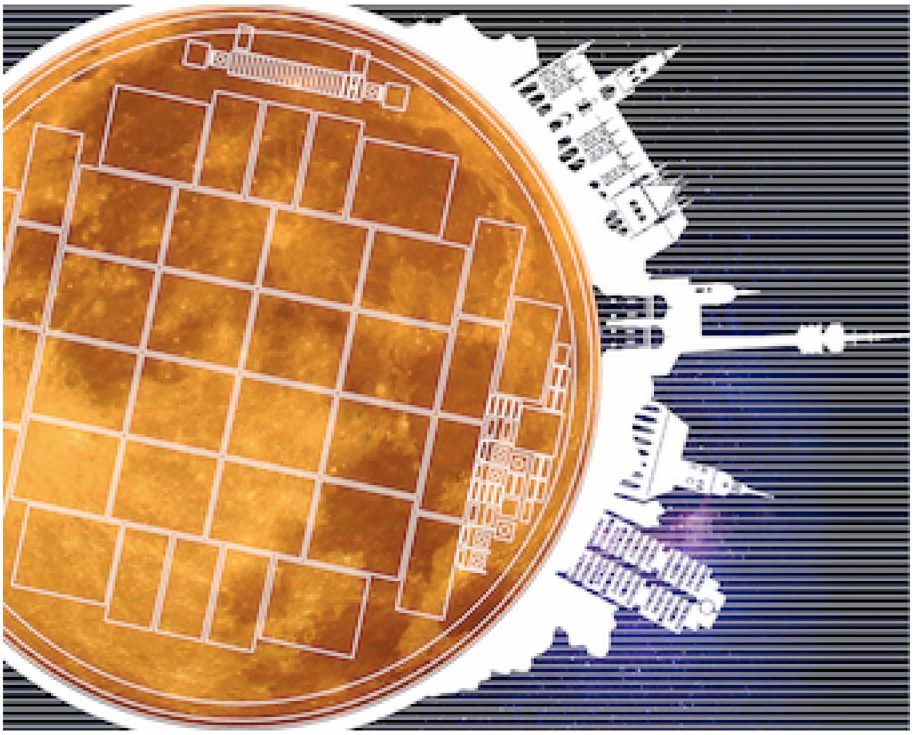
13th "Trento" Workshop on Advanced Silicon Radiation Detectors

Monday, 19 February 2018 - Wednesday, 21 February 2018

Max-Planck-Institut für Physik, Munich



Book of Abstracts

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FBK-INFN-LPNHE thin n-on-p pixel detectors: beamtest results

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In view of the LHC upgrade phases towards the High Luminosity LHC (HL-LHC), the ATLAS experiment plans to upgrade the Inner Detector with an all-silicon system.
The n-on-p silicon technology is a promising candidate to achieve a large area instrumented with pixel sensors, since it is radiation hard and cost effectiveness.
The paper reports on the performance of 130 µm thick n-in-p planar pixel sensors produced by FBK-CMM.
After discussing the sensor technology an overview of 2017 testbeam results of the produced devices will be given, before and after irradiation, including hit and charge collection efficiency and space resolution.
Preliminary testbeam results for the new thin and edgeless productions at FBK-CMM will be also presented,
with a special focus on the hit efficiency at the detector edge.

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Qualification measurements of INFN-FBK 3D modules for High Luminosity LHC

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Due to their radiation hardness, 3D sensors are a promising option for the innermost pixel layers at the High
Luminosity LHC. However, the required very high hit-rate capabilities,
increased pixel granularity, extreme radiation hardness, and reduced
material budget call for a device downscale as compared to existing 3D
sensors, involving smaller pitch (e.g., 50×50 or 25×100 µm2), shorter
inter-electrode spacing (˜30 µm), narrower electrodes (˜5 µm), and reduced
active thickness (˜100-150 µm). Within a joint R&D effort with INFN, FBK has produced a new generation of 3D pixel sensors with these challenging features. In this talk preliminary
results from the electrical and functional characterization of the first
prototypes are reported, included their behaviour after large radiation
fluences, close to the ones expected in the High Luminosity LHC environment.
Their use for the new ATLAS tracker will be also discussed.

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Depleted monolithic CMOS pixels using column drain readout for the ATLAS Inner Tracker

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The Inner Detector of the ATLAS experiment will be replaced by a new Inner Tracker (ITk) after the high-luminosity upgrade of LHC, which requires major improvements of the silicon pixel detectors in terms of radiation hardness, rate capability, etc. Monolithic CMOS pixels with depleted sensing volume (DMAPS) are part of the R&D program for the ITk outer pixel layers. Manufacturing these sensors in a commercial HV/HR CMOS process permits fast charge collection by drift and high volume production at affordable cost.

This work jointly presents two DMAPS prototypes, namely LF-Monopix01 and TJ-Monopix. They both integrate full readout electronics on the sensor substrate, employing the column drain readout architecture. LF-Monopix01 is a realization of the so called large fill-factor design in a 150nm CMOS process, which has proven to be a radiation hard approach thanks to the large charge collection electrode. The characterization of LF-Monopix01 has been performed both in lab and in test beams, showing a stable operational threshold <2000e^- and detection efficiency ˜99% even for chip samples after fluence of $10^{15}n_{eq}$ /cm^2. TJ-Monopix is a small fill factor design in a 180nm CMOS technology. By using an innovative modified process, fully depleted sensing volume is expected despite a small collection electrode used. The aim of using small electrodes is to have an ultra low power analog front-end design, thus reducing significantly the total sensor power consumption. The wafers for TJ-Monopix were received from the foundry, and first measurement is expected to start in two weeks after chip dicing.

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Recent Results with Ultra-Fast Silicon Detectors

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The performance of Ultra-fast Silicon Detectors (UFSD) has been measured pre-rad and after neutron irradiation up to 6e15 n/cmˆ2.
Of special interest are UFSD with 35 and 50 micron thickness.
The measured time resolution is traced back to the evolution with fluence of internal gain, rise time and noise.

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Characterization of H35 HV-CMOS Sensors before and after Proton Irradiation

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Characterization of H35 HV-CMOS Sensors before and after Proton Irradiations

ABSTRACT

In view of applications at the High Luminosity LHC (HL-LHC) upgrade, we developed a new generation of radiation tolerant High Voltage CMOS (HV-CMOS) sensors, that was fabricated at AMS Foundry (Austria) in 350 nm Technology. To evaluate their performance and operational stability within HL-LHC environment, four different substrate resistivity spanning from 20 to 1000 Ω×cm were considered in an aim to optimize the charge collection efficiency through the compromise between smaller dead areas at the pixel array periphery and a larger depleted volume. High resistivity substrate creates a larger depletion volume when biased, as a result, charge multiplication effects but also increased leakage current and premature electrical breakdown could be noticed after irradiation. A thorough experimental study is thence necessary to assess the device intrinsic behavior before and after irradiation campaigns. To this purpose, we have used standalone pixels, single pitch diode, and diode arrays. A dedicated campaign has been carried out that included Proton irradiations at different facilities: i) 24 GeV/c Proton in CERN Proton Synchrotron (PS) beam and (ii) 18 MeV Proton Cyclotron at University of Bern (Switzerland). The electrical characterization of the sensors was made before and after irradiation using a precise environmental chamber, Cascade Microtech 300 probing system. We report here the selected results retrieved from these investigations that give a greater insight of sensor's inherent behavior as well as their good compatibility to ATLAS ITk compliance.

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Resistive AC-Coupling: a new read-out paradigm in 4D tracking with Ultra-Fast Silicon Detectors

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In this contribution we describe the project "Resistive AC-Coupled Silicon Detectors" (RSD), a novel approach to the design of Low-Gain Avalanche Detectors (LGAD) that will eliminate the problem arising from the segmentation of the gain layer.
RSD are essentially LGAD designed to reach the limit of 100% in the fill-factor. Such scheme is based on the presence of a resistive *n*-electrode, necessary to store the charges for an opportune discharging time, and a top layer, which induces a capacitive signal on the readout pads.
Since the AC-coupling does not need for the segmentation of active areas, RSD will completely eliminate the dead space between pixels, i.e. the no-gain region used in the present technology for the insulation between neighboring sensors.
This improvement will be beneficial in most of particle physics applications, especially in high-luminosity environments, where 4D tracking needs for the most uniform response, in terms of both geometrical acceptance and detection efficiency.

Preliminary numerical simulations are presented, and the most important physical and technological parameters of RSD are also discussed.

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Radiation Damage Effects on LGADs and Deep Diffused APDs

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For their operation at the CERN High Luminosity Large Hadron Collider (HL-LHC), the ATLAS and CMS experiments are planning to implement dedicated systems to measure the time of arrival of minimum ionizing particles with an accuracy of about 30 ps.
The timing detectors will be subjected to radiation levels corresponding up to a 1-MeV neutrons fluence (Φ_{eq}) of 10^{15} cm^{-2} for the goal integrated luminosity of HL-LHC of 3000 fb^{-1}.
Some of the proposed systems will employ Low Gain Avalanche Detectors (LGADs).
The gain of these detectors lies usually between 5 and 50.

This talk summarizes the results obtained in the characterization of LGADs and deep diffused Avalanche Photodiodes (APDs).
These APDs have a gain of up to 500 and are used for direct particle detection, without the use of radiating materials.
The results obtained with proton-irradiated LGADs and neutron-irradiated APDs irradiated up to $\Phi_{eq} = 10^{15}$ cm^{-2} are reported.

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Random Telegraph Signal evidence in Proton Irradiated CMOS SPADs

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CMOS SPADs are recently gaining the attention of the scientific and industrial world, because of their excellent performance. Due to their working principle, they are sensitive down to the single photon level with no need of an external amplification and provide a temporal resolution, which reaches tens of picoseconds. Further, the CMOS integration, allowed integrating the auxiliary electronics, necessary for device quenching, signal processing into the device itself.
Beyond all these advantages, the SPADs performances are strongly controlled by defects located in the silicon bulk or along the interfaces of the device. Defects are naturally introduced during the manufacturing process steps, such as etching or implant. These defects can introduce energy levels in the silicon band gap, leading to a degradation of the device performances as dark counts rate increase and dark counts rate discrete fluctuations referred as Random Telegraph Signal (RTS). RTS is the main issue for applications requiring long integration times with low and stable noise, and require the continuously recalibration of the device.
RTS increases when the SPAD sensors operate in a radiation environment, such as space missions or HEP experiment, due to radiation induced silicon bulk defects.
This work presents an analysis of dark counts RTS in SPADs fabricated in a 150nm CMOS technology. Several devices have been irradiated at different fluences with protons of different energies up to 60 MeV.
RTS behaviour, like frequency of occurrence, amplitude, time constants, activation energy, etc. have been measured in order to understand the mechanisms responsible for this phenomenon

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Displacement Damage Test of CMOS SPAD sensors for Space Application

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The next generation of HEP space experiments impose extreme requirements on their detectors, that cannot be still satisfied by PMTs. An appealing alternative is offered by Single-Photon Avalanche Diode (SPAD) devices manufactured in deep sub-micron CMOS processes, which offer sensitivity down to the single photon level, with pico-second time resolution and micrometric position resolution.
CMOS-SPAD detectors in space must conserve useful performances despite being bombarded with high fluxes of particles. Understanding and modelling the effects of space radiation is crucial to enabling new spatial applications that require single-photon detection.
In this work, we investigate the radiation tolerance of SPADs sensors fabricated in a CMOS 150nm process. An irradiation campaign has been performed on several SPAD arrays implemented in different dimensions and junction layouts with protons up to 60 MeV at the LNS-INFN laboratories in Catania (Italy).
We characterized the dark count rate (DCR) as a function of the delivered proton fluence and estimate the equivalent space mission duration on several suitable space orbits, in order to provide the limits of operability in a such environment. All SPADs showed a significant increase in the DCR behaviour. Furthermore, for a large fraction of irradiated SPADs, DCR discrete fluctuations between

two or more values have been observed, phenomenon known as Random Telegraph Signal (RTS). Furthermore, a measurement campaign has been performed as function of temperature in order to gain some understanding about the radiation induced damage and the mitigation of their effects on the detector's performance at low temperature.

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Radiation hardness of 3D pixel sensors up to unprecedented fluences of 3e16 neq/cm²

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At the High-Luminosity upgrade of the Large Hadron Collider (HL-LHC), the particle density will increase and fluences up to $2.5\times10^{16} n_{eq}$/cm^2 are expected for the innermost pixel layer of the ATLAS and CMS experiments after an integrated luminosity of 4,000 fb^{-1}. To meet these requirements, a new generation of CNM 3D pixel sensors with small pixel sizes of 50x50 and 25x100 μm^2 and reduced electrode distances are developed. For the first time, pixel detectors are irradiated and studied up to the unprecedented fluence of $3\times10^{16} n_{eq}$/cm^2, i.e. beyond the full expected HL-LHC life time to explore the limits of the 3D technology. Since a readout chip with the desired pixel size developed by the RD53 collaboration was not yet available, first prototype small-pitch pixel sensors were designed to be matched to the existing ATLAS IBL FE-I4 readout chip for testing. Irradiation campaigns with such pixel devices have been carried out at KIT (Karlsruhe) with a uniform irradiation of 23 MeV protons up to a fluence of $1\times10^{16} n_{eq}$/cm^2, as well as at CERN-PS with a non-uniform irradiation of 23 GeV protons in several steps up to a peak fluence of $3\times10^{16} n_{eq}$/cm^2. The hit efficiency has been measured in several beam tests at the CERN-SPS. The performance of these devices is significantly better than for the previous generation of 3D detectors or the current generation of planar silicon pixel detectors, demonstrating the excellent radiation hardness of the new 3D technology.

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Mupix: A Monolithic Pixel Sensor for the Mu3e Experiment

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Mupix8 is the latest and largest prototype of a High Voltage-Active Monolithic Active Pixel Sensor (HV-MAPS) based on the 180 nm HV-CMOS process from AMS. It was developed for the Pixel Tracker of the Mu3e-Experiment at PSI which will search for the lepton flavor violating process muon -> eee with unprecedented sensitivity.
The Mupix8 prototype has a size of 2x1 cm2, integrates about 25000 cells with a active pixel size of 80 x 80 mu2, a data driven readout and several 1.25

Gbit/s serializer.
After a short introduction to the Mu3e experiment and the requirements of the ultra-light Pixel Tracker the Mupix design and results obtained with several Mupix prototypes are discussed.

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CMS Pixel detector development for the HL-LHC with first results for HPK prototype sensors

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The LHC is planning an upgrade program which will bring the luminosity up to about 7.5E34 cm-2s-1 in 2027, with the goal of an integrated luminosity of 3000 fb-1 by the end of 2037. This High Luminosity scenario, HL-LHC, will present new challenges of higher data rates and increased radiation tolerance for the pixel detector (2E16 neq/cm2, or equivalently 1 Grad, is expected for the inner pixel layer for 3000 fb-1 integrated luminosity). To maintain or even improve the performance of the present system, new technologies have to be fully exploited for the so-called Phase-2 upgrade. Among them is the future version of front-end chips in 65-nm CMOS by the CERN RD53 Collaboration which supports small pixel sizes of 50x50 or 25x100 μm2 and lower thresholds (˜1000 e-). For the development of the appropriate planar pixel sensor, CMS has recently launched a submission of n-in-p sensors on 6 inch wafer with an active thickness of 150 μm at Hamamatsu. The submission consists of physical thinned, direct bonded and deep diffused wafers with p-stop or p-spray isolation. A variety of sensors with and without biasing scheme is designed to match the different read-out chips (RD53A, ROC4Sens, etc.) and first hybrid modules are assembled at Fraunhofer IZM. In this talk, we will present an overview of the Phase-2 pixel R&D program and report on first results obtained at the DESY testbeam for HPK sensors bump bonded to the ROC4sens R&D readout chip.

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Study of the radiation resistance of different LGAD gain layer designs.

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I will report on the radiation resistance of 50-micron thick LGAD detectors, manufactured at the Fondazione Bruno Kessler, employing several different types of gain layer. LGAD detectors with gain layer doping of Boron, Boron low-diffusion, Gallium, Carbonated Boron and Carbonated Gallium have been designed and successfully produced. These sensors have been exposed to neutron fluences up to φn ~ $3 \cdot 10^{16}$ n/cm^2 and to proton fluences up to φp ~ $9 \cdot 10^{15}$ p/cm^2 to test their radiation resistance. The data show that Gallium-doped LGAD are more affected by initial acceptor removal than Boron-doped LGAD, while the presence of Carbon reduces the initial acceptor removal for both type of doping. Boron low-diffusion shows a higher radiation resistance than that of standard Boron implant, indicating a dependence of the initial acceptor removal mechanism upon the implant width. This study also demonstrates that proton irradiation is at least twice more damaging than neutron irradiation.

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The INFN Pixel Sensor R&D for the HL-LHC Upgrade of the CMS Experiment

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The talk will report on the INFN research activity, in collaboration with FBK foundry, which is aiming at the development of new, thin, n-in-p pixel sensors for the CMS HL-LHC (Phase-2) upgrade. The talk will illustrate the main aspects of the research program, starting from the sensor design and fabrication technology, with an overview on next plans using both Direct Wafer Bonded (DWB) and Silicon On Insulator (SOI) wafers. The INFN RD covers both planar and columnar 3D pixel devices. Hybrid modules with R&D sensors connected to the PSI46dig readout chip have been tested on beam test experiments: recent results on planar Active Edge devices, with peripheral staggered trenches, and 3D pixel sensors will be reported.

18

Research and development of new radiation tolerant pixel Silicon sensors for the high-luminosity phase of the CMS experiment at LHC

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The CMS experiment has a vast R&D program on silicon pixel sensors for the HL-LHC upgrades. In this talk we will focus on activities and results obtained with 100 and 130um thick planar pixel sensors produced by FBK, in the framework of a collaborative agreement with INFN. Pixel single-chip modules have been tested in the Fermilab Test Beam Facility before and after proton irradiation, during different test beam sessions spanning from December 2015 to November 2017. We will give a comprehensive review of results obtained up to now, with details on the data analysis, summarising the main findings and limits reached.

19

Operational Experience and Performance with the ATLAS Pixel detector with emphasis on radiation damage

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The tracking performance of the ATLAS detector relies critically on its 4-layer Pixel Detector, that has undergone significant hardware and software upgrades to meet the challenges imposed by the higher collision energy, pileup and luminosity that are being delivered by the Large Hadron Collider, with record breaking instantaneous luminosities of 2 x 10ˆ34 cm-2 s-1 recently surpassed.
The key status and performance metrics of the ATLAS Pixel Detector are summarised, and the operational experience and requirements to ensure optimum data quality and data taking efficiency will be described, with special emphasis to radiation damage experience.

In particular, radiation damage effects will be showed and signs of degradation which are visible but which are not impacting yet the tracking performance (but will): dE/dX, occupancy reduction with integrated luminosity, under-depletion effects with IBL in 2016, effects of annealing that is not insignificant for the inner-most layers. Therefore the offline software strategy to have a better matching between MC and data will be discussed.
In addition the strategy to contain the readout bandwidth limitation will be discussed,
required by the LHC over-performing to more than 2x10ˆ34 cm-2.s-1 and to ATLAS luminosity leveling. The strategy would be reduce the front-end threshold in order to maximize the Pixel hit.
We should therefore address our readout budget and push the DAQ to allow operating as much as possible to full readout bandwidth.
Numbers and strategy will also be discussed.

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Studies of the MaPSA-light Module for the CMS Phase II Upgrade

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One key feature of the HL-LHC outer tracker upgrade is the use of "pt modules" to reject low pt tracks and reduce the required L1 bandwidth. These consist of two closely spaced silicon layers which are capable of creating "stubs", which are pairs of hits compatible with tracks above a certain

pt threshold. These modules are divided into the "PS" and "2S" types, and are designed to work in conjunction to reject tracks below 2 GeV at the L1 trigger.

This talk will concentrate on the PS module, specifically characterizing the readout chip, the MPA. Currently available is the prototype chip, the MPA-light, which is used to test the front end circuitry. These MPA-light chips are then used in the MaPSA-light assembly test, which is composed of six MPA-light chips and a bump bonded sensor. We will present the first tests of the MaPSA-light assembly using the Fermilab Main Injector.

21

Modeling Radiation Damage to Pixel Sensors in the ATLAS Detector

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Silicon pixel detectors are at the core of the current and planned upgrade of the ATLAS detector at the Large Hadron Collider (LHC). As the closest detector component to the interaction point, these detectors will be subjected to a significant amount of radiation over their lifetime: prior to the High-Luminosity LHC (HL-LHC), the innermost layers will receive a fluence in excess of 10ˆ15 neq/cm2 and the HL-HLC detector upgrades must cope with an order of magnitude higher fluence integrated over their lifetimes. Simulating radiation damage is critical in order to make accurate predictions for current future detector performance that will enable searches for new particles and forces as well as precision measurements of Standard Model particles such as the Higgs boson. We present a digitization model that includes radiation damage effects to the ATLAS pixel sensors for the first time and considers both planar and 3D sensor designs. In addition to thoroughly describing the setup, we compare predictions for basic pixel cluster properties on leakage currents, depletion voltage, charge collection efficiency, Lorentz angle etc. with real data collected at LHC proton-proton collisions.

22

Performance of the H35DEMO chip monolithic matrices before and after irradiation

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Depleted Monolithic Active Pixel Sensors (DMAPS) based on High Voltage CMOS (HV-CMOS) technology are investigated as an option to cover large areas in the outermost layers of the future pixel detector of the ATLAS Inner Tracker (ITk) at HL-LHC.

The H35DEMO is a large area demonstrator chip for ITk developed by the collaboration of KIT, IFAE, University of Liverpool and University of Geneva. It has been produced in AMS 350 nm CMOS technology on wafers with different substrate resistivities ranging from 20 Ω to 1 kΩcm.

The chip is divided in four matrices consisting of active pixels with a 50x250 μm^2 pitch. It features a large fill factor design in which the transistors are embedded in the same deep n-well acting as collecting electrode. Two of the matrices include also digital electronics in the periphery and can thus be operated standalone as monolithic detectors.

H35DEMO chips have been irradiated with reactor neutrons at JSI and with 23 MeV protons at KIT up to the particle fluences expected for the fifth pixel layer of ATLAS at HL-LHC. The performance of the monolithic matrices before and after irradiation has been investigated in different beam test campaigns in 2017 using a readout system fully developed at IFAE. The results of this characterisation will be presented

23

X-ray Detectors at PSI and Recent Developments using LGADs for Low Energy X-ray Detection

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The detector group of the Swiss Light Source at the Paul Scherrer Institut (PSI) develops cutting-edge X-ray detectors in-house, including photon-counting detectors for synchrotron radiation sources and charge-integrating detectors for Free-Electron Lasers (FELs). Planar silicon strip and pixel sensors are commonly used for X-ray energies from a few keV up to 20 keV. In addition, high-Z sensors, e.g. CdTe and GaAs, are being studied to improve the quantum efficiency for X-ray energies above 20 keV, while Low Gain Avalanche Diode (LGAD) sensors and silicon sensors with thin entrance windows are being investigated for the detection of soft X-rays below 4 keV. In this talk, an overview of the detector development at PSI will be given. Results from recent measurements with LGAD microstrip sensors wire-bonded to Mythen-II, a photon-counting readout chip (ROC), and to Gotthard-1.7, a charge-integrating ROC, will be presented. The requirements of LGAD sensors with thin entrance windows for soft X-ray detection will be discussed.

24

Advances on TCAD numerical modeling of silicon detectors operations at HL-LHC fluences

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Silicon detector operations at HL-LHC expected fluences will pose severe challenges in terms of tracking capabilities and radiation resistance.
TCAD tools can be therefore proficiently exploited in order to optimize detector performance in terms of charge collection, which mainly determines the detection efficiency and position resolution. To this purpose, proper combination of surface and bulk radiation damage effects modeling scheme should be adopted.
We developed a surface radiation damage effects model based on the introduction of amphoteric deep-level defects distribution, as extracted from experimental measurements. This enables a non-trivial analysis of the interplay between oxide properties, metal contact shaping (overhang) and width/pitch ratio for heavily irradiated structures. Electric field profiles near the junction corner of a strip-like detector for different pitch options, e.g. pitch=160 um and pitch=80 um for the same implant width (40 um) can be evaluated at different fluences. Actually, different electric field profiles will affect the amount of generated and collected charge.
The trend of the amount of collected charge as a function of the position of an impinging particle can be therefore extrapolated. A significant variation in the amount of the collected charge has been obtained, mainly due to different charge multiplication effects that can be experienced by different particle trajectories.
The effect of bulk radiation damage on charge collection, as well as electric field profiles, is being investigating as well, aiming at defining a set of "dominant"bulk defects which can be experimentally measured, at the same time reducing the model fitting parameters.

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Effect of thinning and backplane processing on charge collection properties of irradiated CMOS detectors

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Two sets of passive CMOS detectors were studied: thinned with processed and metalized backplane and not thinned without backplane processing with substrate biased through the implant on top of the device. Detectors were irradiated with neutrons in reactor in Ljubljana. Collected charge was measured with electrons from Sr-90 source using an external amplifier. Depletion depth and charge collection was measured also with Edge-TCT and compared with Sr-90 measurements. Results obtained with two sets of devices were compared and it was found that thinning and backplane processing improves charge collection after irradiation.

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Test Beam study of small-pitch 3D pixel sensors from CNM

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Silicon pixel sensors of cell size 50um x 50um fabricated at CNM using 3D, doubled-sided n-on-p technology were bump-bonded to ROC4Sens readout chips and tested in an electron test beam at

DESY. We show initial results of efficiency, charge collection, charge sharing, noise and resolution for different track incidence angles. The sensor+ROC assemblies were later irradiated with protons to a fluence of 3e15 neq/cm2. Preliminary results of irradiated sensors are also shown.

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New approaches to HEP sensors at CiS

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The CiS Forschungsinstitut fuer Mikrosensorik is engaged in developments of radiation detector technologies on several different fields. Current projects include active edge sensors, 3D sensors as well as new quality control methods.

One active edge sensor run is finished. Three different side wall doping methods (plasma implantation, ion implantation, diffusion) have been tested in combination with two wafer thicknesses as well as with n- and p-substrates. Electrical measurements show the functionality of sensors with inactive edge widths down to 50 µm.

New quality control methods are being tested for planar pixel sensors: one wafer run with a new approach to bias grids is being finished. These new bias grids are removable after quality assessment and allows sensors to operate without the unwanted loss of charges over the grid, especially after irradiation. The preliminarily tested methods of removal include the burning of the grid with high currents, laser removal as well as wet etching. So far etching showed the most promising results.

A new innovative approach to 3D processed sensors is being pursued by using plasma etched trenches as isolation between pixels in planar pixel sensor technology. This will allow a modular design and a reduction in cost and time for prototyping for different customers and applications.

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Design of 3D silicon sensors for high resolution time measurements

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In future high luminosity LHC experiments, planned over the next 10 years, the number of collisions per unit of time is expected to increase by more than a factor of 2. The new experimental conditions require new detector systems with increased performances compared to the current state of the art. In this context, spatial and especially time resolution play an increasingly important role. The TIMESPOT project, an INFN financed initiative, is focused in the development of a time and space (4D) tracking detector based on a silicon and diamond sensor with a requested resolution around 50 µm in space and better than 50 ps in time. The 3D sensor technology has been chosen for the pixel technology.

In order to optimize the timing response of the single pixel sensor, different geometry solutions have been explored and simulated. The one with the best electric field performance in terms of coverage and amplitude was selected for further investigations. The behavior of the sensor when crossed by a high energy particle was also simulated and the output signal was collected in order to have first timing information regarding the charge collection time. Simulations were performed using Sentaurus Technology CAD with Geant4 support for a better energy deposit and modelling of the particle track.
Results concerning sensor response will be illustrated.

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Study of performances of 3D pixel devices from radioactive source measurements

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During the $2023 - 2024$ shutdown, the Large Hadron Collider (LHC) will be upgraded to reach an instantaneous luminosity up to 7×10 $cm^{-2}s^{-1}$. This upgrade of the accelerator is called High-Luminosity LHC (HL-LHC). ATLAS and CMS tracking detectors will be replaced to meet the challenges of HL-LHC: an average of 200 pile-up events in every bunch crossing and an integrated luminosity of 3000 fb^{-1} over ten years. Italian groups are involved in the R&D on the design and production of 3D sensors with thickness in the range 100 to 200 μm, 5 μm diameter columns and smaller size pixel cells. The first pixel sensors produced by FBK in Trento have been bump-bonded by Leonardo to FE-I4 chips, the read-out electronics used in the new Pixel layer installed in ATLAS in 2014 (IBL).

This contribution is meant to be a poster reporting the laboratory measurements of 3D devices. The main purpose is to compare charge collection performance with two different radioactive sources (^{241}Am and ^{90}Sr) between IBL modules and the new FBK sensors, with the same pixel size of 50x250 μm^2 but different thickness. Furthermore an analysis of source scans for the FBK modules with different pixel cells, either 50x250 μm^2 or 50x50 μm^2, but same thickness, is performed. Both analysis compare for the same tuning threshold the results of ToT and clustering process.

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Silicon Sensors of the CMS High Granularity Calorimeter

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The CMS experiment at CERN will undergo significant improvements during the so-called Phase-II Upgrade to cope with a 10-fold increase in integrated luminosity with the High Luminosity LHC (HL-LHC) era. Especially the forward calorimetry will suffer from very high radiation levels and intensified pileup in the detectors. Consequently, the CMS collaboration is designing a High Granularity Calorimeter (HGCAL) to replace the existing endcap calorimeters. It features unprecedented transverse and longitudinal segmentation for both electromagnetic (CE-E) and hadronic (CE-H) compartments. This will facilitate particle-flow calorimetry, where the fine structure of showers can be measured and used to enhance pileup rejection and particle identification, whilst still achieving good energy resolution. The CE-E and a large fraction of CE-H will consist of a sandwich structure with silicon as active detector material. The sensors will be of hexagonal shape, maximizing the available 8-inch circular wafer area. Each sensor comprises 192 or 432 individual cells, each of 0.5 - 1 cmˆ2 in size without any common biasing structure. Biasing of the cells will be performed through the readout chip on the module level, but poses several complications for the electrical characterization of the bare sensors in the laboratory. In this talk, the current status of the detector development is presented, including the different vendors having an 8-inch sensor production available. Moreover, radiation hardness studies and the construction of a dedicated test system to cope with the challenging testing of those sensors will be presented.

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MoVeIT strip silicon detectors for proton beam monitoring: preliminary results

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The MoVeIT project of the INFN-CSN5 aims at studying, modeling and verifying the biological impact on charged particle therapy of some complex physical and biological effects, so far neglected in treatment planning systems (TPS) currently used. The preclinical testing of biologically optimized TPS requires dedicated devices for its validation, able to analyze beam particle fluences and beam energy at the same time. The work-package 4 of the MoVeIT project is investigating the use of low-gain avalanche detectors (LGAD) optimized for time resolution (Ultra Fast Silicon Detectors - UFSDs) for proton beam monitoring. Two prototype devices are being developed, one to directly count individual protons at high rates (hundreds of MHz/cm^2), the second to measure beam energy with time-of-flight techniques. This requires the design of custom UFSD sensors as well VLSI readout electronics. From simulations'results and first beam tests with UFSD pads, strip detectors were produced by FBK in Trento, with two geometries (30 mm and 15 mm length) and different doping modalities to improve radiation hardness. Radiation damage, in fact, represents the main issue to be investigated, together with pileup effects. In parallel, prototypes of a new TERA10 readout chip have been submitted to the foundry. The aim of this contribution is to review the advancement of the project and to report on the results of the tests of UFSD strip sensors with the therapeutic proton beam of CNAO (Pavia).

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The CMS Outer Tracker Upgrade for the High Luminosity LHC

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The High Luminosity LHC scenario, HL-LHC, with a planned instantaneous luminosity of the upgraded machine of 5x10ˆ34 cmˆ-2 sˆ-1 by year 2028, and an integrated luminosity of 3000 fbˆ-1 by the end of year 2037, requires the complete replacement of the CMS Tracker detector to cope with the extremely challenging new operating conditions. The talk will focus on the CMS Outer Tracker system for the Upgrade Detector, describing the new proposed layout and the technological choices which have to provide robust tracking and also Level-1 trigger capabilities. Recent progress on Outer Tracker R&D activities will be reported.

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Development of Strip-type Low-Gain Avalanche Detectors

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Low-Gain Avalanche Detectors (LGADs) have potential to be a critical element in applications for collider physics, medical instrumentation, etc., with its high spatial and timing resolution. The strip-type LGAD detector is required in large-scale application for covering wide area with low cost. We have fabricated LGAD strip sensors, DC-type, together with LGAD diodes, and evaluated their characteristics including such as spatial response to infrared laser, before and after proton and neutron irradiations. We have observed that a substantial gain is obtained in the inter-strip region after irradiation where the gain is unity before irradiation. The radiation-induced gain variation and potential improvement to obtain gain in the inter-strip region before irradiation are discussed with TCAD simulations.

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Univ. Tsukuba: Kyoji Onaru, Sayaka Wada, Kazuhiko Hara, Junki Suzuki
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An in-depth study of Inverse-LGAD sensors

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An in-depth study of a p-in-p LGAD sensor (Inverse-LGAD) is presented. Contrary to the conventional LGAD, the baseline device for the HL-LHC mip timing detectors, the I-LGAD has a non-segmented deep p-well (the multiplication layer). Therefore, I-LGADs should ideally present a constant gain value over all the sensitive region of the device without gain drops between the signal collecting electrodes; in other words, I-LGADs should have a 100% fill factor by design. We have experimentally confirmed this feature on a strip-like segmented i-LGAD and compare it against a conventional strip-like LGAD and PIN devices. Tracking performance was determined with MIPs using the AIDA telescope at the SPS H6 test beam line. Finally, a timing resolution of tens of picoseconds was determined using a dedicated laser test-stand.

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Characterization and simulation of small-pitch 3D diodes after irradiation up to 3.5×10ˆ16 neq cmˆ-2

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Using 3D diodes, we have investigated the radiation tolerance of 3D sensors from the first batch fabricated at FBK on Si-Si DWB 6"substrates with a single-sided technology. The active layer thickness is 130 μm. Diodes reproducing the same layout details of their parent, small-pitch pixel sensors were irradiated with neutrons at the TRIGA Mark II reactor at JSI (Ljubljana, Slovenia) up to a fluence of 3.5×1016 neq cm-2. After irradiation, the breakdown voltage is higher than 200 V, so that sensors have a wide operational margin.
For functional tests, we used a vacuum chamber allowing to operate the samples at around -15C without any humidity problem. The samples are biased from the back side by placing the silicon dice on a metallic thermal finger covered with a conductive paste. The signals are read-out from the front side by contacting the probing pads by microneedles. The read-out chain includes a charge amplifier and a shaper.
By using a position resolved pulsed laser (wavelength 1055 nm, nominal pulse width 40 ps), we have collected 2-d maps of the relative signal intensity across a 3D basic cell at different bias voltages. Data were then normalized to the signals acquired on non-irradiated samples. The relative efficiency reaches up to 75%(55%) for sensors irradiated to 1×1016 neq cm-2 (3.5×1016 neq cm-2). The 2-d signal maps were compared to those calculated according to Ramo's theorem with input data obtained from TCAD simulations incorporating the new Perugia model for radiation damage, and the agreement was satisfactory.

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Status of 3D Sensor Developments at FBK

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Since 2014, within the framework of the INFN-FBK "Phase 2"R&D program and the AIDA 2020 project, FBK has developed a new generation of small-pitch, thin 3D pixel sensors oriented to the innermost tracking layers of ATLAS and CMS at the High-Luminosity LHC (HL-LHC). Sensors are made on either Si-Si Direct Wafer Bonded or SOI 6"substrates with a single-sided technology, while ensuring the bias be applied from the back side. Sensors feature a thin active region (˜100 μm), narrow electrodes (˜ 5 μm), reduced electrode spacing (down to ˜ 30 μm), and very slim edges (˜ 50 μm). Two batches were fabricated so far, including several different pixel designs compatible both with present (e.g., FEI4) and future (e.g., RD53A) read-out chips.
More recently, in the framework of the INFN TIMESPOT project, FBK has started the development of a modified technology for 3D pixel sensors optimized for timing applications. In order to ensure the most uniform electric field distribution necessary to improve the timing properties, 3D pixels based on trench electrodes are being explored, and technological tests are under way to investigate possible process constraints for their manufacturability.
The talk will cover technological aspects and experimental results from the electrical characterization of sensors and test structures.

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Results on Proton Tomography

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Proton Computed Tomography (pCT) is a medical imaging method aimed at improving the accuracy of treatment planning in hadron therapy through a direct measurement of tissues' stopping power distribution. A pCT image can be obtained, with a single event approach, by directly measuring each proton position and direction upstream and downstream the volume under study using a tracker and, at the same time, evaluating the particle residual energy by a calorimeter or a range counter.
A pCT system based on a silicon microstrip tracker and a YAG:Ce scintillating calorimeter has been developed within the INFN-RDH-IRPT collaboration and recently tested with a 228 MeV proton beam at the Proton Therapy Center (Trento, Italy).
Algebraic iterative reconstruction methods, together with the most likely path (MLP) formalism, have been used to obtain stopping power images of an anthropomorphic phantom and an electron density calibration cylinder.
Due to the heavy computation load required by the algebraic algorithms and the MLP trajectory determination, the reconstruction programs have been written to fully exploit the high calculation parallelism of Graphics Processing Units.
The phantoms' proton tomographies, together with the experimental methodologies used to acquire, analize and reconstruct data, will be presented and discussed.

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Silicon detectors in medical applications and for characterization of laser-driven ion sources

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Silicon detectors are widely used in medical applications, ranging from imaging to dosimetry, treatment verification and quality assurance in radiation therapy. Also in a pre-clinical environment, they exhibit great potential for beam diagnostic of novel ion sources, such as laser-driven ion (LION) sources. There is major interest in pushing this unique acceleration mechanism towards biomedical applications. The special features of LION sources include an ultra-short duration ($\sim 1\,\mathrm{ps}$ at the source) of the polyenergetic ion bunches hosting a huge number of protons ($\sim 10^{12}$ per bunch).
After a general overview of silicon detectors in medical applications, two setups for characterization of LION bunches in terms of energy spectra are presented. In the first setup, a $10\,\mu\mathrm{m}$ thin prototype silicon microdosimeter is used to measure the time-of-flight signal of ns-short proton bunches. Spectra are deconvolved from the measured current, taking into account the device specific response of detector and electronics. In the second setup, the sensor chip of a Timepix detector is irradiated edge-on, hence the energy deposition of all protons along the entire penetration depth in the chip is measured.
The ability of the two setups to enable energy spectra reconstruction was tested at a Tandem accelerator, where 3D-printed passive absorbers were used to generate polyenergetic proton bunches from few-ns short monoenergetic bunches. Reconstructed spectra are compared to spectra expected from Monte Carlo simulations, showing very promising agreement encouraging future application.

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Recent developments on monolithic CMOS pixel sensors in TowerJazz 180nm technology

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Monolithic CMOS sensors represent a potential alternative to hybrid pixel detectors for the future of high energy physics experiments.
Over the last few years, the TowerJazz 180nm CMOS process has been under investigation as a candidate for pixel detectors at the High Luminosity Large Hadron Collider (HL-LHC).
First tests on prototype chips have shown that this technology can qualify for the design of the outer

pixel layers of the ATLAS Inner Tracker (ITk).
In particular, there are more and more convincing indications that radiation tolerance at the required levels can be achieved.
These results have triggered the development of novel high-speed readout architectures, which are optimized for the high particle density expected at pp-collisions at HL-LHC.
In this talk, the status of these studies is presented, as well as current and future activities.

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LHCb VELO Upgrade

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The Large Hadron Collider Beauty (LHCb) detector is a flavour physics detector, designed to detect decays of b- and c-hadrons for the study of CP violation and rare decays. At the end of Run-II, many of the LHCb measurements will remain statistically dominated. In order to increase the trigger yield for purely hadronic channels, the hardware trigger will be removed and the detector will operate at 40 MHz in combination with the five-fold increase in luminosity.

The upgraded VELO modules will each be equipped with 4 hybrid pixel tiles, each read out with by 3 VeloPix ASICs. The silicon sensors must withstand an integrated fluence of up to $8\times10^{15} 1 MeV n_e q/cm^2$, equivalent to 400MRad TID. The tiles are mounted onto a cooling substrate composed of thin silicon plates with embedded micro-channels that allow the circulation of liquid CO_2. The highest occupancy ASICs have hit rates of 900Mhit/s and produce a data rate of over 15Gbit/s. The back-end readout is performed by the LHCb's common readout board which is used to time reorder the data-driven packets generated by the ASICs.

An additional challenge is the non uniform nature of the radiation damage, which requires a high voltage (1000V) tolerant design. A collection of preliminary results will be presented, as well as a comparison of the performance of the different sensor prototypes before and after irradiation.

The design of the complete VELO upgrade system will be presented together with the latest results from the R\&D.

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Radiation-hard passive CMOS-sensors

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The utilization of radiation-hard CMOS processes for sensors of hybrid pixel-detectors is investigated. The benefit of such an approach is industrial sensor fabrication on large wafers with potential high throughput and yield, and low costs. Further, CMOS processes offer multiple metal and polysilicon layers, as well as metal-insulator-metal capacitors that can be employed for AC-coupling and redistribution layers. Passive CMOS-sensors with 50 x 250 $\mu\mathrm{m}^2$ pixels are investigated in view of the ATLAS pixel-detector upgrade. They are thinned to 300 μm and 100 μm, backside processed, and read out with the ATLAS FE-I4. Break-down behavior, yield, and hit-detection efficiency after irradiation to $1.1 \cdot 10^{15}\mathrm{N_{eq}/cm^2}$ are discussed. The influence of AC-coupling and a small collection node on capacitance and hit efficiency is also investigated. Preliminary findings for 50 x 50 $\mu\mathrm{m}^2$ pixel-sensors compatible with future pixel readout-chips are presented.

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Experimental Characterization and Future Sensor Developments for ARDESIA, a 4-Channels Fast SDD X-ray Spectrometer for Synchrotron Applications

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ARDESIA is an SDD-based multichannel x-ray spectrometer optimized for synchrotron applications, such as X-ray fluorescence (XRF) and X-ray absorption fine structure (XAFS) techniques. The spectrometer was developed to simultaneously achieve high count-rate (>1 Mcps/chanel) and high energy resolution (below 150 eV FWHM at shaping time faster than 200 ns) for soft x-rays detection.
The module is based on a 2x2 monolithic SDD array with a pixel pitch of 5 mm and a thickness of 450 µm, designed and produced by FBK. This array was produced with two different pixel shapes, one with square pixels to maximize the active area and the other one with circular pixels to minimize and homogenize the charge drift time all over the sensitive area. The SDD array is connected to a 4-channel monolithic CUBE preamplifier chip [2] whose extremely low white series noise guarantees good energetic resolution even at short pulse processing times. The complete module has dimensions of 16 mm x 16 mm and several modules can be combined together to cover larger area, if needed. We present the prototype of a complete instrument based on this detection module and we report on the first experimental characterization of this instrument at the LNF DAΦNE-Light DXR1 soft X-ray beamline. During this characterization, XRF tests on low atomic number elements were performed measuring the correspondent near absorption edge XANES spectra.
We also report on the current simulation and design work that is being carried on to develop thicker SDD sensors, having a thickness of 800-1000 µm.

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Production and design of LGAD with high radiation resistance

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Over the last few years, Fondazione Bruno Kessler, in collaboration with the universities of Trento and Turin, has been involved in the development of silicon sensors with low internal gain (x10-x20), the so-called LGAD or UFSD (Ultra Fast Silicon Detectors). Despite such a technology exhibits outstanding performance in terms of timing resolution, it is well known that LGADs are affected by a pronounced gain loss effect when irradiated by neutrons and protons.
A new LGAD batch has been produced at FBK on Silicon-to-Silicon wafers with a thickness of 50 μm, in order to improve both the timing performance and test new mechanisms to increase the radiation hardness of the devices. In particular, two different dopant elements (Boron and Gallium) have been used to realize the multiplication junction (or Gain layer), as well as carbon co-implantation has been tested on some wafers. In addition, we realized samples with different doping profiles of the Gain layer, by controlling the thermal diffusion of Boron.
We will report on the electrical and functional characterization of these devices, discussing the effect of doping and carbon co-implant on the detector noise and gain.

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E-TCT characterisation of irradiated backside biased H35DEMO pixel demonstrators

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A Phase II upgrade is proposed for ATLAS to take full advantage of the upcoming High Luminosity-LHC (HL-LHC). High Voltage-CMOS (HV-CMOS) pixel detectors are considered for the outer pixel layers of the Inner Tracker (ITk), where detectors will need to cover a large area and withstand irradiation to fluences of the order $10^{15} n_{eq} cm^{-2}$. Monolithic HV-CMOS detectors remove the need for the expensive assembly processes required by hybrids, as the front-end electronics can be directly embedded in the sensor chip. Sensing diodes can be biased at high voltages for fast charge collection by drift and high radiation tolerances. However, as recent measurements have demonstrated, the maximum achievable tolerance is about one order of magnitude lower than that of hybrids.

The H35DEMO is an HV-CMOS pixel demonstrator in the 0.35 µm process from ams AG and fabricated in different substrate resistivities between 20 Ω·cm and 1 kΩ·cm. A 1 kΩ·cm wafer of H35DEMOs was thinned to 100 µm and processed to allow backside biasing. This contribution presents results of edge-TCT measurements of the processed H35DEMO sensors before and after irradiation to fluences up to $2 \times 10^{15} n_{eq} cm^{-2}$. The measured results are in line with those obtained with TCAD simulations which indicate that backside biased H35DEMO sensors have a stronger more uniform electric field, giving faster charge collection times and therefore higher radiation tolerances than top biased counterparts. Further studies of backside processed H35DEMOs irradiated to fluences beyond those expected in the outer pixel layers of the ATLAS ITk are currently planned.

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Radiation hardness study of HV-CMOS sensors using Transient Current Technique

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For operation at the High Luminosity LHC, the ATLAS detector will be upgraded in 2025-2026. Its Inner Detector will be replaced by an all-silicon tracking system called the Inner Tracker (ITk), consisting of an inner pixel detector of five layers and an outer strip detector. This detector will cope with the harsher radiation environment and the higher pile-up of collisions.
Sensors produced in the High Voltage CMOS (HV-CMOS) process are considered for the outer layers of the pixel detector. Since HV-CMOS allows for a monolithic design, the material budget in ITk can be reduced and the production is simplified since no additional front-end board to be bonded to the sensors is necessary. A study of the radiation hardness of prototype HV-CMOS sensors will be presented in this talk. In particular, a characterisation of the depletion depth with the Transient Current Technique will be shown. The study covers the performance before and after proton irradiation with fluences up to $1.5 \cdot 10^{15}$ 1 MeV n_{eq}. Two proton beams with different energies were exploited for the studies. The irradiation with protons of 24 GeV was performed at the CERN Proton Synchrotron, while an irradiation with 16.7 MeV protons was done at the Bern Cyclotron.

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Compilation of the results on characterization of ADVACAM edgeless pixel sensors

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The first part of the work is devoted to the study of the performance of active and slim edge ATLAS planar pixel sensors (PPS) in various test conditions including irradiation fluences (1e15 and 2e15 $n_{eq}cm^2$) and sensor inclination. For the performing of testbeam measurements CERN and DESY beam facilities have been used.
In the second part of the present work another method to characterize the PPS is described. This method uses an infrared laser and gives a possibility to characterize the PPS in situ before going to testbeam facilities. Using a laser we get the very flexible charge injection with well-defined hit position. The laser test bench setup is developing in the clean room at LAL (Orsay). Current status of the laser test bench setup and the first results are presented in this work.

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Characterization of acceptor removal in epitaxial silicon pad diodes

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The so-called acceptor removal effect has been studied on a set of p-type silicon sensors irradiated with protons and neutrons up to 7E15 neq/cm2. Two sets of diodes were used: thin epitaxial diodes with different resistivities (10, 50, 250 and 1000 Ohm.cm) and high resistivity float zone diodes with different thicknesses (100, 150, 200 and 285 um). CV, IV and TCT measurements were performed to extract the effective doping concentration of these devices. TCT collected charge vs voltage was used to evaluate the sensor's bulk space charge, providing evidence of type inversion in low resistivity p-type silicon sensors when irradiated by protons. Additionally, defect spectroscopy was conducted using TSC technique in order to study the correlation between BiOi concentration and acceptor removal. The Neff vs fluence plots were fitted, from which acceptor removal rate parameters were extracted.

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Two Photon Absorption-TCT of irradiated LGADs

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Low Gain Avalanche Diodes (LGAD) with different implantation dose and irradiated with 24 GeV/c protons at CERN-PS up to a fluence of 1e14 1 MeV neutron equivalent will be presented. The results of these measurements support the interpretation of a double junction effect as the primary responsible for the reduction of gain observed in these devices. The shape and magnitude of electric field was calculated profiting from the point-like spatial resolution of this technique. This method was also applied to PIN diodes of different runs.

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EDET DH80K- A DEPFET based Ultra High Speed Camera System for TEM Direct Electron Imaging

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We present a camera system for high time-resolved direct electron imaging on a TEM furnished with a pulsed electron source to observe dynamic processes in real space. The sensors use an SOI detector substrate with 50 μ to 30 μ thickness. The high intensity of the electron source requires tailored DEPFET devices with inherently high signal-to-noise, high speed readout capability, and nonlinear response matching the high dynamic range, arranged in arrays of 512 x 512 pixels with 60 x 60 μ^2 size. Readout is done in 4-row parallel rolling-shutter mode; customized multichannel readout ASICs read a DEPFET array in 12.8 μs, corresponding to a maximum source pulse frequency of 80 kHz, and digitize the data with 8 bit. The data stream is serialized and buffered by custom ICs with sufficient memory for a burst of 100 frames. In this way, stroboscopic movies can be recorded at a time resolution of 13μs. The subsequent DAQ components permit a burst rate of up to 100 bursts per second. All ASICs are bump bonded to the substrate of the detector array itself, which is provided with the corresponding metal track system to form a ultra- compact all-silicon-module (ASM). Each ASM, combined with individual mechanical support, electrical services and readout electronics, is an independent subsystem. The complete focal plane with its 3 x 3 cm^2 area consists of four tile modules integrated on a common baseplate optimized for low background and thermal management within a customized vacuum box fitting all prevalent TEM types.

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Detector development for the WFI of Athena

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The ATHENA X-ray observatory was selected as ESA's second large-class mission, scheduled to be launched in 2028. The Wide Field Imager (WFI) is one of its two primary instruments and will provide single photon spectroscopy in an energy band of 0.2 keV to 15 keV. To achieve unprecedented spectroscopic and imaging capabilities with a large field of view of 40' x 40', its focal plane is covered by DEPFET (depleted p-channel field effect transistor) active pixel sensors.
In the course of the detector development for the WFI, various variant of prototype DEPFETs – regarding the fabrication technology and layout –have been produced and investigated. Within these studies, an excellent performance was achieved, by e.g. operating 64x64 pixel detectors at noise levels below 2 e-ENC or readout speeds faster than 2.6 µs/pixel.

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Status of ATLAS Diamond Detectors

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Silicon is the standard material for particle detector sensors. Especially in high radiation environments diamond is a suitable alternative. In comparison to silicon it is more radiation hard but a smaller signal is generated per particle. Planar pixelated diamond detectors, read out by the FE-I4 chip, are installed in the ATLAS experiment. The current status and the performance of the Diamond Beam Monitor (DBM) of ATLAS will be presented.

One problem with diamond is the small signal and the high trapping probability of charge carriers. To further improve the diamond sensors a 3D electrode configuration penetrating the bulk is under investigation. The electrodes are fabricated by femtosecond laser pulses which transform locally the diamond into graphite. Within ATLAS a group of institutes are developing a 3D diamond detector with the FE-I4 as read-out chip. The production and status of a prototype will be presented.

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The CT-PPS project: detector hardware, operational experience and prospects for 2018

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The CMS-TOTEM Precision Proton Spectrometer (CT-PPS) allows extending the LHC physics program by detecting protons in the very forward regions of CMS. CT-PPS consists of tracking and timing detectors installed along the beam line at ~210 m from the CMS interaction point on both sides of the LHC tunnel. In 2017 the tracking system consisted of a station of silicon strip detectors

and a station of silicon pixel detectors on each side, this latter composed of six planes of 3D silicon pixel sensors, bump-bonded to the PSI46dig chip developed for the CMS Phase1 Pixel Tracker upgrade. The plan for 2018 is to replace the present strip stations with pixel ones in order to ensure better performances in multi-track event reconstruction. In 2017 each timing station was made of three planes of diamond detectors plus one of Ultra-Fast Silicon Detector (UFSD), while the plan for 2018 is to install double-sided diamond detectors. This contribution will describe the hardware characteristics and the status of the CT-PPS project. The operational experience during the 2017 data taking will be presented, along with the prospects for 2018.

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Status of 3D detector development at SINTEF for ITk upgrade

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SINTEF in collaboration with University of Oslo have been performing R&D activities on 3D detectors with the aim to qualify to be a production site for ITk upgrade. In this context, a 3D detector fabrication run has been completed recently with very promising results. Various sensor geometries with active edges were implemented, and the fabrication was carried out on 6-inch Si-Si wafers with sensor substrate thicknesses of 100 µm and 50 µm using single-sided processing approach. We will present the electrical test results; assembly, irradiation and test beam plans; and the plans for the next fabrication run.

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Silicon pixel-detector R&D for CLIC

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Mupix: A Monolithic Pixel Sensor for the Mu3e Experiment

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Ultra-thin active pixel detector for the Belle II VXD

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Development of N-on-P planar technology at SINTEF MiNaLab

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SINTEF MiNaLab has a long-standing experience in the production of planar radiation detectors on N-type silicon substrates. In recent years, a growing interest in sensors produced on P-type substrates was demonstrated on many fronts. N-on-P sensor technology is now becoming the "to-go choice", especially in fields where radiation hardness is crucial (e.g. CERN experiments) and/or a faster response time is needed.
In the past two years SINTEF MiNaLab has invested heavily in the development of its own N-on-P silicon sensors technology. Great effort was put into assessing different layout implementations that would optimize the sensor's electrical characteristics while achieving the desired surface radiation hardness.
We have recently completed a new prototyping fabrication run of N-on-P silicon sensors. The device of reference for the development of the technology was the standard SINTEF test diode. Many geometrical implementations were included, featuring variable numbers of guard-rings and field-plate designs. Two different sets of pixels detectors were also included together with other test structures for technology evaluation. Surface isolation was realized with P-spray and a total of 6 different implantation doses where tested to understand their impact on the electrical characteristics of the sensors and identify a dose that can provide a good isolation before and after irradiation. This work will briefly describe the wafer layout, the fabrication process and will focus on the electrical characterization results, finally outlining the plans for irradiation tests. Conclusions will be drawn on the status of the technology and the capability for future sensor production will be discussed.

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Ultra-thin Active Pixel Detector for the Belle II VXD

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The asymmetric electron/positron accelerator SuperKEKB at KEK in Japan is designed to provide an instantaneous luminosity of 8×10^{35} $cm^{-2}s^{-1}$ - 40 times higher than that of the KEKB collider. For high-precision track reconstruction,e.g. for measurements of time-dependent CP-violating decays and secondary vertices, the Belle II detector will be equipped with two layers of ultra-thin (75µm) active pixel detectors (PXD) close to the interaction point. The PXD consists of roughly 8M DEPFET pixels, which provide in-pixel amplification,high signal-to-noise ratio and non-destructive pulse height readout. The read-out and control ASICs are integrated onto the all-silicon module. The large stream of PXD data will be handled by several FPGA based data acquisition systems (DHE, ONSEN and DATCON). For the commissioning of the Belle II detector and SuperKEKB accelerator the BEAST detector is currently installed. Next to several radiation monitors it consists of 2 layers of the PXD and 4 layers of SVD. After machine tuning the first collisions are expected for the spring of

2018. In the meantime the production and commissioning of the final PXD is ongoing at full swing. This contibution will give an overview of the pixel detector and the status of the BEAST and final PXD detectors.

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The LHCb VELO Upgrade

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The CMS Outer Tracker Upgrade for the High Luminosity LHC

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Towards the realization of a SiPM-based camera for the Schwarzschild-Couder Telescope proposed for the Cherenkov Telescope Array

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The Italian Institute of Nuclear Physics (INFN) is involved in the development and construction of a Silicon Photomultiplier (SiPM) camera for the prototype of the Schwarzschild-Couder Telescope (pSCT) proposed for the Cherenkov Telescope Array (CTA).

SiPMs are particularly suitable to detect the fast and low-intensity Cherenkov light emitted in the atmosphere. Fondazione Bruno Kessler (FBK) has produced photosensors optimized for the detection of Cherenkov light in the Near-Ultraviolet spectral range (NUV SiPMs). After a deep characterization and study of these devices, the third generation of high-density NUV SiPMs (NUV-HD3) was chosen to equip a part of the camera of the pSCT. Each sensor is based on a 40 um x 40 um micro cell and has an area of 6 mm x 6 mm, providing high gain and excellent photo-detection efficiency (PDE) in the NUV wavelengths. SiPMs have been arranged in 4x4 sensor matrices, which will be used to equip a sector of the pSCT camera. For this purpose, 40 matrices have been built and tested. Here we present the results of the preliminary tests made on these matrices adopting an ad-hoc 16-channel read-out electronics. The performances and homogeneity in terms of gain and signal-to-noise ratio will be highlighted.

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The INFN Pixel Sensor R&D for the HL-LHC Upgrade of the CMS Experiment

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3D sensors (II) / 65

Radiation hardness of 3D pixel sensors up to unprecedented fluences of 3e16 neq/cm²

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The Quadropix DEPFET concept

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Currently, several development activities for the European Solar Telecope, a next generation, large aperture solar telescope are ongoing. Among its observational capabilities, EST will provide high time resolution, high precision polarimetric imaging of the solar atmosphere that can be utilized to determine the magnetic fields within and their temporal evolution. For these measurements, a new kind of polarimetric camera system providing modulation frequencies of the order of several kHz, frame rates of 400 Hz and an intrinsic storage capability for up to 4 modulation images is currently in development.
At the MPG HLL we developed a sensor concept for such a system - the Quadropix DEPFET. This novel concept provides in-situ storage of the information for four images. According to simulations, switching between different storage nodes is done within 100 ns and orders of magnitudes faster than the foreseen modulation frequencies. Furthermore, the modulation is decoupled from the frame

rate that is proposed to be 400 Hz for a 1 MPixel device. Within the scope of GREST and EST these devices can be used for high precision polarimetry. In this presentation we present the concept itself, a simulation study of Quadropix variants and the current development status.

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Qualification measurements of INFN-FBK 3D modules for High Luminosity LHC

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Characterization and simulation of small-pitch 3D diodes after irradiation up to 3.5×10^16 neq cm^-2

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Study of performances of 3D pixel devices from radioactive source measurements

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Design of 3D silicon sensors for high resolution time measurements

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Planar pixel sensors (I) / 72

FBK-INFN-LPNHE thin n-on-p pixel detectors: beamtest results

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CMS Pixel detector development for the HL-LHC with first results for HPK prototype sensors

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New approaches to HEP sensors at CiS

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Compilation of the results on characterization of ADVACAM edgeless pixel sensors

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Radiation-hard passive CMOS-sensors

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Characterization of H35 HV-CMOS Sensors before and after Proton Irradiation

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Depleted monolithic CMOS pixels using column drain readout for the ATLAS Inner Tracker

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Performance of the H35DEMO chip monolithic matrices before and after irradiation

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Effect of thinning and backplane processing on charge collection properties of irradiated CMOS

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E-TCT characterisation of irradiated backside biased H35DEMO pixel demonstrators

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Test Beam study of small-pitch 3D pixel sensors from CNM

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Recent developments on monolithic CMOS pixel sensors in TowerJazz 180nm technology

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Development of N-on-P planar technology at SINTEF MiNaLab

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Studies of the MaPSA-light Module for the CMS Phase II Upgrade

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Research and development of new radiation tolerant pixel Silicon sensors for the high-luminosity

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Recent Results with Ultra-Fast Silicon Detectors

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Development of Strip-type Low-Gain Avalanche Detectors

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Resistive AC-Coupling: a new read-out paradigm in 4D tracking with Ultra-Fast Silicon Detectors

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Radiation Damage Effects on LGADs and Deep Diffused APDs

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Study of the radiation resistance of different LGAD gain layer designs

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An in-depth study of Inverse-LGAD sensors

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Production and design of LGAD with high radiation resistance

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Two Photon Absorption-TCT of irradiated LGADs

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Operational Experience and Performance with the ATLAS Pixel detector with emphasis on radiation damage

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Silicon Sensors of the CMS High Granularity Calorimeter

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Modeling Radiation Damage to Pixel Sensors in the ATLAS Detector

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TCAD simulation of RD53A compatible pixel cells and sensor productions at MPP

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Advances on TCAD numerical modeling of silicon detectors operations at HL-LHC fluences

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Silicon detectors in medical applications and for characterization of laser-driven ion sources

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Results on Proton Tomography

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MoVeIT strip silicon detectors for proton beam monitoring: preliminary results

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Detector development for the WFI of Athena

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Displacement Damage Test of CMOS SPAD sensors for Space Application

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Random Telegraph Signal evidence in Proton Irradiated CMOS SPADs

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Monolithic Active Pixel Sensors for space applications: the case of ALPIDE

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Experimental Characterization and Future Sensor Developments for ARDESIA, a 4-Channels Fast SDD X-ray Spectrometer for Synchrotron Applications

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The DSSC Detector for the European XFEL: sensor options, readout electronics and experimental results.

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APiX: a pixelated avalanche sensor for digital charged particle detection.

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The APiX sensor is a position-sensitive detector operating in Geiger-mode regime.
This novel device, formed by two vertically-aligned pixel arrays, exploits the coincidence between two simultaneous avalanche events to discriminate between particle-triggered detections and dark counts.
This concept allows to reduce the material budget and the power consumption in the presence of a high granularity and fast timing response.
A proof-of-concept two-layer sensor with per-pixel coincidence circuits was designed and fabricated in a 150 nm CMOS process and vertically integrated through bump bonding.
The sensor includes a 48 × 16 pixel array with 50 μm × 75 μm pixels, with different active areas from 43 × 45 to 30 x 30 μm2.
The first prototype has been characterized and then tested with a high energy particle beam at CERN SPS, featuring a reduction of the dark-count rate (DCR) at room temperature by more than 4 orders of magnitude and a detection efficiency limited only by the geometric factor.
Extensive testing to evaluate radiation hardening are ongoing.
A second prototype, addressing the goal to improve the present fill-factor, has been designed and it is being manufactured.
A new and more refined beam test campaign has been planned at CERN SPS/PS before the end of the year, in order to better characterize the current demonstrator and test the new prototype.
Potential applications of this sensor include high spatial resolution tracking in high-energy experiments, radiation monitoring in space and imaging in nuclear medicine.
A small hand-held demonstrator is under construction for radio-guided surgery.

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APiX: a pixelated avalanche sensor for digital charged particle detection.

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Status of ATLAS Diamond Detectors

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The CT-PPS project: detector hardware, operational experience and prospects for 2018

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Characterization of acceptor removal in epitaxial silicon pad diodes

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Status of 3D detector development at SINTEF for ITk upgrade

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Radiation hardness study of HV-CMOS sensors using Transient Current Technique

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The Quadropix DEPFET concept

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EDET DH80K- A DEPFET based Ultra High Speed Camera System for TEM Direct Electron Imaging

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Towards the realization of a SiPM-based camera for the Schwarzschild-Couder Telescope proposed for the Cherenkov Telescope Array

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X-ray Detectors at PSI and Recent Developments using LGADs for Low Energy X-ray Detection

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TCAD Simulations of Silicon Sensors at HL-LHC Conditions

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Radiation-induced damage in silicon can be modeled in TCAD simulations through effective states in the energy gap,
what we call radiation damage models.
After a brief introduction about radiation-induced damage in silicon, in this talk I will present you some of the available
radiation damage models, how to implement them in TCAD tools and what are typical observables you can study in simulations.
I will also comment on some issues related to annealing and charge collection efficiency.
To conclude I will try to present the outlook for radiation-induced damage studies with TCAD simulation tools.

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Silicon Photomultipliers developed at FBK for Physics Applications

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Silicon Photomultipliers developed at FBK for Physics Applications

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Recent developments in Silicon Photomultiplier (SiPM) technology make it an attractive choice for large-scale Physics experiments, as an alternative to traditional Photomultiplier Tubes (PMTs). Potential advantages of SiPMs include high sensitivity, compactness, lower operating voltage, low cost, high gain uniformity and high radio purity.
Near Ultra Violet, High Density (NUV-HD) SiPM technology features peak photon-detection efficiency (PDE) of 65% at 410 nm, DCR at room temperature of 50 kHz/mm2, correlated noise of 10% at 55% PDE, and microcell pitch ranging from 15um to 40um. Recent interest in the SiPM readout of liquid scintillators (mainly Ar and Xe) triggered the development of a Low-Field variant of the NUV-HD technology (NUV-HD-LF). This technology is optimized for operation at such low temperatures and features a DCR of a few mHz/mm2 at 77 K. At this temperature, few-photon counting capability was demonstrated, with S/N of 13.8, using a 24 cm2 SiPM array coupled to a single analog readout channel.
As regards SiPMs application in high-radiation environments, FBK designed the Ultra-High-Density SiPMs (RGB-UHD), based on smaller cells size. Such a technology is aimed at reducing SiPM non-linearity in high dynamic range applications, such as in calorimeters, and to increase radiation hardness. Cell pitch ranges from a 12.5 um down to 5 um, corresponding to the remarkable cell density of 7400 and up to 46000 cells/mm2. The 10 um cell reaches a PDE of 35% at 515 nm, while the microcell recharge time constant is below 5 ns for the 7.5 microcell.

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Onset of shot noise in irradiated LGAD sensors

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In this presentation, I will report on a study of the onset of shot noise in irradiated LGAD sensors. High fluence generates high current, which leads to large shot noise. However, most of the leakage current measured in irradiated sensors does not contribute significantly to the noise, indicating that is collected without multiplication. We will show the strong relationship between noise and gain, and current and bias voltage.

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Edge-TCT results from AMS HV-CMOS test chips irradiated with 800 MeV protons

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The AMS (a)H18 and H35 processes are two of the most promising candidates for HV-CMOS detectors. One issue are their low standard resistivity (10-20 Ohm*cm) and therefore small depletion layers before irradiation of only about 10-20um.

While this issue was addressed by using higher-resistivity substrates (up to 1 kOhm*cm) in dedicated runs, the behaviour of the standard substrate after irradiation is still of interest. Earlier studies have shown that due to the high acceptor concentration, acceptor removal is the main bulk effect of NIEL irradiation. At the same time, the removal rates differ by a large factor between irradiations with reactor neutrons and 24 GeV protons at CERN. Both particle types are not representative for the HL-LHC environment, which will be dominated by mininum bias events generating mainly pions with few 100 MeV of energy. To come closer to this energy regime, a selection of AMS-produced chips have been irradiated with 800 MeV protons at LANCSE up to a fluence of 1.3e16 neq/cm2.

First results from edge-TCT measurements on these samples will be presented and a comparison to earlier neutron- and 24-GeV-proton results will be shown before giving an outlook on the implications of these results.

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edge-TCT results from AMS HV-CMOS test chips irradiated with 800 MeV protons

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TCAD simulation of RD53A compatible pixel cells and sensor productions at MPP

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In view of the high luminosity phase of the LHC (HL-LHC) to start operation around 2026, a major upgrade of the tracker system for the ATLAS experiment is in preparation. The expected neutron equivalent fluence of up to 2.4 × 1016 1 MeV neq./cm2 at the innermost layer of the pixel detector poses the most severe challenge. Thanks to their low material budget and high charge collection efficiency after irradiation, modules made of thin planar pixel sensors are promising candidates to instrument these layers. To optimise the sensor layout for the decreased pixel cell size of 50 × 50 µm2, three dimensional TCAD device simulations are being performed to investigate the charge collection efficiency before and after irradiation.

In addition, results of the latest silicon sensor productions at the Semiconductor Laboratory of the Max-Planck Society (MPG-HLL) will be presented. Amongst others, results of punch-through free testing methods as well as process optimisations with respect to the employed p-spray inter-pixel isolation technique are being shown.

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Monolithic Active Pixel Sensors for space applications: the case of ALPIDE

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In recent years, tracking charged particles has seen the rise of a new technology, based on Monolithic Active Pixel Sensors. With respect to silicon micro-strips and hybrid pixels, MAPS allow for low material budget and cheap sensors production using standard CMOS commercial technologies. Being developed for High Energy Physics, MAPS are currently proposed for uses in Nuclear Physics, Radiation Physics, Dosimetry and Medical Physics. This list still lacks space applications, because of the challenge of making MAPS technologically ready and compliant with space specs. We discuss here the use of MAPS for particle tracking in space, proposing solutions for issues like power consumption, cooling, alignment and readout. For some scientific cases, we describe the advantages of using MAPS in terms of energy threshold, tracking precision ad data compression. Finally, we present the case of ALPIDE, developed at CERN for the ALICE Inner Tracking System Upgrade and recently proposed for the High Energy Particle Detector of the Second China Seismic Electromagnetic Satellite.

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The RD53A chip

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A TCAD based model of double metal layer effects and a review of the radiation damage and monitoring of LHCb Velo

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The VErtex LOcator (VELO) is a silicon-strip detector located around the interaction region of LHCb. It is placed as close as 8 mm from the LHC beams undertaking a very high radiation damage.The

sensors have been exposed to fluences up to $3.5 \times 10^{14} 1MeV - neq/cm^2$. The digital processing performed on back-end boards requires approximately 1 million parameters.
Dedicated runs are performed to calibrate the processing algorithms. Regular voltage scans are taken to measure the collected charge and Cluster Finding Efficiency (CFE), determining the depletion voltage. An analysis over the whole calibration parameters history, the data quality assessment and the overall performance of the VELO and will be presented. The detectors are constructed with two metal layers to cover the R/ϕ strips and route the signal to the front-end chips. A loss of signal amplitude is observed with a dependency on the distance to the routing lines. A TCAD simulation was implemented with the detailed detector geometry.
Using the Perugia n-type bulk model and the Peltola surface damage model it is shown that up to 60\% of the charge is collected by routing lines. This is caused by trapping of the otherwise mobile electron accumulation layer at the oxide-silicon interface, causing the shielding effect on the routing lines to be reduced. The observed drop in CFE can be explained by the angular dependence of charge loss to the second metal layer. The efficiency drop as function of track radius and angle is reproduced combining 2D and 3D TCAD simulations.