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Expected performance of the ATLAS ITk detector for HL-LHC

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The increased instantaneous luminosity levels expected to be delivered by the High-Luminosity LHC (HL-LHC) will present new challenges to High-Energy Physics experiments, both in terms of detector technologies and software capabilities. The current ATLAS inner detector will be unable to cope with an average number of 200 simultaneous proton-proton interactions resulting from HL-LHC collisions. As such, the ATLAS collaboration is carrying out an upgrade campaign, known as Phase-II upgrade, that foresees the installation of a new all-silicon tracking detector, the Inner Tracker (ITk), designed for the expected occupancy and fluence of charged particles. The new detector will provide a wider pseudorapidity coverage and an increased granularity. In this contribution the expected performance of the ITk detector will be presented, with emphasis on the improvements on track reconstruction resulting from the new detector design.

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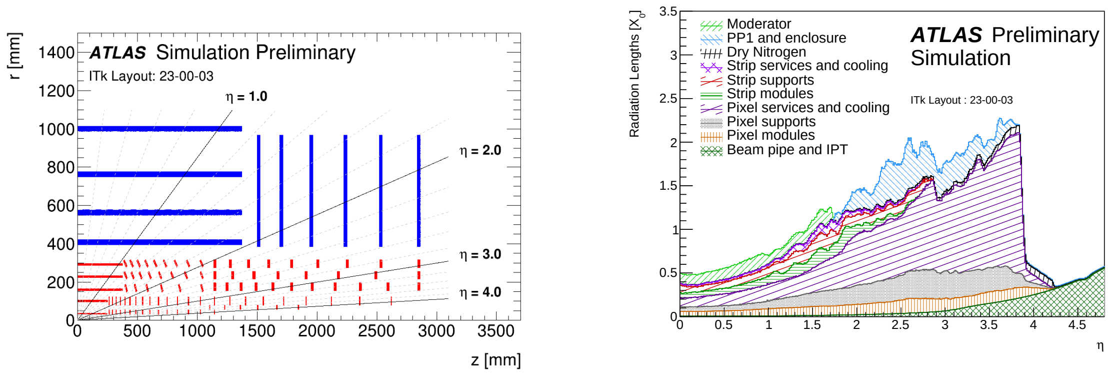
1. The ATLAS Inner Tracker (ITk)

The High-Luminosity (HL) phase of the Large Hadron Collider (LHC) at CERN is expected to deliver an integrated luminosity of up to 4000 fb^{-1}, corresponding to an increase of a up to a factor of seven in the average number of inelastic pp collisions per bunch crossing with respect to the current LHC phase. This will allow physicists to make more precise measurements of Standard Model processes as well as increase the potential of discoveries. To cope with challenges posed by the increased instantaneous luminosity the current ATLAS Inner Detector (ID) [1] will need to be upgraded to a new all-silicon Inner Tracker (ITk) with a higher granularity. After the Technical Design Reports of the strip [2] and pixel [3], new ITk designs have been proposed [4]. The recent ITk pixel detector design reduces the radius of the innermost pixel layer from 39 to 34 mm. The pixel pitch in the central part of this layer was also fixed to 25×100 μm^2 while a pixel pitch of 50× 50 μm^2 is used in the rest of the detector. These changes significantly improved the transverse impact parameter resolution of the reconstructed tracks.

As depicted in Figure 1a, the ITk is made of two subsystems: a Pixel Detector [3] surrounded by a Strip Detector [2]. The Strip Detector has four strip double-module layers in the barrel region and six end-cap disks, covering the pseudorapidity range up to $|\eta| = 2.7$. The Pixel Detector consists of five flat barrel layers and multiple inclined or vertical ring-shaped end-cap disks, extending the coverage up to $|\eta| = 4.0$. Thanks to many optimisation which includes the adaptation of new evaporating CO_2 cooling system with titanium pipes as well as the foreseen innovative serial powering in scheme in the pixel the material budget of the ITk has been reduced by a factor of two compared to the current ID [3], as illustrated in Figure 1b.

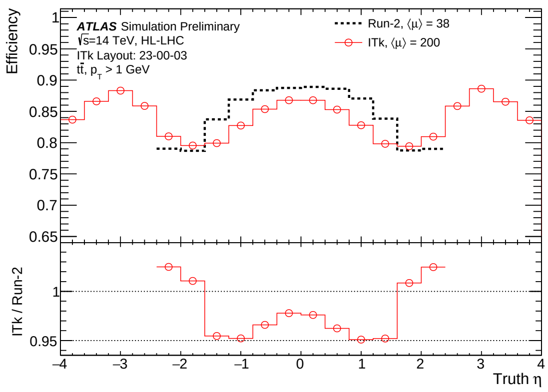


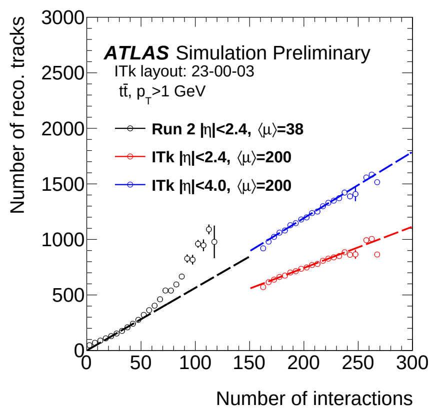
(a) **(b)**

Figure 1: (a) A schematic depiction of the ITk Layout 23-00-03, and (b) Material distribution within the ITk volume in radiation lengths (X0) versus η [5].

2. Expected tracking performance

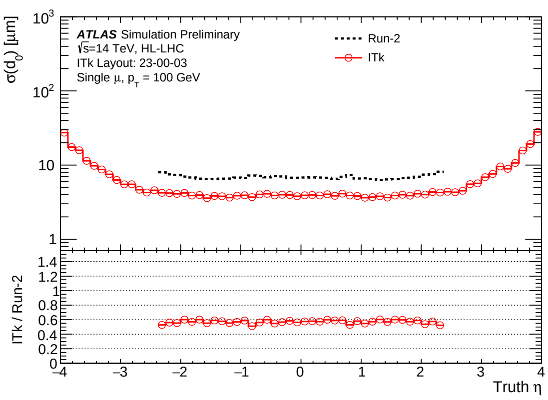
Despite the expected pile-up density at HL-LHC ($< \mu >= 200$), the ITk will roughly maintain the same tracking efficiency as in the one obtained with the ID. In the central region, the tracking efficiency is within 5% with respect to the ID, which is expected to be recovered in future optimisations of the tracking reconstruction configurations. While in the forward region, the ITk has extended the tracking capabilities providing for the first time tracking in this region, as illustrated in Figure 2a. The tracking at 200 pile-up will present an unprecedented challenges in terms of keeping the reconstruction of fake tracks formed from hits of various particles. A new optimised seeding strategy in combination of number of hits requirement, allowed the robustness of the tracking efficiency over a large pileup range and the negligible tracking fake rate, estimated to be around 10^{-4}, as shown in Figure 2b. The expected track parameter resolutions for the transverse (d_0) and longitudinal (z_0) impact parameters are shown in Figure 3. Thanks to the smaller pixel pitch used in the ITk pixel detector, the z_0 resolution was improved by a factor of 4. While the factor 2 imporovement in d_0 resolution is thanks to the better resolution in the bending direction associated with the silicon strip sensors used in ITk.

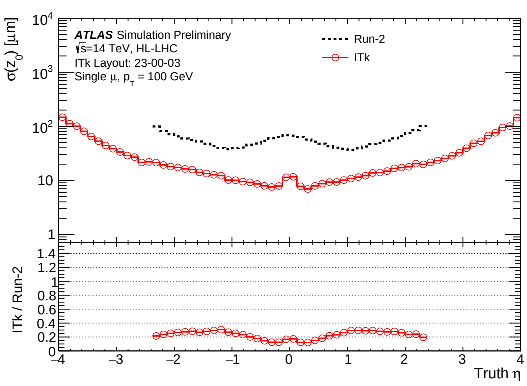




(a) **(b)**

Figure 2: (a) Tracking efficiency for $t\bar{t}$ events at $< \mu >= 200$. (b) Total number of reconstructed tracks per event with $p_T > 1$ GeV, evaluated with a $t\bar{t}$ sample at $< \mu >= 200$ obtained with ITk compared to Run 2 ID [5].



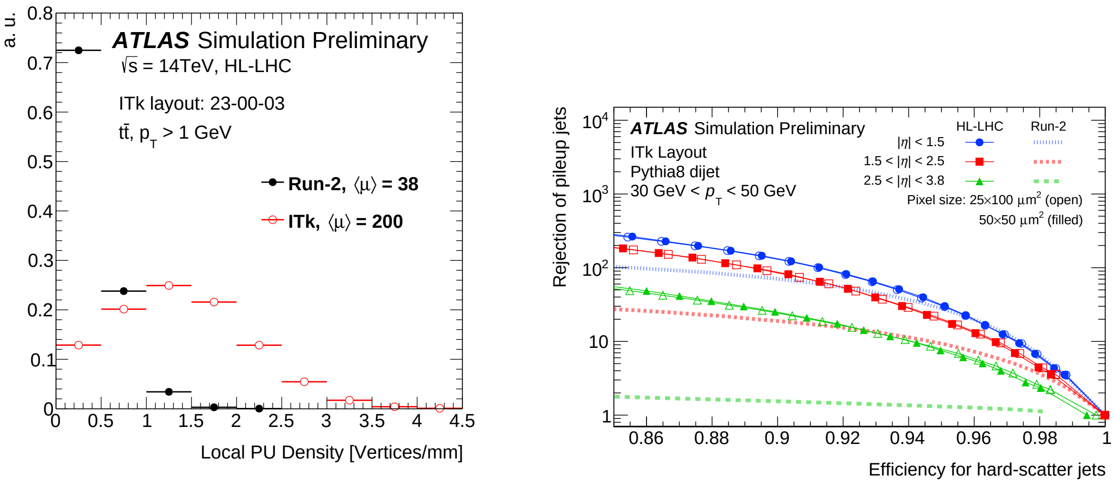


(a) **(b)**

Figure 3: (a) Transverse and (b) longitudinal impact parameter resolution as a function of η for a single muon particle with $p_T = 100$ GeV [5].

3. Expected high-level objects performance

The expected high pile-up density will significantly affect the primary hard-scatter (HS) vertex reconstruction. In order to cope with this, a new Adaptive Multi-Vertex Finder (AMVF) [8] will be utilized which was already commissioned during ATLAS Run 3 data-taking, considering its robustness against pile-up compared the Iterative Vertex Finder utilized in Run 2. The performance of AMVF algorithm at $< \mu >= 200$ are highlighted in Figure 4a. The improvement in z_0 resolution will directly improve the performance of algorithms used to distinguish HS jets from pileup vertices, such as b-tagging or pile-up rejection algorithm as illustrated in Figure 4b which shows a dramatic improvements in the forward region thanks to the extended granularity of the ITk, benefiting vector boson fusion and scattering analyses.

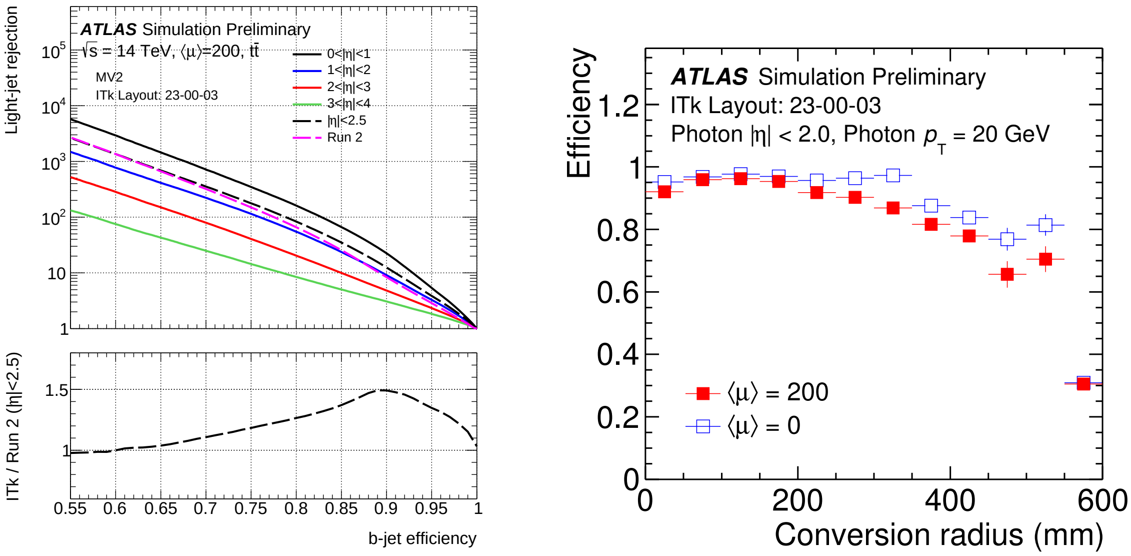


(a) **(b)**

Figure 4: (a) The number of interactions obtained with ITk and the AMVF algorithm [5]. b) The rejection of jets from pileup events as a function of the efficiency for jets from the hard scatter vertex with $30 < p_T < 50$ GeV, compared to Run 2 results [7].

The identification of heavy flavour jets is crucial for several ATLAS analyses such DiHiggs searches. Although ATLAS has recently released more sophisticated algorithms which greatly improved the background rejection for the same signal efficiency operating points. Performance of the ITk has been evaluated using MV2 multivariate algorithm which uses other low-level input algorithms. Thanks to improved impact parameter resolution expected with ITk and the new reoptimised track categorisation a 20% improvement in light-jet rejection at 77% b-tagging efficiency compared to Run 2 detector as illustrated in Figure 5a.

The extended granularity of ITK from $|\eta| = 2.5$ up to $|\eta| = 4.0$ will increase the identification capabilities of photons and electrons. Figure 5b shows the reconstruction efficiency for converted photons which is above 80% up to the first ITk strip layer at $R = 400$ mm.



(a) **(b)**

Figure 5: (a) Light-jet rejection vs b-tagging efficiency for MV2 tagging algorithm at different η ranges and (b) Converted photos reconstruction efficiency vs the conversion radius for photons with p_T = 20 GeV [5].

4. Conclusion

As part of the Phase-II upgrade, the current ATLAS Inner Detector will be replaced by the ITk to meet the challenges of the HL-LHC environment. Recent performance results have been presented and despite the larger pileup as well as the increase detector occupancy expected at HL-LHC, ITk will maintain excellent tracking performance which will ultimately yield to better performance of high-level object reconstruction and identification and therefore increase the sensitivity of physics analyses at HL-LHC.

References

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