Commissioning and Performance of the ATLAS Inner Detector with Proton Collisions at the LHC

* Sub-detector status and performance
* Latest Alignment Status
* Tracking performance

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The University of Melbourne, Australia

35th International Conference on High Energy Physics
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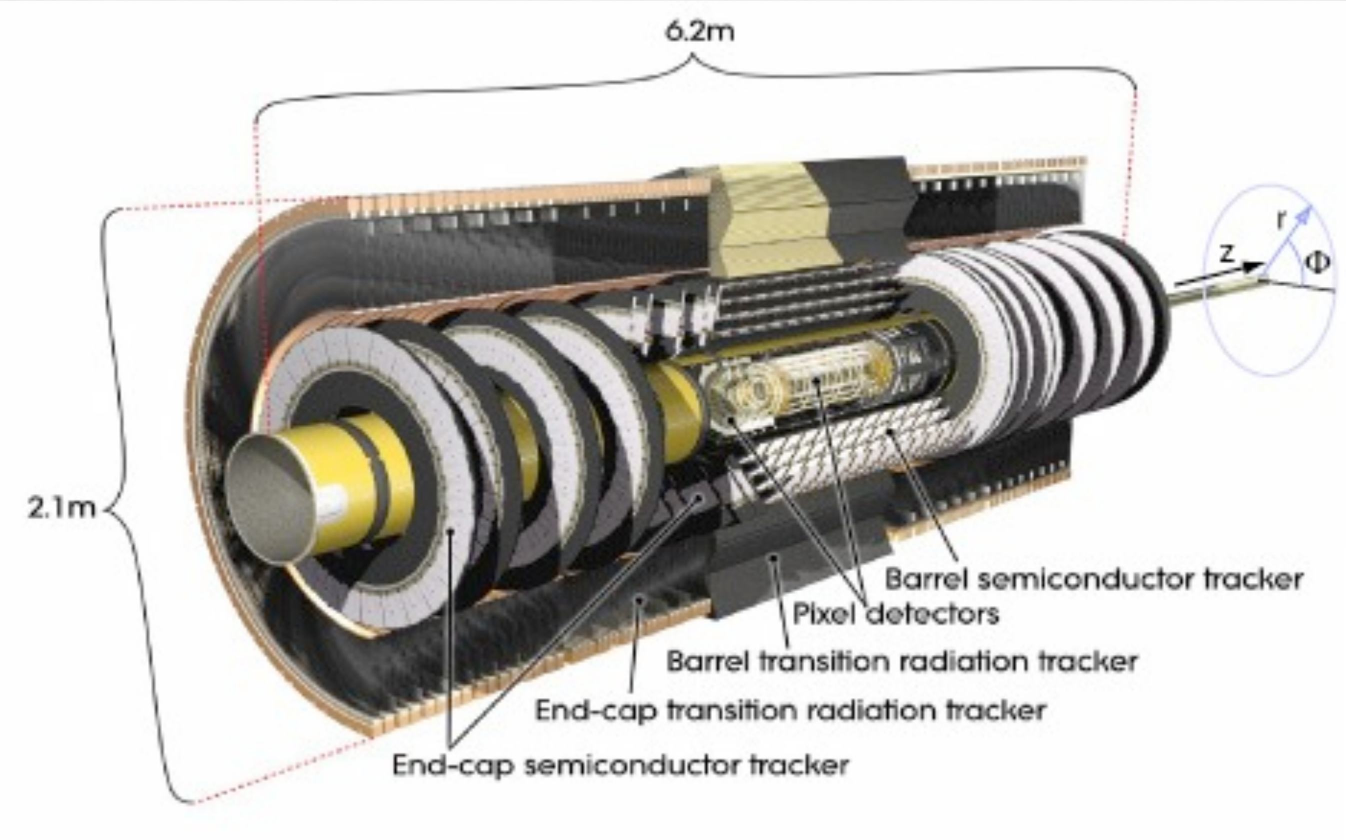
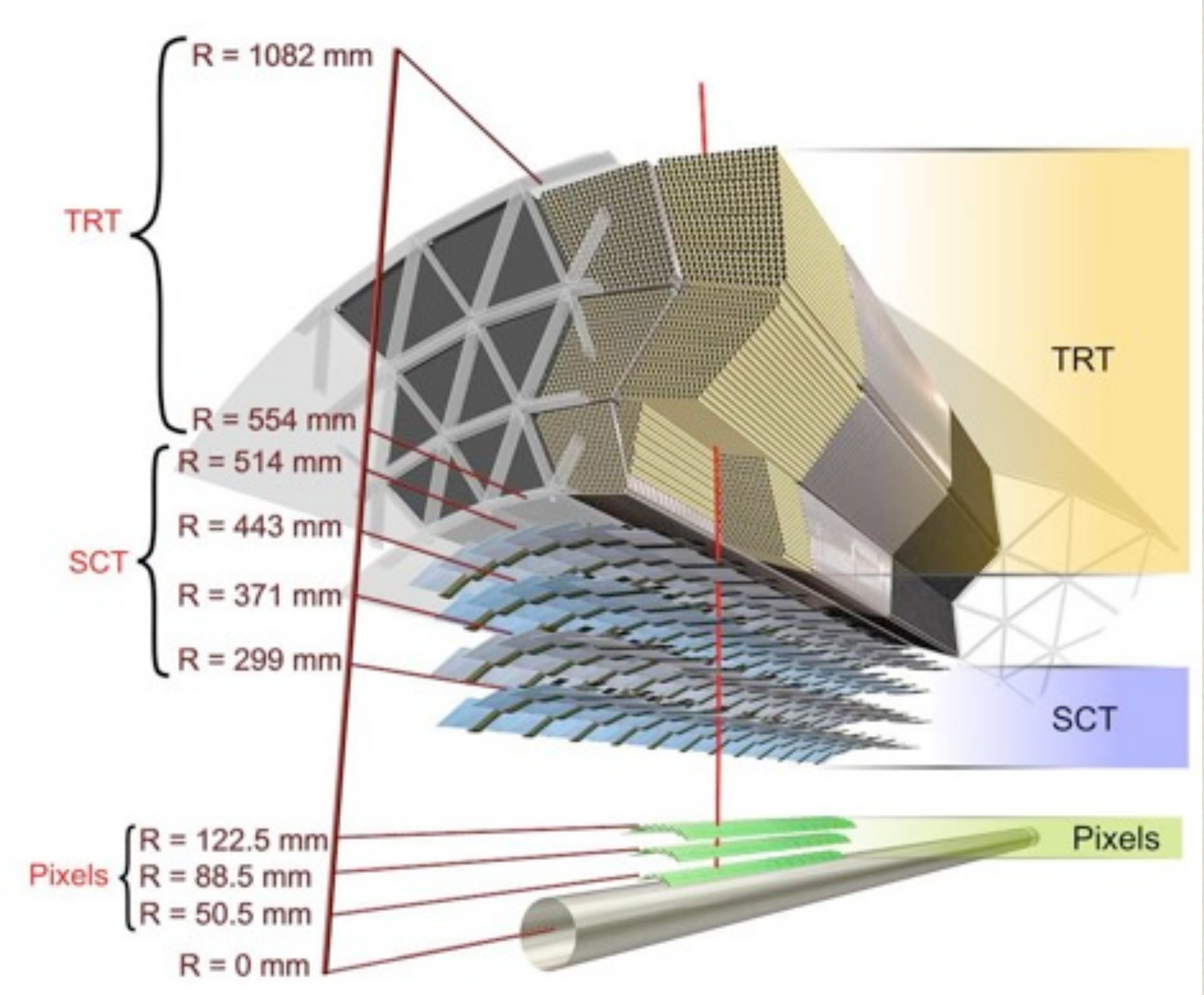
ATLAS Inner Detector



- Total φ coverage & |η| < 2.5
- Immersed in 2 Tesla Solenoidal Field
- Intrinsic position resolution
  - 10(Pixels),17(SCT) and 130(TRT)μm in *rφ*
  - 115 (Pixels) and 580 (SCT-barrel) μm in z

- Pixels
  - Pixel detector, 1744 modules
  - 3 barrel layers, 3 layers in each endcap
- Semiconductor Tracker (SCT)
  - Silicon Strip Detector, 4088 modules
  - 4 barrel double-layers, 9 disks in endcap
- Transition Radiation Tracker (TRT)
  - Proportional drift tubes, 298K straws

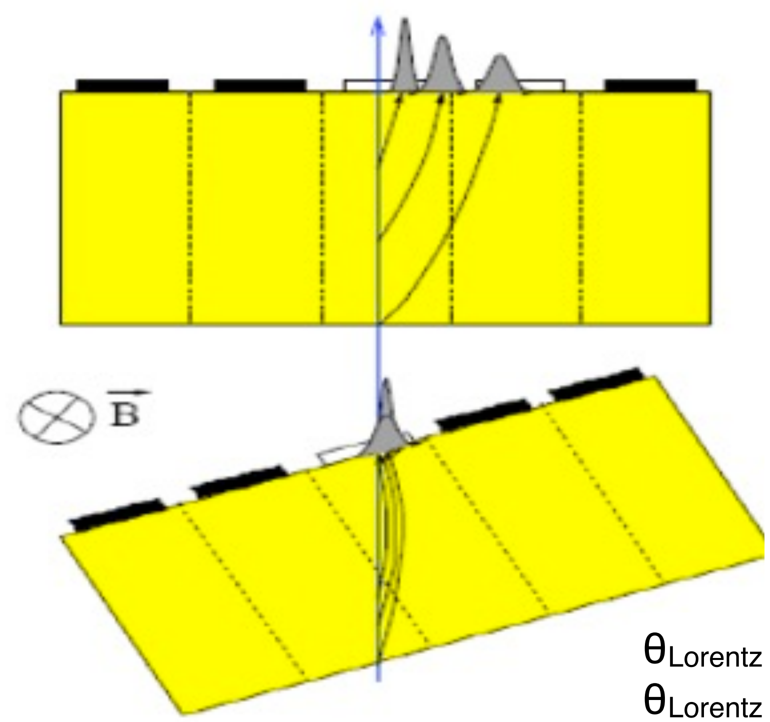


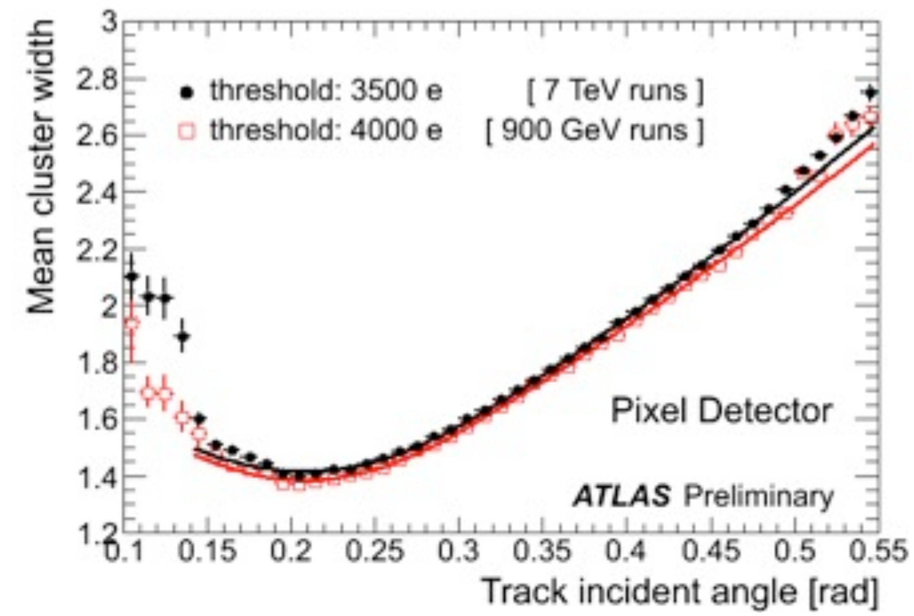
Pixels status and performance

LORENTZ ANGLE

MEAN CLUSTER WIDTH

- Fully integrated in ATLAS
- 46 of 1744 modules inactive : 2.64% inactive fraction



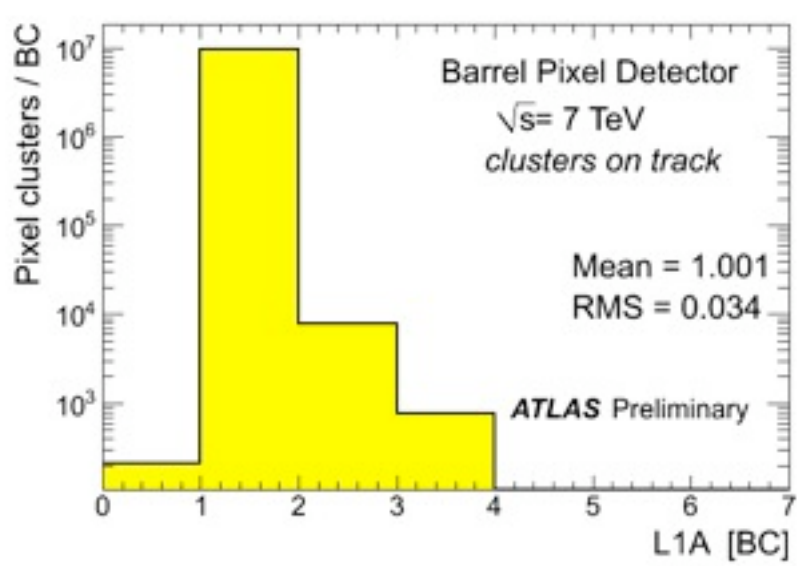


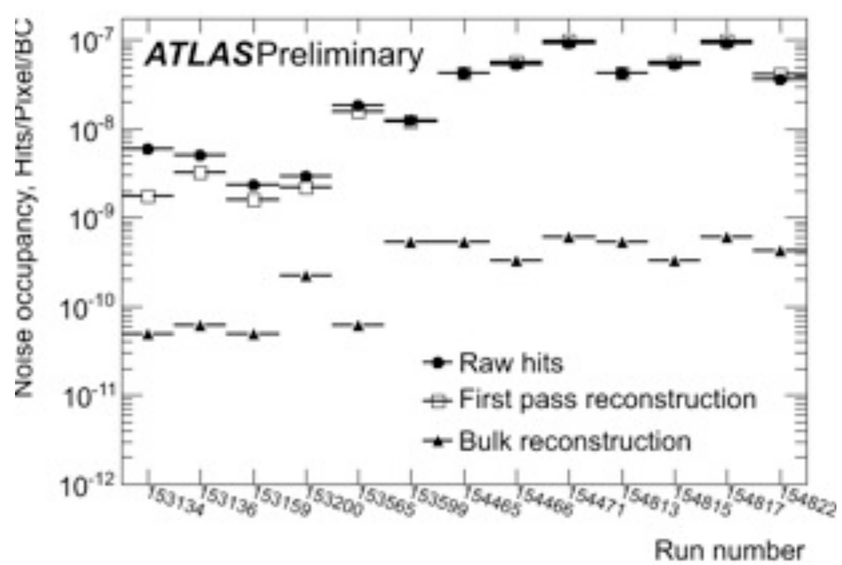
$\theta_{Lorentz}$ = (211.6 ± 2.6) mrad : 900 GeV
$\theta_{Lorentz}$ = (211.3 ± 2.6) mrad : 7 TeV

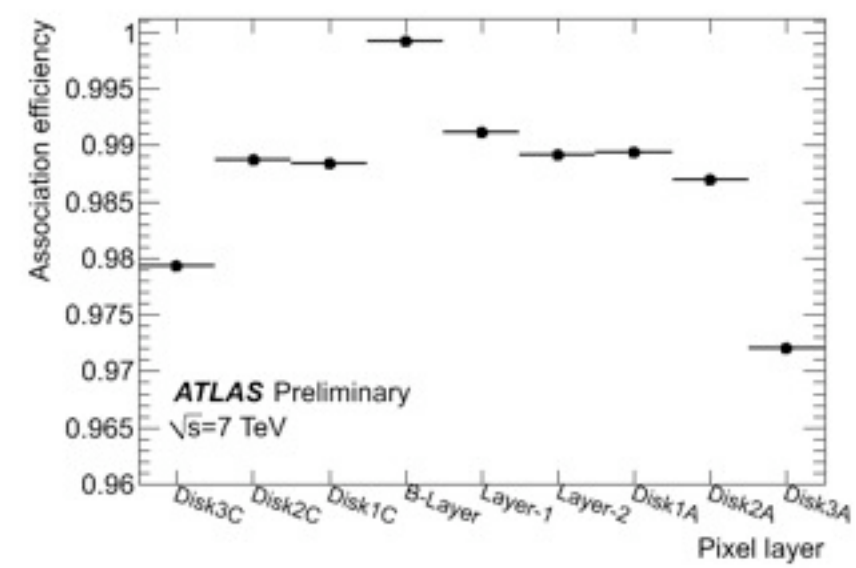
PIXEL HITS PER BC

NOISE OCCUPANCY

HIT EFFICIENCY



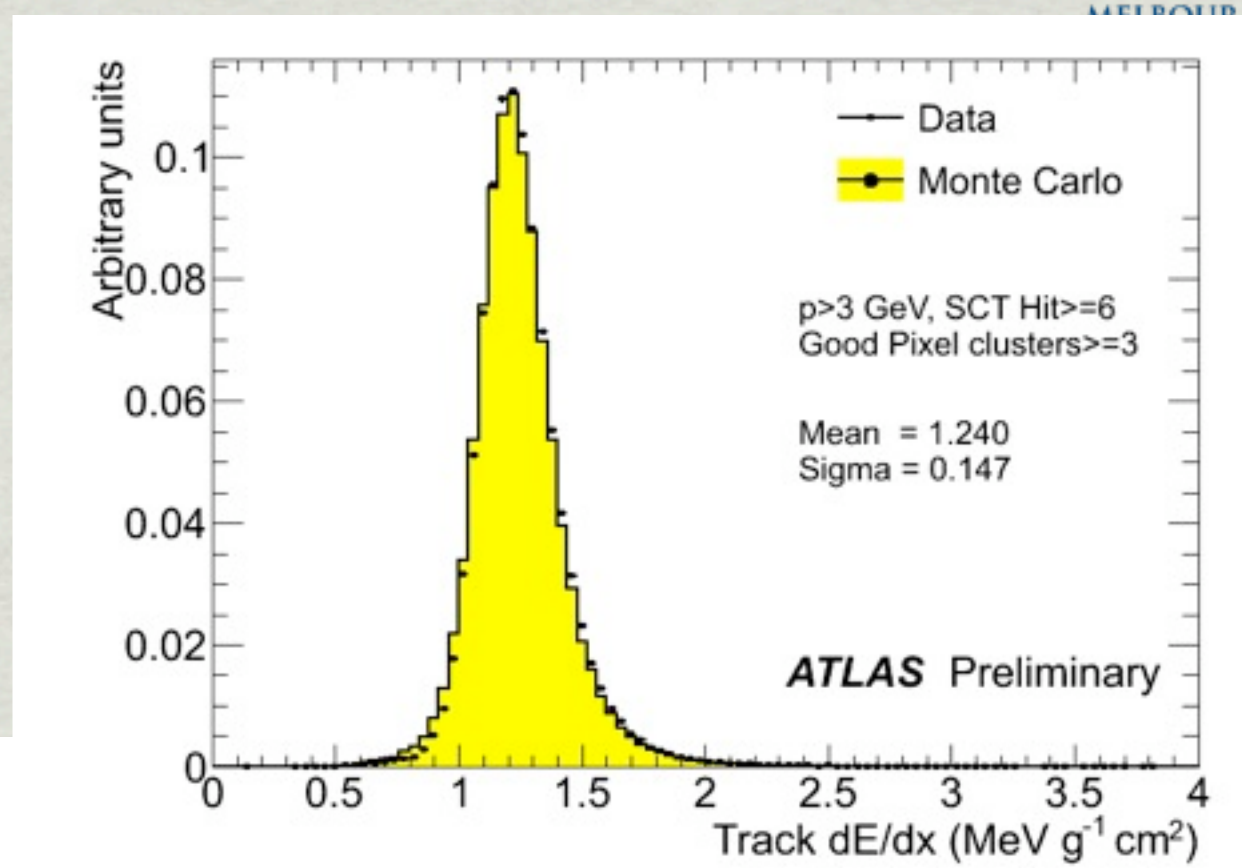


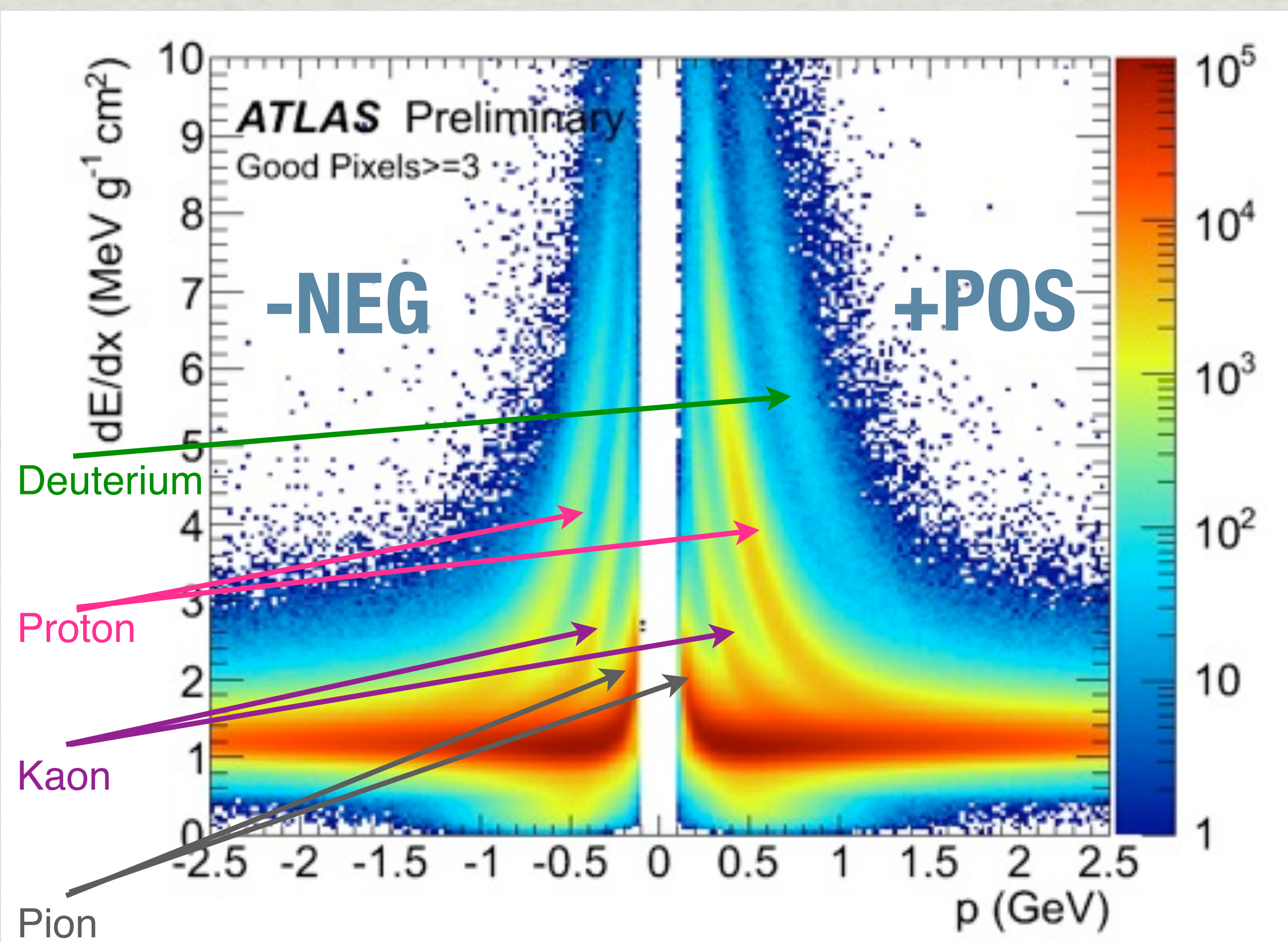


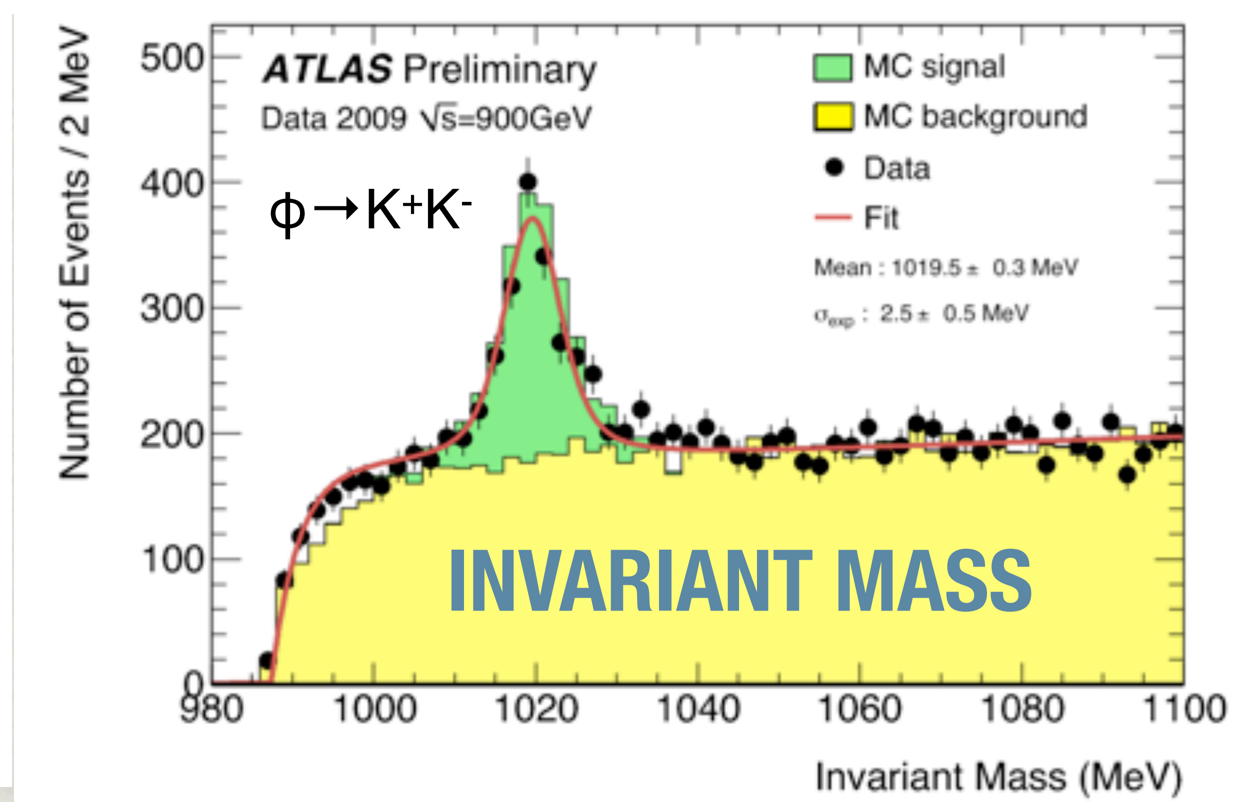
- Hits well timed in to beam crossing (BC)
- Noise occupancy < 10^{-9} hits / pixel / beam crossing
- High pixel hit efficiency. Dead modules are excluded but dead regions contribute to the inefficiency.

Ionisation Energy loss: Hadron ID

- Time over Threshold is proportional to collected charge so is sensitive to the ionisation energy loss
- Specific energy loss due to ionisation is modeled by Bethe-Bloch function. Parameters depend on mass of ionising particle.
- Tracks with three pixel hits provide a useful dE/dx measurement



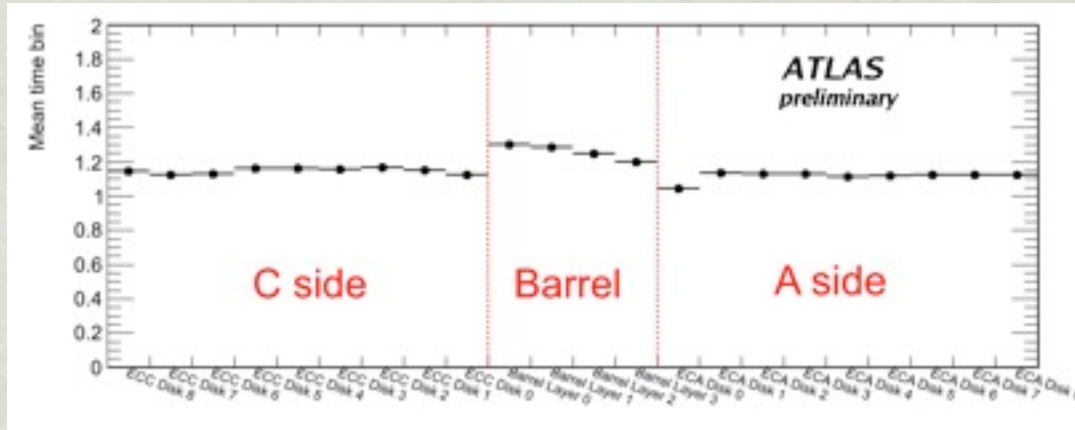




SCT status and performance

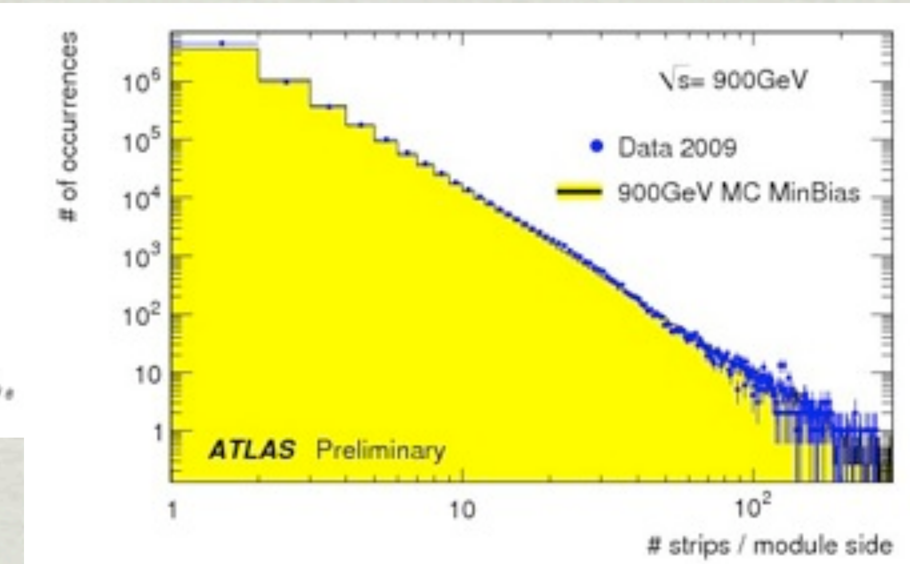
- Fully operational!
- 30 of 4088 modules inactive
- 0.97% inactive fraction. Includes dead chips, masked strips

TIMING



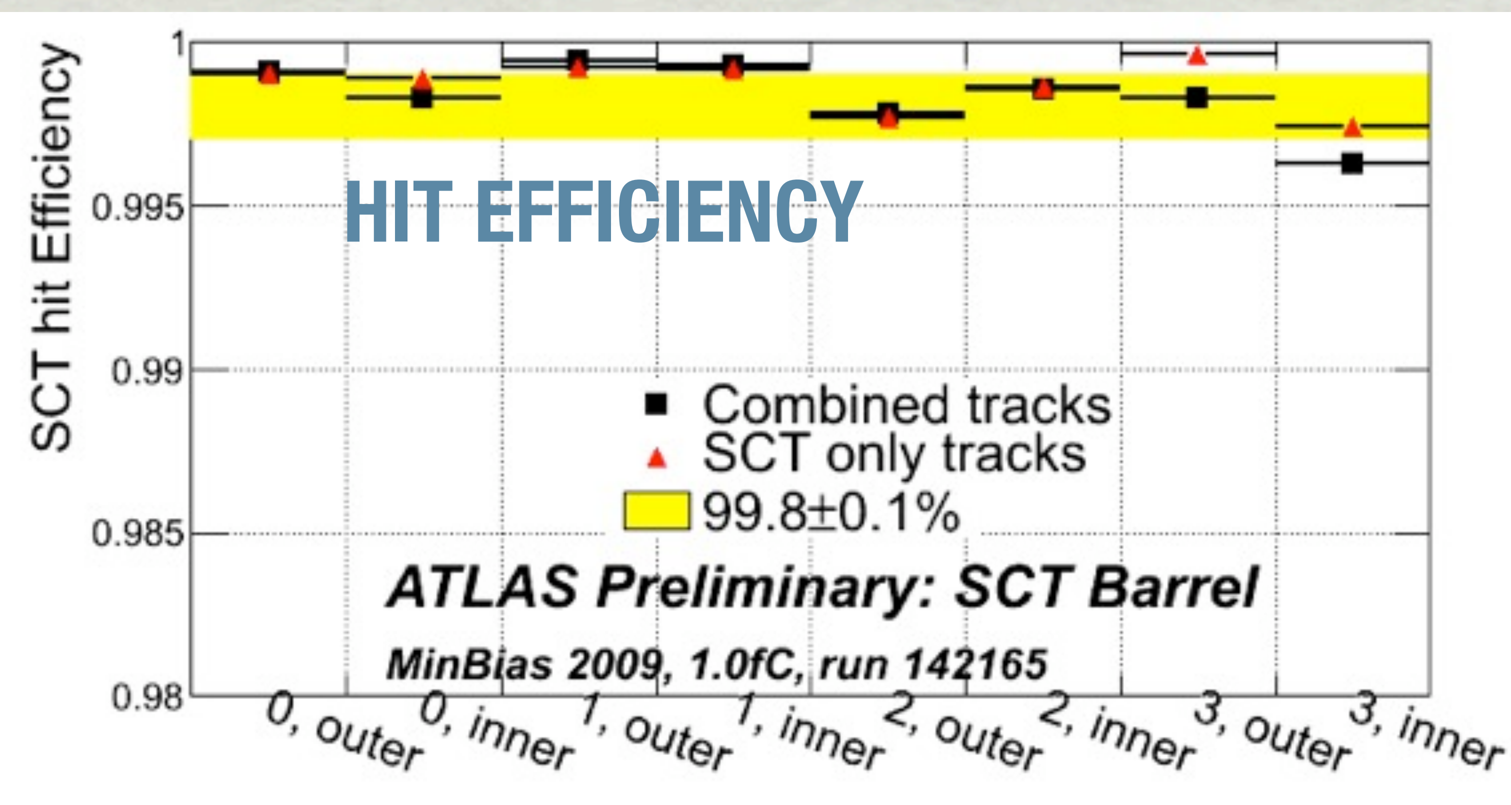
- Read-out in 3 BCs, average of Mean Time Bin close to 1 as expected, thus well timed-in.

OCCUPANCY



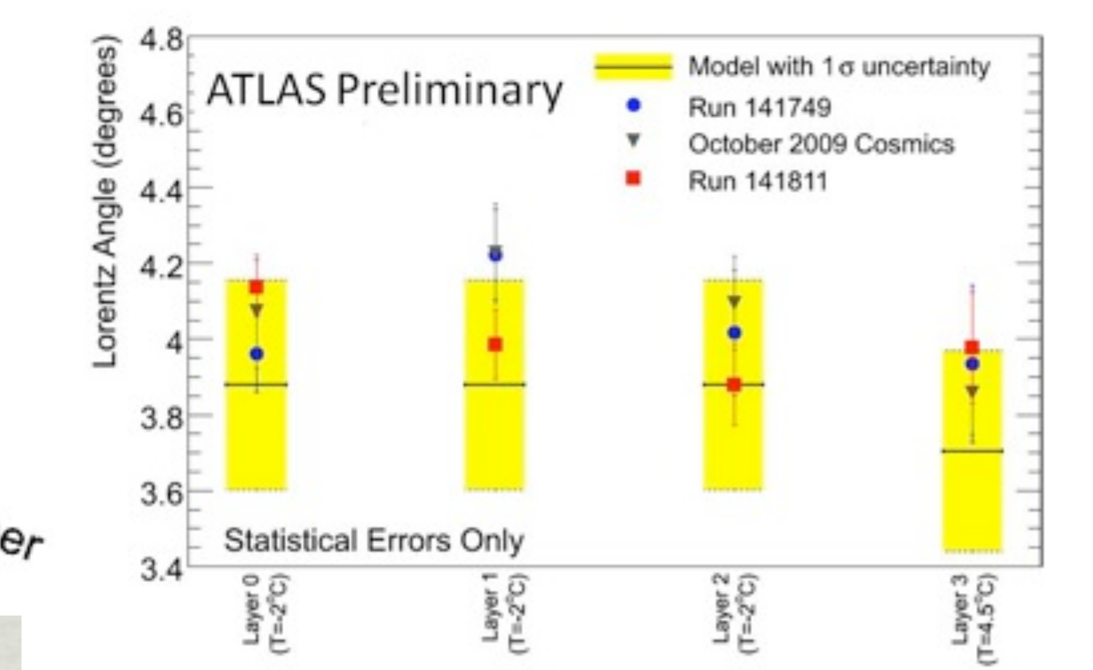
- Hits per module. Average SCT occupancy low. Good agreement with simulation

HIT EFFICIENCY



- Hit Eff. ~ 99.8% (99% benchmark). Dead modules and readout chips are taken into account.

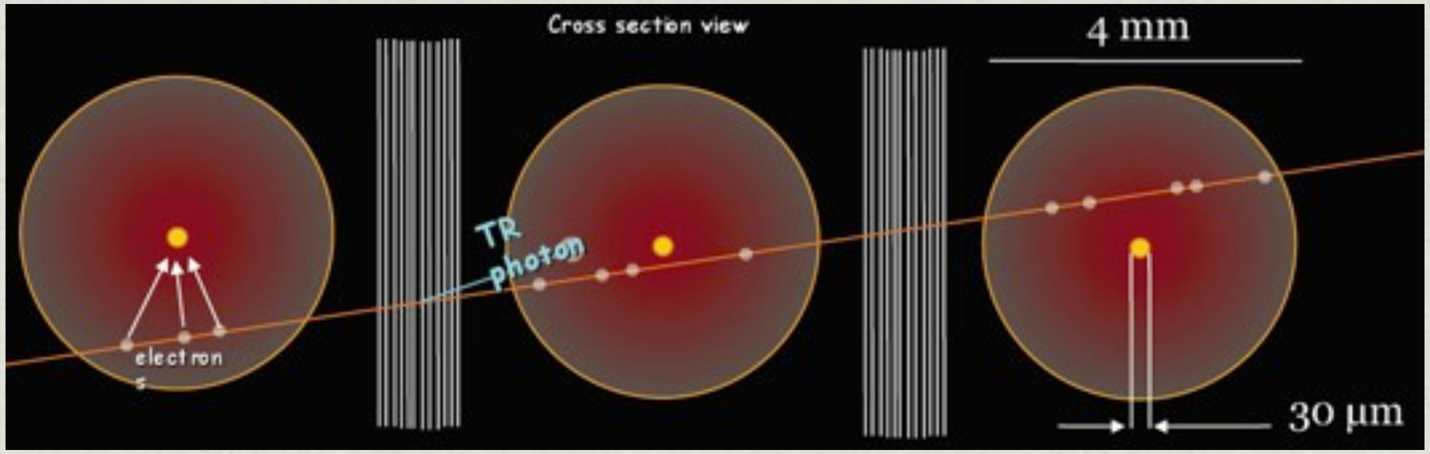
LORENTZ ANGLE



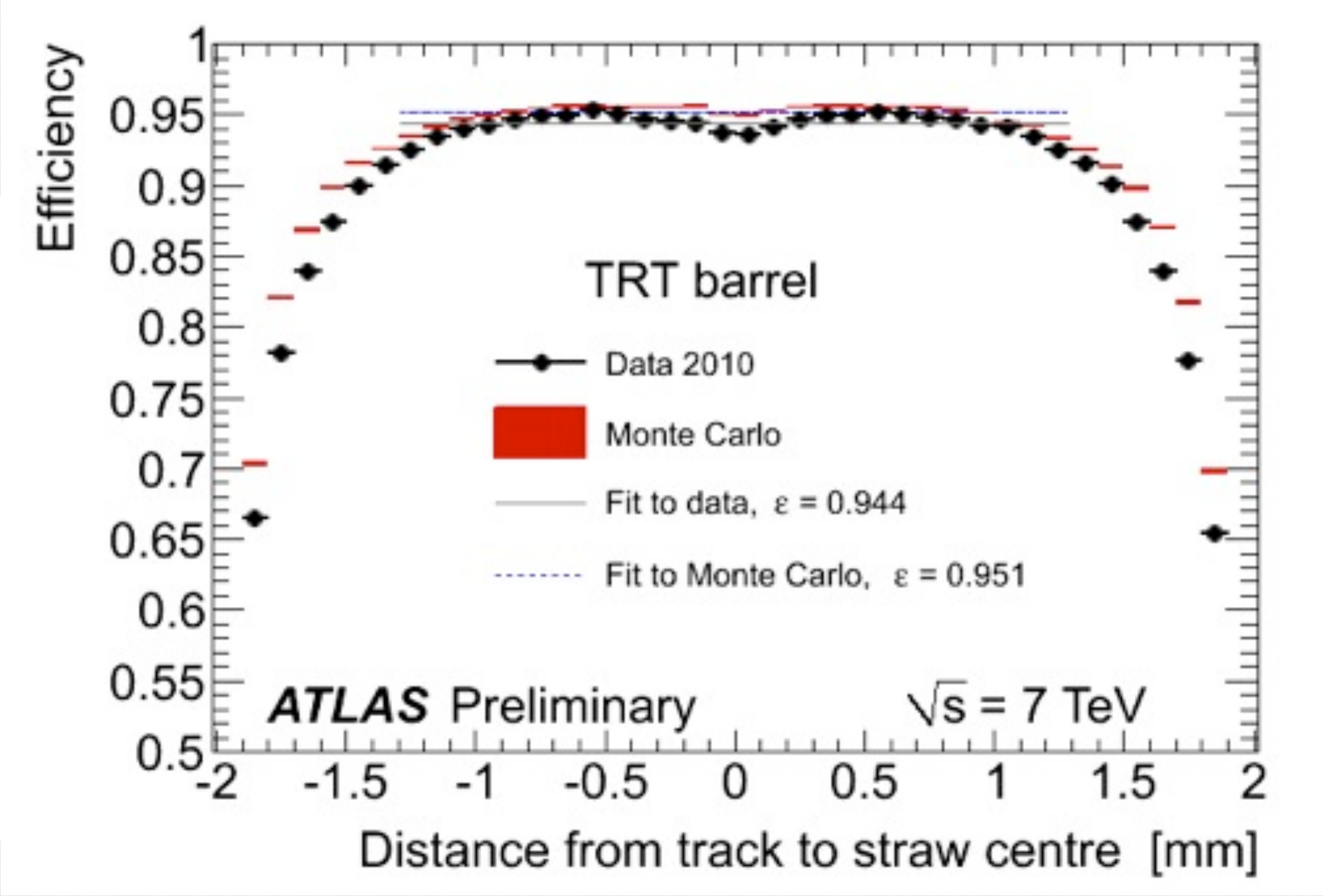
- Stable over time, consistent with model

TRT status and performance

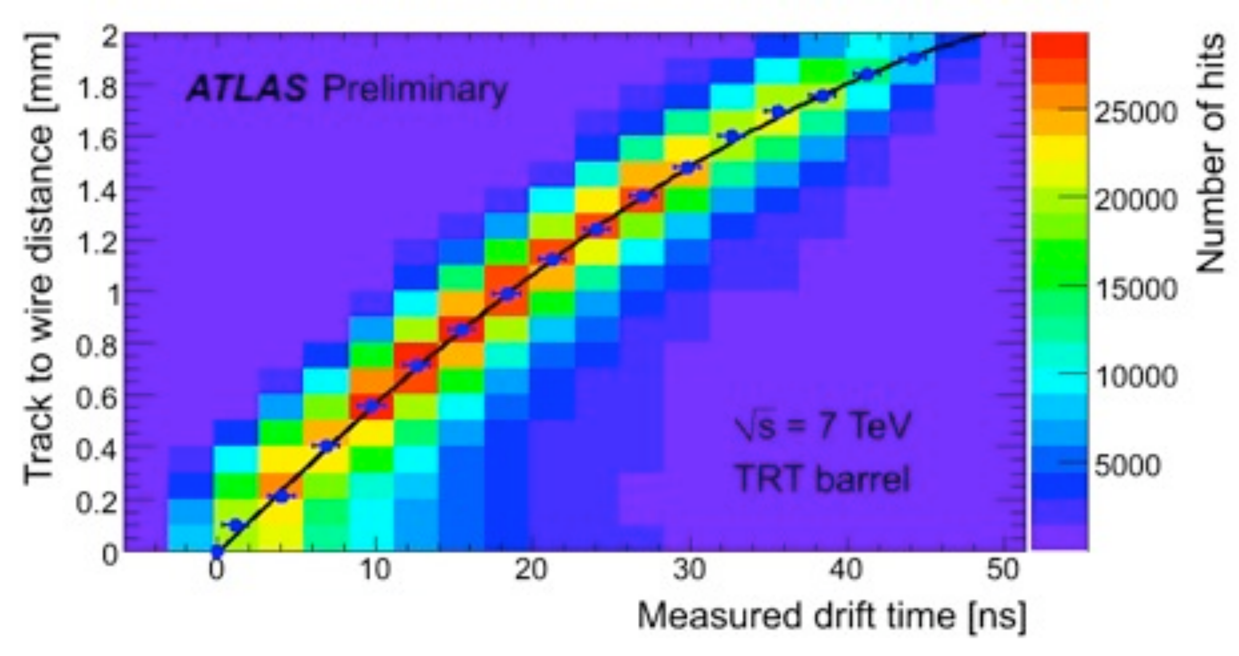
- Fully integrated within ATLAS
- 98% functioning channels
- 4mm straws with drift time measurement for increased spatial resolution.



TRT STRAW EFFICIENCY



TRT R-T RELATION

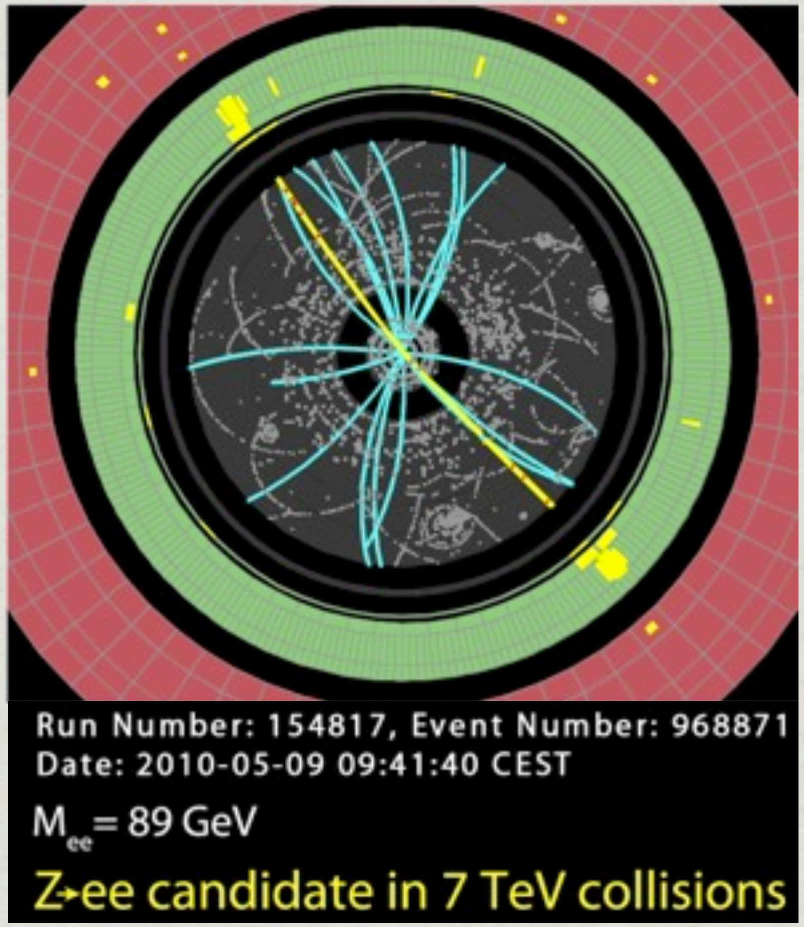


- Initial time offset determined per straw. Convert drift time to drift radius, R-T relation

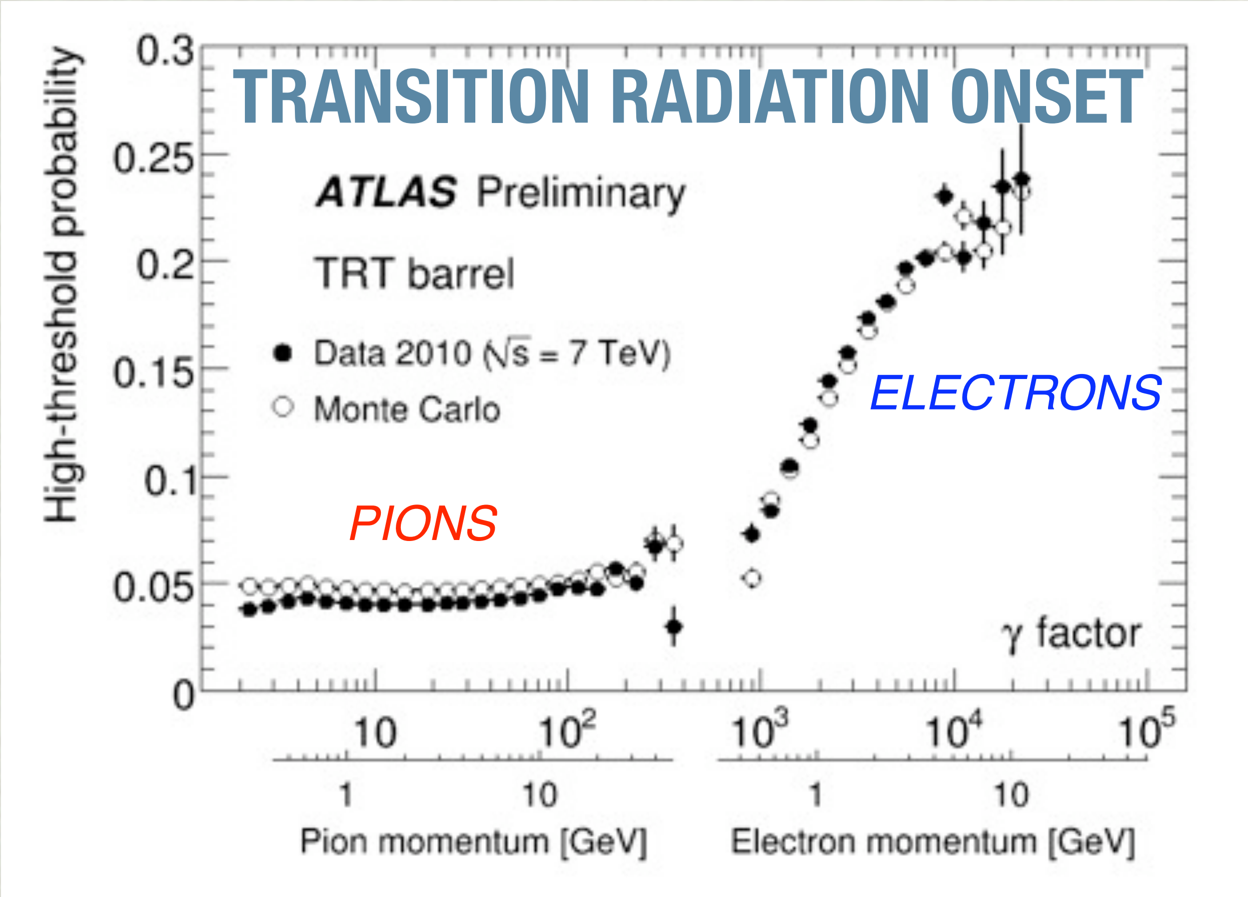
- # straws with hit / # straws crossed ~ 94%(95%) data (MC) in plateau region

TRT Electron identification

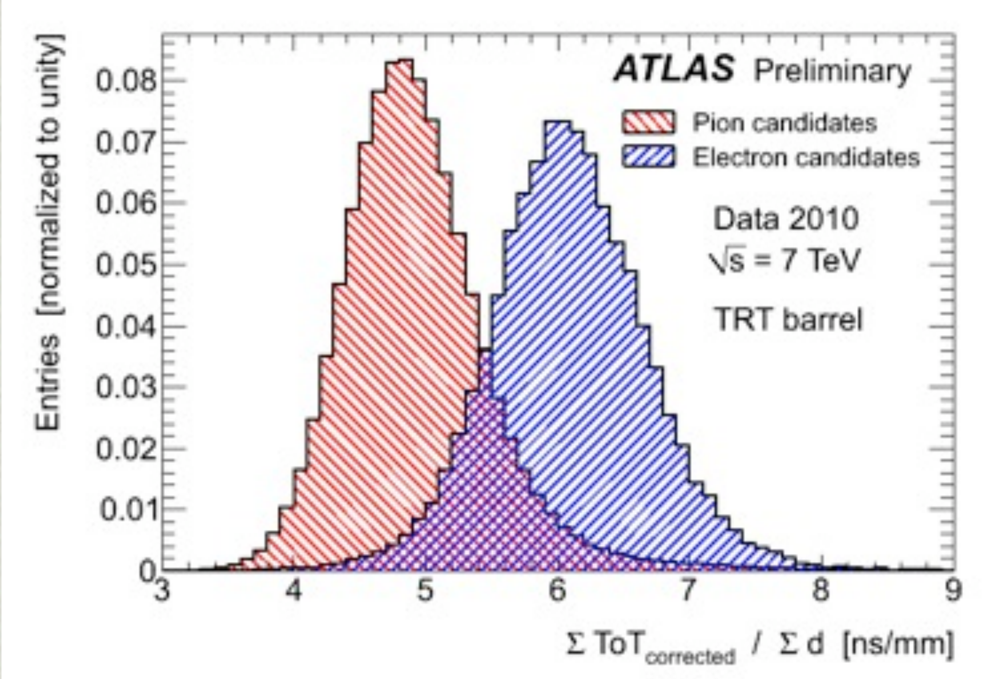
- Particle ID (PID) by transition radiation (TR)
- TR produced when charged particle crosses boundary between materials with different dielectric constants (foils/fibers) and CO_2
- Probability to emit photon is proportional to Lorentz boost (γ)
- Photon absorbed in straw gas (Xe(70%), CO_2(27%), O_2(3%)
- High threshold hits indicate TR



TRANSITION RADIATION ONSET



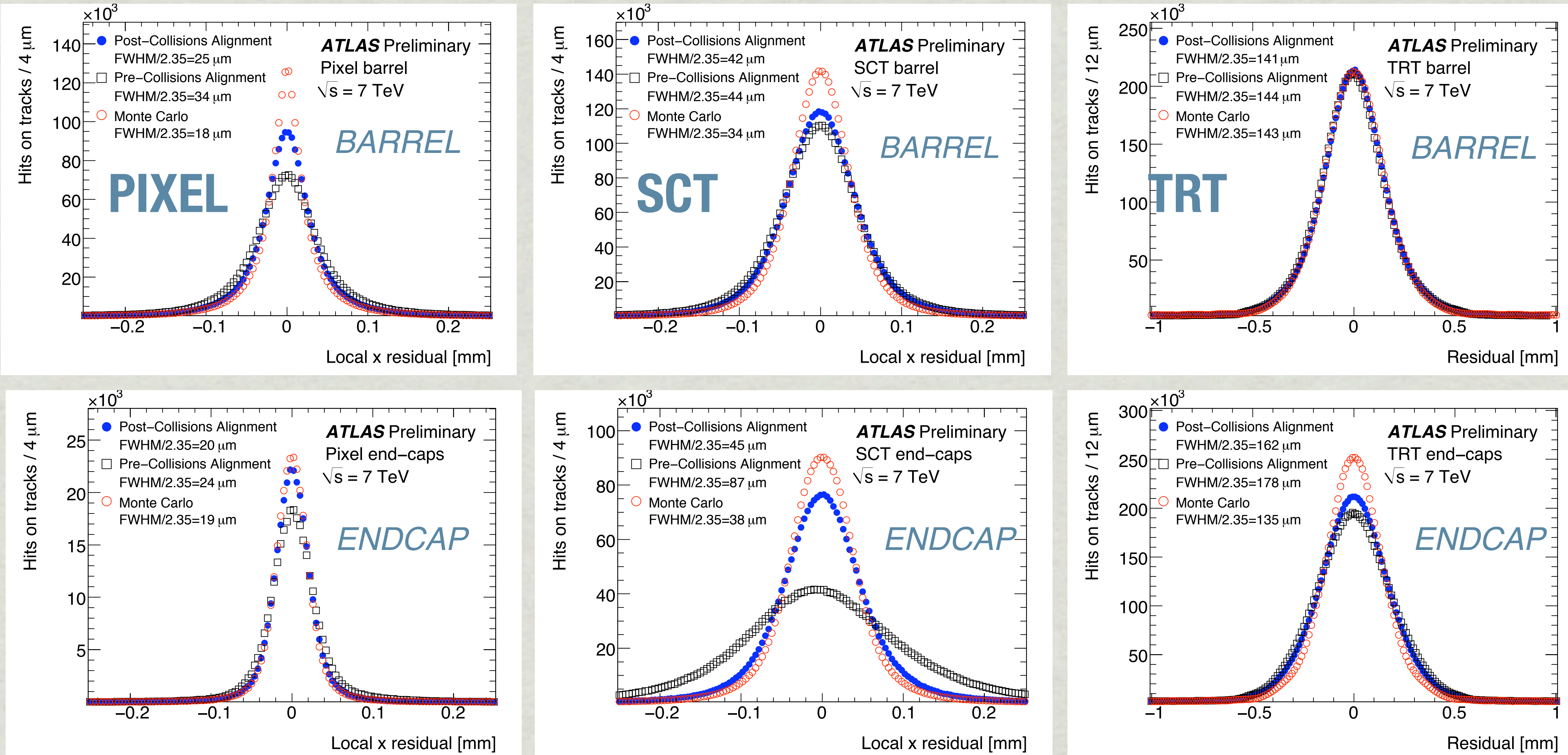
PID USING TIME OVER THRESHOLD



Latest Alignment Residuals

- Track based alignment using a χ^2 minimisation approach is implemented to determine the absolute position of the Inner Detector modules.

UNBIASED RESIDUALS



- Positive effect of collisions data is clearly evident in Pixels and in particular in SCT endcaps, highlighting the lack of illumination from cosmic rays
- Post-Collisions alignment is approaching that of Monte Carlo.

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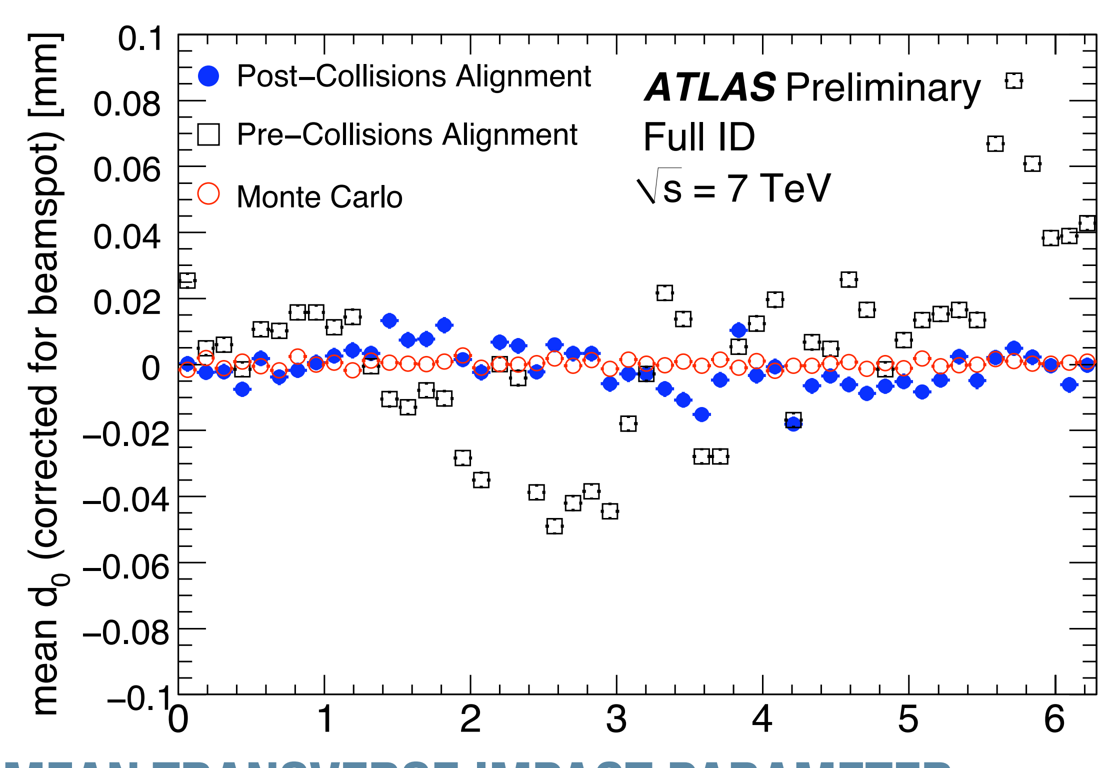
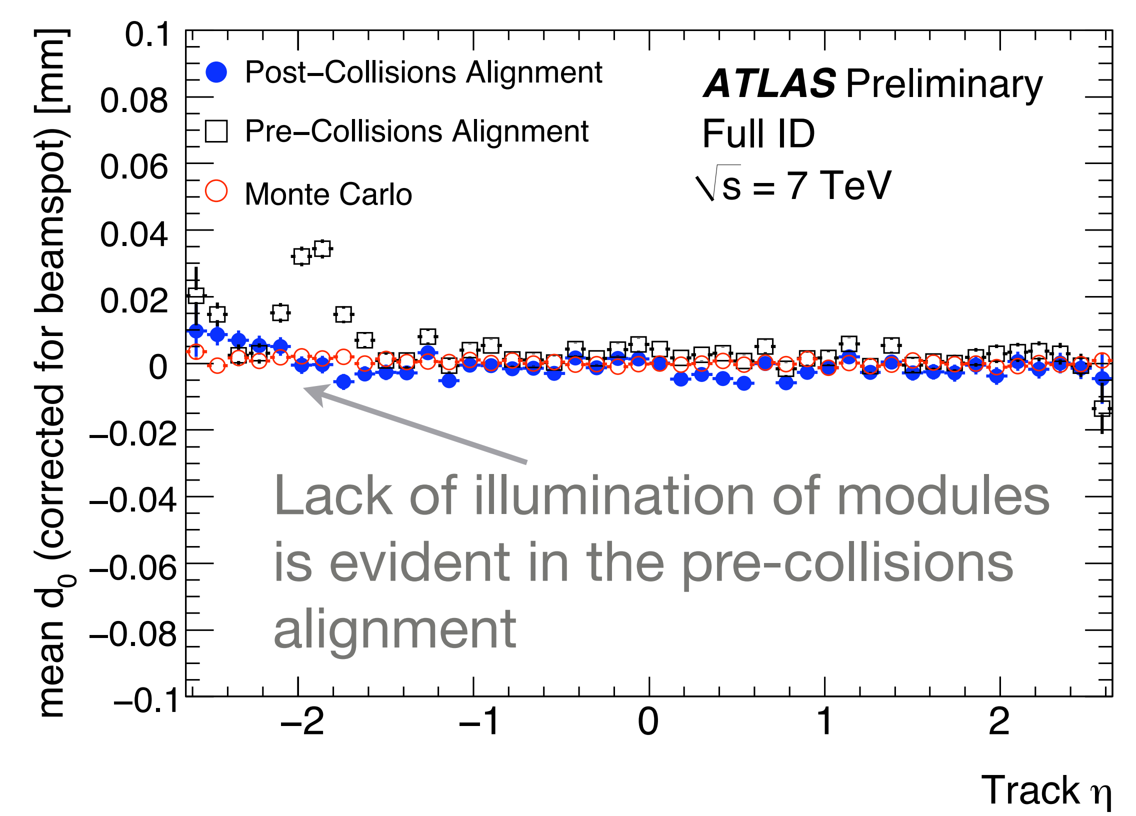
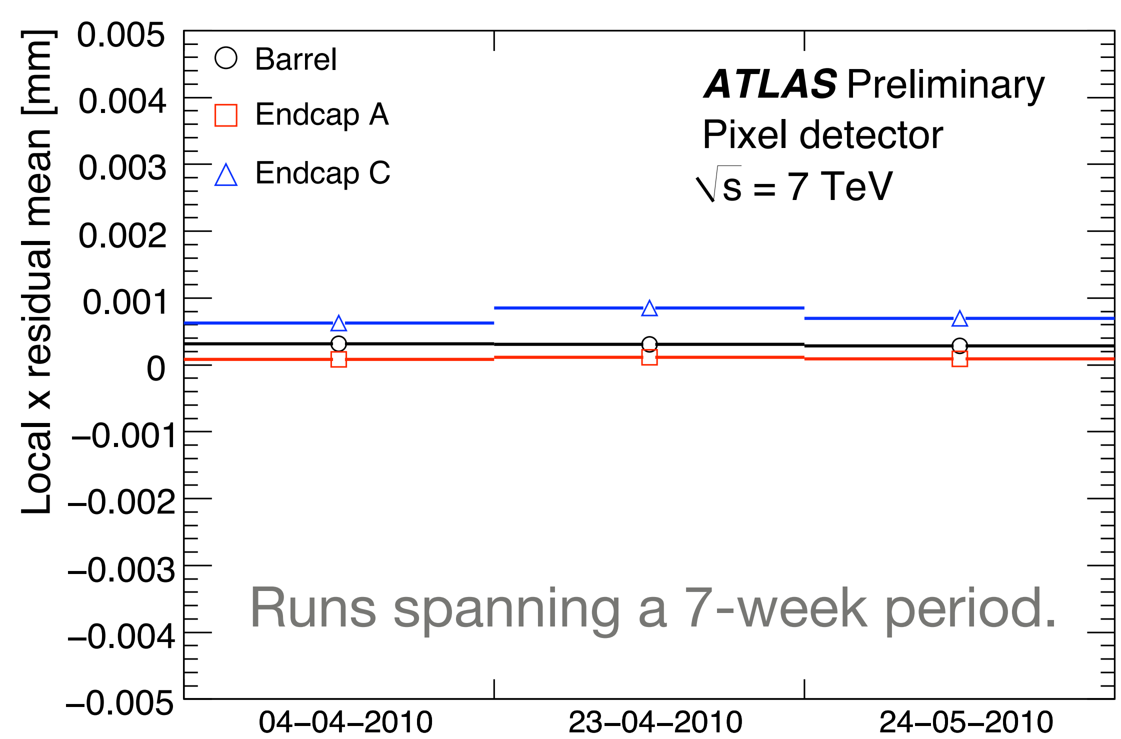
Performance Measures

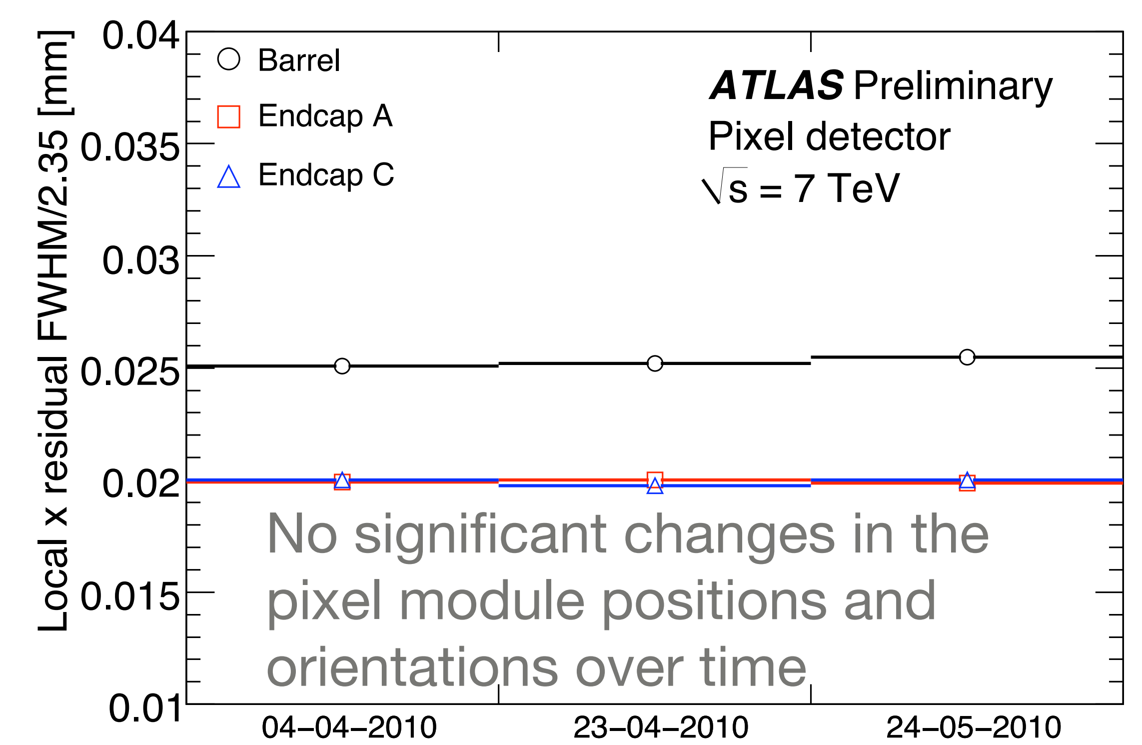


MEAN TRANSVERSE IMPACT PARAMETER





PIXEL RESIDUALS OVER TIME



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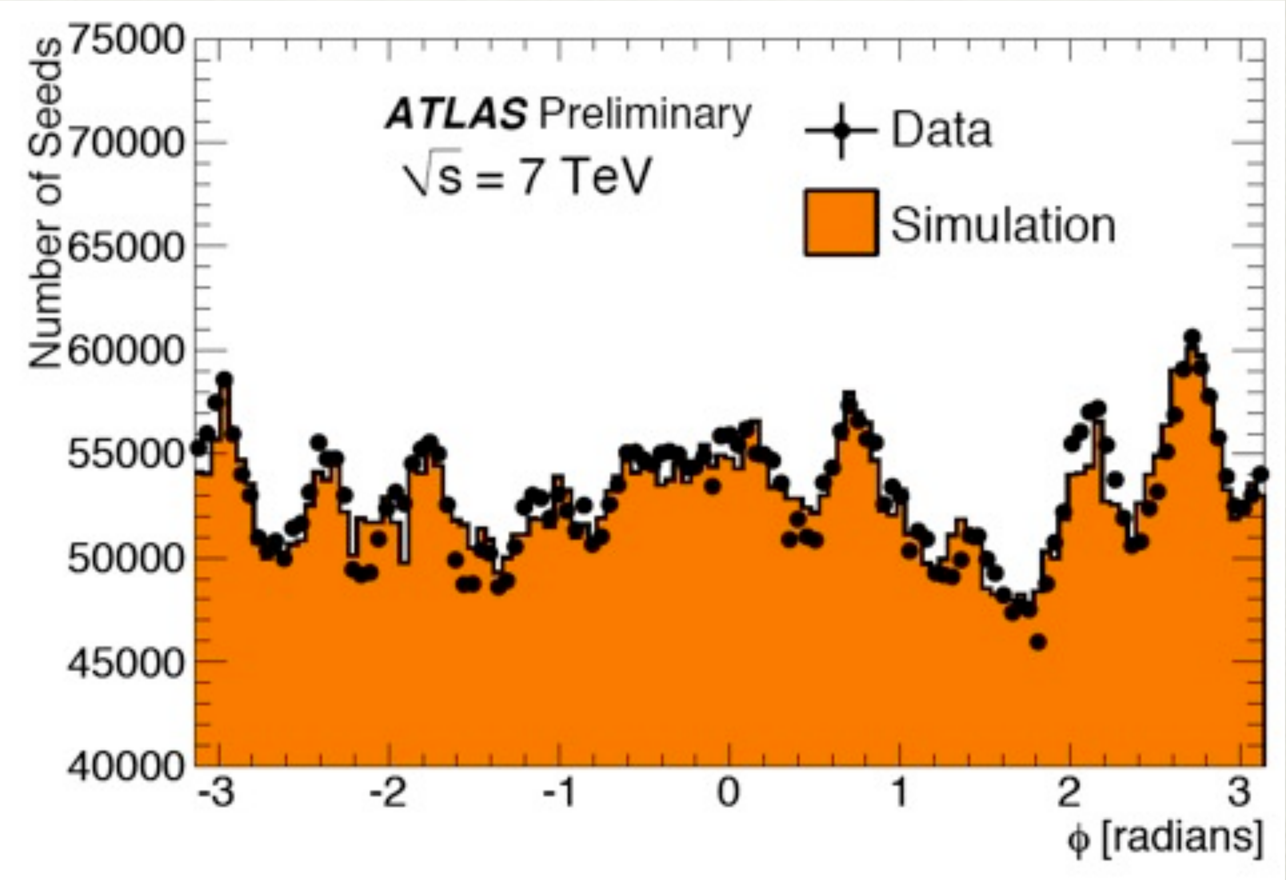
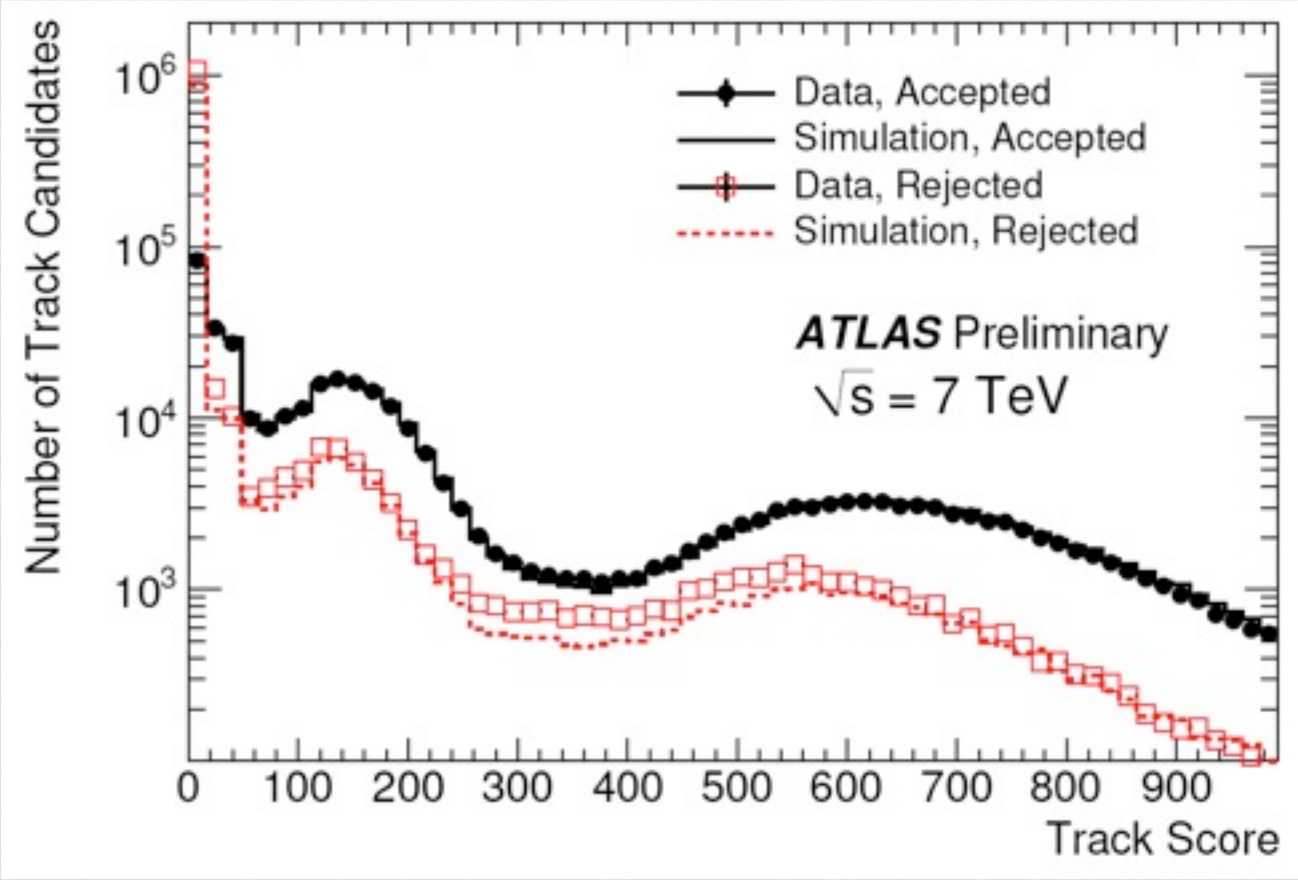
Track Pattern Recognition

- Inside “ATLAS New Tracking” reconstruction
- Begins with seed finding in the innermost silicon layers. Three space points to form a seed.
- Final track candidates are chosen on the basis of a “Track Score” by the “Ambiguity Solver”
- Good agreement between MC and data in accepted tracks.

TRACK SEEDS



TRACK SCORE



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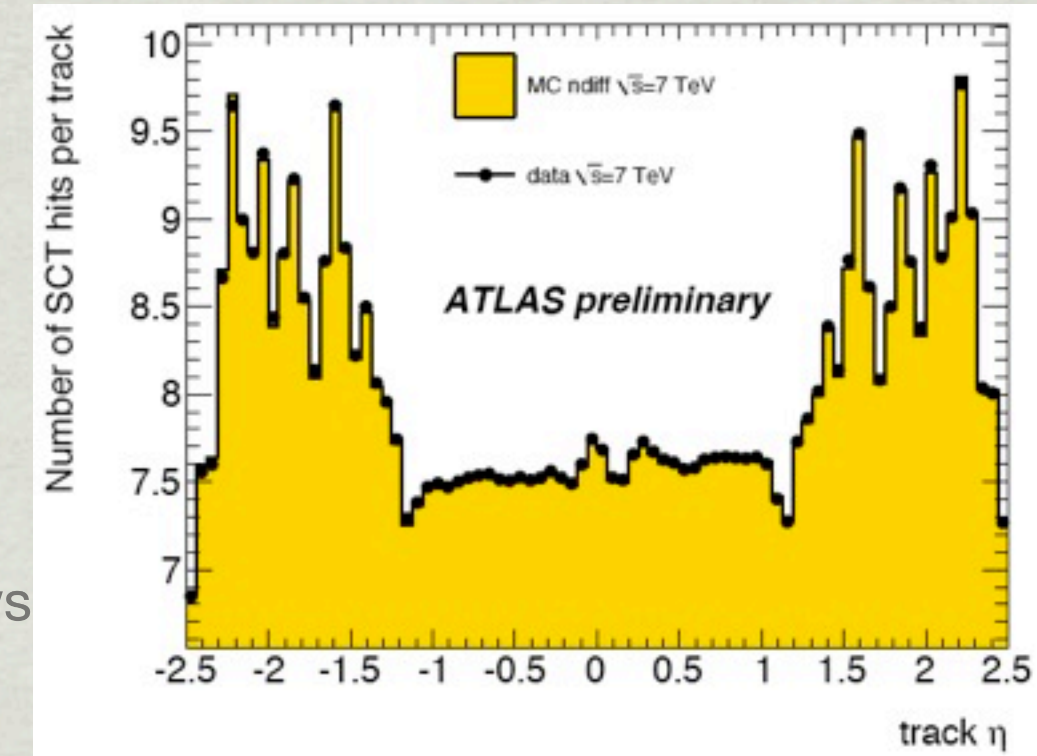
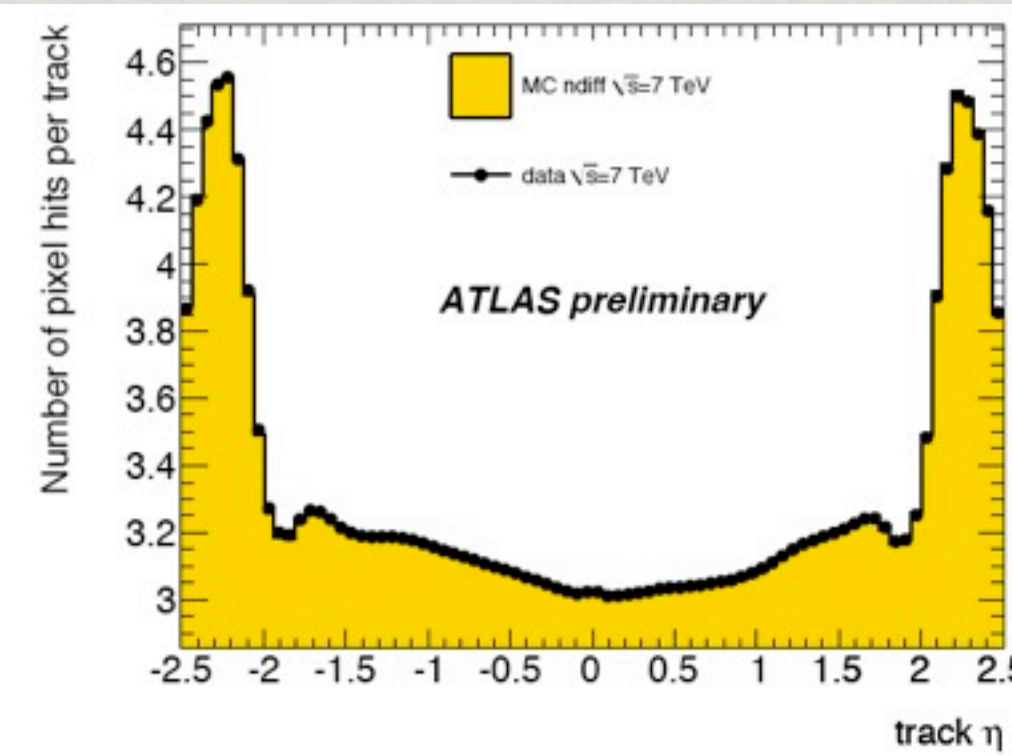
7 TeV data & MC : 100 < p_T < 500 MeV

- ID tracking performance in measurement of charged particle multiplicities
- Comparison at very low momentum shows very good agreement

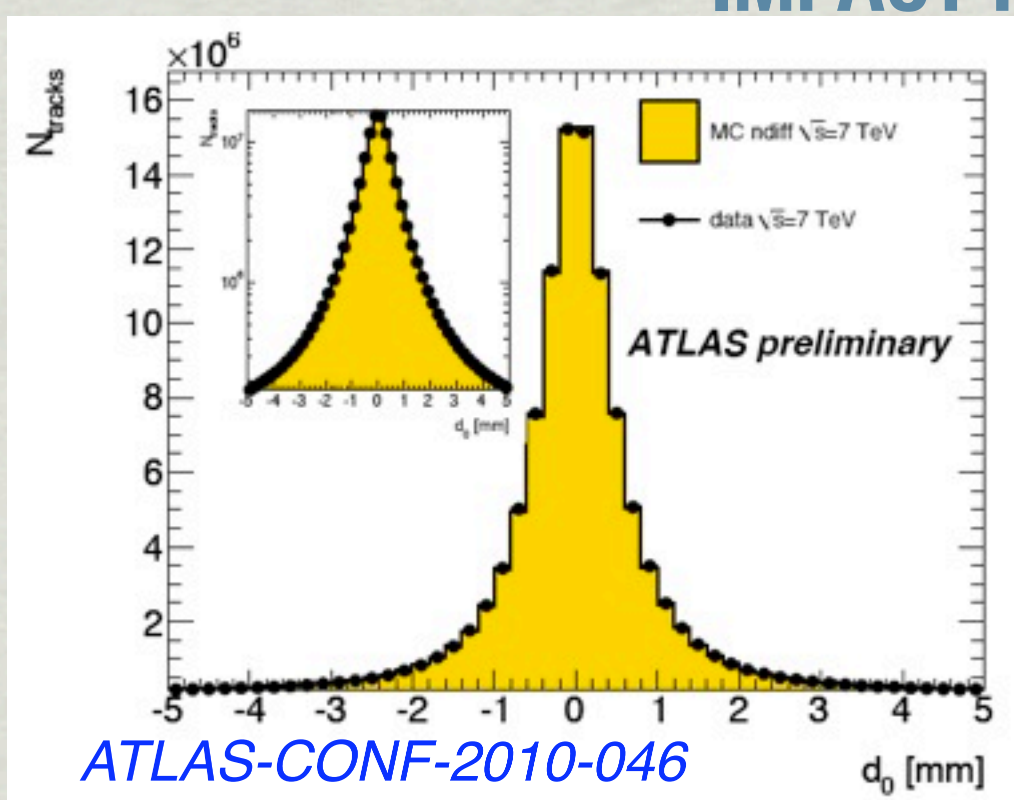
SCT HITS PER TRACK

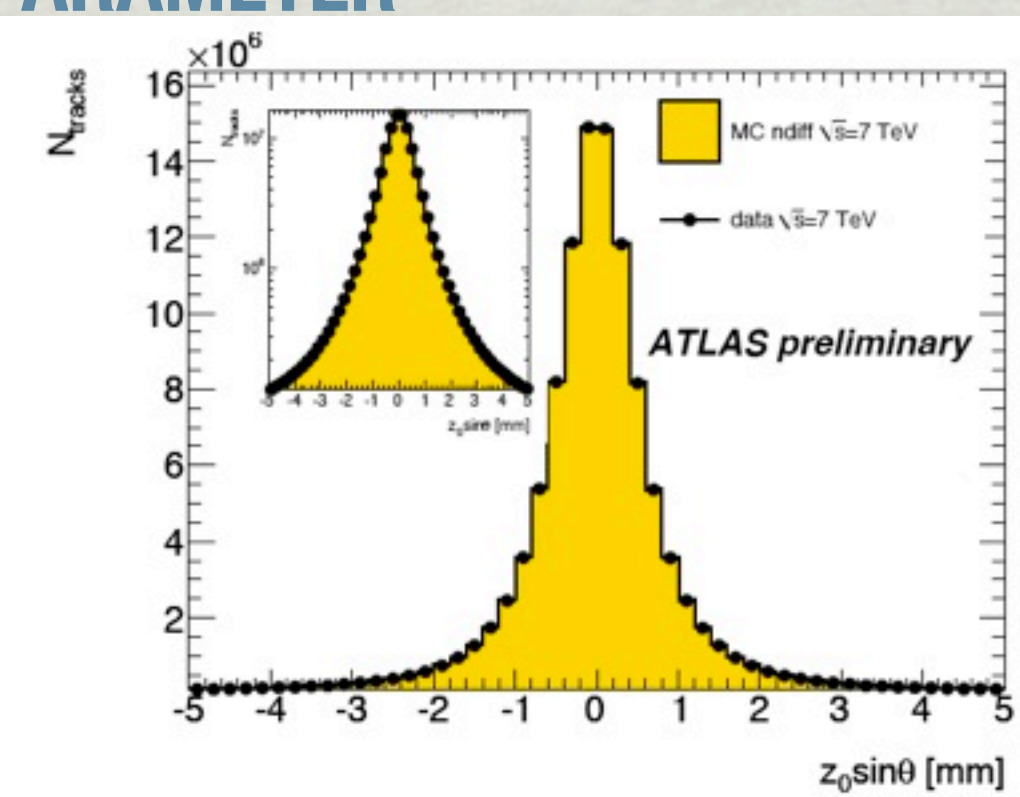


PIXEL HITS PER TRACK



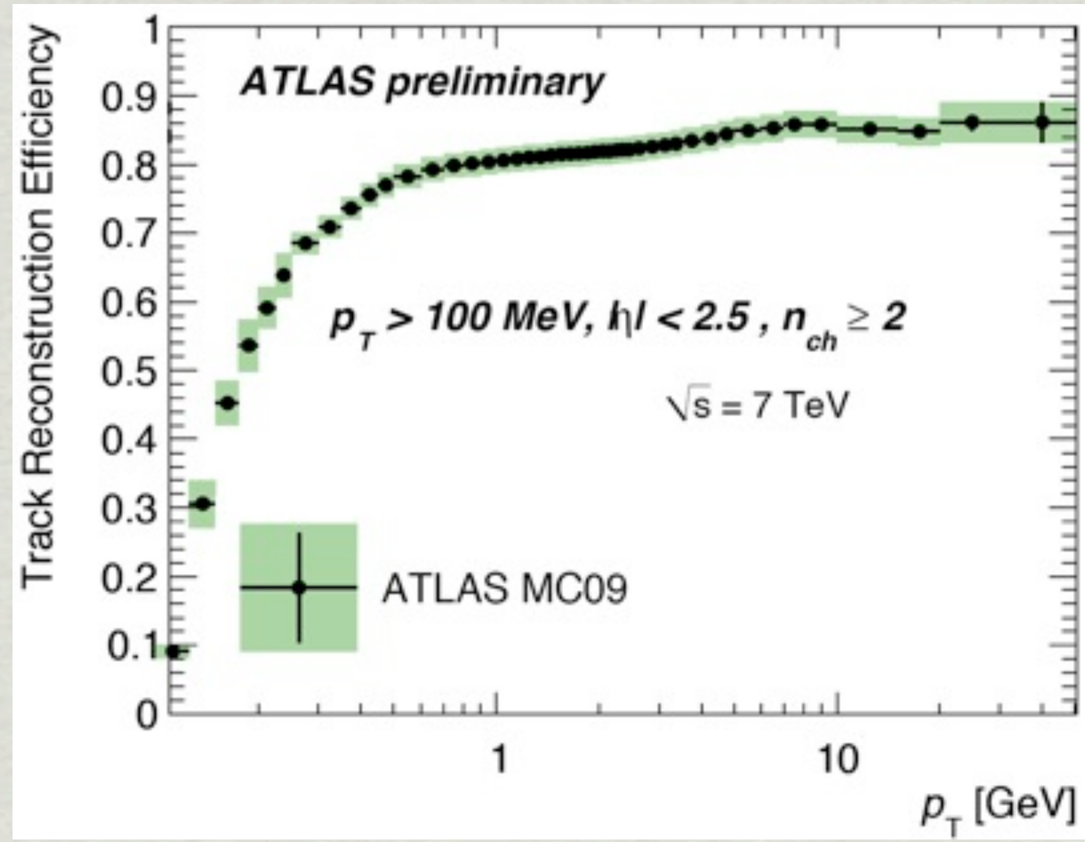
IMPACT PARAMETER



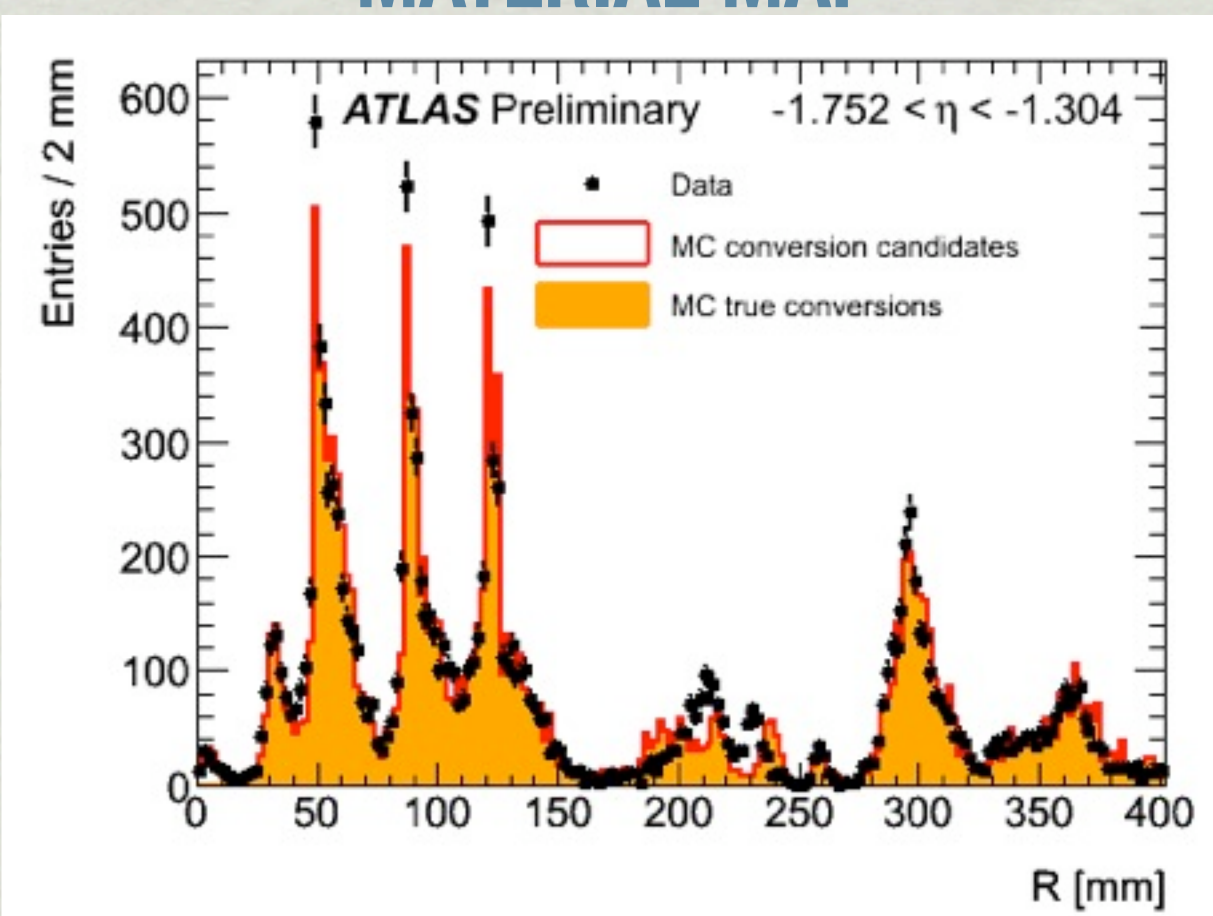


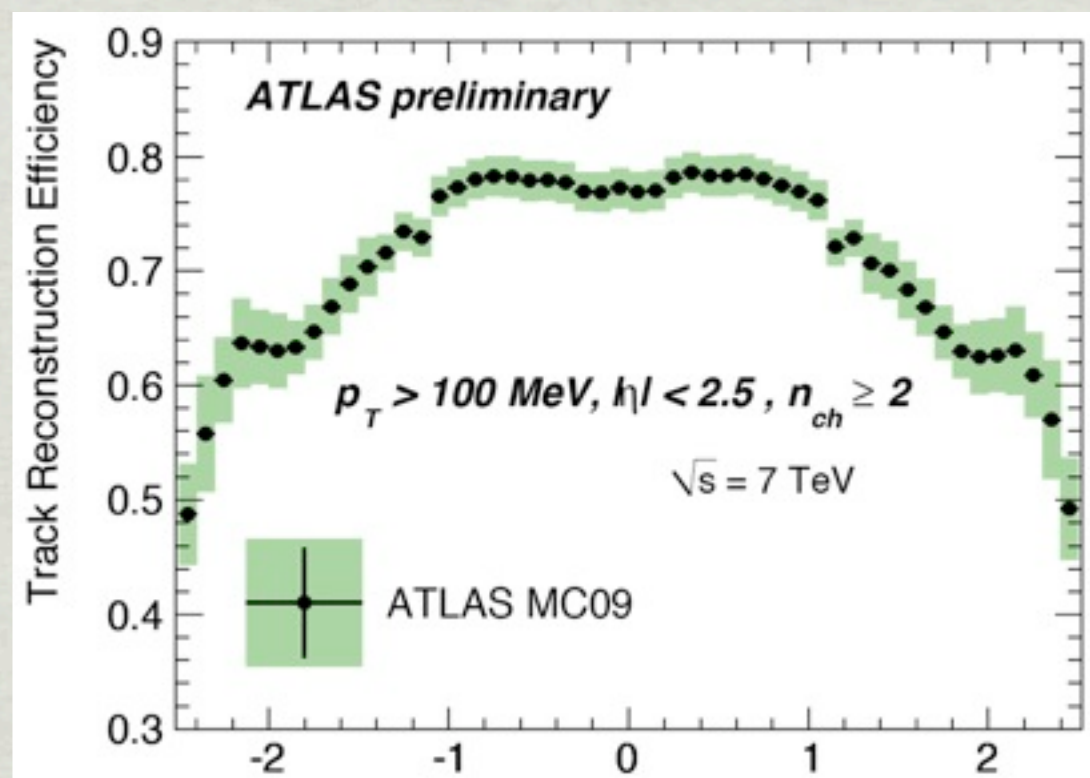
Track Reconstruction efficiency

- Track reconstruction efficiency is determined from MC.
- Assigned uncertainty is based on extensive comparisons between data and simulation.
- Dominant systematic is due to material uncertainty



MATERIAL MAP





See A. Morley's talk "Early Material Studies at the ATLAS Experiment"

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Tracking Systematic uncertainties

CHI-SQUARE PROBABILITY

- MC and data agreement is not perfect. Discrepancies exist and are being explored!

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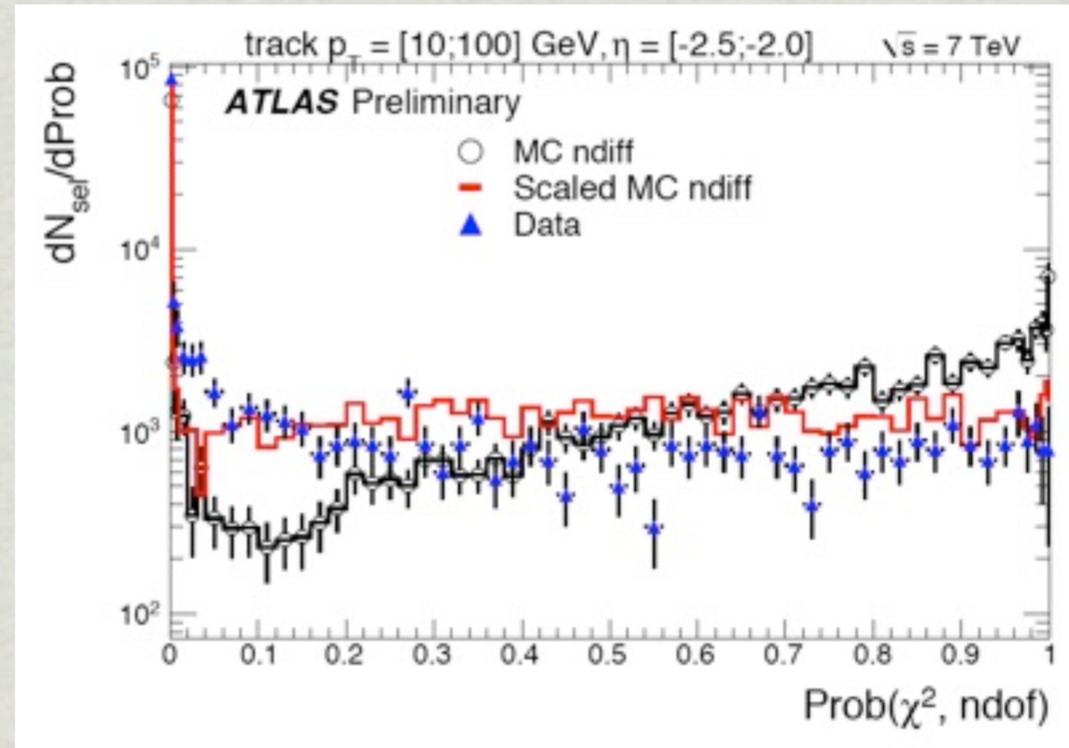
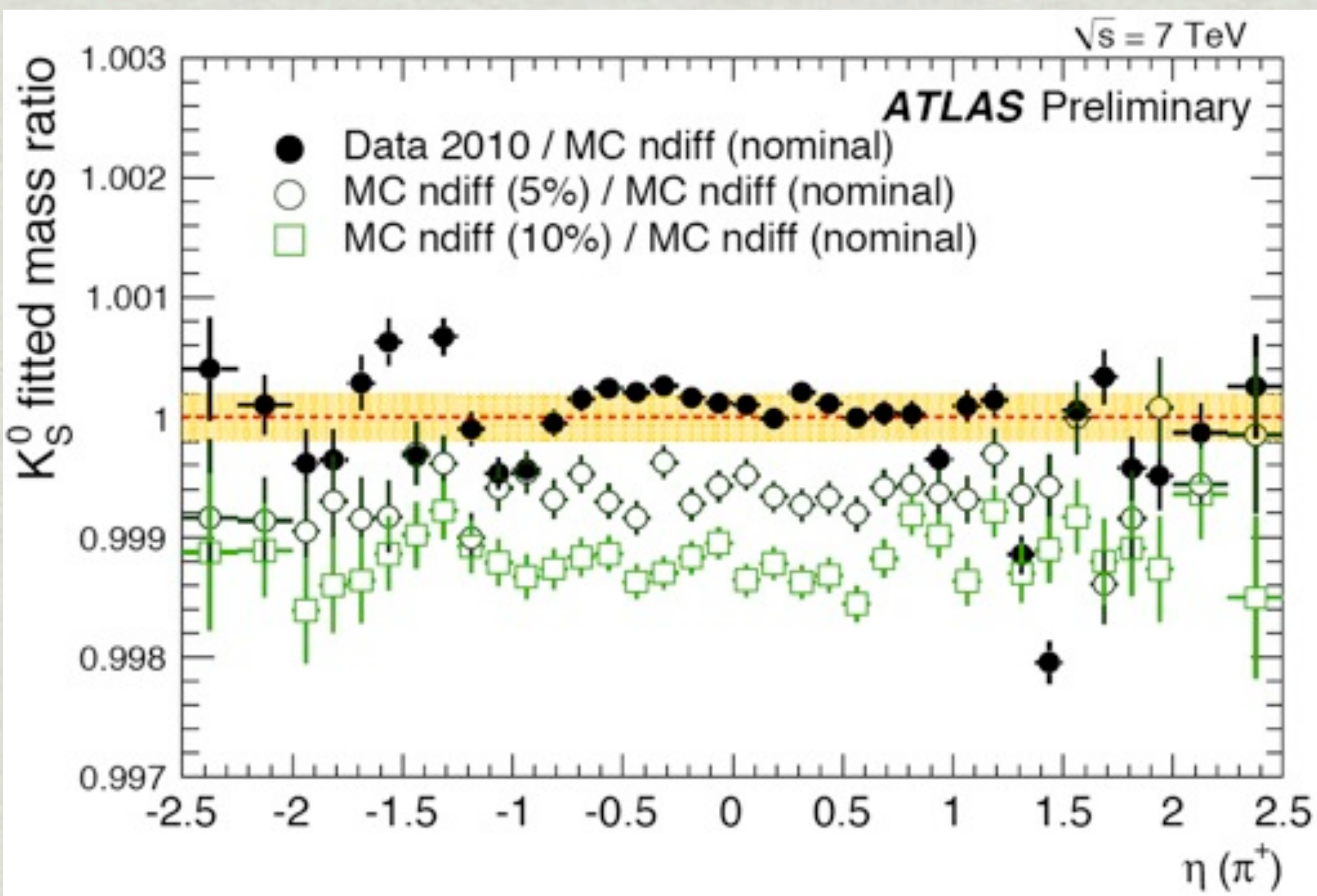
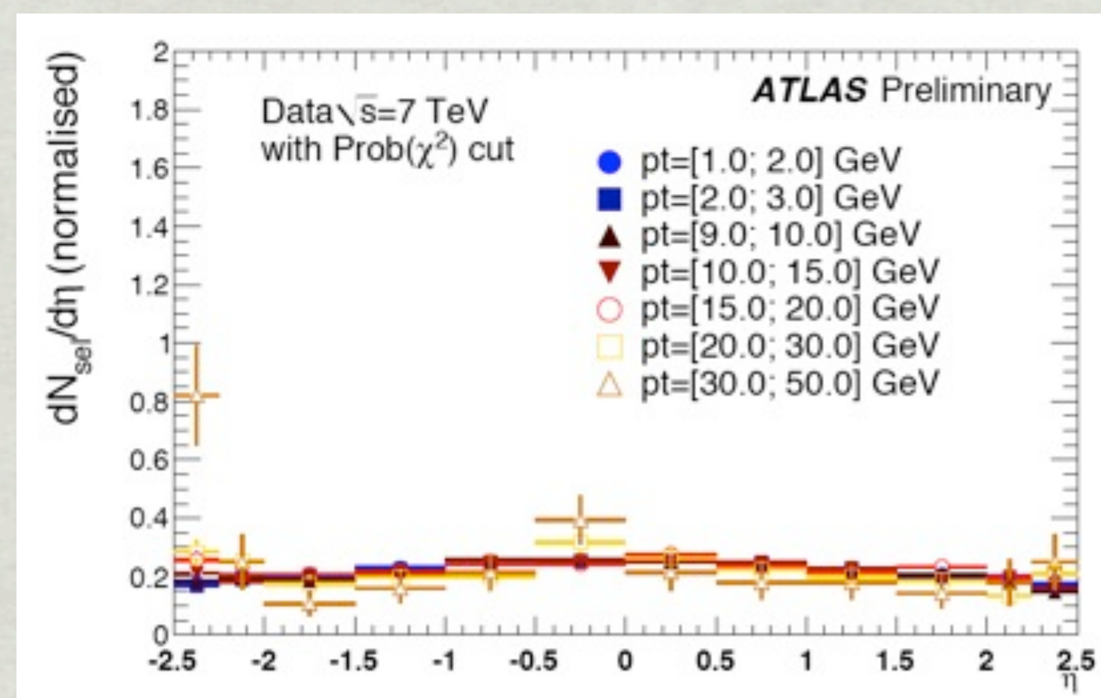


K-SHORT FITTED MASS RATIO



TRACKS AFTER CHI-SQUARE CUT

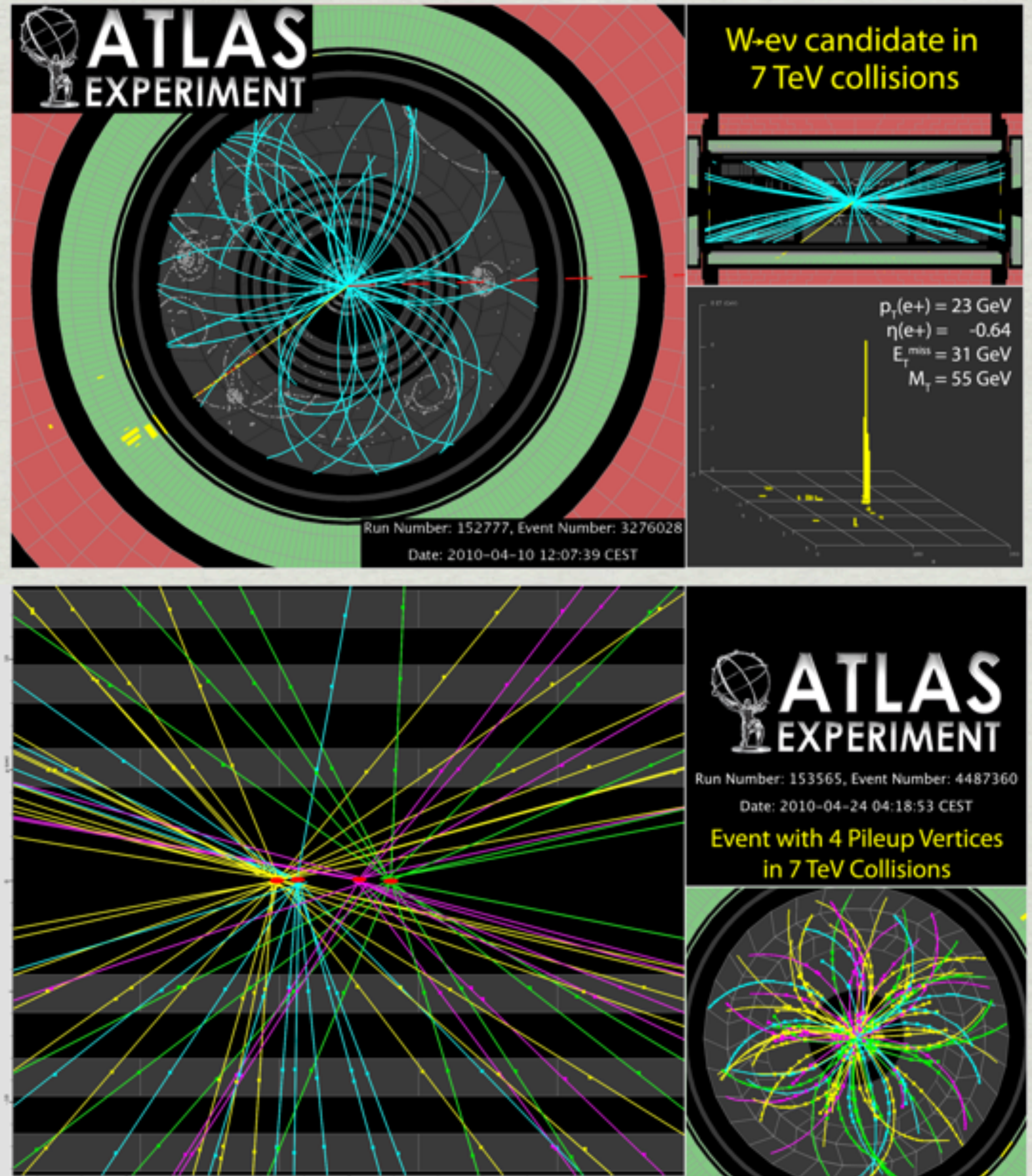


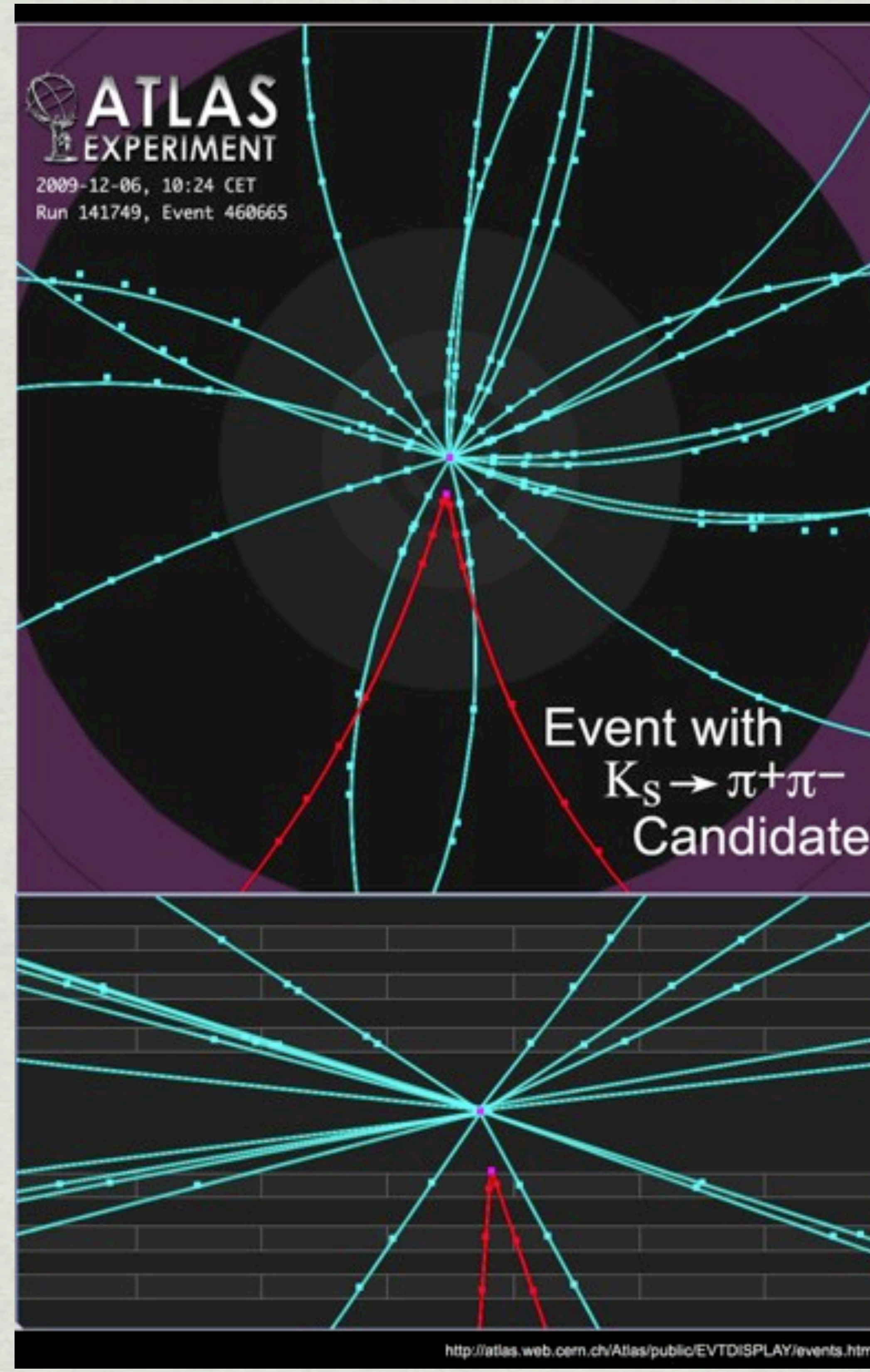
- Sensitive to material discrepancies

Conclusion

- ATLAS Inner Detector fully operational and the level of performance is above the benchmark.
- Alignment in data approaching that of the ideal. Further improvements to come. Effect of systematic weak mode distortions are to be explored.
- Tracking/ID performance studied in fine detail through measurement of charged particle multiplicities. In general good agreement between data and MC.
- Tracker is ready to meet requirements for physics analysis
- See related talks/posters at ICHEP 2010
  - Talk “Performance of Track and Vertex Reconstruction and B-Tagging Studies” J. Fleckner.
  - Talk “Early Material Studies at the ATLAS Experiment” A. Morley
  - Poster “Alignment of ATLAS Inner Detector Tracking System” J. Wang

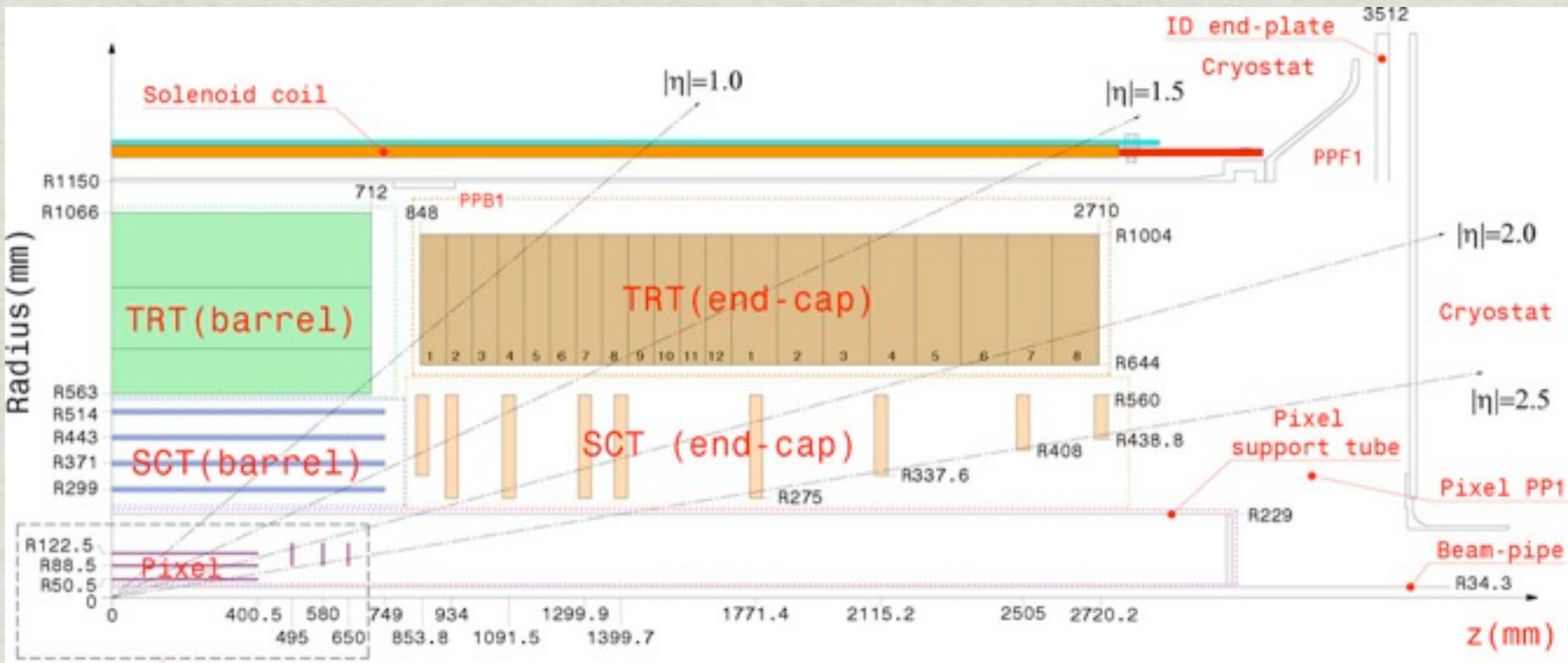
More Inner Detector tracks to come!





Backup Slides

Inner Detector details



Item		Radial extension (mm)	Length (mm)
Pixel	Overall envelope	$45.5 < R < 242$	$0 < \vert z\vert < 3092$
3 cylindrical layers	Sensitive barrel	$50.5 < R < 122.5$	$0 < \vert z\vert < 400.5$
2×3 disks	Sensitive end-cap	$88.8 < R < 149.6$	$495 < \vert z\vert < 650$
SCT	Overall envelope	$255 < R < 549$ (barrel)	$0 < \vert z\vert < 805$
		$251 < R < 610$ (end-cap)	$810 < \vert z\vert < 2797$
4 cylindrical layers	Sensitive barrel	$299 < R < 514$	$0 < \vert z\vert < 749$
2×9 disks	Sensitive end-cap	$275 < R < 560$	$839 < \vert z\vert < 2735$
TRT	Overall envelope	$554 < R < 1082$ (barrel)	$0 < \vert z\vert < 780$
		$617 < R < 1106$ (end-cap)	$827 < \vert z\vert < 2744$
73 straw planes	Sensitive barrel	$563 < R < 1066$	$0 < \vert z\vert < 712$
160 straw planes	Sensitive end-cap	$644 < R < 1004$	$848 < \vert z\vert < 2710$

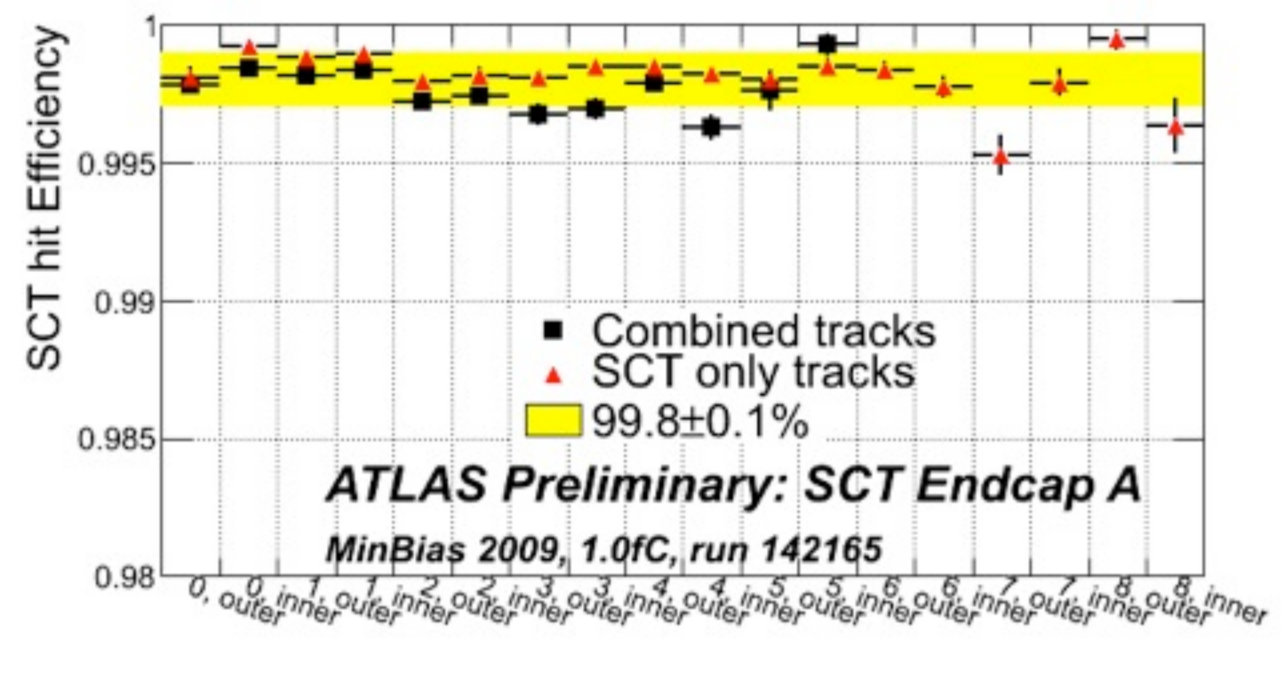
Item	Intrinsic accuracy (μm)	Alignment tolerances (μm)		
		Radial (R)	Axial (z)	Azimuth (R-ϕ)
Pixel				
Layer-0	10 (R-ϕ) 115 (z)	10	20	7
Layer-1 and -2	10 (R-ϕ) 115 (z)	20	20	7
Disks	10 (R-ϕ) 115 (R)	20	100	7
SCT				
Barrel	17 (R-ϕ) 580 (z)[1]	100	50	12
Disks	17 (R-ϕ) 580 (R)[1]	50	200	12
TRT	130			30[2]

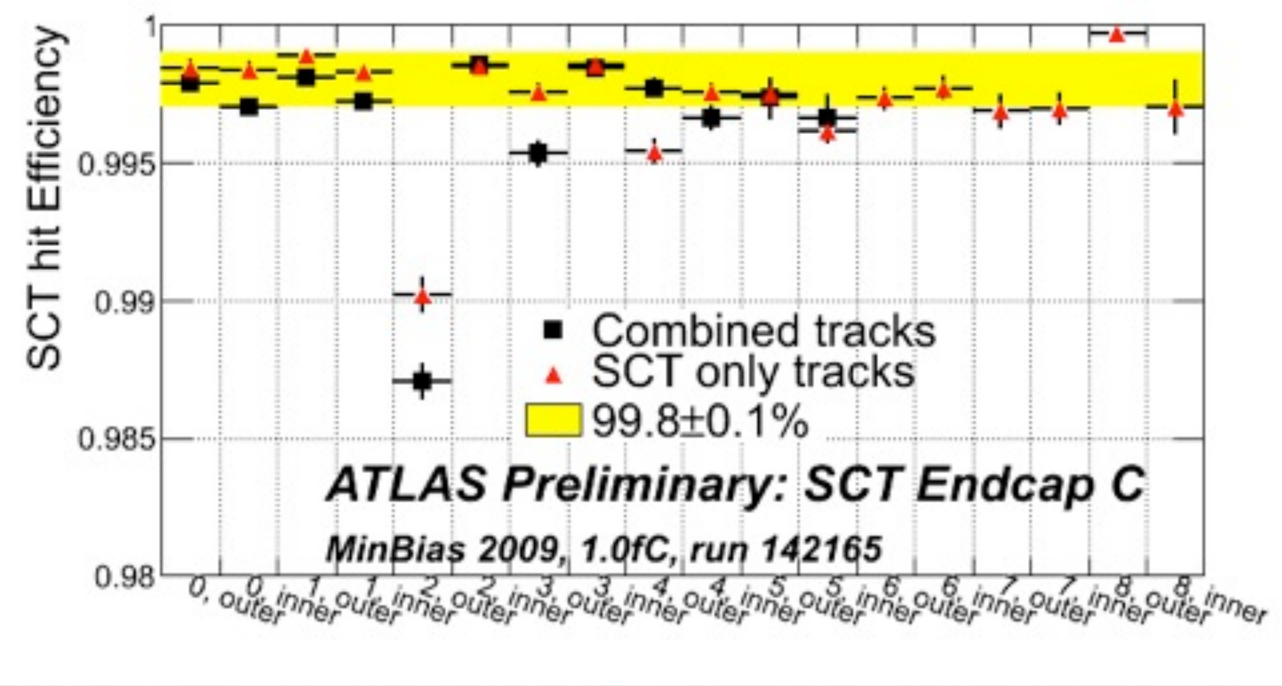
1. Arises from the 40 mrad stereo angle between back-to-back sensors on the SCT modules with axial (barrel) or radial (end-cap) alignment of one side of the structure. The result is pitch-dependent for end-cap SCT modules.
2. The quoted alignment accuracy is related to the TRT drift-time accuracy.

Data and Simulation

- Cosmic Ray data recorded in 2008 and 2009
- Collisions recorded at $\sqrt{s}$=900 GeV (2009), $\sqrt{s}$=2.36 TeV (2009) $\sqrt{s}$=7 TeV (2010)
- Monte Carlo (MC) simulation of non-diffractive proton-proton collisions. PYTHIA is used to generate 2$\rightarrow$2 parton scattering
- Generated events passed through a detailed GEANT4 toolkit based simulation of the ATLAS detector

SCT endcap hit efficiency





TRT Endcap Plots