Expected Performance of the ATLAS Inner Tracker at the High-Luminosity LHC

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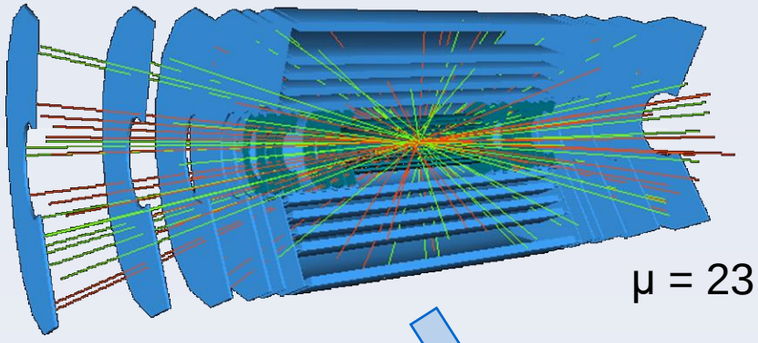
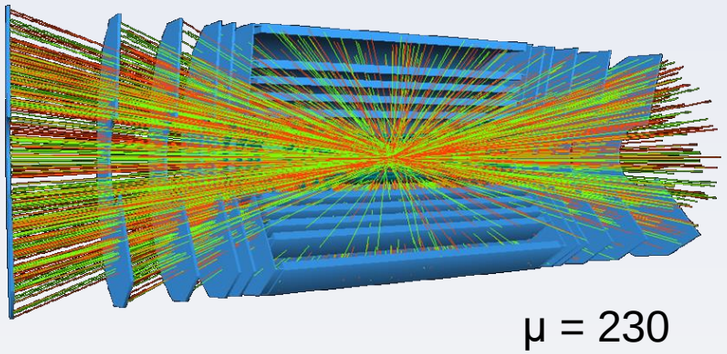
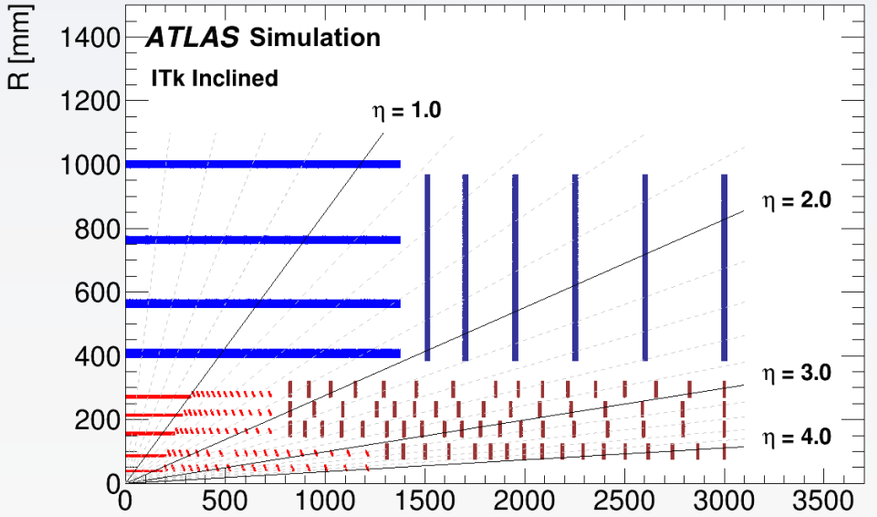
Introduction

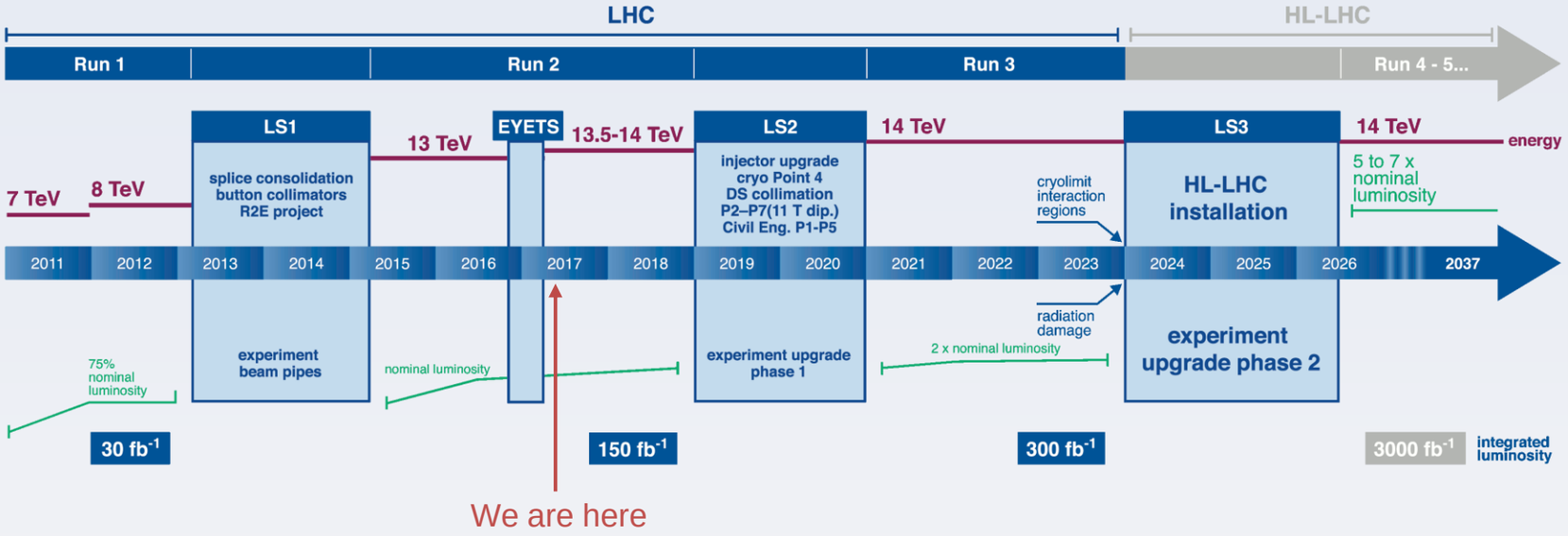
- HL-LHC upgrade due in ~2025
- Plan to deliver 3000 fb^{-1} of integrated luminosity
- Mean interactions per bunch crossing up to μ = 200
- Higher track density => need improved resolution, efficiency to maintain tracking and b-tagging performance
- Inner detector will need replacement due to radiation damage
- Occupancy will be too high to keep TRT
  => Whole new, all silicon Inner Tracker (ITk)



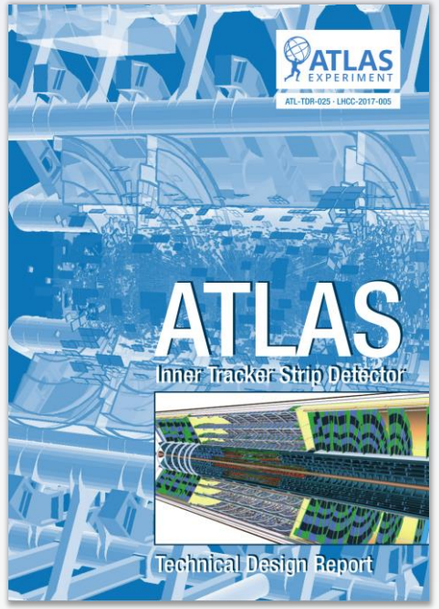




Timeline

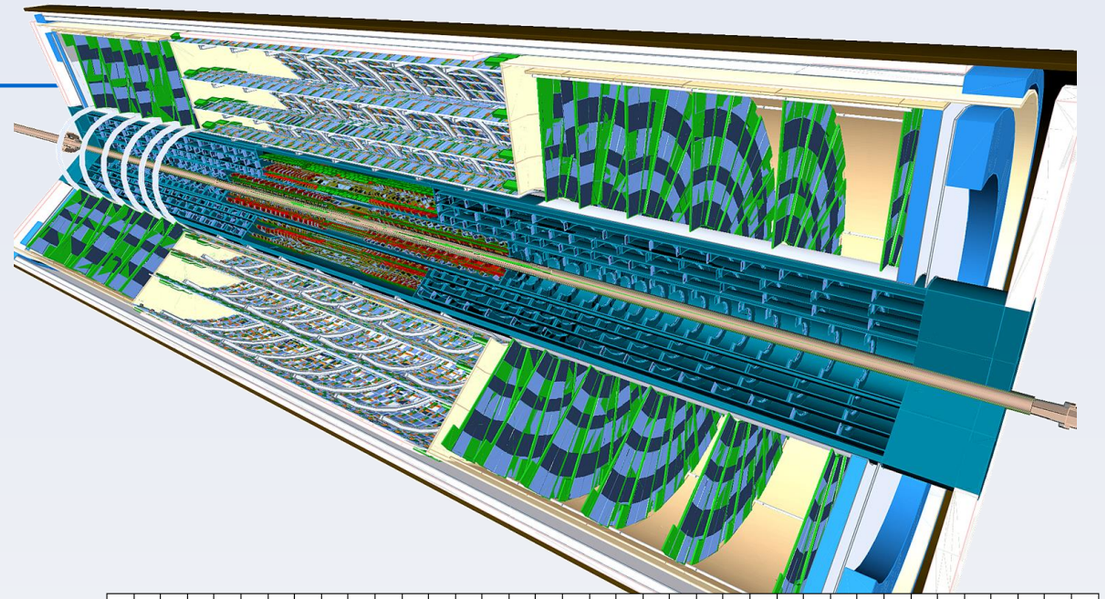


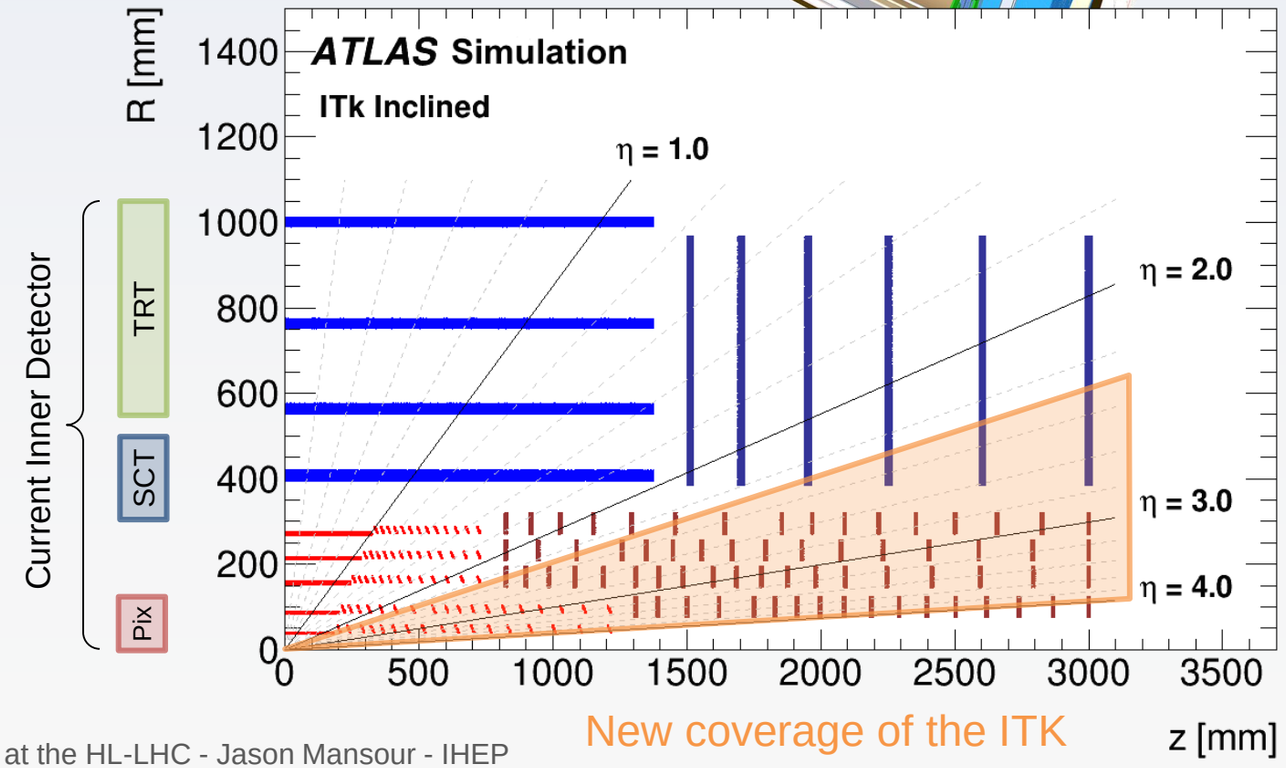
- Important milestones: Strip and Pixel TDRs (Technical Design Reports)
  - Strip TDR approved recently! Results in this presentation from the TDR (ATLAS-TDR-025)
  - Pixel TDR and layout decision coming soon



Overview

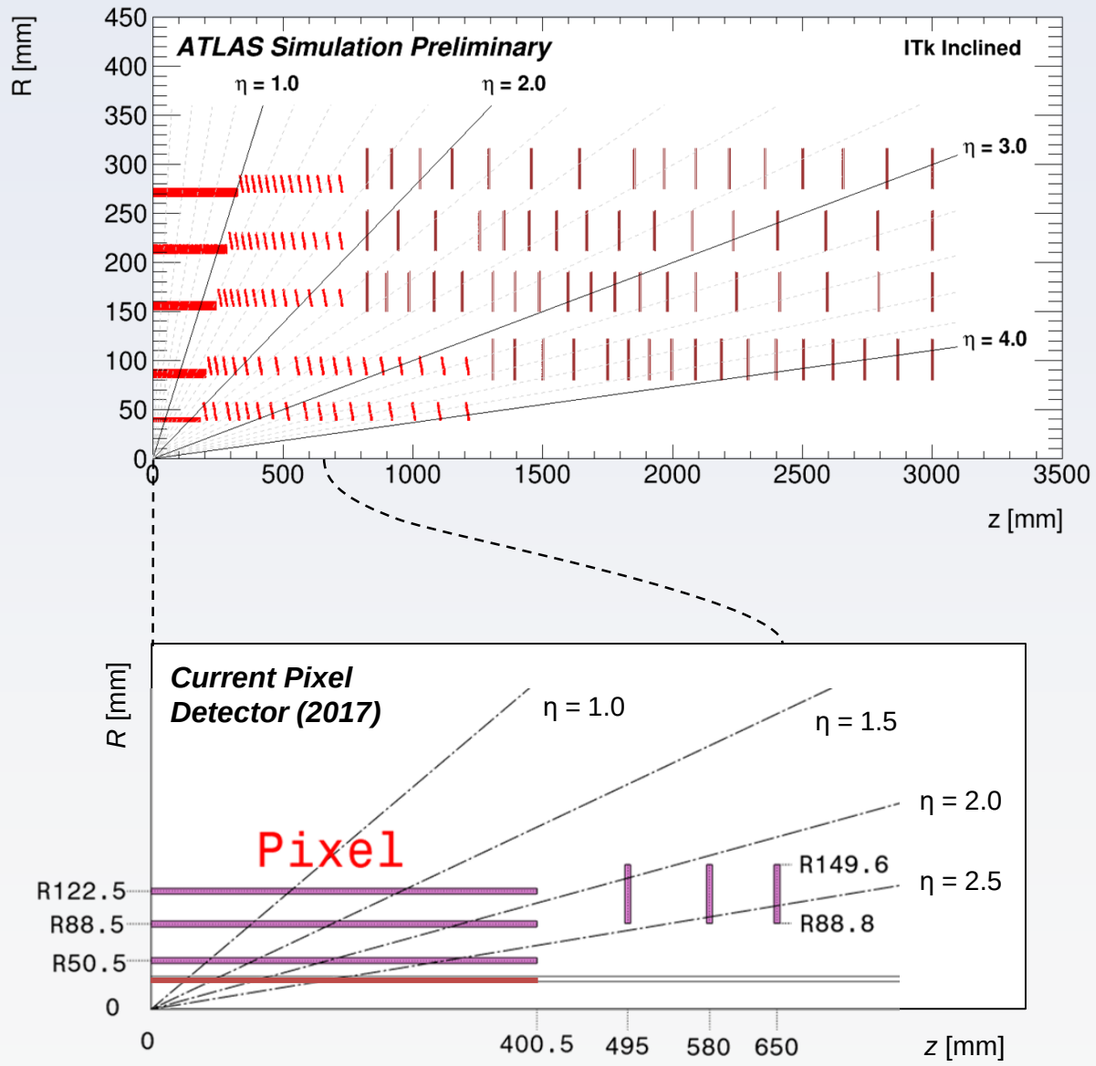
- All new Inner Tracker (ITk) for the High-Luminosity LHC
- Strip detector
  - Extends up to R = 1000 mm
- Pixel detector
  - Coverage up to |η| < 4.0
  - Inclined modules
  - Rings in forward region
- No transition radiation detector





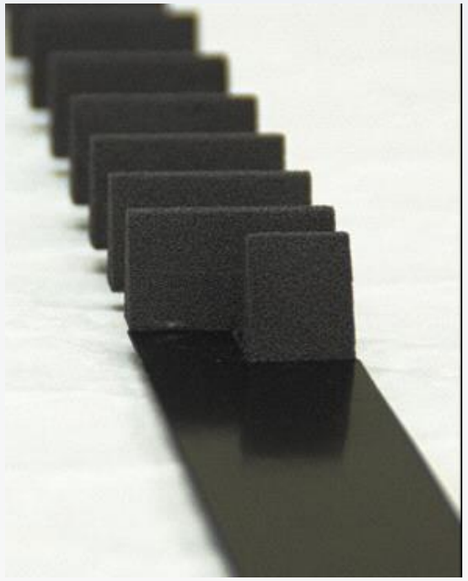
New coverage of the ITK

Pixel Detector - Barrel



Inclined layout:

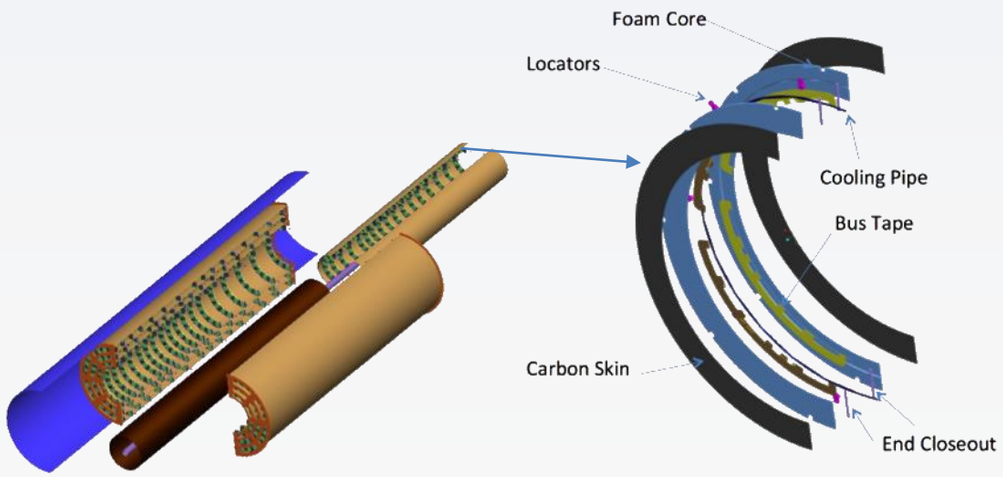
- Tracks ~perpendicular to surfaces
- Less material in forward region
- Multiple clusters/layer
- Less silicon needed



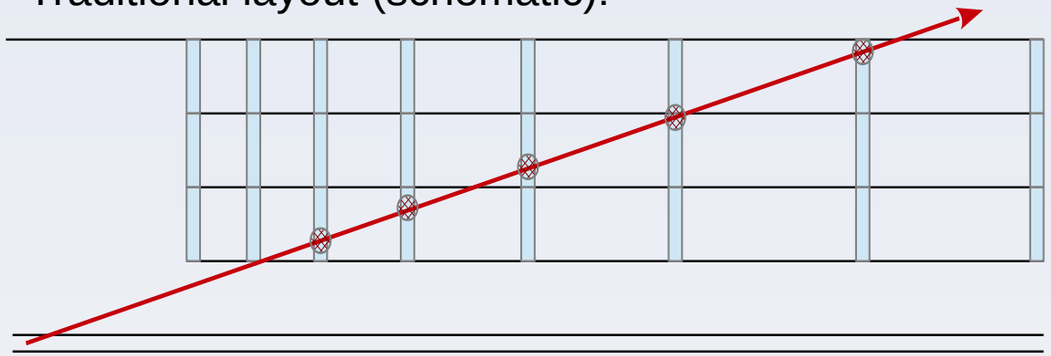
Pixel Detector - Rings

Instead of classical disks, use rings in endcap region

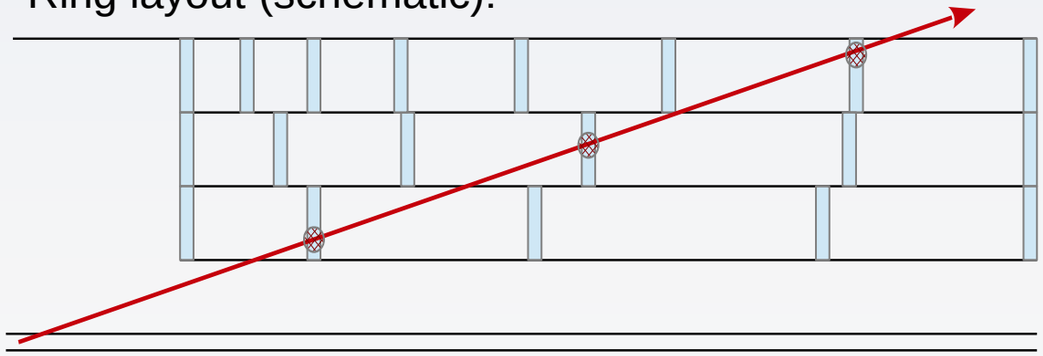
- Constant number of clusters vs. η
- Increase number of rings at high η
- Save silicon surface
- Services routed on support structures



Traditional layout (schematic):

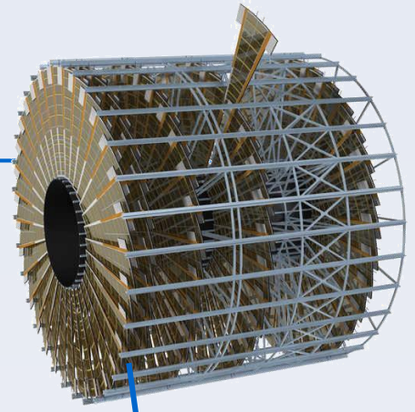


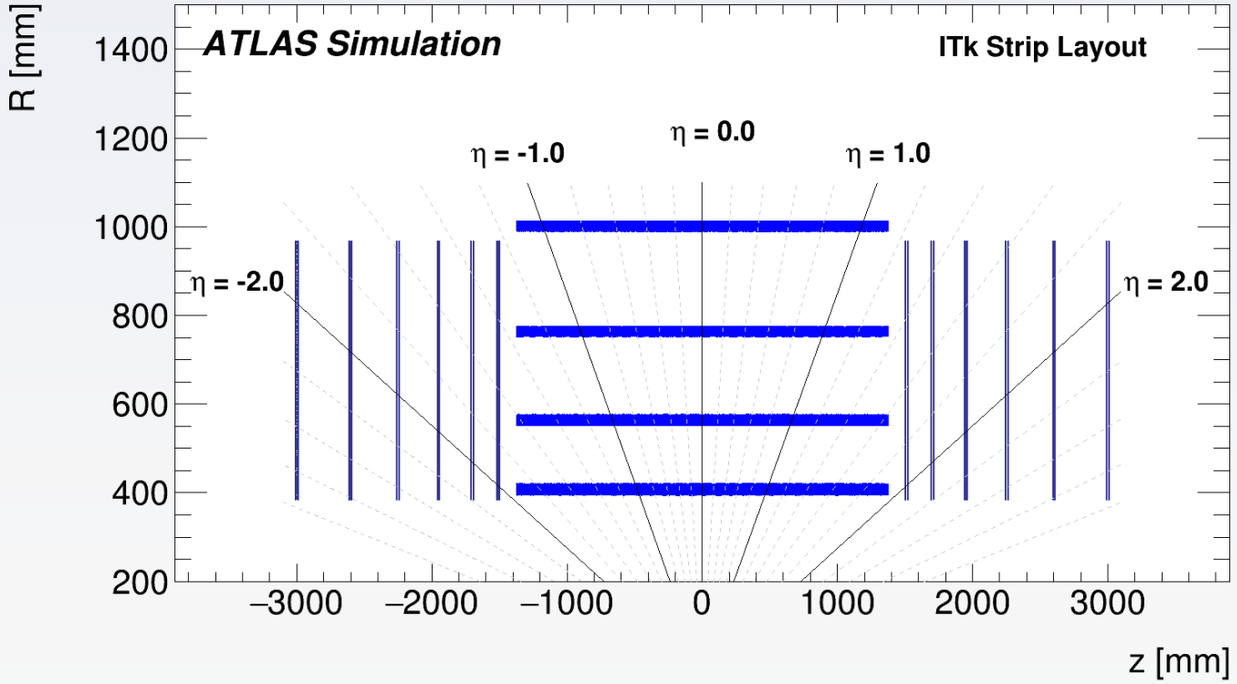
Ring layout (schematic):

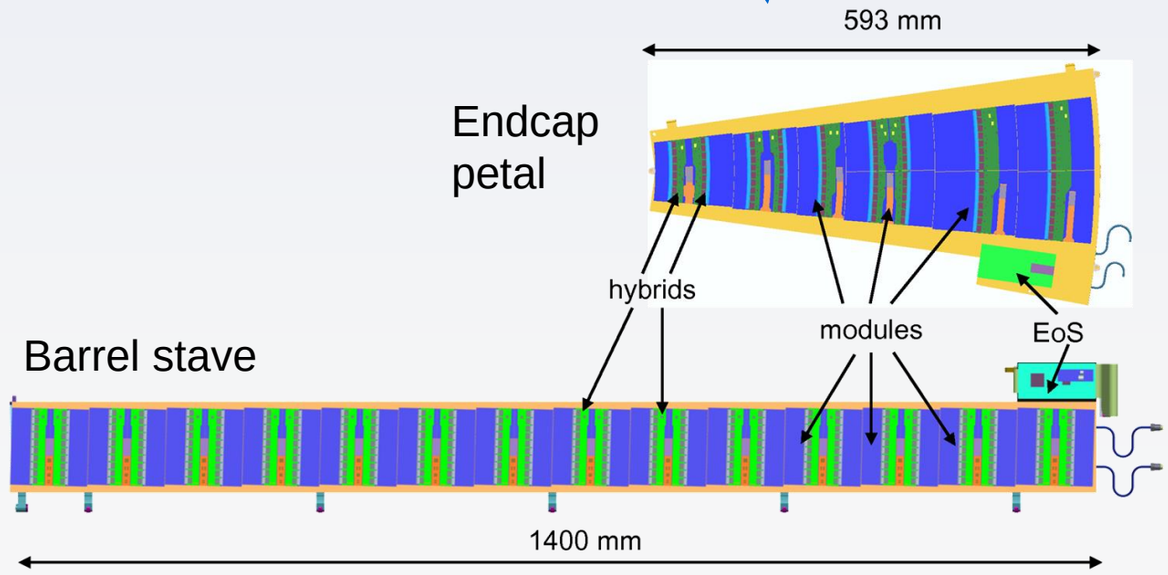


Strip Detector Layout

- Four barrels (full coverage up to |η| = 1.1)
- 2x6 endcap disks (full coverage up to |η| = 2.0)

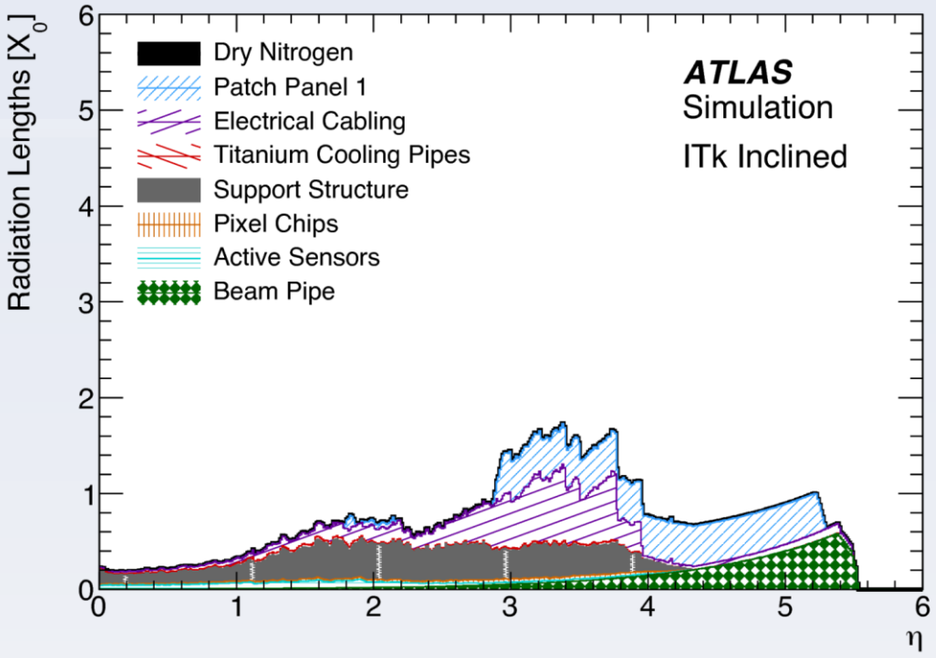


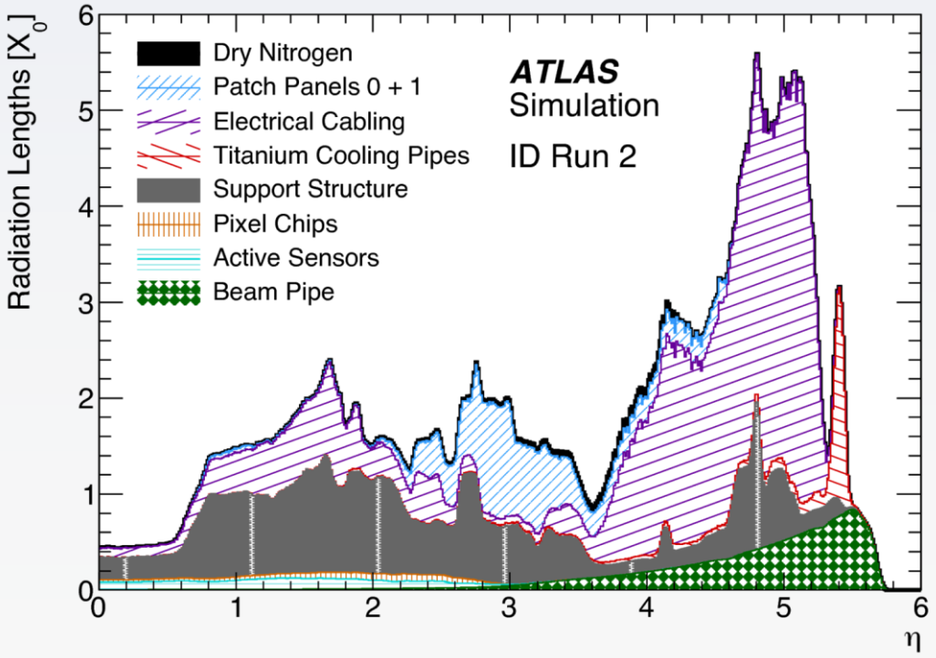




Material Budget

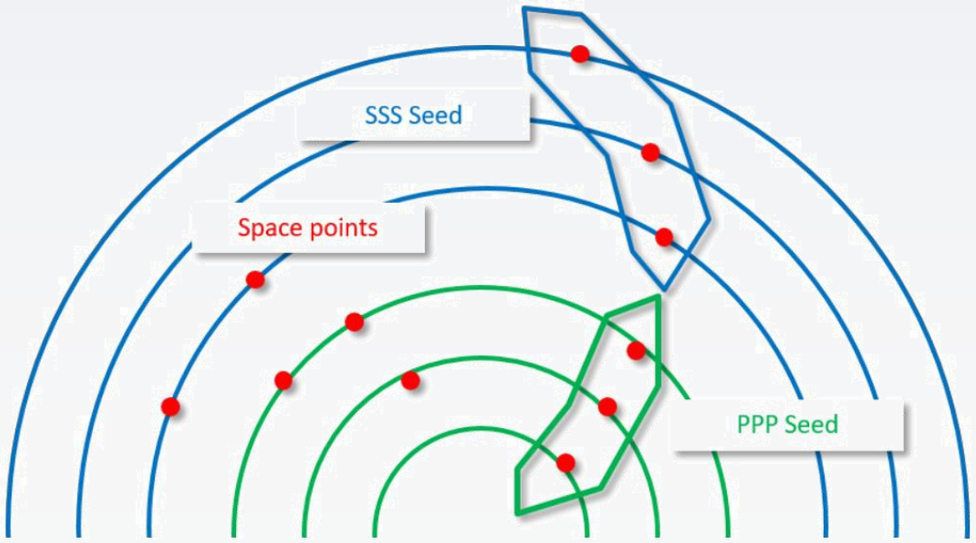
- Preliminary modeling of the material budget
  - Less than 1 radiation length in active tracker volume
  - Less than 1.5 radiation lengths overall before calorimeter, including moderator
  - Greatly reduced compared to current Run 2 layout

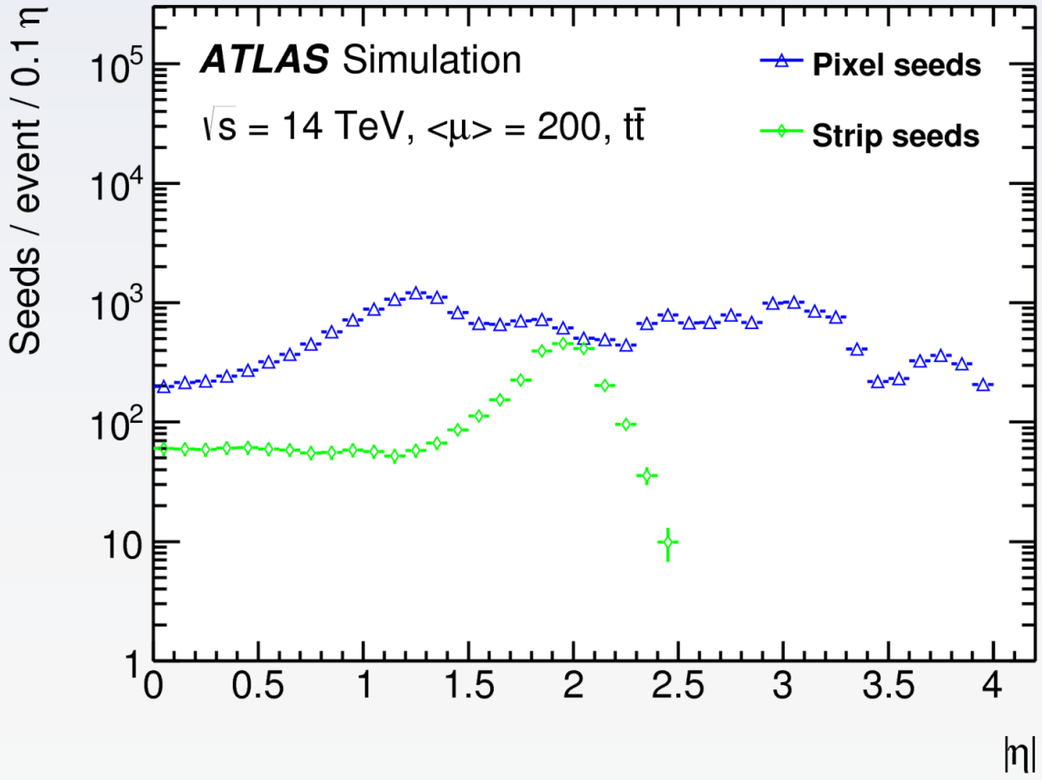




Track seeding

- Track seeds are constructed from 3 pixel or strip space points
  - Pixel: space points are clusters, Strip: combine stereo information from each module side
  - First process strips, then pixel
- Confirm seeds with fourth hit

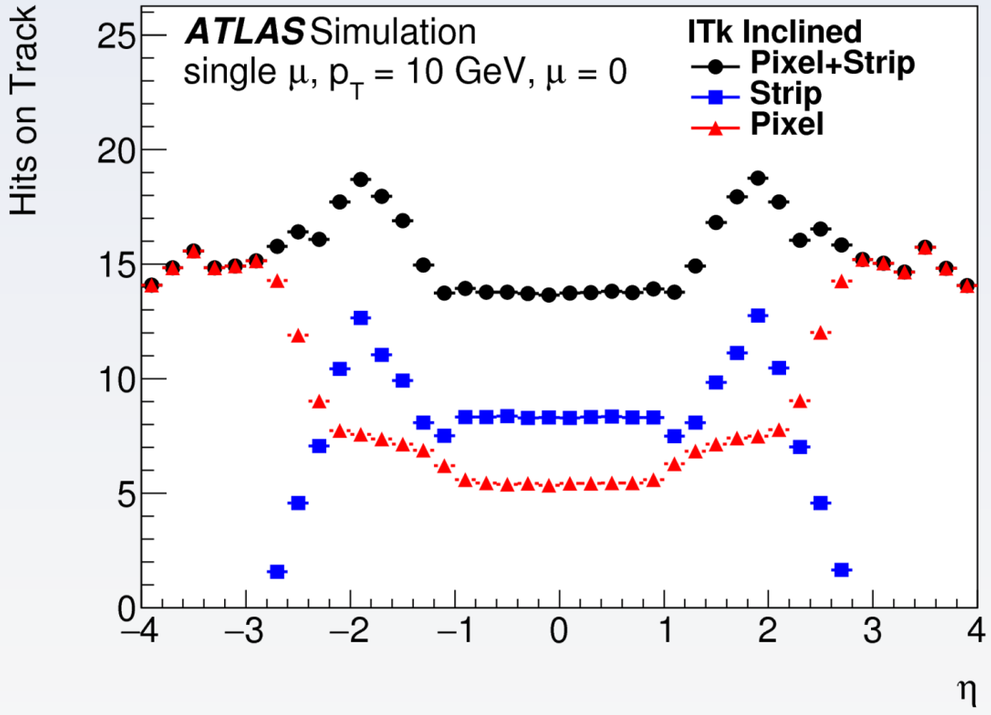




Plot: ATLAS-TDR-025, IDTR-2016-011

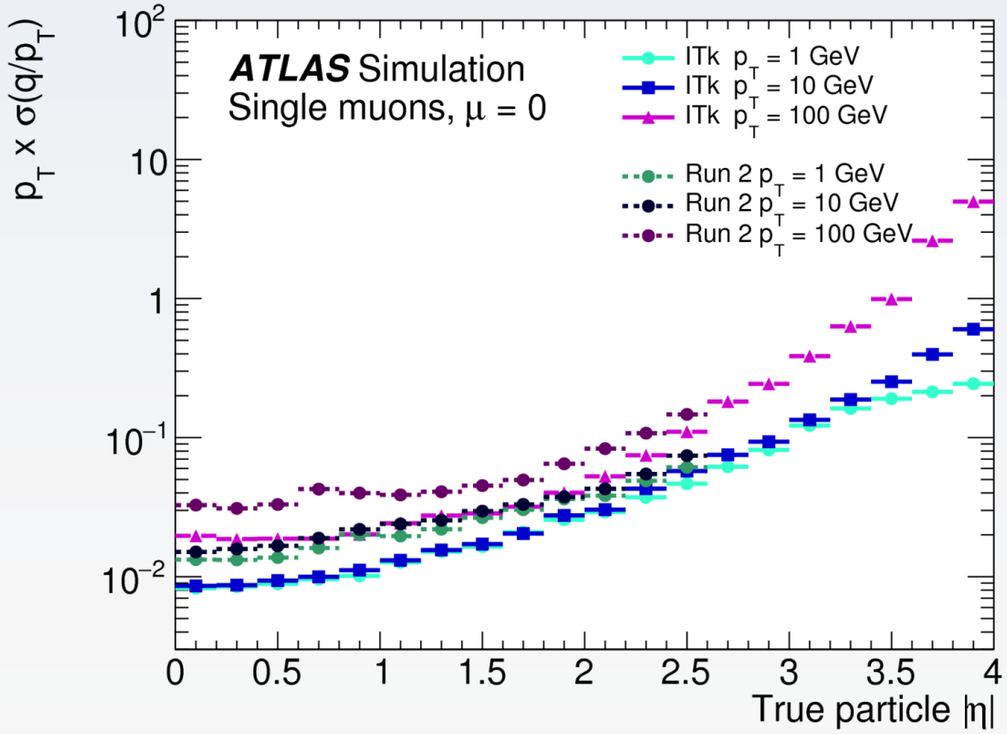
Number of hits per track

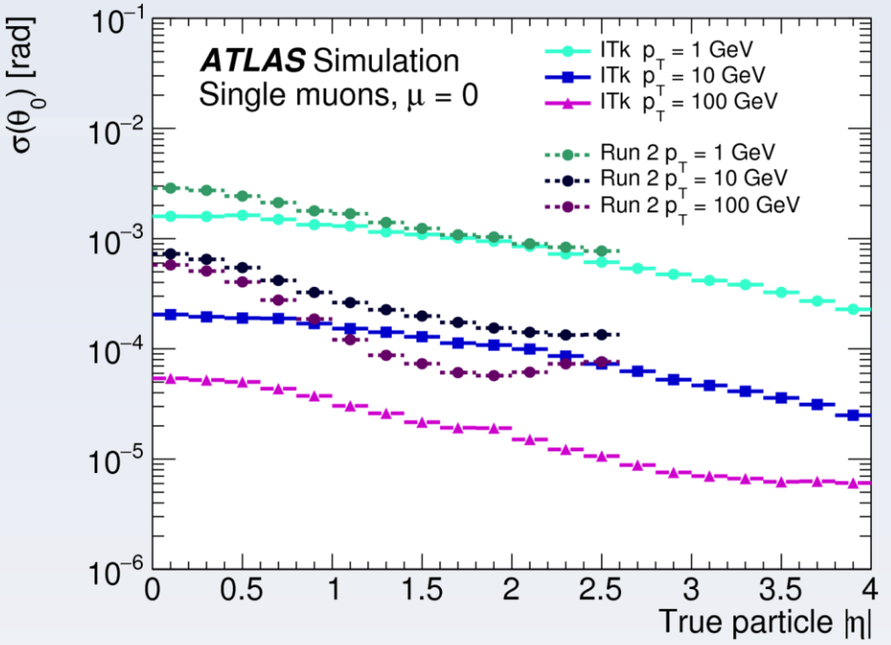
- Number of expected hits in pixel and strip per track
- Over most of the volume, average of 13 hits per track or more
- Less than 0.1 hole (expected, but missing hit) per track
  - Including acceptance gaps, hits below threshold in readout, pattern recognition mistakes
  - Not considering detector defects
- Excellent coverage

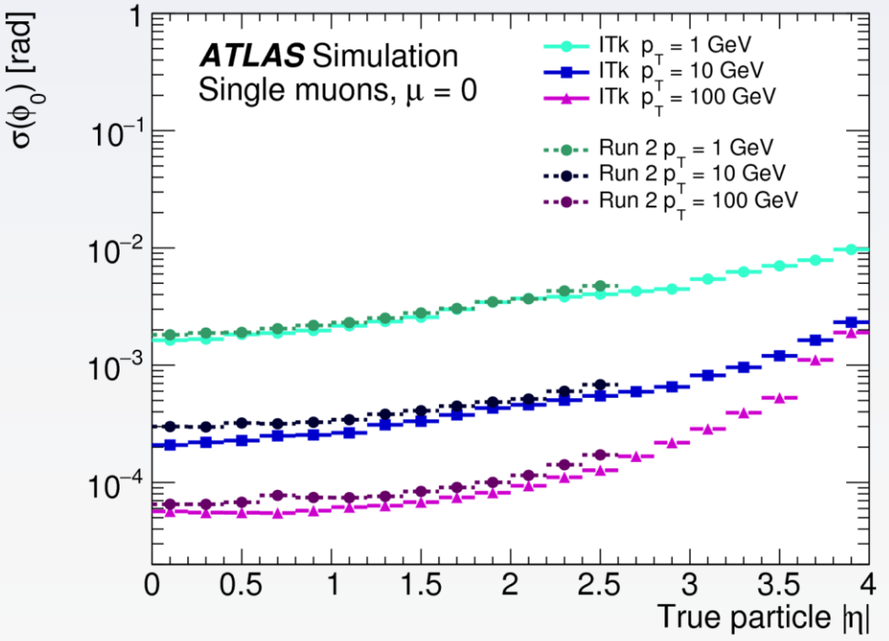


Track Param. Resolution (p_T, φ_0, θ_0)

- Estimated using single muon MC samples (removed outliers)
- Track parameter resolution greatly improved with all-silicon inner tracker

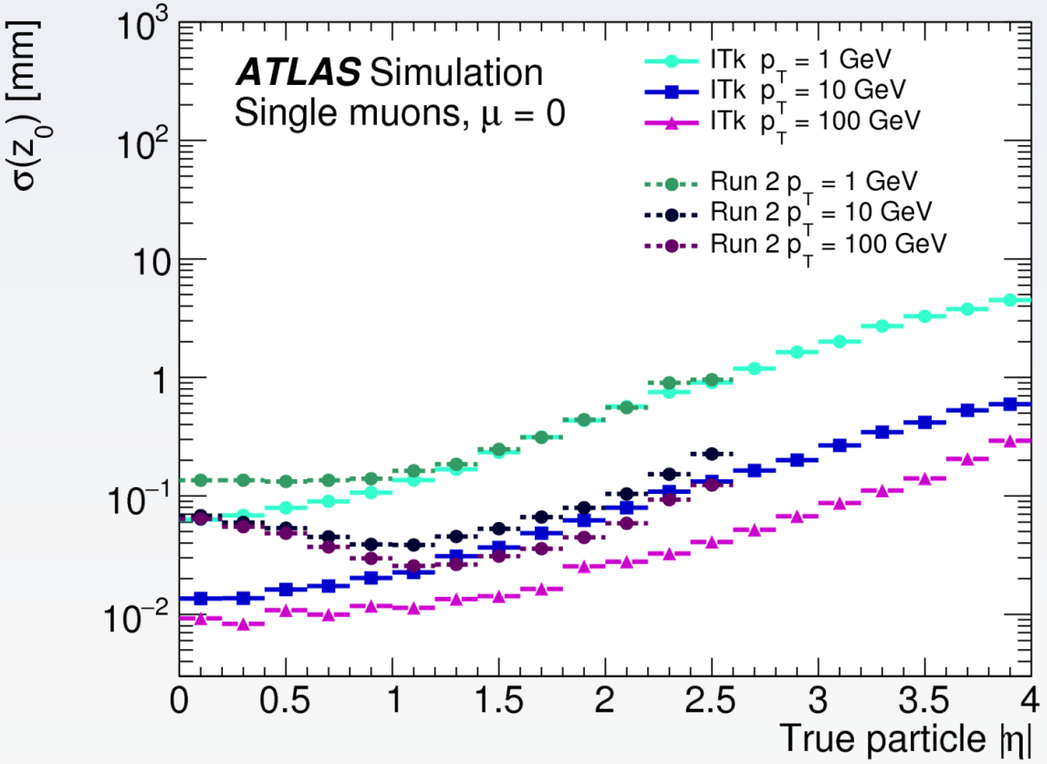


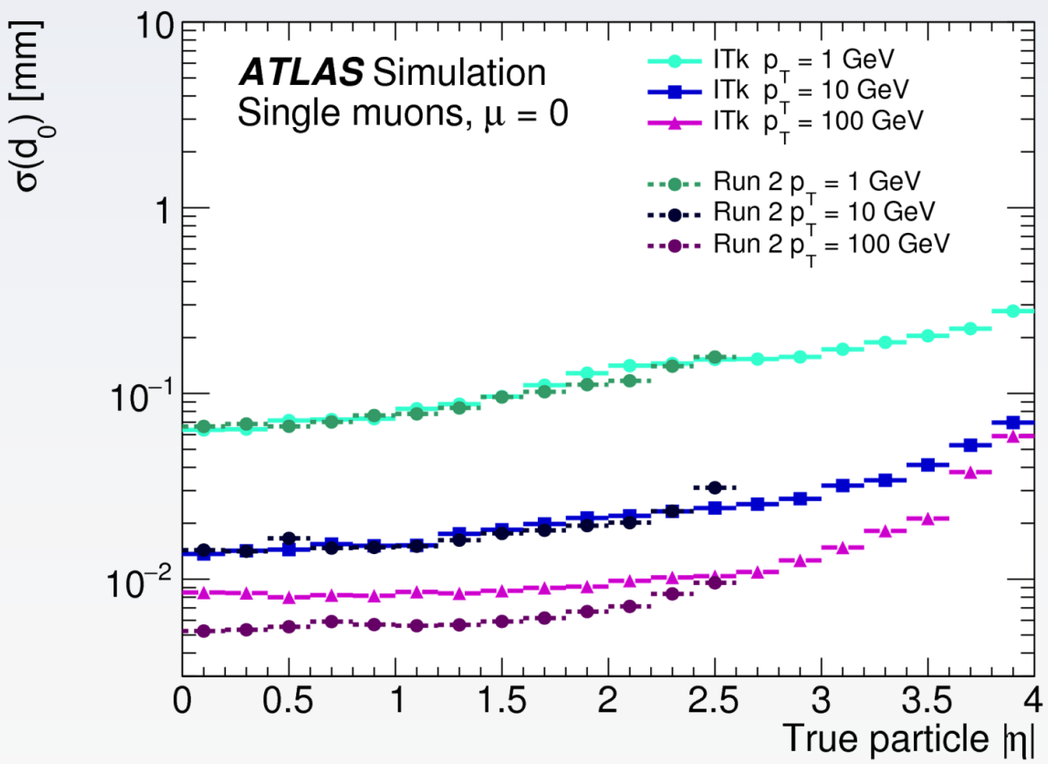




Impact Parameter Resolution (d_0, z_0)

- Main contribution to uncertainty:
  Multiple scattering at low p_T, intrinsic detector resolution at high p_T
- Excellent resolution, comparable or better than current inner detector





Pileup tolerance

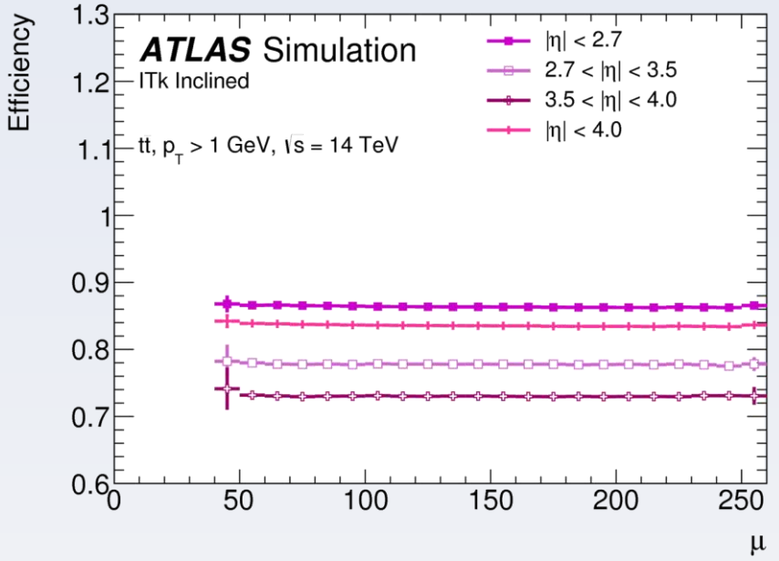
New ITK must handle high pileup environment of the HL-LHC (μ up to 200)

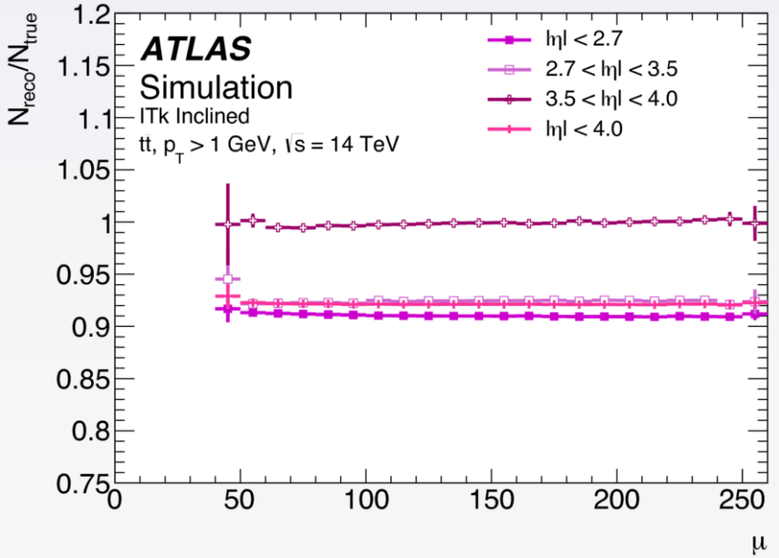
Track reconstruction efficiency:

- nearly unchanged at high μ

Number of all reconstructed tracks over number of truth particles:

- Also flat wrt. μ, no problems with fake tracks at high pileup observed

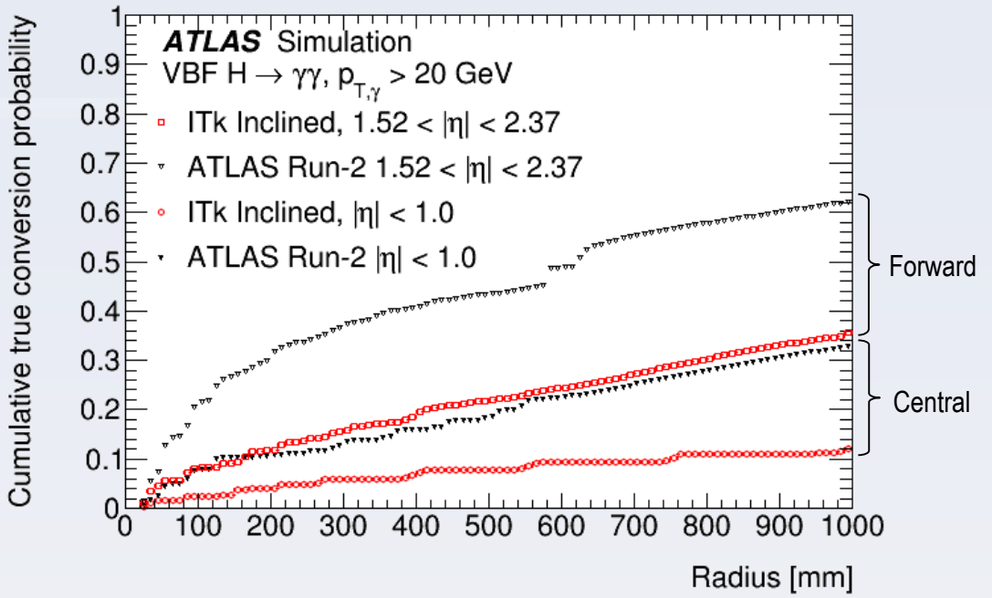


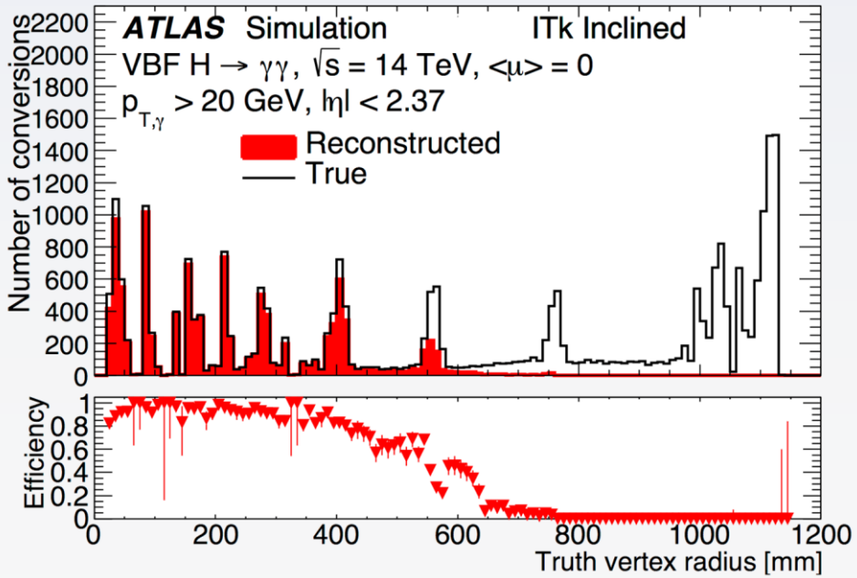


Plots: ATLAS-TDR-025, IDTR-2017-001

Photon conversions

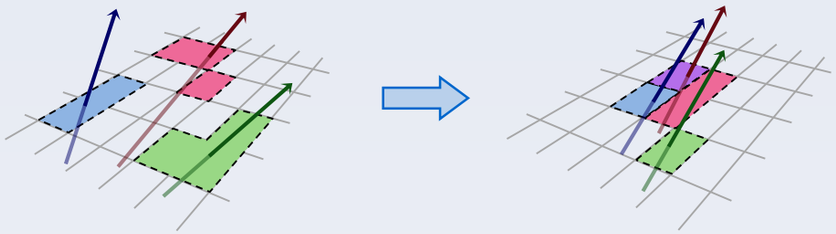
- Dedicated photon-conversion finding algorithm
  - Runs after track finding
  - Builds tracks with loosened requirements from unused clusters
    - Fewer clusters, not pointing to PV, …
- Overall efficiency 35% (photons from VBF H → ɣɣ, p_T > 20 GeV and |η| < 2.37), considerably higher at smaller radii
- Rate of conversions much lower than in Run 2 due to lighter tracker

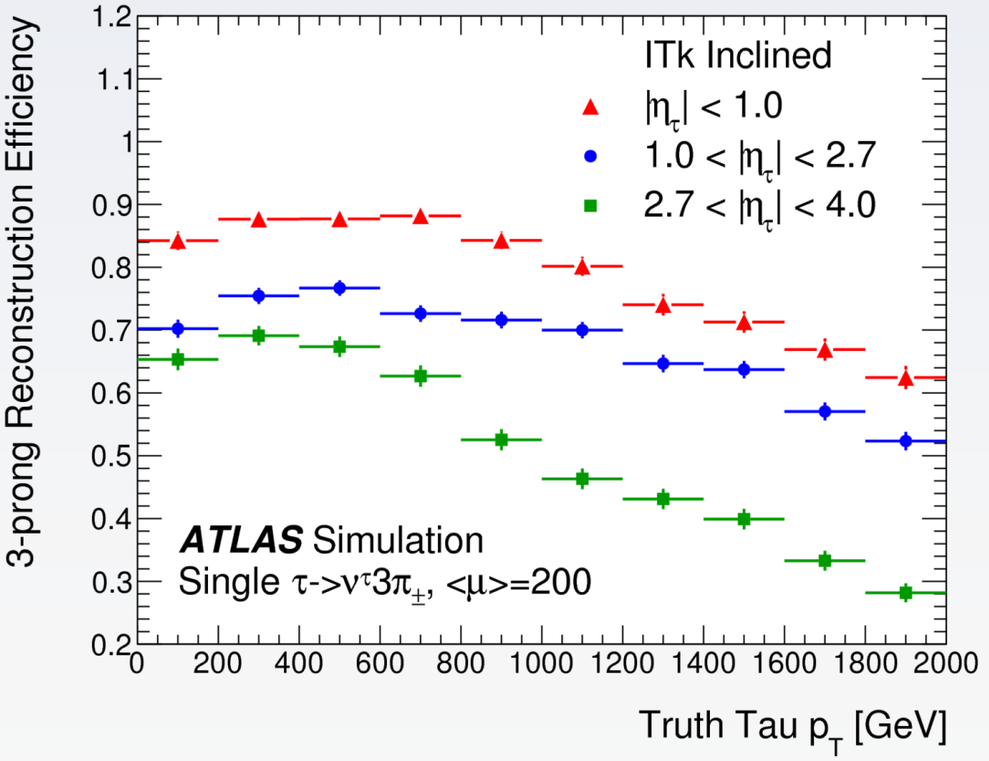




Tracking in Dense Environments (TIDE)

- Maintain performance in core of high pT jets => Important for b-jets, jet substructure, JES calibration
- In jets, hit clusters may merge, leading to loss of tracks
  - Clusters with multiple tracks are normally only used once to suppress fakes
  - Currently, ATLAS uses a neural network to identify truly merged clusters and not penalize them
  - Algorithm not available yet for ITk: emulate performance using truth information
- Performance investigated with 3-prong tau decays and b-jets



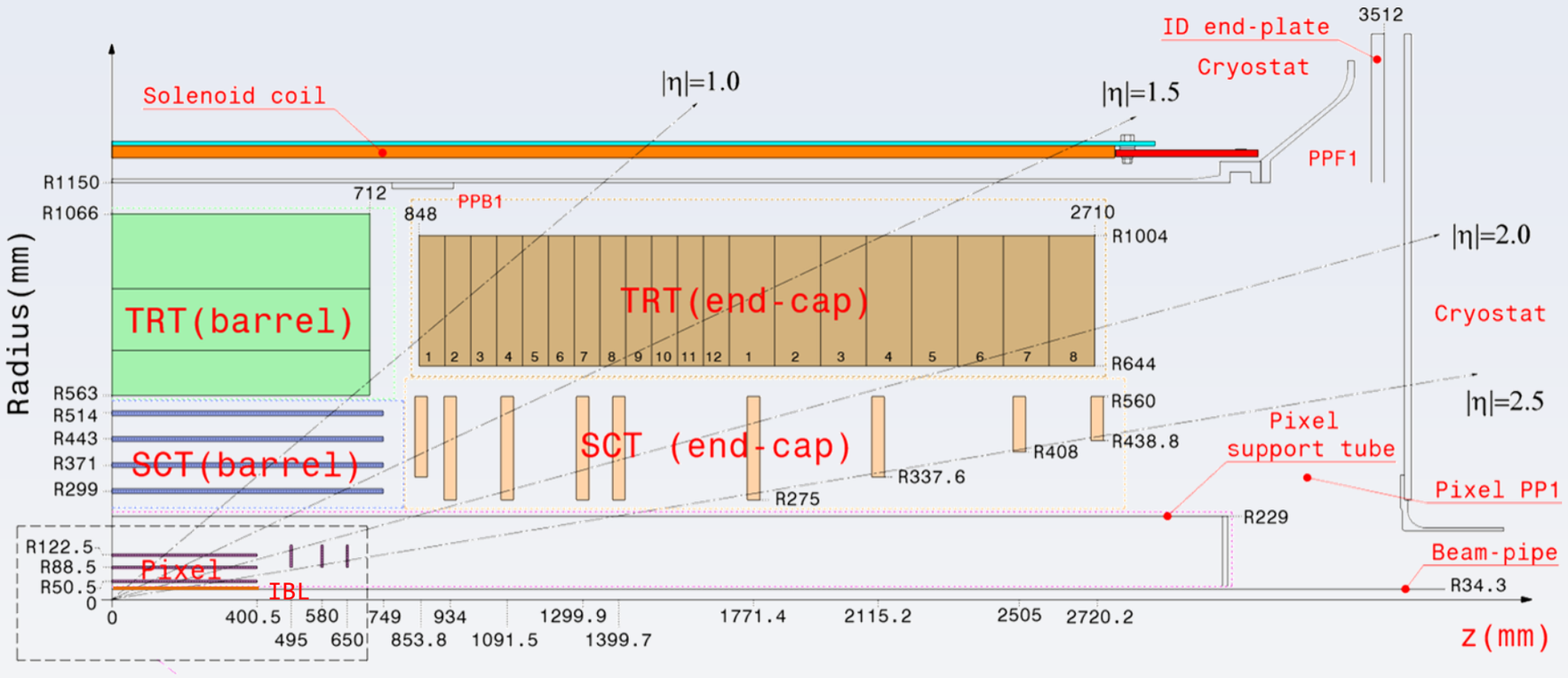


Conclusions

- An all new inner tracker for HL-LHC!
  - Full silicon, no TRT
  - Tracking acceptance up to |eta| < 4.0
- Excellent performance observed in simulation
  - Comparable or improved wrt. current detector despite pileup up to 200
  - Better IP and track parameter resolution
  - Reconstruction efficiency satisfactory in dense environments
- Still many parameters open
  - Finalize pixel layout
  - 3D sensors in inner pixel layers / monolithic in outer pixel layers?
  - Optimize tracking algorithms for ITk
- Well on track for high-luminosity upgrade!

Backup

Current Layout



Pixel detector:

- 4 layers including IBL, 6 endcap discs
- 92m pixels
- 2 m^2 active area

Semiconductor Tracker (SCT)

- 4 barrel layers, 18 endcap discs
- 4100 stereo strip modules
- 60 m^2 active area, 6M channels

Transition Radiation Tracker (TRT)

- Straw tubes w. 4 mm diameter
- 50k + 250k straws
- Helps with particle identification