TIPP 2011 - 2nd International Conference on Technology and Instrumentation in Particle Physics

Contribution ID: **33** Type: **Oral Presentation**

Performance of Silicon n-in-p Pixel Detectors irradiated up to 5E15 n eq. /cm**2 for the future ATLAS Upgrades

Thursday 9 June 2011 15:00 (20 minutes)

We present the results of the characterization of novel n-in-p planar pixel detectors, designed for the future upgrades of the ATLAS pixel system. N-in-p silicon devices are a promising candidate to replace the n-in-n sensors thanks to their radiation hardness and cost effectiveness, that could allow for an increased pixel instrumented area at larger radius.
The n-in-p modules presented here are composed of pixel sensors produced by CiS (Germany) connected with bump-bonding to the FE-I3 ATLAS readout chip. Differently than for the n-in-n technology, the n-in-p pixel sensors, 285 microns thick, are characterized by a guard-ring structure implemented on the front-side, avoiding the necessity of a double-side process. An additional passivation layer of Benzocyclobutene (BCB) has been applied on the sensor surface to prevent sparks between the sensor edges, at high voltage, and the chip, kept at ground, facing each other at a distance of about 25 microns.
The characterization of these devices has been performed with the ATLAS pixel read-out systems, TurboDAQ and USBPIX, before and after irradiation with 24 GeV/c protons and neutrons up to a fluence of 5E15 n eq. /cm**2. The CCE measurements carried out with radioactive sources have proven the feasibility of employing this kind of detectors up to these particle fluences. The collected charge has been measured to be always in excess of twice the value of the FE-I3 threshold, tuned to 3200 e-. In particular, pixel detectors irradiated at a fluence of 5E15 n eq. /cm**2 yield a charge of 8000 e- at a bias voltage of 800V.
The analysis of the data from a beam test with pions at CERN-SPS, also presented, yield high tracking efficiency of these devices before and after irradiation.
A new pixel production at CiS is in preparation for sensors compatible with the new ATLAS FE-I4 chip and reduced thickness (down to 150 microns) to investigate the radiation hardness of thinner detectors at HL-LHC (High Lumi HLC) fluences.

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Session Classification: Semiconductor Detectors

Track Classification: Semiconductor Detectors