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The upgrade of the ATLAS Inner Detector

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ABSTRACT

With the Large Hadron Collider (LHC) successfully collecting data at 7 TeV and even at 8 TeV since April 2012, plans are actively advancing for a series of upgrades in phase with the three long shutdown periods leading to detector improvement. The ATLAS collaboration will upgrade at the next shutdown in 2013–2014 its semiconductor pixel tracking detector with a new Insertable B-Layer (IBL) between the existing innermost pixel layer and the vacuum pipe of the LHC. The extreme operating conditions at this location led considering the development of new radiation hard pixel sensor technologies and a new front-end readout chip. The IBL community is currently working for producing modules with silicon planar and 3D technology towards the loading on 14 local stave structures as well as the integration around the beam pipe and in the ATLAS detector. The High-Luminosity LHC (HL-LHC) will eventually increase to about five times the LHC design-luminosity some 10-years from now requiring a complete Inner Detector replacement. With the increase luminosity, the cumulated radiation damages and the significant increase of the occupancy the current Inner Detector will not provide the required performances to fully exploit the discovery potential. An overview of the IBL features and construction will be described as well as some R&Ds investigations towards Phase-2 HL-LHC inner tracker upgrade.

1. Introduction

The ATLAS detector is a general purpose detector [1] at the CERN Large Hadron Collider that was designed to be sensitive to a wide range of physics signatures to fully exploit the physics potential of the LHC at a nominal luminosity of $1\times10^{34}\ \mathrm{cm^{-2}\,s^{-1}}$. After the successful commissioning and operation in the last two years, it is planned to extend the LHC physics program at the High-Luminosity LHC (HL-LHC) by increasing the instantaneous luminosity by a factor of five. The three-phase upgrade of the LHC will necessitate the upgrade of the ATLAS detector. The first phase (Phase-0) will take place during the 20-months long shutdown in 2013–2014 and will include the LHC magnets repair to achieve the designed 14 TeV energy in the center-of-mass proton–proton colliding system. The peak luminosity will reach $1\times10^{34}\ \mathrm{cm^{-2}\,s^{-1}}$ and an integrated luminosity of $\sim50\ \mathrm{fb^{-1}}$. The second phase (Phase-1) will occur during the second 12-months long shutdown in 2017–2018 and will aim at a further increase of the instantaneous luminosity to $2\times10^{34}\ \mathrm{cm^{-2}\,s^{-1}}$ with an integrated luminosity of $300\ \mathrm{fb^{-1}}$. The third phase (Phase-2) will take place after 2022 and will initiate the High Luminosity LHC (HL-LHC) era aiming at $3000\ \mathrm{fb^{-1}}$ integrated luminosity to be collected during the following years.

The Insertable B-Layer (IBL) [2] is a fourth pixel layer which will be added at the Phase-0 upgrade between a new vacuum beam pipe and the current innermost pixel layer of the existing Inner Detector (ID). The principal motivations of the IBL are to provide increased tracking robustness as the instantaneous luminosity of the LHC increases beyond the design luminosity of $1\times10^{34}\ \mathrm{cm^{-2}\,s^{-1}}$, to maintain an excellent vertex detector performance and to compensate possible inefficiencies of the current b-layer Pixel Detector [3]. It is designed to operate until a full tracker upgrade is planned for the HL-LHC operation. It consists of 14 tilted and overlapping staves mounted around the beam pipe at an average radius of 32.7 mm. Each stave is instrumented along 664 mm with planar and 3D silicon sensor technologies which are bump bonded to the new front-end electronics (FEI4) fabricated in the 130 nm technology. The IBL is in a construction phase with most of the components already in production.

For HL-LHC operation, the current ID will become inefficient and its replacement is foreseen for the long Phase-2 shutdown in approximately 2022. The future ATLAS tracker under consideration for such replacement should consist of an all silicon-based system with new detector technologies. Its layout and design are under investigation and the baseline consists in having the innermost region covered by a pixel detector and the intermediate and outer radii regions by respectively short and long micro-strip detectors. The sensor R&D and the FE developments are the

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key topics where early effort has started as well as the module design and the integration on local support structures. The microstrip community is investigating two options for the barrel region (called the '*stave*' and the '*super-module*' options) allowing an evaluation of the integrated readout chain and powering into system tests.

2. The IBL upgrade during the Phase-0 shutdown

2.1. The IBL layout description

The IBL package consists of a cylindrical layer of active length 640 mm and full length of ± 3.5 m including the support structure and services on each side. It will not be accessible once integrated inside the ATLAS ID. Fig. 1 shows an IBL cross-section end view. The inner most radius corresponds to the new beam pipe radius of 23.5 mm while the outermost radius of 43 mm is the IST external carbon fiber skin. The inner radius of the IBL detector is defined at 31 mm with the outer radius at 40 mm while the sensor will be at a mean radius of ~ 33 mm. A total of 14 staves with a length of 740 mm will be precisely mounted inside the IBL ring envelope with tight clearances (1–2 mm) with respect to the surrounding staves and structures. Each stave is mounted on three mechanical supports: on the end rings at the two side of the stave that are attached to the IST and on the middle support ring which will be left floating inside the IST. The current beam pipe radial position is defined by the wire suspension system which will be used for the IBL Support Tube (IST) radial suspension while the new beam pipe will be free inside the inner IBL radius. Several spacers will mounted along the IST in the service region to prevent the beam pipe touching the instrumented region and the service cables and pipes. Such design allows for beam pipe insertion and removal while the IBL will remain attached to the ID.

As sketched in Fig. 2 each pixel stave will be equipped with a mixed sensor technology, with 12 planar [4] and 8 3D [5] modules (four mounted at the two sides). The planar sensor with a length of 40.9 mm is bump-bonded to two front-end readout chips and the 3D sensor of about half that size is connected with a single front-end chip. Each module is precisely assembled to the stave with the precision of the sensor cutting edge of ± 10 μm and with a physical gap of 200 μm between the modules. The mechanical stave design aimed for building a light support structure with keys thermo-mechanical features such as highly thermally conductive material, stable assembly and low thermal expansion coefficient. A titanium cooling pipe of 1.5 mm diameter with 0.1 mm wall thickness is embedded in the stave carbon foam during the construction and allows for CO_2 evaporative cooling to maintain the silicon sensor temperature below −20 °C.

2.2. The module and stave description

2.2.1. The planar and 3D silicon sensors

The IBL planar sensors are based on the proven technology of the current ATLAS Pixel Detector, n-on-n pixels on a diffusion oxygenated float-zone silicon bulk. The chosen thickness for the substrate is 200 μm, almost 30% less than the current Pixel Detector, reducing the overall material budget. Isolation between the n+ implants is obtained through the moderated p-spray

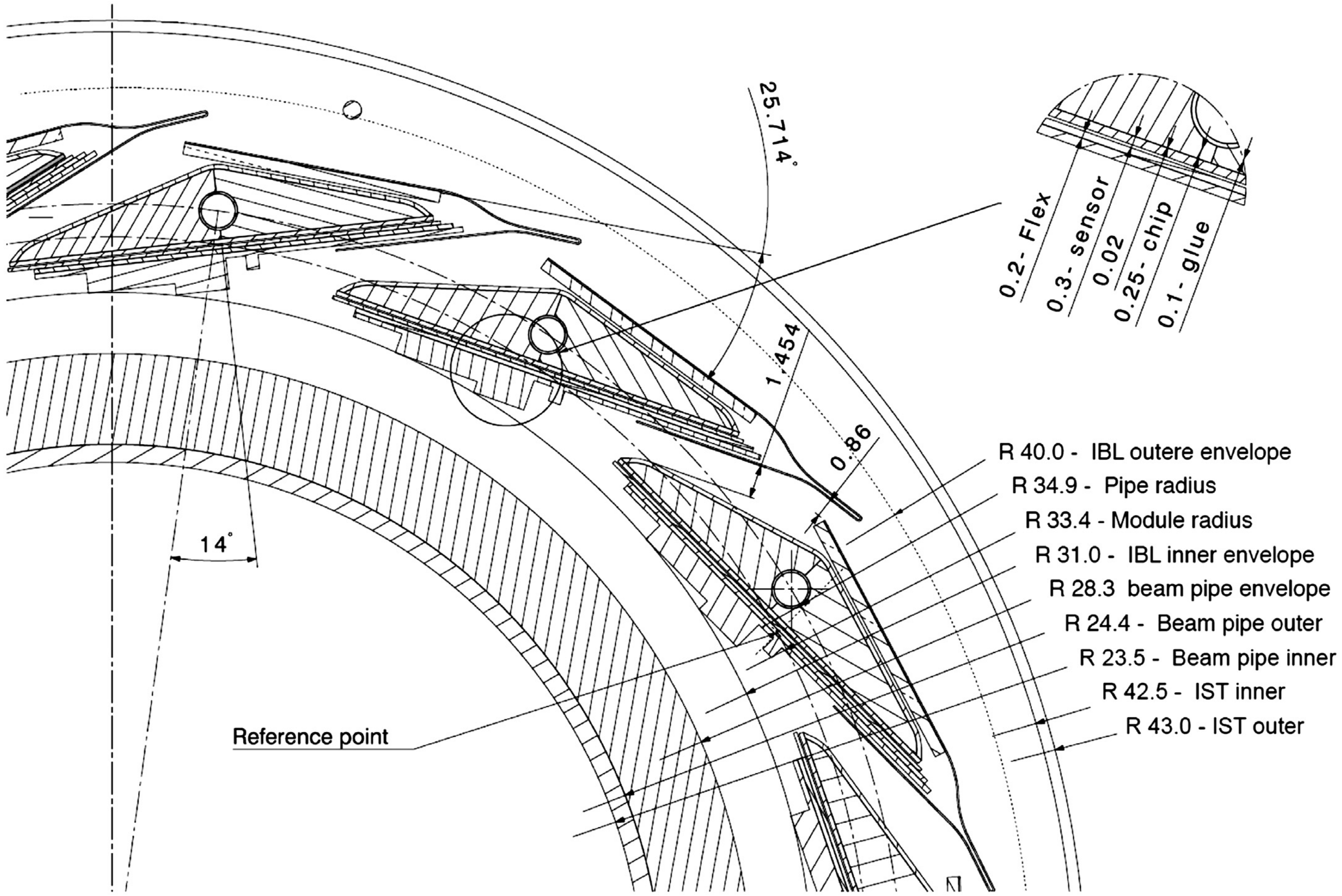

Fig. 1. IBL end view section where the stave envelope is drawn with respect to the surrounding beam pipe and IBL Support Tube (IST).