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Recent progress of the ATLAS Planar Pixel Sensor R&D Project

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Abstract

The foreseen luminosity upgrade for the LHC (a factor of 5-10 more in peak luminosity by 2021) poses serious constraints on the technology for the ATLAS tracker in this High Luminosity era (HL-LHC). In fact, such a luminosity increase leads to increased occupancy and radiation damage of the tracking detectors.

To investigate the suitability of pixel sensors using the proven planar technology for the upgraded tracker, the ATLAS Planar Pixel Sensor R&D Project was established comprising 17 institutes and more than 80 scientists. Main areas of research are the performance of planar pixel sensors at highest fluences, the exploration of possibilities for cost reduction to enable the instrumentation of large areas, the achievement of slim or active edge designs to provide low geometric inefficiencies without the need for shingling of modules and the investigation of the operation of highly irradiated sensors at low thresholds to increase the efficiency.

In the following I will present results from the group, concerning mainly irradiated-devices performance, together with studies for new sensors, including detailed simulations.

Keywords: Silicon pixel detectors, planar sensors, radiation damage to detector materials (solid state), detector simulations, ATLAS upgrade, HL-LHC, SLHC

1. Introduction

ATLAS [1] is a general purpose detector for the study of primarily proton-proton collisions at the LHC [2].

The ATLAS Inner Detector [3, 4] provides charged-particle tracking with high efficiency over the pseudorapidity range $|\eta| < 2.5$. The pixel detector system [5] is the innermost element of the Inner Detector. The pixel detector contains approximately 80 million channels and provides pattern recognition capability in order to meet the track reconstruction requirements of ATLAS at the full luminosity of the LHC of $\mathcal{L} = 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$.

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`https://twiki.cern.ch/twiki/bin/view/Atlas/PlanarPixelUpgrade`

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Consisting of three barrel layers (at radii between 50.5mm and 122.5mm), and six discs, the pixel detector counts a total of 1744 pixel modules, which are mounted allowing for a three-hit track-reconstruction of charged secondary-particles. Each module contains a 250 μm thick n-in-n pixel sensor of 62.6×18.6mm^2 with pixel cells of 50×400 μm^2. Connected to each sensor are 16 7.4×11.0mm^2 ATLAS FE-I3 [6] readout chips with a total of 46080 channels. Both the sensors as well as the electronics of the present ATLAS pixel modules were specified to work up to a fluence of 10^{15}n$_{eq}$/cm^2 and an ionising dose of 50 MRad.

While the nominal luminosity of the present LHC accelerator is 10^{34}cm^{-2}s^{-1}, an upgrade to increase the luminosity by a factor of ten (five with luminosity leveling) is planned to be carried out in a two phase process [7]. After a first shutdown, foreseen for 2017, the *Phase 1* of LHC will start, with the target luminosity of $(2-3) \times 10^{34}$cm^{2}s^{-1}. A second shutdown will take place after 2020; then the *Phase 2* will start, and the expected luminosity is 5×10^{34}cm^{-2}s^{-1} with luminosity levelling. By 2030 a total integrated luminosity of $O(3000\text{fb}^{-1})$ is envisaged. Based on this scenario the innermost layer of the ATLAS pixel system will have to sustain fluences above 1×10^{16} n$_{eq}$/cm^2 [8]; see also figure 1.

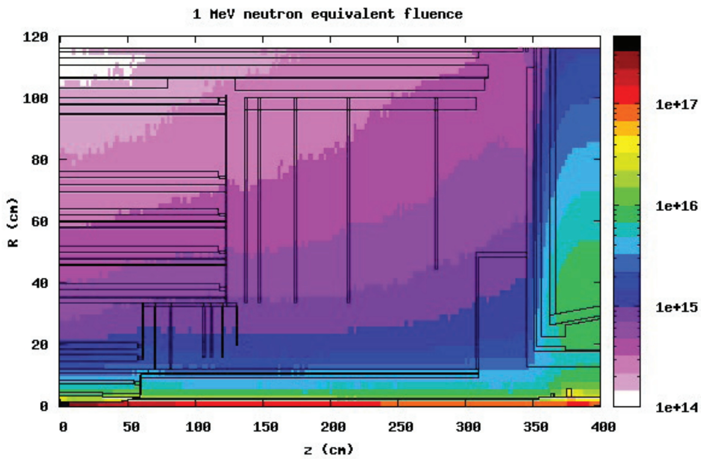

Fig. 1. Fluences in n$_{eq}$/cm^2 expected for a phase II integrated luminosity of 3000 fb^{-1}. A safety factor of 2 is applied.

The main effects on the pixel sensors from these large fluences are an increase of the leakage current and a reduction in the charge collection efficiency. The final goal is to retain a good hit-efficiency up to the final integrated luminosity.

Another high-luminosity related effect is the increase of the occupancy of the detector. A natural option is to reduce the size of the elementary pixel cell; at the same time the spatial resolution will improve. The reduced size of the elementary cell is just one of the features of the new read-out chip for the pixel system, the FE-I4 [9] chip; the total surface of the FE-I4 chip is 20.0×18.6 mm^2. Moreover, replacing the strips of the Inner Detector with pixel detectors might be an option to handle the occupancies foreseen at the HL-LHC.

Hence, in view of a possible pixel system replacement in 2017; and then, maybe, for a whole new tracking system after 2020, a new Pixel System is under study. The new pixel sensors will have not only to sustain the harsher environment, but also to show high geometrical acceptance: for the future the material budget restrictions and the geometrical limitations ask for geometry inefficiency to be below 2.5%. Hence the inactive areas of the future pixel sensor should be less than 450 μm wide [10].

Different sensor options are being developed in parallel to address the challenges imposed by the forseen luminosity upgrades. They include diamond sensors [11] and 3D-sensors, with implants going through the silicon bulk [12]. Optimizing the well-known technology of planar silicon pixel sensors for the ATLAS