate, and to suppress threshold dispersion across the matrix. For an input capacitance of 250 fF and a maximum photon counting rate of 12 x 10⁷ photons/s/mm², simulation results indicate an input referred equivalent noise charge of 42 e-rms and a high response linearity for photon energies between 2 and 10 keV. A new feedback technique has been implemented that allows a very high conversion gain of 72 mV/keV while maintaining low pixel to pixel dispersion. Moreover, the pixel has been optimized for low power consumption of 5.2 μW/pixel. The pixel can be programmed in a ‘two energy threshold’ mode with 2 x 12-bit counters, or ‘one energy threshold’ mode with a 24-bit counter. Furthermore, leakage current is compensated up to 10 nA/pixel. The Plato ASIC has been designed in TSMC CMOS 0.13 μm technology and is scheduled for a fabrication run in May 2016. The prototype chip should be tested electrically, as well as bump bonded to silicon detector.
A high spatial resolution, high speed X-ray imaging gaseous detector has been successfully developed with Glass Gas Electron Multiplier (G-GEM), scintillating gas, and mirror-lens-CCD-camera system. The imaging system consists of a chamber filled with Ar/CF4 scintillating gas mixture, inside of which G-GEM is mounted for gas multiplication. In this system electrons are generated by the reaction between X-rays and the gas, and high yield visible photons by excited Ar/CF4 gas molecules during the gas electron multiplication process in the G-GEM holes. These photons are detected by a mirror-lens-CCD-camera system and a radiograph is rapidly formed. Here, we report on the detector design and demonstration of high resolution, rapid X-ray imaging with G-GEM as a digital X-ray imager with a large sensitive area. Since the imaging system is based on a gaseous detector, it shows high sensitivity to low-energy X-rays (such as < 20keV), which results in a high contrast radiograph for elements with low atomic numbers. We succeed in forming a digital X-ray image in less than a second, and moreover we succeed in taking an X-ray transmission movie with 10ms integration time in each frame.
A wide FOV x-ray imaging detector for the imaging beamline at the Australian Synchrotron

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The Imaging and Medical Beam Line (IMBL) at the Australian Synchrotron is used for both radiography and radiotherapy research. It is a versatile x-ray facility, primarily built for biomedical research imaging. One distinguishing feature of IMBL is the size of the beam. With widths up to 400 mm it is unique amongst synchrotron radiographic beamlines in its capability to rapidly image large objects. Experiments using IMBL require several x-ray imaging detectors to cover the range of requirements. One that is missing is a large field of view imager with moderate resolution (< 50 micron pixels) and moderate readout speed (> 10 fps). For the future clinical imaging work and for work with large specimens, this will be an essential component.

In 2014 GPixel in China and the silicon foundry TowerJazz in the USA announced the development of a large CMOS optical imaging sensor. With a large aspect ratio it suits the IMBL beam better than other similar sensors. We have purchased an evaluation kit for the smaller of the two chips being produced by GPixel: the GMAX1250. This device has 12000 x 5000 pixels and readout speeds of 9.6 Gbps, giving close to 10 full frames per second. We have designed a prototype x-ray imager around this chip. The lens coupled scintillator x-ray detector will image a 388 mm width beam at 32 microns resolution. The prototype has recently been tested on IMBL. This presentation will describe the detector and the recently acquired performance results.
High Resolution X-ray imaging with pnCCDs

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Fully depleted pnCCDs were originally developed for spectroscopic X-ray imaging in spaceborn X-ray telescopes, their main advantages being radiation hardness, speed and high quantum efficiency. This advantages are due to backside illumination, thick sensitive volume and a several micron deep charge storage and transfer suppressing interaction with the MOS interfaces. Usually rather large pixel sizes above 75 Micrometers are used, which allow best spectroscopic performance and oversample the position resolution of imaging systems only slightly.

We present pnCCDs with a smaller pixel size of 36 Micrometers, resulting in charge splitting between neighbouring pixels for nearly all events. The CCDs are produced at the MPG Semiconductor Laboratory in formats up to 2M pixels (divided into storage and frame store regions) and will be operated at 400 frames per second.

The reconstruction of events requires a high framerate and moderate photon flux to be able to separate individual events within frames. Also a framestore area and a very fast transfer into the storage area is necessary to avoid incorrect assignment of events. The spectroscopic information is only slightly reduced by the necessity to add the signals of neighbouring pixels, but charge splitting allows a determination of the interaction position within pixel borders. Different methods for event analysis are evaluated. We show results from recently fabricated sensors read in column parallel mode at 400 frames/second with a frame transfer time below 100ns/line. A position resolution for 5.9 keV photons of better than 2 Micrometer is achieved together with an energy resolution below 200 eV FWHM.
Proton beam radiotherapy is highly effective in treating cancer thanks to its conformal dose deposition. This superior capability in dose deposition has led to a massive growth of the treated patients around the world, raising the need of treatment monitoring systems. An in-treatment PET system, DoPET, was constructed and tested at Catana beam-line, LNS-INFN in Catania, where 62MeV protons are used to treat ocular melanoma.

The PET technique profits from the beta+ emitters generated by the proton beam in the irradiated body, mainly 15-O and 11-C. The actual DoPET prototype consists of two planar 15cm x 15cm LYSO-based detector heads. The system was enlarged and the DAQ up-graded during the years so now also anthropomorphic phantoms, are used to characterize the DoPET performances.

To demonstrate the capability of DoPET to detect changes in the delivered treatment plan with respect to the planned one, different treatment plans were used delivering a standard 15Gy fraction to the anthropomorphic phantom. Data were acquired during and after the treatment delivery up to 10 minutes.

If the in-treatment phase was long enough (more than 1 minute), the corresponding activated volume was visible just after the treatment delivery, yet with the presence of a noisy and structured background. The after-treatment data, acquired for about 10 minutes, were segmented to study how long the data acquisition phase has to last, finding that few minutes are enough to be able to detect changes. These experiments will be presented together with the studies performed with PMMA phantoms where the DoPET response was characterized in terms of different dose rates and in presence of range shifters: the system response is linear up to 16.9 Gy/min and has the ability to see a 1 millimeter range shifter.
Stellar explosions are relevant and interesting astrophysical phenomena. Since long ago we have been working on the characterization of nova and supernova explosions in X and gamma rays, with the use of space missions such as INTEGRAL, XMM-N and SWIFT. We have been also involved in feasibility studies of future instruments in the energy range from several keV up to a few MeV, in collaboration with other research Institutes, such as GRI, DUAL and ASTROGAM. High sensitivities are essential to perform detailed studies of cosmic explosions and cosmic accelerators, e.g., Supernovae, Classical Novae, Supernova Remnants (SNRs), Gamma-Ray Bursts (GRBs).

In order to fulfill the combined requirement of high detection efficiency with good spatial and energy resolution, an initial module prototype based on CdTe pixel detectors is being developed. The detector dimensions are 12.5mm x 12.5mm x 2mm, with a pixel pitch of 1mm x 1mm. Two kinds of CdTe pixel detectors with different contacts have been tested: ohmic and Schottky. Each pixel is bump bonded to a fanout board made of Sapphire substrate and routed to the corresponding input channel of the readout VATAGP7.1 ASIC, to measure pixel position and pulse height for each incident gamma-ray photon. The study is complemented by the simulation of the CdTe module performance using the GEANT 4 and MEGALIB tools, which will help us to optimise the detector design, e.g. pixel size vs angular resolution.

We will report on the spectroscopic characterisation of the CdTe detector module, as well as on the study of charge sharing.
Low Gain Avalanche detectors (LGAD) is part of family of Avalanche Photodiodes but have only small gain of order of magnitude 10 and work in the reach-through mode with a depleted thick (200-300um) substrate. LGAD’s have been shown to have a very fast response time, order of picoseconds, which can make them useful in many applications, including concurrent excellent time and position resolution tracking for particle physics and synchrotron applications. The gain of the LGAD would allow pixelated hybrid detectors to operate comfortably in the region 1 keV to 4 keV that is used in applications such as long wavelength crystallography at synchrotron facilities. In addition, when coupled to dedicated read-out ASICs, LGADs would allow to build faster detectors for time resolved experiments.

In this work we present results of TCAD detector simulations, fabrication and characterisation. Synopsis TCAD software was employed to perform fabrication process simulations, electrical properties modelling, detector response to incident charge and influence of doping on gain variations. Several simple diode LGAD test devices and nominal no-gain sensors were fabricated at Micron Semiconductor Ltd. The doping profiles obtained for the test devices were measured via SIMS and compared to the process simulation and process adjustments performed as required. The test devices were characterised using laser and alpha Transient Current Technique (TCT) and fluorescence X-rays for charge collection, gain variation and sensitivity.

Under test these devices have shown to match within error to the simulated results for both IV and CV measurements. The TCT measurements have shown to compare well with the CV measurements in obtaining the full depletion voltage. The gain measured by the TCT was also comparable to the simulated results of 4.8.
Grating interferometry (GI) [1] has been shown to provide diagnostic information in the medical field. At the moment a number of challenges still limit its applicability in a medical setting. Such challenges include: the dose efficiency (analyzer grating G2 blocks half of the photons), the long acquisition times (multiple images due to phase stepping) and the fabrication challenges of G2. The authors propose a single shot, G2-less grating interferometer based on direct conversion detectors with single photon sensitivity which allows us to address the aforementioned limitations.

We performed experiments with two detectors the MOENCH [2] (pixel detector) and the GOTTHARD (strip detector), featuring a physical pixel/stip size of 25 μm that is suitable for medical imaging but can achieve micrometer resolution by exploiting the charge sharing effect. This allows the direct recording of the interference pattern with pitch of a few μm, and consecutively the retrieval of absorption and differential phase images [3]. The validation of the propose method was performed at the TOMCAT beamline, SLS, Switzerland. A polyethylene sphere of 625 μm was used as a validation sample. The results showed that quantitative absorption and differential phase contrast signals can be retrieved. Our approach tackles the major obstacles regarding fabrication limitations of G2 and increases the flux efficiency of the interferometer without compromising the sensitivity and resolution. Therefore, our approach presents a promising technique for practical phase contrast imaging in clinical applications.

References
Measurements with MÖNCH, a 25 μm pixel pitch hybrid pixel detector

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MÖNCH is a hybrid silicon pixel detector based on charge integration and with analog readout, featuring a pixel size of 25x25 μm². The latest working prototype consists of an array of 400x400 identical pixels for a total active area of 1x1 cm². Its design is optimized for the single photon regime.

An exhaustive characterization of this large area prototype has been conducted in the past months, and it confirms an ENC in the order of 35 electrons RMS and a dynamic range of ~4x12 keV photons in high gain mode, which increases to ~100x12 keV photons with the lowest gain setting.

The low noise levels of MÖNCH make it a suitable candidate for X-ray detection at energies around 1 keV and below. Its energy reconstruction and imaging capabilities have been tested for the first time at a low energy beamline at PSI, with photon energies between 1.75 keV and 3.5 keV, and results will be shown.

Imaging applications in particular can benefit significantly from the use of MÖNCH: due to its extremely small pixel pitch, the detector intrinsically offers excellent position resolution. Moreover, in low flux conditions, charge sharing between neighboring pixels allows the use of position interpolation algorithms which grant a resolution at the micrometer-level. Therefore, in order to precisely quantify the position resolution achievable with this method, a dedicated scan across one pixel using an X-ray beam with ~100 nm wide focus has been conducted. The outcomes of this test will also be presented. The same scan also provided a first indication of the radiation hardness of the device, and with its nanometric focal spot provided a good opportunity to identify possible radiation sensitive pixel components.

Finally, the prospects for future design optimization and commissioning of a larger area module will be discussed.
First measured results on AMS H35 CMOS devices for application in the ATLAS tracker upgrade

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The High-Voltage CMOS (HV-CMOS) technology has recently been introduced in the high energy physics community. The opportunity to include the pixel electronics within the sensor substrate brings major advantages to particle tracking detectors. HV-CMOS sensors can be thinner, faster and cheaper with respect to the silicon detectors currently in use.

H35Demo chips have been produced in order to study the radiation hardness of such detectors and verify the possibility to introduce this technology in the next ATLAS tracker upgrade for the high luminosity LHC. These chips are HV-CMOS devices produced in the 350nm AMS technology (H35). They have been produced on wafers with different substrate resistivity ranging from 20 to 1000Ω·cm.

Each chip includes four different pixel matrices. Two of them can be read out using a readout chip only, whilst the other two are completely monolithic. All the matrices can be bump bonded or glued to the FE-I4 readout chip. Moreover the chip includes three test structures too characterize the sensor properties. The test structures characterised with the Transient Current Technique (TCT) at IFAE consist of a single diode with eight neighbours that do not include additional electronics allowing to directly sample the signal waveform. Illuminating the sensors from the side (edge-TCT) it is possible to study the signal generation at different depths.

An experimental set-up based on a custom made PCB and the ZC706 Xilinx evaluation board has been developed by the Liverpool group. The set-up allows measuring one of the monolithic matrices that contains nMOS only discriminators with and without time-walk compensation inside the pixel area.

Features such as gain, speed and sensitivity to a radioactive source of the tested matrix will be shown together with the results of TCT and edge-TCT studies performed on irradiated and irradiated samples with different substrate resistivity.
Investigation on the effect of Exposure Time on Scintillator Afterglow for Ultra-Fast Tomography Acquisition

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Thanks to the ultra-fast endstation of the TOMCAT beamline, it is possible to do a tomographic scan with a sub-second temporal resolution which allows following dynamic processes in 4D (3D space + time). This ultra-high-rate tomography acquisition, exploiting the distinctive peculiarities of synchrotron radiation, provides nondestructive investigation of many dynamic processes which were not possible in the past. For example a continuous tensile test has been conducted recently in-situ for the first time with a frequency of 20 tomograms per second (20 Hz acquisition frequency). In the ultra-fast endstation a scintillator is used to convert X-ray to visible photons that can be detected by the camera. However, this conversion is not ideal and the scintillator decays exponentially with afterglow. Afterglow can cause resolution degradation and artifacts (such as ring and band) especially with high rotation speed. On the other hand, to achieve a higher scan speed, thicker scintillators are more common because they result in higher emission intensities that can compensate the short exposure time in fast scans. However, the resolution deteriorates as the scintillator’s thickness increases and thicker scintillators show higher afterglow. Performing many ultra-fast scans at the TOMCAT beamline with different acquisition rates, we demonstrate how the rotation speed effects on the projection data and reconstructed images. Using two different thicknesses of LAG scintillator we also investigate the afterglow artifacts for different acquisition rate and exposure time.
HV-CMOS detectors for High Energy Physics: characterization of BCD8 technology and controlled hybridization technique.

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Radiation detectors in high-voltage and high-resistivity CMOS technology are an interesting option for the large area pixel-trackers sought for the upgrade of the Large Hadron Collider experiments. A possible architecture is an hybrid design, where CMOS sensors are readout by front-electronics coupled through a thin dielectric layer. A critical requirement is the radiation hardness of the sensor and interconnections up to a dose of 1-10 MGy, depending on the distance from the interaction region.

A characterization of the BCD8 technology by STMicroelectronics has been performed to evaluate its suitability for the realization of CMOS sensors. The shift of transistor threshold and transconductance has been evaluated after irradiation with $\gamma$ rays and protons up to 1 MGy, showing little performance degradation. Sensors consisting of 50×250 $\mu$m$^2$ pixel size on a 125 $\Omega$ cm substrate have been characterized showing a uniform breakdown at 70 V, and a capacitance of about 80 fF at 50 V bias voltage. At this bias, the depletion is suitable for charged particle detection, as demonstrated with radioactive source and X-ray measurements.

A hybridization process for capacitive coupling has been developed. It consists of the gluing of CMOS sensor to readout electronics by dielectric epoxy, whose thickness is controlled by SU8 pillars deposited on the readout chip surface. Uniformity of better than 100 nm on the pillar surface is obtained. Assemblies have been performed using FE-I4 and prototype CMOS sensors. Measurements show a planarity better than 1.5 $\mu$m peak-to-peak on the 5 mm length of the HV-CMOS chip. To evaluate more precisely the uniformity dummy chips of FE-I4 sizes have been manufactured. The measurement of 24 capacitors on each chip is expected to provide a precise estimation of the real thickness uniformity. The goal is to achieve less than 0.5 $\mu$m variation on the glue thickness.
Radiation hardness and timing studies of a monolithic TowerJazz pixel design for the new ATLAS Inner Tracker

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A major part of the upcoming HL-LHC upgrade of the ATLAS Detector is the construction of a new Inner Tracker. Together with the possibilities offered by the upgrade, also the corresponding challenges in terms of occupancy and radiation hardness are pushed even further.

Hybrid sensors containing passive silicon sensors and connected readout chips are the currently used technology. Custom made components and non-commercial production steps like bump-bonding are weak points of this approach.

Part of the endeavours are the investigations of CMOS silicon-sensors to include stages of the readout chain already in the silicon sensor material. Following this idea leads to the design of monolithic active pixel sensors for which the need of additional readout chips becomes even obsolete.

Being a commercial manufacturing process, active CMOS sensors are an opportunity to decrease the cost of several square meters of pixel layers. In case of the monolithic sensors, the omittance of readout chips and therefore also connection techniques like bump-bonding grants even further cost and material reduction.

In order to be used in the outer layers of the new ATLAS Inner Tracker, pixel sensors must cope with radiation of 10¹⁵ neq/cm² and reach a timing resolution < 25ns.

The presented TowerJazz process proofed its capability regarding the more relaxed requirements of the upcoming tracker of the ALICE experiment. Using this promising starting point, the presented program of radiation hardness and timing studies on an analoge TowerJazz chip has been launched to investigate this technology’s potential for the new ATLAS Inner Tracker.
An approach to proton Computed Tomography

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Proton Computed Tomography (pCT) is an imaging method with a potential for increasing accuracy of treatment planning and patient positioning in hadron therapy.

A pCT system based on a silicon tracker and a YAG:Ce calorimeter has been developed within the INFN-RDH collaboration. The prototype has been tested with an 180MeV proton beam at the Svedberg Laboratory (Uppsala, Sweden) with the aim to collect data to be used to reconstruct a tomographic image.

Algebraic iterative reconstruction methods (ART), together with the most likely path calculation, have been used to obtain inhomogeneous phantom images to eventually extract density and spatial resolutions of the system. These results will be presented and discussed together with the resolutions dependence on the dose delivered to the phantom.

The Filtered Back Projection algorithm has been applied to the same data set obtaining tomographic images which can be used as initial seed for the ART algorithm. This accelerates the ART convergence reducing the reconstruction time.

Due to the heavy computation load required by the algebraic algorithms the reconstruction programs have been written within the CUDA environment to fully exploit the high calculation parallelism of Graphics Processing Units. This computation scheme substantially reduces the image processing time.

Furthermore an extended field-of-view pCT system, which is in an advanced construction stage, will be presented. This system will be able to reconstruct objects of the size of a human head making possible to use this system in pre-clinical studies. First results on the apparatus characterization under proton beam will be presented.
This work presents a multichannel IC which is able to process and digitize simultaneous current pulses in every input channel with no deadtime. The analog to digital conversion is performed in two steps: 6 MSBs are quantized by the charge pulse system (CPS) and 8 LSBs are obtained from a later ADC for a total of 14 ENOB at the output.

The CPS can process bipolar input current. The core of the CPS is an integrator controlled by two comparators. When the output voltage exceeds any of two fixed thresholds, an auxiliary capacitor is connected and charge pumping to the integration capacitor is produced, keeping its value inside a given range. As a consequence the CPS behaves as an asynchronous and self-regulating system. The integrator can work in continuous time, with no reset operation of the integration capacitor. Moreover the dynamic range of the input current is increased by over two decades and at least 20 dB SNR improvement can be obtained.

The number of pulses produced by the charge pump is stored in an asynchronous counter and represents the MSBs. A maximum of 100 charge pulses can be achieved due to settling time limitations for an integration period of 1us, thus obtaining 6.6 MSBs. The remaining voltage (LSBs) is the difference between the integrator outputs at the beginning and at the end of the integration period which are quantized later by an ADC.

The IC is designed for sensors with fast pulse current responses such as SiPM. The CPS extended input range can take advantage of high gain sensors thus improving overall SNR of the detector. Energy resolution dependent applications such as PET might benefit from this novel DAQ architecture.
Diamond Based Detectors for High Temperature, High Radiation Environments

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Single crystal CVD diamond has many desirable properties as a radiation detector; exceptional radiation hardness and physical hardness, chemical inertness, low Z (close to human tissue, good for dosimetry and transmission mode applications), wide bandgap (high temperature operation with low noise, solar blind), an intrinsic pathway to fast neutron detection through the $^{12}$C$(n,\alpha)^{9}$Be reaction. This combination of radiation hardness, temperature tolerance and ability to detect mixed radiation types with a single sensor makes diamond particularly attractive as a detector material for harsh environments such as nuclear power station monitoring (fission and fusion) and oil well drilling diagnostics.

Effective exploitation of these properties requires the development of a metallisation scheme to give contacts that remain stable over extended periods at elevated temperatures (~250 °C in this instance). Due to the expense of the primary detector material, computational modelling is essential to best utilise the available processing methods for optimising sensor response through geometry and conversion media configurations and to fully interpret experimental data. Monte Carlo simulations of our diamond based sensor have been developed, primarily using MCNP6 and FLUKA2011, assessing the sensor performance in terms of spectral response and overall efficiency as a function of the detector and converter geometry. Sensors with varying metallisation schemes for high temperature operation have been fabricated at at Brunel University London and industrial partner Micron Semiconductor Limited. These sensors have been tested under a varied set of conditions including irradiation with fast neutrons and alpha particles at high temperatures. The presented study indicates that viable metallisation schemes for high temperature contacts have been successfully developed and the modelling results, supported by preliminary experimental data from partners, indicate that the simulations provide a reasonable representation of detector response.
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The trend of x-ray image sensor has been evolved from an amorphous silicon sensor to a crystal silicon sensor. A crystal silicon x-ray sensor, meaning an x-ray CIS (CMOS Image Sensor), is consisted of three transistors, i.e., a Reset Transistor, a Source Follower and a Select Transistor, and a photodiode. They are highly sensitive to radiation exposure and this is proven by dramatically decrease quality of imaging device in response to increase in frequency of exposure to radiation. The most well-known effects of an x-ray CIS due to the radiation damage are increments in the reset voltage and dark current. These effects leads the image quality degradation. To overcome these problems, many sensor recovery methods were studied. The annealing is the best method among any other method. For the assembled sensor, the heat annealing is most suitable. In this study, a pixel array of an x-ray CIS were made from 11 x 1 pixels and this pixel array was exposed to a high radiation dose. We also simulated the radiation effects of the pixel by MCNP (Monte Carlo N-Particle transfer code) simulation. From the irradiated pixel data and simulation data, we can determine the radiation damage of pixels. To recover the pixel performance, we annealed the irradiated sensor at high temperature.
Timepix3 based detectors for Controlled Molecule Imaging

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We perform ion and electron imaging experiments to spatially and temporarily unravel ultrafast molecular dynamics. Time-resolved pixelated detectors allow to simultaneously record position and timing information, and, therefore, the three dimensional momentum vector, for each detected ion at relatively high count rates of multiple ions per shot at kHz rates. This paves the way to unravel the dynamics of complex molecular systems, e.g., to identify and simultaneously follow multiple reaction channels upon photo fragmentation. The contained correlation information is extracted using momentum conservation and statistical covariance analysis. We discuss the construction of a Timepix3 based detector system that allows to detect multiple fragment ions with the spatial and timing information of ~< 15 microns and ~< 10 ns, respectively, combined in one measurement. The Timepix3 chip specification covers these experiment requirements in spatial and timing resolution, as well as the average and instantaneous hit rate. We present the results of computer simulations as well as benchmark results of the experimental setup with simple molecules.
The upgrades of the LHC accelerator and the experiments in 2019/20 and 2023/24 will allow to increase the luminosity to $2\times10^{34} \text{ cm}^{-2}\text{s}^{-1}$ and $5\times10^{34} \text{ cm}^{-2}\text{s}^{-1}$, respectively. For the ultimate HL-LHC phase the expected mean number of interactions per bunch crossing will increase from 55 at $2\times10^{34} \text{ cm}^{-2}\text{s}^{-1}$ to 140 at $5\times10^{34} \text{ cm}^{-2}\text{s}^{-1}$. This increase, drastically impacts the ATLAS trigger and trigger rates. For the ATLAS Muon Spectrometer, a replacement of the innermost endcap stations, the so called “Small Wheels” operating in a magnetic field, is therefore planned for 2019/20 to be able to maintain a low $p_T$ threshold for single muon and excellent tracking capability in the HL-LHC regime. The New Small Wheels will feature two new detector technologies, Resistive Micromegas and small strip Thin Gap Chambers conforming a system of $\sim2.4$ million readout channels. Both detector technologies will provide trigger and tracking primitives fully compliant with the post-2024 HL-LHC operation. To allow for some safety margin, the design studies assume a maximum instantaneous luminosity of $7\times10^{34} \text{ cm}^{-2}\text{s}^{-1}$, 200 pile-up events, trigger rates of 1 MHz at Level-0 and 400 KHz at Level-1. A radiation dose of $\sim 1700$ Gy (inner radius) is expected. The electronics design of such a system will be implemented in some 8000 front-end boards including the design of 4 different custom front-end ASICs. Among them the 64 channels VMM, a common frontend ASIC for both detector technologies and charge-interpolating trackers, providing amplitude, timing measurements, per channel analog-to-digital conversions and in parallel direct trigger outputs. The candidate selection is designed within the budget latency of 1 us, and 6 us after 2024. Moreover, the design integrates the GBTx (Gigabit transceiver) ASIC and a Slow Control ASIC developed at CERN. The data flow is designed through a high-throughput network approach. The overall design will be presented.
Small-Strip Thin Gap Chambers for the Muon Spectrometer Upgrade of the ATLAS Experiment

Gerardo Vasquez

1) ATLAS Muon Collaboration

The instantaneous luminosity of the Large Hadron Collider at CERN will be increased up to a factor of seven with respect to the design value. The largest phase-1 upgrade project for the ATLAS Muon System is the replacement of the present first station in the forward regions with the so-called New Small Wheels (NSWs) during the long-LHC shutdown in 2019/20. Along with Micromegas, the NSWs will be equipped with eight layers of small-strip thin gap chambers arranged in multilayers of two quadruplets. All quadruplets have trapezoidal shapes with surface areas up to 2 m$^2$. To retain the good precision tracking and trigger capabilities in the high background environment of the high luminosity LHC, each sTGC plane must achieve a spatial resolution better than 100 μm to allow the Level-1 trigger track segments to be reconstructed with an angular resolution of approximately 1mrad. The basic sTGC structure consists of a grid of gold-plated tungsten wires sandwiched between two resistive cathode planes at a small distance from the wire plane. The precision cathode plane has strips with a 3.2mm pitch for precision readout and the cathode plane on the other side has pads for triggering. The position of each strip must be known with an accuracy of 30 μm along the precision coordinate and 80 μm along the beam. On such large area detectors, the mechanical precision is a key point and must be controlled and monitored along the process of construction and integration. A full size sTGC quadruplet has been constructed and equipped with the first prototype of dedicated front-end electronics. The performance of the full size sTGC quadruplet has been studied at the Fermilab (May 2014) and CERN (October 2014) test beam facilities. We will describe the technological novelties, production challenges, performance and test results of the sTGC detectors.
The phase 1 upgrade of the CMS pixel system

Neeti Prashar

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The innermost layers of the CMS tracker are built out of pixel detectors arranged in three barrel layers (BPIX) and two forward disks in each endcap (FPIX). The original CMS detector was designed for the nominal instantaneous LHC luminosity of $1 \times 10^34 \text{ cm}^{-2} \text{ s}^{-1}$. Under the conditions expected in the coming years, which will see an increase of a factor two of the instantaneous luminosity, the CMS pixel detector will see a dynamic inefficiency caused by data losses due to buffer overflows. For this reason, the CMS Collaboration has been building a replacement pixel detector which is scheduled for installation in an extended end of year shutdown during Winter 2016/2017.

The Phase I upgrade of the CMS pixel detector will operate at full efficiency at an instantaneous luminosity of $1 \times 10^34 \text{ cm}^{-2} \text{ s}^{-1}$ with increased detector acceptance and additional redundancy for the tracking, while at the same time reducing the material budget. These goals are achieved using a new readout chip and modified powering and readout schemes, one additional tracking layer both in the barrel and in the disks, and new detector supports including a CO2 based evaporative cooling system, that contribute to the reduction of the material in the tracking volume.

This contribution will review the design and technological choices of the Phase I detector, and discuss the status of the construction of the detector and the performance of its components as measured in test beam and system tests. The challenges and difficulties encountered during the construction will also be discussed, as well as the lessons learned for future upgrades.
The conventional end-readout PET detectors have shown limitations in achieving high spatial, energy, and timing resolution simultaneously. Meanwhile, detectors using an axial PET detectors with lateral readout, have appeared to have promising spatial, energy, and timing resolution; however, those detectors require huge number of readout circuits, which adds the production cost and difficulty tremendously. Therefore, the key challenge of this type of detector is to realize the channel-reduction. One method is to use a Time-over-Threshold (ToT) based charge-to-pulse width converter and a channel-reduction ASIC which is being developed in our lab. The charge integrations of the analogue signals from each sensor are converted to different logic signals with different pulse lengths, and the logic signals are processed towards the DAQ to pull out signals only from the maximum output channel and from its two neighbor channels to apply a center-of-gravity technique to estimate the interaction position. The sum analogue signal is processed, through an ASIC to eliminate pile-up signals, and to trigger timing signals. As a pre-step, a Monte-Carlo simulation using GATE was first done in this study, to test whether a TOF PET with fine spatial and energy resolution is achievable with the suggested lateral-readout axial PET detector geometry. The proposed detector was composed of a 3x3x100mm LYSO and ten 2x2mm sensors along the LYSO. Without considering the limitations of SiPM and circuits, the initial simulation results showed around 0.6mm-FWHM of axial-spatial resolution, 13% of energy resolution, and 270ps-FWHM of coincidence resolving time (CRT). If we optimize the time triggering and apply the time-walk correction, the CRT would certainly improve. As the feasibility of such detector geometry was proven, the readout circuit will be constructed and tested for the next step.
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Superconducting Series-Junction X-Ray Detector

This X-ray detector system is capable of detecting X-rays with high resolution, high detection efficiency and high speed. After more than a decade of development, Techno-X has succeeded in commercializing this technology.

- X-ray analyzer for nano-scale materials and devices
- High-sensitivity & high-resolution analysis of light elements in electric materials
- High-resolution analysis of radiation

Features

State-of-the-art technology
- High-energy resolution of 63.5 eV (@5.9 keV)
  - about 2 times better resolution compared to conventional solid-state detector (SDD)
- Higher count rate (up to 20 kcps), highly accurate quantitative analysis
- High detection efficiency without dead layer, applicable to low-energy and high-energy X-ray.
- 2D position resolution: high energy resolution and imaging of X-ray
- Can be cooled with a convenient cryogen free automatic 3-He refrigerator.

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