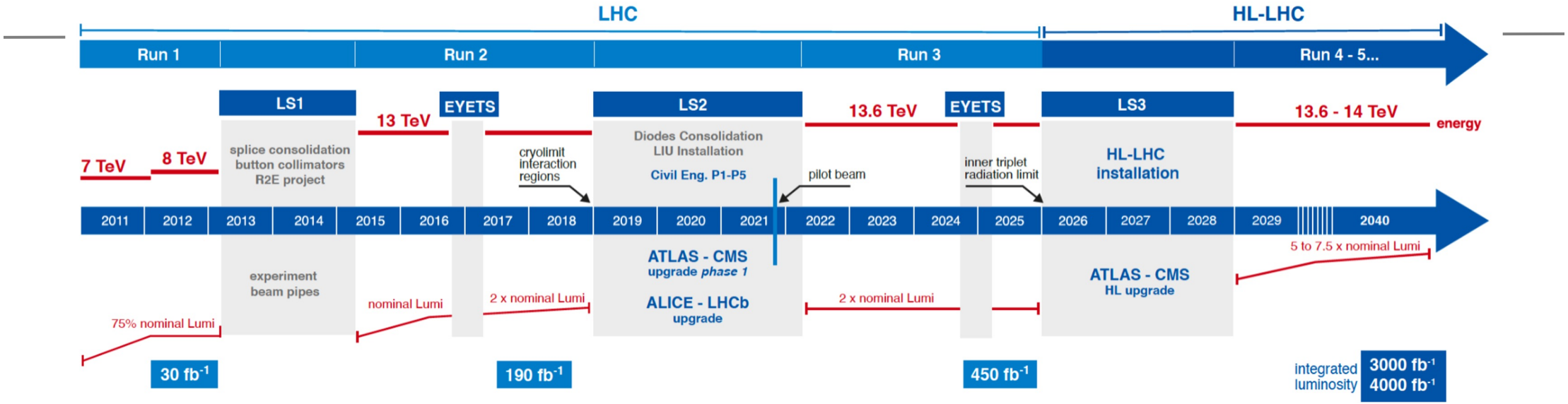
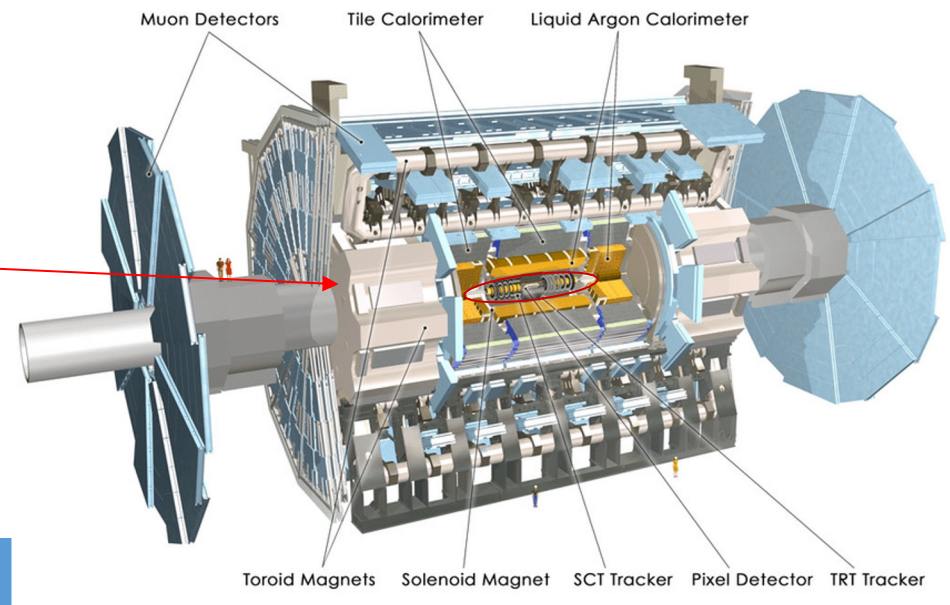
Expected performance of the ATLAS ITk detector for HL-LHC

Helen Hayward



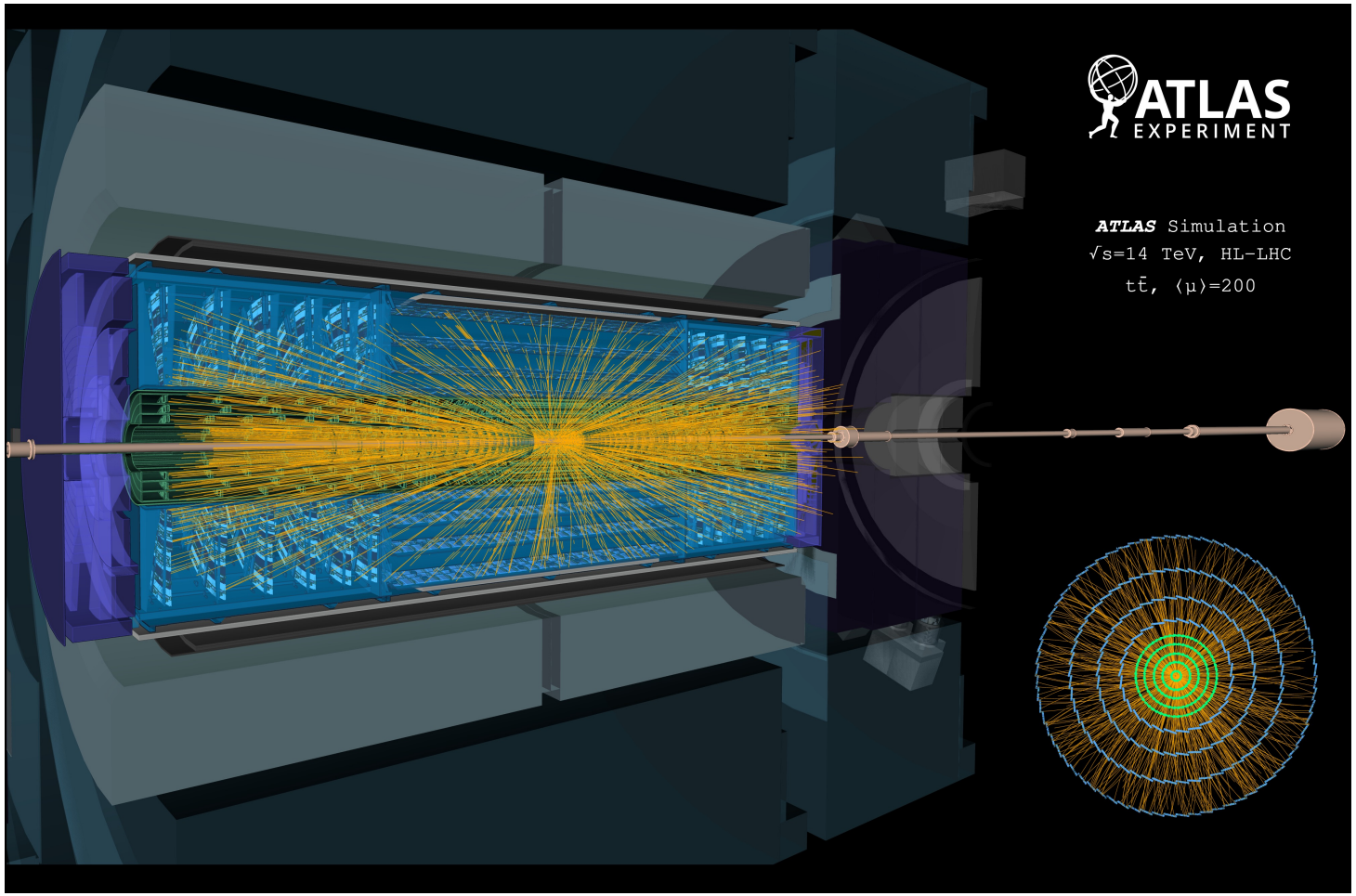
The LHC will upgrade to the HL-LHC in LS3 (2026-28)

The ATLAS inner detector will be replaced by a new all-silicon Inner TracKer for the ATLAS detector (ITk)



https://hilumilhc.web.cern.ch/content/hl-lhc-project

The ITk is designed for :



(A simulated event at the HL-LHC, with a future inner tracker.
Credit: ATLAS)

Increase by factor 7 on the instant luminosity

- Higher granularity of sensors

Increase in data rate:

- Average multiple pp collisions (pile-up) increases from <μ> = 50 to <μ> = 200

Improved radiation tolerance:

- Radiation levels will increase by a factor~10,
- Integrated luminosity of up 3000fb^{-1}

Increased acceptance up to pseudorapidity of 4

ITk Design

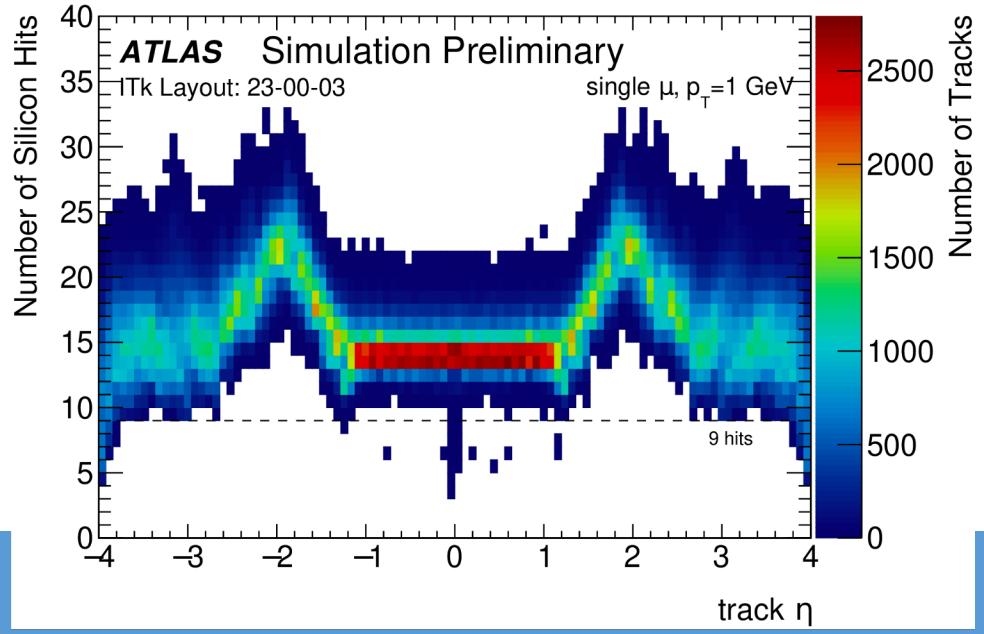
Strips: 4 barrel layers, 12 disks

Pixels: 5 pixel layers

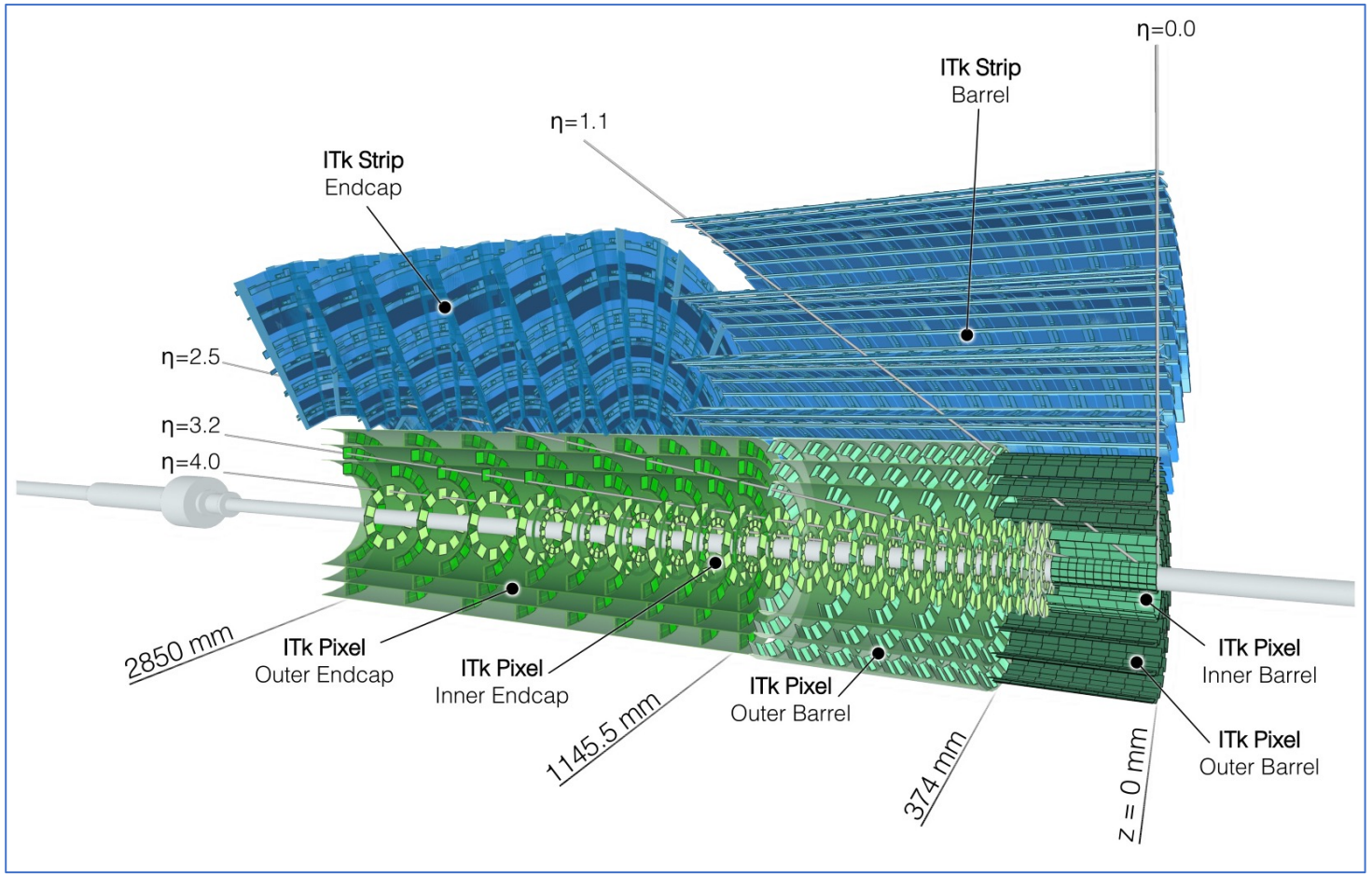
Together: ≥ 9 Si Hits per track

(Hermetic down to 1GeV)

All supported on low mass CF supports.



(ATL-PHYS-PUB-2021-024)



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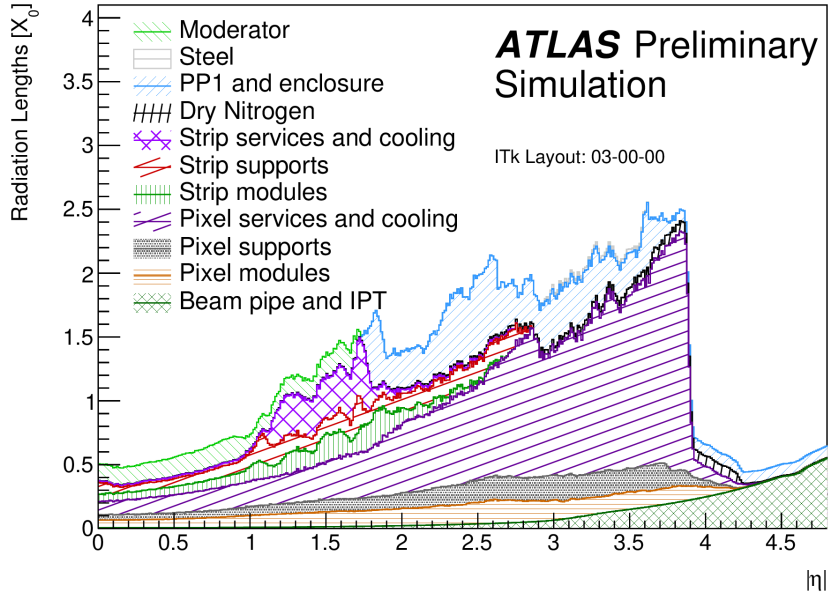
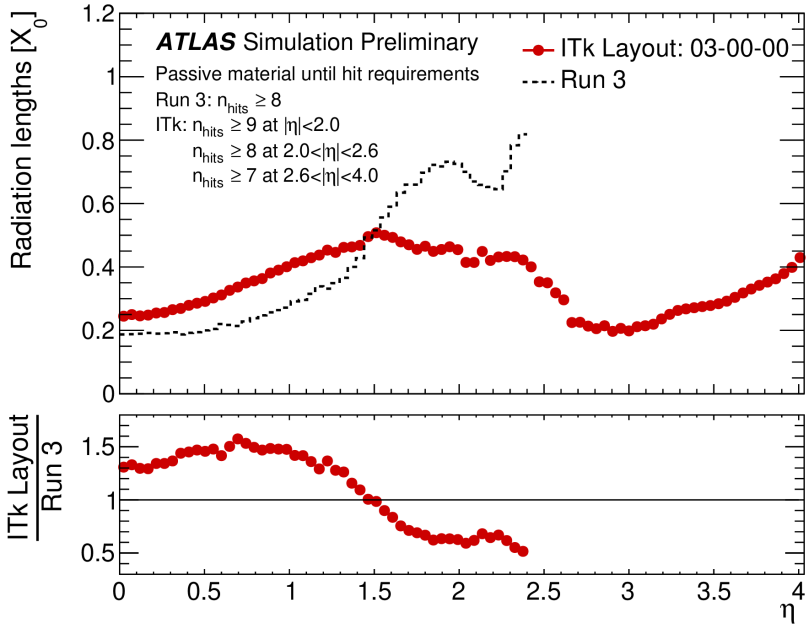
Material Budget

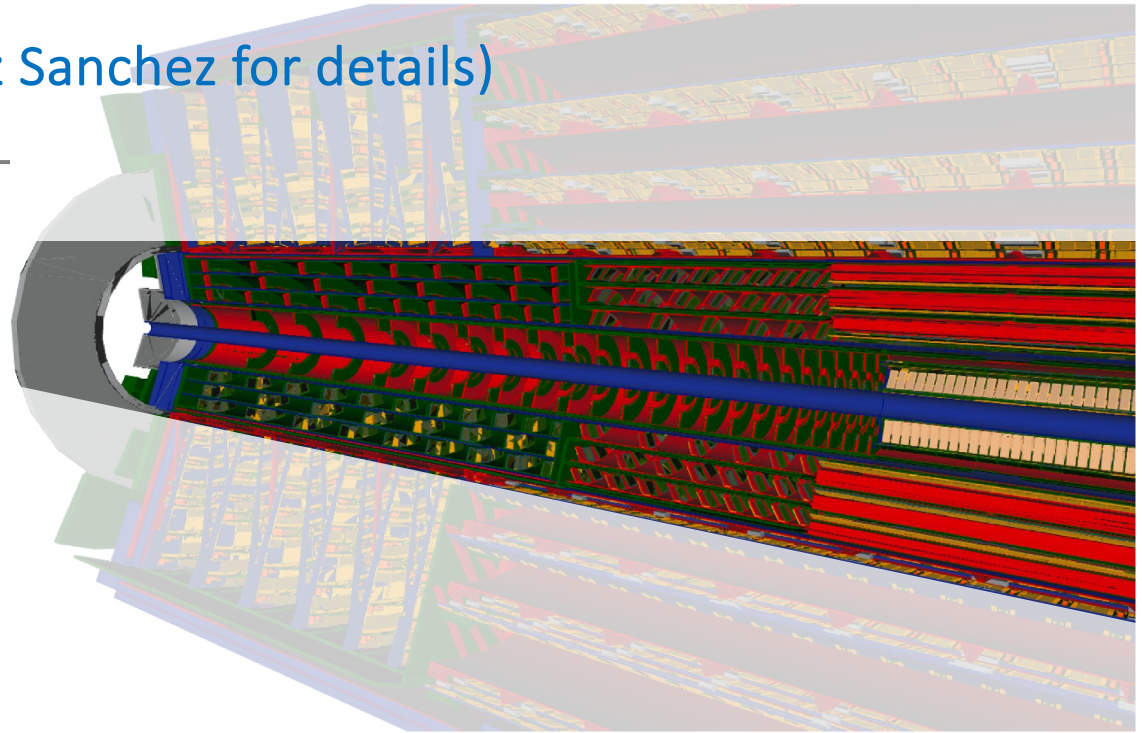
- Reduced material budget w.r.t. Run-3:
- Evaporative CO_2 cooling with titanium pipes
- Carbon fibre supports
- Serial powering
- Optimised number of readout cables using link sharing
- Material budget being refined using real production part measurements

Pixel InnerSystem mock-up





Pixel Detector. (See talk by Francisa Munoz Sanchez for details)

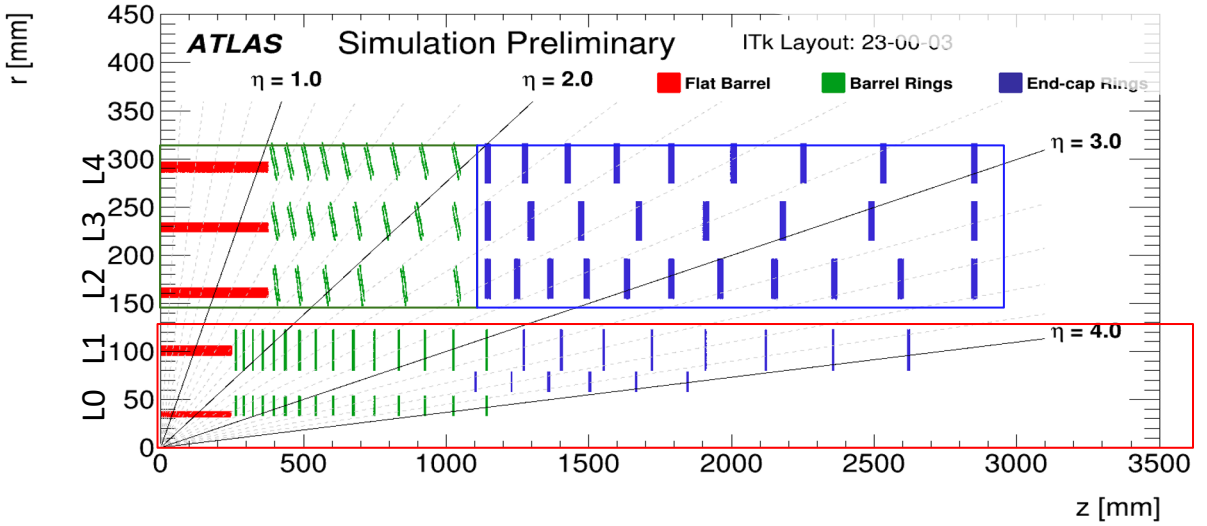


Outer System (L2, L3, L4)

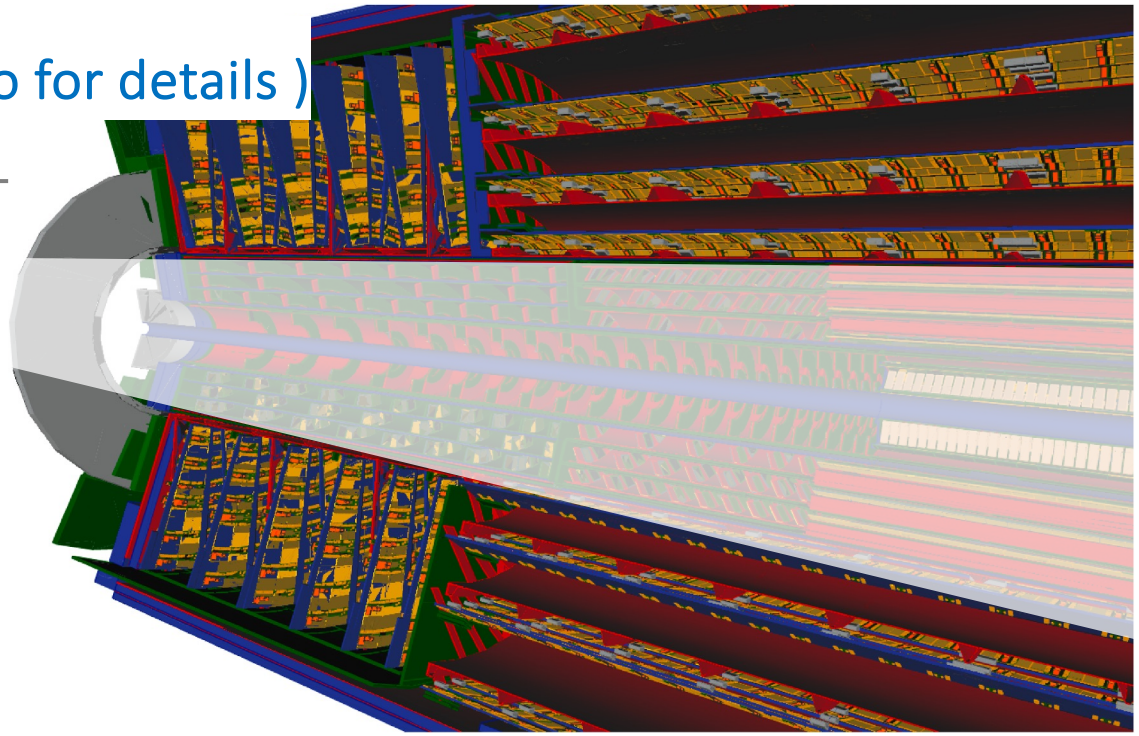
- 3 layers of 50x50 µm Planar Quad Modules
- Designed for HL-LHC@4000fb^{-1}
  - Fluence upto ~ 5x1015neq/cm2 (2.5 safety factor)

Inner system (L0, L1)

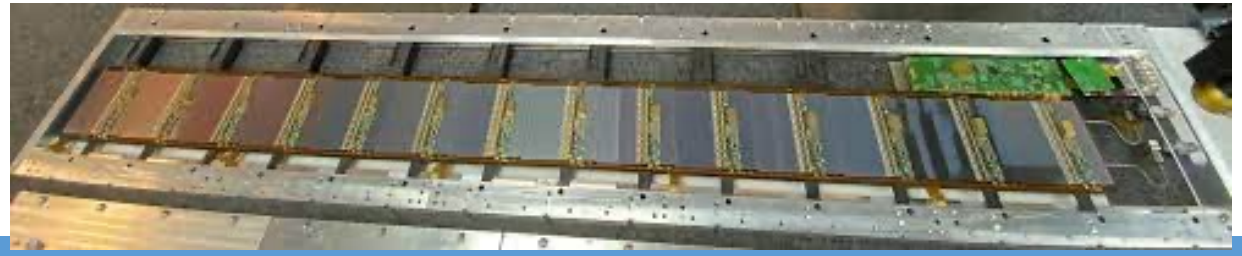
- Inner System: Flat staves and rings.
  - L0: 3D pixel sensors - (50x50 µm or 25x100 µm)
  - L1: 50x50 µm Planar Quad Modules
  - Designed to be replaced
- HL-LHC@2000fb-1 (2.5 safety factor)
  - Fluence upto 1.9x10^{16}neq/cm^2
  - TID upto 10MGy

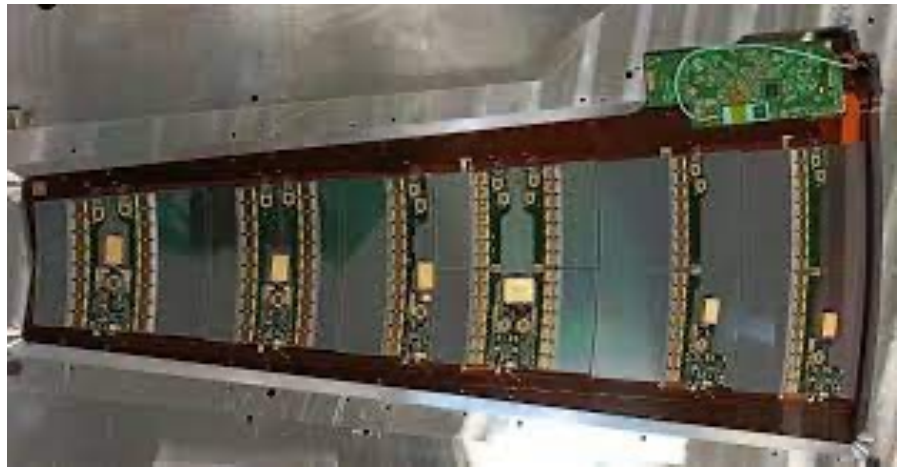


Strip Detector . (See talk by Zhengcheng Tao for details)



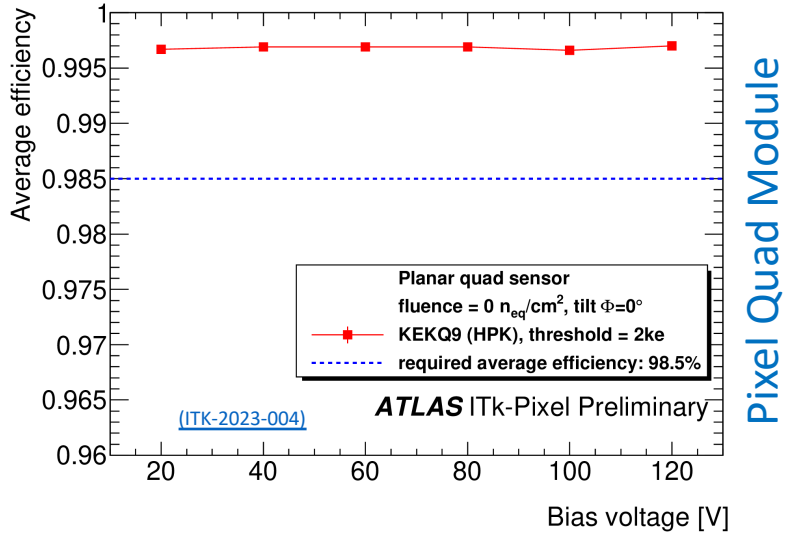
- Barrel
  - Modules arranged on staves in 4 layers
  - Radius: 40-100 cm; |z|< 1.4m
- EndCap:
  - Modules arranged in Petals on 6 disks in 2 endcaps
  - 1.5 <|z|< 3.0 m |η| < 2.7
- Designed to perform for HL-LHC@4000fb^{-1}
  - L_{peak}=7.5x10^{34} cm^{-2}s^{-1}
- In total: 165 m^2 of strips (vs. 68 m^2 of SCT)
- Strip pitch: 75.5 mm

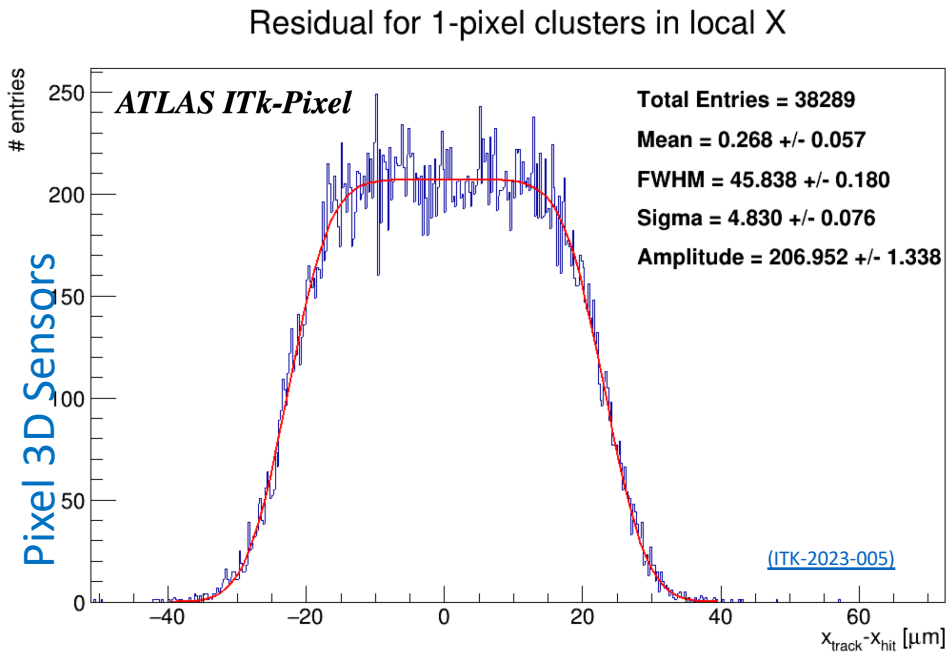


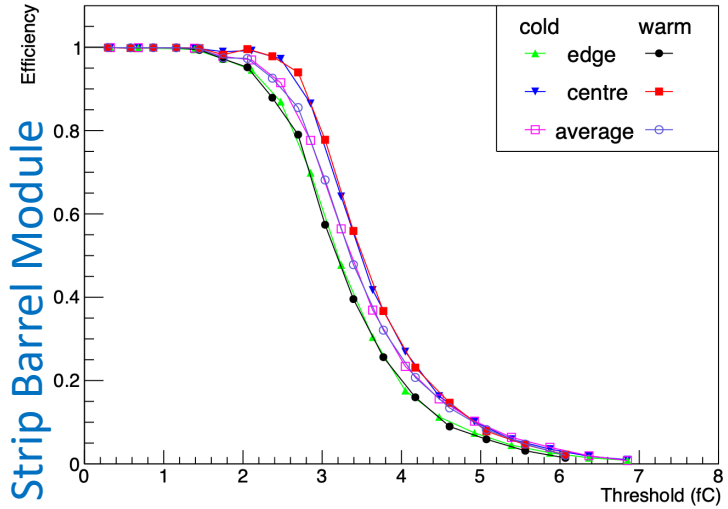


TestBeam Results

- Extensive program of testbeam qualification of pixel and strip modules
  - Before and after irradiation
  - i.e. “beginning” and “end – of –life” of ITk







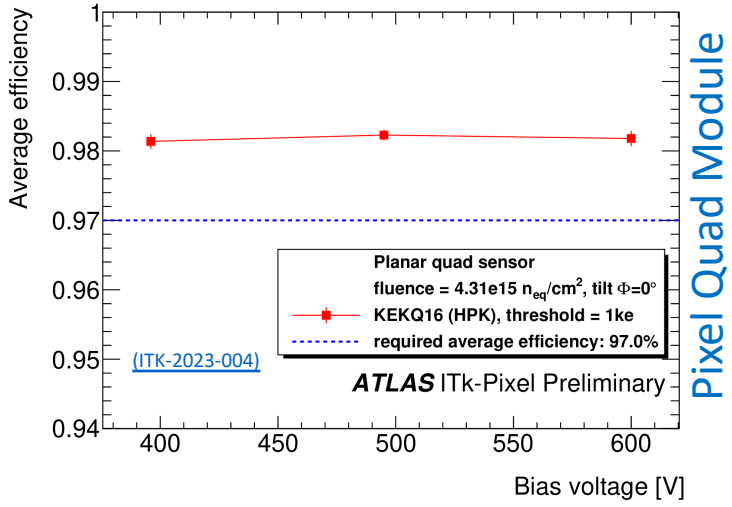
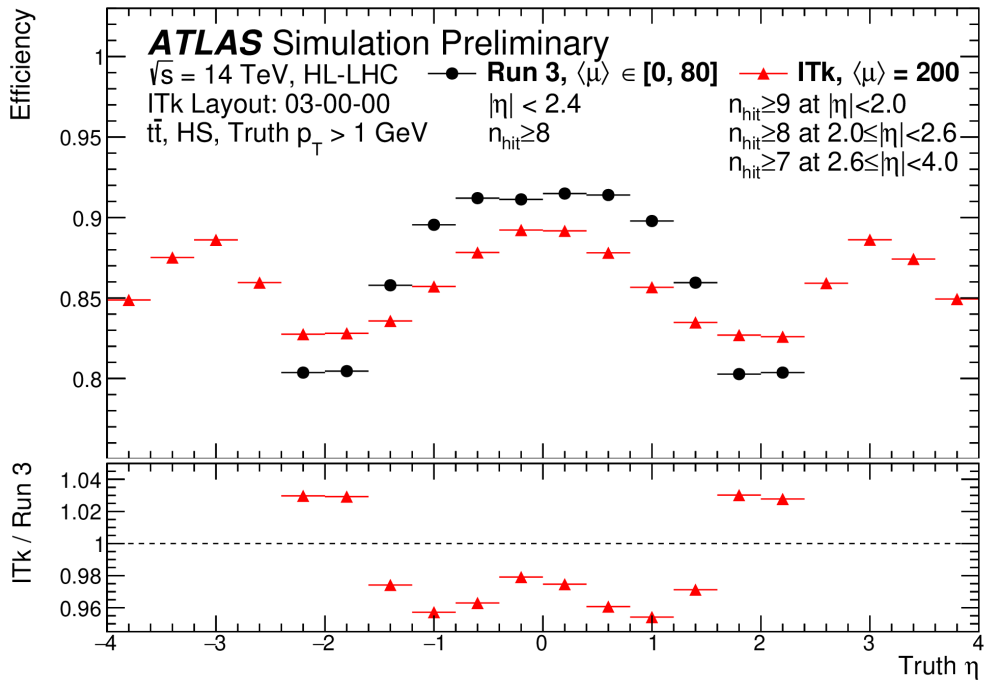


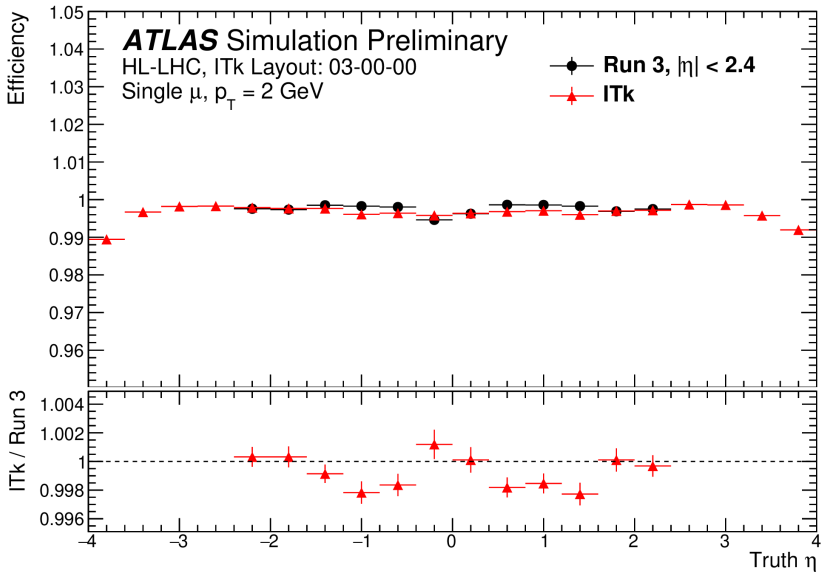
Figure 11. Detection efficiency of the ITk SS module measured cold (−30 °C) and warm (+30 °C).

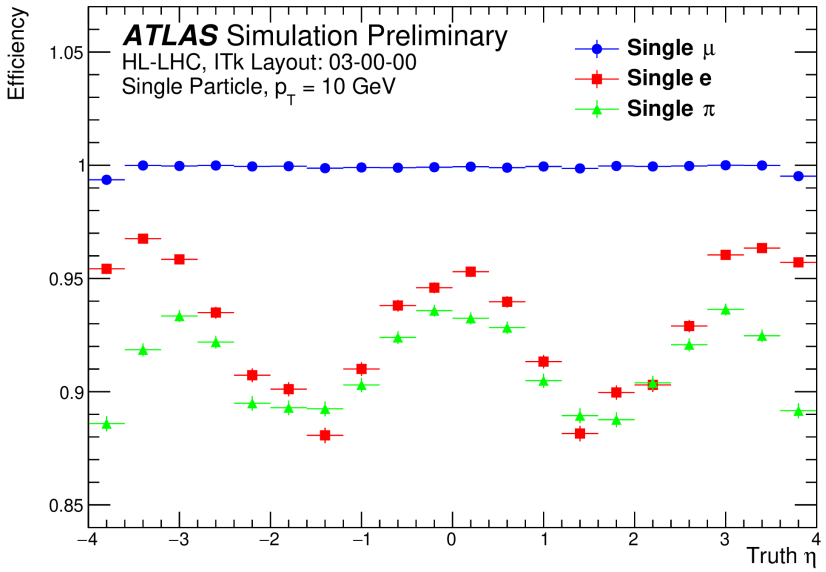
(J.-H Arling *et al* 2023 *JINST* **18** P03015)

Tracking Efficiency

- The ITk is predicted to have the similar tracking efficiency as observed in Run 3
  - But over an extended eta range

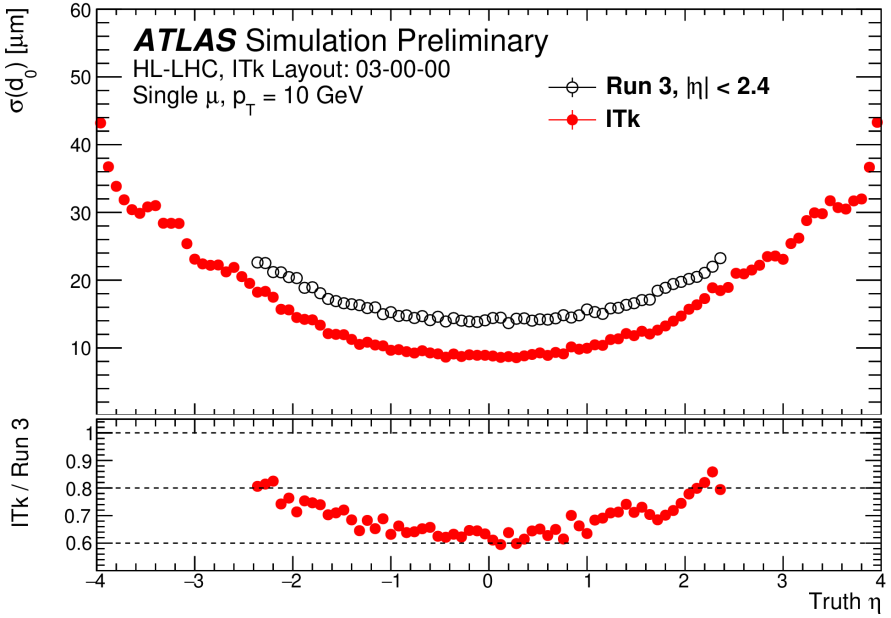


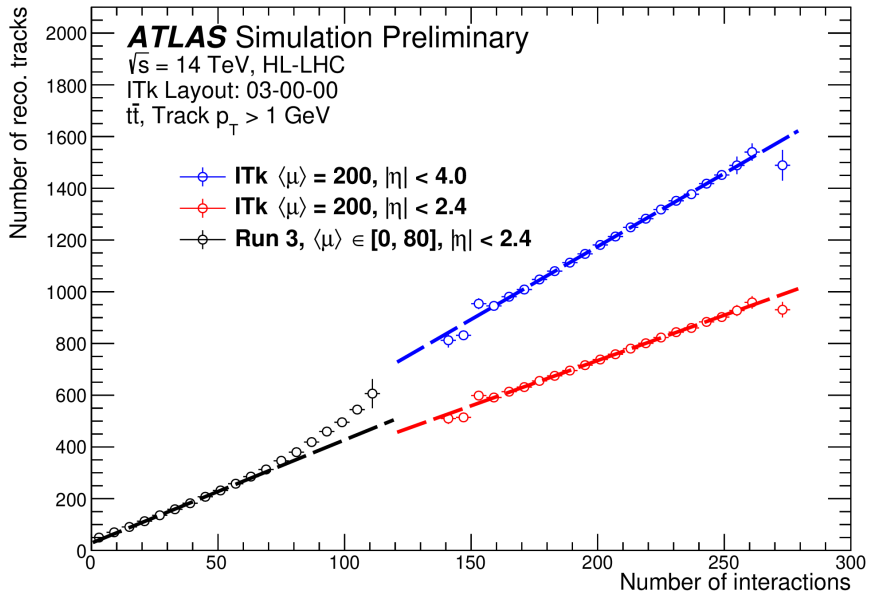




Tracking

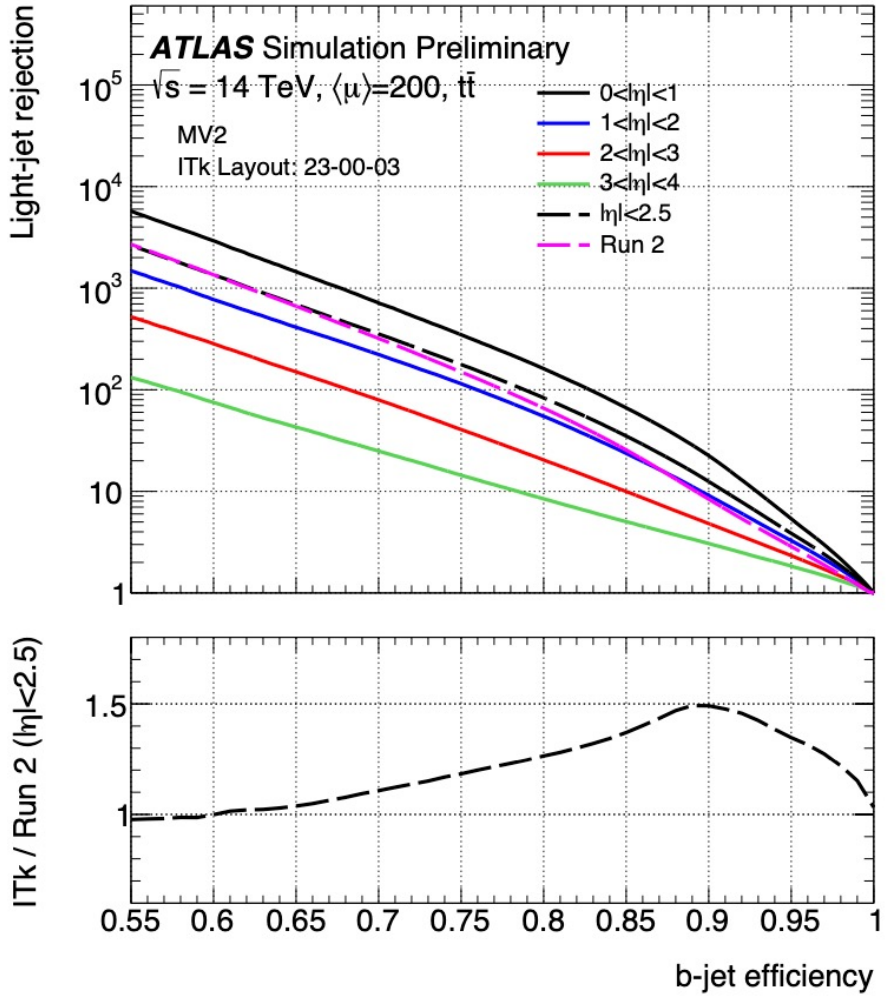
- The Itk is expected to have a superior transverse impact parameter
  - Driven by the performance of L0, 3D modules
- Number of reconstructed tracks with $pT>1$~GeV per event for tt^{-}
- The non-linear scaling of the number of tracks with the number of interactions of the Run 3 reconstruction





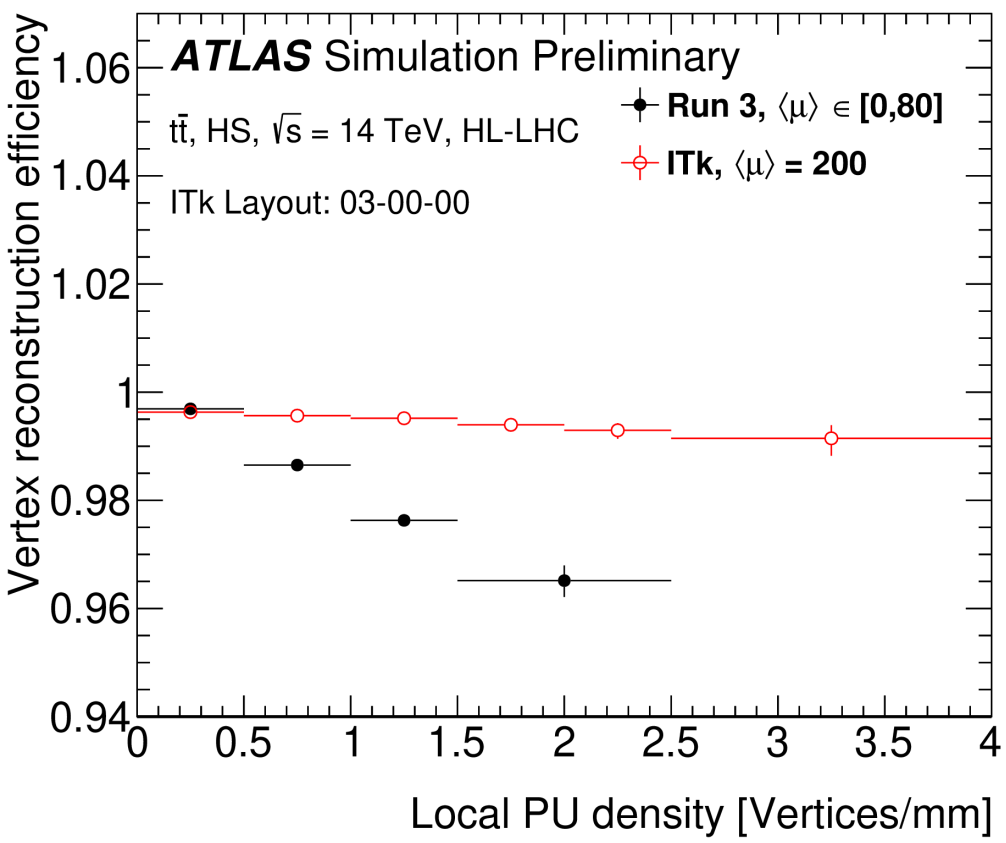
B-tagging

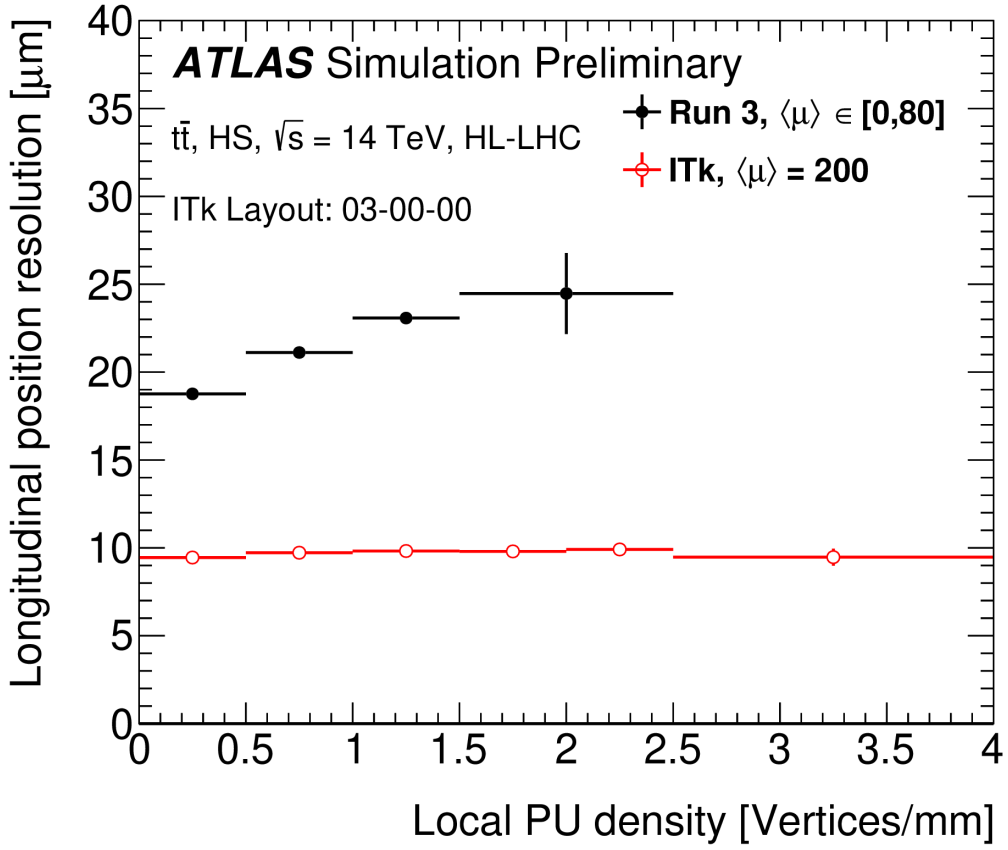
- Quality impact parameter resolution, and track reconstruction are required for b-jet identification
- E.g. light-jet rejection as a function of b-jet efficiency for one example algorithm (MV2)
- Further improvements can be made using NN algorithms
  - ATL-PHYS-PUB-2022-047



(ATL-PHYS-PUB-2021-024)

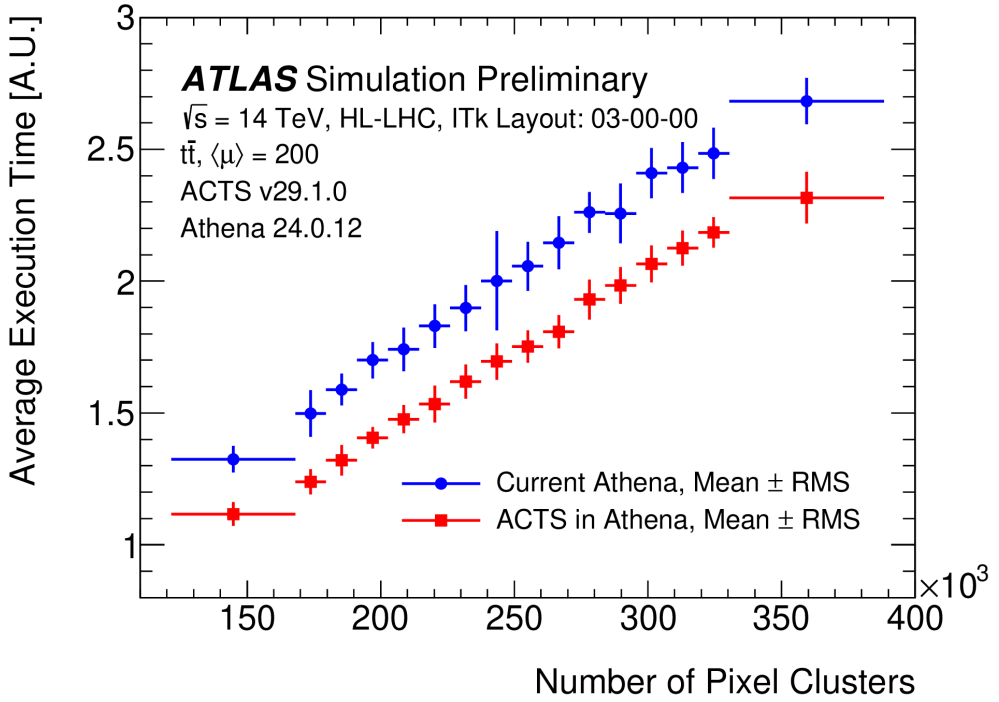
Vertex efficiency





Aside: Continued improvements to tracking algorithms

- In addition to the new Itk there is a comprehensive software upgrade program
  - Critical to reduce resource consumption in the 14-200 pile up event environment
- ATLAS to use ACTS at phase 2
  - Ai X. et al., *A Common Tracking Software Project*, Comput Softw Big Sci 6, 8 (2022)
  - experiment-independent toolkit for track reconstruction



Summary

- New ATLAS Tracker is required to take full advantage of the increased collision rate of HL-LHC
- Entering the production phase of the ATLAS Inner Tracker construction
  - Real production measurements being used to validate simulation
- HL-LHC will provide unprecedented challenges in terms of track and vertex reconstruction
  - Excellent performance for tracking and vertex reconstruction for the ITk wrt the current detector despite the increase in pile-up
    - Pseudorapidity range extended to 4.0
    - For $\langle\mu\rangle = 200$
- Improvements being made to software to reduce resource consumption