LAPP
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The layout and design of the Phase-II upgrade of the Inner Tracker of the ATLAS experiment

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ICHEP2018 SEOUL
XXXIX INTERNATIONAL CONFERENCE ON high energy PHYSICS
JULY 4 - 11, 2018 COEX, SEOUL

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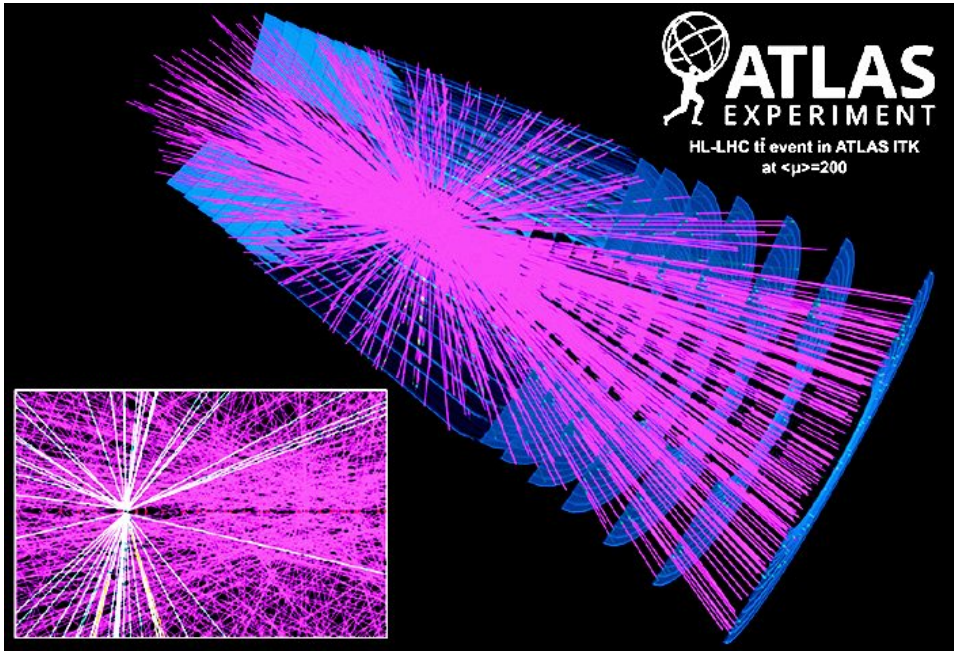
ATLAS

Introduction

- HL-LHC is expected to deliver 4000 fb^{-1} with an instantaneous luminosity of 7.5 10^{-34} cm^{-2} s^{-1} to both ATLAS and CMS, producing an average of 200 collisions per bunch crossing.

Challenging environment!

- The Inner Tracker (ITk) @HL-LHC requires:
  - Increased radiation hardness.
  - Higher granularity.
  - Reduction of material.
  - Extended coverage up to $|\eta| < 4.0$.



- In this talk:
  1) Description of the design and layout of the ITk detector.
  2) Expected tracking, vertexing, flavour tagging, … performance.

Presented results are based on the ITK-2018-001
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PLOTS/ITK-2018-001/

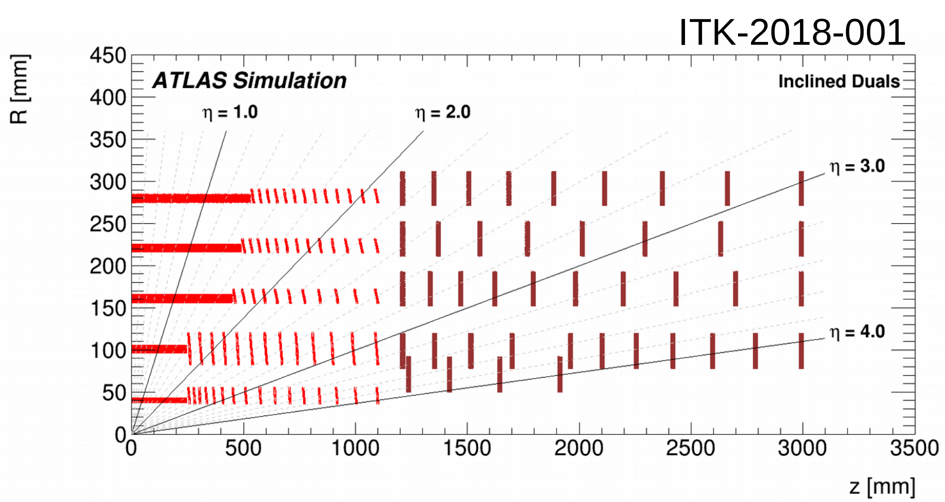
The Pixel Detector

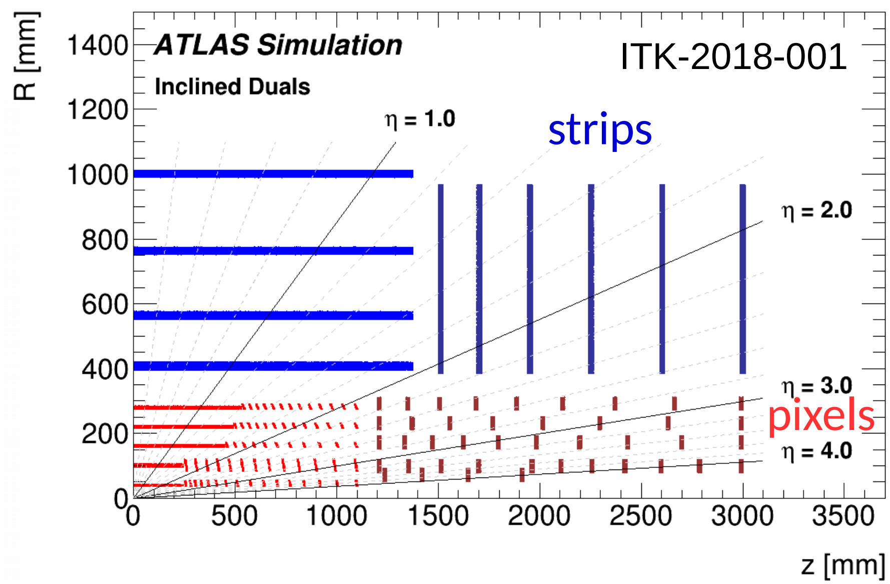
- Five barrel layers with inclined sensors from |η| > 1.4:
  - Reduces the material traversed by particles, improving tracking performance.
  - Requires less Silicon surface than a traditional barrel for the same coverage.
- Endcap rings replacing disks to improve the coverage while reducing Silicon surface.
- Two pixel pitches under consideration: *50x50* and *25x100* μm^2.

Only 50x50 μm^2 results shown here.

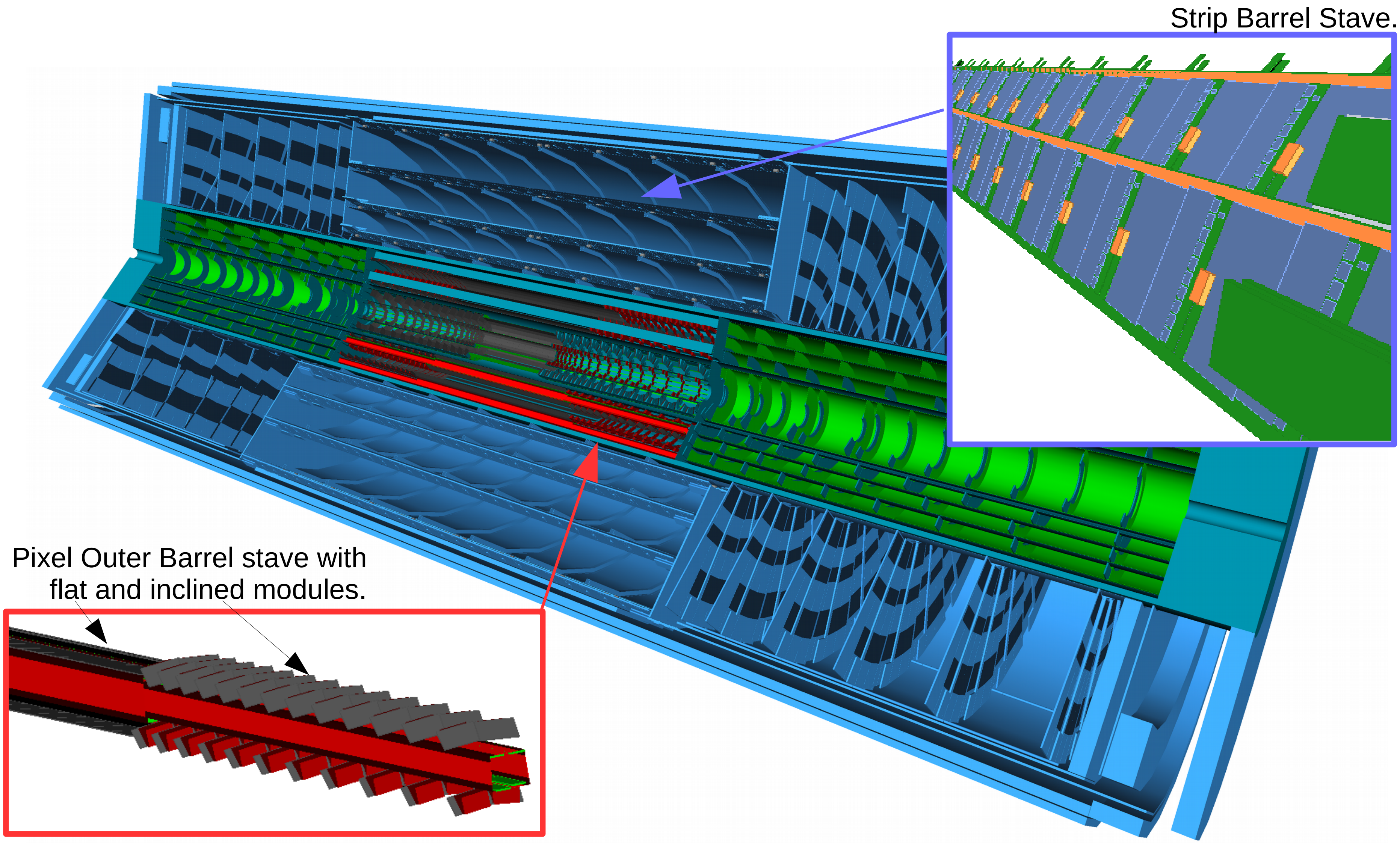
The Strip Detector

- Four strip barrel layers and six endcap disks on each side covering up to |η| < 2.7
  Further details on S. Stucci Talk!





Layout of the Inner Tracker Phase-II Upgrade

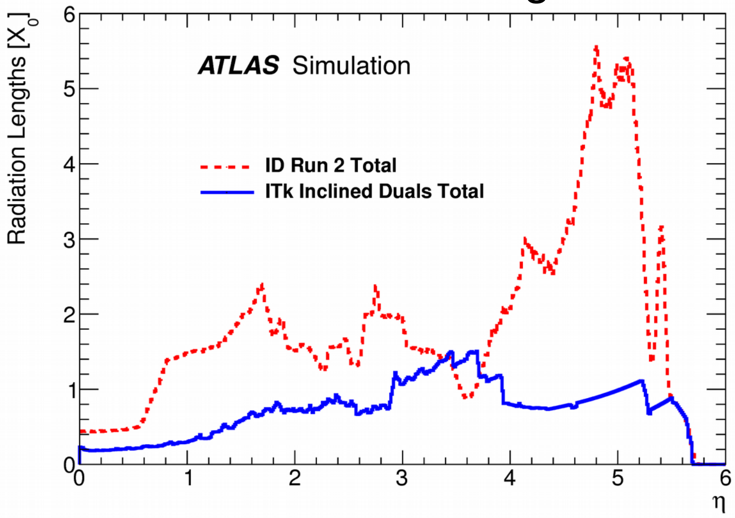


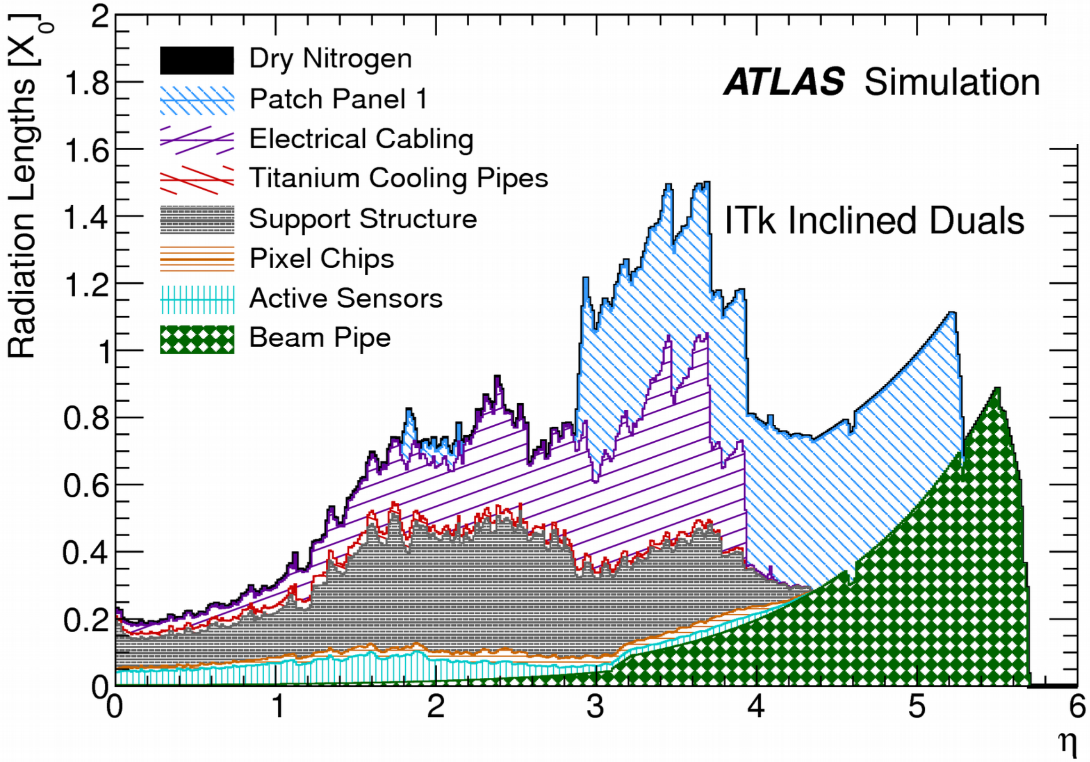
- Extreme level of detail in Geant-4 to ensure reliable performance assessment.

Material Budget

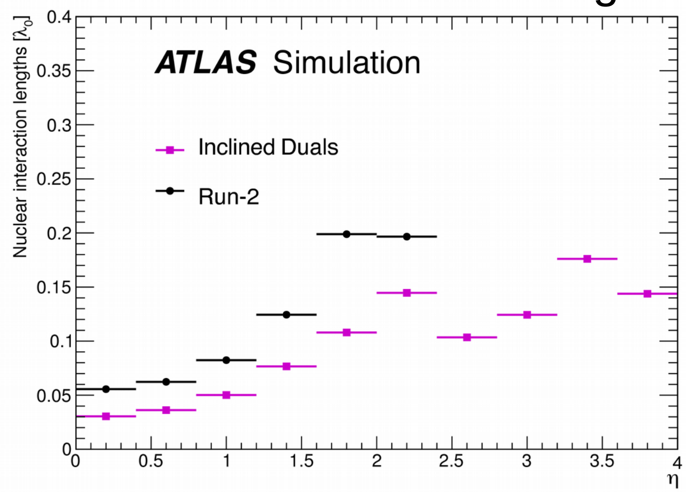
- Material reduction up to a factor of five in radiation length and up to a factor of two in nuclear interaction lengths.
- Expected improvement in tracking performance and calorimetry!

Radiation Length



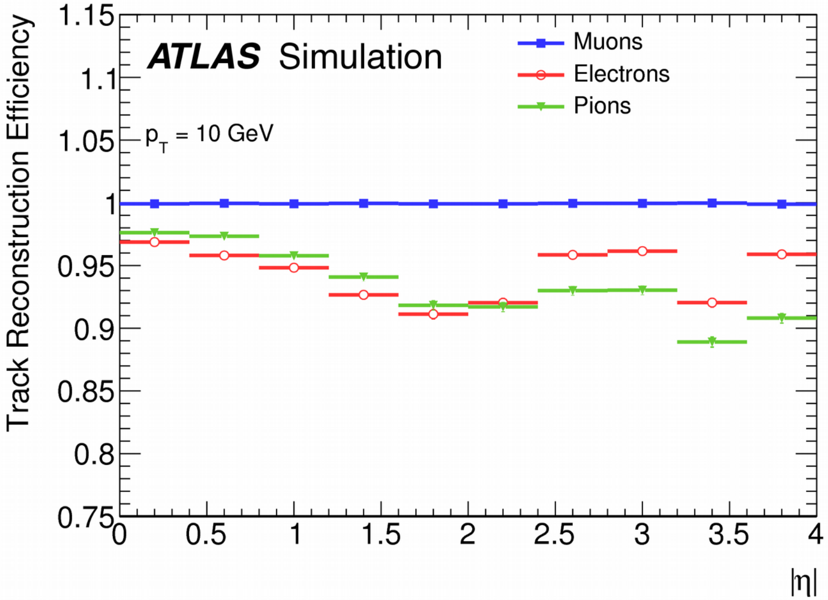


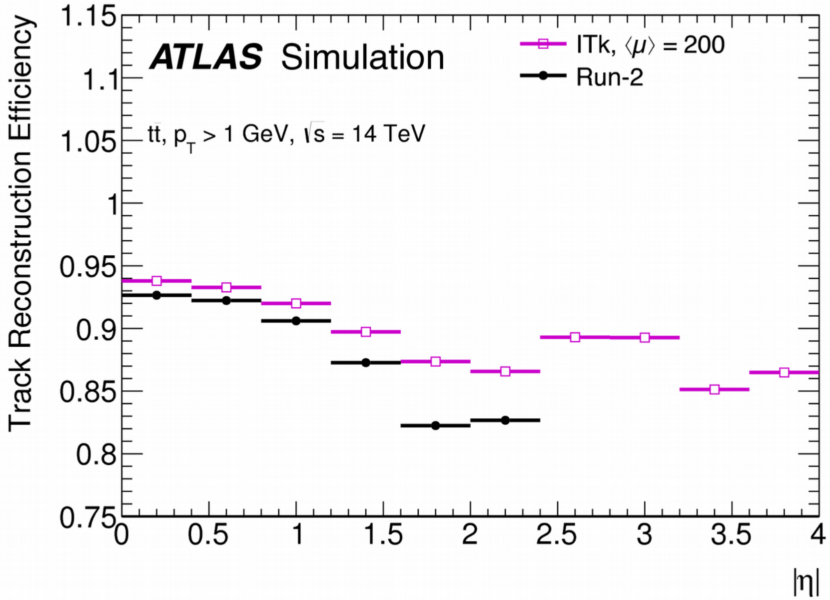
Nuclear Interaction Length



Tracking Efficiency

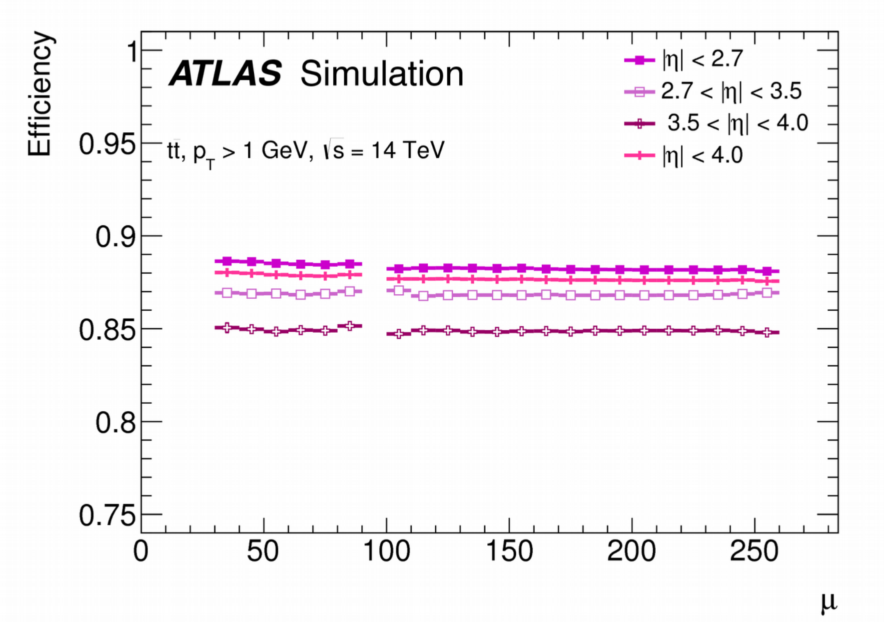
- High tracking efficiency for single muon over the whole η-range: >99% for p_T>10 GeV.
- Great tracking efficiency for single electrons and pions: inefficiencies due to bremmsstrahlung and inelastic hadronic interactions, respectively, with the detector.
- Great overall tracking efficiency for $t\bar{t}$ events (higher then the current ATLAS ID) thanks to the reduction in radiation and interaction length.

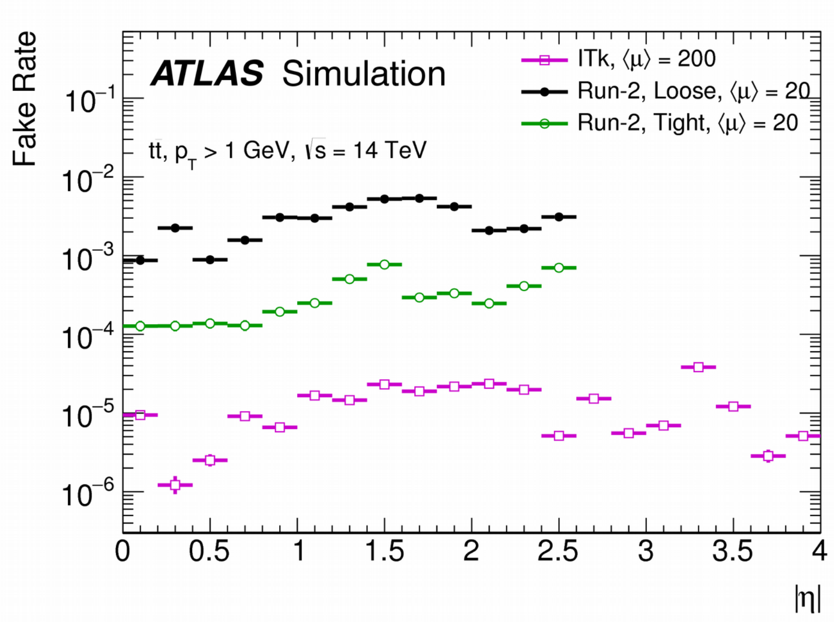




Tracking Fake Rate

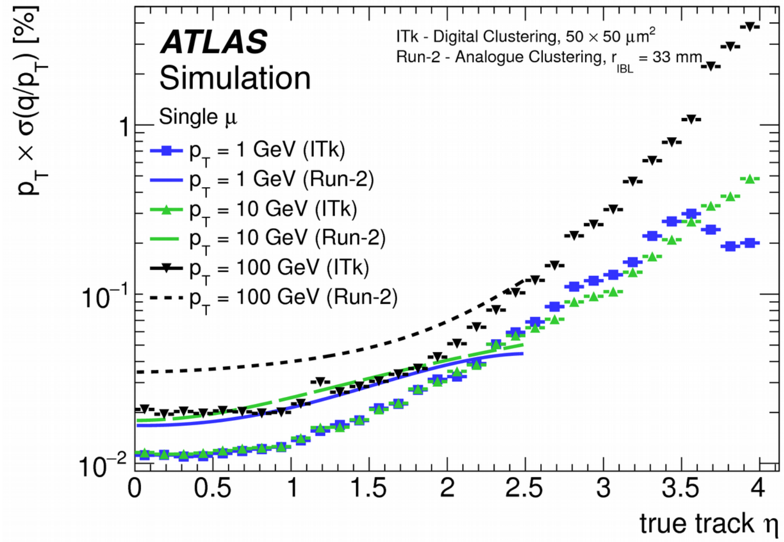
- Track reconstruction efficiency as a function of the average number of pile-up collisions (μ) is stable to better then 1% for all η-ranges.
- The fraction of tracks without a Geant4 truth match (fake rate) is at the level of 10^{-5}.
    - ITk outperforms the current ATLAS tracker despite a factor of 4 more in μ thanks to enlarged lever arm and increased granularity of the Pixel and Strip detectors.
- A minimum of 9 (7) hits is required to ensure a track reconstruction that is fully efficient and robust against pile-up for |η|<2.7 (2.7<|η|<4).

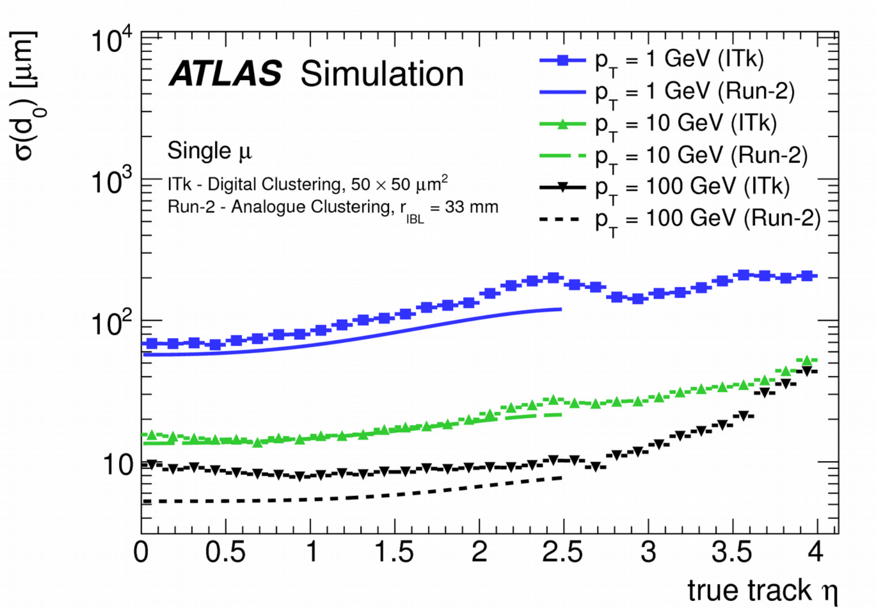


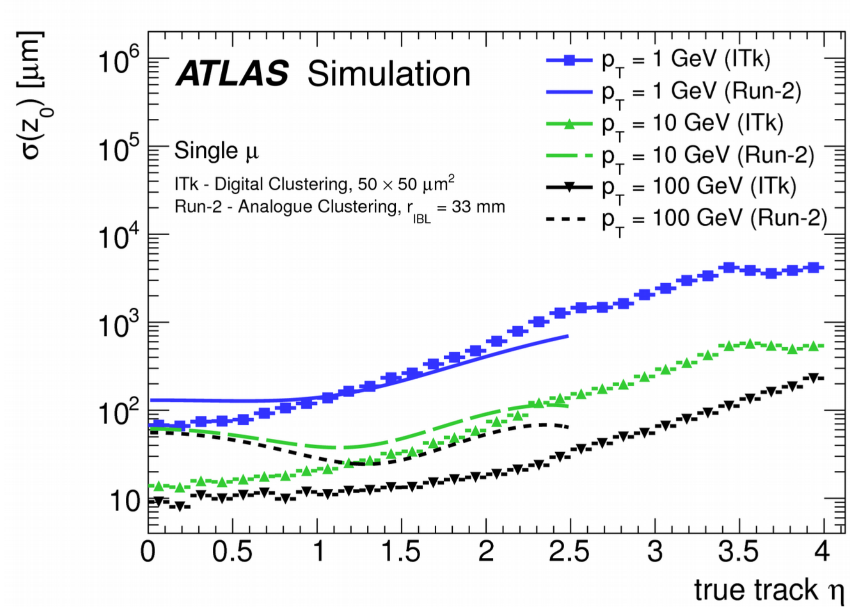


Track Parameters Resolution

- Great position and momentum resolutions.
- Transverse impact parameter (IP) resolution similar to ID: improved ITk performance at high pT with analogue clustering.
- Significant improvement in longitudinal IP resolution thanks to reduced pixel pitch.
- Improved momentum resolution thanks to higher precision measurements.

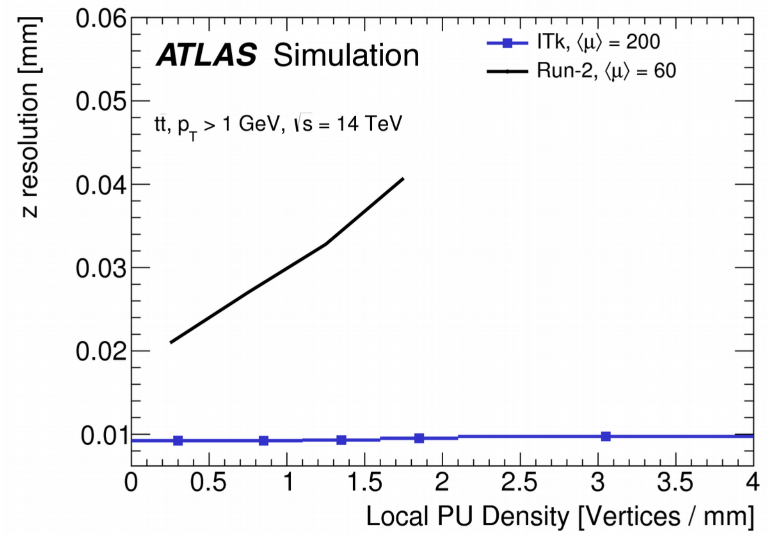


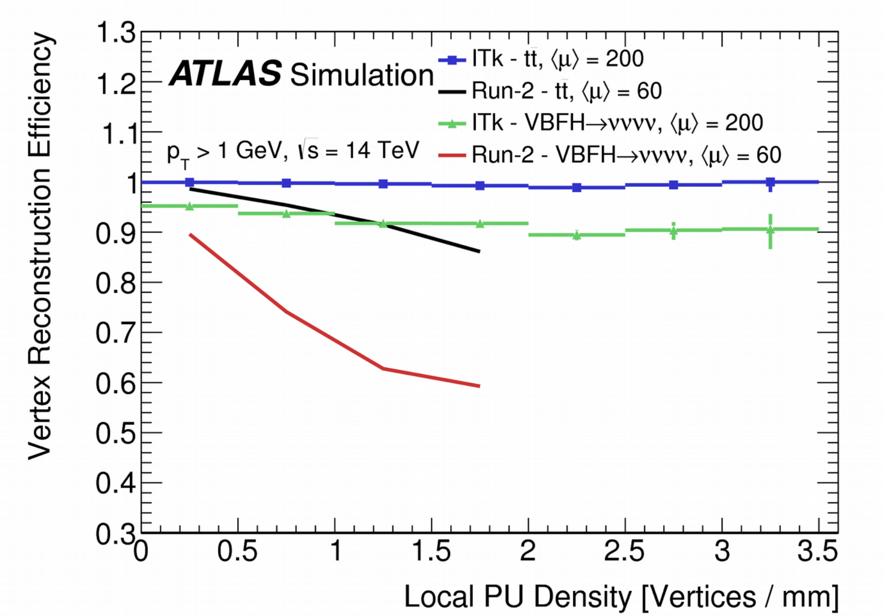


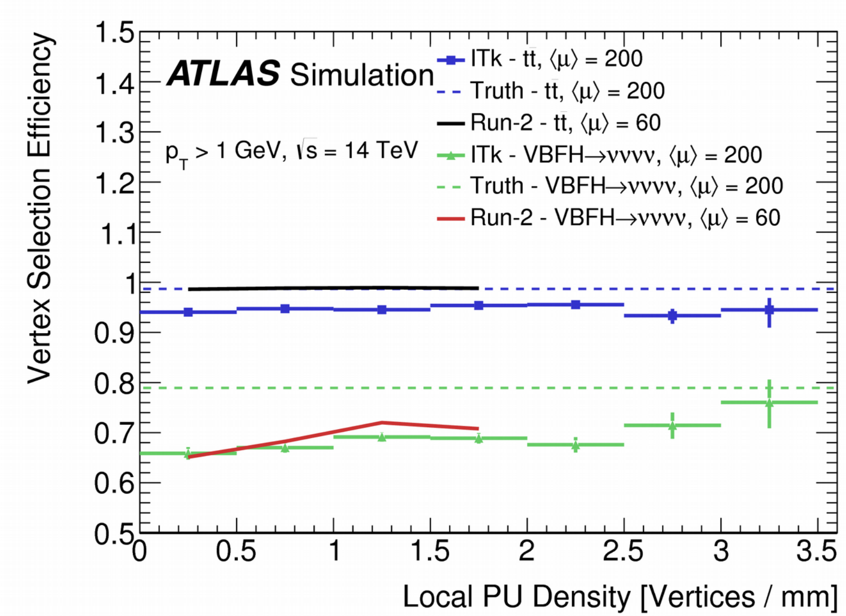


Vertex Reconstruction

- Position resolution of hard-scatter (HS) interaction extremely stable versus local pile-up density.
- Very high and stable HS vertex reconstruction efficiency.
- Good identification of HS vertex.





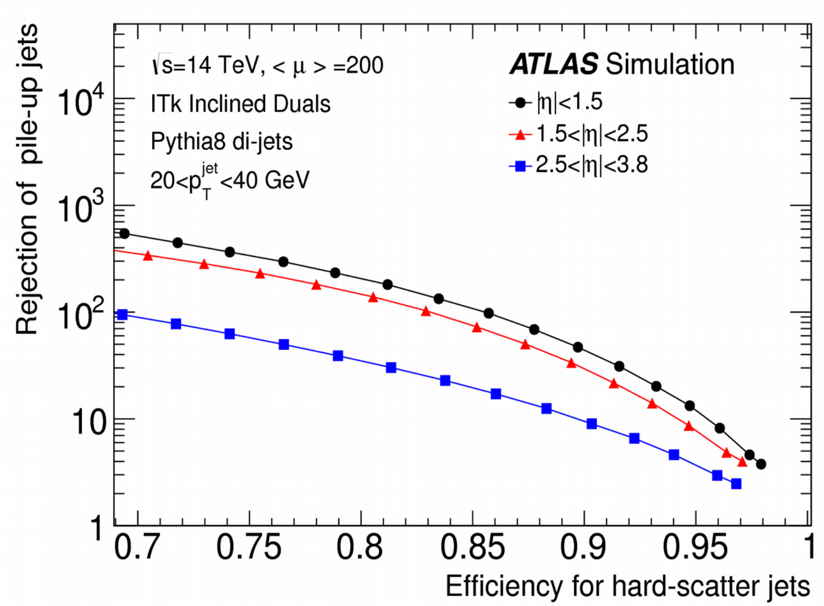


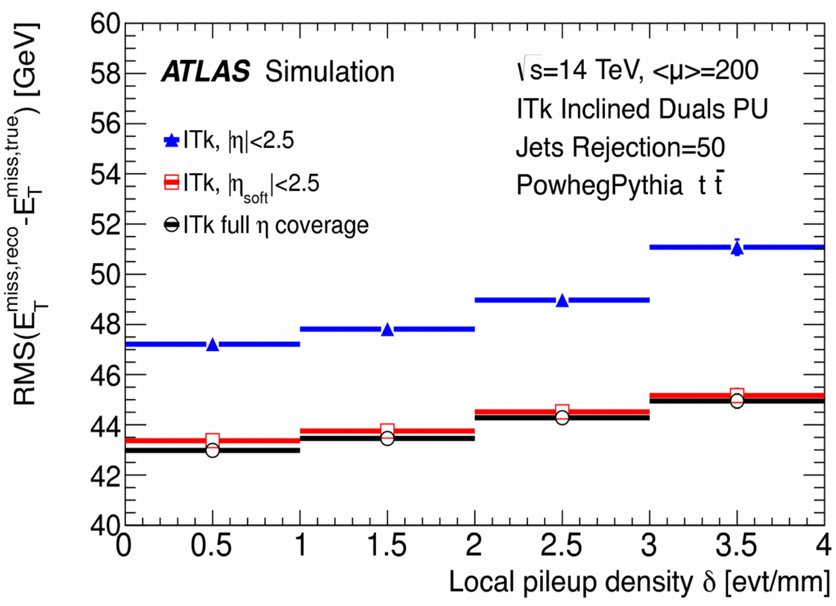
Pile-up Jet Rejection and E_T^{miss} Resolution

- With ITk, pile-up mitigation techniques can exploit the improved vertex separation along z and the larger η-range under which such information is available.
- Good HS jet efficiency is obtained for a typical working point of 50 in pile-up jet rejection for the most forward η-bin.

$$R_{pT} = \frac{\Sigma_k p_{\mathrm{T}}^{\mathrm{trk}_k}(\mathrm{PV}_0)}{p_{\mathrm{T}}^{\mathrm{jet}}}$$

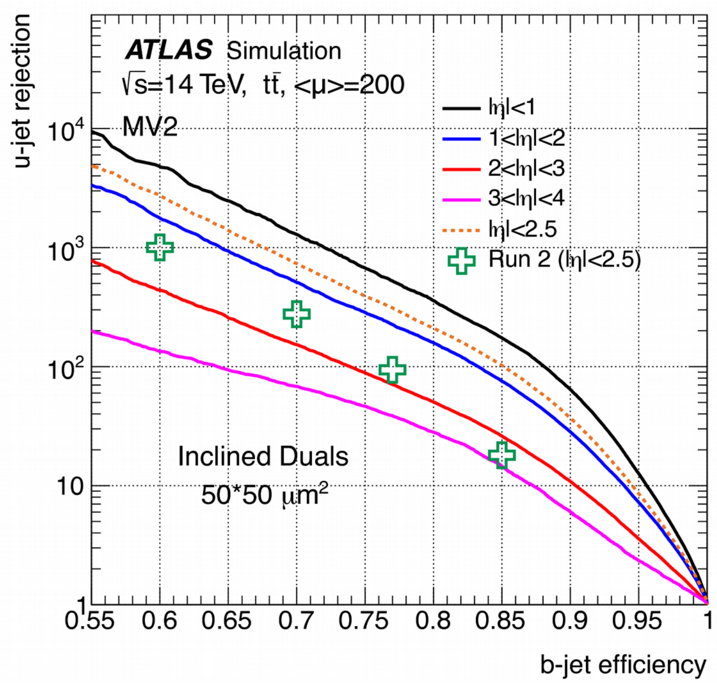
- Improved E_T^{miss} due to a more efficient association of soft tracks to the HS vertex.

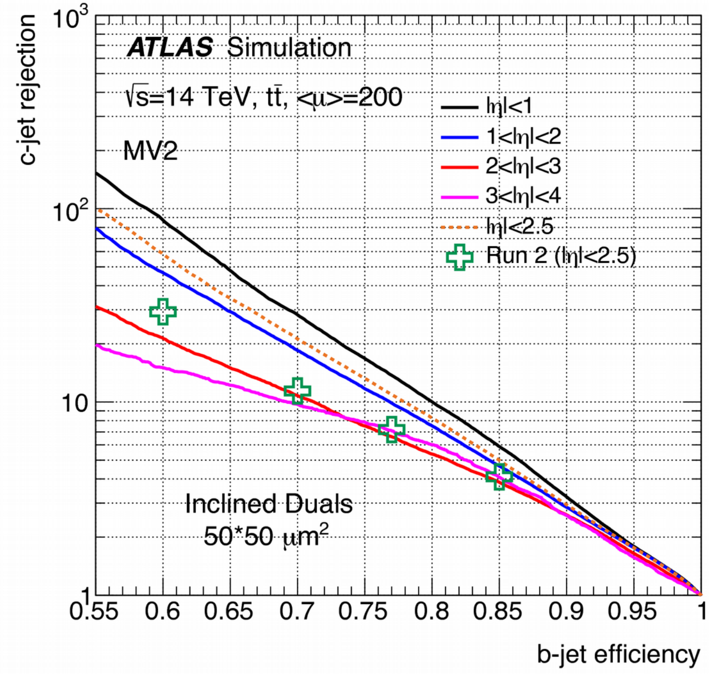




Flavour Tagging Performance

- Identification of jets originating from B-hadrons using multivariate techniques.
- After specific calibration for ITk, the MV2 algorithm, originally developed for ID, leads to a better light and c-jet rejection for $|\eta|<2.5$ for any working point in b-jet efficiency.
  - Possibility to extend flavour tagging capabilities up to $|\eta| = 4$.





Conclusions

- Maintaining similar performance as the current ATLAS Inner Detector in the harsher HL-LHC environment with <μ> = 200 is a tough challenge.
- The layout of the ATLAS Inner Tracker as developed for the Phase-II Pixel technical design report (TDR) [ITK-2018-001] has been presented.
- Tracking performance and vertex reconstruction show improvement for all investigated quantities and results are robust against local pile-up density.
- The improved tracking reconstruction and vertex association are exploited to develop pile-up mitigation and flavour tagging techniques.

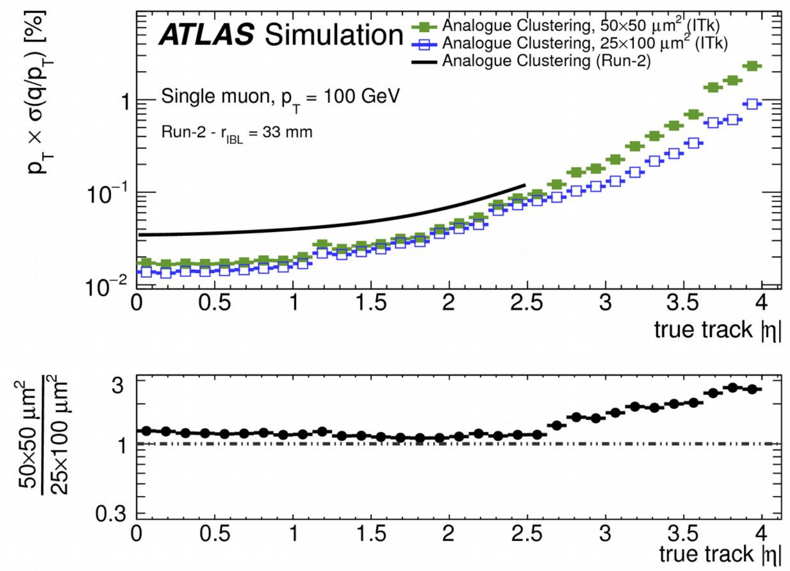
- Further studies are ongoing and further improvements are expected.
  - Notably, studies to decide on the use of 25x100 μm^2 pixel pitches.

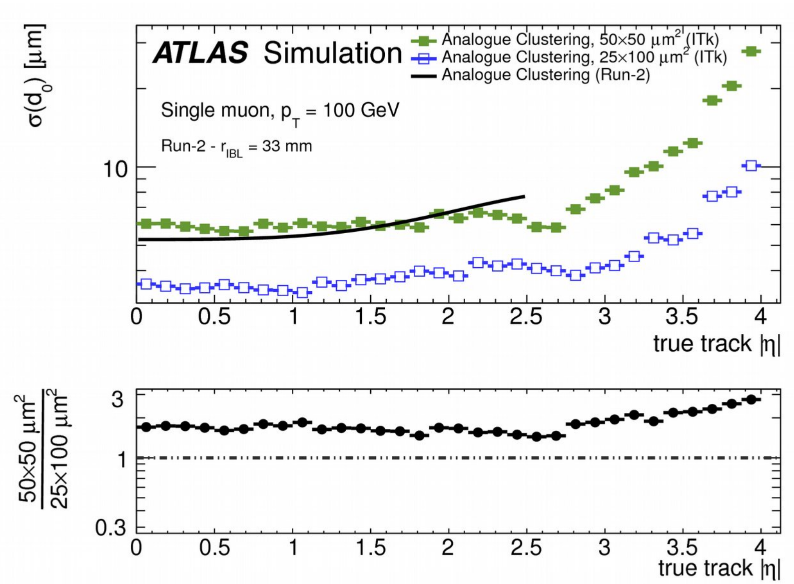
- TDR and post-TDR results pave the road for the success of physics analysis at HL-LHC.
  - Great times for Physics await us!

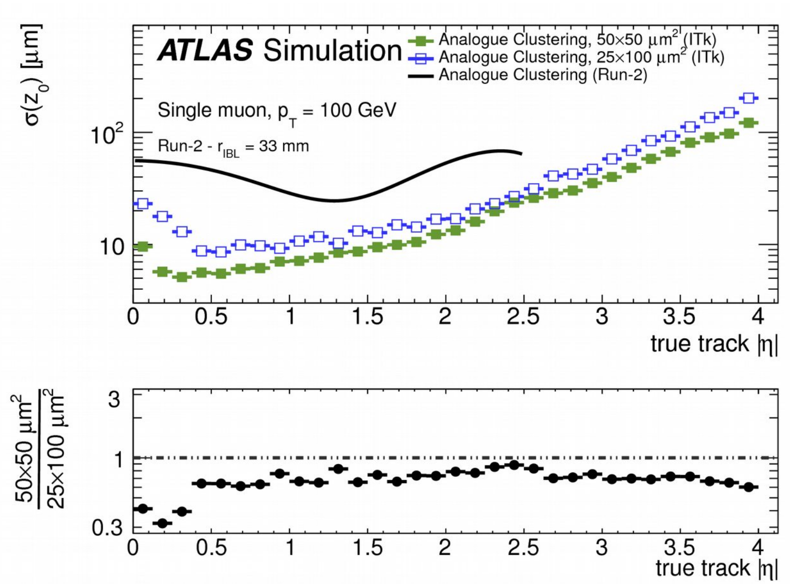
Bonus slides

Track Parameters Resolution: 25x100 μm² studies

- Studies performed with analogue clustering on high-p_T single muons.
- With 25x100 μm² pixel sensors, momentum resolution is improved by 20% (a factor of two) in the barrel (forward) region.
- The d_0 resolution with 25x100 μm² sensors is improved by a factor of 2 over the full η-range at a cost of 35% loss in z_0 resolution.

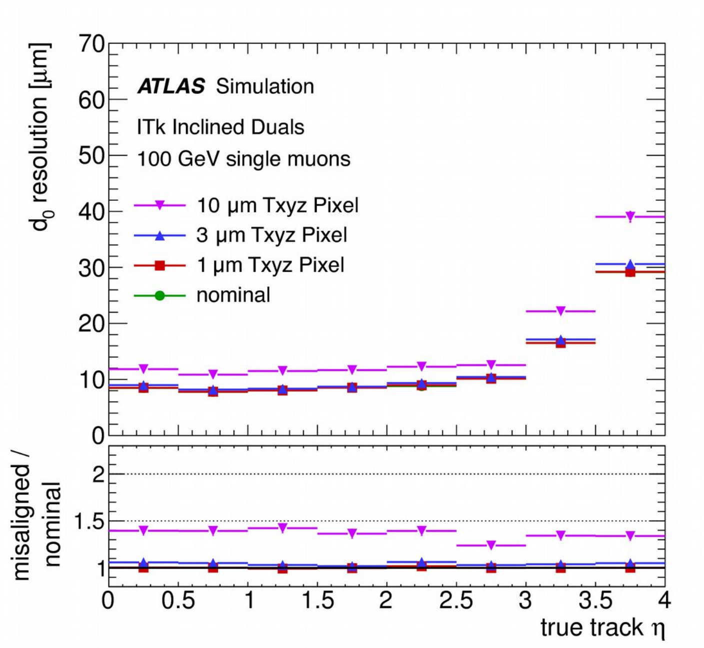


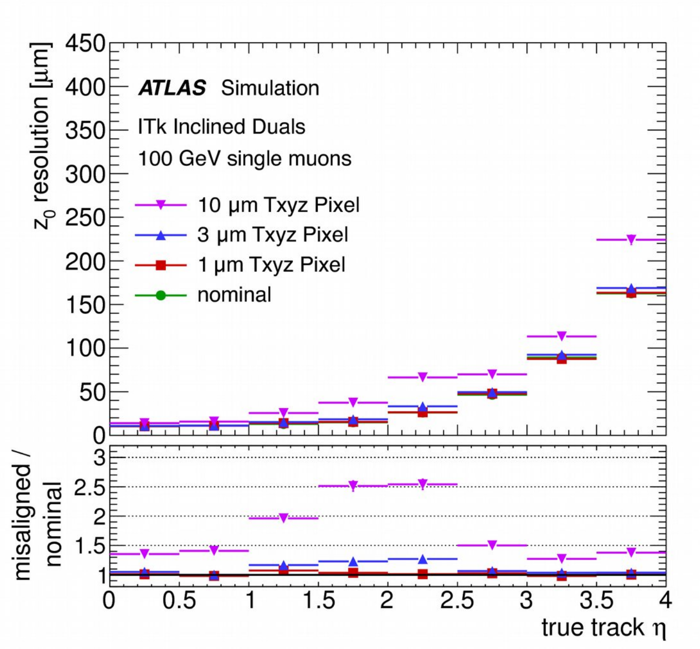




Track Parameters Resolution: Alignment studies

- Resolution studies shown in main material assume a perfectly aligned detector.
- In reality, module and structural misalignment will degrade performance.
- Short-term detector instabilities within a data-taking run are the most difficult to correct.
- No significant resolution degradation is observed for 3 µm random misplacements in XYZ, while 10 µm misplacements lead to a loss up to a factor of 1.4 in d_0 and a factor of 2.5 in z_0 resolutions.





Performance Stability with Ageing and Component Failures

- ITk must preserve robust tracking also in presence of eventual detector defects.
- Two types of defects are considered:
  - Component failures during operations, that lead to inactive modules.
  - Detector inefficiencies leading to loss of hits.