Application for Transnational Access to the CERN Testbeam and usage of the EUDET telescope

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on behalf of the ATLAS PPS collaboration

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For the LHC phase I upgrade a new innermost layer for the ATLAS pixel detector is being developed, the Insertible B-Layer, IBL. For this detector upgrade the ATLAS Planar Pixel Sensor (PPS) R&D collaboration is currently researching ways to improve radiation hardness and performance of the proven planar silicon sensor technology.
To test various new sensor structures a test beam measurements will be performed in the CERN SPS testbeam area between 5^{th} and 19^{th} november 2009. The EUDET pixel telescope will be used for tracking and triggering purposes. We would like to apply for travel support for 4 people for 14 days.

1 Introduction

The current ATLAS Pixel Detector is designed to withstand a non-ionizing dose of up to $2 \mathrm{x} 10^{15}$ n_{eq} cm^{-2}. The innermost layer will accumulate this dose after about five years of operation and will start to degrade. Therefore a new pixel layer will be inserted close to the beampipe. This small radius of 3.7 cm results in an expected lifetime dose of about $4 \mathrm{x} 10^{15}$ n_{eq} cm^{-2}.
Within the R&D project on Planar Pixel Sensors (PPS) for the ATLAS pixel detector upgrade, the use of planar pixel sensors for highest fluences as well as large area silicon detectors is investigated. The main research goals for the IBL upgrade are optimizing the signal size after irradiation, reducing the inactive area at the sensor edges, and adjusting the readout electronics to the radiation induced decrease of the signal size.
Available data on strip detectors from RD50 indicate that planar pixels based on electron collection might provide satisfactory charge collection for all pixel layers. The pixel geometry needs to be optimized with regards to charge collection efficiency and charge sharing at high proton fluences.

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2 Research areas

2.1 Evaluation and improvement of radiation hardness

The properties of n- and p-type silicon under irradiation are rather well known to fluences on the order of $2\text{x}10^{15}$ n_{eq} cm^{-2}. The dose of non-ionizing radiation, that the insertible B-Layer is expected to accumulate during it's lifetime is about a factor of two higher, with the expected dose for the phase II upgrade about a factor of ten higher.
Recent studies of the charge collection efficiency of both n-in-n and n-in-p strip and pad sensors have shown evidence of some kind of charge multiplication effect, taking place in highly irradiated sensors in the presence of high electric fields. Under these conditions charge collection efficiencies of 1 and even above have been demonstrated for float-zone silicon sensors irradiated to $2\text{x}10^{16}$ n_{eq} cm^{-2} [1].

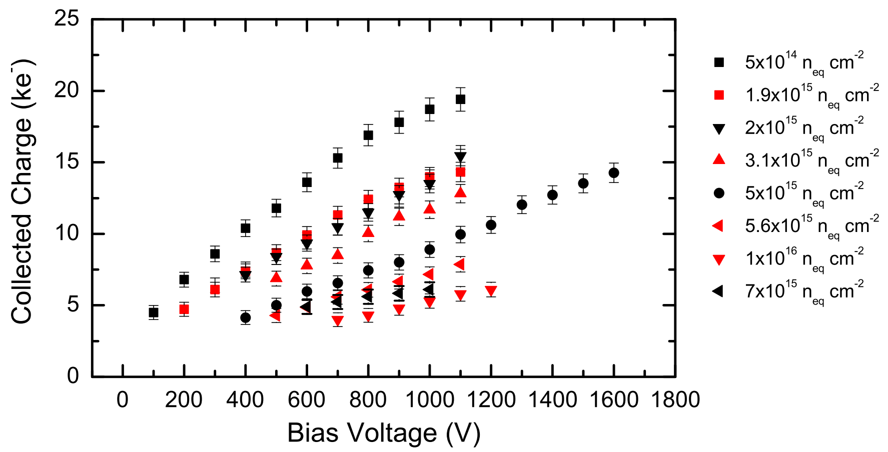

Figure 1: Collected charge for a MIP traversing a 300μm thick sensor as a function of bias voltage after different proton fluences [2].

A further parameter being studied is the thickness of the sensor. First results show that 140μm thick sensors might be superior to thicker sensors, regarding charge collection efficiency after irradiation.
Recent productions of sensors both on n-type and on p-type float-zone material have produced prototypes of sensors whose design is close to that of the current ATLAS pixel sensor. Some of these prototypes are currently being irradiated with neutrons and protons to fluences similar to the IBL fluence to study their performance and possibly the onset of the charge multiplication effect.

To be able to study the spatial resolution of highly irradiated sensor the excellent resolution of the EUDET telescope of few μm is crucial.

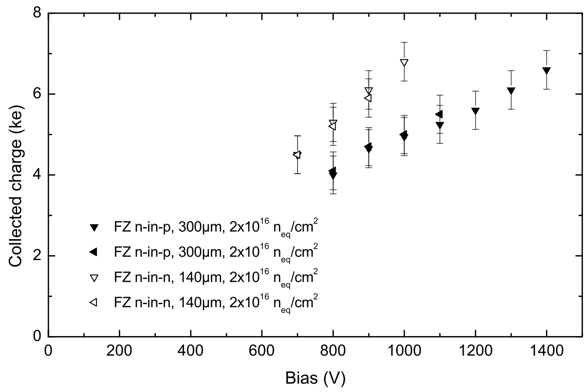

Figure 2: Comparison of 300 μm and 140 μm thick sensors after neutron irradiations [2].

2.2 Low threshold operation

As the total collected charge after irradiation is expected to be on the order of 5000 to 10000 electrons it is necessary to minimize the effective discriminator threshold of the readout electronics. For this purpose studies are being conducted into the operation of the current FE-I3 readout chip at thresholds below the ATLAS standard threshold of 4000 electrons.
First results show that the chip can be operated stably at a threshold of 1100 electrons with a noise occupancy that is still compatible with the requirements for ATLAS. This kind of threshold configuration however has to be tested under real operating conditions, like the testbeam environment, to verify the stable operation.

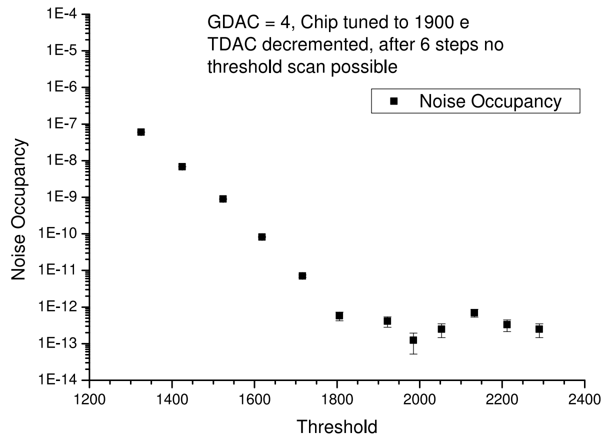

Figure 3: Noise occupancy as a function of discriminator threshold for a FE-I3 single-chip assembly with 250 μm thick sensor [3].

2.3 Reduction of inactive area

The current baseline mechanical design for the IBL consists of flat local support structures that do not allow shingling of neighboring modules. Therefore the inactive region at the edge of the sensor has to be minimized, to obtain the maximum active area of the detector. Studies are being conducted on the possibility of slimming the guard ring structures, reducing the overall number of guardrings on the sensor or moving the innermost guardrings opposite to the outermost pixel implantations.
One way to further reduce the minimum number of guardrings necessary is to use etching techniques to cut the sensor dice from the wafers instead of sawing them, which damages the silicon lattice structure thus increasing conductivity along the edge of the sensor.
For the different samples produced using these technologies the hit efficiency as well as the charge collection efficiency close to the edge of the sensor have to be studied to determine the influence of the different shapes of electric fields in this region. One of the goals of the testbeam measurements is therefore to concentrate on these regions, making use of the excellent position resolution of the EUDET telescope.

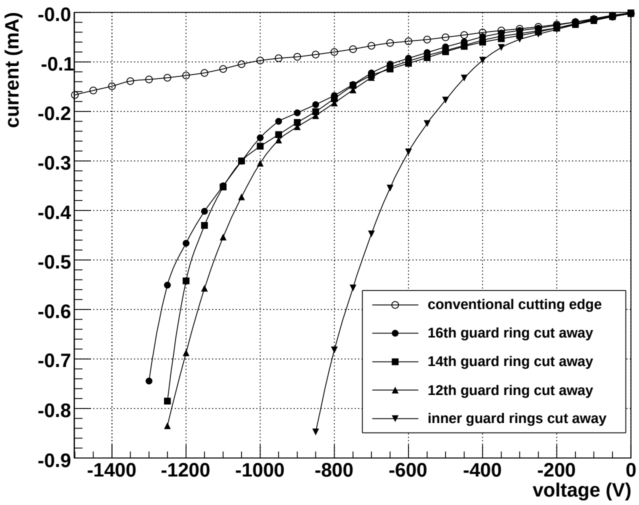

Figure 4: Leakage current characteristics of pixel sensors irradiated to $2\text{x}10^{16}$ n_{eq} cm^{-2} with different number of guard rings [2].

3 Measurement program

The measurement program for this testbeam period will concentrate on the spatial resolution and the charge collection efficiency of the various devices. Especially we will focus on hit efficiency of trench etched devices close to the edge of the sensor and two-dimensional mapping of the charge collection efficiency of sensors irradiated to IBL fluences.

4 People and Funds

The people participating in the measurements and the setup of the system are members of the ATLAS PPS R&D collaboration. The preparation of the testbeam is coordinated by Jens Weingarten (Goettingen University) in close contact with Georg Troska (Dortmund University). Also Andre Rummler (Dortmund University) and Mathieu Benoit (LAL Orsay) will be participating in the testbeam effort at CERN. These are the four people, for which we request travel support for the whole period of 14 days.

References

[1] A. Affolder, P. Allport, G. Casse, *Charge Collection Efficiency Measurements of Heavily Irradiated Segmented n-in-p and p-in-n Silicon Detectors for Use at the Super-LHC*, IEEE TNS Vol. 56, No. 3, 2009

[2] M. Beimforde, *The ATLAS Planar Pixel Sensor R&D project*, to be published in proceedings of 7th International "Hiroshima" Symposium, 2009

[3] M. Backhaus, diploma thesis in preparation, University of Bonn, 2009