Improvements to ATLAS Inner Detector Track Reconstruction for Run-2

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Outline

Introduction

Upgrade of Inner Detector
- ATLAS Inner Detector
- Long Shutdown 1 (LS1)
- Insertable B-Layer (IBL)
- Track Reconstruction
- Tracking in Dense Environments

Commissioning
- Inner Detector Alignment
- Basic Performance
- Vertexing
- Physical Checks
- Charged Particle Production

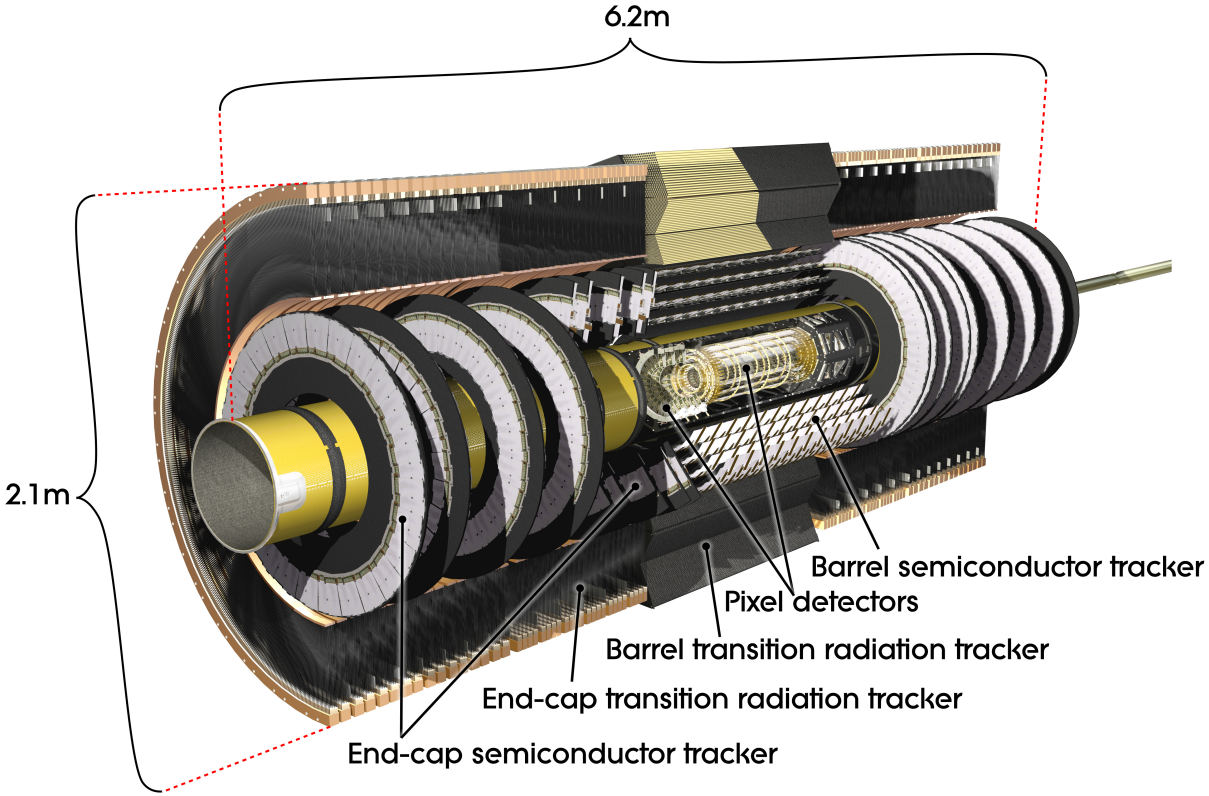
Conclusion

Backup

Introduction

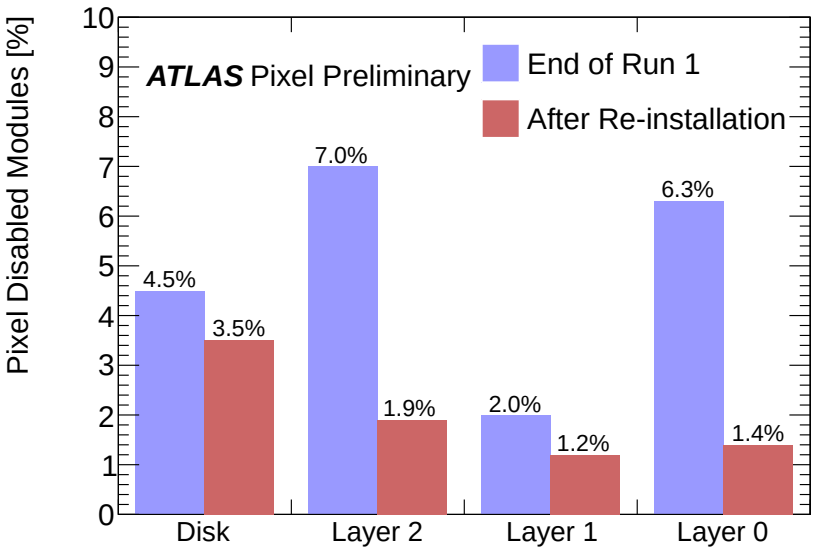
- Run-2 of the LHC provides new challenges in the form of greater luminosities and higher energy.
- In preparation, ATLAS has made developments in hardware, algorithms, and software.
- We will highlight key developments and their impact on performance.
- A brief glance at early Run-2 data will be provided.

ATLAS Inner Detector (Run-1)



- Pixel detector - 82 million silicon pixels
- Semiconductor Tracker (SCT) - 6.2 million silicon microstrips
- Transition Radiation Tracker (TRT) - 350k drift tubes
- Barrel ($|\eta| \lesssim 1$) and endcap ($1 \lesssim |\eta| \lesssim 2.5$) for each
- 2 T axial magnetic field

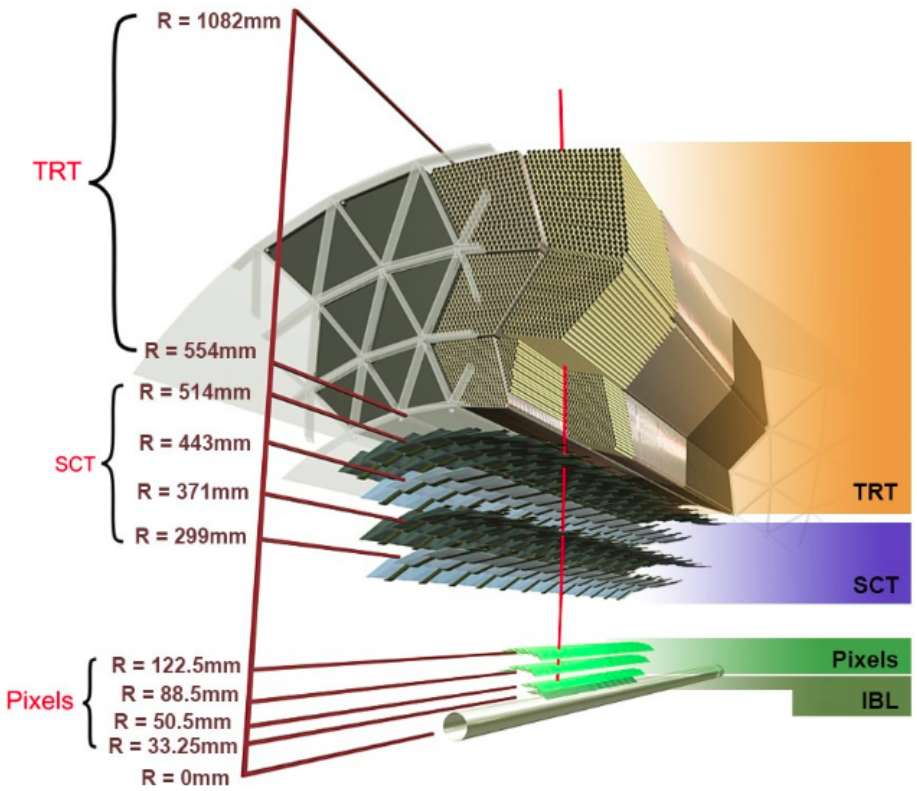
Long Shutdown 1 (LS1)



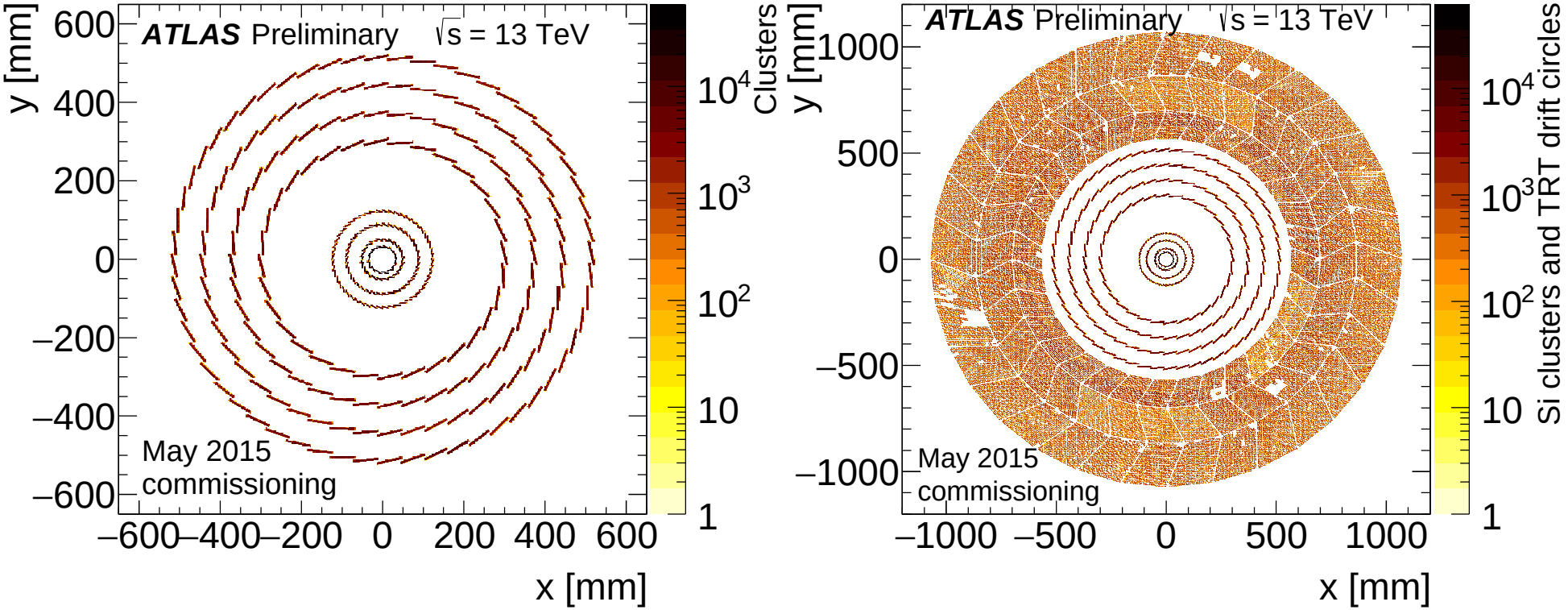
- During LS1, the pixel detector and beampipe were removed completely.
- This allowed the recovery of 3% of the pixel modules; now at 98% capacity (see figure)
- Diamond Beam Monitor (DBM) - upgrade/addition to luminosity detector
- Size of beampipe was reduced, allowing for an...
- ...all-new pixel layer, the Insertable B-Layer (IBL)

Insertable B-Layer (IBL)

- Improves track and vertex reconstruction performance for higher luminosities
- Will alleviate effect of radiation damage
- Extra point → more robust tracking
- 99.5% of modules active
- See talk earlier today by Shih-Chieh Hsu for more detail



Transverse position of clusters

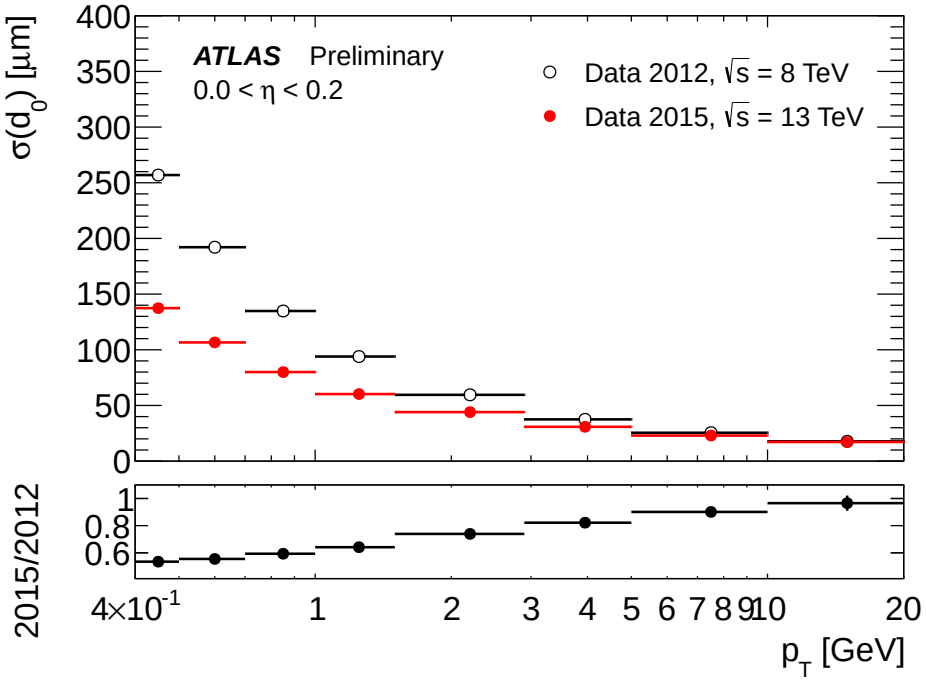


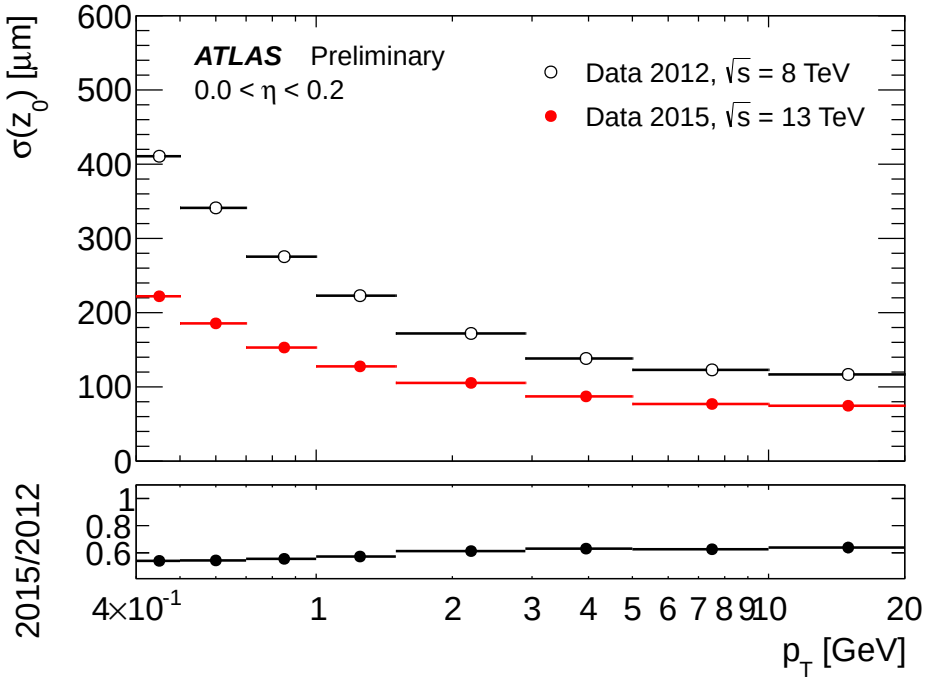
x-y position of inner detector component clusters in the barrel region. The left is a zoomed in version of the right. These come from studies used to map out detector material. Note that some HV TRT lines were disabled in the test run.

Refer to: IDTR-2015-001

Impact Parameter Resolution (d_0 and z_0)

The differences in IP resolution from Run-1 to Run-2.

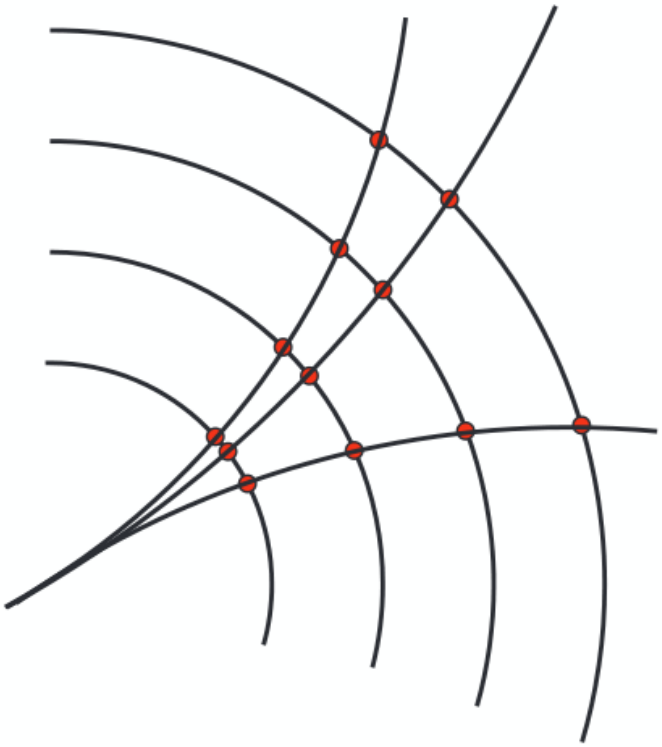




- d_0: transverse impact parameter
- z_0: longitudinal impact parameter
- IBL improves IP resolution of down to a factor of 1/2
- IBL pixels smaller in z-direction than other layers
- Note: these are with pre-final alignment

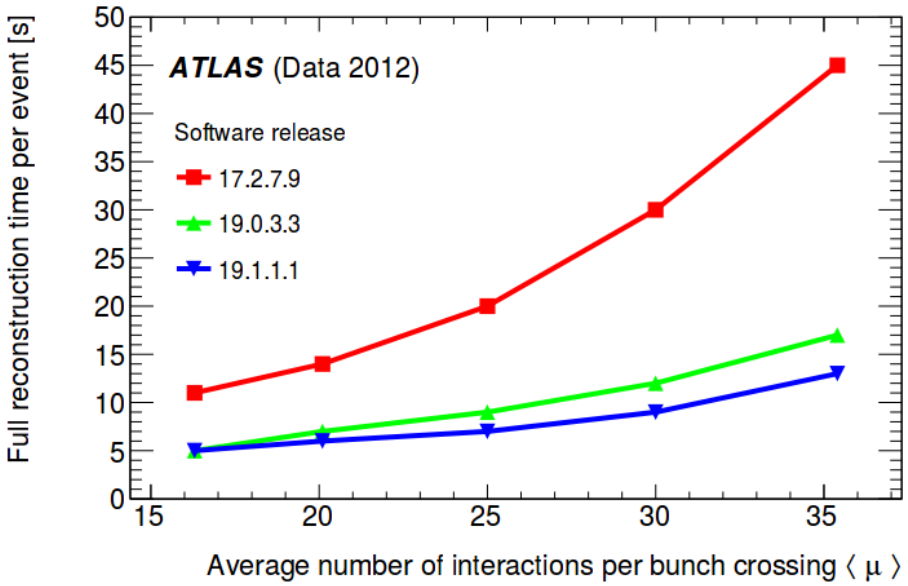
Refer to: IDTR-2015-007

Summary of Inner Detector Track Reconstruction



1. space point formation
   - clusters formed from adjacent cells in Si detectors
2. seeded track finding
   - 3 space points used as seeds
   - Kalman filter evaluates seeds and attempts to complete tracks
3. ambiguity solving
   - awards good, unique hits
   - penalizes holes, shared hits
4. TRT extension
   - in certain regions, resolution improved by looking at hits in TRT

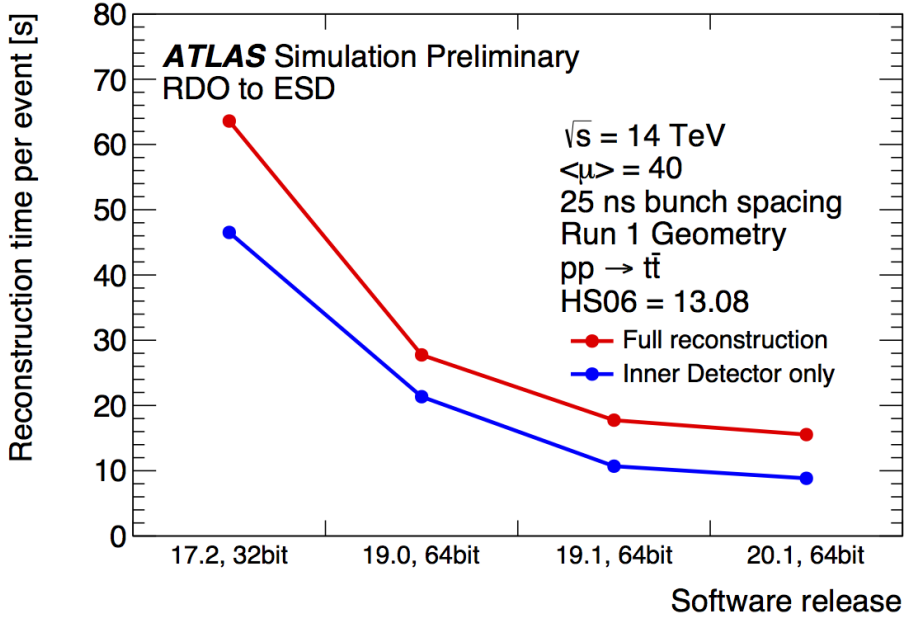
Software techniques



Factor of 4 speedup in ID reconstruction for Run-2

- coding improvements
- tracking in dense environments (more on this later)

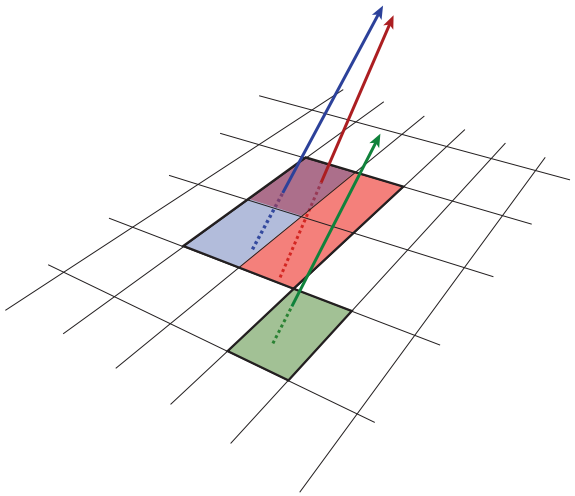
- algorithmic changes (process good seeds first)
  - categorize seeds based on hit content (e.g. 2 Pixel + 1 SCT)
  - categorization used to determine order of seed processing
  - additional space point required to process



Refer to: ATL-SOFT-PUB-2014-004

Tracking in Dense Environments (TIDE)

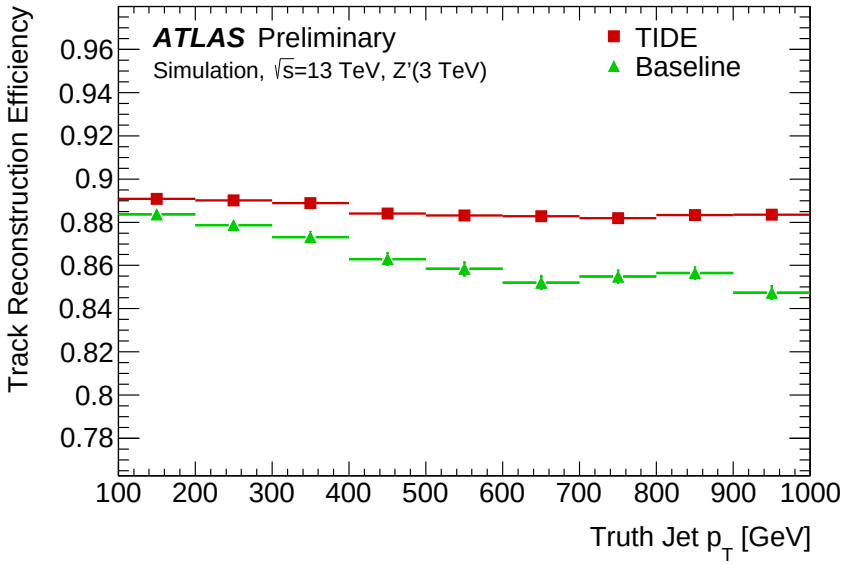
- In the cores of high-p_T jets and τ-leptons, track separations are of a distance comparable to the spacing of the Inner Detector sensors
- In the track reconstruction, an artificial neural network (NN) is employed to resolved ambiguities in cases where multiple tracks overlap in a pixel cluster

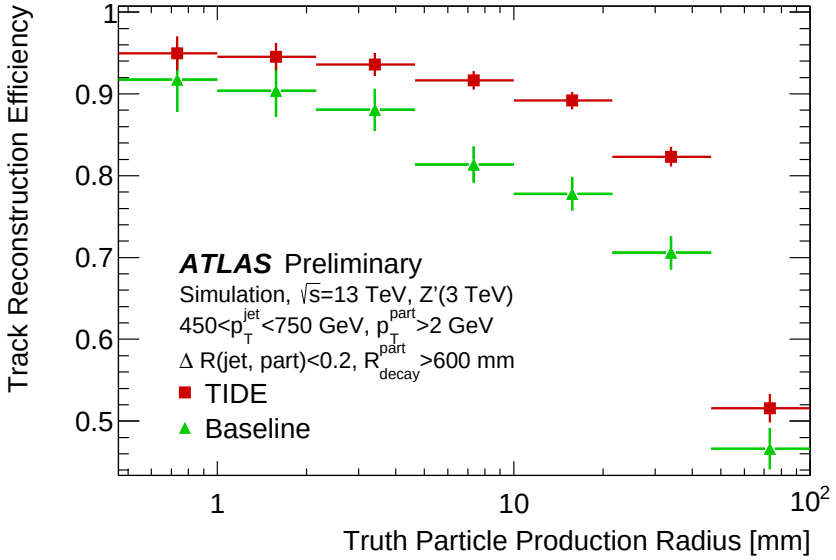


- The application of this NN has been delayed to later in the track reconstruction sequence so that is now able to use track information
- NN is better able to identify shared pixel clusters from multiple charged particles
- 10% decrease in CPU demands

Refer to: arXiv:1406.7690, ATL-PHYS-PUB-2015-006

Improvement to track reconstruction efficiency

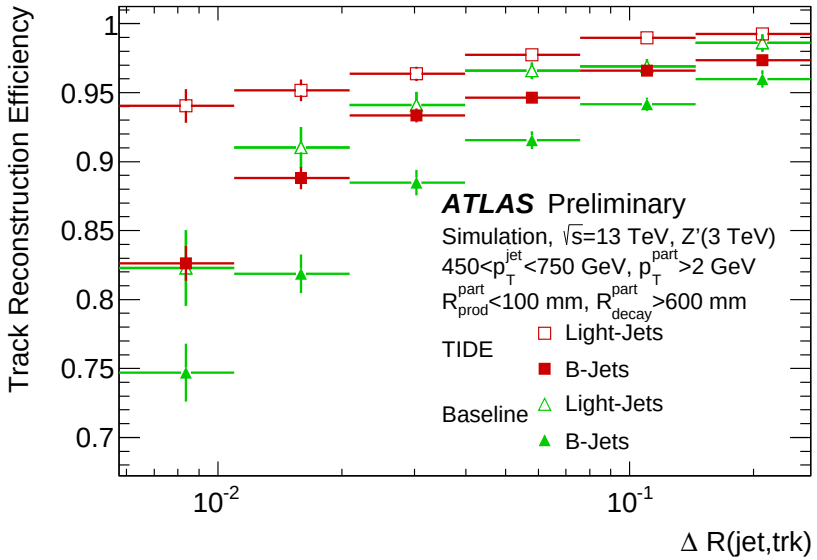


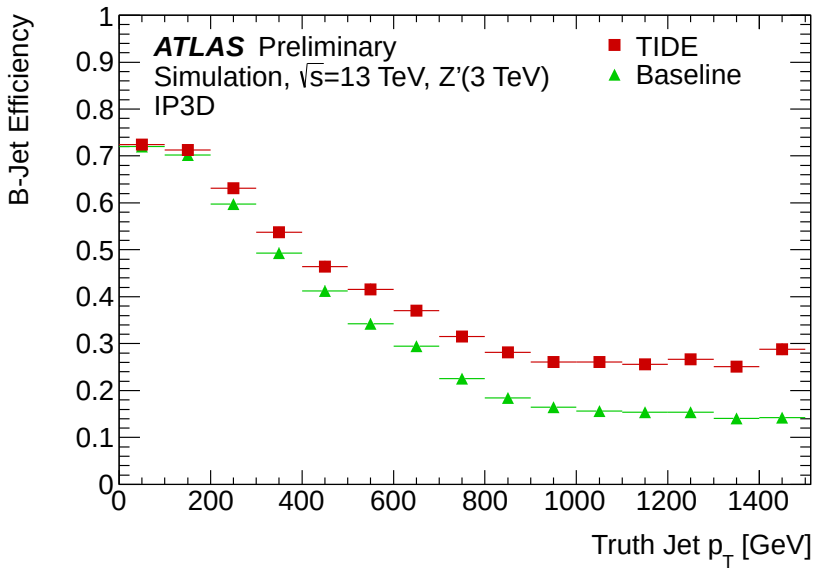


- Measureable improvement in efficiency to reconstruct a track inside a jet
- Reconstruction efficiency is less p_T-dependent
- Recovers nearly half of previously-missed jet decay particles produced out to a few centimeters (given that the particle makes it through the silicon layers)

Impact on *b*-tagging

- Improved setup improves reconstruction in the core of both light and *b*-jets
- Up to nearly a factor of 2 improvement in *b*-tagging efficiency at high p_T
- here light jet rejection is comparable to Run-1 configuration (at working point of 70% *b*-jet identification)



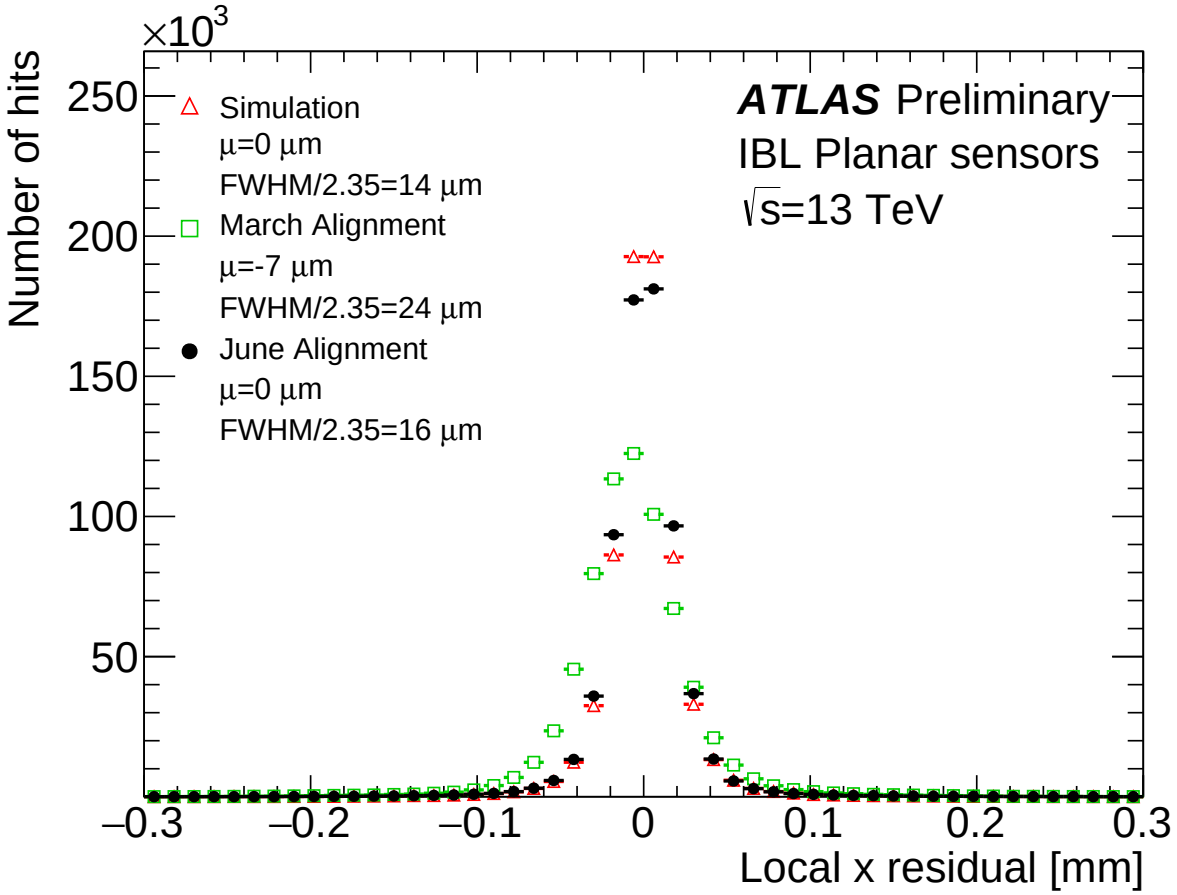


Inner Detector Alignment

- determine position/orientation of entirely new layer (IBL)
- removal / refurbishing of pixel layer caused components to be displaced from where they were in Run-1 (within $\sim 0.1\ \mathrm{mm}$)
- minimize a global χ^2 w.r.t. many tracks, where d.o.f. are position and rotation of the components, to align the description of the detector components
- alignment is done on 3 scales sequentially: big structures, layers, modules
- several iterations
  - March: alignment performed with cosmic ray data
  - June: alignment improved with $\sqrt{s} = 13\ \mathrm{TeV}$ commissioning beam

Refer to: ATL-PHYS-PUB-2015-009 (cosmics), ATL-PHYS-PUB-2015-031 (collisions)

Inner Detector Alignment: Performance

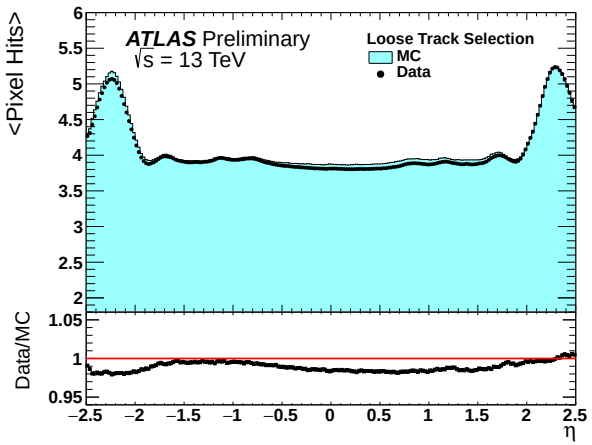


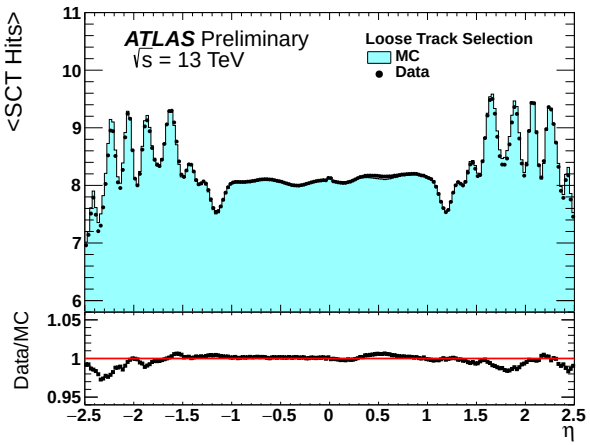
Refer to: ATL-PHYS-PUB-2015-031

Shown here: (unbiased) track-hit residuals, the distance from the extrapolated track in a detector element to the hit recorded in that element.

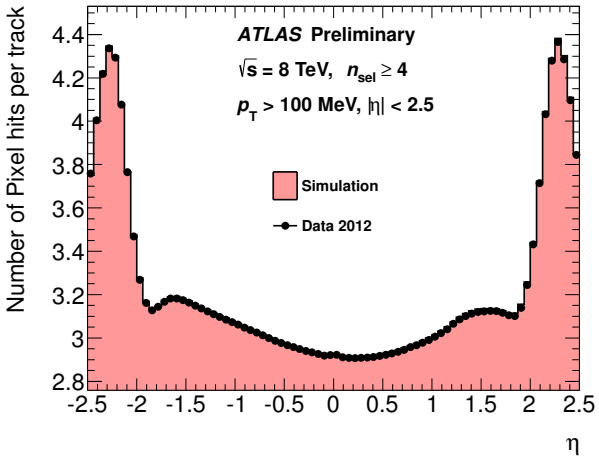
Basic performance

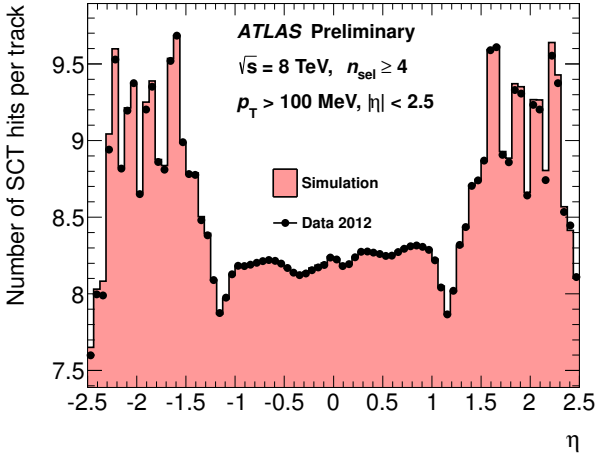
Run 2:





Run 1:



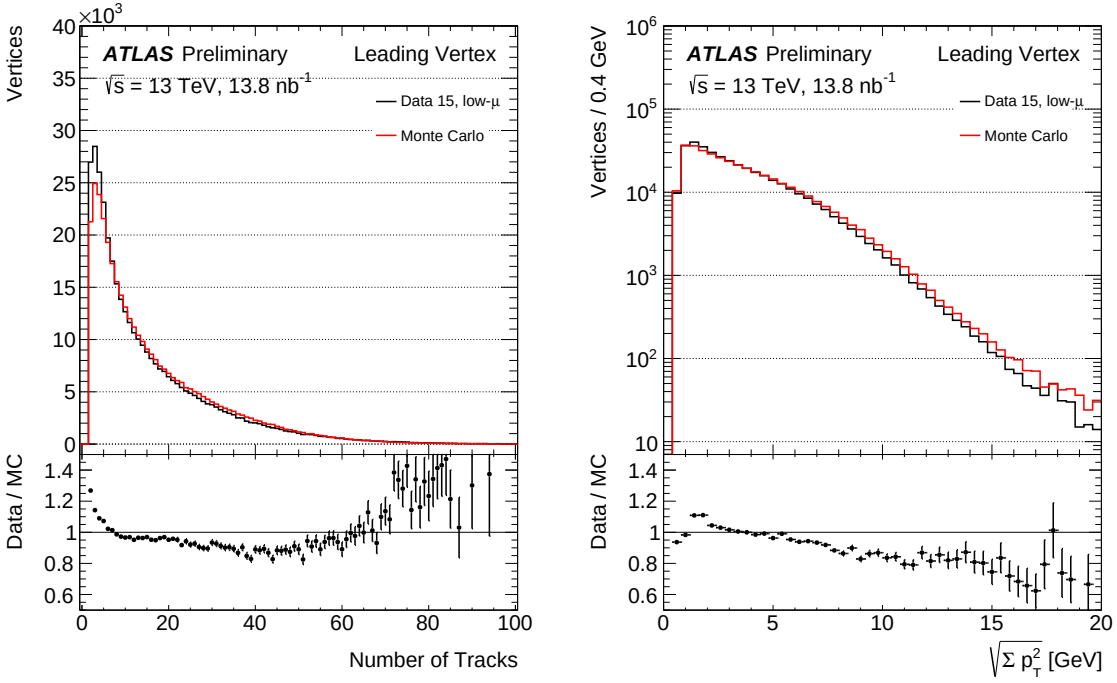


Discrepancy in pixel hits understood: different description of overlap of IBL staves in MC and data. Drop-off at negative η from temporarily disabled modules not accounted for in simulation. (see backup)

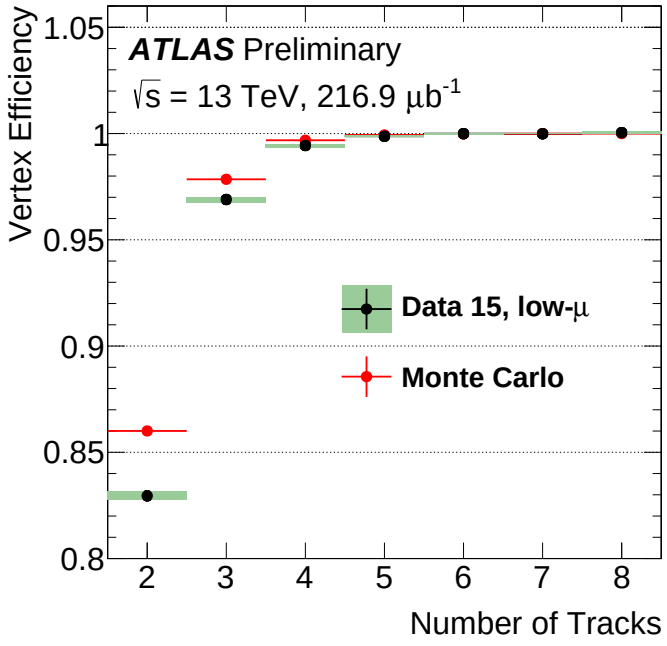
Refer to: ATL-PHYS-PUB-2015-018

Vertexing performance

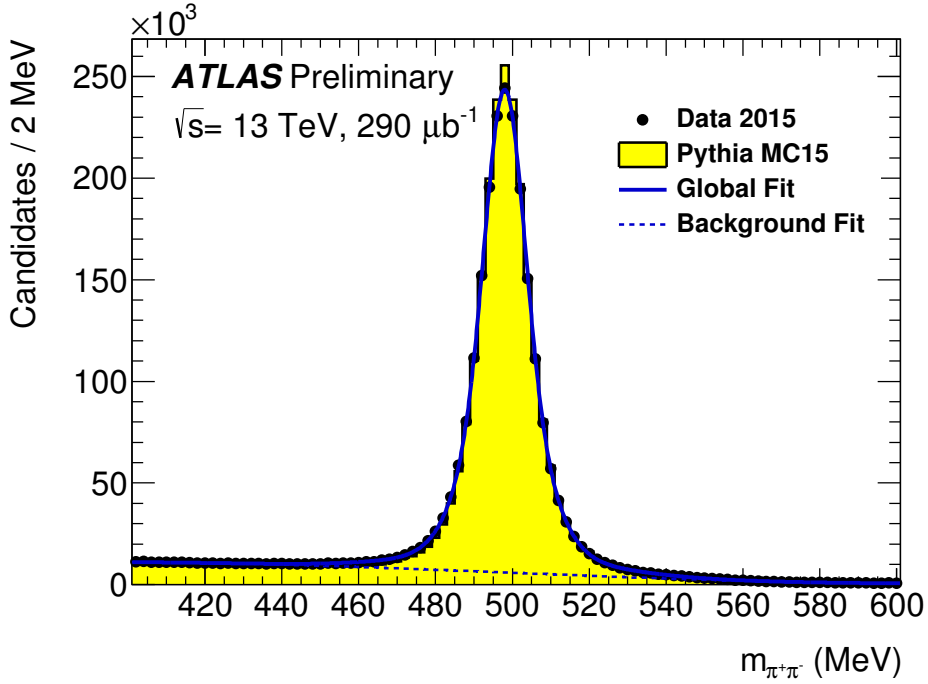
Good performance; reasonable data/simulation agreement. Compatible with the agreement in physics modelling described by the first minimum-bias measurement at $\sqrt{s} = 13\ \mathrm{TeV}$ (ATLAS-CONF-2015-028).

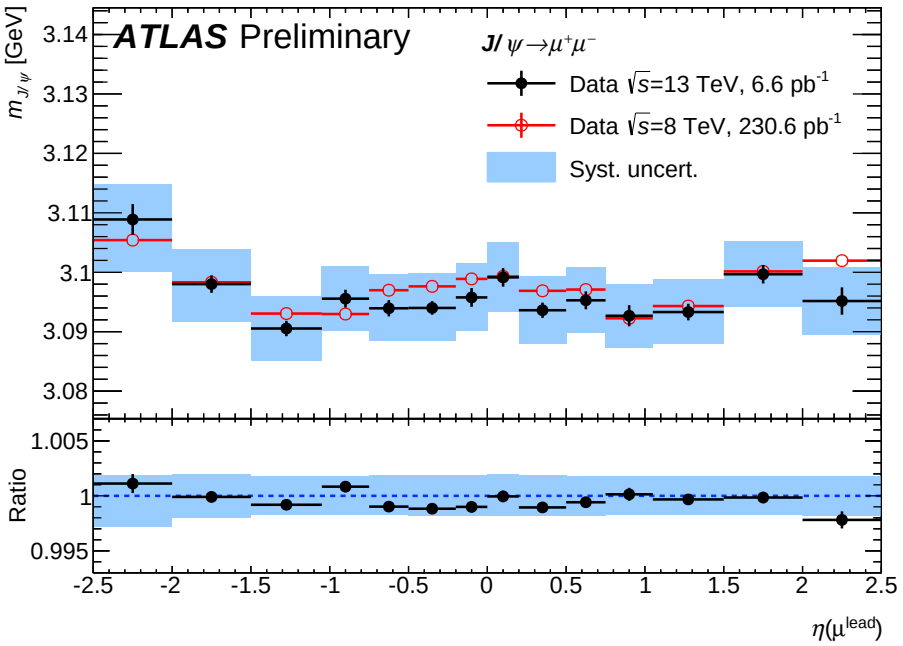


Efficiency to reconstruct a vertex as a function of the number of tracks in the vertex. Determined in low-μ data by taking ratio of events with reconstructed vertex to events with 2 or more reconstructed tracks.
Refer to ATL-PHYS-PUB-2015-026



K_S^0 and J/ψ





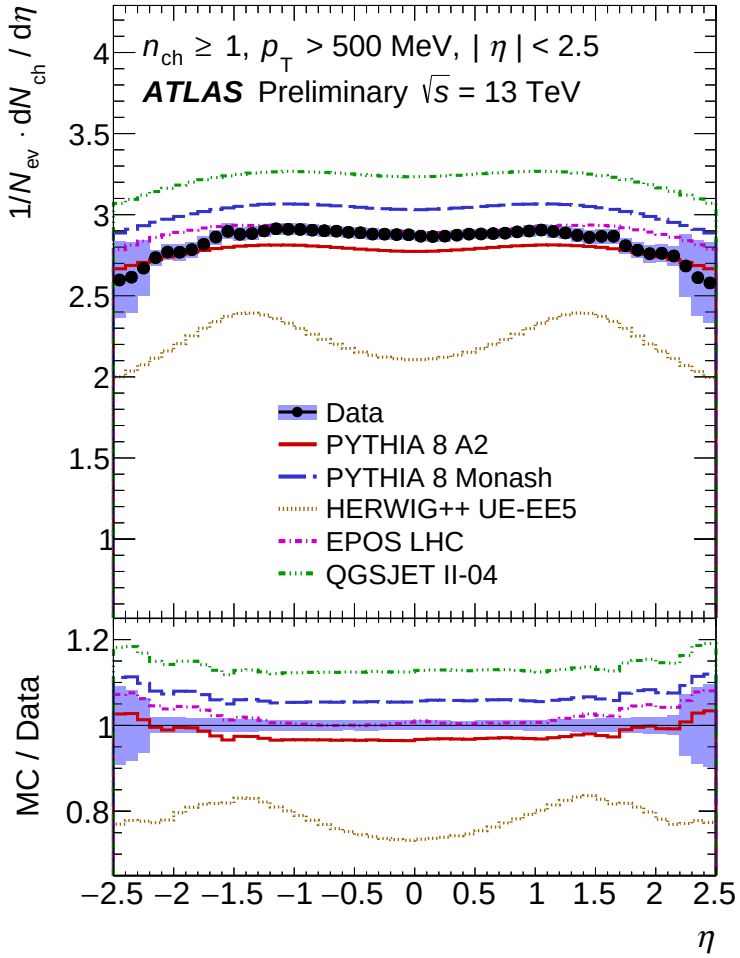
The K-short mass peak is clear, and in good agreement with MC. This shows that the momentum resolution is well-simulated, which is a check on e.g. alignment.

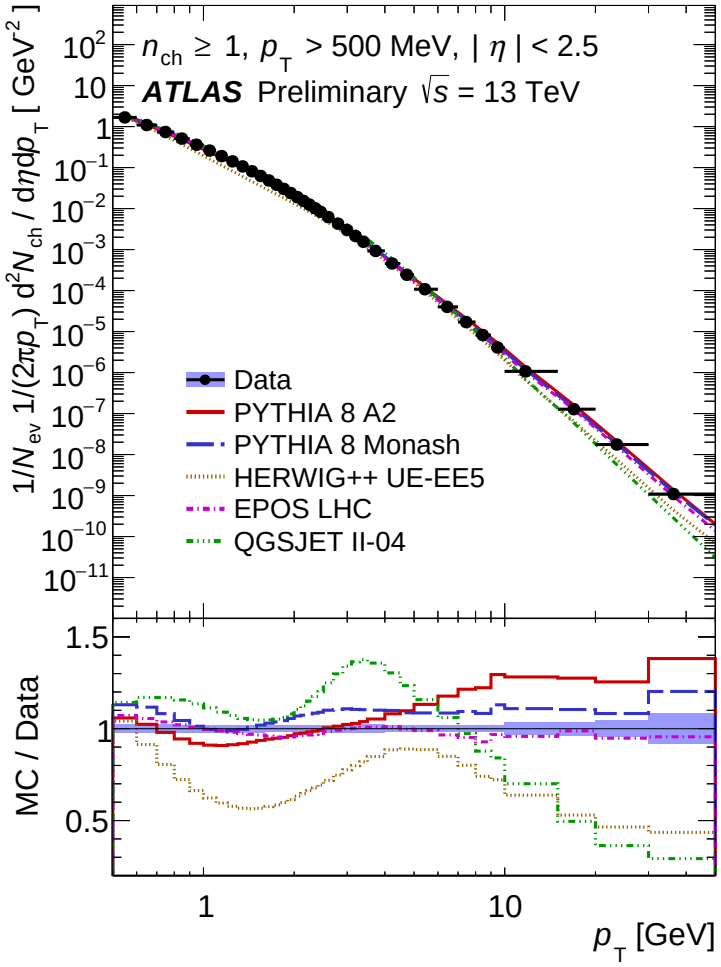
Refer to: IDTR-2015-006

J/ψ mass from reconstructed muons is in very good agreement with Run-1.

Refer to: MUON-2015-002

Charged particle production





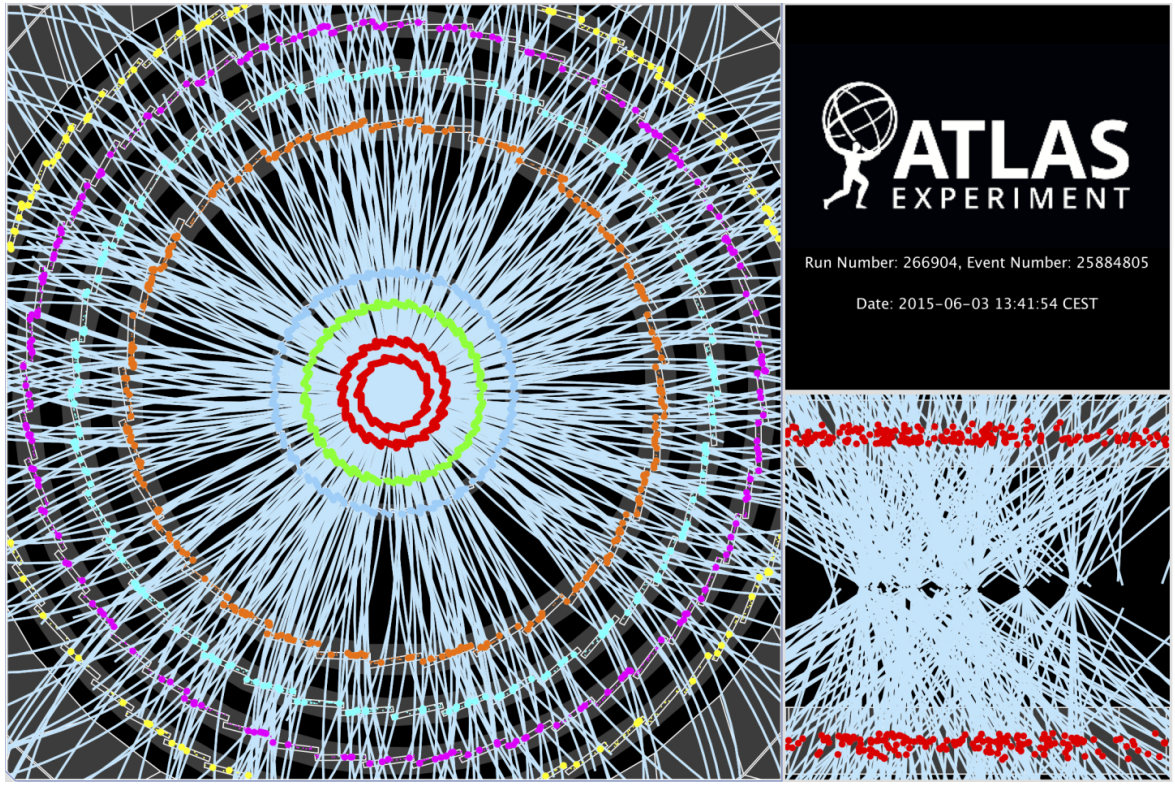
First measurements of minimum-bias charged particle distributions: 8.9 million events with $< \mu >= 0.005$. Reasonable agreement with baseline ATLAS tune, Pythia A2

Refer to: ATLAS-CONF-2015-028

Conclusion

- ATLAS has extended and upgraded their detector and several aspects of their software
- Commissioning with Run-2 data well underway
- Improvements to reconstruction efficiency and resolution will come without a significant increase in computing demands

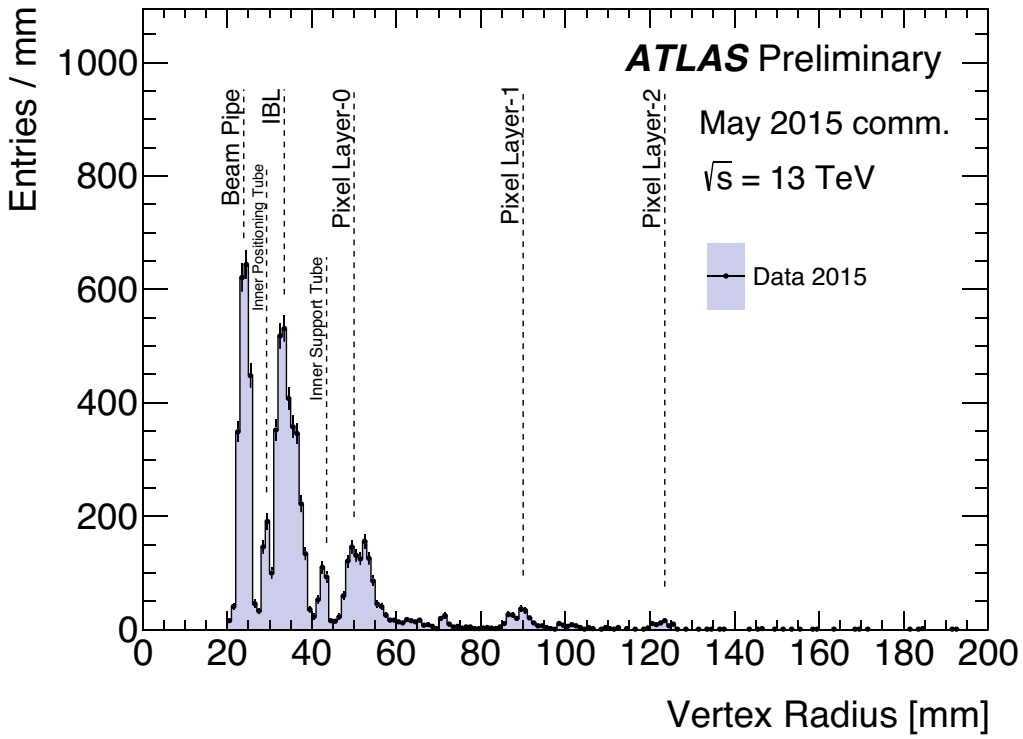
- Inner detector track reconstruction utilized in measurement of charged-particle production
- Exciting time to continue to apply these enhancements in the search for new physics!

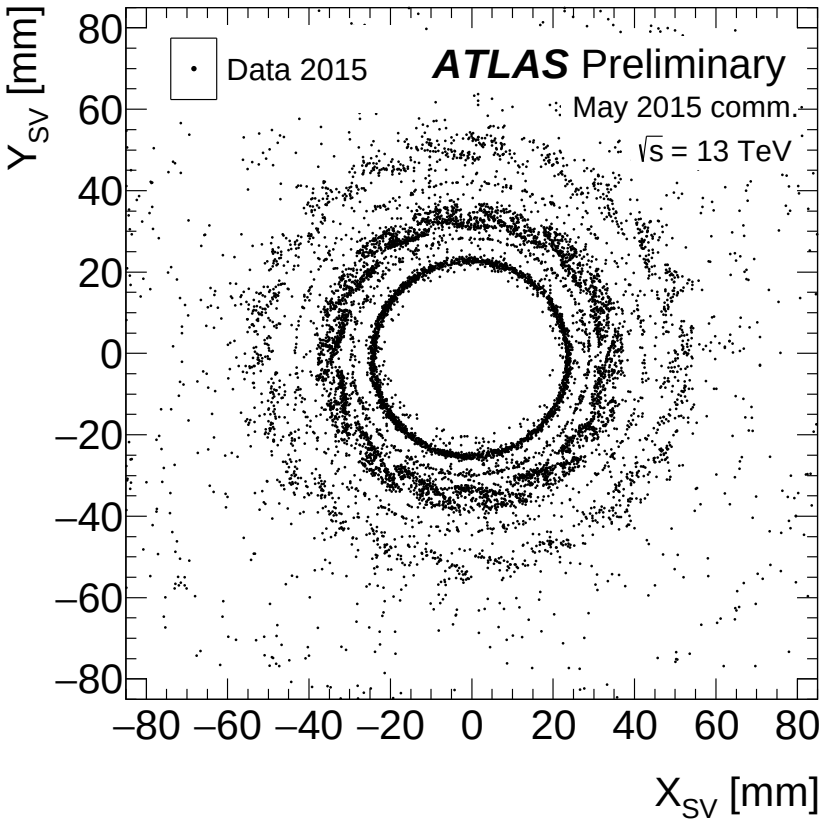


Conclusion

Thank you!

Hadronic interactions

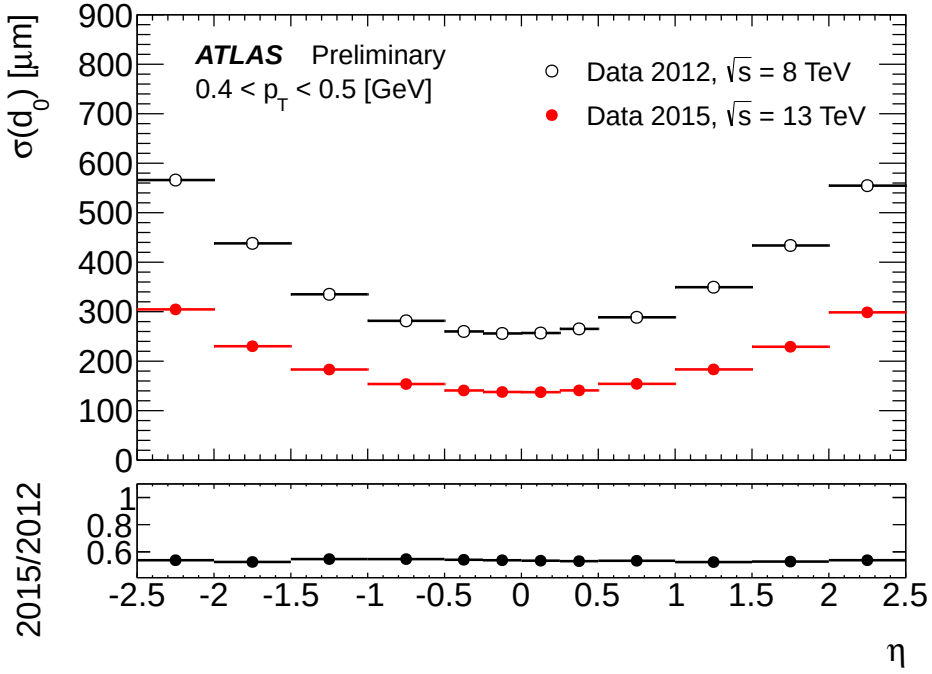


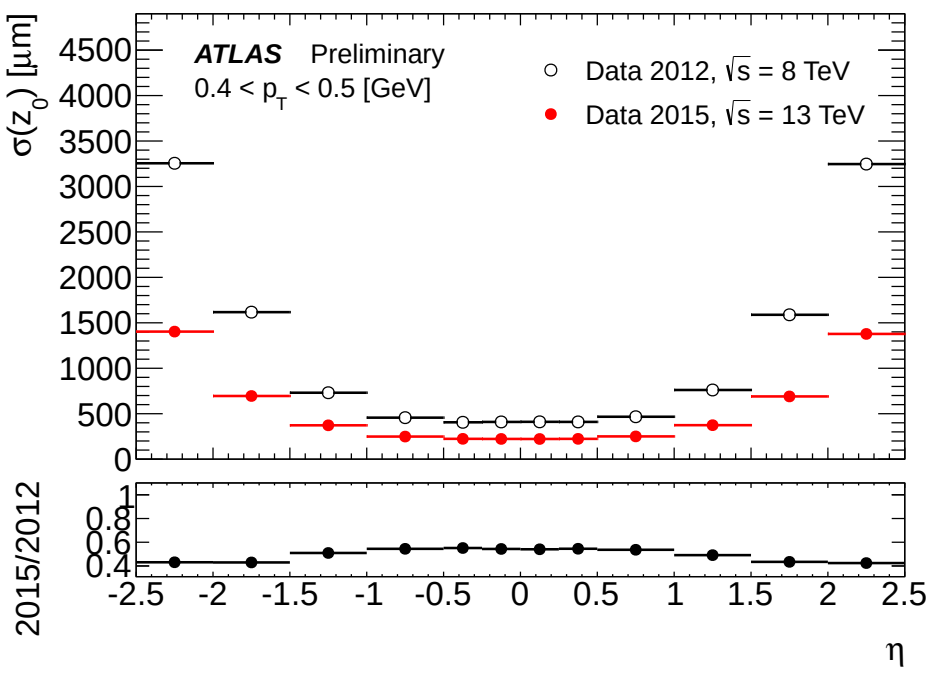


Transverse position of reconstructed secondary vertices from hadronic interactions in the updated pixel detector. On the right, the new beampipe and IBL are profiled.

Impact Parameter Resolution (d_0 and z_0)

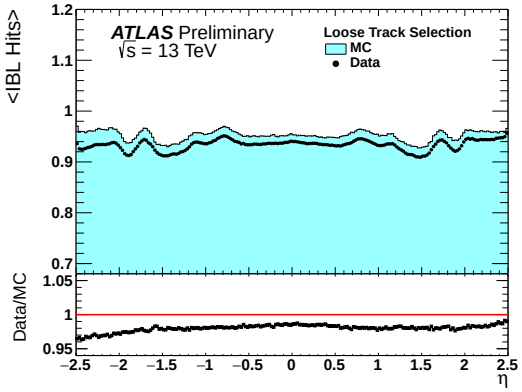
The difference in IP resolution from Run-1 to Run-2 as a function of η.

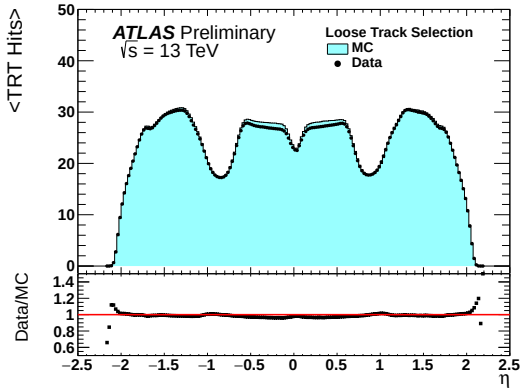


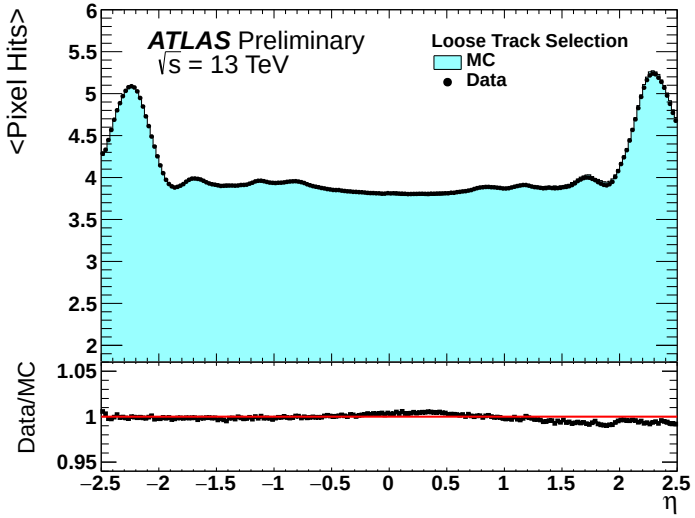


The improvement to IP resolutions from the IBL as a function of pseudorapidity amounts to a factor of roughly 1/2.

Resolution of depleted pixel hits



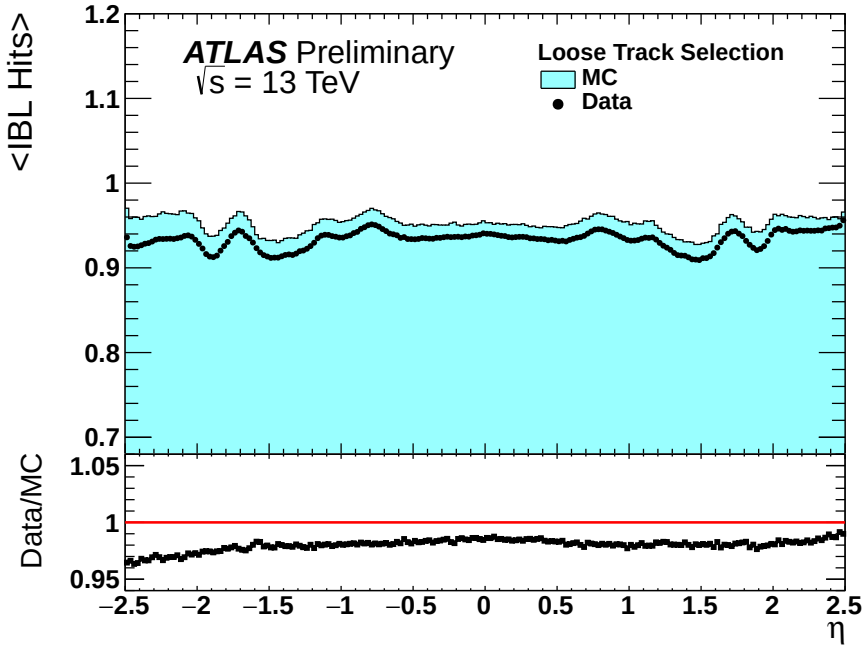


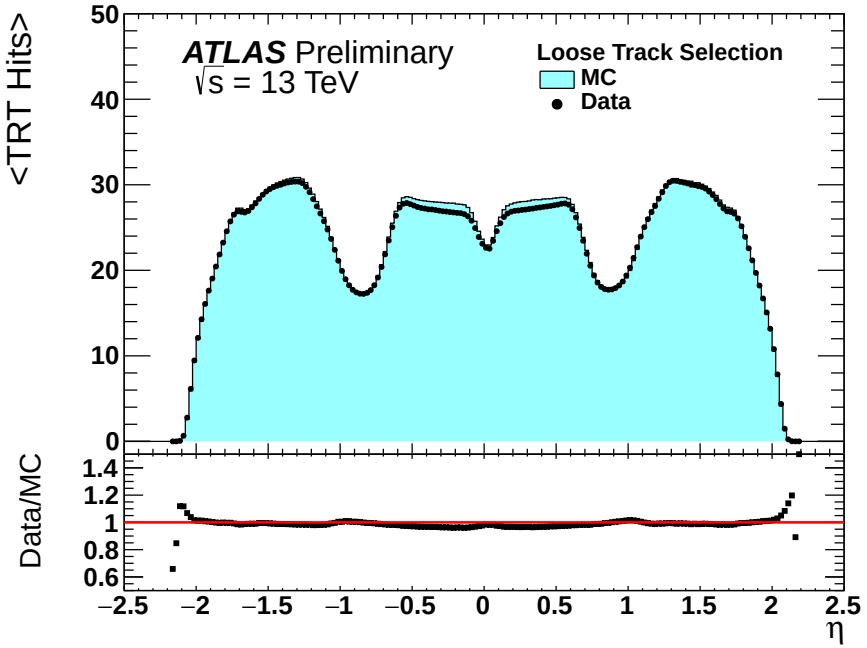


updated:

Updating the MC simulation's description of dead and inefficient modules improves agreement between data and MC.

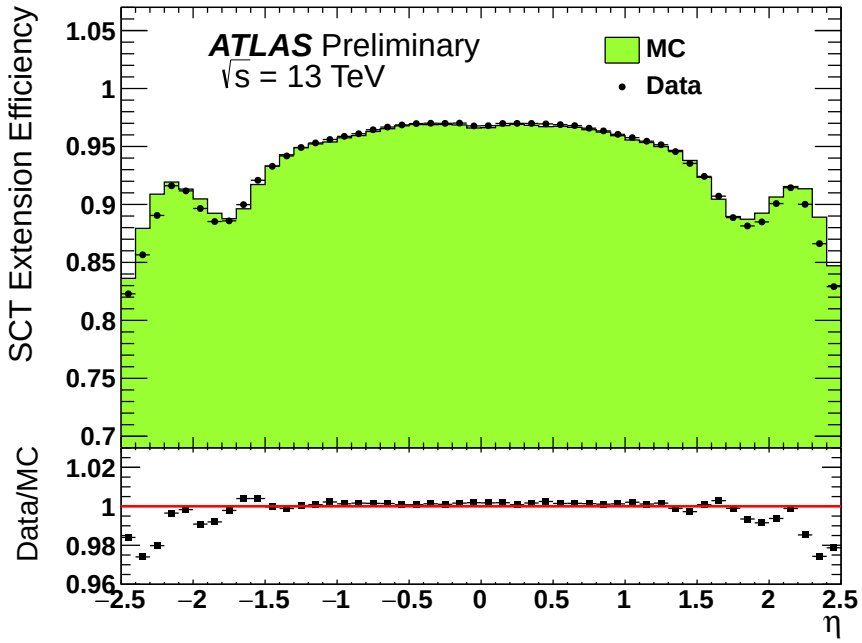
Other basic performance plots

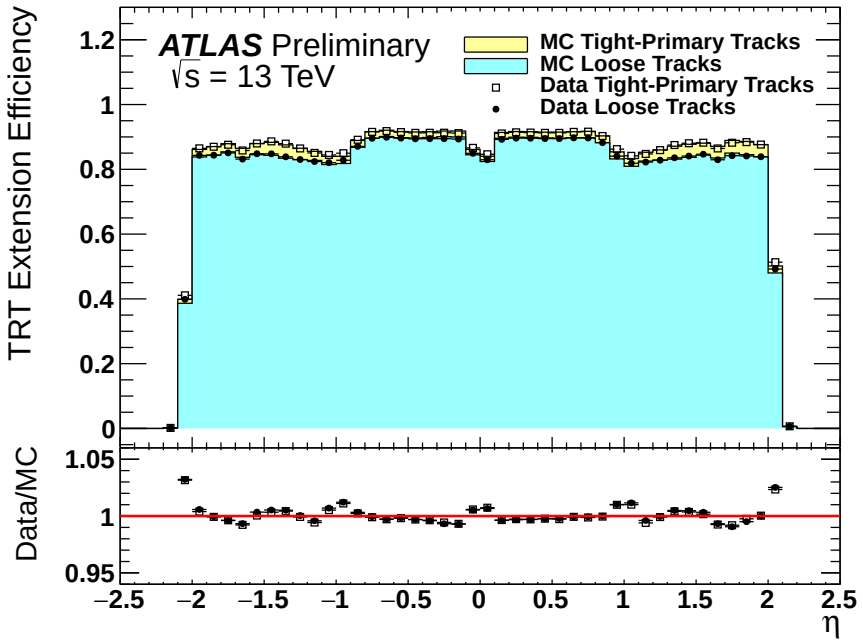




Discrepancy in IBL hits comes from different description of IBL stave overlap, as explained before.

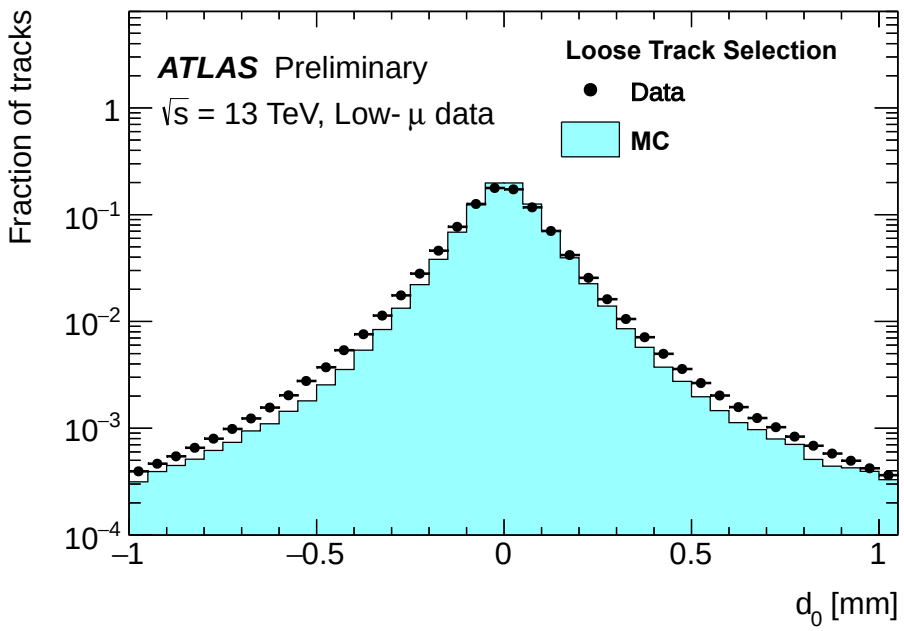
Efficiency to extend track

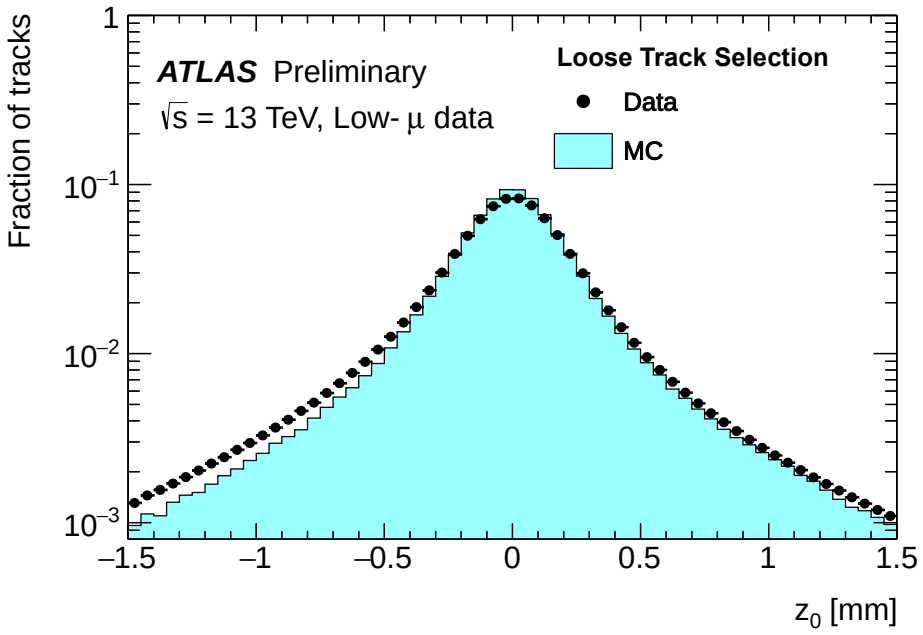




The probability to extend a track reconstructed in the pixel detector to the SCT (left) and from the silicon detectors to TRT (right)

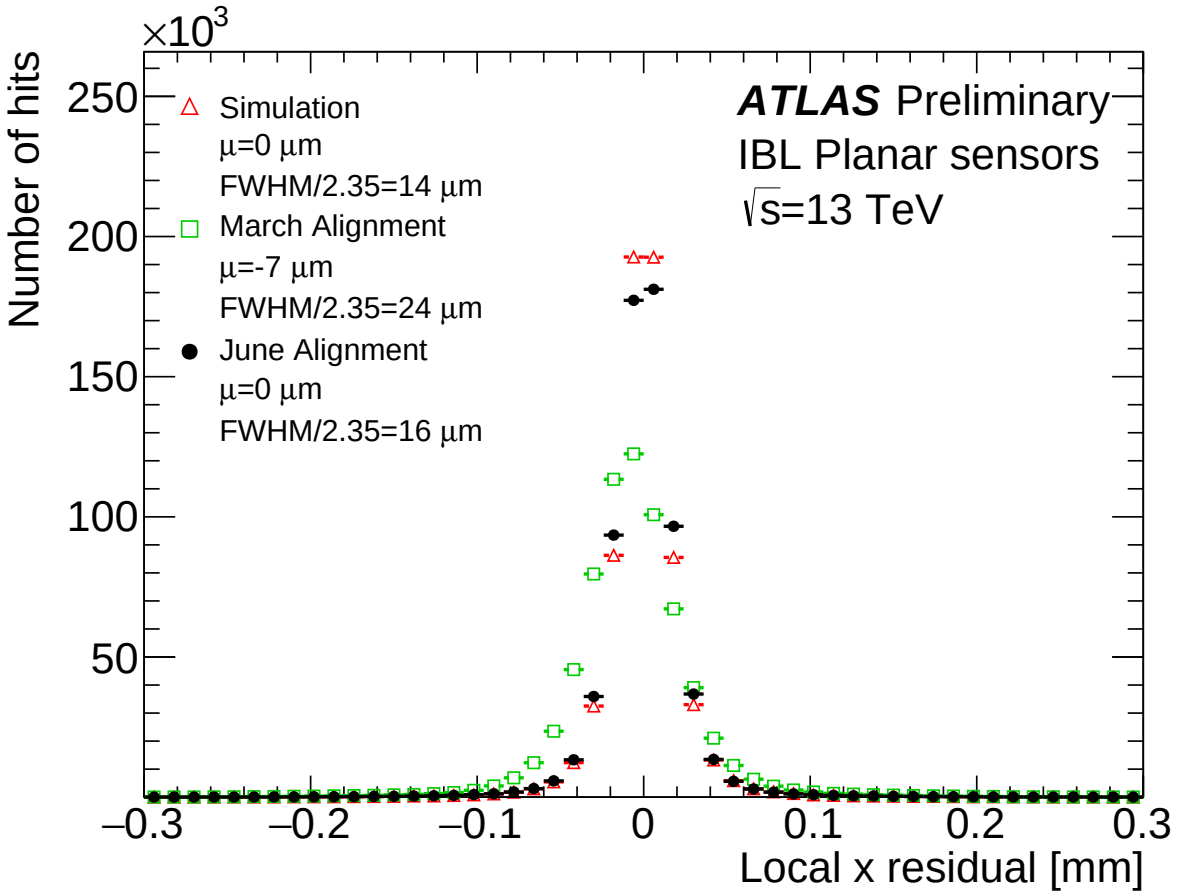
Impact Parameter distributions





Transverse (left) and longitudinal (right) impact parameter distributions w.r.t. the primary vertex, at $\langle\mu\rangle \approx 0.005$.

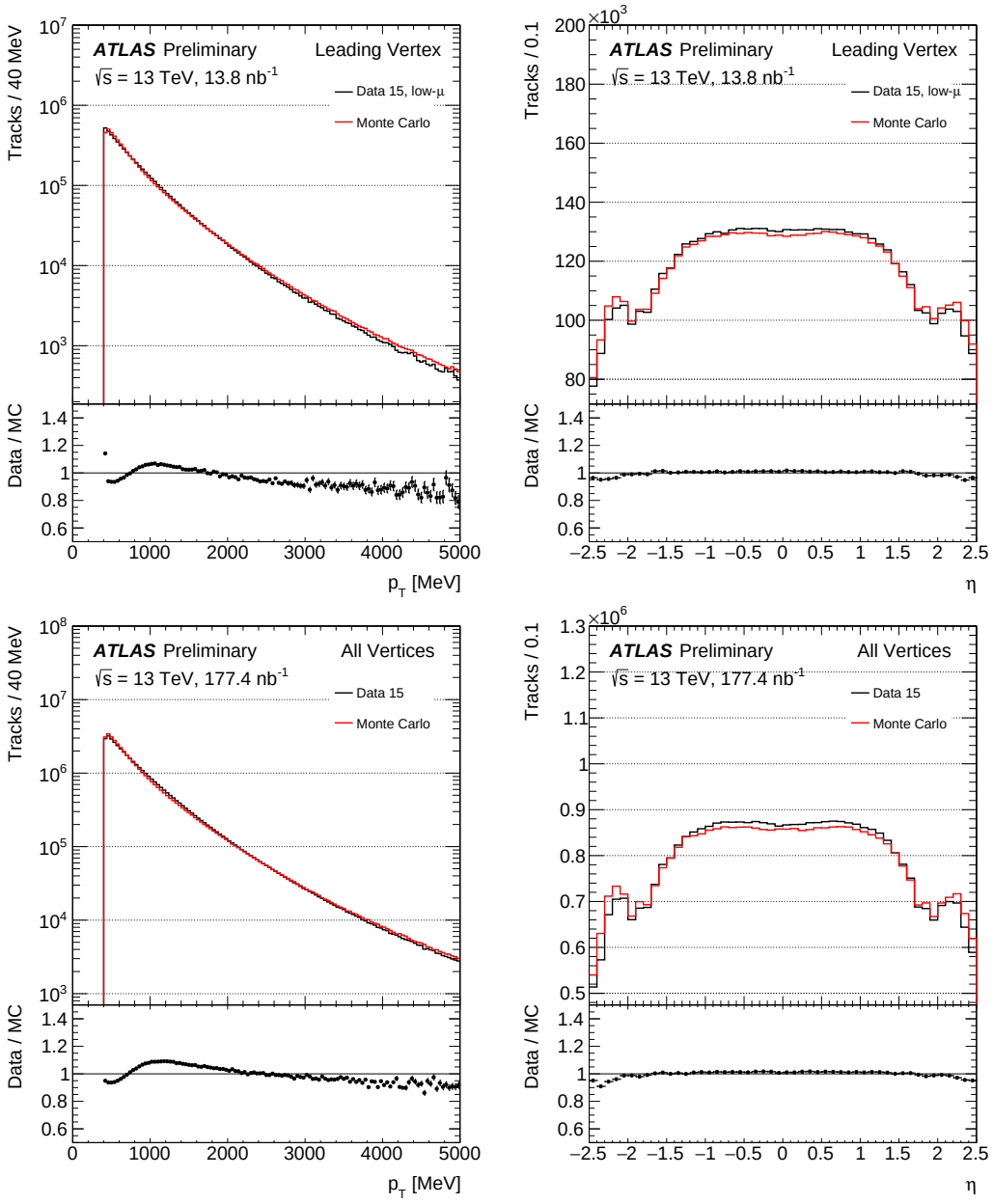
Inner Detector Alignment: Performance



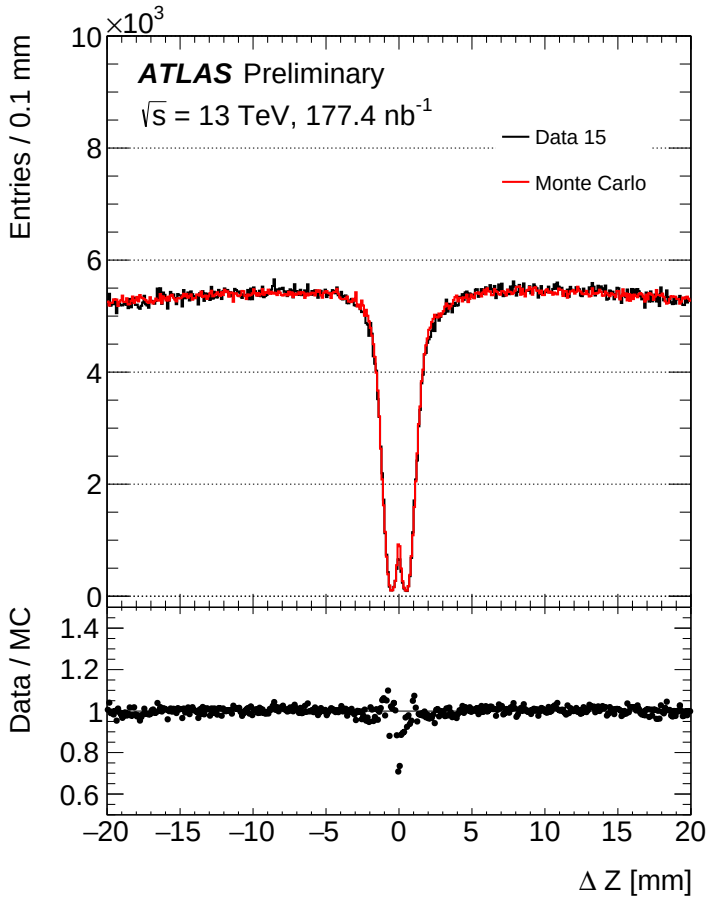
Shown here is an example of (unbiased) track-hit residuals, the distance from the extrapolated track in a detector element to the hit recorded in that element.

Vertexing

Track kinematic variables for leading vertex in low-μ (top) and all vertices in high-μ (bottom)

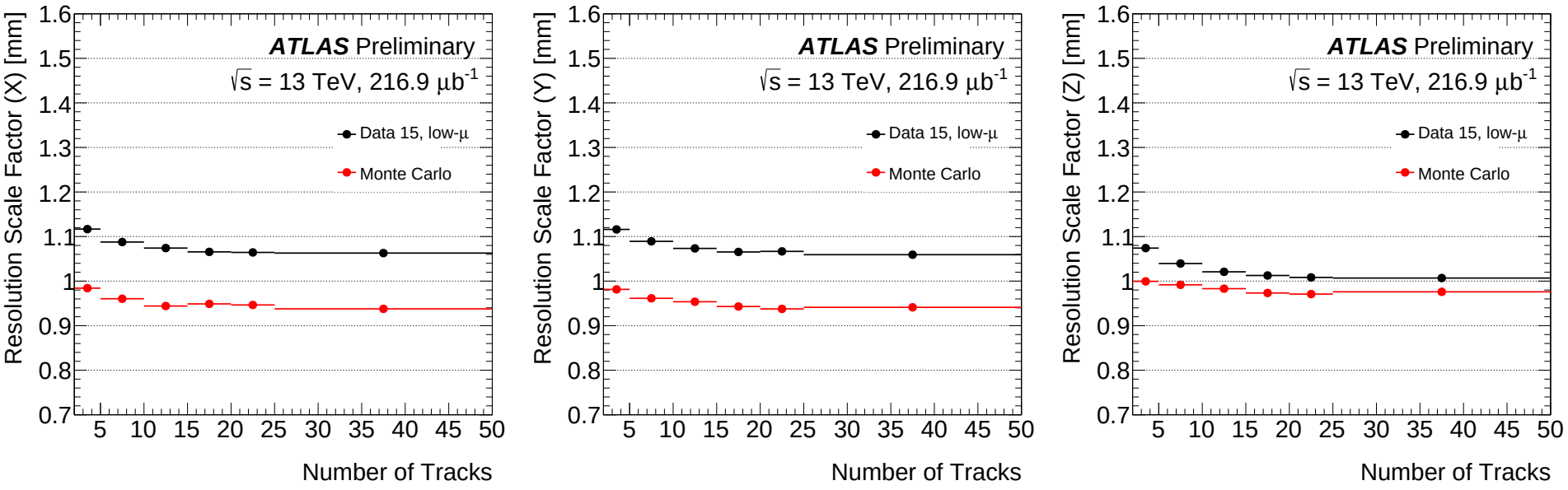


Vertexing performance



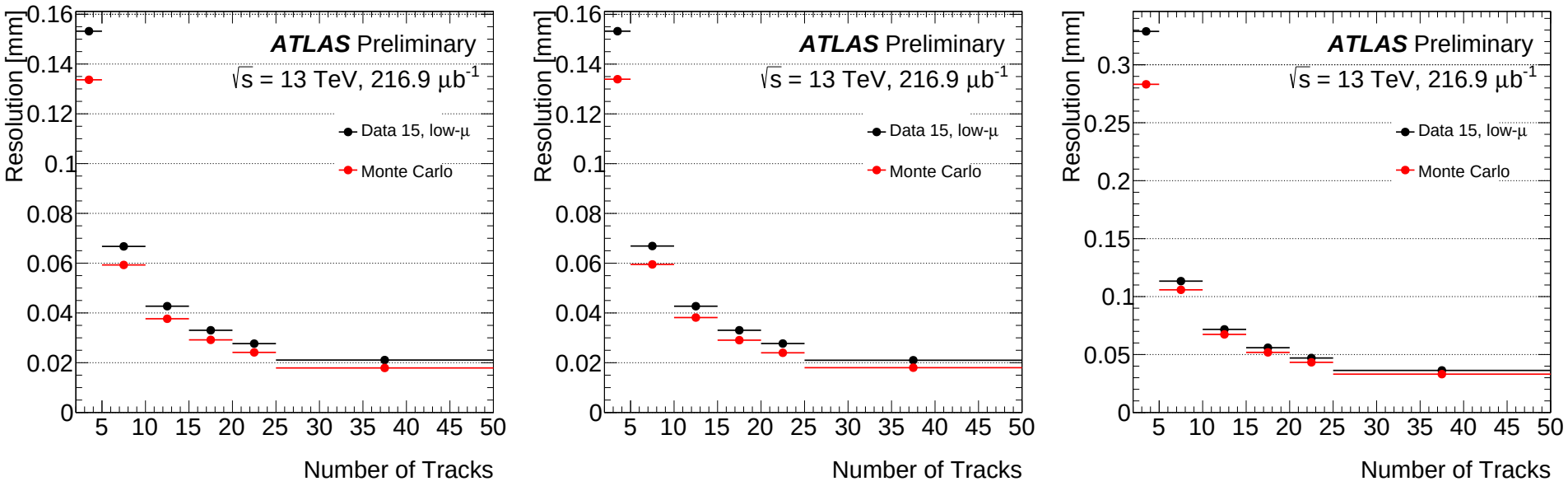
Longitudinal separation of reconstructed vertices, in high-μ data. This shows the resolving power of the vertex reconstruction.

Resolution scale factors



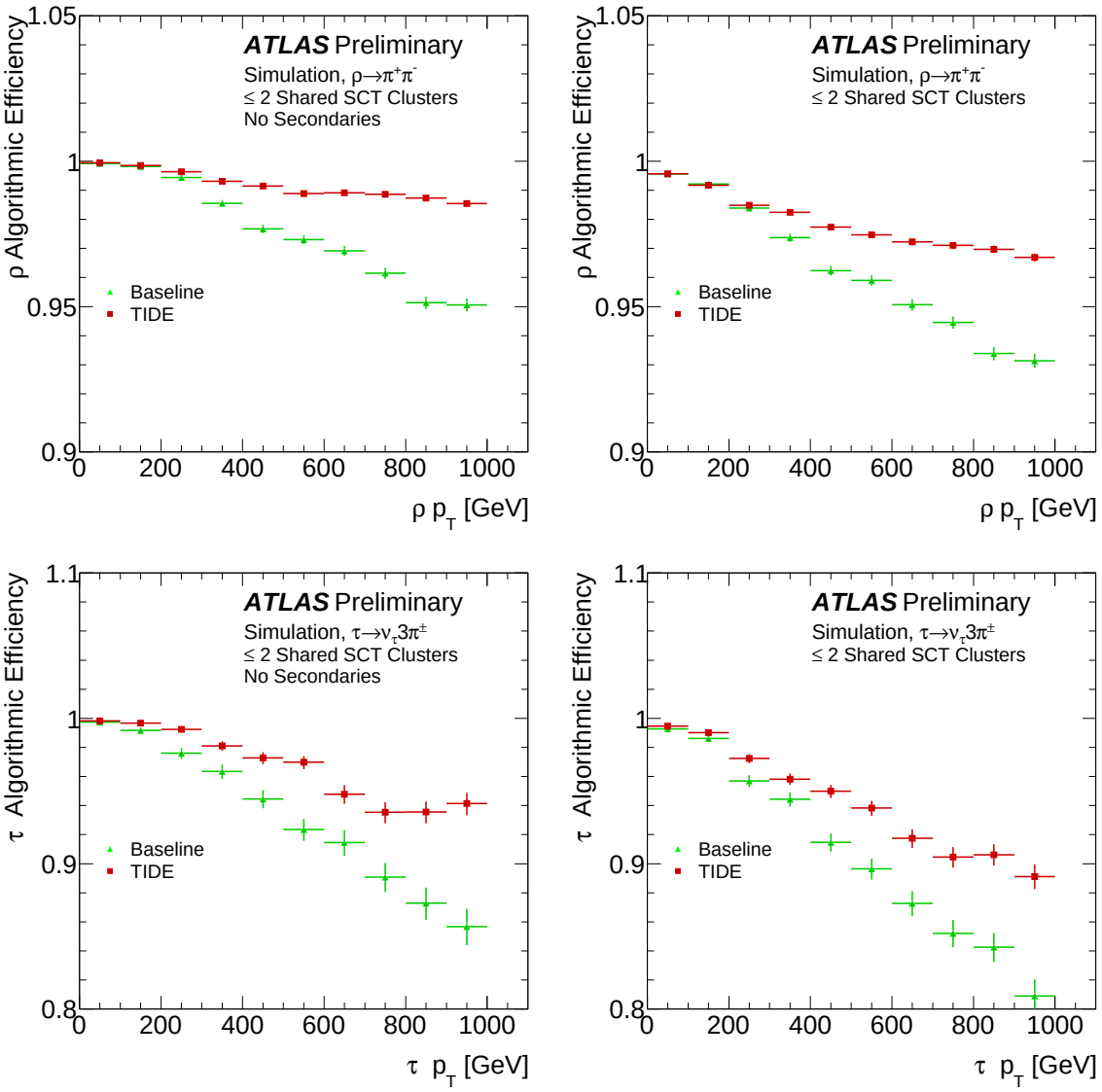
Resolution scale factors using the split-track method (in the x, y, and z directions, respectively)

Primary Vertex resolution



Primary Vertex resolution (scaled by K-factors) vs. number of tracks, in the x, y, and z directions respectively. K-factors are derived from the split-track method.

TIDE



Efficiency to reconstruct 2-prong ρs and 3-prong τs, with the new TIDE compared to the Run-1 baseline. The left plots have the additional requirement that there are no secondary decays from interactions with the detector material.