PROCEEDINGS OF SCIENCE

ATLAS Inner TracKer Upgrade

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With the startup of the High-Luminosity Large Hadron Collider (HL-LHC), the Inner Detector (ID) will be replaced with a fully silicon detector known as the ATLAS Inner TracKer (ITk). This new tracking detector is composed of silicon pixel sensors and silicon strips which will extend the tracking detector range up to a pseudorapidity of 4. The demand for a new tracking detector comes as a result of the particle dense collisions produced by HL-LHC. With the increased particle density and radition levels, the success of the ITk requires that it must tolerate the expected dose of radiation while maintaining efficient tracking. Tests have demonstrated that the ITk Pixel detectors' 3D $50 \times 50\ \mu m^2$ sensors maintains hit efficiency beyond the expected fluence. Additionally, simulations have demonstrated that the ITk, under an average interaction per bunch crossing of $<\mu> = 200$, will achieve similar tracking efficiency to that of the ID under an average interaction per bunch crossing of $<\mu> = 38$.

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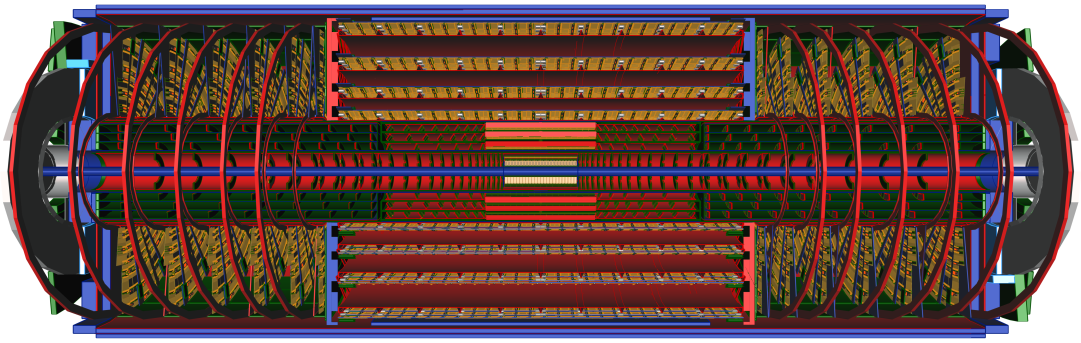

Figure 1: The ATLAS Inner TracKer [8].

1. Introduction

The ATLAS Inner TracKer (ITk) is the keystone upgrade of the ATLAS detector[1] to be implemented for the start of the High-Luminosity Large Hadron Collider (HL-LHC) in 2029[2]. At high luminosity, the LHC experiments such as ATLAS will be capable of unveiling new physics currently hidden within rare processes. With the ITk, ATLAS is expected to measured a total of 4000 fb^{-1} of data. During the running of the HL-LHC, the ATLAS detector will see a seven-fold increase in instantaneous luminosity as well an average interactions per bunch crossing of 200. These running conditions exceed the capabilities of the currently utilized Inner Detector (ID)[3]. For these reasons its successor, the ITk, is designed to maintain efficient and granular tracking under the increased radition expected during the running of the HL-LHC.

2. Setup

The ITk is an all silicon detector with coverage up to a pseudorapidity of 4. As shown in Figure 2, the innermost detector is composed of silicon pixels while the outermost region is composed of silicon strips. The detector is further divided into a central region known as the barrel and two forward regions known as endcaps. A model of the ITk can be seen in Figure 1.

2.1 Pixels

The ITk pixels detector marks a significant improvement over the ID pixels detector. Composed of over 5 billion individual channels over an area of approximately 180 m^2[4]. There are two different types of pixel technologies used in the ITk known as planar and 3D sensors. In planar sensors, the electrodes sit on the bulk, while in 3D sensors, the electrodes are vertically implanted inside the bulk. The benefits of the latter are the preserved size of the bulk as well as the reduced drift length allowing for increased radiation tolerance. For this reason the 3D sensors are featured in the innermost layer of the ITK Pixels detector[4] .

This highlights an important requirement for the ITK Pixels detector as well as the rest of the ITk detector in that it must be capable of withstanding the fluence produced by the HL-LHC. The innermost pixel sensors which are susceptible to the highest dose of radiation must withstand a fluence exceeding 10^{16} n_{eq}/cm^2 all while maintaining a hit efficiency of >97% after irradiation. To test this, a 3D 50×50 μm^2 pixel sensor was first irradiated with a 14 MeV proton beam at Bonn

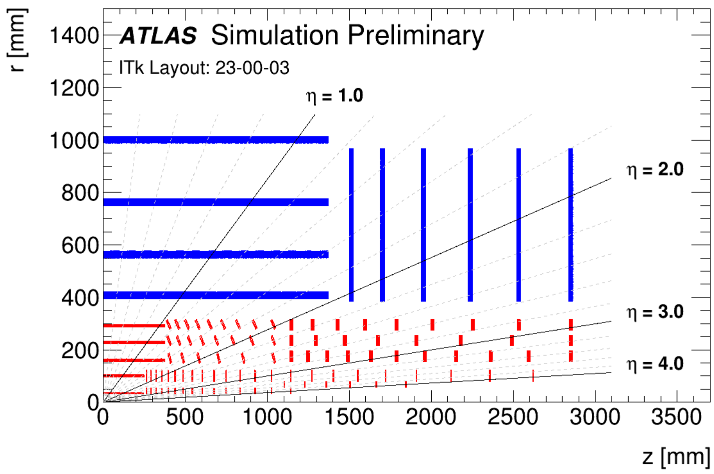

Figure 2: Cross section of the ATLAS Inner TracKer layout. Pixel detectors are shown in red. Strips detectors are shown in blue [9].

University, up to a fluence of $1 \times 10^{16}\ n_{eq}/cm^2$. Subsequent hit efficiency measurements conducted at the CERN SPS demonstrated a 97% hit efficiency achieved with bias voltage of 40 V. A second round of irradiation was conducted with a 24 GeV proton beam at the CERN IRRAD facility. The subsequent tests demonstrated that the mark of 97% efficiency could be achieved with a bias voltage of 100 V[5].

To further mitigate the loss of sensor efficiency to radiation damage, the first two rows of pixel sensors, known as the inner system are designed to be replaceable. This set of sensors is planned to be replaced with around 2000 fb^{-1} of data collected. A new inner system of pixel sensors will be inserted in its place[4].

2.2 Strips

The ITk Strips detector is composed of 4 barrel layers made up of flat staves and 12 endcap disks composed of wedge shaped petals. The two innermost layers of the barrel host Short Strip (SS) staves which have a reduced strip length as opposed to the Long Strip (LS) staves in order to increase granularity and tracking. Overall, the ITk Strips detector is designed with a reduced strip length and strip pitch compared to its predecessor within the ID. This allows for increases in tracking efficiency, while maintaining an occupancy below 1% in the particle dense environment produced by the HL-LHC. With the absence of the Transition Radiation Tracker in the ITk design, the strips detector can be extended outward into the previously occupied space. As a result, the area covered by the silicon strips increases from 60 m^2 up to a total of 165 m^2. Subsequently, with the shortened strip length and increased coverage area, the total number of channels will be increased from 6 million to 60 million[6].

In order to minimize radiation damage effects, both pixel and strip detectors will be operated at cold temperatures. With most testing of these detectors taking place at warm temperatures, it is important to understand how performance changes across this range in temperatures. Tests conducted at DESY-II testbeam facility where signal-to-noise ratio (SNR) tests were conducted at both +30 °C and -30 °C demonstrated that at cold operating temperatures, the SNR was well below the maximum allowed value[7]. To further mitigate radiation effects, the expected lifetime radiation fluence for the strips detector is an order of magnitude lower than its designed tolerance with a safety factor of 1.5[6].

3. Expected Performance

Under the increased pileup conditions of the HL-LHC it is important that the ITk maintain a tracking efficiency comparable to the ID. To test the tracking efficiency of the ITk[8], $t\bar{t}$ events were generated at 14 TeV using POWHEG interfaced with Pythia8 under the HL-LHC pileup conditions. The detector is simulated using the GEANT4 toolkit. This allows for the particle-detector interaction to be simulated, after which the subsequent digitization and detector response are taken into account. To draw a comparison, these steps are reproduced for the ID with the pileup equivalent of run 2.

The results of the simulation can be seen in Figure 3. In the distribution of pseudorapidity, the tracking efficiency of the ITk is within 5% of that of the ID. Additionally, the coverage by the ITk is extended further in the forward directions. In the distribution of transverse momentum spectrum, the tracking efficiency of the ITk is within a few percent of that of the ID.

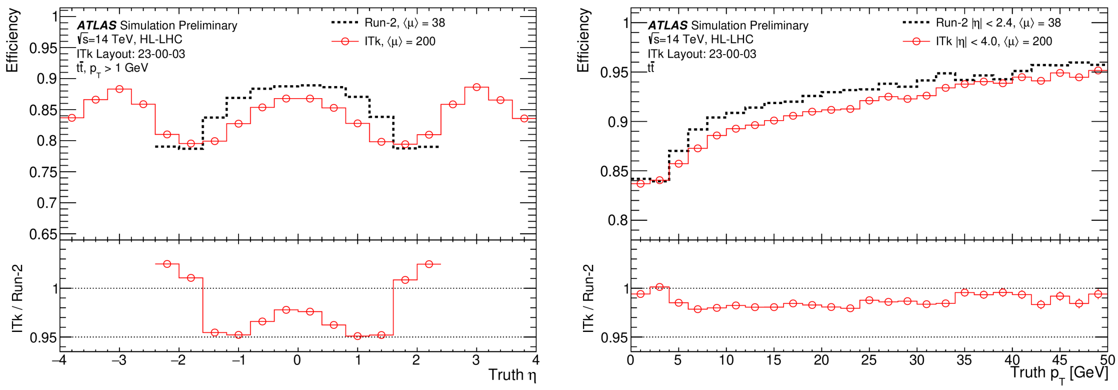

Figure 3: Simulated tracking efficiency distributions with respect to pseudorapidity (left) and transverse momentum (right) of $t\bar{t}$ events for the ID in run 2 with $<\mu>$ = 38 and ITk with $<\mu>$ = 200 [8].

4. Current Status

The ITk Strips detector components will soon have completed the pre-production phase. This paves the way for production, which has already started for sensors, the ASICs and will soon begin for modules and staves. On this timeline, the insertion of the barrel and endcaps will begin in early 2024. Pre-production of the ITk Pixel detector components has been ongoing since Summer 2022. The pixel sensors have since entered into production. Integration of the pixel components will begin by mid 2024. With both prepared, the pixels and strips detectors will integrated together to form the ITk in 2027, being set for installation in 2028.

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References

[1] ATLAS Collaboration, *The ATLAS Experiment at the CERN Large Hadron Collider*, 2008 JINST 3 S08003

[2] ATLAS Collaboration, *High-Luminosity Large Hadron Collider (HL-LHC): Technical design report*, *CERN Yellow Reports: Monographs*, CERN-2020-010, CERN, Geneva (2020), doi:10.23731/CYRM-2020-0010.

[3] ATLAS Collaboration, *Inner Detector Technical Design Report*, CERN-LHCC-97-016, CERN, Geneva (1997) url: https://cds.cern.ch/record/331063

[4] ATLAS Collaboration, *ATLAS Inner Tracker Pixel Detector: Technical Design Report*, CERN-LHCC-2017-021, CERN, Geneva (2017), url: https://cds.cern.ch/record/2285585

[5] G. Calderini *et al*, *Qualification of the first pre-production 3D FBK sensors with ITkPixV1 readout chip*, 2023 JINST 18 C01010

[6] ATLAS Collaboration, *ATLAS Inner Tracker Strip Detector: Technical Design Report*, CERN-LHCC-2017-005, CERN, Geneva (2017), url: https://cds.cern.ch/record/2257755

[7] J.-H Arling *et al*, *Test beam measurement of ATLAS ITk Short Strip module at warm and cold operational temperature*, 2023 JINST 18 P03015

[8] ATLAS Collaboration, *Expected tracking and related performance with the updated ATLAS Inner Tracker layout at the High-Luminosity LHC, ATL-PHYS-PUB-2021-024*, CERN, Geneva (2021), url: https://cds.cern.ch/record/2776651

[9] ITk Public Plots, *ITk Pixel Layout Updates*, ITK-2020-002