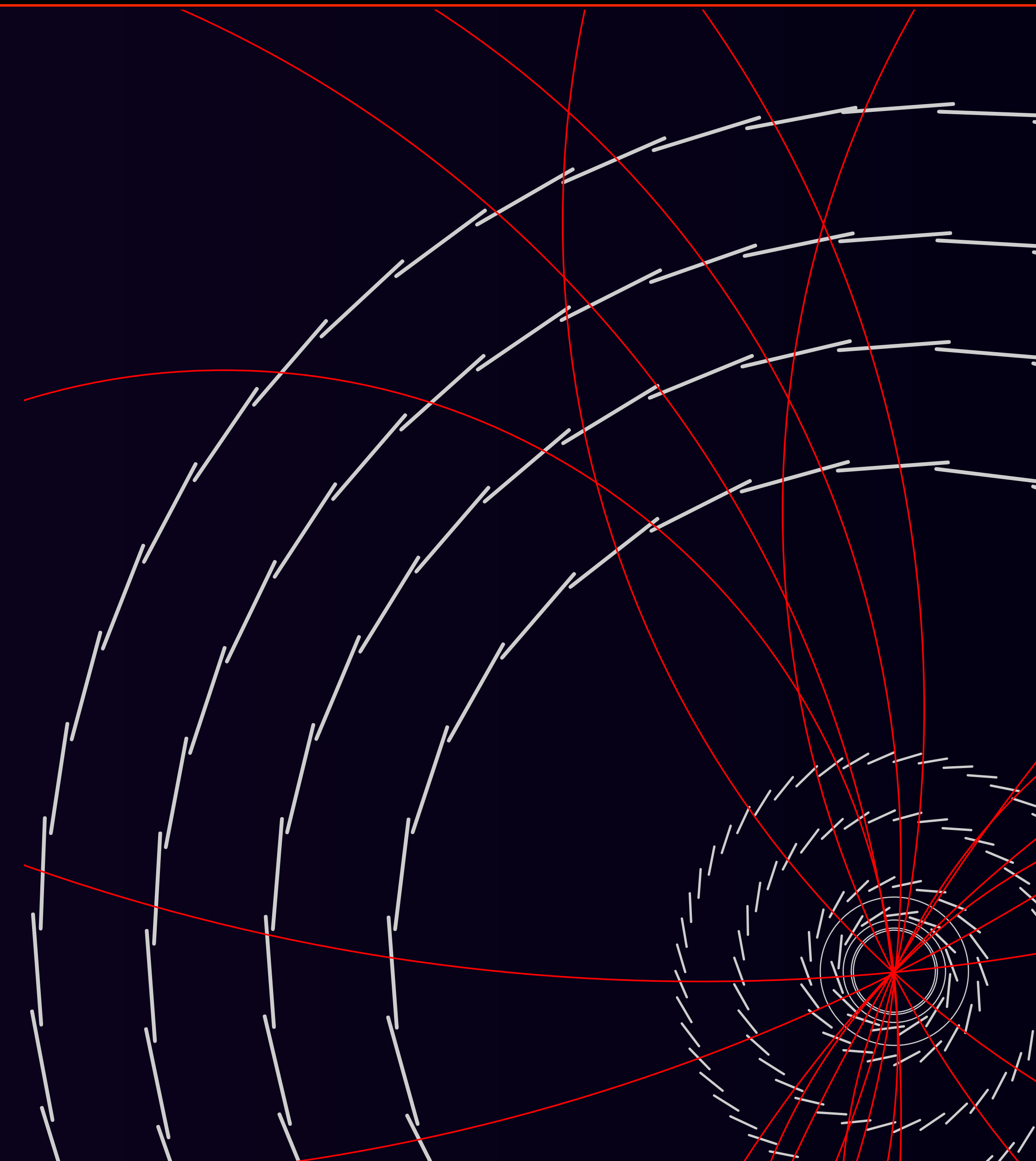
Performance of the ATLAS Track and Vertex Reconstruction in the LHC Run 2

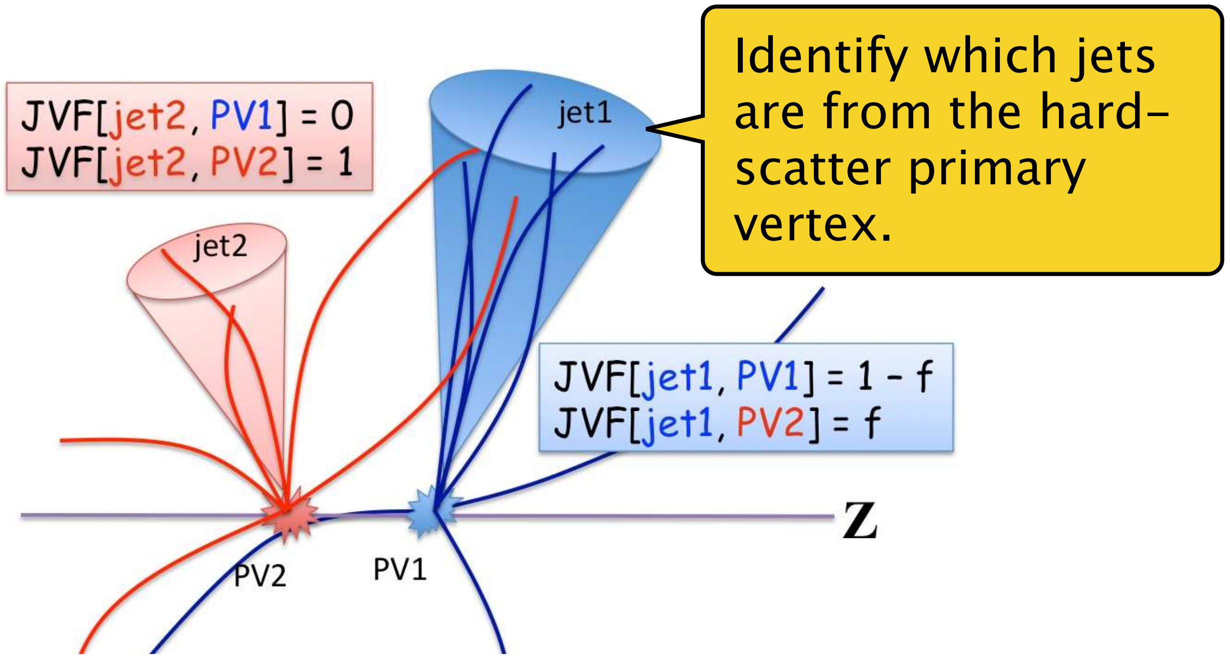


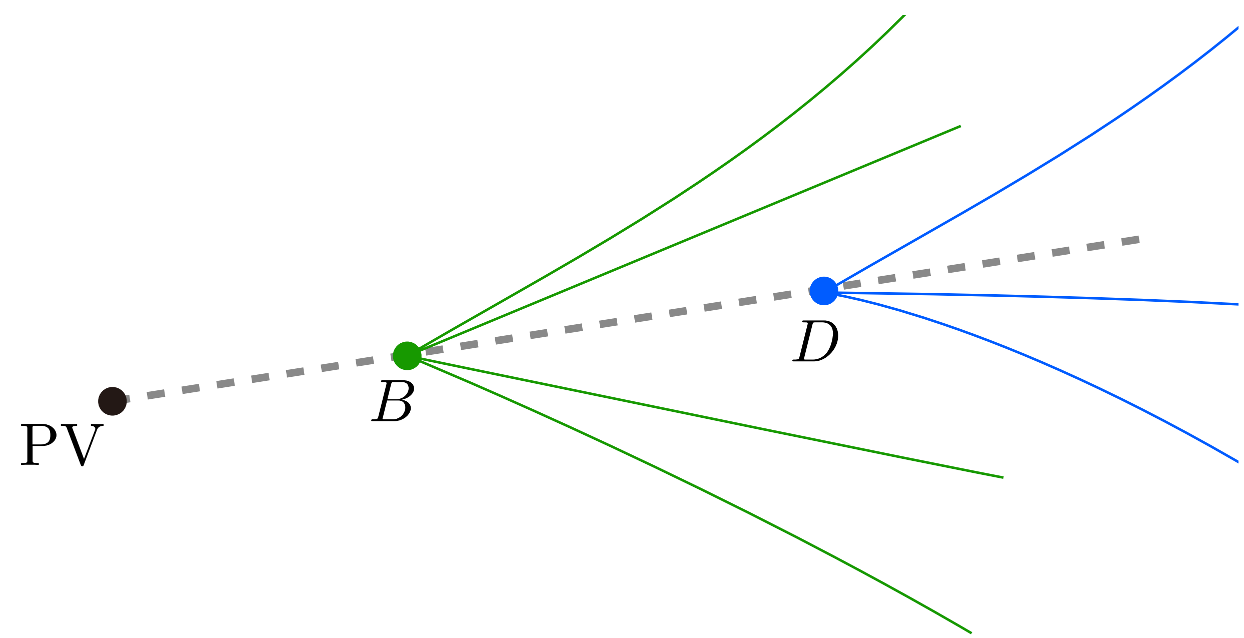
Hideyuki Oide (INFN-Genova)

on behalf of the ATLAS Collaboration

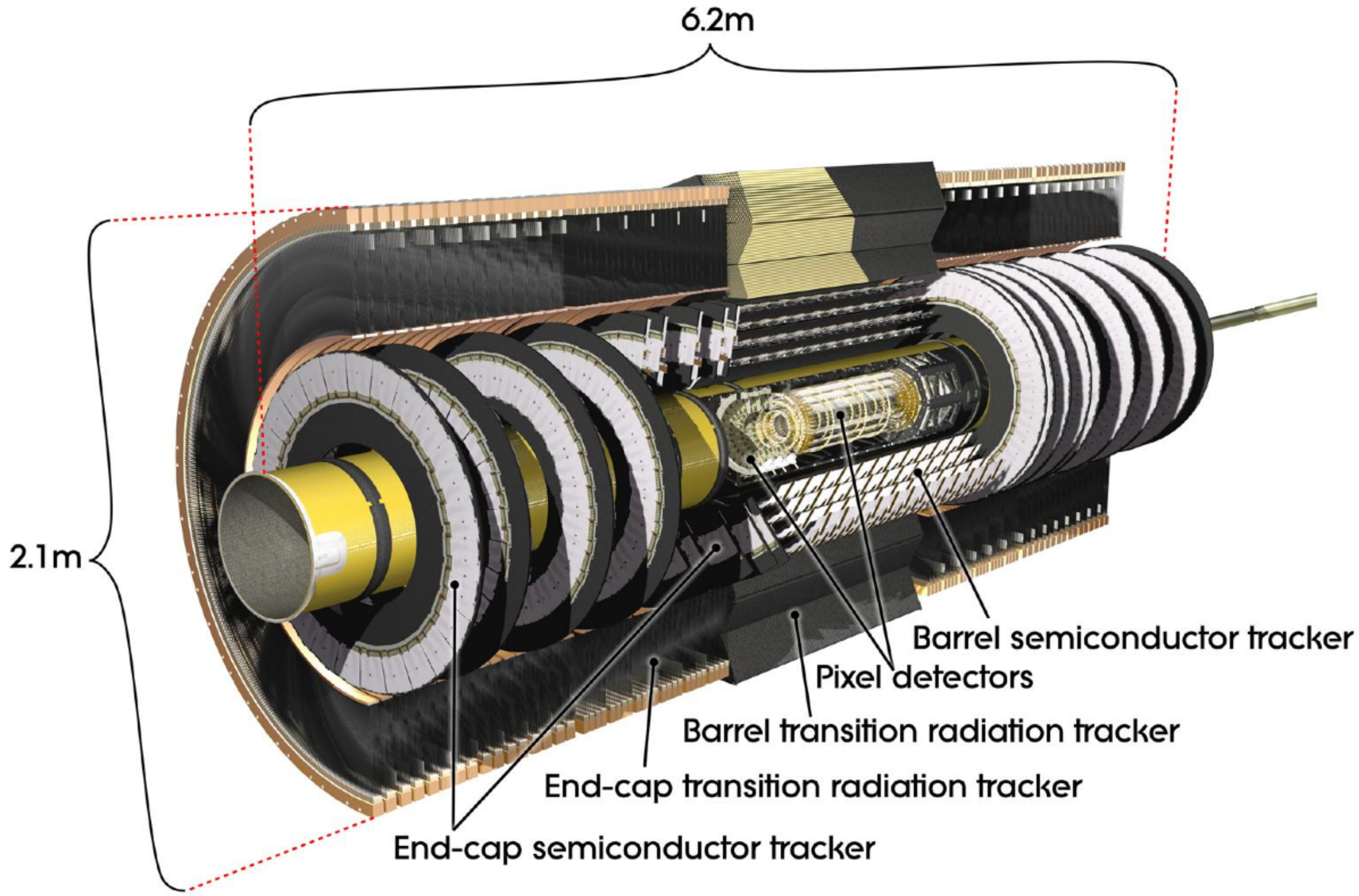
Introduction: why tracking is crucial in the LHC Run 2?

- Reconstruction of charged particle trajectories (tracks) is fundamental input into many ATLAS physics objects and analysis quantities.
- Helps combat effects of pile-up:
  - Closest subdetector to interaction point → provides precise measurements allowing the primary vertex to be distinguished from pile-up vertices.
- Provides precise information on the topology of the jet structure.
  - One of key ingredients to identification of e.g. boosted objects.
- Flavour tagging
  - B-tagging is an indispensable tool for the majority of analysis channel in ATLAS.
- Exotic tracking signatures
  - Displaced vertices, large dE/dx,…

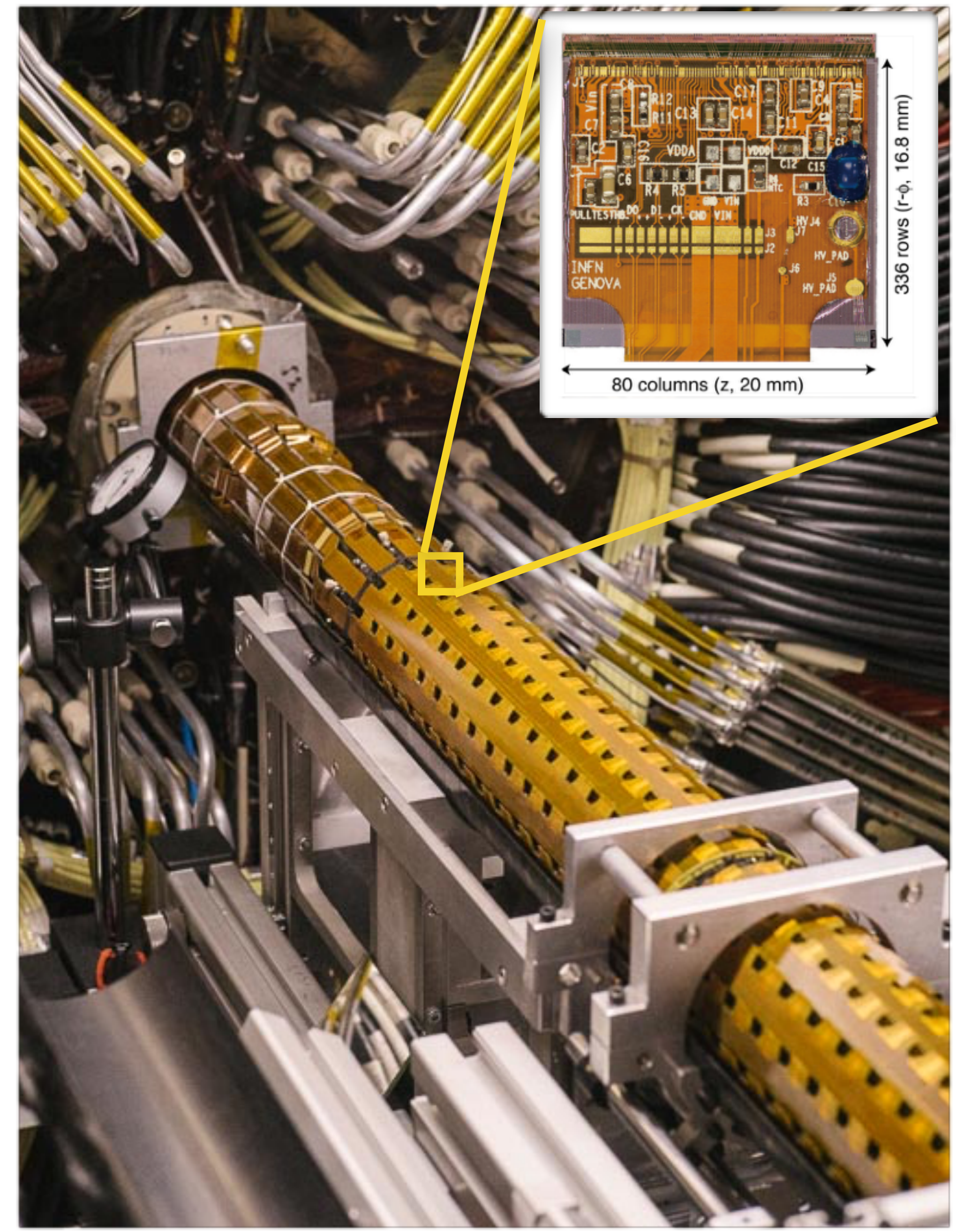




Run 2: ATLAS Inner Detector



- B = 2 T, hermetic coverage of |η| < 2.5
- 3-layer detector subsystems.
  - Pixel detector (3 barrel + 3x2 endcaps)
  - Semiconductor Microstrip (4 barrel + 9x2 endcaps)
  - Transition radiation straw drift tube
- New Insertable B-Layer (IBL) introduced since Run 2 (2015-).
  - In addition, refurbishing the Pixel detector.



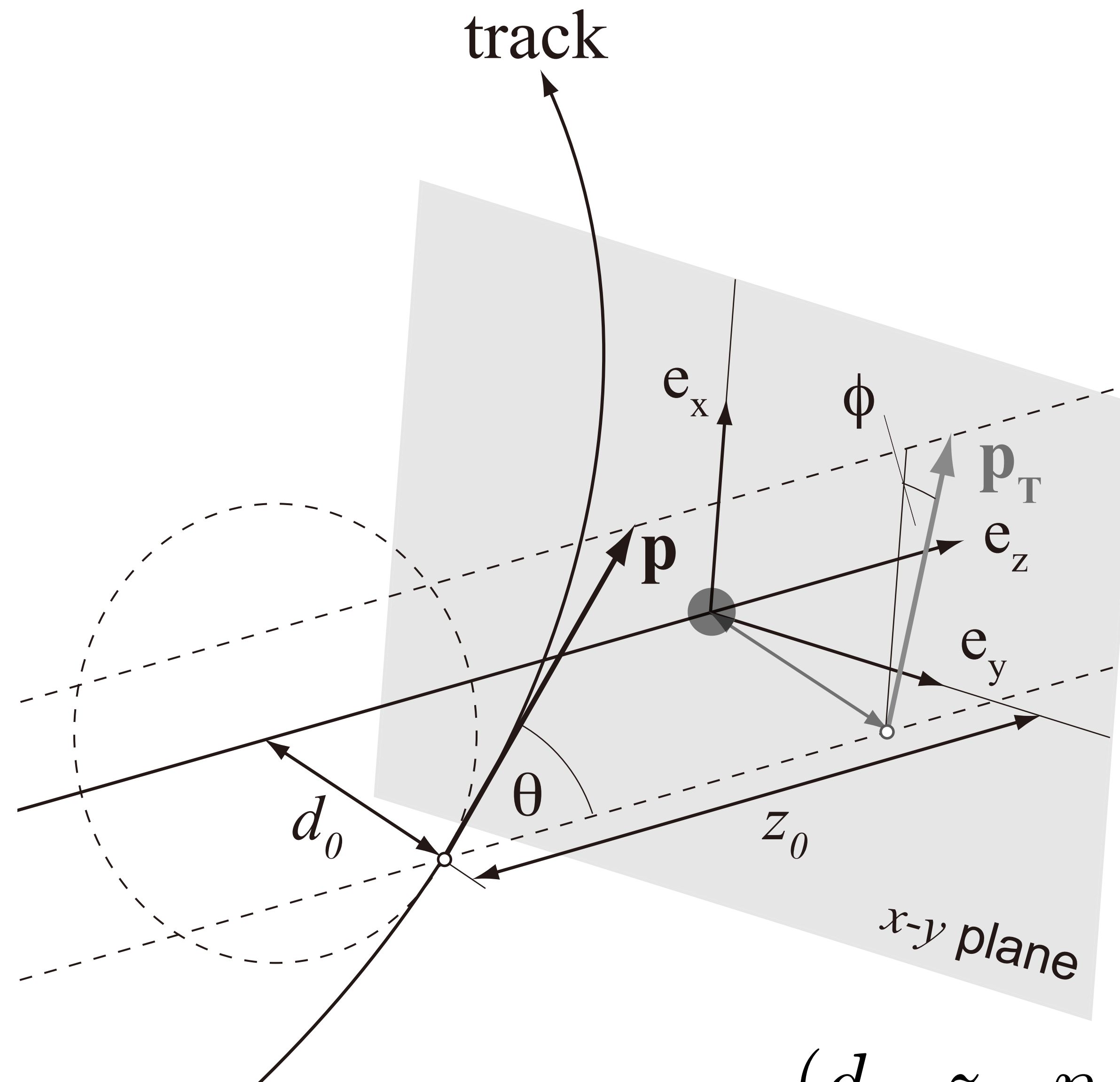
- r ~ 33 mm. 14 staves surrounding the new beam pipe.
- Each stave hosts 32 front-end chips (FE-I4).
- 50 μm (r—ϕ) × 250 μm (z) pixel size (~12 Mpx total).
- Planar (|η| < 2.5) and 3D (2.5 < |η| < 3.0) silicon sensors.
- Readout bandwidth tolerable up to <μ> ~ 80.

ATLAS Track Reconstruction

pre-processing
- ➡ Pixel+SCT clustering
- ➡ TRT drift circle formation
- ➡ space points formation

Combinatorial track finder
- ➡ iterative :
  1. Pixel seeds
  2. Pixel+SCT seeds
  3. SCT seeds
- ➡ restricted to roads
- ➡ bookkeeping to avoid duplicate candidates
- ➡ Bremsstrahlung Recovery

Ambiguity solution
- ➡ precise least square fit with full geometry
- ➡ selection of best silicon tracks using:
  1. hit content, holes
  2. number of shared hits
  3. fit quality…
- ➡ Brem Recovery



$$(d_0, z_0, \eta, \phi, q/p)$$

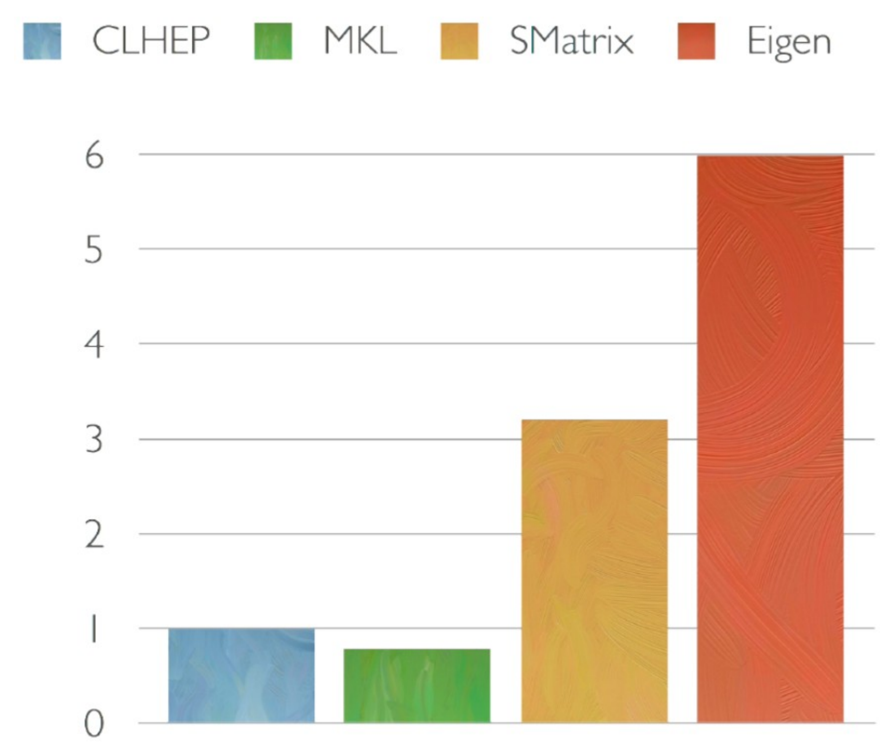
Extension into TRT
- ➡ progressive finder
- ➡ refit of track and selection

Plus, TRT back-tracking.
Optionally, large-d_0 tracking

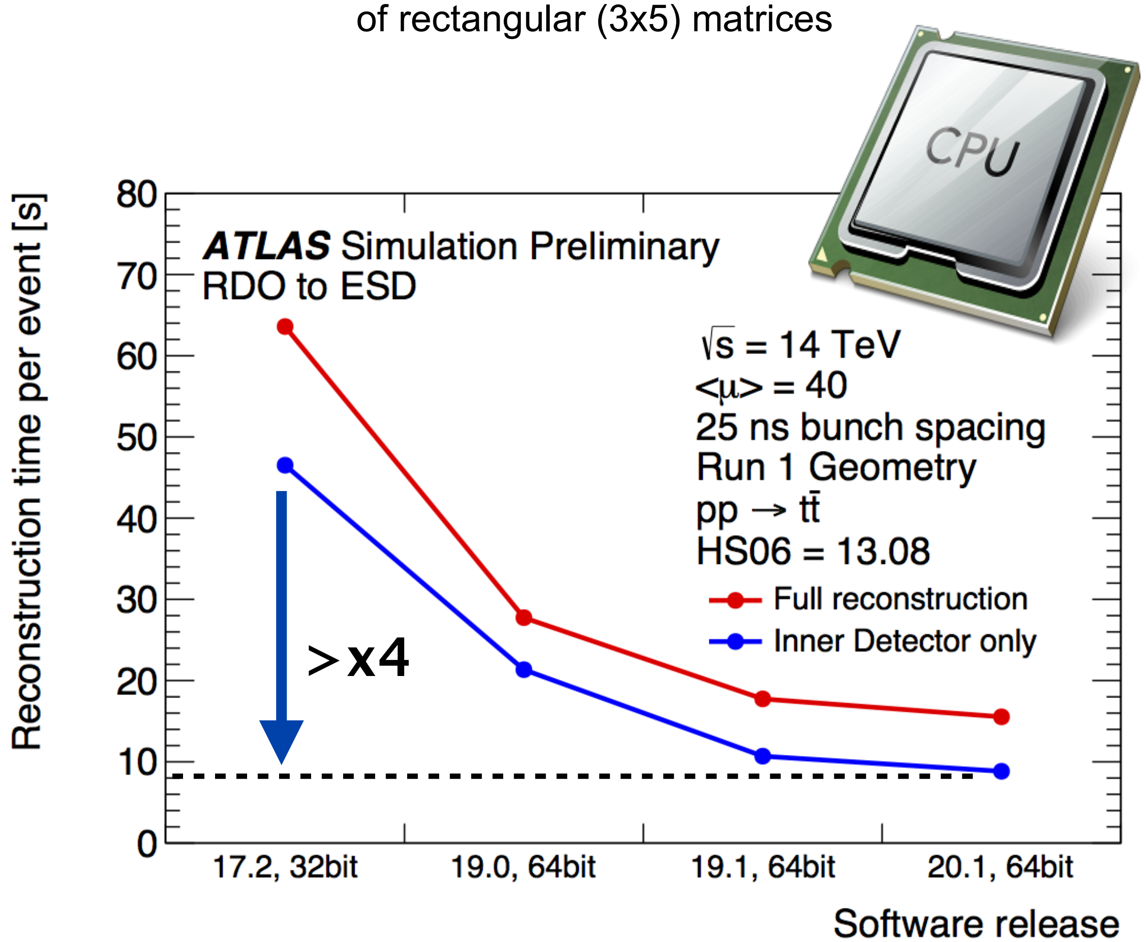
vertexing
- ➡ primary vertexing
- ➡ conversion and V0 search

Track reconstruction algorithms: Improvements in Run 2

- For Run 2, reduction in CPU overhead necessary.
  - Target: ~1 kHz throughput at Tier0 (the prompt reconstruction site).
  - Needed a factor-3 improvement in CPU-time with available computing at pile-up of $\mu = 40$.
- Improvement in Run 2:
  - Revisiting seeding procedure optimised for IBL.
  - Linear algebra solver from CLHEP to EIGEN.
  - Migration of Fortran90 magnet description to C++ native, and associated code-tunings.
  - Less object-oriented and using templates (reducing the number of inheritances).
  - O(1000) software packages were updated.
  - Simplified Event data model: xAOD.

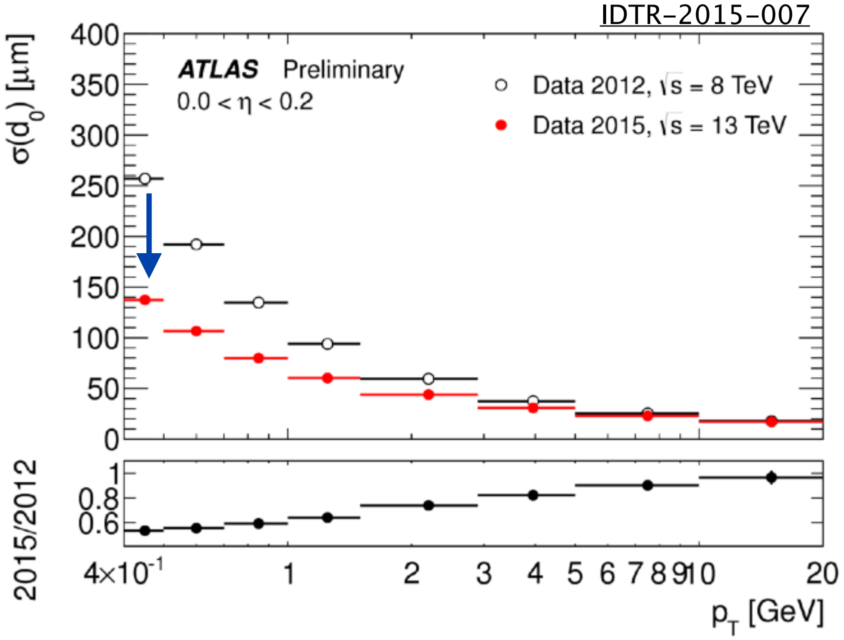


Speed-up WRT CLHEP for multiplication of rectangular (3x5) matrices



σ_{d0} vs. p_T Run1 vs Run2

IDTR-2015-007



σ_{d0} vs. pT data vs MC

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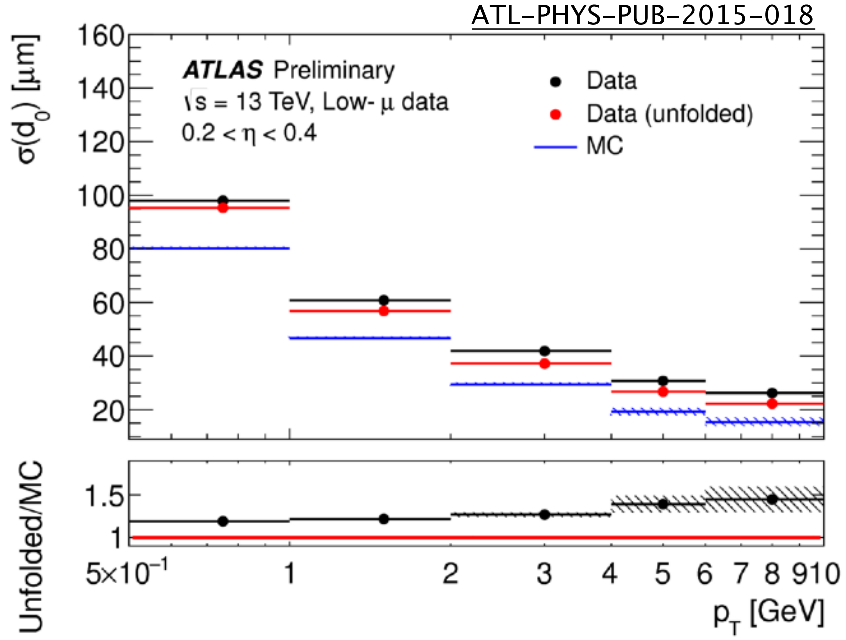
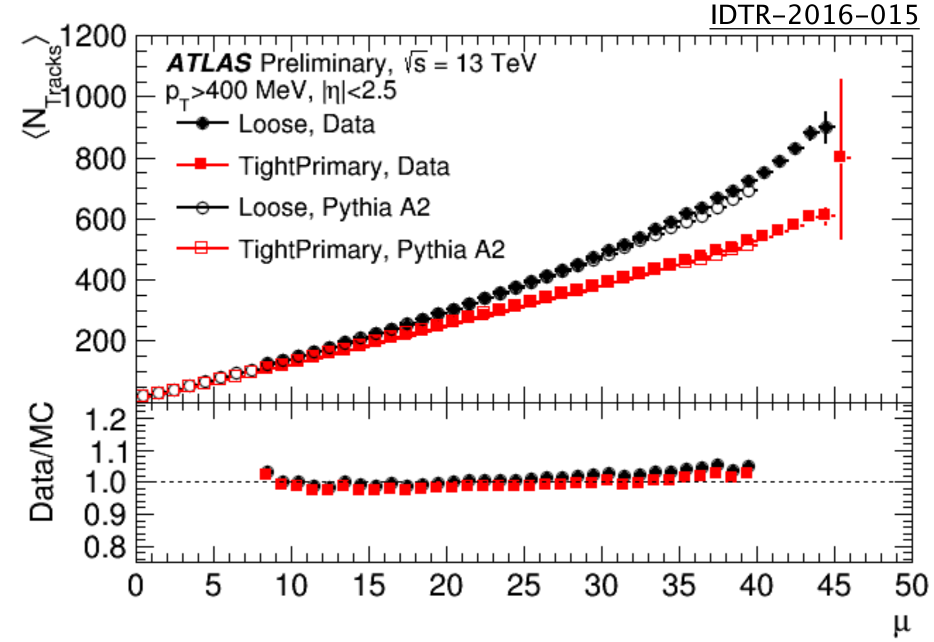


Fake rate vs. μ

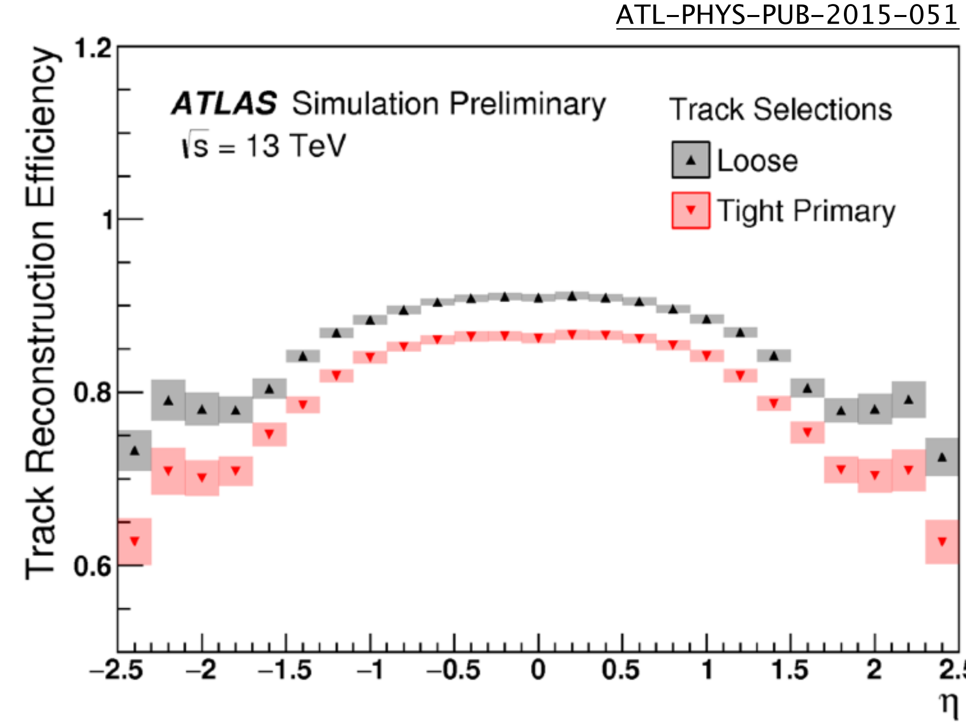
IDTR-2016-015



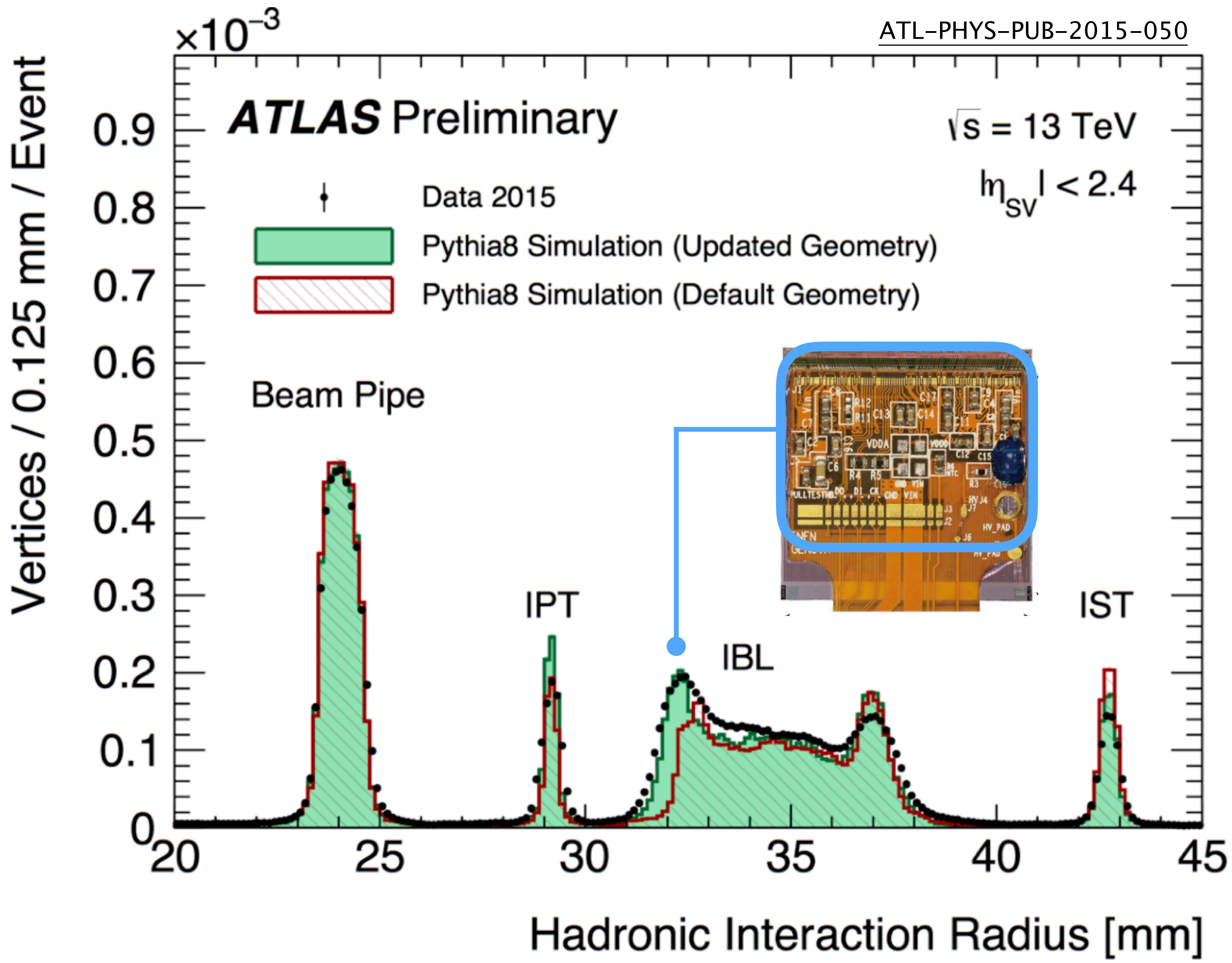
- ~40% improvement in d_0 resolution compared to Run 1 thanks to IBL.
- d_0 resolution vs p_T: difference between data and MC reflecting the material description.
  - Smearing MC brings better agreement.
- Fake track rate increases with pile-up.
- Material uncertainty is dominating tracking efficiency uncertainty.

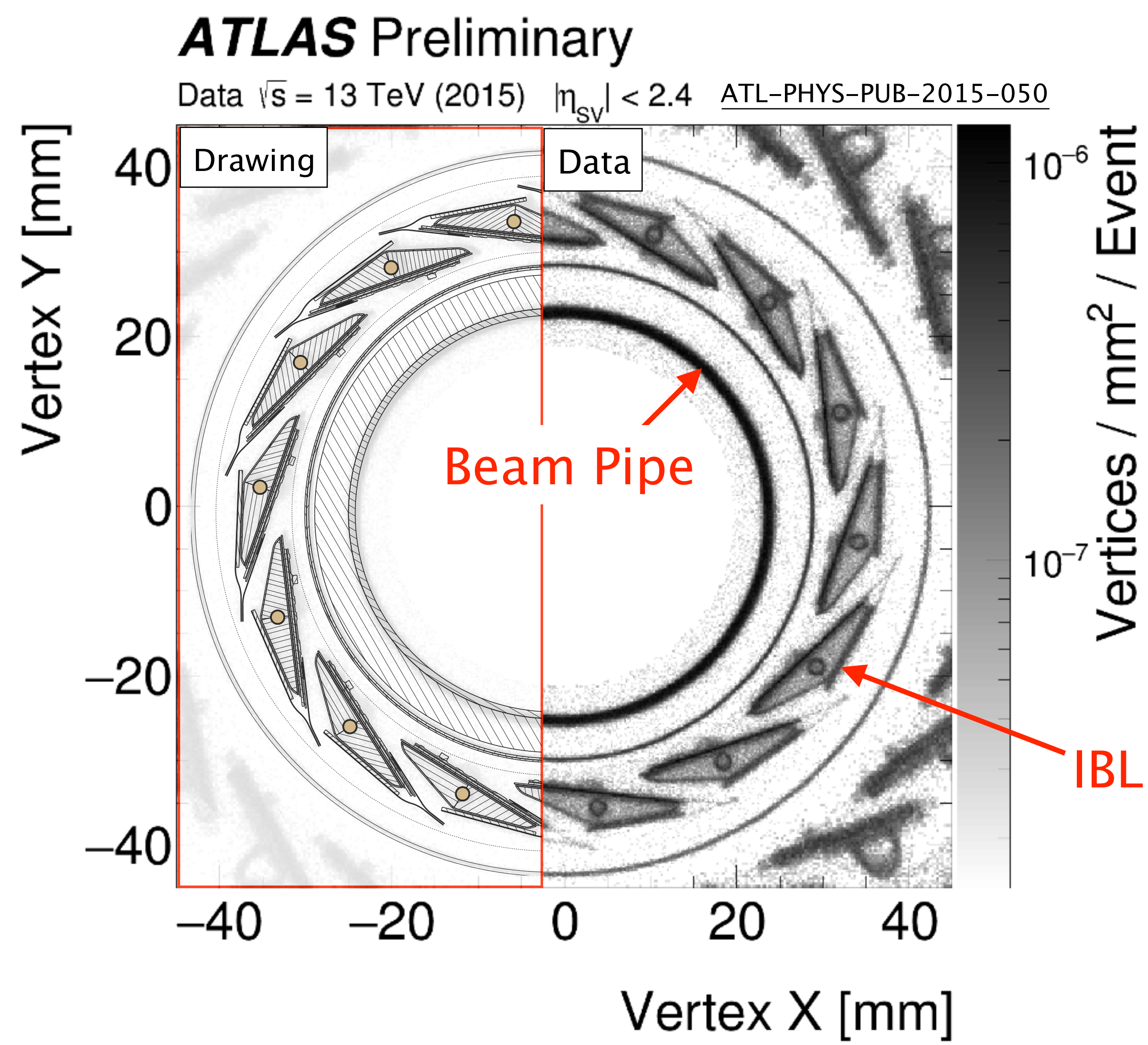
MinBias reco-eff. vs. η

ATL-PHYS-PUB-2015-051

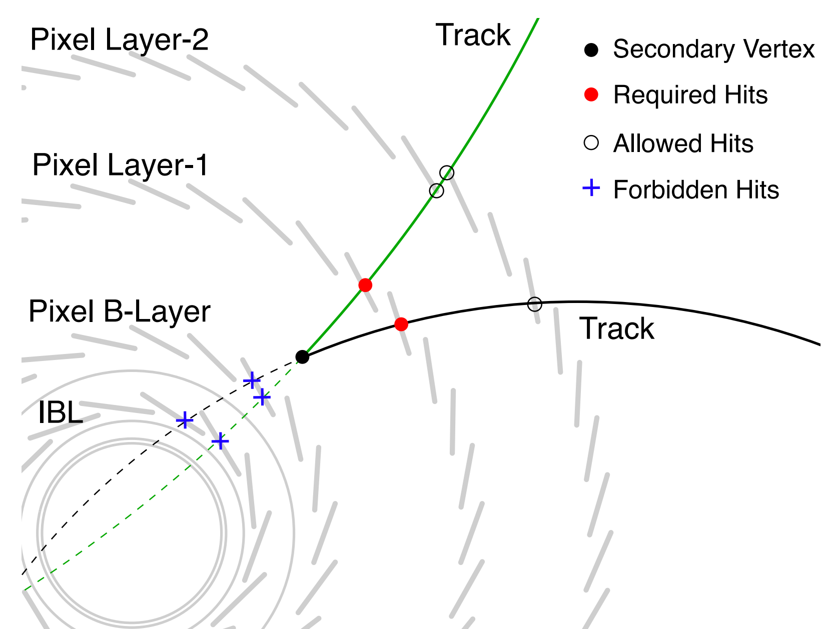


Material and Geometry Validation

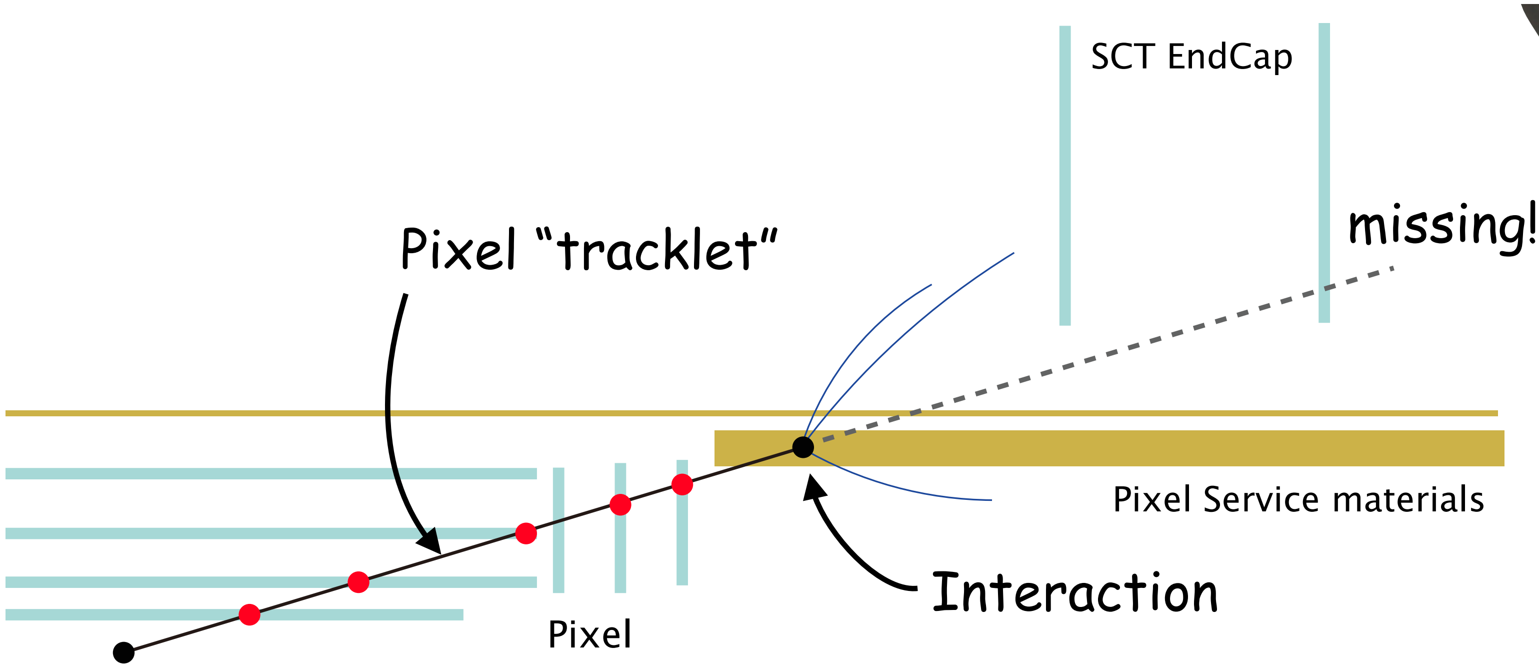


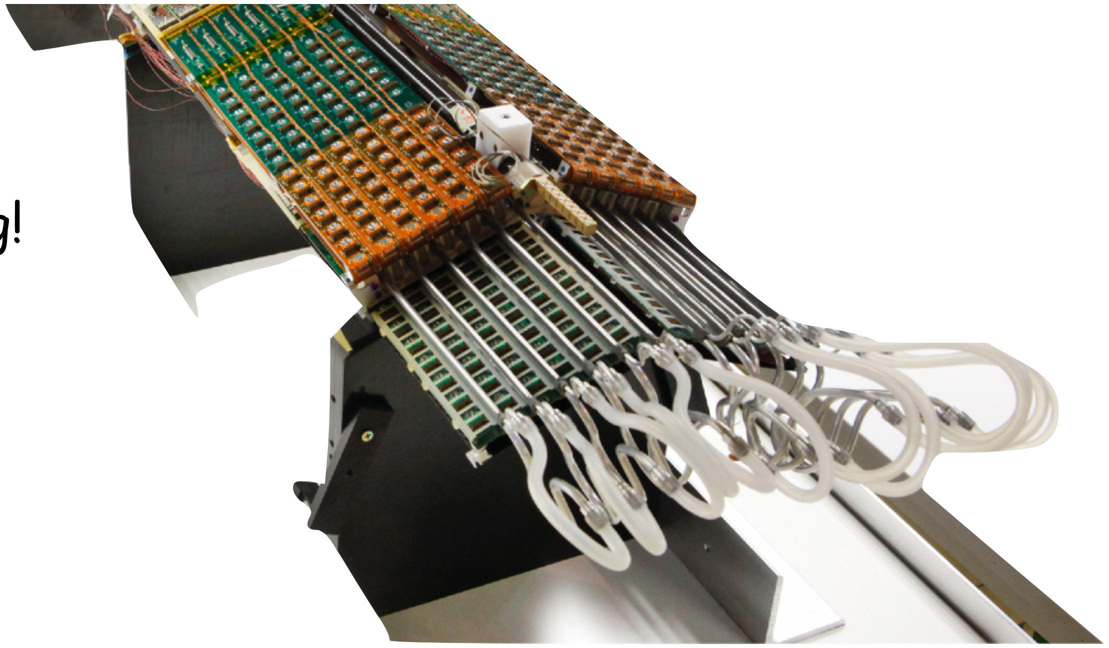


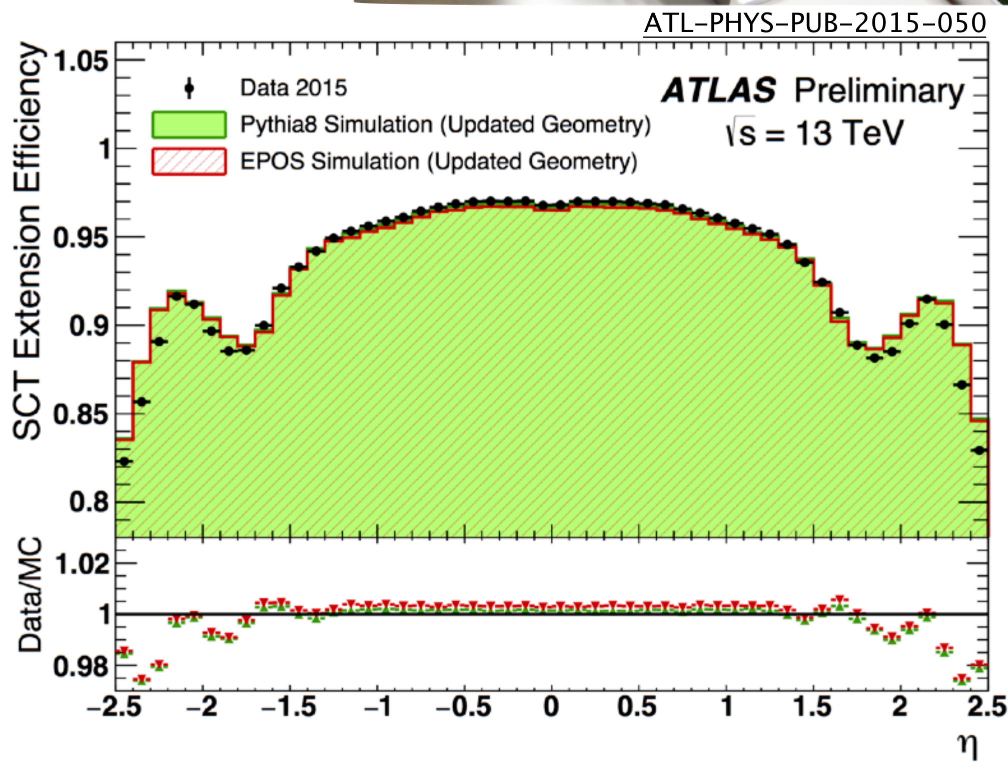
- "Radiographic diagnosis" based on the reconstruction of displaced vertices from hadronic interactions and photon conversions.
  - Even missing surface-mount capacitors on the IBL front-end chips are identified!
  - The new beam pipe: known to ~1% precision (i.e. up to 1 sheet of Kapton tape). The "standard candle" of the entire Inner Detector (Run 1: ~3%).
- The updated MC geometry will be used for analyses based on the full Run 2 dataset.



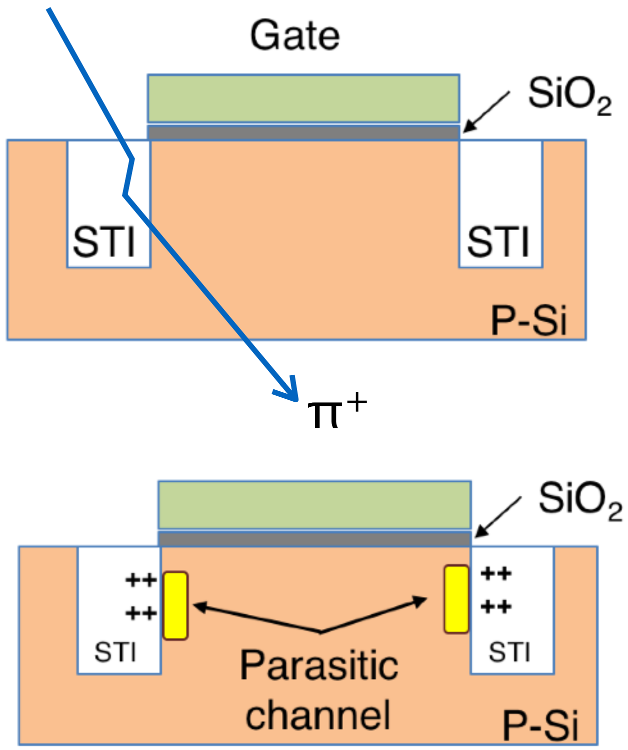
Forward service materials studies

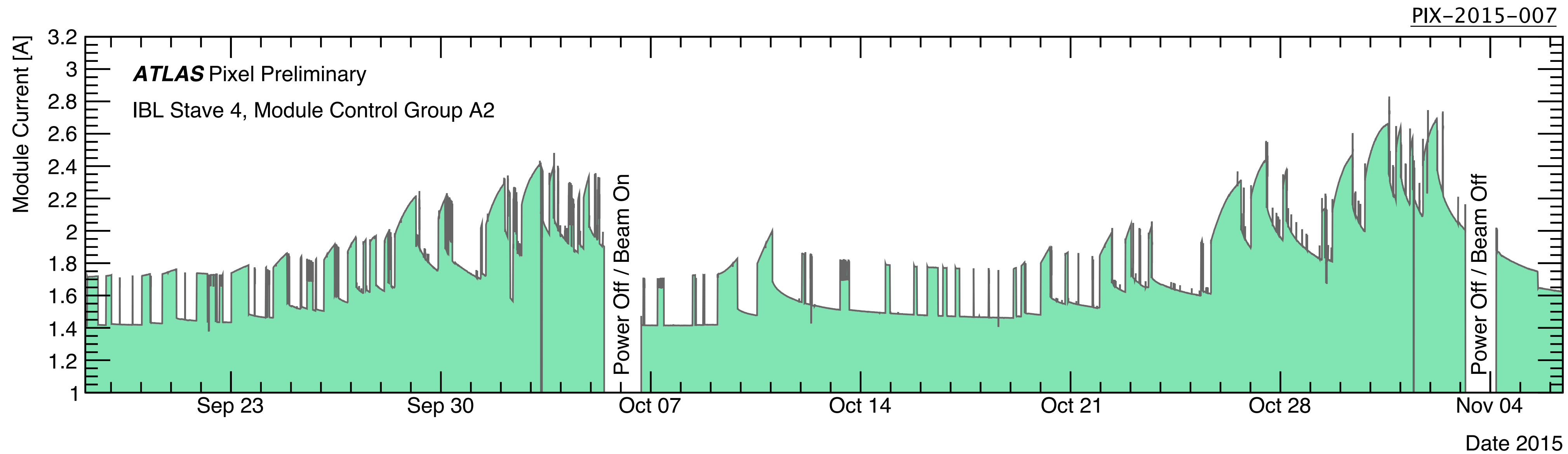


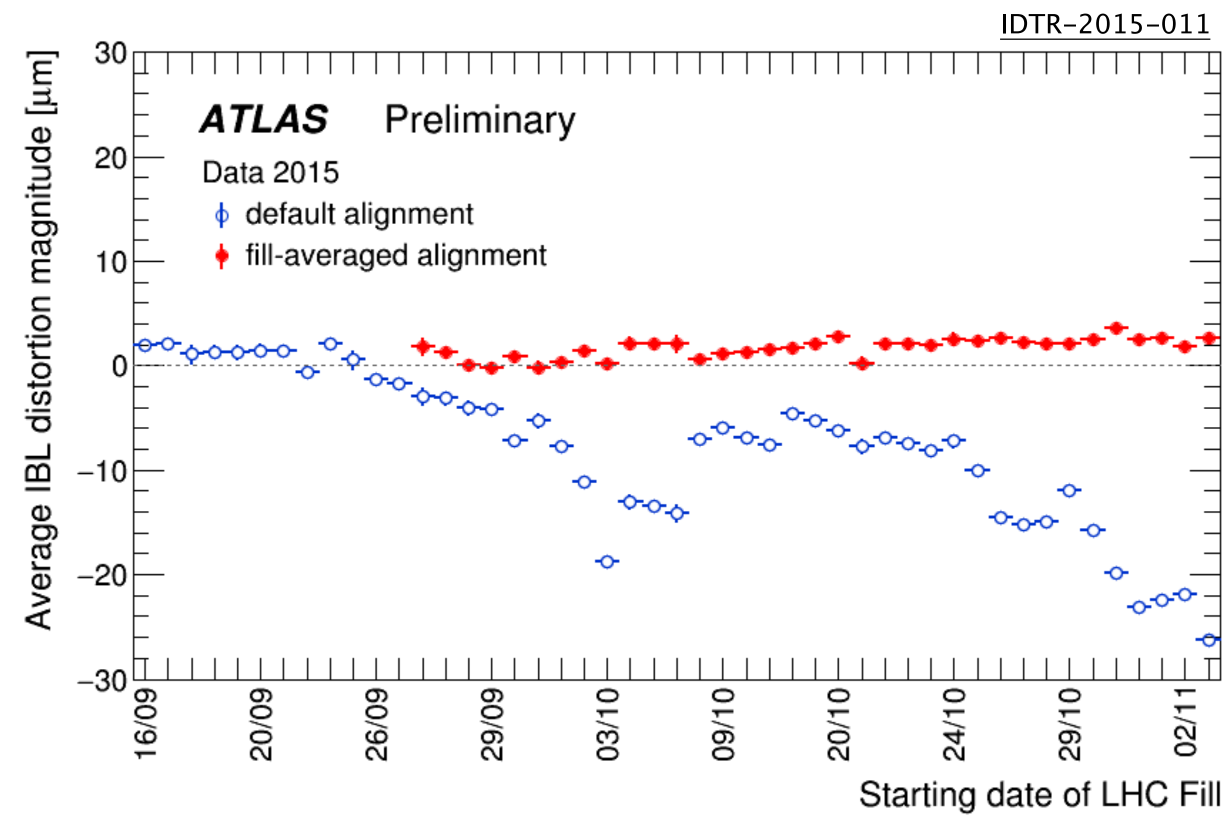




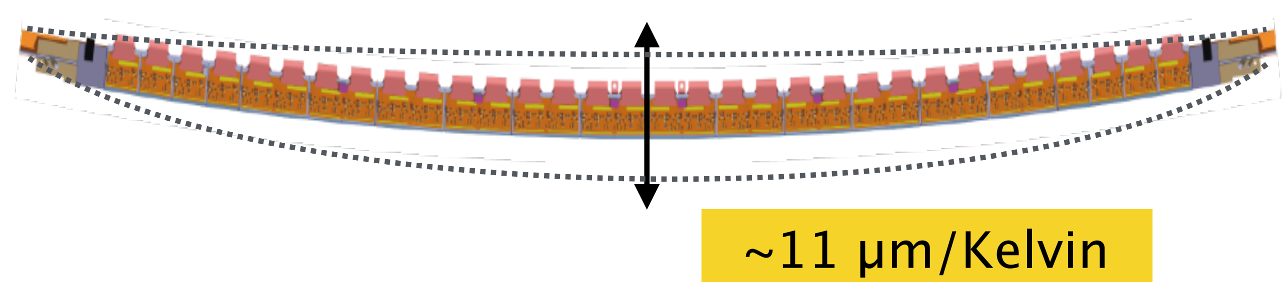
- Check "extensibility" of pixel "tracklets" to outer layers.
- Efficiency can be interpreted in terms of the amount of material between Pixel and SCT.
- Decays in-flight (e.g. strange baryons like Σ^+ or Ξ^-) can be a background source.
- Some discrepancy is observed in the forward region indicating the presense of missing material in the pixel services.
- IBL forward cable materials at $|\eta| > 3$ have a non-negligible impact on the performance of the forward calorimetrs, very tricky to simulate but we are trying!





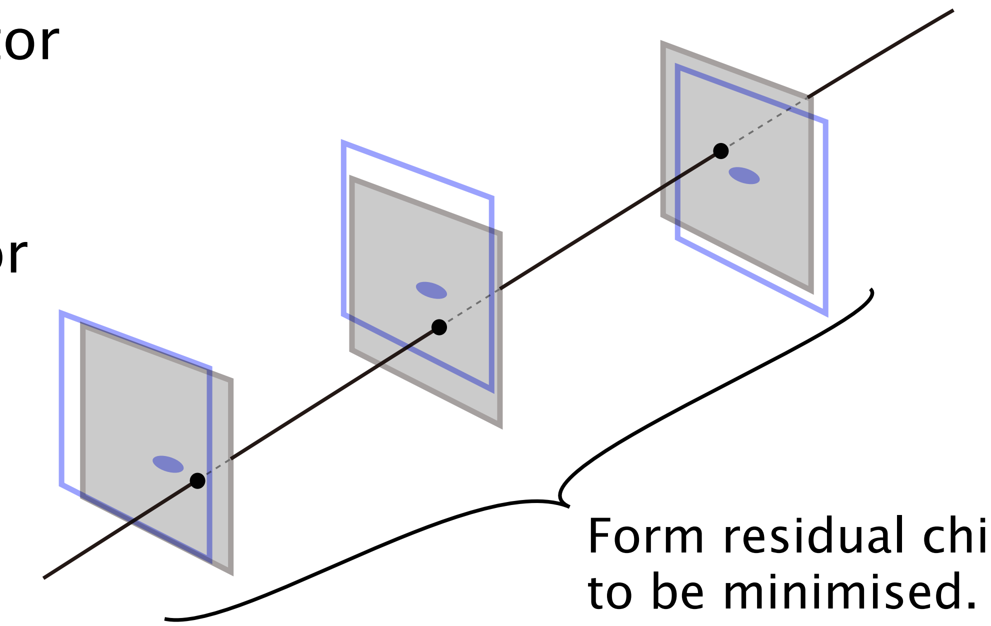


- Accumulation of ionising dose opened the leakage channels in the transistors of the IBL front-end electrocnics. Making the IBL power consumption unstable.
- Thermal expansion mismatch inside the IBL stave is sensitive to the front-end power consumption change (=local temp. change).
- Consequently, causing rapid change of IBL stave's bowing distortion.



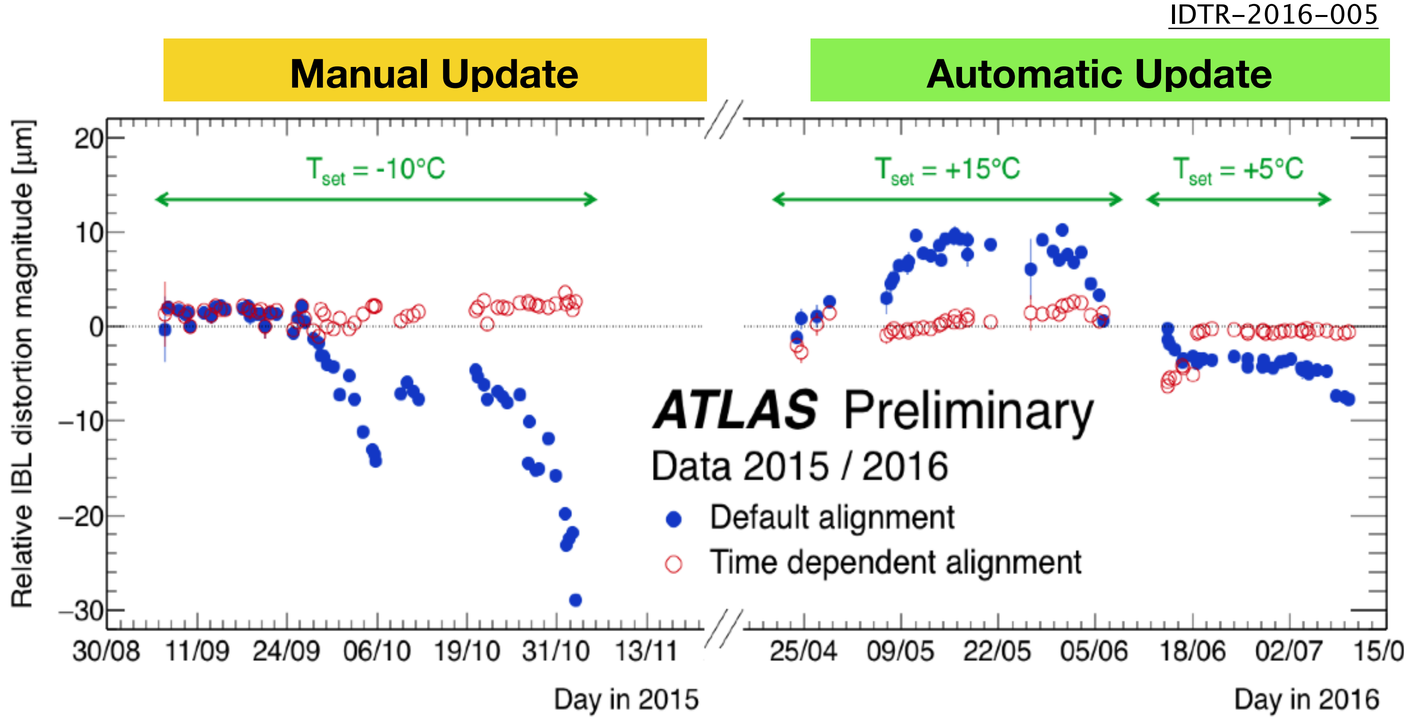
Adaptation - dynamic alignment

- Track-based alignment: in-situ determination of detector element positions by minimising the residusl chi2.
- Strategy in 2016: calculate 'perturbation' of the detector package movement from the precisely-determined alignment (baseline) every 100 min.
  - Including the IBL distortion and Pixel vertical movement.
- Running inside the prompt calibration process.
  - Updated within 24h after run finished.
- Generally successful automated operation in 2016.

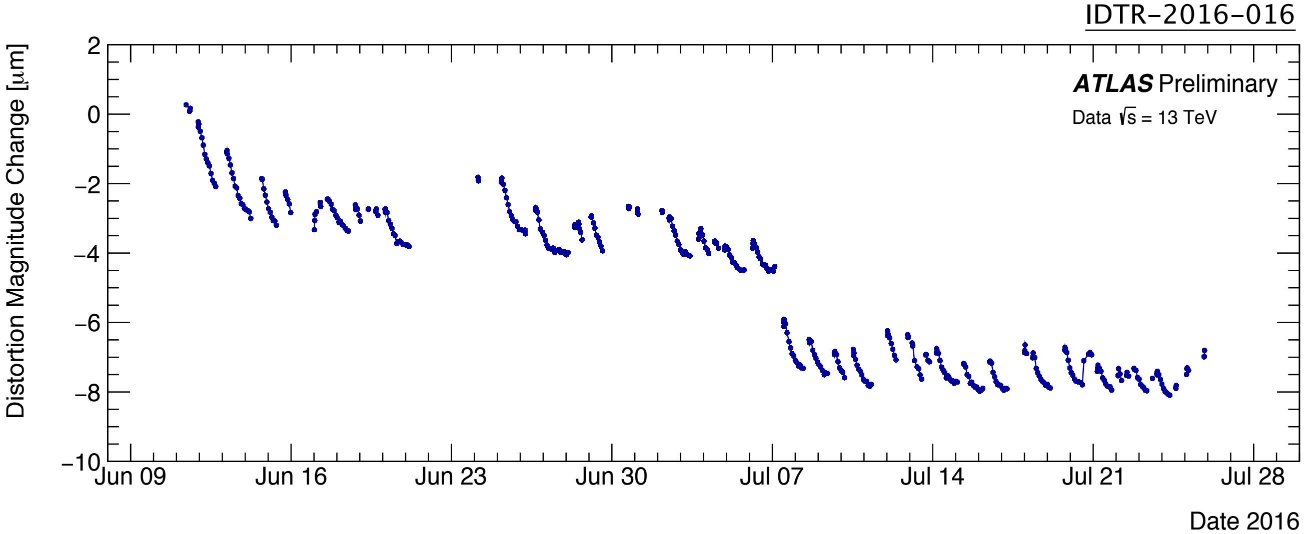


Dedicated talk by Salvador Marti i Garcia

IDTR-2016-005

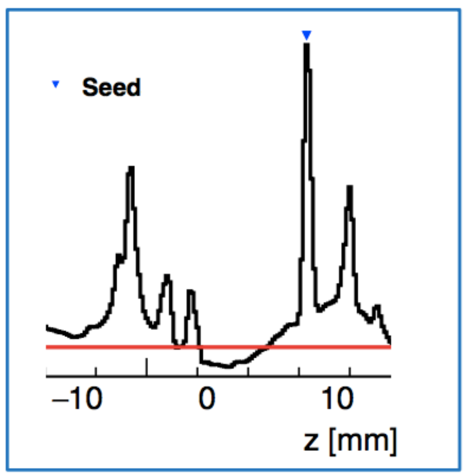


IDTR-2016-016

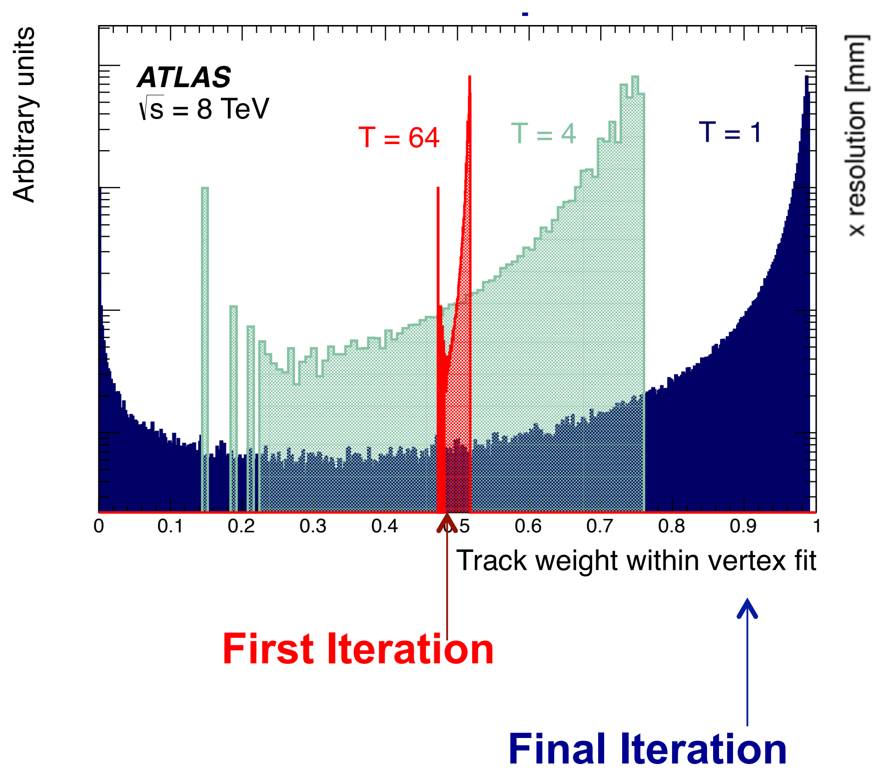


Vertex Reconstruction

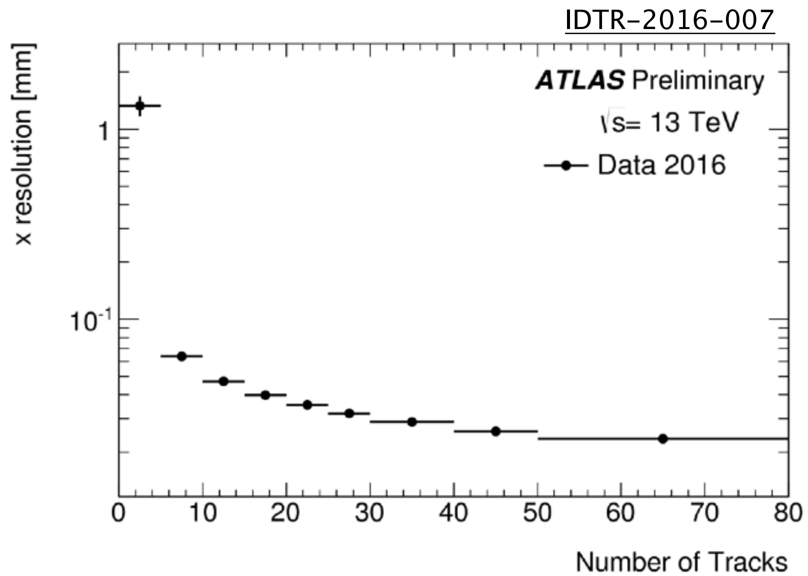
Seeds



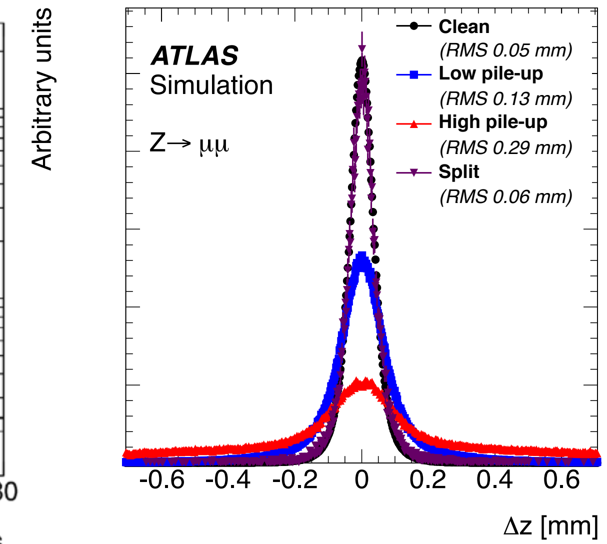
Iteration illustration



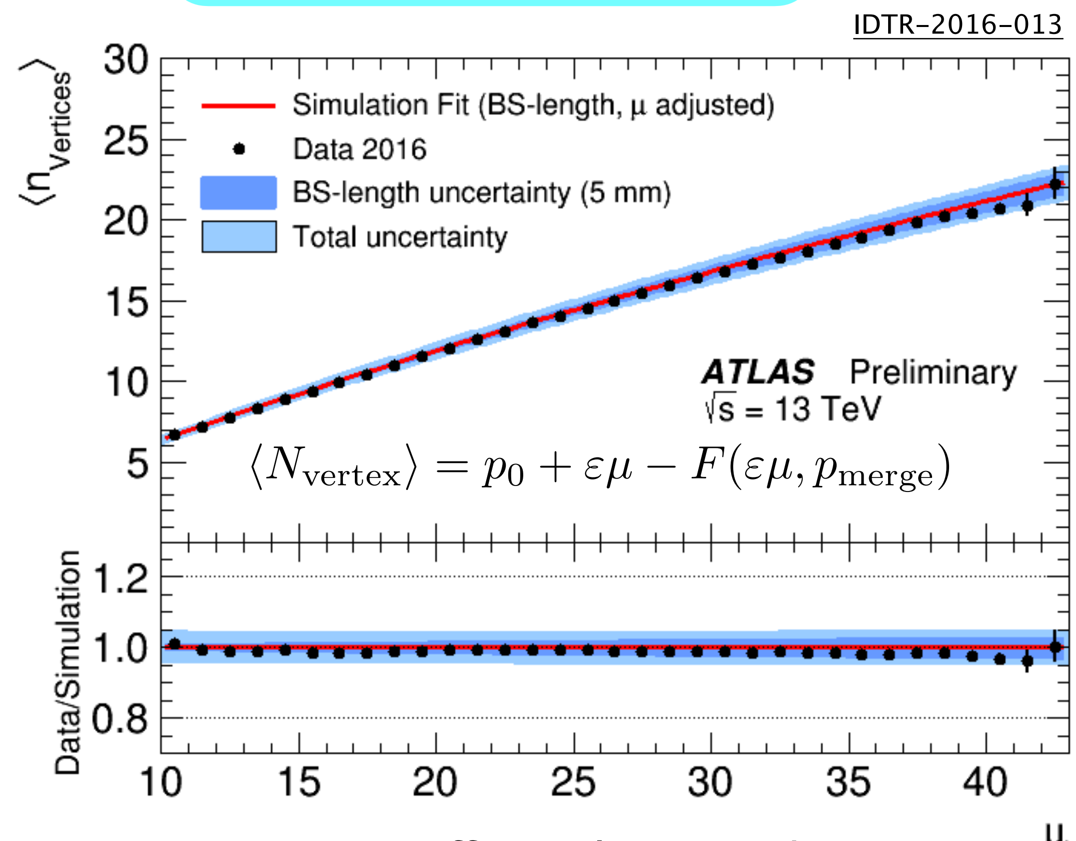
Hor. vertex resolution



z resolution vs. μ



Reconstruction eff. vs μ

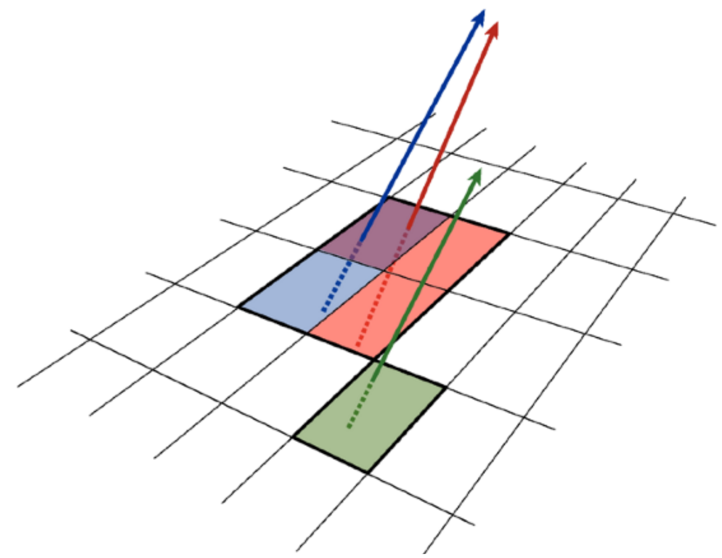


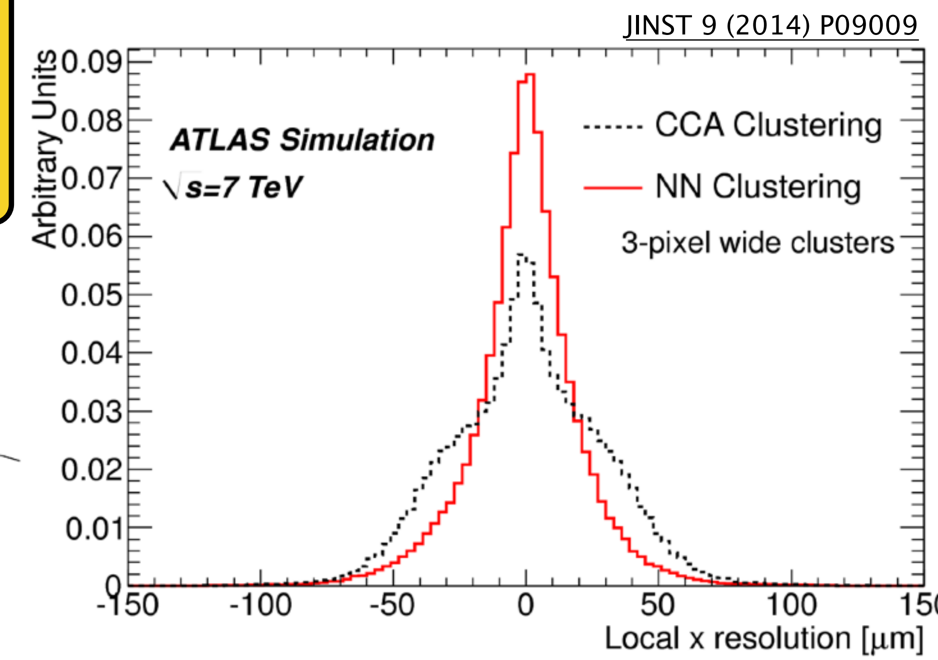
Vertex reco. eff non-linearity due to merging is largely dependent on the beam spot shape.

- Iterative vertex reconstruction algorithm.
  - In each iteration, less compatible tracks are down-weighted and the vertex position is recomputed.
- Vertex resolution is…
  - Dependent on n_{tracks} (statistically)
  - Degrades with contamination of pile-up tracks: dependent on μ.
- Vertices may merge when they are closer than the resolution: reconstruction efficiency loss dependent on μ.
- Hard-scatter vertices defined as the one w/ largest $\sum_{\text{trk}} p_{\mathrm{T}}^2$

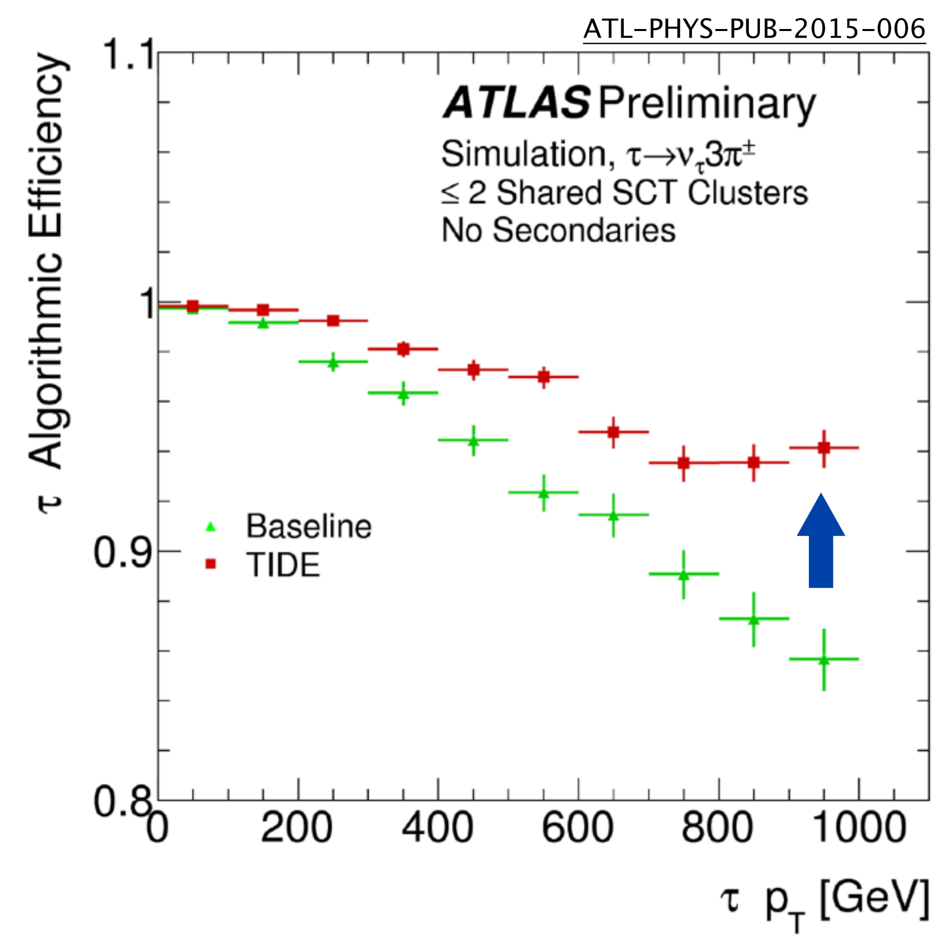
Tracking in Dense Environment (TIDE)

Identify merged pixel clusters by pattern recognition (neutral network) to recover tracking efficiency.

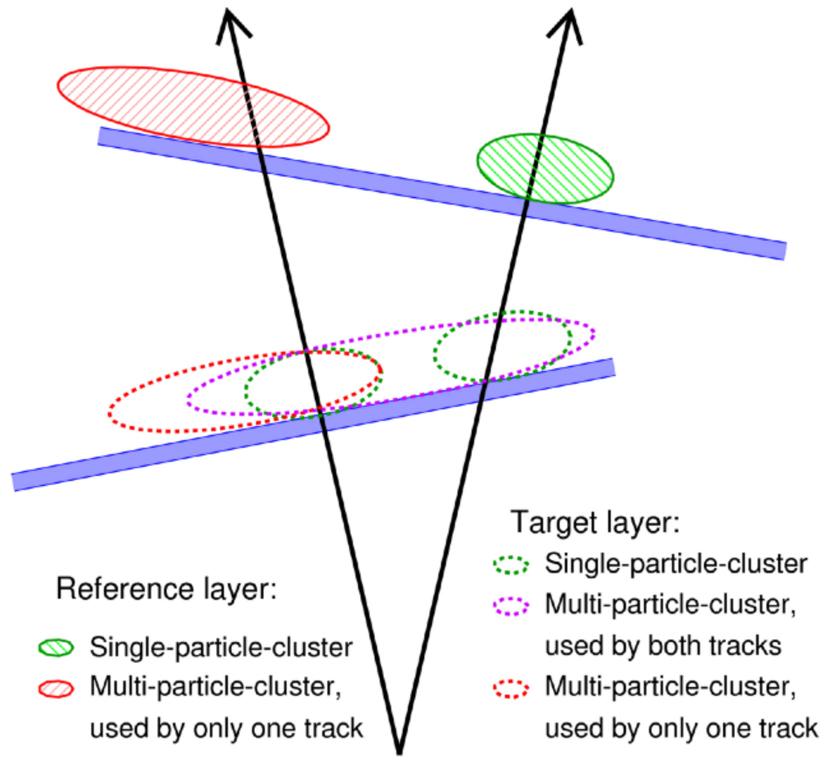




- Loss of tracking efficiency inside the jet core ("dense environment") due to cluster merging.
- Run 2: novel algorithmic optimisation of the usage of the information of the neural network clustering during reconstruction.
  - Input: hit pattern (7×7 pixels) and charge deposit.
  - Output: #tracks, positions, errors (3 steps).
  - Greedy optimisation at the stage of ambiguity solving.



Tracking in Dense Environment: Performance



Method 1

Control sample tracks selected from the overlap phi region of the detector.

Showing the 'turn-on' curve of cluster merging as a function of 2-track distance on the layer.

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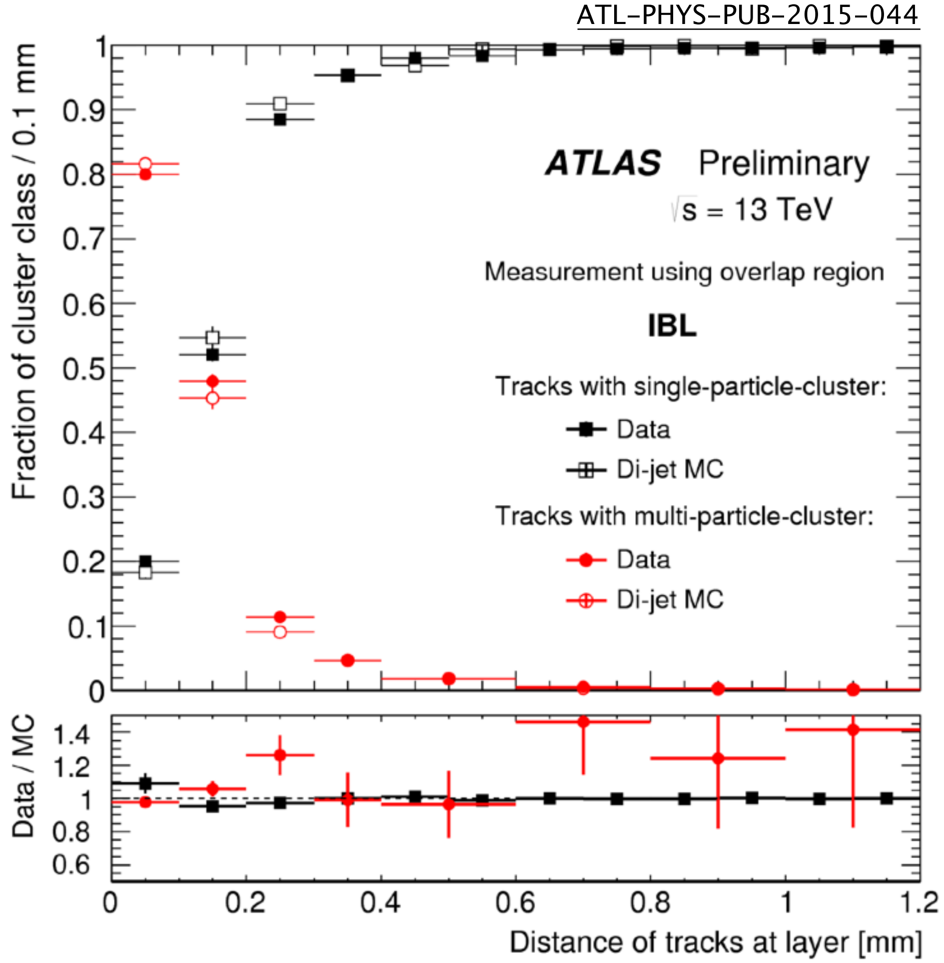
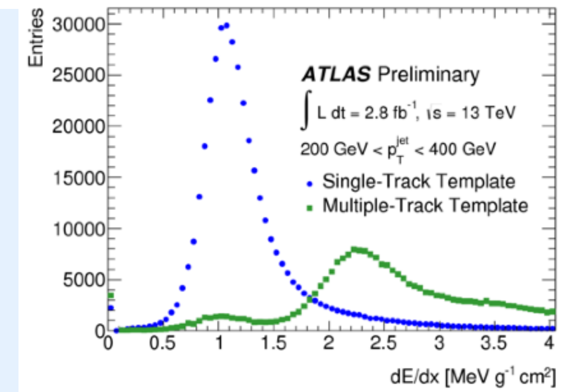


Method 2

Measurement of the fraction of tracks of double dE/dx clusters inside the jet core.

Template fitting for data and MC individually.

Good agreement between data and MC within generator dependence.



dE/dx Template

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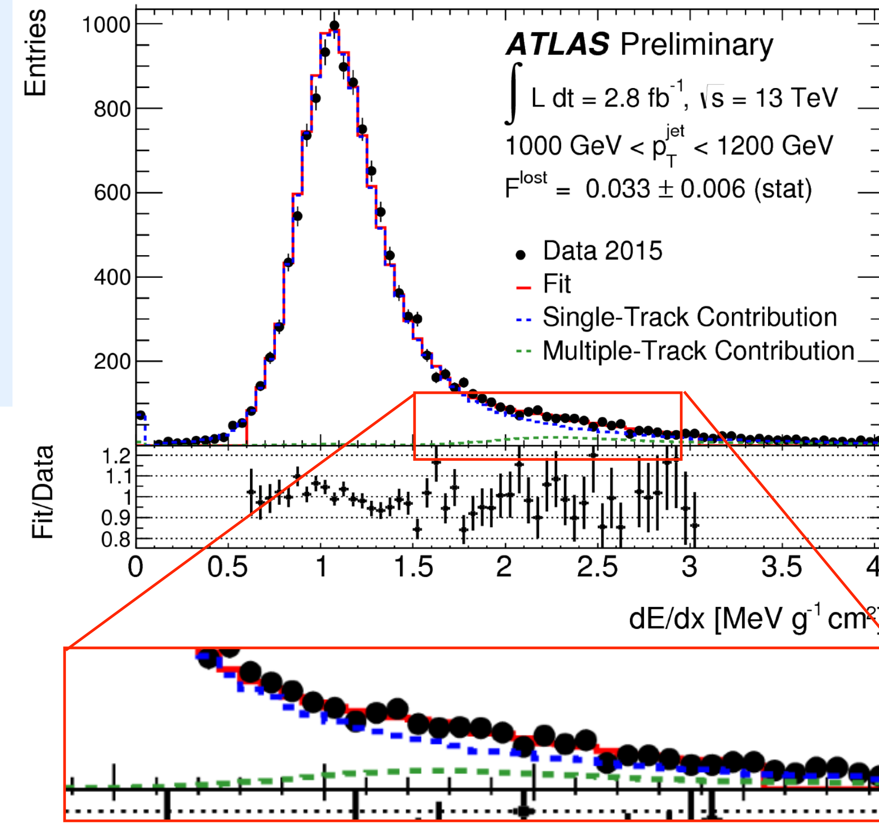

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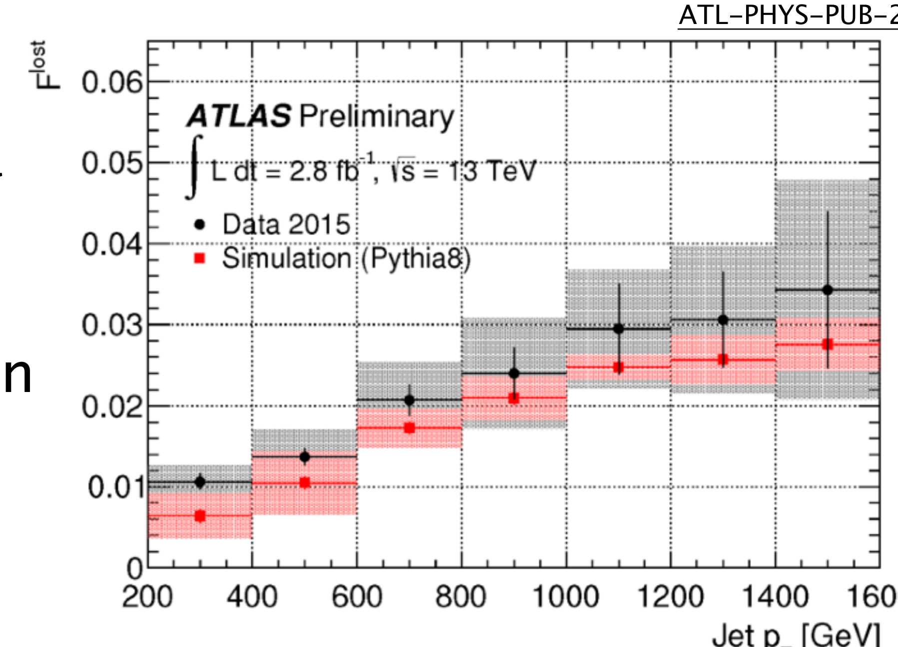
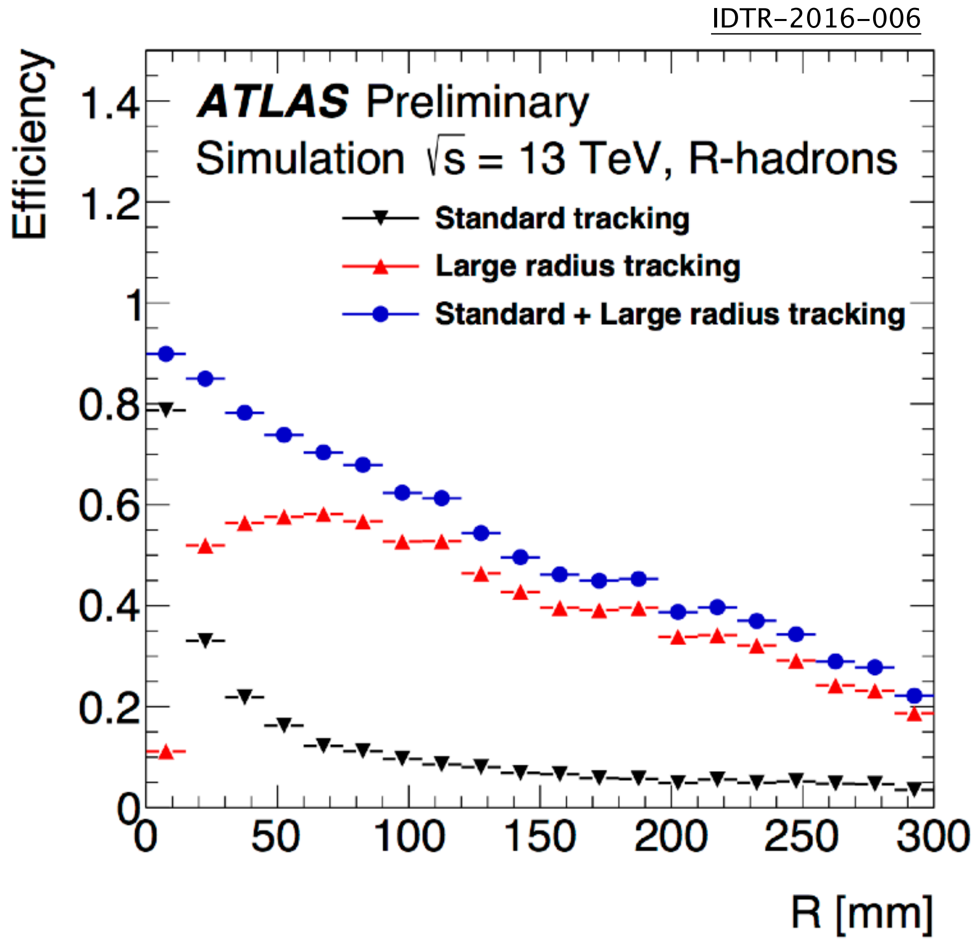
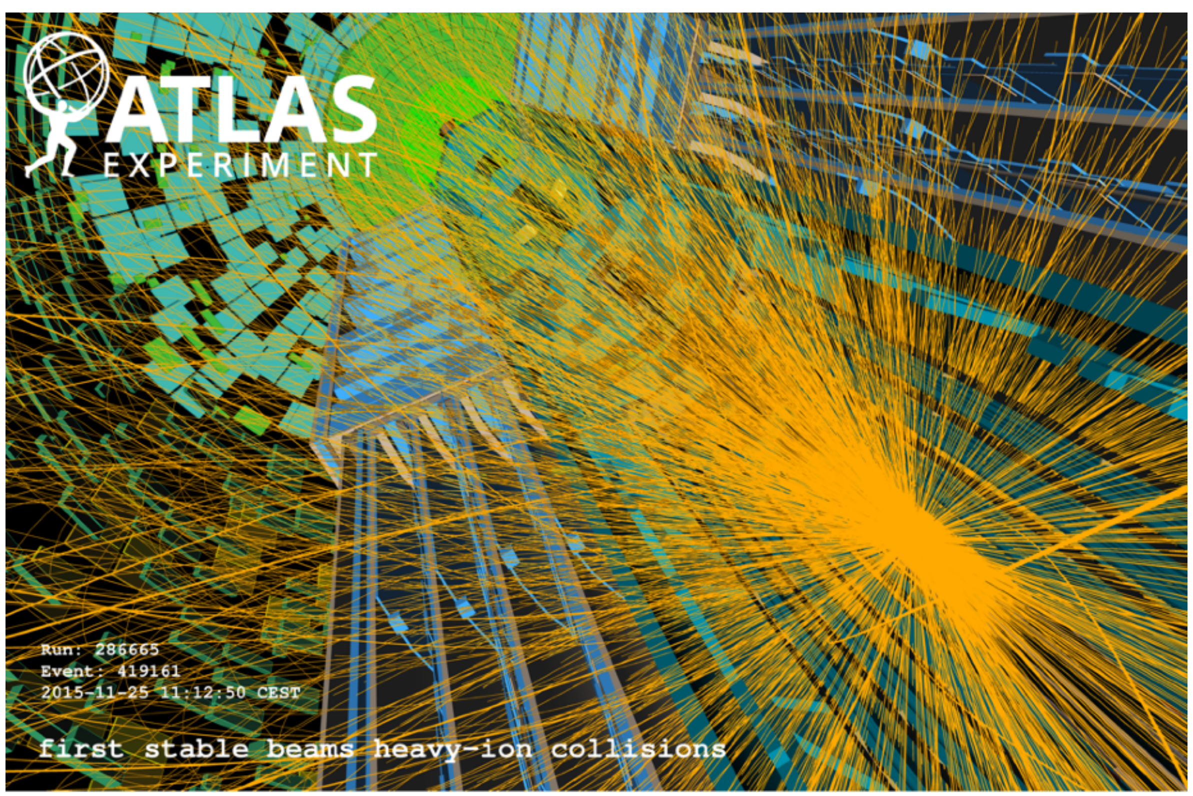
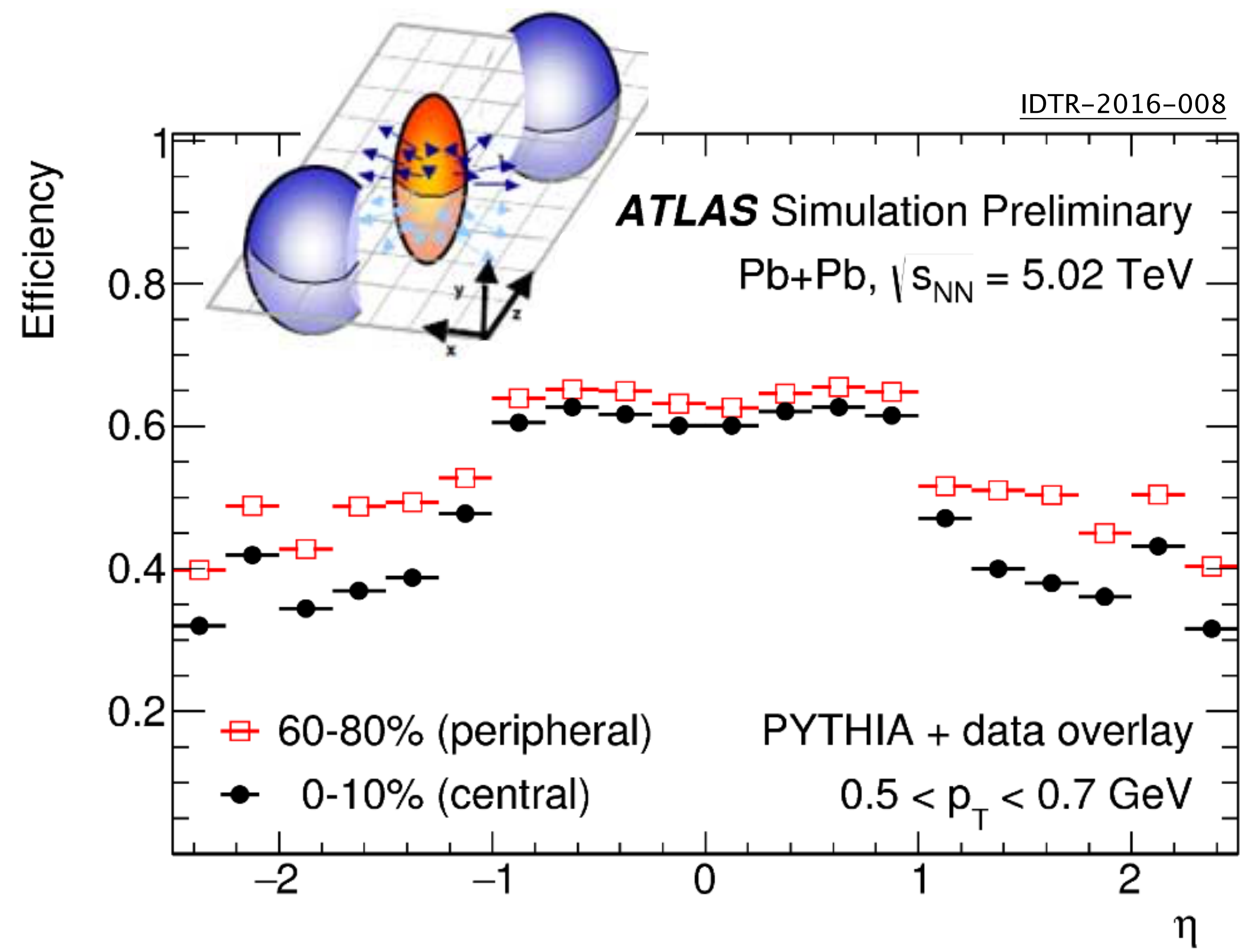


Tracking performance in special conditions



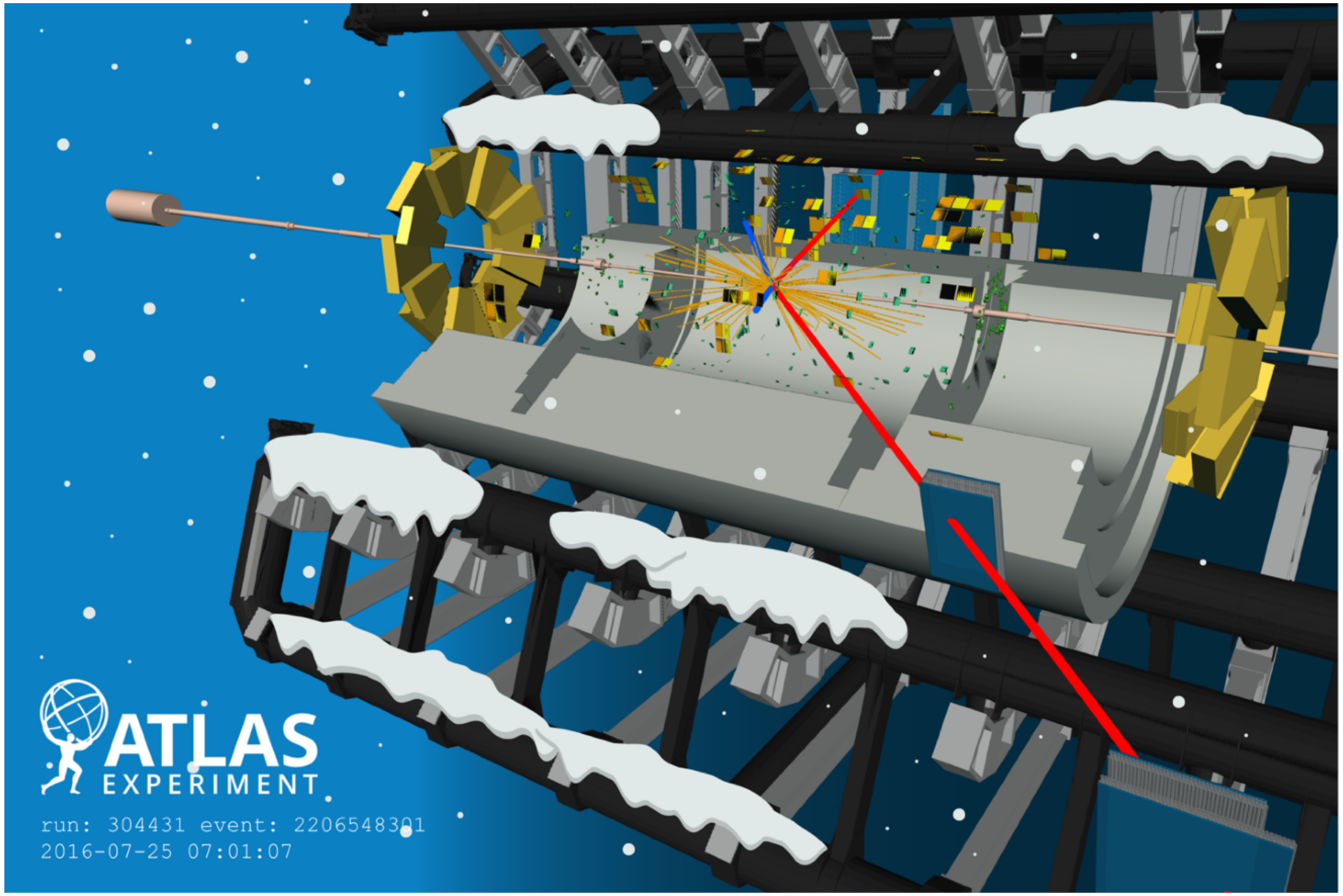
- Tracking for $|d_0|>5$ mm tracks is "standardised" in special trigger streams for displaced vertex signature new physics searches (e.g. R-hadrons).
- Track reconstruction for heavy ion collisions is challenging. Evaluation of track reconstruction efficiency using a data-overlay method (depending on eccentricity of HI collisions) .





Summary

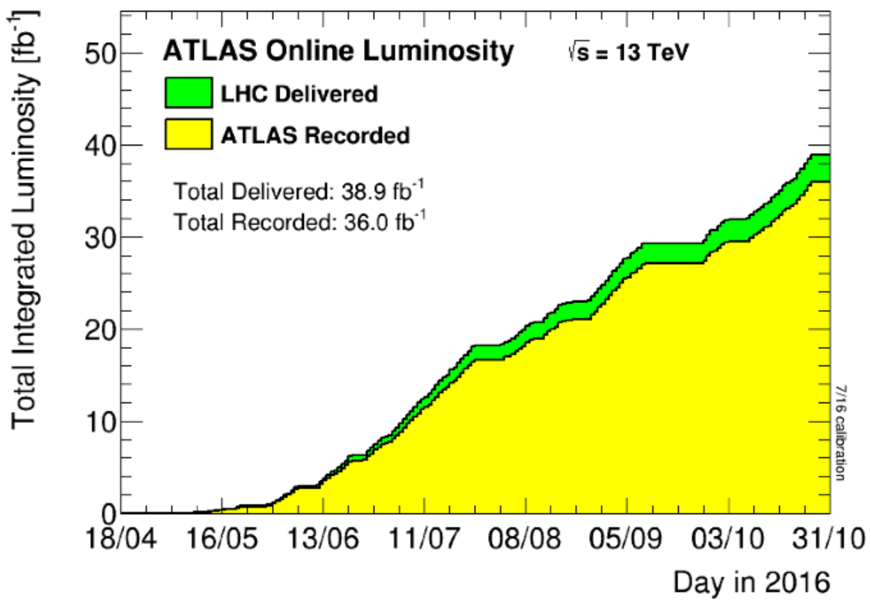
- Run 2 tracking: an exciting period with the upgraded detector and challenging situations of the detector condition changes together with fast luminosity ramp-up.
- Performance of key features of the tracking have been evaluated.
- Upcoming years: software and conditions are being optimised for the final Run 2 environment, and further improving robustness to cope with even higher luminosity.

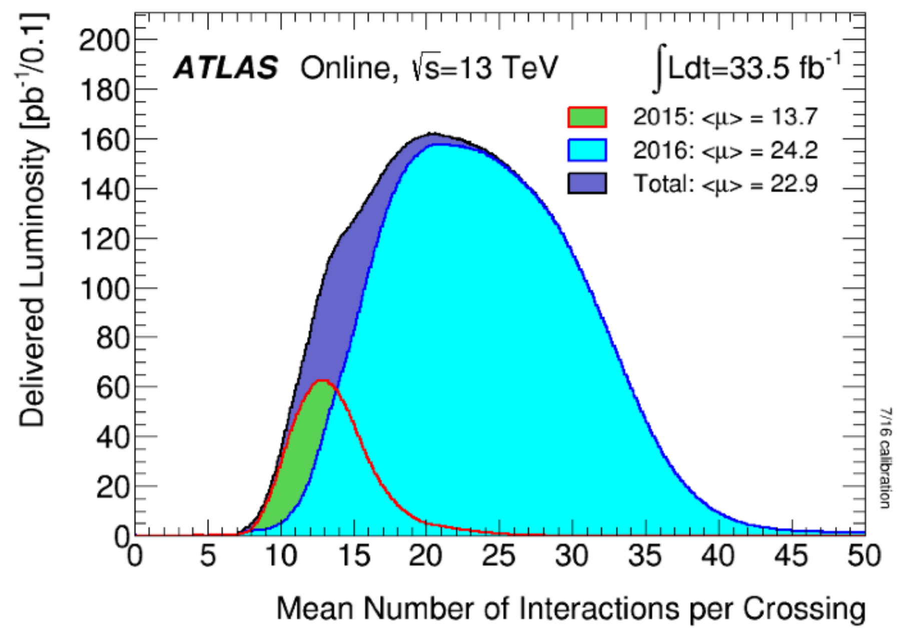


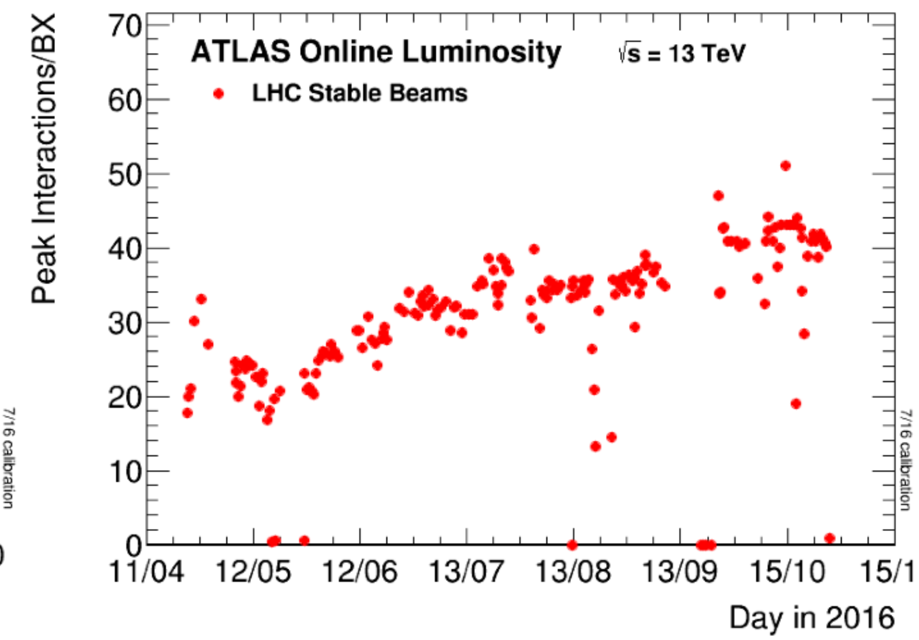
A happy snow day!

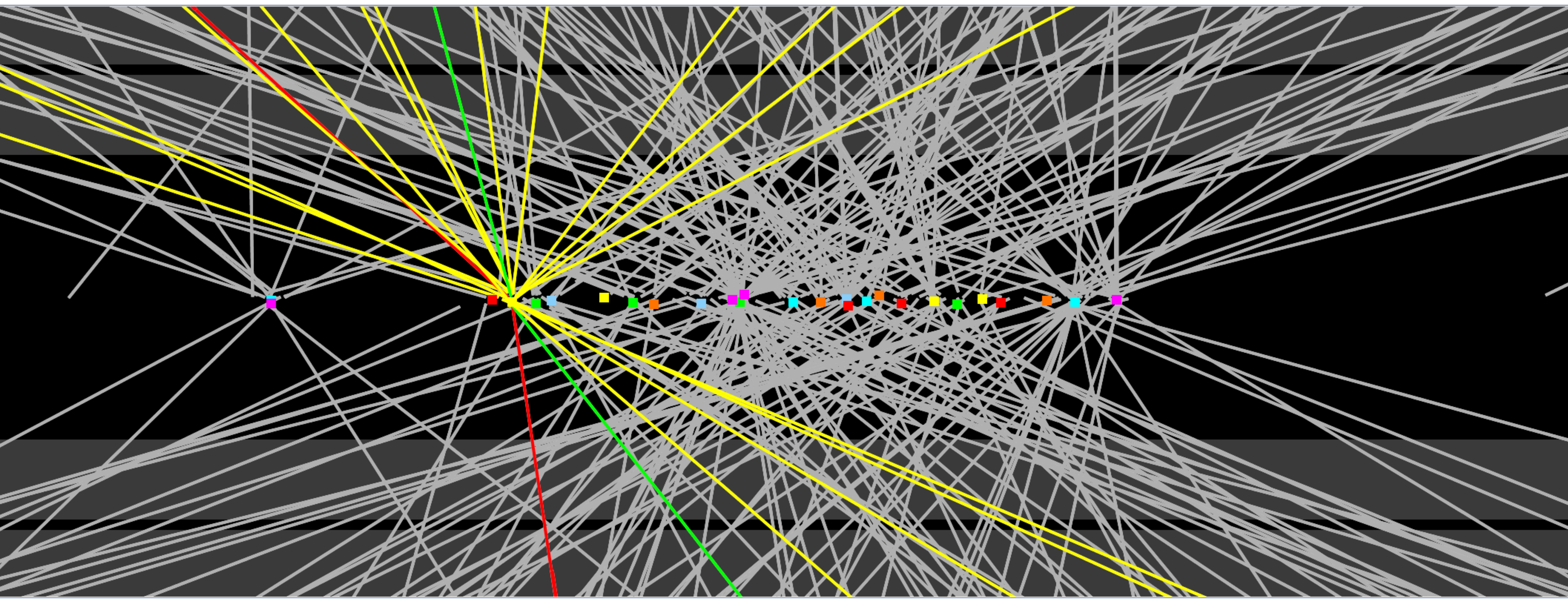
Backup

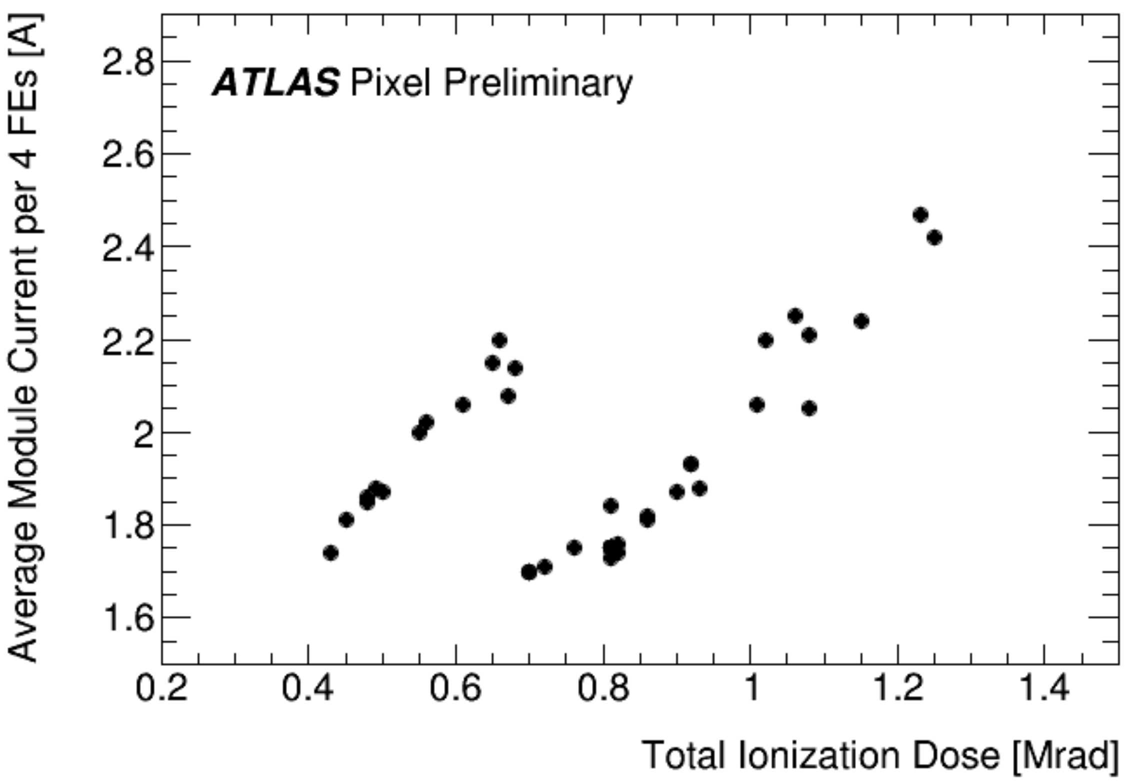
Run 2: LHC Operation

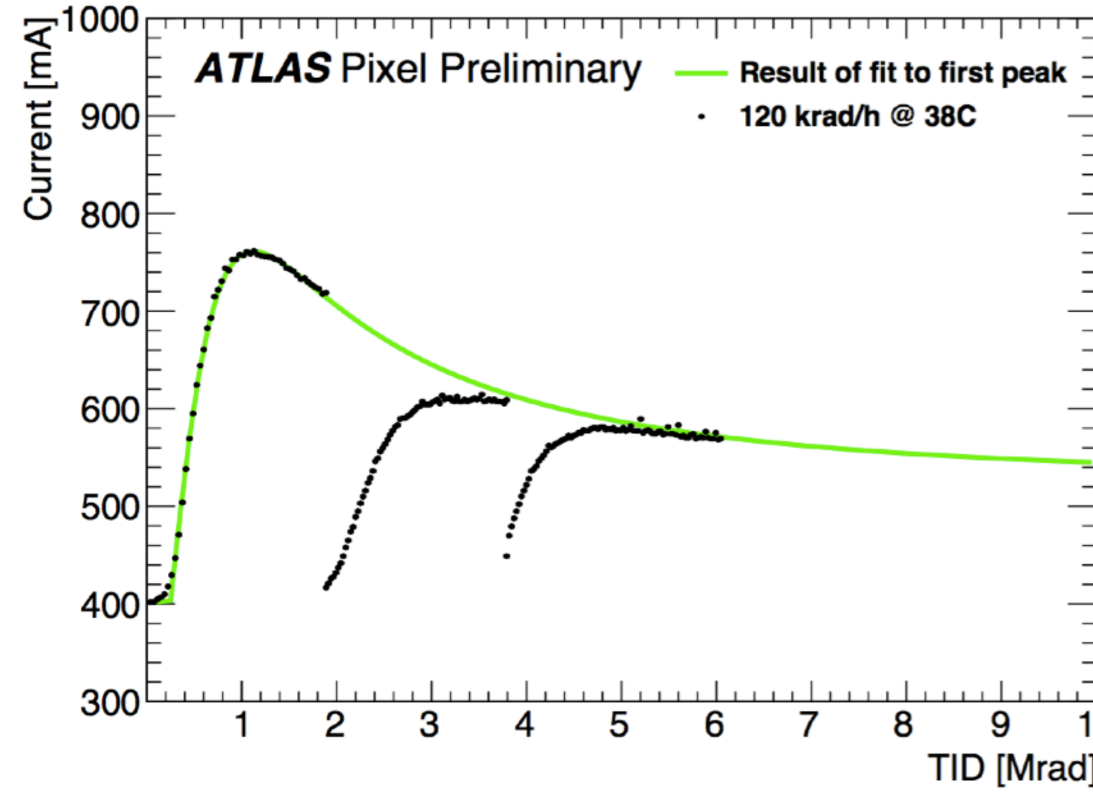


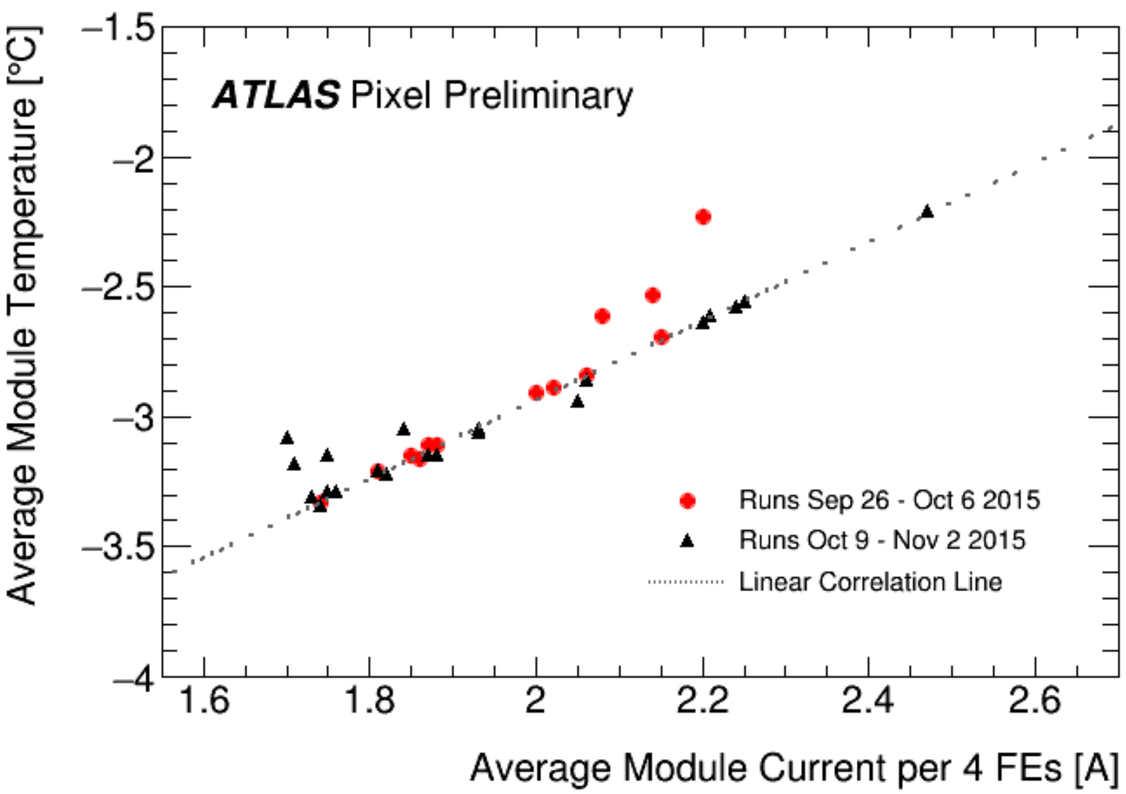


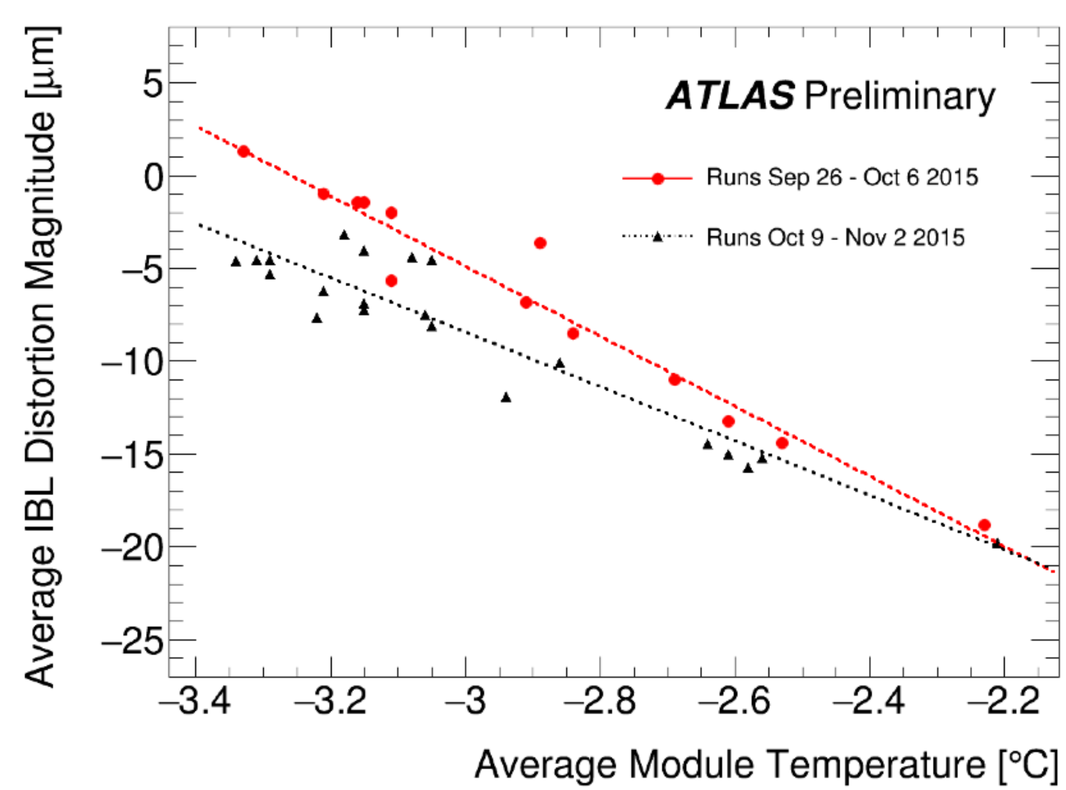




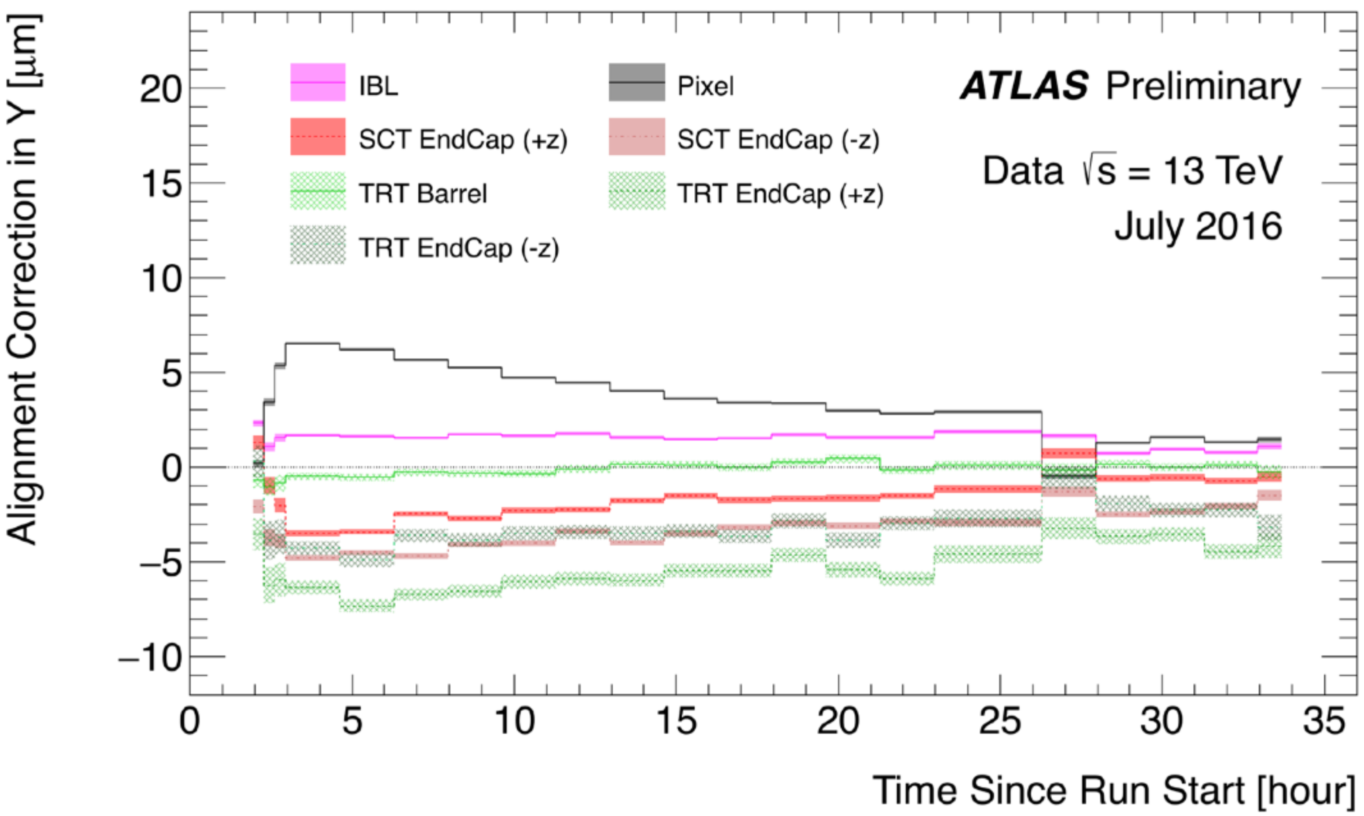

ATLAS Pixel Preliminary
Average Module Current per 4 FEs [A]
Total Ionization Dose [Mrad]

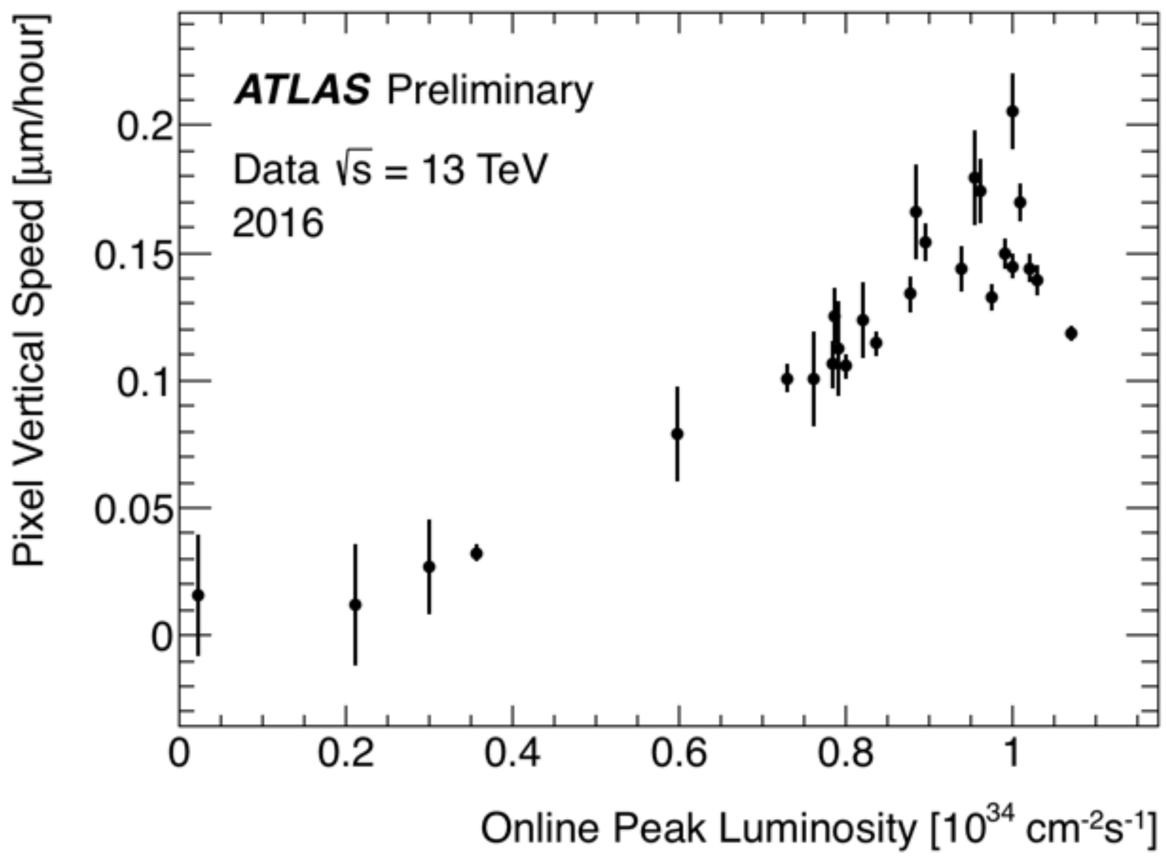

ATLAS Pixel Preliminary
Result of fit to first peak
120 krad/h @ 38C
Current [mA]
TID [Mrad]


ATLAS Pixel Preliminary
Runs Sep 26 - Oct 6 2015
Runs Oct 9 - Nov 2 2015
Linear Correlation Line
Average Module Temperature [°C]
Average Module Current per 4 FEs [A]


ATLAS Preliminary
Runs Sep 26 - Oct 6 2015
Runs Oct 9 - Nov 2 2015
Average IBL Distortion Magnitude [µm]
Average Module Temperature [°C]

Pixel vertical movement





Dynamic alignment