Journal of Instrumentation

Overview of the ATLAS insertable B-layer project

To cite this article: F Djama 2013 *JINST* **8** C01034

View the article online for updates and enhancements.

PUBLISHED BY IOP PUBLISHING FOR SISSA MEDIALAB

RECEIVED: *October 8, 2012*
ACCEPTED: *December 2, 2012*
PUBLISHED: *January 22, 2013*

14th INTERNATIONAL WORKSHOP ON RADIATION IMAGING DETECTORS,
1–5 JULY 2012,
FIGUEIRA DA FOZ, PORTUGAL

2013 JINST 8 C01034

Overview of the ATLAS insertable B-layer project

F. Djama[1]

CNRS/CPPM, Aix-Marseille Université, CNRS/IN2P3,
163 Route de Luminy, Case 902, 13288, Marseille Cedex 9, France

E-mail: djama@cppm.in2p3.fr

ABSTRACT: The upgrades for the ATLAS Pixel Detector will be staged in preparation for high luminosity LHC. The first upgrade for the Pixel Detector will be the construction of a new pixel layer which will be installed during the first shutdown of the LHC machine, foreseen in 2013-14. The new detector, called the Insertable B-layer (IBL), will be installed between the existing Pixel Detector and a new smaller radius beam-pipe. The IBL will be located at an average radius of 3.3 cm. The IBL required specific developments to cope with increased radiation and pixel occupancy and also to improve the physics performance through reduction of the pixel size and a more stringent material budget. Two silicon sensor technologies have been pushed forward to fulfill the IBL requirements: thin planar sensors and 3D double side sensors, both with slim edge. An overview of the IBL project, of the module design and qualification with particular emphasis on irradiation tests will be presented.

KEYWORDS: Particle tracking detectors; Large detector systems for particle and astroparticle physics; Particle tracking detectors (Solid-state detectors)

[1]On behalf of the ATLAS collaboration.

doi:10.1088/1748-0221/8/01/C01034

Contents

1 Introduction

The ATLAS [1] Collaboration at the LHC (Large Hadron Collider) [2] is constructing an additional fourth layer to its silicon Pixel Detector [3], called the IBL (Insertable B-Layer). This barrel layer will be at 3.3 cm from the beam axis (present innermost B-Layer is at 5 cm), will have a smaller pixel size ($50\,\mu$m $\times$ $250\,\mu$m) compared to the present $50\,\mu$m $\times$ $400\,\mu$m, and will be readout by the newly developed FE-I4 circuit [4]. The IBL package, consisting in a new beam pipe, the IBL itself and its services will be inserted inside the present Pixel Detector in 2014, during the first long shutdown of the LHC.

The IBL will operate untill 2022 at a maximal peak luminosiy of $2 \times 10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$. It has to withstand a NIEL (Non Ionizing Energy Loss) of 5×10^{15} 1 MeV neutrons equivalent per cm^2 and a dose of 2.5 MGy, which is five times the requirements for the B-Layer.

A fourth pixel layer will compensate for module failures and luminosity induced saturation effects in the present Pixel Detector. Having smaller pixels and being closer to the beam, the IBL will reduce the fake tracks arising from random combinations of hits and enhance efficiency of tagging heavy flavour quarks. Tracking in dense hadronic jets and b quark tagging capability are key performance to measure the Higgs boson properties in the $WH \to b\bar{b}$ channel. These studies will benefit from the neural network based clusterization method [5], which allows to split large clusters induced by several particles, in dense high momentum hadronic jets.

2 Requirements

Simulation studies [6] set requirements for IBL, to fullfil the goals mentioned above. The very small available space prevents overlaps between sensors along the beam axis, resulting in a strong requirement for the sensor inactive edge, to minimize the unvoidable inefficiencies. The amount of

2013 JINST 8 C01034

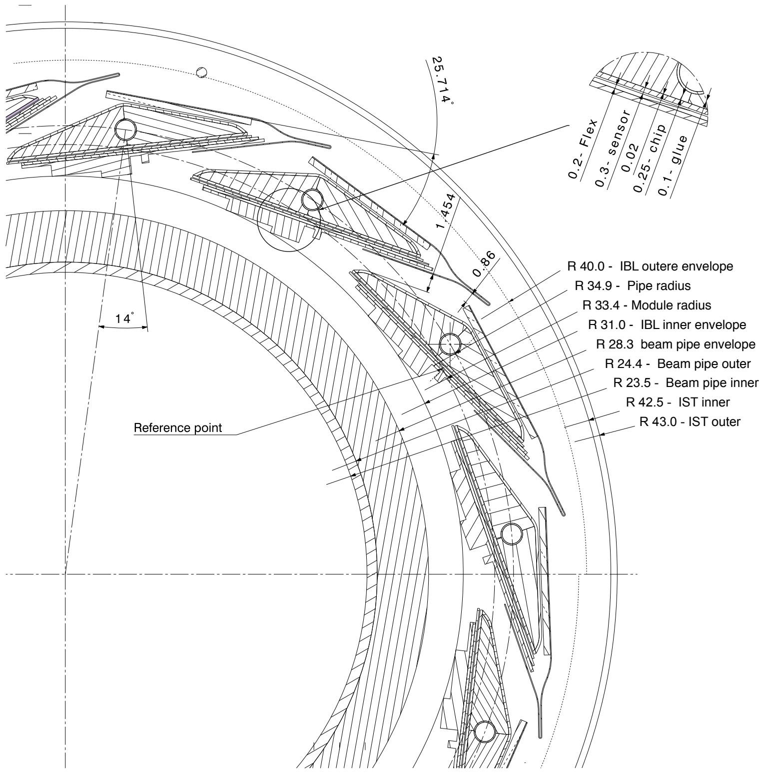


Figure 1. Drawing of the IBL pixel layer in the ATLAS experiment [7].

material should not be higher than 1.5% of a radiation length. This have consequences not only on sensors and front-end chips, but also on mechanics, cooling system and services.

Increasing the bias voltage (up to 1 kV for n-in-n silicon planar sensors) will compensate for radiation effects. A maximal power dissipation of $200\,\mathrm{mW/cm^2}$ is required to allow the cooling system to be operational at the end of the IBL lifetime. A hit efficiency as large as 97% is also required.

3 Mechanics and services

The IBL will be a 72 cm long cylindrical layer, formed by 14 staves around the beam axis, at an average radius of 3.3 cm (figure 1) [7]. Staves are loaded with pixel modules, which consist in sensor-readout chips assemblies.

Staves are assemblies of carbon foam, housing a titanium cooling pipe and stiffened by a carbon fiber laminate shell (figure 2) [7]. Services (low and high voltage, configuration, data readout, monitoring) are routed using a polyimide-aluminium-copper multilayer circuit, called flex, glued on the stave. It is connected to front-end chips by dedicated wings.

4 Sensors

The ATLAS collaboration chose n-in-n planar silicon sensors with a slim edge [8] and the newly developed silicon 3D sensors [9] to equip the IBL. 3D sensors are placed at high pseudorapidity (at

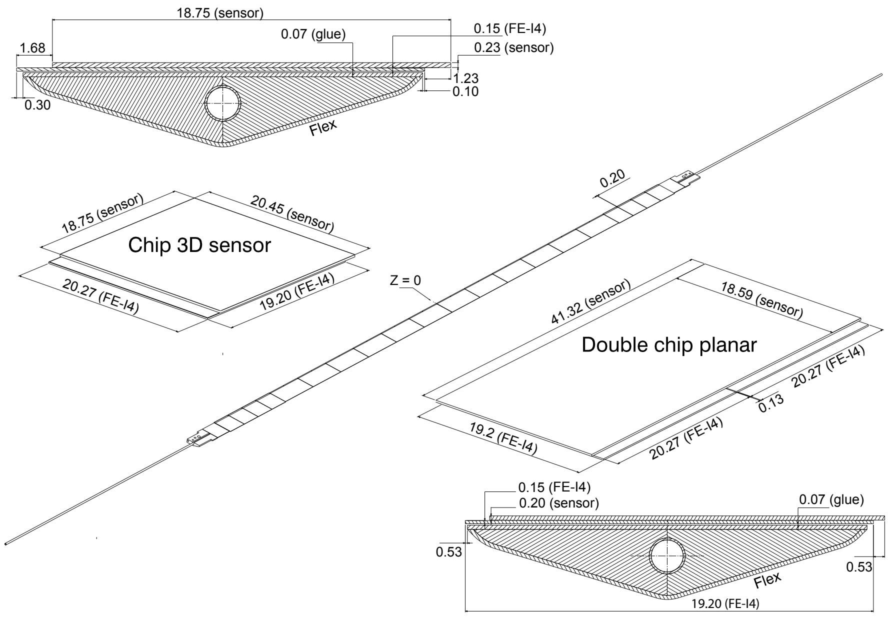


Figure 2. Sketch of individual pixel staves, indicating the placement of planar and 3D pixel modules, on the IBL pixel detector [7]. 3D sensors (single chip) are located at stave ends while planar sensors (double chip) are located in the central region.

the stave ends), to benefit from the vertical orientation of electrodes in measuring the coordinate along the beam axis, especially after heavy irradiation. Each stave is loaded with 12 planar and 8 3D modules, distributed at both ends (figure 2). The IBL provides a total of about 12 million pixels.

Slim edge planar sensors are manufactured by CiS.[1] They make use of moderate p-spray to isolate n-pixels. The slim edge is achieved by extending the external row (first and last pixel along the beam axis) beyond the guard rings, and make them 500 μm long instead of the normal 250 μm, and thus, leaving only 200 μm between the physical edge and the pixel end. The IBL 3D silicon sensors are manufactured by CNM[2] and FBK.[3] Dimensions of both types of sensors are given in figure 2.

5 Front-end chips

IBL sensors will be readout by a new developed front-end chip, the FE-I4 [4]. It is manufactured in IBM 130 nm CMOS process. It has a thickness of 150 μm and amplifies, shapes and discriminates signals from 80 $\times$ 336 pixels. Planar and 3D sensors are read by two and one FE-I4 chips respectively. Digital processing is shared between 2 $\times$ 2 neighbouring pixels. Output signal are encoded over a dynamic range of 4 bits, and transmitted to external readout at a rate of 160 Mb/s. FE-I4 chips are bump-bonded to sensors by silver-tin solder.

[1] Erfurt, Germany.
[2] Barcelona, Spain.
[3] Povo di Trento, Italy.

2013 JINST 8 C01034

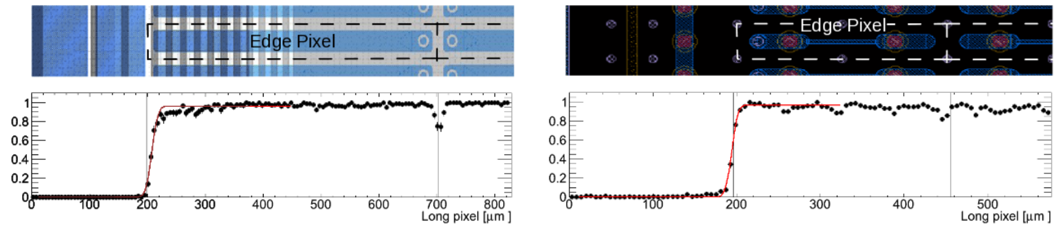
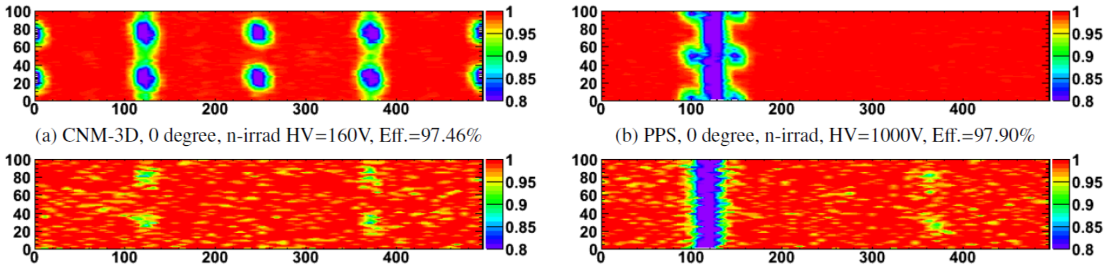


Figure 3. Edge efficiency measurements following irradiation [7]. Left: A planar edge pixel photo-lithography drawing with the efficiency projection at a bias voltage of $-1000\,\mathrm{V}$. Right: A 3D CNM edge pixel photo-lithography drawing with the efficiency projection at a bias voltage $-140\,\mathrm{V}$.



(a) CNM-3D, 0 degree, n-irrad HV=160V, Eff.=97.46%

(b) PPS, 0 degree, n-irrad, HV=1000V, Eff.=97.90%

(c) CNM-3D, 15 degree, p-irrad, HV=160V, Eff.=98.96%

(d) PPS, 15 degree, p-irrad, HV=940V, Eff.=97.65%

Figure 4. Cell efficiency map for sensors irradiated to an equivalent NIEL of 5×10^{15} 1 MeV neutrons per cm^2, with neutrons (top) and protons (bottom) for both technologies (a and c for 3D, b and d for planars) and for two different incidence angles (normal incidence for a and b, 15° incidence for c and d) [10]. Inefficient areas due to passthrough electrodes are visible for both technologies and both incidences: p-type and n-type columns for 3D and bias grid for planar sensors.

6 Beam tests

Several runs of beam tests have been carried out during the development of sensors and readout chips. They included testing of unirradiated and irradiated modules, several incidence angles and operation inside a magnetic field. Only few important results will be shown here. IBL modules were operated with a typical threshold of 1500 electrons. Bias voltage was around 20 and 150 V for unirradiated 3D and planar sensors respectively and about 150 and 1000 V for irradiated sensors.

The edge tracking efficiency of sensors is shown on figure 3 [7]. Both technologies managed to reduce the inefficient edge to about 200 μm.

Figure 4 shows cell efficiency after irradiation [10]. Inefficiencies are observed under the bias grid of planar sensors after irradiation and at electrode positions in 3D sensors. The later is reduced for tilted tracks. Overal efficiency is always higher than 97%.

7 Schedule and conclusion

The ATLAS detector will have a 4-hits Pixel Detector after the first long LHC shutdown. Tests under particle beam showed that the required performance is met, including after irradiation.

2013 JINST 8 C01034

The ATLAS Collaboration already received 100% of the IBL sensors, including spares. Most of the FE-I4 have been delivered and their bump-bonding to sensors has started and will be completed by the end of 2012. Module loading on staves shall be completed by May 2013. IBL should be installed inside the ATLAS detector in 2014.

Acknowledgments

I wish to warmly thank the IWORID 2012 organizers at Figuira da Foz, for their welcome, their help and care during the conference and the friendly atmosphere which prevailed all along.

I am also indebted to my ATLAS Pixel Detector and IBL colleagues, for helpful discussions and support.

References

[1] ATLAS collaboration, G. Aad et al., *The ATLAS Experiment at the CERN Large Hadron Collider*, 2008 *JINST* **3** S08003.

[2] L. Evans and Ph. Lyndon (eds.), *LHC Machine*, 2008 *JINST* **3** S08001.

[3] G. Aad et al., *ATLAS pixel detector electronics and sensors*, 2008 *JINST* **3** P07007.

[4] M. Garcia-Sciveres et al., *The FE-I4 pixel readout integrated circuit*, *Nucl. Instrum. Meth.* **A 636** (2011) S155.

[5] K.E. Selbach and K. Prokofiev, *Neural network based cluster reconstruction in the ATLAS pixel detector*, ATL-PHYS-PROC-2012-112 (2012).

[6] ATLAS collaboration, *ATLAS Insertable B-Layer Technical Design Report*, ATLAS Insertable B-Layer Technical Design Report, CERN-LHCC-2010-013.

[7] ATLAS IBL collaboration, J. Albert et al., *Prototype ATLAS IBL Modules using the FE-I4A Front-End Readout Chip*, 2012 *JINST* **7** P11010 [arXiv:1209.1906].

[8] D. Muenstermann, *R&D on Planar Pixel Sensor Technology for the ATLAS Inner Detector Upgrade*, CERN EDMS NOTE ATU-RD-MN-0029.

[9] C. Da Via et al., *Development of Full 3D Active-Edge and Modified 3D Silicon Pixel Sensors with Extreme Radiation Hardness*, CERN EDMS NOTE-ATL-PA-MN-0007.

[10] I. Rubinsky, *Irradiation and beam tests qualification for ATLAS IBL Pixel Modules*, ATL-INDET-PROC-2012-007 (2012).

2013 JINST 8 C01034