26th RD50 Workshop (Santander)

Monday, 22 June 2015 - Wednesday, 24 June 2015

Santander

Book of Abstracts

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Defect and Material Characterization / 0

Analysis of electron mobility dependence on electron and neutron irradiation in silicon

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Irradiation by electrons causes rather small decrease of electron mobility, only at high fluence the tendency to appear of microinhomogeneities appear. The electron mobility decreases up to twice in the neutron irradiated up to fluence 1e16 cm-2. An origin of electron mobility change investigated by analyze of its temperature dependence. A possible fit to experimental data was found if the scattering on phonons, point defects, clusters and dipoles were includded in the consideration.
A desity functional method was used to analyze the electron charge distribution insice the cluster, and an existence of the dipole properties was observed.

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Status of CNM RD50 Projects

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I will report the status of the RD50 projects for LGAD and 3D detectors.

LGAD / 2

TCT measurements on neutron and proton irradiated LGAD diodes

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Red and IR LASER TCT measurements have been performed on LGAD samples fabricated in the Run7062. The study focuses on charge collection and gain properties before and after irradiation with neutron and protons up to fluences of 1E16$n_{eq}cm^{-2}$. A second focus is the analysis of inhomogeneous behavior observed during TCT surface scans with front and back side exposure. In unirradiated LGAD diodes this effect seems to appear only at low bias voltages while a shift to higher bias voltages can be observed after irradiation.

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New iLGAD detector development at CNM

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We will present the first technological developments at CNM to fabricate a new p-on-p position-sensitive-detector with low signal amplification useful as well for timing applications. This device is based on a double-sided LGAD with pad-like multiplication structure in the back-side and ohmic read out in the front side. It is has been named "inverted"LGAD (iLGAD).

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Time resolution of thin LGADs

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Thin Low-Gain Avalanche detectors are expected to have very good time resolution.
We analyze data from a CERN beam test and show the requirements for truly ultra-fast silicon detectors (UFSD).

LGAD / 5

Timing performance of the last CNM LGAD production

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In this talk I will present the most recent timing measurements performed in the last CNM LGAD production using the laser system in Torino.

HVCMOS / 6

E-TCT and charge collection studies with irradiated HV-CMOS detectors

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The charge collection mechanism in HVCMOS detectors produced by AMS was studied with Edge-TCT and by measuring signals from minimum ionizing particles before and after neutron irradiation with up to 5e15 n/cm2. The sensors were produced for investigation of HVCMOS technology for pixel and strip detectors for the experiments at HL-LHC. In reverse biased HVCMOS sensors studied in this work depleted layer is formed in relatively low resistivity p-type silicon. It was found that the change of depletion thickness with neutron fluence can be explained by initial acceptor removal process. Because of this effect charge collected after a MIP passage with irradiated sensor can significantly exceed the charge collected before irradiation in certain fluence range.

3D detectors / 7

Status of 3D detector activities at CNM

Author: Giulio Pellegrini[1]

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I will present the last fabrication run ongoing at CNM-IMB on 3D detectors activityes ofr the LHC upgrade.

Technological improvements / 8

TiN ALD layers for future pixel detector applications

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Atomic layer deposition (ALD) is well-established and reliable method for depositing thin film layers. Earlier we have demonstrated the use of ALD alumina (Al2O3) layers in the passivation of p-type silicon sensors. With alumina passivation we can leave out p-stop and p-spray structures and, thus, simplify the sensor manufacturing process. In the sensors used in the future upgrades of LHC experiments, the pixel size will be considerably smaller than in the current sensors. As a consequence, the small pixel size makes the realization of punch-through biasing structures very difficult. We have studied the use of ALD thin films as resistor material for the future pixel sensor applications. We will present the first results of Titanium nitride (TiN) thin films grown by plasma enhanced atomic

layer deposition (PEALD). This work has been done in collaboration with University of Helsinki, Department of Inorganic Chemistry and Micronova Centre for Micro and Nanofabrication.

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HV-CMOS device fabrication

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There are several on-going device submissions in HV-CMOS technology from groups working on ATLAS pixel and strip systems. The main objective of these submissions is device evaluation as a possible alternative to the sensor modules in pixels and strips. Along with functional evaluation of these monolithic devices, the basic questions regarding sensor radiation hardness need to be addressed for the relevant fluences. Some RD50 member groups already started working on this topic. The new submissions give the option of devices fabricated on intermediate resistivity wafers. We will present the test structure options and test possibilities that are available.

Test beams and lab tests / 10

Long term performance of silicon strip detectors under high bias voltage: charge collection and laser measurements

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Recently it has been shown that silicon strip detectors, especially irradiated and showing charge multiplication, have decreasing performance when tested for several days under high voltage conditions.
This behaviour has been in some cases explained in some cases by a surface effect[1], coming from the dose released in the silicon oxide by the source used for the measurements. Other studies[2] showed that the phenomenon didn't come from the source but from the high voltage stress.
In this work we present new performance results by means of charge collection and laser measurements on ATLAS detectors irradiated up to 2e15n_eq/cmˆ2.
They proof that the high voltage (higher than 1kV) is definitely a stressing factor and that part of the initial performance can be recovered by a resting time without bias or by thermal treatments.

[1] Klanner, TIPP, talk, 06.2014.
[2] Mori et al., NIM A proceeding, 03.2015.

Test beams and lab tests / 11

Tests of 50 µm thick silicon micro-strip sensors after extreme fluences up to 3x10^{16} neq cm^{-2}

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The development of silicon detectors tolerant to extreme fluences for future high energy and high luminosity hadron colliders (like the upgrade of the present Large Hadron Collider to high luminosity at CERN) is demanded not only for instrumenting the innermost layers (where pixel sensors will be deployed) but also for particle flow calorimetry. The anticipated fluence levels range from 2x10^{16} neq in the inner pixel layers to possibly 1x10^{17} neq cm^{-2} in the forward calorimeter region. The challenge is daunting, because of the large increase of the reverse current and the severe decrease of the signal recorder by the irradiated devices. The use of thin silicon detectors in charge multiplication regime could take the tolerance of silicon detectors further towards satisfying this requirement. We show here the experimental result obtained with silicon micro-strip sensors with a thickness of 50 µm irradiated to various fluences up to 3x10^{16} neq cm^{-2}. After irradiation the signal is studied with fast electrons from a radioactive source, to mimic the signal of minimum ionising particles. Additional IV measurements show the current of highly irradiated silicon sensors.

Defect and Material Characterization / **12**

Studies of initial acceptor removal in p-type silicon

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The studies of initial acceptor removal in high resistivity
p-type silicon detectors are scarce, mainly due to minor impact on operation of standard p-type detectors at high fluences expected at HL-LHC.
On the other hand initial acceptor removal is of prime importance for radiation
hardness of new detector technologies such as Low Gain Amplification
Detectors and HV-CMOS sensors, where the doping levels are up to several
orders of magnitude higher than in standard p-type sensors.

In this work the impact of acceptor removal in different detector
structures will be reviewed after neutron and charged hadrons irradiations.
The initial acceptor removal rate was found to depend on the concetration
and it is faster for charged hadrons than neutrons. The removal constants
for different material resistivities ranging from ˜1 Ohm cm to >10 kOhm cm
will be presented. Possible reasons for such behavior will be investigated
with means to mitigate or enhance the effect.

Test beams and lab tests / **13**

Update on Surface Studies of n-on-p Silicon Strip Sensors after irradiation to HL-LHC fluences: Prague status

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Surface properties of ATLAS12 n-on-p silicon sensors developed for the upgrade of the strip tracker of the ATLAS experiment were evaluated before and after irradiation. Different types of end-cap and barrel mini sensors were irradiated by gamma and protons at different irradiation sites. Influence of different sensor geometries, wafer resistivities and types of PTP structures on sensor stability and inter-strip properties was studied up to fluence 1E16 neq/cm2.

Summary:

It was verified that different geometries of end-cap and barrel sensors do not influence their stability; the sensors should provide acceptable strip isolation up to proton fluence 3E15 neq/cmˆ2.

LGAD / 14

A Compact/Educational-TCT presentation

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A presentation of small portable TCT will ge given. The system can be used as a tool for material studies or for educational purposes.

Technological improvements / 15

Embedded pitch adapters as a proposal for high-yield interconnection for strip sensors

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A status will be given on the proposal of the use of a second metal layer for the integration of pitch adaptors in the fabrication of large-área strip sensors for high energy physics experiments.

Summary:

The interconnection of sensors and readout electronics is a subject of critical importance in the realization of the module design for high energy experiments like ATLAS. The sensors are made progresively larger, and the readout electronics smaller, and both contain incleasingly more channels. The realization of the electronic connection between their channels is not trivial and becomes a yield issue when the

experiment contain millions of strip channels. The question is not anymore if the bonding can be done, but if it can be done reliably enough to build a whole tracker.
A proposal to fabricate large área strip sensors with built-in or embedded pitch adapters have been made for the End-Cap part of the Inner Tracker in the ATLAS upgraded experiment. Considerations on noise, pick-up, cross-talk, and yield effect on the sensors have been taken into account in the design and fabrication of the sensors. Test on interstrip capacitance will be shown that reveal the importance of a proper design. Technological limitations will be discussed and results on the tests of the different batches fabricated will be shown.

3D detectors / 16

Proposal for a new RD50 project "Strip sensors made of N-rich FZ silicon"

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Within this project we want to produce mini strip sensors on FZ and N-rich FZ wafers to compare CCE at high fluences.

LGAD / 17

Study of irradiated NinN production and LGAD dopping profiles

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Trough SiMS measurements, the evolution of the doping profile is been studied for irradiated NinN samples at fluences of 10e15neq/cm2, while the transient current technique is used on diodes of the same implantation profile n order to evaluate the electrical characteristics evolution as a function of the received dose. Comparison and conclusions are established with the non-irradiated case both for the profile evolution and the intrinsic characteristics of the samples. A SiMS vs process simulation approach is used to model and control the new LGAD production in an attempt to understand post irradiation behavior and electrical characteristic.

Test beams and lab tests / 18

Update on radiation hardness of Silicon Diodes for the future CMS High Granularity Calorimeter (HGCAL).

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The CMS collaboration is planning to upgrade the forward calorimeters as these will not be sufficiently performant with the expected HL-LHC (High Luminosity LHC) conditions. After CMS committee decision, the High Granularity Calorimeter (HGC) is the technology chosen for this upgrade. It is realized as a sampling calorimeter with layers of silicon detectors that feature very high longitudinal and lateral granularities, and a coarser segmentation backing hadronic calorimeter based on scintillators as active material. The sensors are realized as pad detectors of size in the order of 1 cm2 with an active thickness between 100µm and 300µm depending on the position respectively the expected radiation levels. After the first results on neutron irradiation of 300µm, 200µm and 100µm n-on-p and p-on-n devices that have been irradiated to fluences up to 1.5E16 n/cm2 at Ljubljana Nuclear Reactor; We present, the latest results in terms of radiation hardness of these pad detectors.

3D detectors / **19**

Recent progress on 3D pixel detectors

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3D pixel detectors have advanced rapidly recently, leading to their first successful installation in the ATLAS IBL and the decision to install them in the ATLAS Forward Proton (AFP) experiment, which is foreseen as early as this year's winter shutdown. 3D detectors are also a promising candidate for the innermost layer of trackers in the HL-LHC experiments. This presentation will summarise the recent developments with a focus on studies concerning radiation hardness and slim-edge properties, which includes laboratory and testbeam characterisations before and after irradiation.

3D detectors / **20**

Recent testbeam results of 50 µm pitch 3D sensors at high incidence angle for HL-LHC

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Highly segmented (50x50 µm^2) silicon sensors imply a challenge on the forward regions of the tracker (high-ŋ). Although under such conditions the total charge deposited is large, due to the high segmentation, the charge deposited per pixel is ˜3.3ke along the 50 µm pitch pixel (1-2 times the typical

threshold in an FE-I4 chip). This low charge collection could lead to high pixel inefficiencies and cluster splitting, reducing and biasing the spatial resolution of the tracker.
Structures with 50x50 µm² pixels are not yet available for testbeam studies, so standard FE-I4 compatible 3D sensors with pixel pitch 50x250 µm² were studied under high incidence angle (80°) with respect to the short pixel direction in order to investigate the behaviour of small-sized pixels in the forward region of the tracker. Per pixel efficiency (as opposed to the standard hit efficiency per cluster) and charge collection along large clusters of IBL-like CNM and FBK 3D designs are studied before and after irradiation.

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Modelling Radiation Induced Vacancy-Interstitial Clusters

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High energy particle irradiation created cluster defect model is based on the particle bombardment process scenario. The incident particle strikes the crystal lattice at the point of interaction and initiate the movement of lattice ions along with itself. The moving group of ions leave the vacancy region behind itself and further destroy the lattice structure causing other ions to leave their stable crystalline positions. By the end of destruction process the three defect regions are formed: region of vacancies, disordered region of randomly distorted lattice ions and the region of interstitials. These three subregions form the vacancy-interstitial defect cluster. After the irradiation the relaxation of defect region may take place with interstitials returning back to the vacancy positions thus partially restoring crystalline lattice structure within a defect cluster.
The electronic states within such a cluster and its environment are calculated using density functional method. Compared to earlier simulation results obtained by E. Holmström et al (2010) and our group (E. Zasinas et al, 2014, 24th Cern RD50 workshop) the newly proposed cluster defect model has a much richier deep level structure. The earlier studied cluster model was considered as a region of randomly displaced ions giving rise to acceptor type of deep level states originating from the broken interatomic valency bonds. The model presented in this work exhibit both acceptor states and donor states. It is suggested that the broken valency bonds in vacancy subregion give rise to the deep level acceptor states and the valency electrons of the extra atoms in the interstitial atoms subregion give rise to the deep level donor states. Thus sush an assymetric deffect cluster may act both as acceptor and donor type of deffect in electronic devices.
E. Holmström et al, Phys. Rev. B 82, 104111 (2010).

Simulations / **22**

Signal formation in segmented Si planar detectors: TCAD simulated effect of SiO2 passivation layer

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Measurements have shown a reversal of the pulse polarity in the detector response to short-range charge injection

[V. Eremin et al., NIM A 500 (2003) & E. Verbitskaya et al., IEEE TNS 52 (2005) NO. 5]. Since the measured negative
signal is about 30–60% of the peak positive signal, the effect strongly reduces the CCE even in non-irradiated detectors.
For further investigation of the phenomenon the measurements have been reproduced by TCAD simulations. Similar to
the measurement, the simulation study was applied for the p-on-n strip detectors with each strip having a window
in the metallization covering the p+ implant allowing the generation of electron-hole pairs under the strip implant.
Red laser scans across the strips and the interstrip gap with varying laser diameters and Si-SiO2 interface charge
densities were carried out. The scans were repeated with an IR laser and for the n-on-p strip detectors. The simulation
results offer a further insight to the role of the oxide charge density in the signal formation. Also results of
the dependence on the charge injection depth and sensor polarity will be presented.

Summary:

The effect of SiO2 passivation layer to the signal formation in segmented Si p-on-n and n-on-p detectors was TCAD simulated by both red (670 nm) and infrared (1060 nm) laser injections.

LGAD / 23

Progress on the Two-Photon-Absortion TCT technique

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After the first proof-of-concept of the TCT technique based on the Two-Photon-Absortion process using a 1300nm femtosecond laser on non-irradiated silicon diodes. we aim to complete the feasibility study of the TPA-TCT technique on irradiated sensors. As it is well known, irradiation creates localized deep energy levels (DL) inside the semiconductor's forbidden gap between the conduction and valence bands. The radiation-induced DLs will enhance the photon absorption cross-section of the single photon absorption process (SPA) and two-step photon absorption process (TSPA). This project aims to quantify this increase of the SPA and TSPA cross-section in irradiated sensors with respect to the TPA cross-section.

Test beams and lab tests / 24

Investigation of hit efficiency of n-in-p pixels with different designs

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We present results of n-in-p pixel sensor prototypes of 100 to 270 µm thickness with different designs, focusing on alternative implementations of punch-through structures. A comparative study has been performed on pixel modules by means of radioactive sources and beam test measurements at the CERN-SPS and DESY. The results of these measurements will be discussed for devices irradiated up to a fluence of 3e15 neq cm-2. In addition, the charge collection properties at different depths inside the silicon bulk have been studied before and after irradiation with the grazing angle technique. The results will be compared to predictions of TCAD simulations. Charge collection and power dissipation properties have been investigated as a function of different operational temperatures.

Simulations / **25**

Status of 3D Detectors TCAD Simulations

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We will present our results with TCAD Simulations of three different 3D Devices (ROC4Sense, Fermilab, PSI46). We have I-V, C-V and MIP simulations before and after irradiation up to 2e15 n_eq/cm2. Also include will be a glimpse of our present effort for LGAD device simulations on MIP hit.

Summary:

TCAD Simulations (IV, CV, MIP, Irradiated (IV, CV, MIP)) of 3D Detectors

Defect and Material Characterization / **26**

Defect generation and damage functions in electron irradiated silicon-dependence on particle energy

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The study of high resistivity n-type silicon diodes irradiated with electrons of energies ranging from 1.5 MeV to 27 MeV have enabled us to scan the generation, time evolution and generation rates of point defects and small defect clusters having a direct impact on the device performance over a large irradiation fluence range. It is shown that this offers the unique opportunity to follow the different formation of point and cluster defects as correlated with Non Ionizing Energy Loss NIEL calculated either with binary code (BCA) or molecular dynamics (MD) approaches. The generation

of point defects is well described by the "classical NIEL"(BCA), the formation of small defect clusters is better described by the "Effective NIEL"(MD).

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Welcome speech by UIMP vice-dean

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Technical information

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Ongoing R&D Activities at CiS Forschungsinstitut fuer Mikrosensorik: Bump Bonding

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Smaller dimensions for CMS and ATLAS pixel sensors require smaller dimensions for the under bump metallisation (UBM) and for the solder bumps which are connecting the radiation sensors to the FE-I chips. Whereas 40 to 50 µm large solder bumps are state of the art, future bumps have to be smaller than 30 µm. Another future task is to increase the number of solder bumps per area. CiS is working at overcoming these challenges by applying maskless, less expensive technologies as (single) solder ball placement and light induced plating.

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Sensor Development for the LHCb VELO Upgrade

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The upgrade of the LHCb experiment, planned for 2018, will transform the experiment to a trigger-less system reading out the full detector at 40 MHz event rate. All data reduction algorithms will be executed in a high-level software farm with access to the complete event information. This will enable the detector to run at luminosities of 2 1033cm-2s-1 and probe physics beyond the Standard Model in the heavy
avour sector
with unprecedented precision.
The Vertex Locator (VELO) is the silicon vertex detector surrounding the interaction region. The current detector will be replaced with a hybrid pixel system equipped with electronics capable of reading out at 40 MHz, designed to withstand the irradiation expected at an integrated luminosity of 50 fb1 and beyond. The upgraded VELO will form an integral part of the software trigger, and must provide fast pattern recognition and track reconstruction while maintaining the exceptional resolution of the current detector. The detector will be composed of silicon pixel sensors with 55 55 m2 pitch, read out by the VeloPix ASIC which is being developed based on the TimePix/MediPix family. The hottest region will have pixel hit rates of 900 Mhits/s yielding a total data rate more than 3 Tbit/s for the upgraded VELO.

An additional challenge is the non uniform nature of the radiation damage, which results in a need for excellent high voltage control on the sensor guard ring design. The performance of the sensor-ASIC bump bonded assemblies has been investigated in a test-beam in which the two arms are equipped with Timepix3 sensors, and the device to be tested can be mounted, rotated, and cooled in the central region. This allows tests of the speed and time tagging performance of the ASIC, together with the performance of the sensor after irradiation. Photos and gures from the testbeam setup are shown in gure 1.

The material budget will be minimised by the use of evaporative CO2 coolant circulating in microchannels within 400 m thick silicon substrates. Microchannel cooling brings many advantages: very ecient heat transfer with almost no temperature gradients across the module, no CTE mismatch with silicon components, and low material contribution. This is a breakthrough technology being developed for LHCb.
Results from the irradiation and testing campaign will be shown, including the calibration of the Timepix, the operation of irradiated assemblies and charge collection, and the high voltage behaviou before and after irradiation. Results will be showsn from testbeam and lab environments.

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Discussion on HVCMOS and discussion on Simulations

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Radiation hardness of neutron irradiated HVCMOSv3

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Radiation hardness of HVCMOSv3 to neutron irradiation was studied by using edge-TCT. The fluence range covered was 0, 1e15, 7e15 and 2e16 neq/cm-2. A test diode providing analog signal was readout using a fast current amplifier. The detector was mounted on a very simple PCB which allowed for a clean signal readout. Results on charge collection and depletion width are presented. Due to the very low resistivity of the substrate (10 Ohm.cm) the active region thickness is smaller than the beam width. A first attempt to calculate the true active thickness was essayed.

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Test beam and clean room studies of ATLAS PPS modules with alternative bias rail geometries

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It is known that for the current design of planar pixel sensors, there is a drop of efficiency at the punch-through structure of the biasing system at the edge of pixels. Various geometries, as part of the ATLAS Inner Tracker (ITK) upgrade, are being investigated to reduce this inefficiency.

Planar pixel sensors with multiple alternative bias rail geometries have been tested at the SPS beam test facility at CERN in late 2014 with the FE-I4 beam telescope, with results focusing on the efficiency within the pixel. Measurements of the pixel detectors in a clean room before and after irradiation were performed to study the noise for the varied designs. Future plans for further investigations are also discussed.

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A preliminary look at HV-CMOS eTCT data after p-irradiation

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First look at the results of proton irradiated detectors will be presented

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Hands on demonstration from Alibava

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