Tracking and Vertexing with the ATLAS Inner Detector in the LHC Run-2

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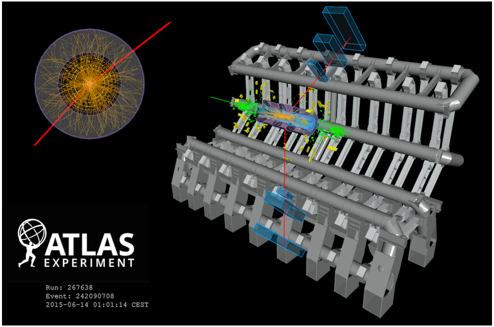
on behalf of the ATLAS Collaboration

TIPP '17
May 22, 2017

Outline

1. Overview of the ATLAS Inner Detector system in Run-2
2. Track reconstruction algorithm of the ATLAS Inner Detector
3. Time-dependent alignment
4. Tracking performance
5. Vertexing performance

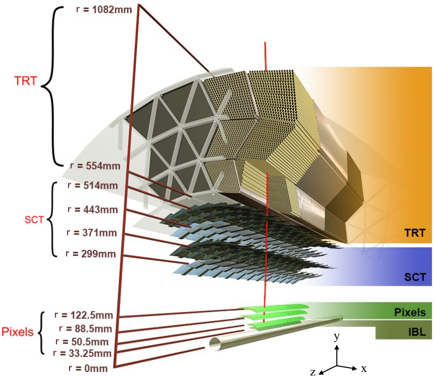


The ATLAS Inner Detector system in Run-2

- The ATLAS Inner Detector (ID), surrounded by 2 T solenoid magnet, provides position measurements for charged particles in the range $|\eta| < 2.5$ by combining information from three subdetectors.

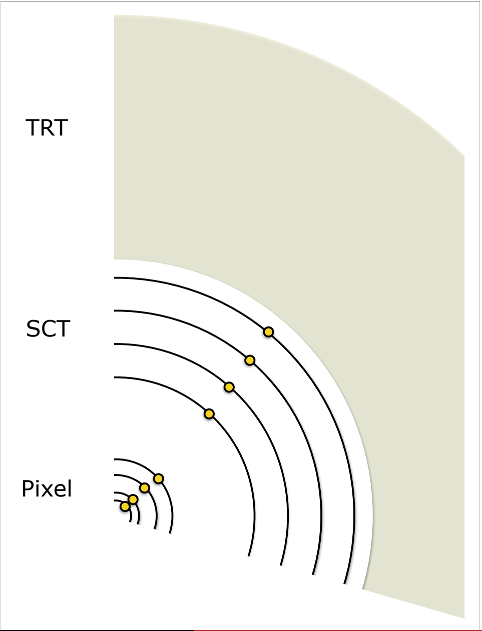
*pseudorapidity $\eta \equiv -ln[tan(\frac{\theta}{2})]$

1. **Pixel detector**
   - 4 barrel layers and 3 end-cap layers
   - **New innermost Insertable B-Layer (IBL) added for Run-2**
   - Intrinsic resolution in $r-\phi \times z$: $8\times40\ \mu m$ (IBL), $10\times115\ \mu m$ (Pixel)
2. **Semiconductor strip Tracker (SCT)**
   - 4 double-sided barrel layers and 9 end-cap layers
   - Intrinsic resolution in $r-\phi$: 17 μm
3. **Transition Radiation Tracker (TRT)**
   - Gas-filled straw tubes with electron identification capability using Transition Radiation (TR) photons
   - $\sim$30 hits expected for the pseudorapidity region $|\eta| < 2.0$
   - Intrinsic resolution: 130 μm



ATL-PHYS-PUB-2015-031

Track reconstruction algorithm of the ATLAS ID



1. **Space-point formation:**
   - Pixels and SCT: cluster creation then transformation into 3D space points
   - TRT: drift circle creation
2. **Space-point seeded track finding:**
   - Sets of 3 space-points (Pixel-only, SCT-only or Mixed) as seeds
   - Additional 4th space-point confirmation, p_T and impact parameter cuts
   - Combinatorial Kalman filter to complete track candiates within silicon detector
3. **Ambiguity solving:**
   - Track candidates are ranked based on quality of fit, holes, ...
   - Track candidates with highest score assigned shared hits preferentially, dropping track candidates below quality requirements
4. **TRT extension:**
   - Extend to TRT if valid extension then refit to improve momentum resolution

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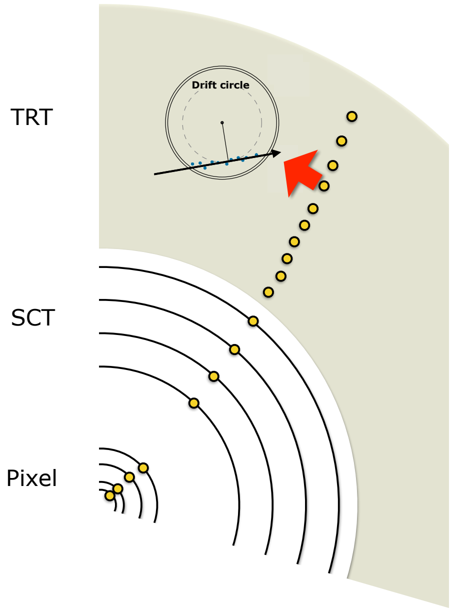

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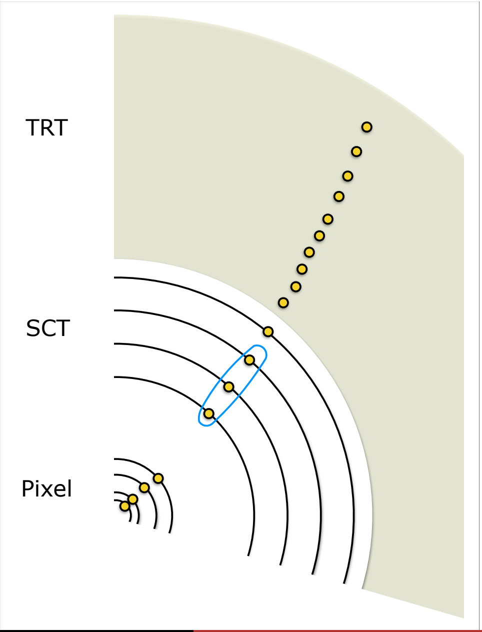

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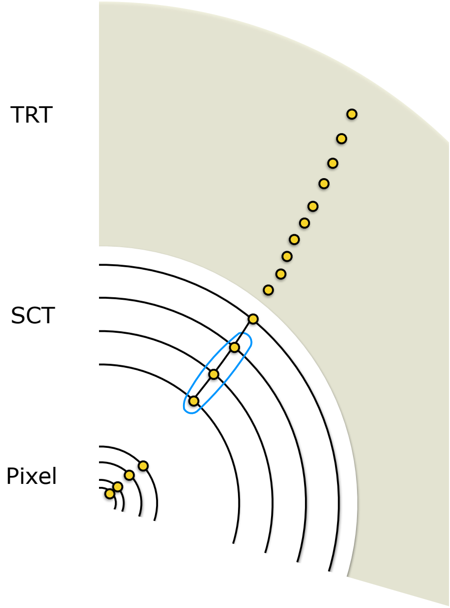

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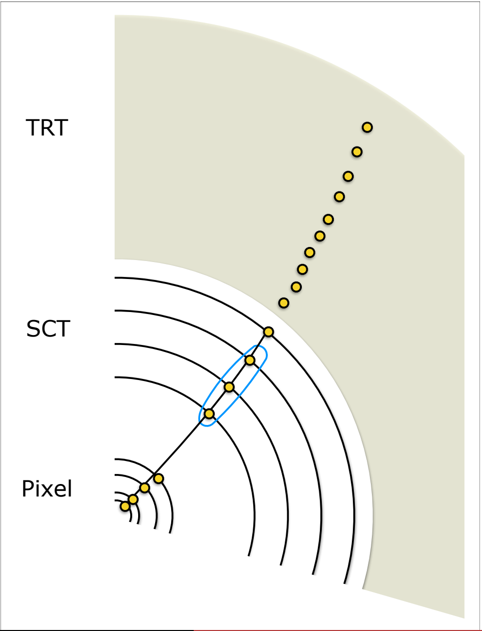

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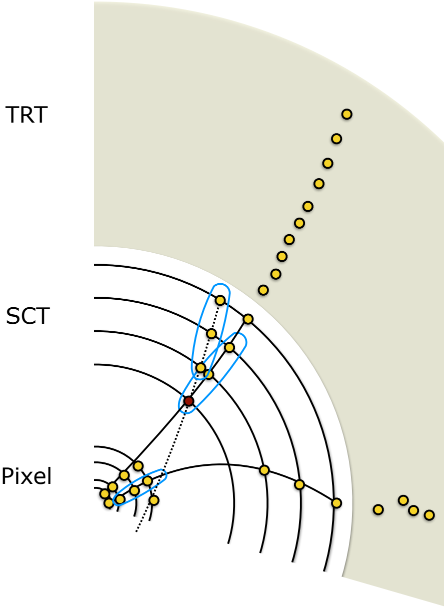

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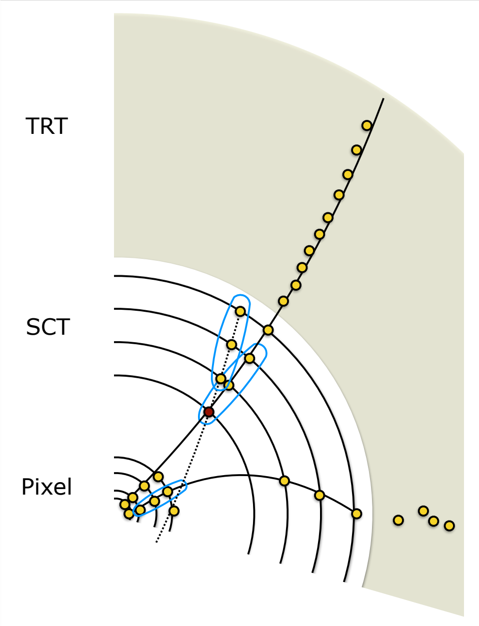

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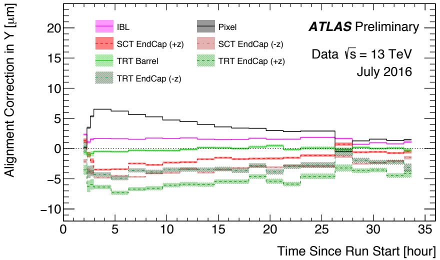
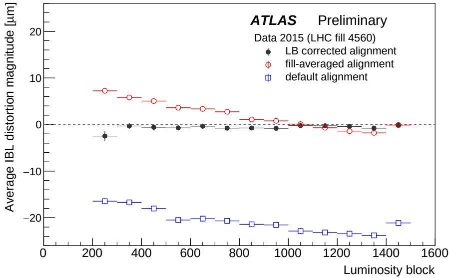
Time-dependent alignment

- **Track-based alignment algorithm based on track-hit residual minimization**
  ATL-PHYS-PUB-2015-031
- **Dynamic alignment within a single run:**
  - Pixel drift: increased cooling required after enabling the sensor preamplifiers at the start of each run before stabilising
  - IBL bowing: increased power consumption change of the front-end electronics with Total-Ionising Dose (TID)

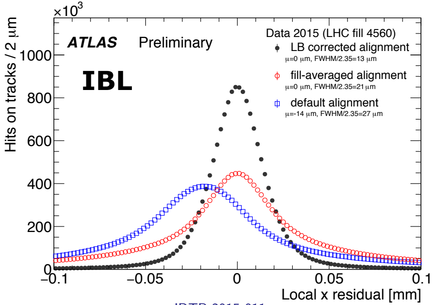
→ **Fully automated alignment** every 20 minutes during first hour of the fill then every 100 minutes after



IDTR-2016-009

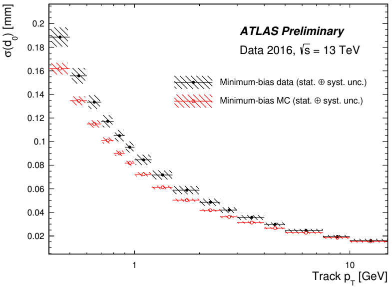


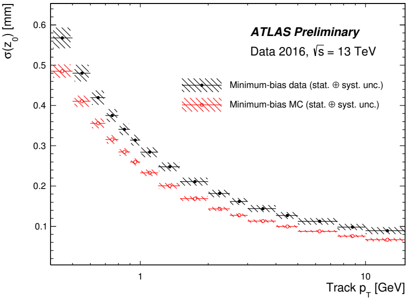
IDTR-2015-011

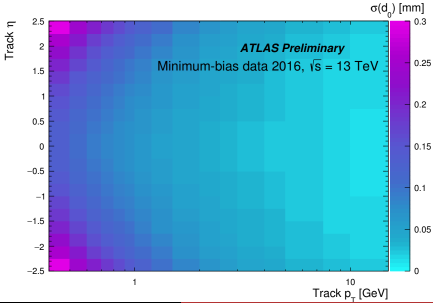


IDTR-2015-011

Impact parameter resolution



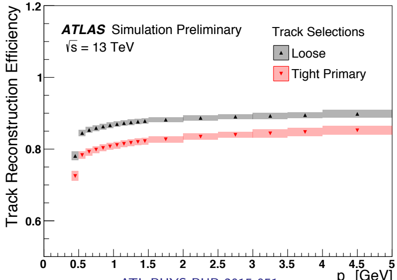




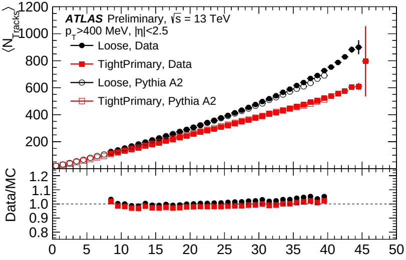
- The intrinsic transverse impact parameter (d_0) resolution is below 200 μm for low p_T tracks then reaches 20 μm at higher p_T
  - → **allows a very good primary and secondary separation**
- The intrinsic longitudinal impact parameter (z_0) resolution is below 600 μm for low p_T tracks then reaches 100 μm at higher p_T

IDTR-2016-018

p+p

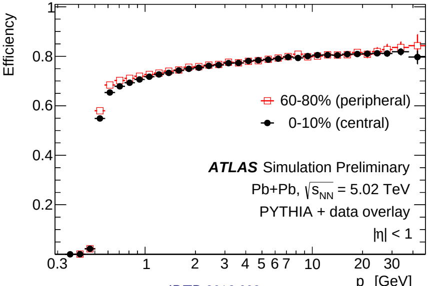


ATL-PHYS-PUB-2015-051



IDTR-2016-015

Pb+Pb

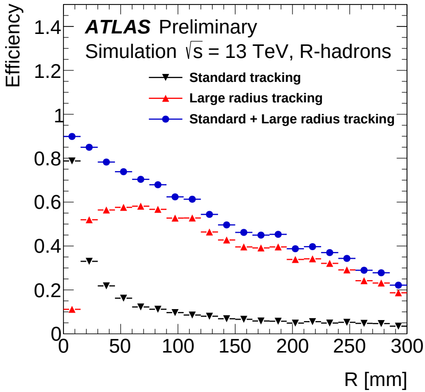


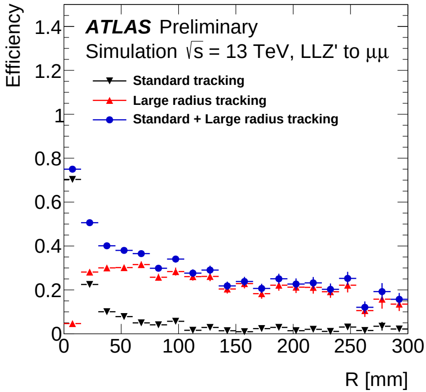
IDTR-2016-008

- Excellent track reconstruction efficiency in p+p collisions
- Good agreement between data and MC and Tighter track selections to mitigate an increase of fake tracks at high instantaneous luminosity
- Very good track reconstruction efficiency under very high track multiplicity by Pb+Pb central collisions
  → **insight for high occupancy p+p events**

Large radius tracking

- Long-lived particles predicted in several physics models beyond the Standard Model can be produced at large radial distance (displaced vertex)
- Large radius tracking is a **second pass** after the standard tracking using unused hits with tighter p_T and looser impact parameter requirements
- Sizeable increase in the signal track reconstruction efficiency with the large radius tracking for tracks with a special topologies



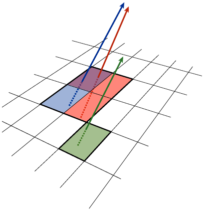


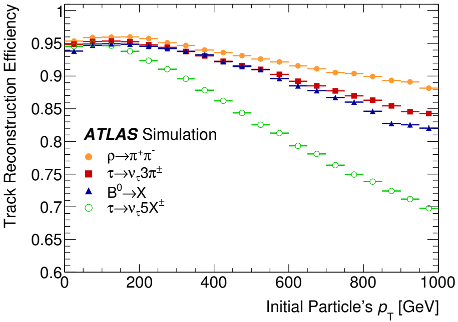
IDTR-2016-006

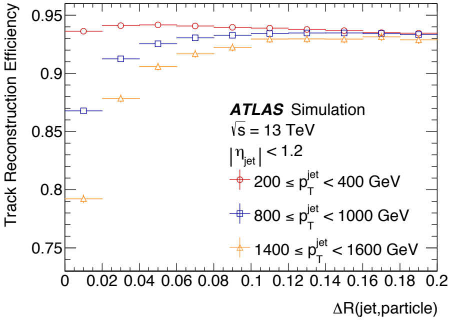
Tracking in Dense Environment (TIDE)

- A pixel cluster can be shared by multiple tracks in dense environment, typically jets with $p_T > 1$ TeV
- Neural-network clustering algorithm separates multiple particles within a merged cluster, then estimates the track parameters of each
- Algorithmic optimizations in the pattern recognition stage of the track reconstruction

→ Improves b-tagging, τ-reconstruction, jet mass and energy reconstruction

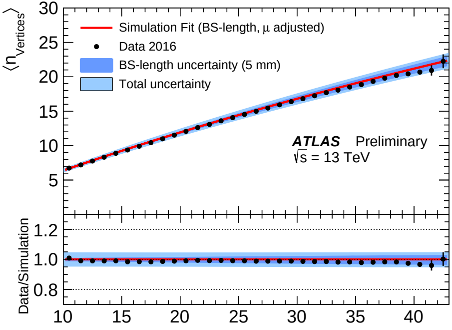




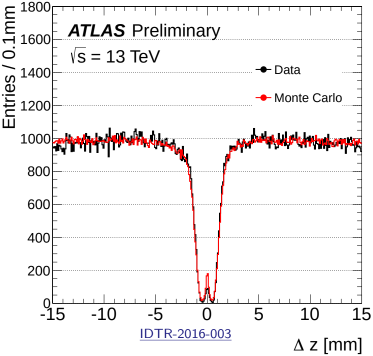


arXiv:1704.07983

- Iterative primary vertex finding algorithm arXiv:1611.10235
  - → Progressive down-weighting of track outliers
- The average number of reconstructed vertices is modeled very well as a function of the average number of interactions per bunch crossing (μ) between data and MC
- Non-linearity in μ due to merged vertices in higher μ
  - A steep decrease of the number of reconstructed vertices for small longitudinal distance of primary vertices ($|\Delta z| < 2$ mm) due to merged vertices.
  - A single vertex is reconstructed as two primary vertices causes a small spike around $\Delta z = 0$ mm



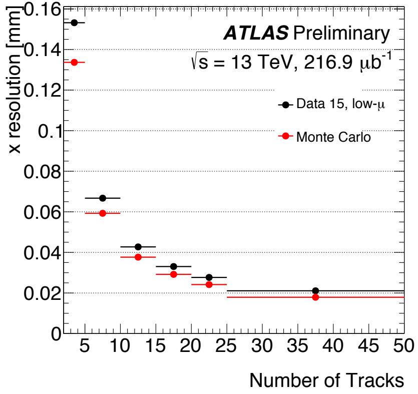
IDTR-2016-013

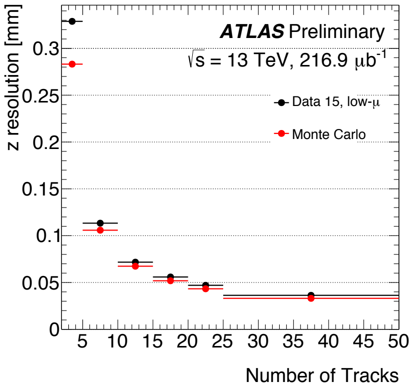


IDTR-2016-003

Vertexing resolution

- Vertex resolution ranges from 20 to 155 μm in x and from 35 to 330 μm in z depending on the number of tracks without the constraint of the beam-spot
- Underestimation in MC due to imperfect description of material, multiple scattering, residual mis-alignment, etc.

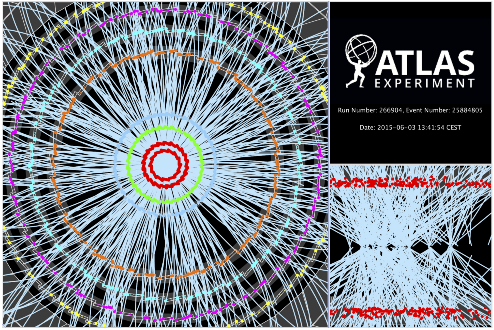




ATL-PHYS-PUB-2015-026

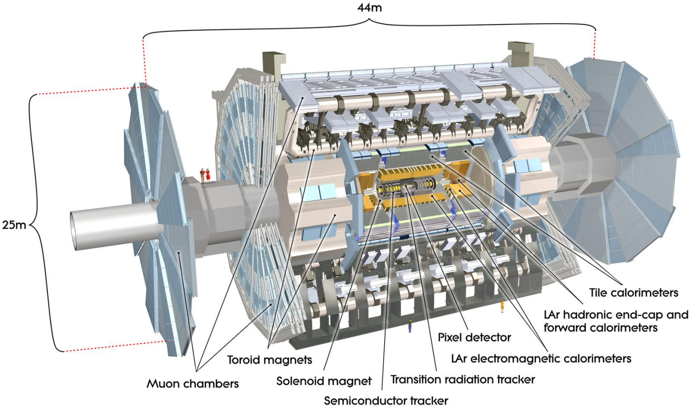
Summary

- ATLAS Inner Tracking shows an excellent performance under very busy environment in Run-2
  - → The average number of pp interactions per bunch crossing reached up to 50
  - → Very high track multiplicity in the central heavy ion collisions
- Stable operation and performance of the newly added Insertable B-Layer (IBL) closer to the beampipe
- Tracking in Dense Environment (TIDE) allows an excellent reconstruction performance inside jets
- Precise and good understanding of vertex performance



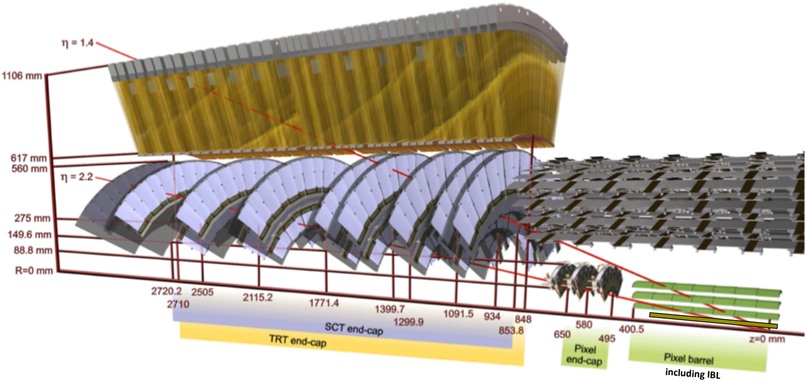
Backup

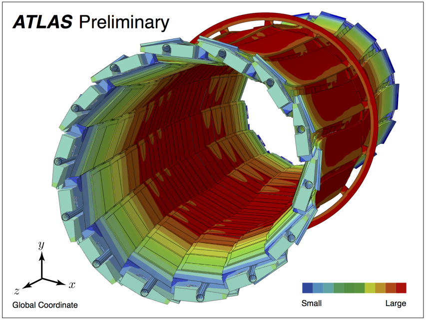
The ATLAS Detector

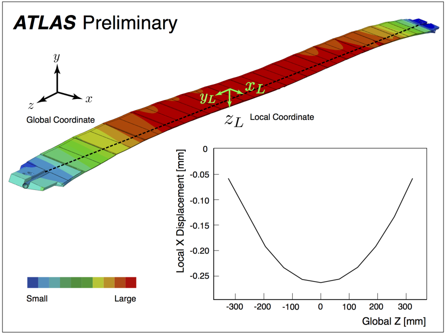


- **Inner Detector (ID):** Silicon Pixels and microstrip detectors, Transition Radiation Tracker (TRT)
- **Calorimetry:** high-granularity electromagnetic and hadronic calorimeters outside solenoid
- **Muons:** 4 different chambers technologies (precision tracking and trigger)
- **Magnets:** inner solenoid and 3 outer toroid systems

The ATLAS Inner Detector



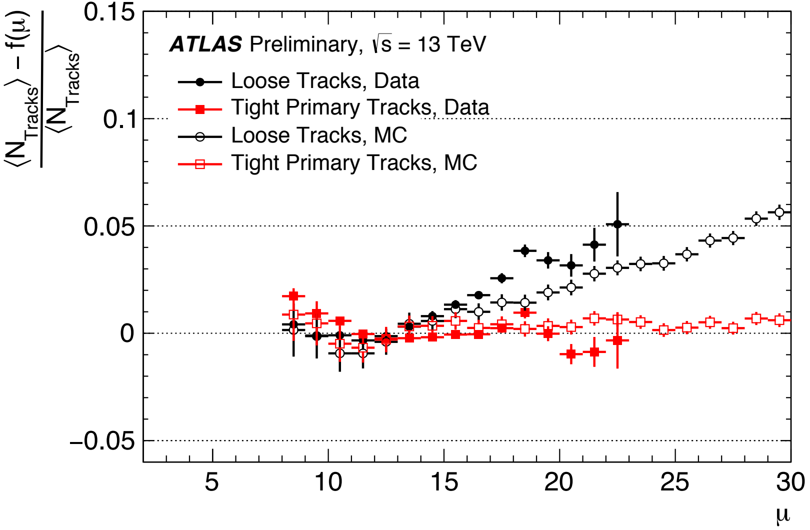




ATL-INDET-PUB-2015-001

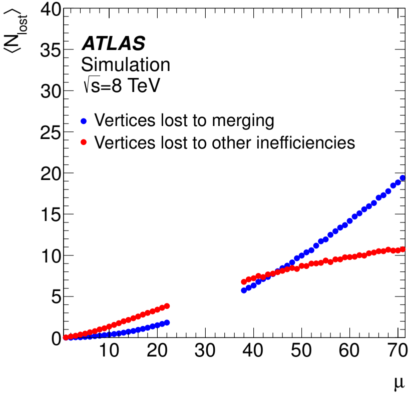
- The size of the distortion is magnified for visualization
- The color represents the relative size of the local displacement

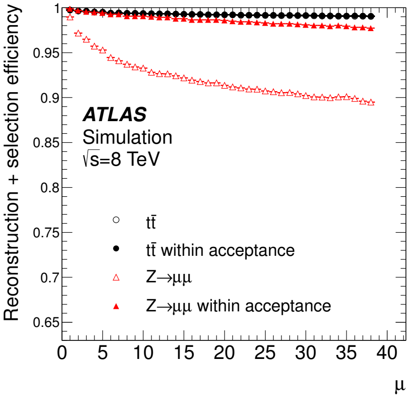
Fake rate vs. μ in p+p collisions



ATL-PHYS-PUB-2015-051

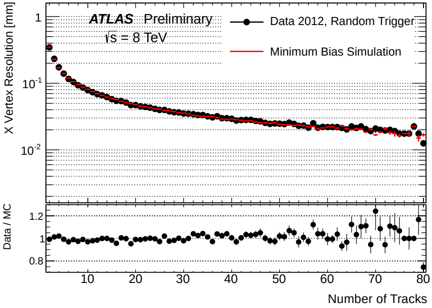
- Left: efficiency to reconstruct then select the hard-scatter primary vertex as a function of the average number of interactions per bunch crossing
- Right: average number of lost vertices due to merging and other inefficiencies





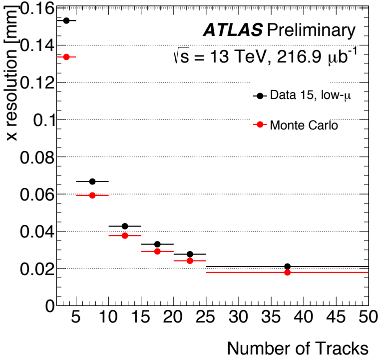
arXiv:

Run-1



ATL-COM-PHYS-2012-474

Run-2



ATL-PHYS-PUB-2015-026

The average number of interactions per bunch cross