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Book of Abstracts
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Beyond the temporal resolution limit of silicon image sensors

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The temporal resolution limit of silicon image sensors is 11.1 ps as we proved. We defined the super temporal resolution (STR) as the resolution less than this limit, since most image sensors are silicon-based [1]. To achieve the STR, mixing effects along the travel route of signal electrons in a pixel, elongating the temporal resolution, are separately analyzed and the countermeasures are proposed. A branching gate image sensor is proposed with a resistive gate for the center guide gate [2]. It is verified by simulations that the proposed sensor structure can achieve theoretically noiseless imaging at the temporal resolution of 100 ps with an existing 120-nm process. A finer process with a germanium photodiode, in addition, will achieve the STR (<11.1 ps) in the near future [3].


Effect of nozzle geometry features on the nozzle internal flow and cavitation characteristics based on X-ray dynamic imaging

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Nozzle geometry features directly impact the nozzle internal flow which significantly affects the spray atomization, as well as in-cylinder combustion and fuel economy. In this study, the nozzle internal transient flow was visualized through X-ray phase-contrast imaging technology. The experimental results indicated that the sac-orifice relative positions and the structural asymmetry of the nozzle orifice prominently influence the in-nozzle cavitation strength and distribution. Some nozzle geometry features with general applicability such as inlet normal inclination angle, orifice inlet included angle and orifice concinity angle are defined to better elaborate their effects on the internal flow characteristics. A 3D simulation of the nozzle internal flow demonstrated the relevance between the nozzle geometry and the cavitation characteristics. It is found that the cavitation phenomenon is intensified when the wall inclination angle is positive and will be inhibited when it is negative. The cavitation development is facilitated with smaller orifice inlet included angle. The nozzle orifice conicity, which obviously alters the pressure distribution in the orifice, also has a significant influence on the cavitation characteristics.
10ps Time-of-Flight PET scanner with a new generation of SiPMs: From Hope to Practice

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The potential of photon detectors to achieve precise timing information is of increasing importance in many domains, e.g., PET and CT scanners in medical imaging and particle physics detectors. The goal to increase by an order of magnitude the sensitivity of PET scanners and to deliver, via time-of-flight (TOF), true space points for each event, requires a further quantum step in time resolution, reaching eventually 10ps in coincidence (CTR) @511keV to be compared to about 200ps obtained with state-of-the-art silicon photomultipliers (SiPM) in the Siemens Biograph Vision PET scanner. The interest is to reduce the radiation dose (currently 5-25 mSv for whole body PET/CT), scan time (currently > 10 minutes), and costs per patient (currently > 1000 € per scan), all by an order of magnitude. To achieve this very ambitious goal it is essential to significantly improve the performance of each component of the detection chain: light production, light transport, photodetection, readout electronics. Such a ‘paradigm’ shift must go hand-in-hand with a similar break with traditional methods. The possibility to reach 10 ps time-of-flight resolution at small energies, as required in PET scanners, although extremely challenging, is not limited by physical barriers. This talk will show how combining transformation optics light concentrators, hyperbolic metamaterial QE increase, ultra-fast, backside illuminated silicon cell and ultrafast electronics directly integrated in the device will offer new perspectives for the development of new concepts of 3D digital SiPM structures and open the way to new radiation detector concepts with unprecedented performance. The ultimate goal will be creating a Quantum Silicon Detector (QSD), with close to 100% PDE even with non-collimated light, a few ps Single Photon Time Resolution (SPTR), ultra-high cell density, negligible correlated noise and beyond state-of-the-art primary noise, opening new prospects for the construction of very compact, low power and ultrafast photodetectors with space-time imaging capability.

A picosecond avalanche detector in SiGe BiCMOS

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The MONOLITH ERC Advanced project aims at producing a monolithic silicon pixel ASIC with picosecond-level time stamping by using fast SiGe BiCMOS electronics and a novel sensor concept, the Picosecond Avalanche Detector (PicoAD). The PicoAD uses a multi-PN junction to engineer the electric field and produce a continuous gain layer deep in the sensor volume, generating a thin absorption layer that limits the impact of charge collection noise on the timing performance. The result is an ultra-fast current signal with low intrinsic jitter in a full fill factor highly granular monolithic detector. In addition to that, the manufacturing process of the PicoAD makes it extremely versatile to enhance the timing capability of existing sensor designs. A proof-of-concept ASIC prototype not yet optimized for timing confirms that the PicoAD principle works according to simulations. Testbeam measurements show that the prototype is fully efficient and achieves time resolutions down to 24ps. An optimization of the sensor design and the development of new fast, low-power electronic are the next steps to achieve the picosecond time resolution target.
Integration and first operation of the Gotthard-II detector at the European XFEL

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Gotthard-II (G-II) is a silicon microstrip hybrid detector developed by Paul Scherrer Institut (PSI) within the framework of a collaboration agreement with the European XFEL (EuXFEL).

The G-II ASIC features a dynamic gain switching (DGS) architecture to cope with the requirements of the single photon sensitivity as well as the large dynamic range at the EuXFEL. In addition, it includes a 12-bit Analog-to-Digital Converter with a sampling/conversion rate of more than 18 MS/s, and a Static Random-Access Memory with a depth of 2700 images for temporal on-chip storage in order to match the unique accelerator pulse structure: up to 2700 pulses at 4.5 MHz within one EuXFEL pulse train are generated in a burst.

Two different sensor designs, with a strip pitch of either 50 µm or 25 µm for a total of 1280 or 2560 output channels, are used in the final detector system. These sensors are able to provide a spectral sensitivity allowing either X-ray detection (optimized in the 5 keV – 20 keV range) or visible light detection.

Its exceptionally good compliance with the EuXFEL beam conditions will make G-II the most widely employed detector across the facility with a total of 29 modules of different flavors installed in several scientific instruments and beam diagnostic setups.

Its usage predominantly in spectroscopic measurement will have a variety of applications, including diffraction/emission/absorption measurements, pulse arrival monitoring (of fundamental importance for pump-and-probe experiments), and beam quality monitoring with the possibility for the detector to generate a veto pattern for the large area pixel detectors such as AGIPD, LPD and DSSC.

In this paper, an overview of this detector technology and its usage at the EuXFEL will be presented; then, detector integration in the EuXFEL control, data acquisition and data correction infrastructure will be described, highlighting its challenges. Finally, an overview of the first results obtained with the EuXFEL beam will be given.

Move contrast X-ray imaging and its applications in complex systems

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Move contrast X-ray imaging (MCXI) is introduced, which utilized the different temporal modulation of the incident light field by different moving components to separately image components with different spatial-temporal evolution.
motion modes. Compared with the usual X-ray absorption contrast and phase contrast, move contrast can solve the problem of overlapping of structural information in transmission image caused by high X-ray penetration, and has higher sensitivity and contrast-to-noise ratio for weak signals. MCXI has been applied in several disparate research fields. In medical radiography, MCXI can reduce the dose of iodic contrast medium to only 10%, while maintaining sufficient signal strength (F.X. Wang et. el., IUCrJ (2020). 7). In the aspect of plant physiology, MCXI can be used to observe water refilling along microvessels in leaves and thick opaque plant stems resorting to no contrast agents. In electrolytic reactions, transport routes of clustered ions can be depicted with MCXI, which may provide significant support for further electric field research. In conclusion, owing to the character of high sensitivity and contrast-to-noise ratio for weak signals, MCXI is a promising imaging method in dynamic complex systems of many research fields, where in-vivo and in-operando experiments are in urgent need.

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XIDer: a Novel X-ray Detector for Next-Generation High-Energy Synchrotron Radiation Sources

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The ESRF Extremely Brilliant Source (EBS) is the world’s first fourth generation synchrotron radiation source. Latest generation x-ray sources like the EBS impose increasing demands on sensors and readout electronics. Apart from fast signal processing and high spatial resolution, detectors used at such facilities have to handle a broad dynamic range with fluxes of up to billions of photons per second while still providing single photon sensitivity at low noise levels. Additionally, the targeted high energy range forces detector systems to use less conventional high-Z sensor materials which usually come with additional challenges. As a result, effects like afterglow, sensor leakage and bias- as well as flux-induced leakage have to be handled and corrected for.

The XIDer project aims to build a 2D pixelated hybrid X-ray detector to tackle the aforementioned challenges. It incorporates a novel digital integration readout scheme to combine the high-rate capabilities of charge integration with the noise and leakage suppression of photon counting systems. The final detector is planned to cope with the conditions imposed by the EBS such as fluxes of up to $10^9$ ph/px/s, photon energies of up to 100 keV as well as different beam modes ranging from pulsed to near-continuous illumination.

This contribution is meant to introduce the XIDer project, its challenges and the progress that has been made so far. This will be supported by the presentation of first characterisation measurements of the readout ASIC as well as test prototypes equipped with cadmium telluride sensors.

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Charged-particle tracking with 10ps time resolution using innovative 3D trench-type silicon pixel sensors

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Future collider experiments operating at very high instantaneous luminosity will greatly benefit in using detectors with excellent time resolution to facilitate event reconstruction. For the LHCb Upgrade2, when the experiment will operate at 1.5x10^{34}/cm/s, 2000 tracks from 40 pp interactions will cross the vertex detector (VELO) at each bunch crossing. To properly reconstruct primary vertices and b-hadron decay vertices VELO hit time stamping with 50ps accuracy is required. To achieve this, several technologies are under study and one of the most promising today is the 3D trench silicon pixel, developed by the INFN TimeSPOT collaboration. These 55µmx55µm pixels are built on a 150µm-thick silicon and consist of a 40µm-long planar junction located between two continuous bias junctions, providing charge-carriers drift paths of about 20µm and signals’ total durations close to 300ps. Two sensors’ batches were produced by FBK in 2019 and 2021. The most recent sensors’ beam test was performed at SPS/H8 in 2021. Various test structures were readout by means of low-noise custom electronics boards featuring a two-stage transimpedance amplifier, and the output signals were acquired with an 8GHz 20GS/s oscilloscope. The arrival time of each particle was measured with an accuracy close to 5ps using two 5.5mm-thick quartz window MCP-PMTs. Two 3D trench silicon pixel test structures and the two MCP-PMTs were aligned on the beam line and acquired in coincidence. Signal waveforms were analyzed offline with software algorithms and pixel signal amplitudes, particle time of arrival and efficiencies were measured. A preliminary analysis indicates efficiencies close to 100% for particles impinging at more than 10 degrees with respect to normal incidence, and time resolutions close to 10ps. More up-to-date results, including preliminary measurements on sensors irradiated with neutrons, will be presented at the Conference. 3D trench-type silicon pixels appear to be a promising technology matching the requirements of future vertex detectors operating at very high instantaneous luminosity.

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Induced signals in particle detectors with resistive elements: modelling novel structures.

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Novel detector structures are proposed regularly, mixing old and new ideas, with resistive detectors widening the landscape of possible configurations. In this talk, a universal way of calculating the signals induced in structures with resistive elements is presented. This is done by applying an extended form of the Ramo-Shockley theorem to several different detector configurations using numerical methods. For these, the time dependence of the signals is not solely given by the movement of the charges in the drift medium but also by the time-dependent reaction of the resistive materials. The weighting potential becomes dynamical for these geometries due to the mediums’ finite conductivity and can be computed numerically. COMSOL Multiphysics provides these needed time-dependent solutions, which, coupled with Garfield++ and a general-purpose circuit simulation program (e.g., SPICE) to describe the front-end electronics, allows for the targeting of a universal modelling toolkit for the modelling of the signal induction in particle detectors. This study includes a wide range of MicroPattern Gaseous Detector (MPGD) and silicon-based detectors. Particularly for the PICOSEC Micromegas detector and the AC-coupled Low Gain Avalanche Diode (LGAD), the possibility of modelling the time and position response for different readout patterns could provide key insights for the design of new prototypes and application.

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Precise timing PICOSEC Micromegas and rapid imaging with gaseous detectors
Advances in MicroPattern Gaseous Detector (MPGD) technologies and readout devices allow significant improvements of timing resolution as well as novel imaging approaches. This contribution will focus on PICOSEC Micromegas achieving tens of ps timing precision as well as new developments in the optical readout of gaseous detectors taking advantage of state-of-the-art imaging sensors and fast photon detectors.

PICOSEC Micromegas combine a Cherenkov radiator with a semi-transparent photocathode and Micromegas amplification stage to achieve better than 25ps timing precision for Minimum Ionising Particles (MIPs). The latest developments of this technology towards scalable timing systems include optimisations of multi-pad detector modules for robustness and improved timing uniformity and dedicated readout electronics preserving high bandwidth and timing performance.

Recording scintillation light emitted during avalanche multiplication in MPGDs is a powerful readout approach exploiting high-resolution imaging sensors and the high gain and rate capabilities of gaseous detector technologies. Ultra-fast CMOS sensors offer unprecedented frame rates for rapid imaging and can further enable new approaches for 3D track reconstruction in Time Projection Chambers (TPCs). In addition, hybrid readout approaches and fast photon detectors such as SiPMs offer new possibilities for track reconstruction and fast radiation imaging.

**Timespot1: a Fast-Timing, High-Rate Pixel-Matrix ASIC in CMOS 28-nm technology**

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Vertex detectors being conceived for the next generation of collider experiments will have to operate with an increased number of tracks per event. To cope with this problem, it will be mandatory to operate with pixel sensors and electronics having both high space and time resolutions (tens of µm and tens of ps respectively). Furthermore, high radiation resistance is necessary both for the sensors (around $5 \times 10^{16}$ 1 MeV neutron equivalent per cm$^2$) and the electronics side (1-2 Grad). Dedicated development activities have already started in the last years to study possible technical solutions in this respect. The INFN-funded TimeSPOT project aims to produce a small-scale demonstrator, which includes both a pixel sensor with a size of $55 \times 55 \mu$m$^2$ and a pixel read-out chip satisfying the above mentioned requirements. This demonstrator includes an ASIC, named TimeSpot1, which is described in this paper. The chip is being bump-bonded to dedicated 3D silicon sensors, having already shown a time resolution better than 20 ps. TimeSpot1 is designed in CMOS 28 nm technology. It features a $32 \times 32$-pixel matrix with a pitch of 55 µm. The ASIC is conceived to be capable to read-out pixels with timing resolution below 50 ps on the full chain (sensor, amplifier, Time-to-Digital-Converter). Each pixel is endowed with a charge amplifier, a discriminator, and a Time-to-Digital Converter with time resolution around 30 ps and maximum read-out rates of 3 MHz per pixel. The timing performance are obtained keeping the power budget of per pixel lower than 40 µW per channel. The ASIC has been tested in the laboratory in order to characterize its performance in terms of time resolution, power budget and sustainable rates. The ASIC is being hybridized on a matched $32 \times 32$ pixel sensor matrix and will be soon tested under laser beam and Minimum Ionizing Particles in the laboratory and at test beams.

In this paper we present a description of the ASIC design, its operation and the results obtained from characterization tests concerning its performance in tracking measurements. A typical time resolution of the order of 30 ps has been achieved. The die size is 2.3x2.6 mm$^2$. The ASIC layout has been conceived to be easily scalable in area by design, in such a way to read-out larger pixel matrices with the same pitch. This suggest further developments of this first prototype, which are already under consideration by our collaboration. This item will also be addressed in this paper.

The DSSC soft X-ray Detectors with Mega-frame Readout Capability for the European XFEL

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The DSSC camera was developed for photon science applications in the energy range 0.25-6 keV at the European XFEL in Germany. The first 1-Megapixel DSSC camera is available and is successfully used for scientific experiments at the “Spectroscopy and Coherent Scattering” and the “Small Quantum System” instruments. The detector is currently the fastest existing 2D camera for soft X-rays. The camera is based on Si-sensors and is composed of 1024×1024 pixels. 256 ASICs provide full parallel readout, comprising analog filtering, digitization and data storage. In order to cope with the demanding X-ray pulse time structure of the European XFEL, the DSSC provides a peak frame rate of 4.5MHz. The first megapixel camera is equipped with Miniaturized Silicon Drift Detector (MiniSDD) pixels. The intrinsic response of the pixels and the linear readout limit the dynamic range but allow one to achieve noise values of ~60 electrons r.m.s. at 4.5MHz frame rate. The challenge of providing high-dynamic range (~$10^{-4}$ photons/pixel/pulse) and single photon detection simultaneously requires a non-linear system, which will be obtained with the DEPFET active pixels foreseen for the advanced version of the camera. This technology provides lower noise and a non-linear response at the sensor level. The readout ASICs and the camera-head electronics are compatible with both type of sensors.

We will present the architecture of the whole detector system with its key features, focusing on the sensors and the integrated electronics. We will summarize the main experimental results obtained with the MiniSDD-based camera and give a short overview of the performed user experiments.

We will present for the first time the experimental results with complete sub-modules of the DEPFET
camera which is in the final stages of assembly. Measurements obtained with full size sensors and the complete readout electronics have shown an unprecedented mean noise of ~10 el. rms with MHz frame rate and a dynamic range more than one order of magnitude higher with respect to the MiniSDD camera.

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Commercializing high rep rate burst mode hCMOS imagers

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Nanosecond scale, burst mode hCMOS imagers developed at Sandia National Laboratories (SNL) have provided revolutionary insight and data to a limited few research facilities. As these High Energy Density Physics research facilities typically operate on a shot-per-hour to shot-per-day timescale, little effort has been devoted to fast replication-rate circuitry for hCMOS image sensors. Advanced hCMOS Systems (AHS) was founded by former DOE laboratory employees who developed the hCMOS image sensor and camera concept; their intention is to make these image sensors available to a broader community. For hCMOS to impact an expansive user base, the replication rate needs to be increased and the Read Out Integrated Circuit design must be migrated from the proprietary SNL CMOS7 foundry process to a commercially available foundry process. hCMOS imagers are single die (non-tiled), high spatial resolution, and large pixel count sensors. This pixel count poses a complicated design problem to read out such a large data stream. Existing sensors have 2.1 megapixels equivalent (1024 x 512 x 4 frames) and typically operate at two Frames-Per-Second (FPS), which translates to 4.19 megapixels/s (the sensor has a theoretical maximum of 8 FPS). AHS plans to increase the rep rate to >120 FPS or 251 megapixels/s for an increase of 60x, while porting the design to a radiation-hardened commercially available foundry process.

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How nanophotonics can speed up detection

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This presentation will present the opportunities offered by nanophotonics to improve the performance of detectors including results obtained from the ATTRACT-Photoquant project [1] that aimed at demonstrating that recent nanophotonics innovations such as metalenses and more generally metamaterials could allow a breakthrough in single-photon time resolution. Silicon photomultipliers are bidimensional arrays of single photo-avalanche diodes (SPADs). Many applications would benefit from a single photon time resolution much lower than what is the current state of the art, ideally 10 ps, or even less. Moreover, a photo-detection efficiency as close as possible to 100% is also required. Simulations and measured results show that, using both a light concentrator and including light trapping features to the device stack, the photo-electron generation can be confined in a region as small as 820×780×500 nm3, which could greatly improve the single-photon time resolution and the sensitivity of the device. A concentrator based on a metamaterial gradient index (MM GRIN) lens was created as a 2D square lattice of holes with different diameters [2]. The focusing effect is generated by the refractive index gradient, with bigger holes in the outer region of the concentrator. A concentration factor of about 8 shows the ability of the MM GRIN lens to concentrate light. Moreover, we have shown thanks to numerical simulations that modified SPAD with a thickness reduction of the Si layer down to 500 nm (usually several μm Silicon thickness) and a grating at the
bottom or above of the stack resulted in a photon absorption efficiency of nearly 100% in the Si layer. The societal value of such an achievement will be tremendously high in a plethora of fields, from automotive, medical devices and cancer diagnoses to high energy physics.


Calibration Strategy and Experimental Qualification of the Non-Linear Response of the First DEPFET Pixel Sensors of the DSSC Camera

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A novel design of the Depleted P-Channel Field Effect Transistor (DEPFET) with non-linear response is at the heart of the 1 Mpixel DSSC camera (DEPFET Sensor with Signal Compression) currently being developed for ultra-fast imaging of soft X-rays at the European XFEL. The simultaneous requirement of single-photon detection down to 0.5 keV and dynamic range up to 104 photons/pixel/pulse is here solved by introducing a non-linear compression of the DEPFET transistor response while the readout electronics is kept linear. The first full-size sensors produced by PNSensor GmbH have been mounted to give birth to the first ladder (128x512 pixel), one of the 16 independent units forming the DSSC camera.

Now the calibration of a 1 Mpixel DEPFET sensor with signal compression is the key to reach the desired performances but also the major challenge, due to the need to accurately qualify the response of each pixel in different conditions. The aim of this work is to discuss the general calibration strategy, to present the experimental results of the first calibration campaigns on the DSSC ladder and to discuss the open issues.

X-ray spectra were acquired to assess gain and noise performances in the linear region of the DEPFET response by means of a pulsed X-ray source (PulXar) that can provide trains of X-ray pulses with duration as short as 25 ns at high burst rate (up to 4.5 MHz) which effectively mimics the time structure of the beam at XFEL. The reduced number of ADC bit makes gain calibration from spectra fitting particularly dependent on the fitting model which has been carefully optimized to tailor the specific detector properties.

To qualify the full non-linear response of each pixel, from the linear region to the high intensity end, we conducted a dedicated test at the SQS beam line where we can produce intense shots of monochromatic photons (soft X-rays) with a smooth spatial distribution to allow irradiation of a whole quadrant of the camera. The XFEL beam hits an Aluminum target and the DEPFET ladder is at 90-degree to collect fluorescence photons (Al Kα 1.48 keV).

The presentation will focus on the evaluation of the first DEPFET ladder performance with low energy photons and on the measurement techniques, modelling and parametrization of the DEPFET response. The achieved results validate the calibration strategy of the full DSSC camera and show achievement of noise levels below 20 electrons rms and an input range of deposited energy up to several MeV per pixel per pulse.
Fast timing detectors with applications in cosmic ray physics and medical science

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We first describe the development of a fast readout system of an LGAD detector using the waveform technique. We use this detector to measure the type of particles and their energy in cosmic ray measurements in space in collaboration with NASA. We will show the results of the simulation of the detectors as well as the first tests performed before the launch foreseen by the end of the year. We also describe another application related to the measurement of the dose received by a patient during flash beam treatment of cancer.

FBK SiPM roadmap for ultimate timing performance

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Optimization of the timing resolution in the scintillation light readout has been one of the most important challenges in the SiPM field since the beginning of their development. Several sensor parameters contribute to the timing performance achieved in the application. The latest iteration of the NUV-HD SiPM technology developed at FBK feature Photon Detection Efficiency (PDE) in excess of 60% at 410 nm, Dark Count Rate around 60 kHz/mm<sup>2</sup> and Single-photon Time resolution (SPTR) of 90 ps FWHM for a 4x4 mm<sup>2</sup> device with 40 μm cells, when coupled to a discrete, high-frequency readout. Thanks to these parameters, it was possible to measure an excellent Coincidence Resolving Time (CRT) of 58 ps FWHM in the readout of a 2x2x3 mm<sup>3</sup> LSO:Ce:Ca coupled to a 4x4 mm<sup>2</sup> SiPM with 40 μm cells (98 ps FWHM with a 2x2x20 mm<sup>3</sup> LSO:Ca:Ce). Ongoing developments include the use of metal-filled deep trench isolation, which allows reducing the optical crosstalk probability to 10% with a PDE of 60% (bare die). On the other hand, photon-starved applications, such as BGO readout with the timing resolution enhanced by the detection of Cherenkov photons, further underline the importance of improving the SPTR of the SiPMs. In the current generation of devices, this parameter is heavily affected by both the output capacitance of the sensor and by the characteristics of the front-end electronics reading it. Considering that incremental improvements between subsequent generations of SiPMs are reaching saturation, a deeper redesign of the device structure is needed. In this context, FBK is working on the development of the next-generation of SiPMs, with a strong focus on 3D integration, such as SiPMs featuring fine-pitch Through Silicon Vias and Backside-illuminated (BSI) devices. A fine segmentation of the sensitive area in separated mini-SiPMs, each one connected to a dedicated readout channel through a low-impedance interconnection, will reduce output capacitance and optimize signal integrity. BSI-SiPMs will potentially bring additional advantages, such as reaching a PDE close to 100%, reduced output capacitance, enhanced radiation hardness, single-cell connection to the readout electronics and a uniform light entrance window, suitable for the most advanced optical stacks. In the presentation, FBK roadmap towards 3D integrated SiPMs and the preliminary result obtained so far will be discussed.

Single-pulse multi-frame x-ray imaging with a crystal-based x-ray split-and-delay line

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We developed an x-ray optics solution, called x-ray tomographic-delay-line (XTEL), for studying pico- to nanosecond dynamics of mesoscale materials processes at existing x-ray light sources. This optic lays the groundwork for taking snapshot movies of materials processes with selectable delay times, as well as single-pulse 3D images of materials by recording multiple views simultaneously from different angles. The XTEL has been designed to match the time resolution required to probe materials processes in the pico-second to nano-second range, which is not accessible at existing or soon emerging x-ray light source facilities. It will operate between 5 to 20 keV initially to match LCLS, LCLS-II, the European XFEL, and DCS. In future experiments, the XTEL will enable single-pulse tomographic imaging as well as multi-frame movies created from a single x-ray pulse that enables the user to capture dynamic processes.

We will describe the instrument design choices and initial results from LCLS Run 20 beamtime for a single probe beam. The conceptual design for multiple-probe beams, to be used with the upgraded LCLS MEC facility, will be described.

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Observing light-in-flight and MIPs with a 7.5-ps resolution

Author: Edoardo Charbon

Single-photon avalanche diodes (SPADs), also known as Geiger-mode APDs, have emerged as the detector of choice in many photon-counting and high-performance imaging applications. Recently, CMOS-compatible SPADs and SPAD image sensors have reached unprecedented counting-rate (> 1Gcps) and timing-resolution (< 7.5ps FWHM) capability, while demonstrating high sensitivity to photons in the 400-nm to 950-nm and also to minimum ionizing particles (MIPs), such as 80 GeV/c momentum pions. CMOS SPADs are scalable and thus suitable for large-format image sensors, where massively-parallel, complex functionality is sought, thanks to their digital nature and low power consumption. In this talk we will look at existing and new applications in many fields of science and engineering, often pushing performance to new heights.

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The power of gaining and sharing: introducing internal gain and built-in charge sharing in silicon sensors

Author: nicolo cartiglia
In this contribution, I will review the performance improvements that two design innovations, low-gain (LGAD) and resistive read-out (RSD), have brought to silicon sensors. Large signals lead to improved temporal precision, while charge sharing has removed the need for very small pixels to achieve excellent spatial precision. LGAD- and RSD-based silicon sensors are now adopted, or considered, in several future experiments and are the basis for almost every next 4D-trackers. Finally, I will show how the introduction of multiple sampling front-end electronics and reconstruction methods based on machine learning can further improve the performances of future 4D trackers.

Advanced silicon tracking detector developments for the future Electron-Ion Collider

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The proposed Electron-Ion Collider (EIC) will operate high-luminosity high-energy electron+proton and electron+nucleus collisions at the collision energies from 20 to 141 GeV to solve several fundamental questions in the high energy and nuclear physics fields. Its instant luminosity can reach $10^{33}$ to $10^{34}$ cm$^{-2}$s$^{-1}$ and the bunching crossing rate is around 10 ns. The EIC project has received CD1 approval from US DOE in 2021 and moves towards the machine design and construction. To realize the proposed high precision particle measurements at the future EIC, a low material budget and high granularity silicon vertex/tracking detector with fine spatial and momentum resolutions and nearly 4π solid angle coverage is desired. The Monolithic Active Pixel Sensor (MAPS) and AC Coupled Low Gain Avalanche Diode (AC-LGAD) stand out of several advanced silicon technologies as the top candidates for the EIC silicon detector subsystems. Latest studies and results for the EIC silicon vertex/tracking detector, which includes the conceptual detector design, performance validations in simulation and ongoing MAPS and AC-LGAD detector R&D will be presented. The EIC detector development plan and schedule will be discussed as well.

Radiation damage effects overview of Low Gain Avalanche Diodes

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Radiation damage mechanisms in depleted sensors with intrinsic gain (LGADs) are probed via electrical characterization, timing measurements and acceptor removal estimation. An analytical model is developed to prove gain vs field coefficients in proton and neutron irradiated sensors up to $6 \times 10^{15}$ n$_{eq}$/cm$^2$ with an emphasis on the gain layer geometry. The breakdown, efficiency and stability issues are investigated in deeply carbonated substrates as well as for boron and Gallium implanted gain layers. The series is completed by detailed SiMS measurements, process simulations and single event burn-out studies on CNM and FBK produced LGADs. An emphasis is placed on future developments with defect engineering and gain layer compensation studies using indium and Lithium co-implantation with preliminary results on both techniques.
**Precision Timing with the CMS MIP Timing Detector**

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The Compact Muon Solenoid (CMS) detector at the CERN Large Hadron Collider (LHC) is undergoing an extensive Phase 2 upgrade program to prepare for the challenging conditions of the High-Luminosity LHC (HL-LHC). A new timing detector in CMS will measure minimum ionizing particles (MIPs) with a time resolution of ~30-40 ps for MIP signals at a rate of 2.5 Mhit/s per channel at the beginning of HL-LHC operation. The precision time information from this MIP timing detector (MTD) will reduce the effects of the high levels of pileup expected at the HL-LHC, bringing new capabilities to the CMS detector. The MTD will be composed of an endcap timing layer (ETL), instrumented with low-gain avalanche diodes, as well as a barrel timing layer (BTL), based on LYSO:Ce crystals coupled to SiPMs. In this talk we present an overview of the MTD design, describe the latest progress towards prototyping and production, and show test beam results demonstrating the achieved target time resolution.

**Latest results on timing performance of silicon pixel detectors**

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Monolithic active pixel sensors (MAPS) have recently been used as building blocks of charged particles tracking and vertexing detectors because they offer lower material budget, higher granularity as well as a simpler assembly procedure and lower cost compared to the traditional wide spread hybrid technology.

The interest towards monolithic silicon sensors offering both excellent timing and position resolution has increased and different approaches are being explored. Traditionally large collection electrodes have been used for precision timing to approach a planar structure with large, uniform fields. However, significant improvement of time resolution and speed of charge collection has recently been demonstrated on MAPS built on 180nm TowerJazz CMOS imaging technology and is currently being further explored on 65nm TowerJazz Panasonic Semiconductor (TPSCo) technology. In parallel, structures with amplification layers like SPADS and LGAD are being studied both in CMOS and BiCMOS technologies.

In this presentation I will report on the latest results obtained in the 65 nm CMOS technology and also give an overview of the other developments.

**New Developments in Low Gain Avalanche Diode Fabrication Technology**

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In the last few years, Low Gain Avalanche diodes (LGAD) obtained growing attention as radiation sensors due to some important advantages: larger internal signal, potentially higher signal-to-noise ratio, better time resolution, and higher radiation hardness with respect to standard p-i-n sensors. They are currently considered state-of-the-art silicon detectors for timing application in HEP experiments, and more recently they are also being investigated as low-energy x-ray segmented detectors (< 1 keV) for synchrotron applications.

An increasing number of foundries and R&D laboratories started to work on this technology by proposing novel designs, mainly focused on increasing the radiation hardness of LGAD and optimizing the segmentation technology for fine-pixel and high-fill-factor sensor production.

In this presentation, the major ongoing developments on LGAD will be reviewed and discussed, supported by experimental results, and with particular attention to the fabrication process and to the technological challenges.

Among the others, some novel segmentation strategies aimed at increasing the fill-factor of fine-pixelated sensors will be discussed: i) inverted-LGAD (i-LGAD); ii) Resistive AC-coupled Detectors (RSD) and Resistive DC-coupled Detectors (DC-RSD); iii) Trench-Isolated LGAD (TI-LGAD); iv) Deep-Junction LGAD (DJ-LGAD).

In addition, new strategies for the production of LGAD operating at extreme fluences above 5e15 neq/cm² will be presented. The ideas behind this radiation tolerance are: i) using ultra-thin substrates, ii) optimizing the doping profile by using doping compensation to make it less sensitive to the acceptor removal effect and iii) including some chemical impurities (like Carbon) to mitigate the effect of radiation-induced effects.

A High-Granularity Timing Detector for the ATLAS Phase-II upgrade

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The increase of the particle flux (pile-up) at the HL-LHC with instantaneous luminosities up to \( L \geq 7.5 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1} \) will have a severe impact on the ATLAS detector reconstruction and trigger performance. The end-cap and forward region where the liquid Argon calorimeter has coarser granularity and the inner tracker has poorer momentum resolution will be particularly affected. A High Granularity Timing Detector (HGTD) will be installed in front of the LAr end-cap calorimeters for pile-up mitigation and luminosity measurements.

The HGTD is a novel detector introduced to augment the new all-silicon Inner Tracker in the pseudo-rapidity range from 2.4 to 4.0, adding the capability to measure charged-particle trajectories in time as well as space. Two silicon-sensor double-sided layers will provide precision timing information for minimum-ionising particles with a resolution as good as 30 ps per track in order to assign each particle to the correct vertex. Individual sensor pads will have a size of 1.3 mm × 1.3 mm, leading to a highly granular detector with 3.7 million individual channels. Low Gain Avalanche Detectors (LGAD) technology has been chosen as it provides enough gain to reach the large signal over noise ratio needed.

The requirements and overall specifications of the HGTD will be presented as well as the technical design and the project status. The on-going R&D effort carried out to study the sensors, the readout ASIC, and the other components, supported by laboratory and test beam results, will also be presented.