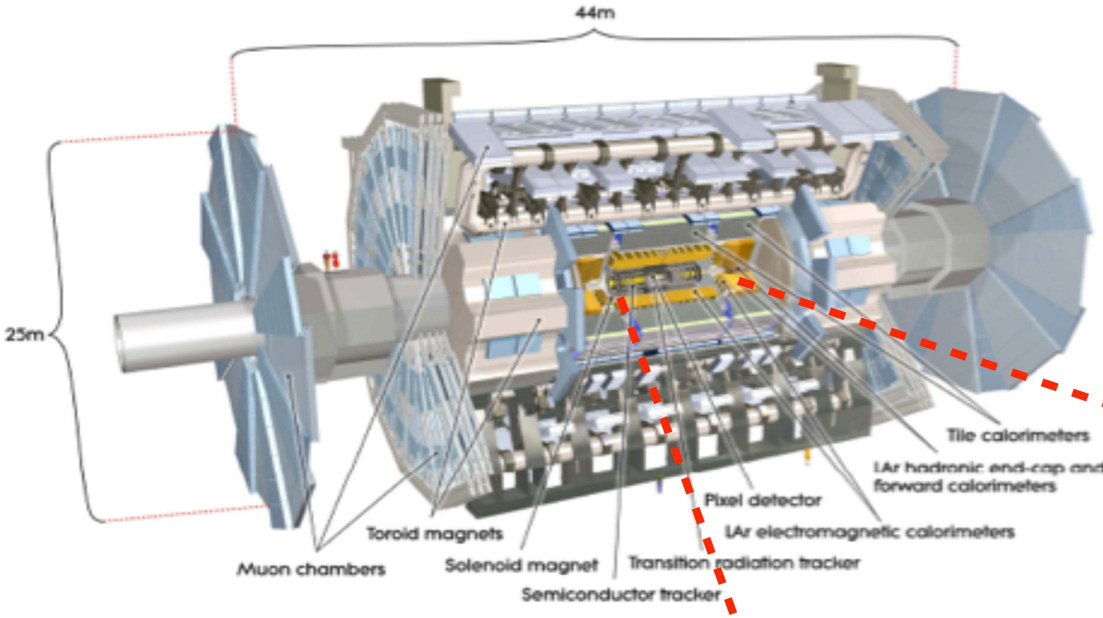
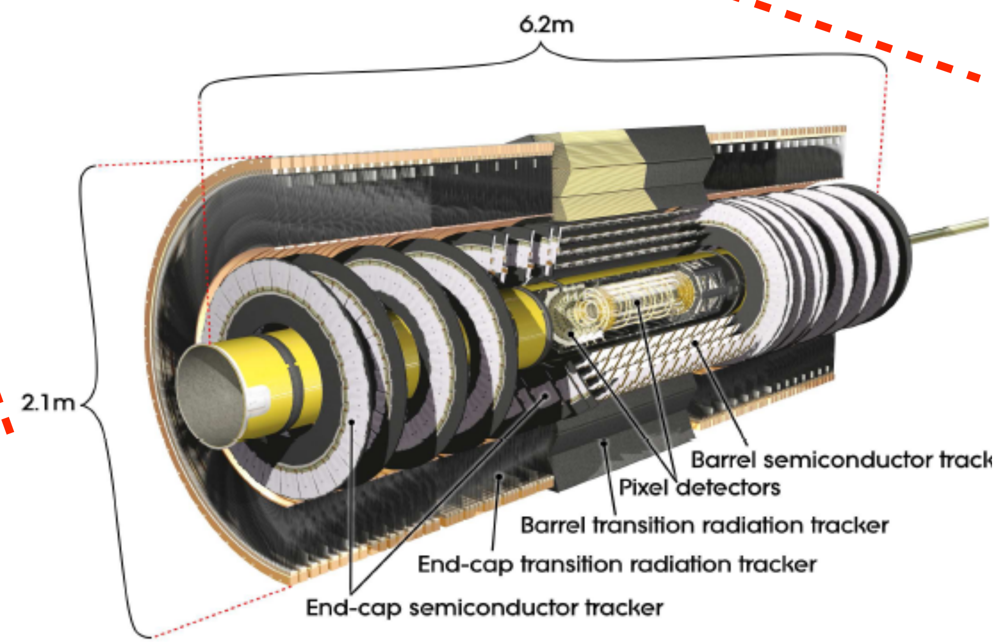
Performance of the ATLAS Transition Radiation Tracker

Introduction to ATLAS

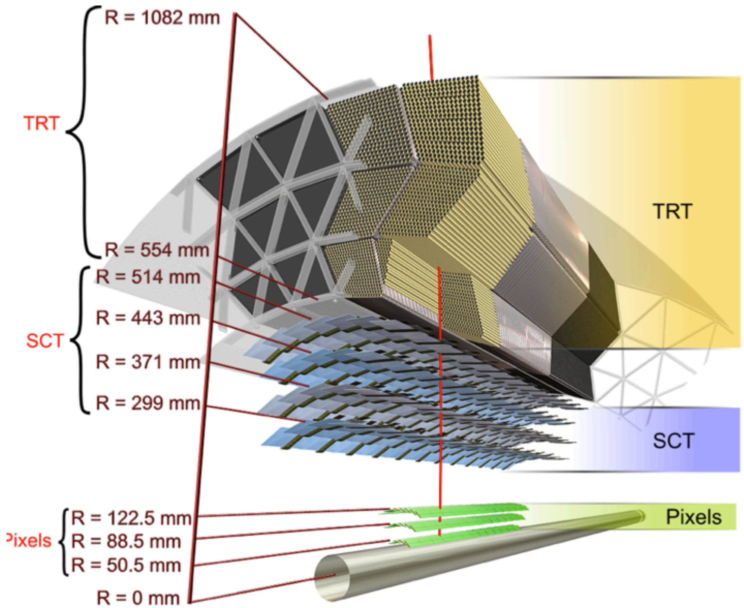


ATLAS is a multi-purpose detector observing proton-proton (or ion-ion) collisions at the LHC. Good tracking, calorimetry and muon systems ....

Inner Detector consists of Pixel detectors, the SemiConductor Tracker (SCT) and the Transition Radiation Tracker (TRT), all immersed in a 2 T solenoid field



The TRT



TRT Barrel

- 3 x 32 (phi) modules
- 1.44 m straws parallel to beam axis
- Wires electrically split in middle to reduce occupancy
- Each end read out separately
  - First 9/73 layers of straws active only for 312 mm on outer ends
- 105,000 readout channels
- Irregularly spaced polypropylene fiber radiators in between straws

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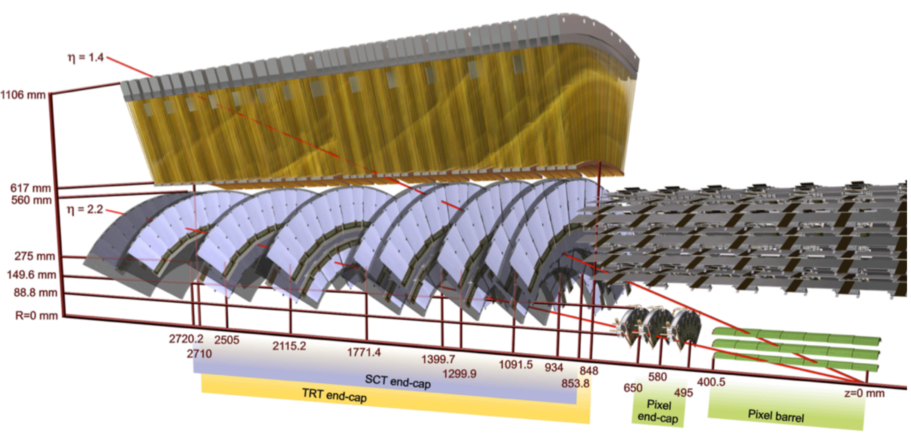
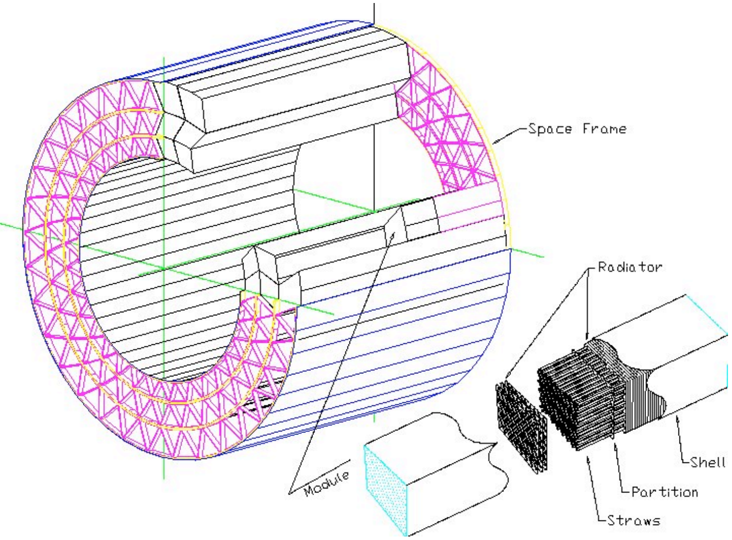


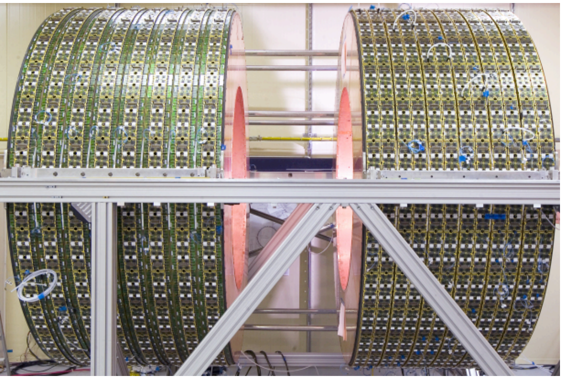
TRT Endcaps

- At smaller z, 6 wheels with 16 layers of straws x 32 (phi)
- At larger z, 8 wheels with 8 layers of straws x 32 (phi)
- Larger spacing at large z
- 39 cm long radial straws
- 123,000 readout channels per endcap
- Plastic radiator foils between each of 160 planes

Assembly

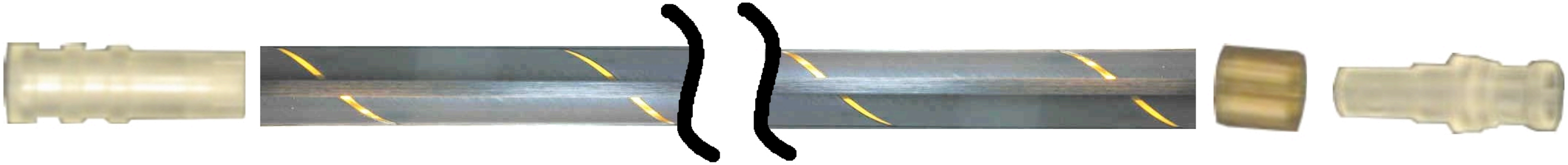


Barrel



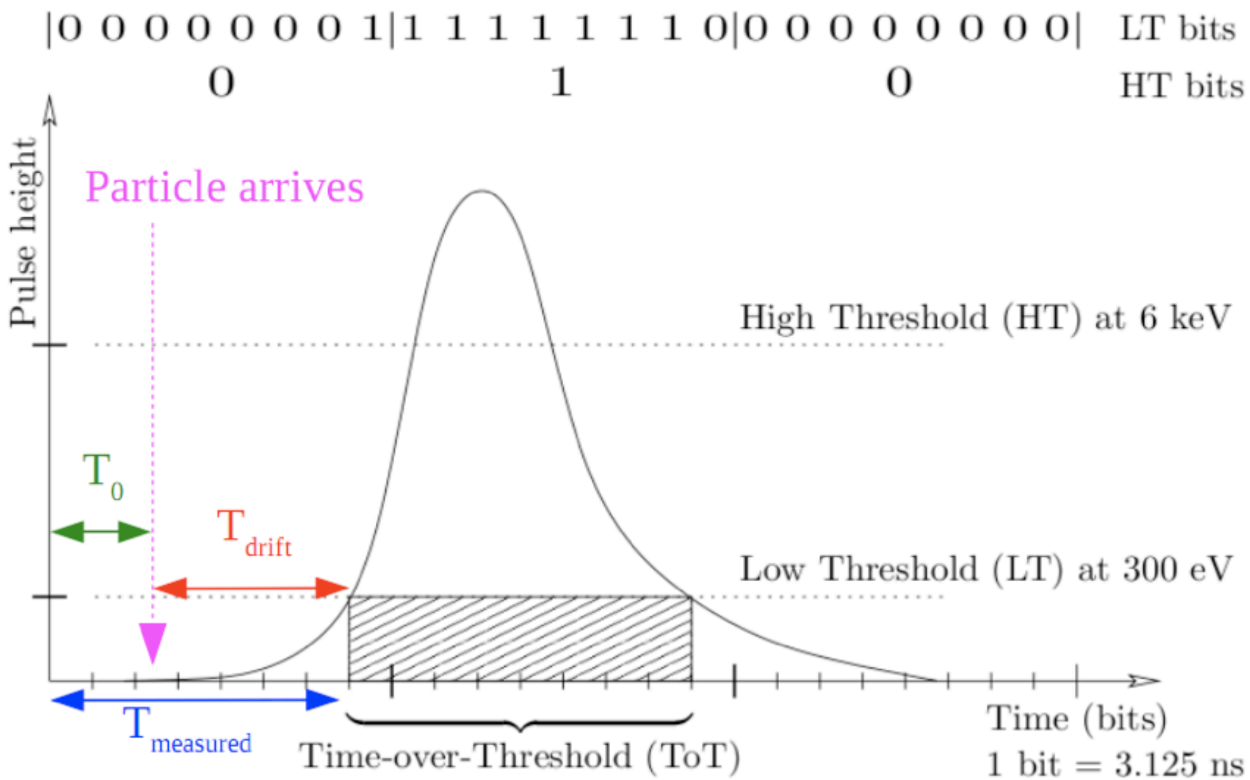
Endcap

The straws



- Diameter of straw = 4 mm
- Straw wall is carbon kapton with carbon fiber supports
  - Straw wall thickness = 70 microns
  - Kept at -1530 volts
- Wire is gold-plated tungsten
  - Diameter = 31 microns
  - Kept at ground
- Gas circulating inside straw: 70% Xe, 27% CO_2, 3% O_2
  - Xenon to absorb transition radiation

Readout

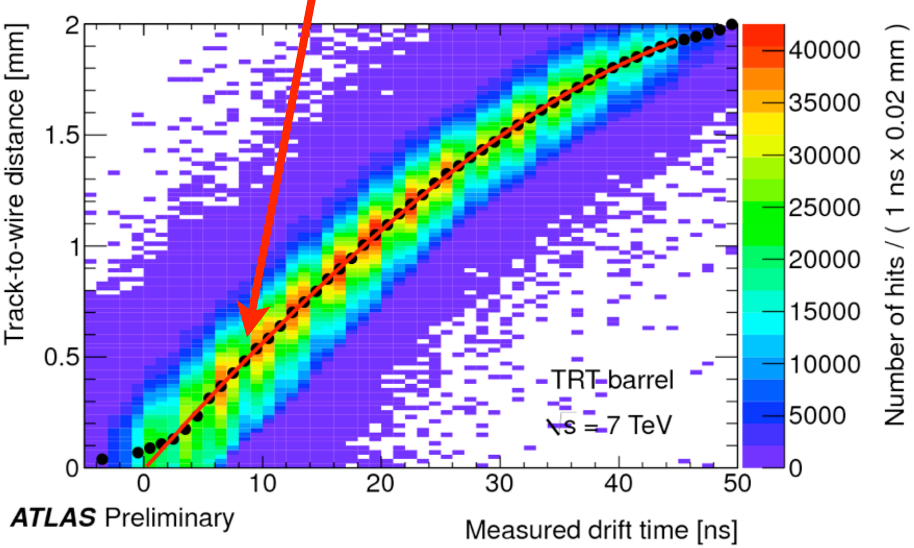


- Each straw signal read out over 75 ns=3 nominal bunch crossings
- The low threshold (tracking) signal is digitized into 24 bins of 3.125 ns
    - Use first 0->1 edge transition for tracking
- The high threshold (TR) signal is digitized 3 times (every 25 ns)

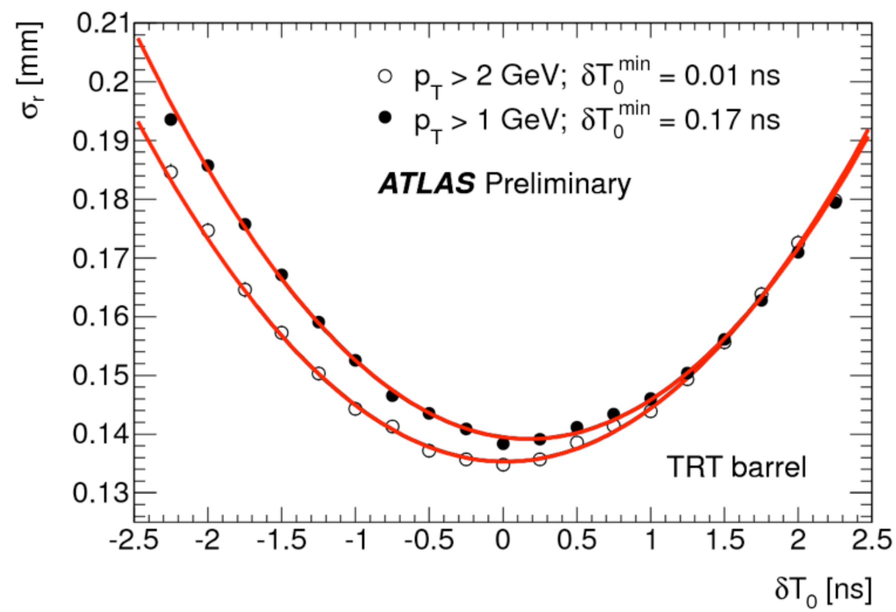
Calibration

- Need to calibrate time offsets (T_0) for two effects:
  - Time of flight. Particles will hit straws further away from interaction region at a later time
  - Any extra electronics/readout/clock shifts

Use T_0-corrected drift time to measure track-to-wire distance

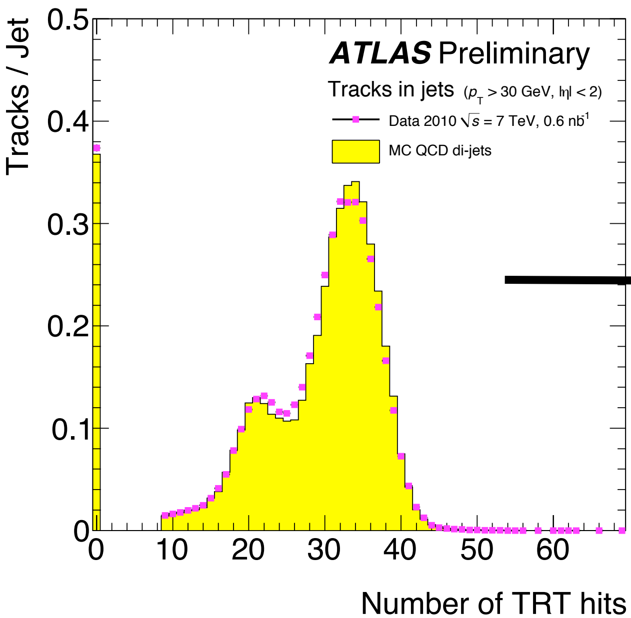


Typically adjust T_0 constants when they shift by more than ~500 ps (resolution shifts by a few microns)

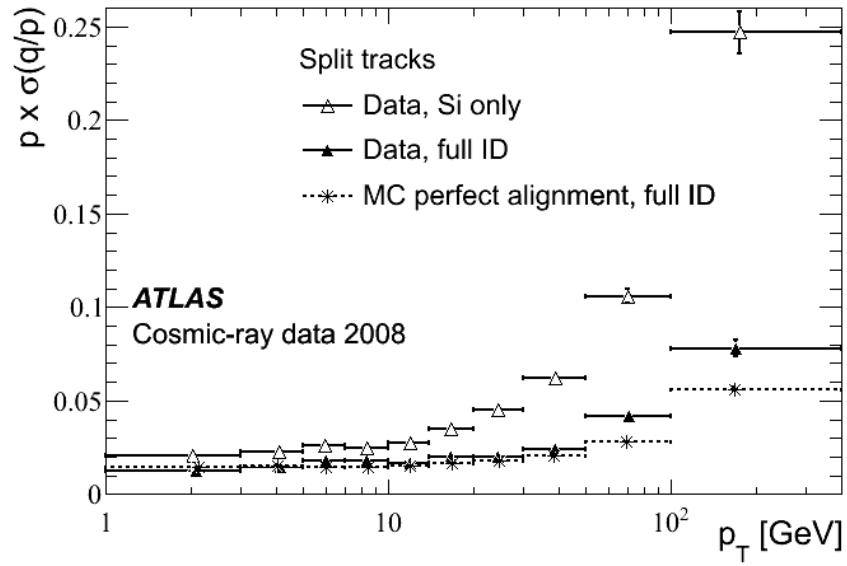


Putting it all together

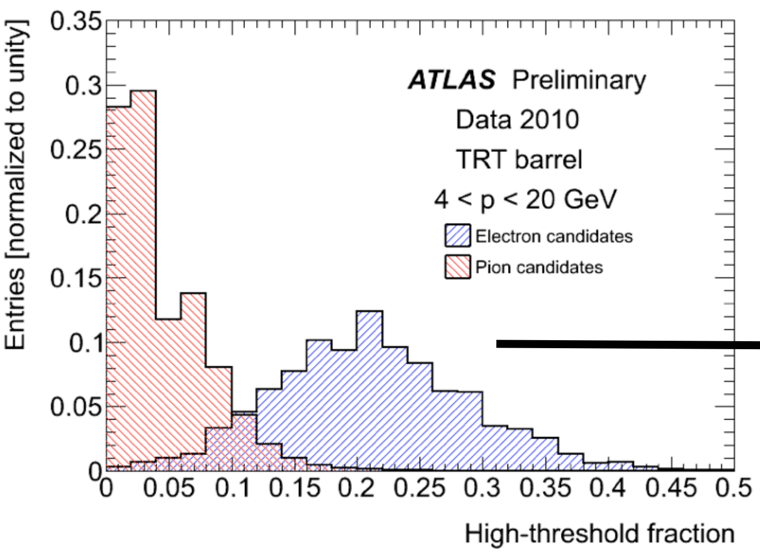
See talks by E. Hines, J.F. Marchand



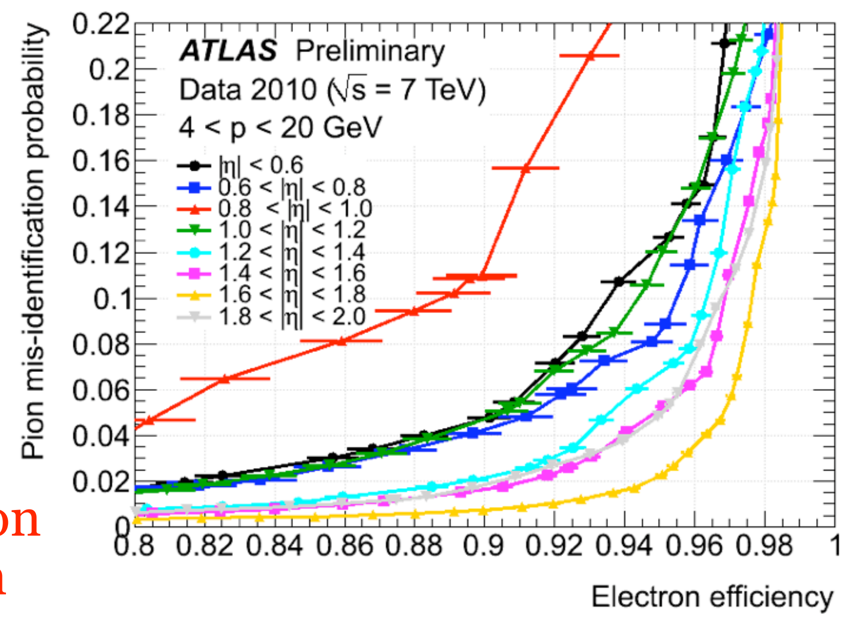
~30 TRT hits per track



TRT contributes significantly to p_T resolution at high pt

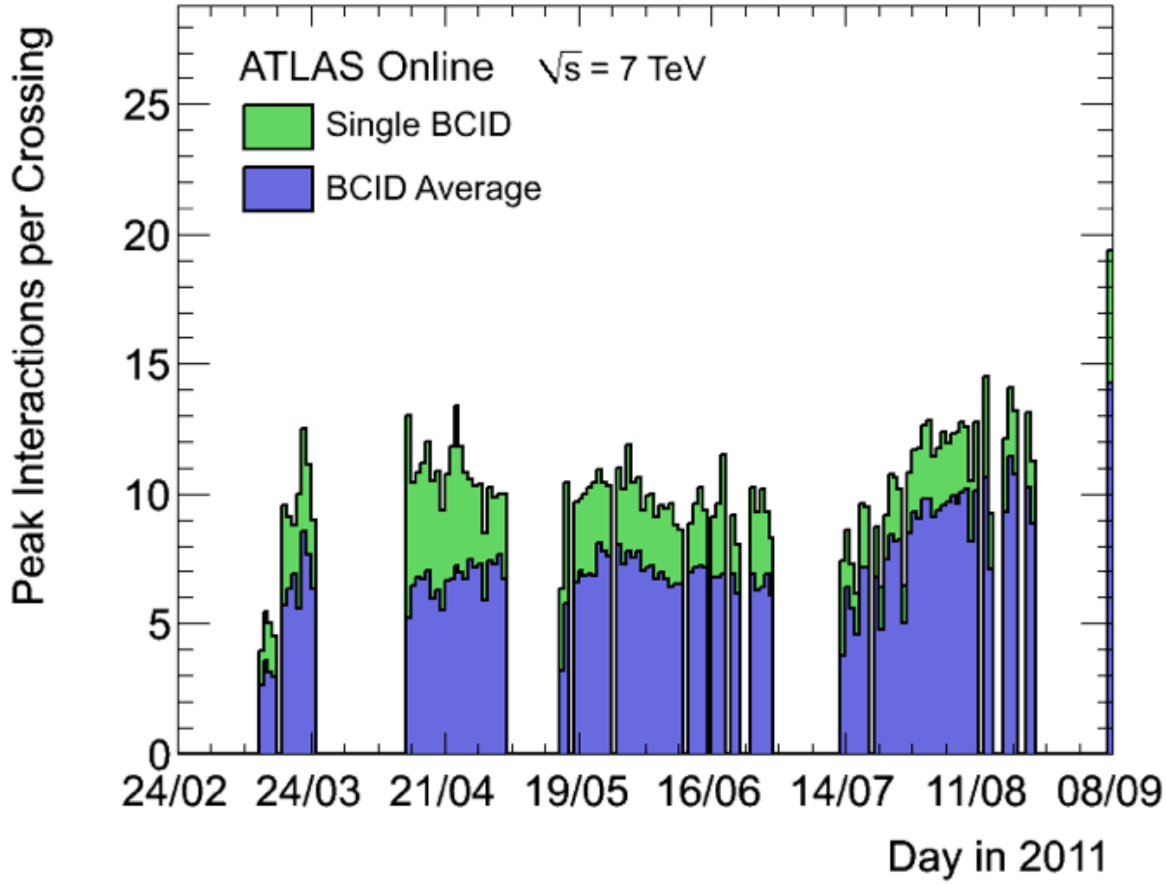


Significant transition radiation



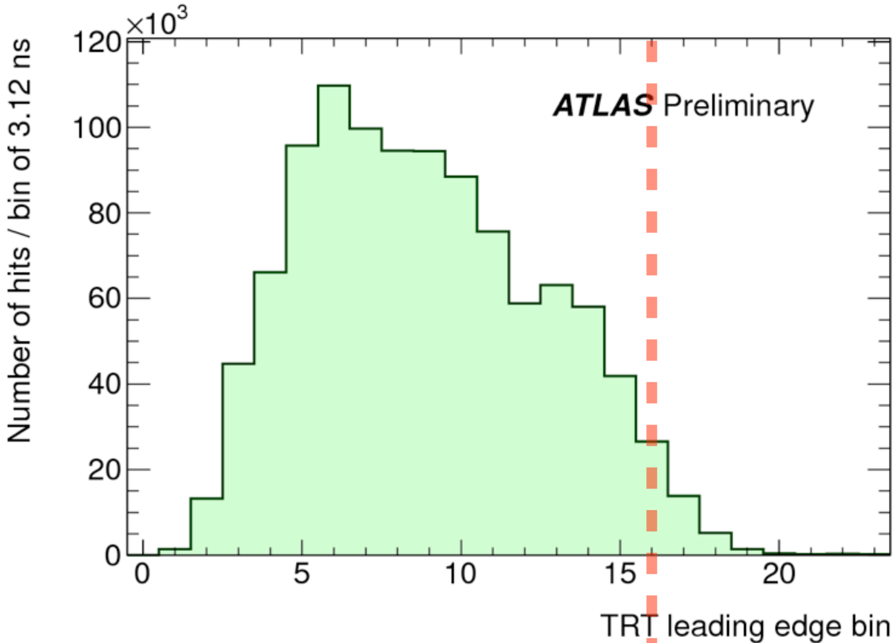
Excellent electron-pion separation

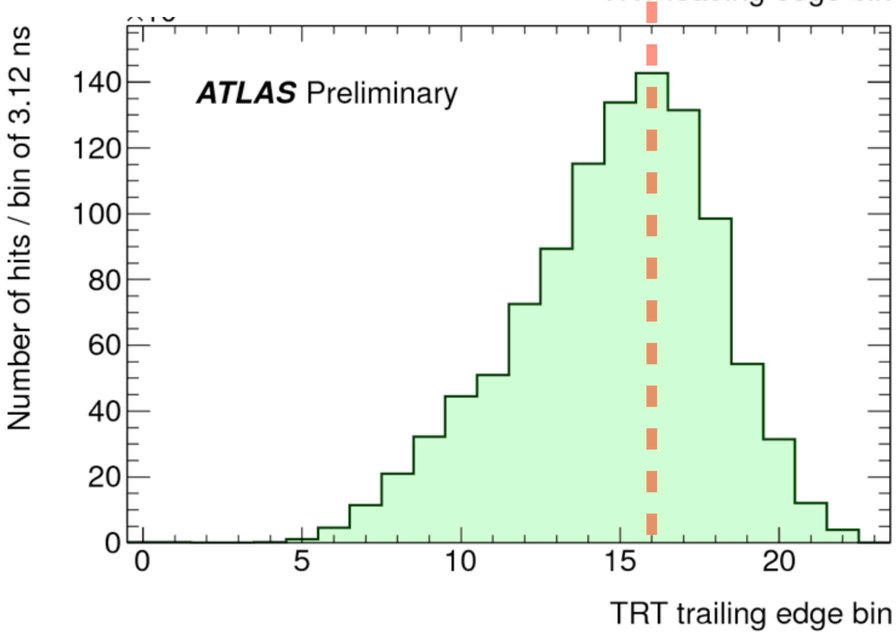
In-time pileup



After recent LHC improvements, close to 15 events per bunch crossing... on average!

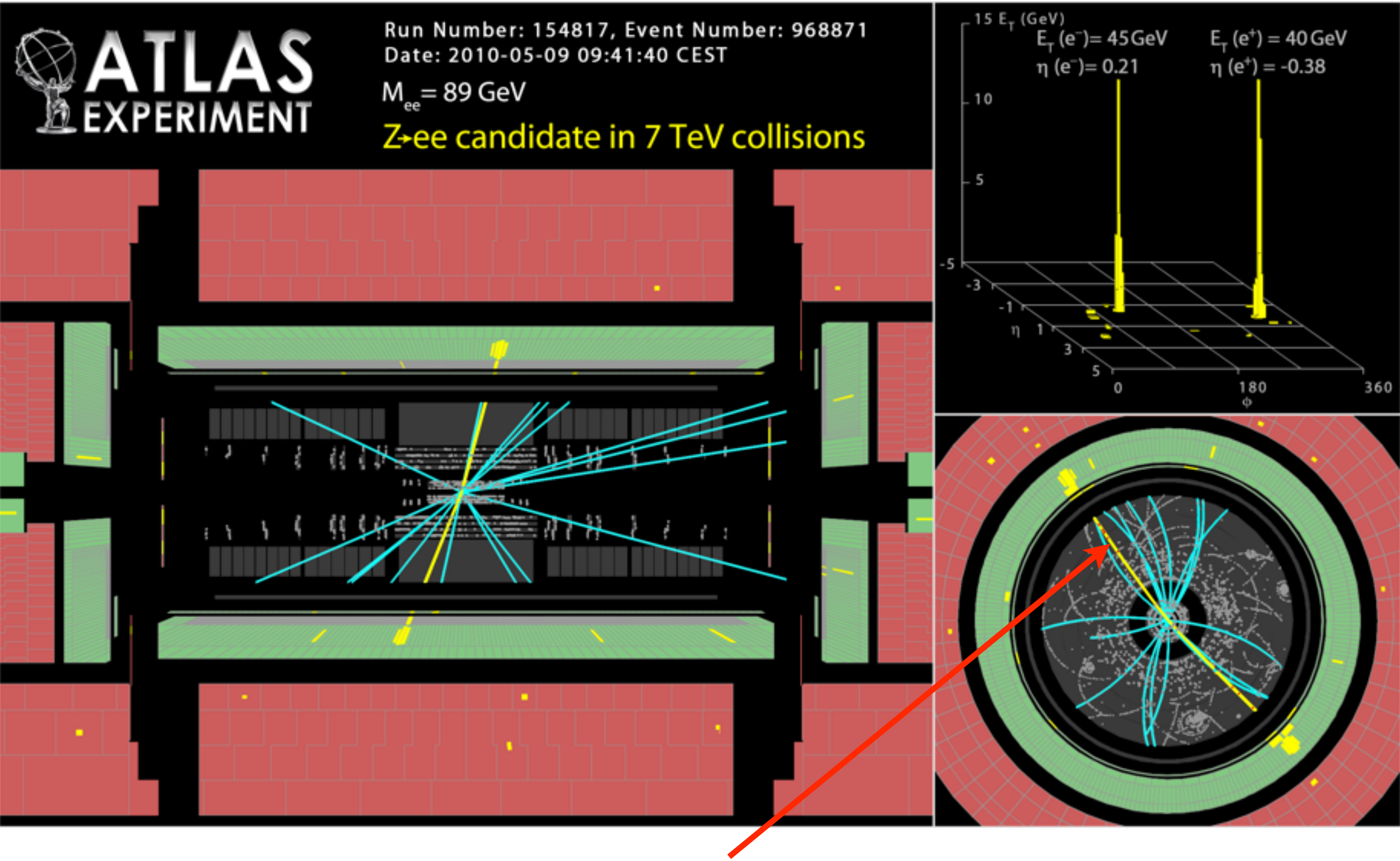
Out-of-time pileup?





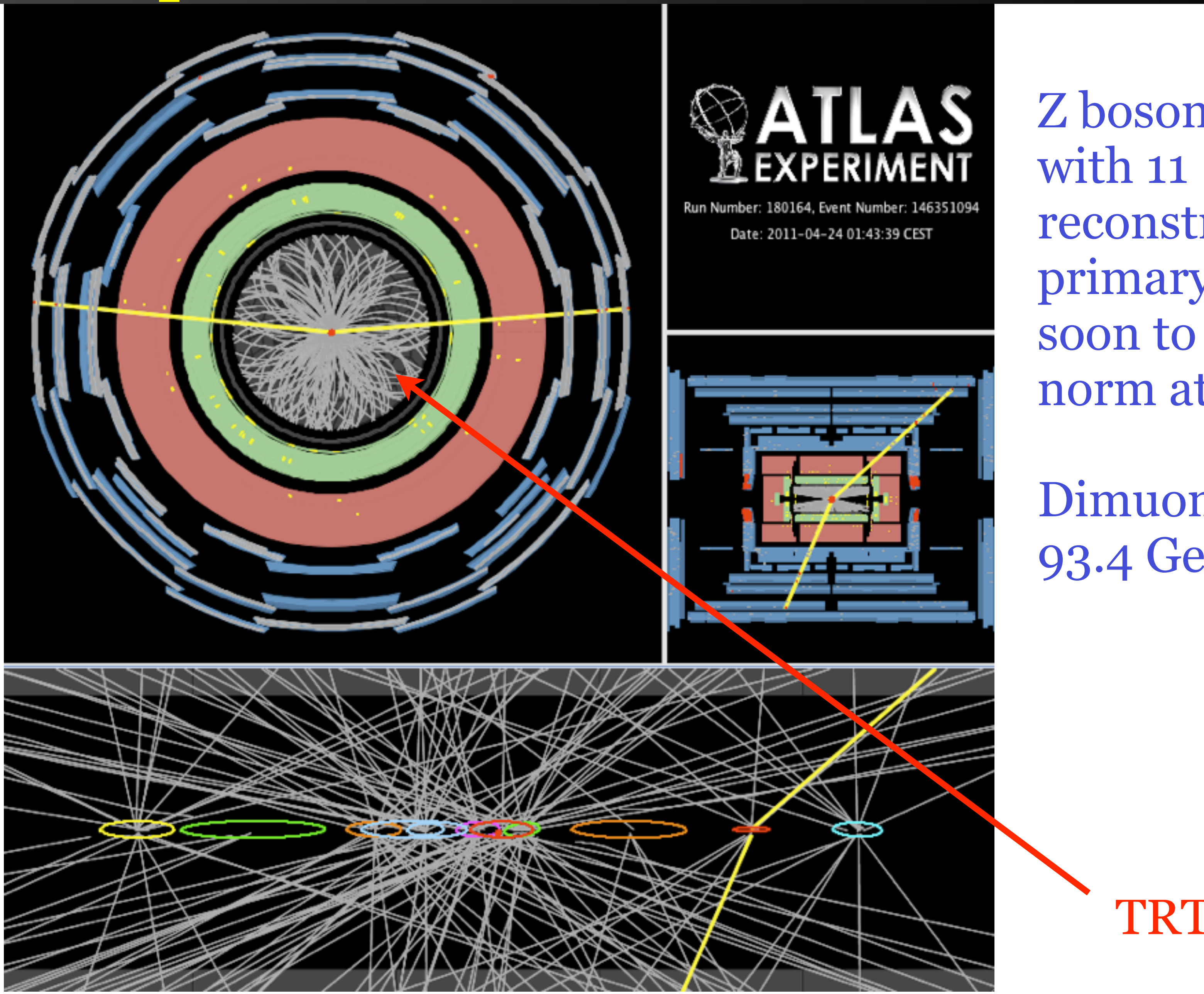
LHC currently running with 50 ns bunch spacing - easily handled by cutting on leading edges that are too large, and requiring valid 0->1 transition. Next year, may see 25 ns spacing!

Z->ee event



TRT High Threshold hits on track

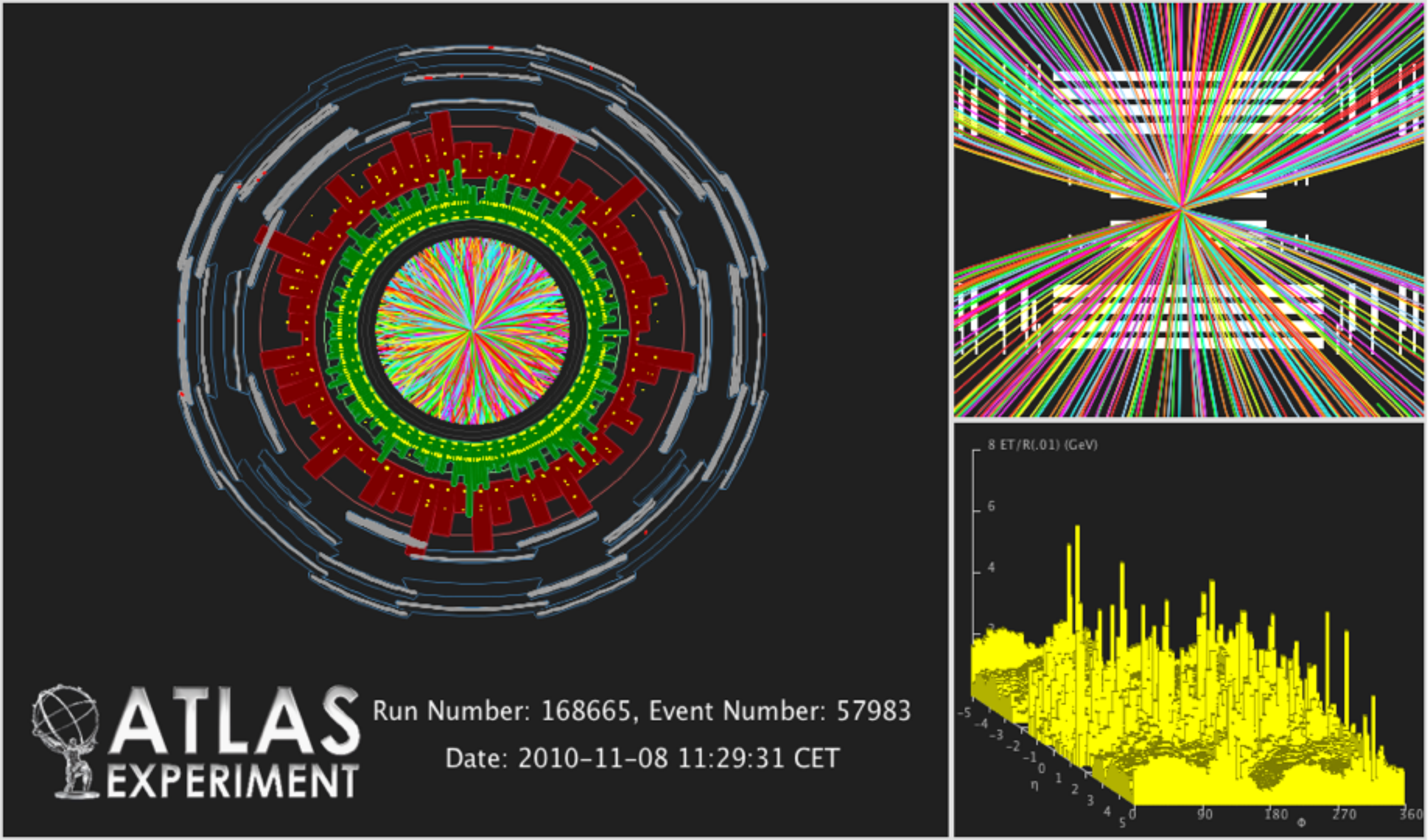
Pileup event



Z boson event with 11 reconstructed primary vertices - soon to be the norm at ATLAS!

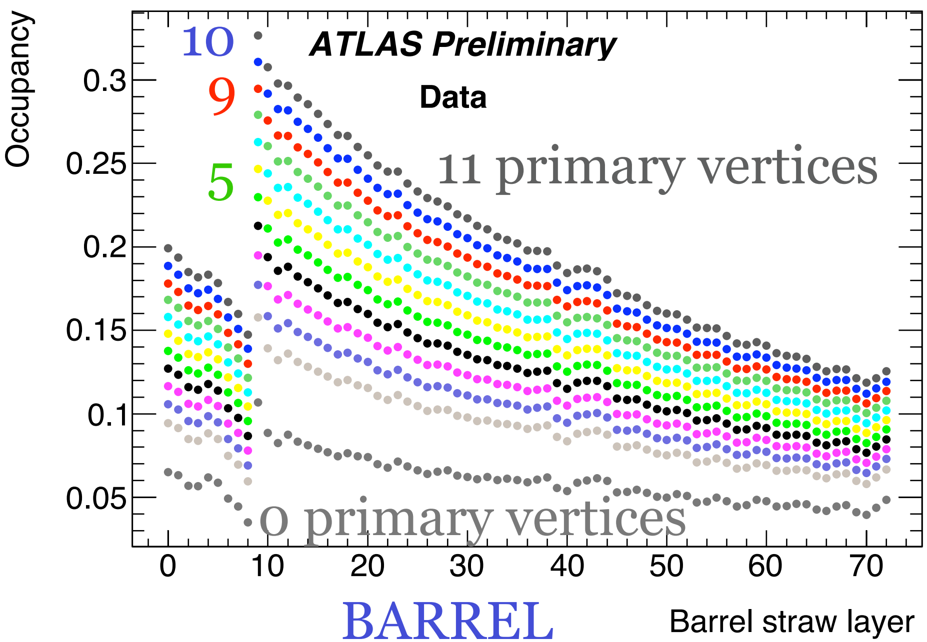
Dimuon mass = 93.4 GeV

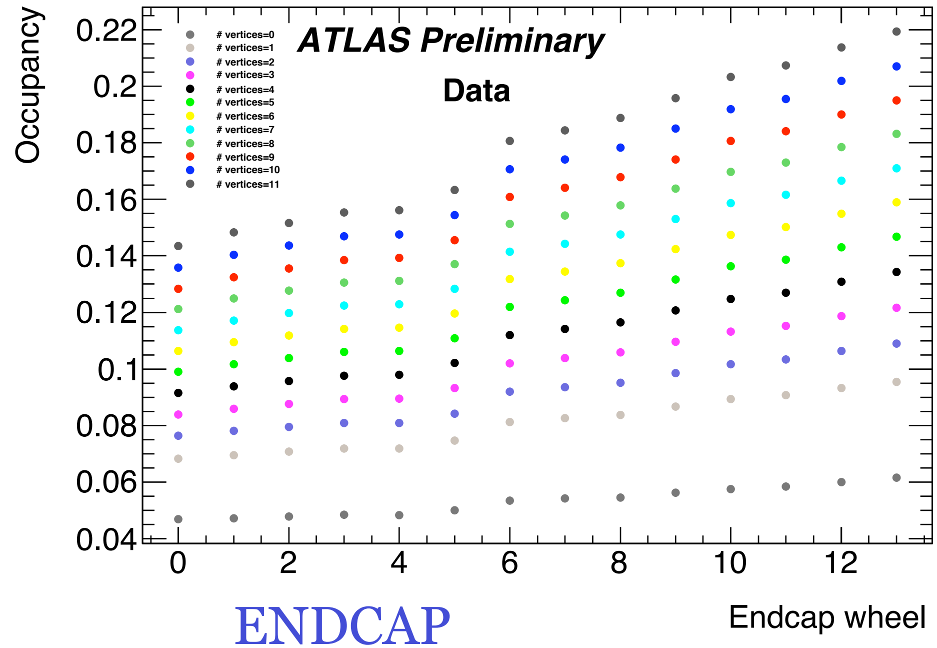
Heavy Ion (Pb-Pb) collision



1115 **reconstructed** tracks with $p_T > 1$ GeV

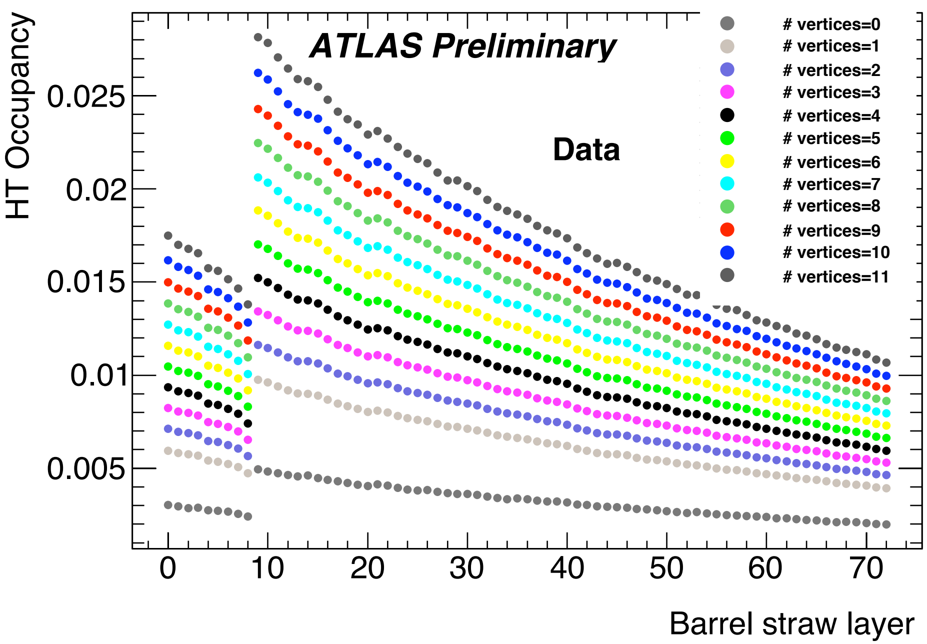
Overall occupancy in pp collisions

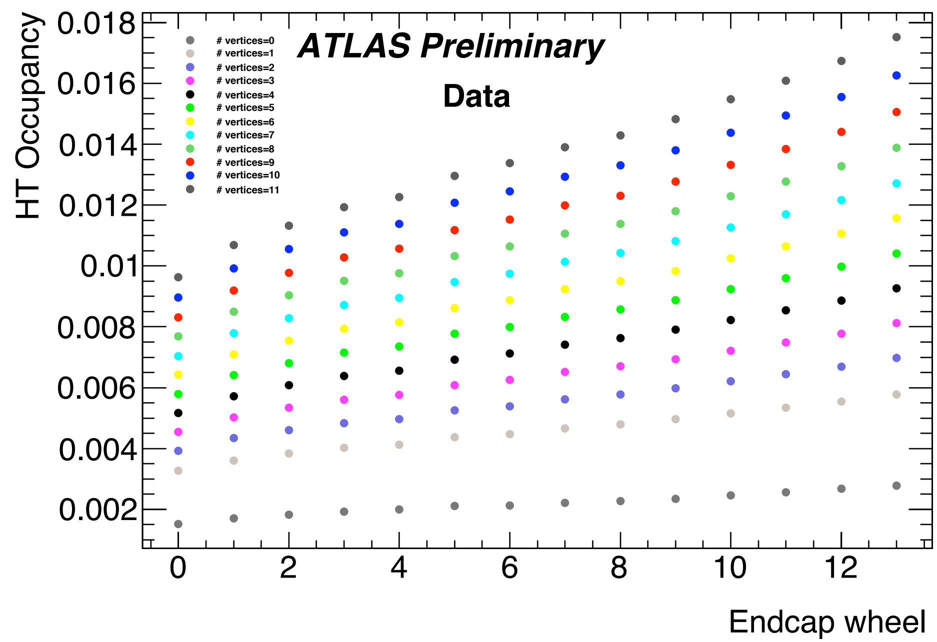




BARREL

ENDCAP

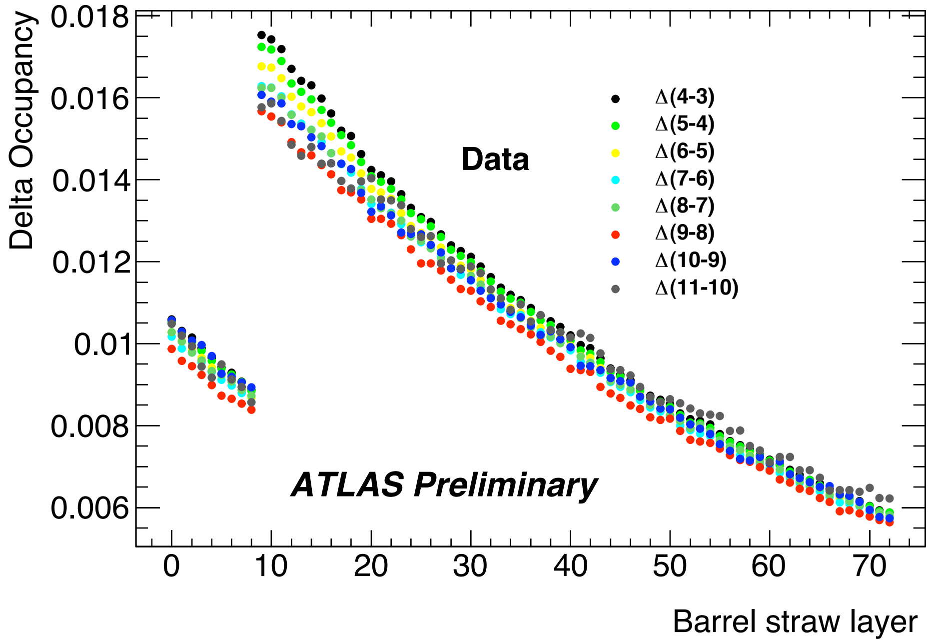


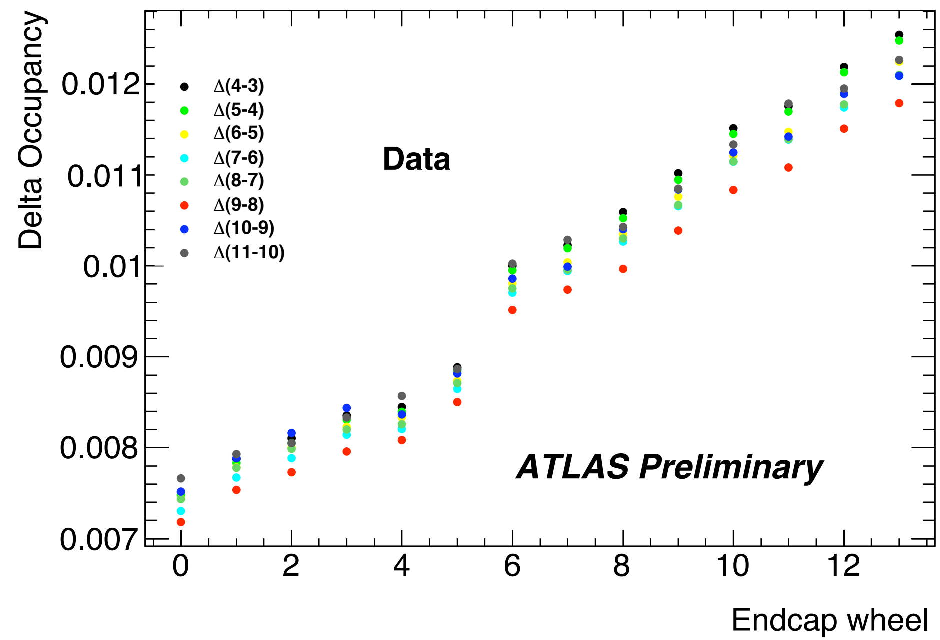


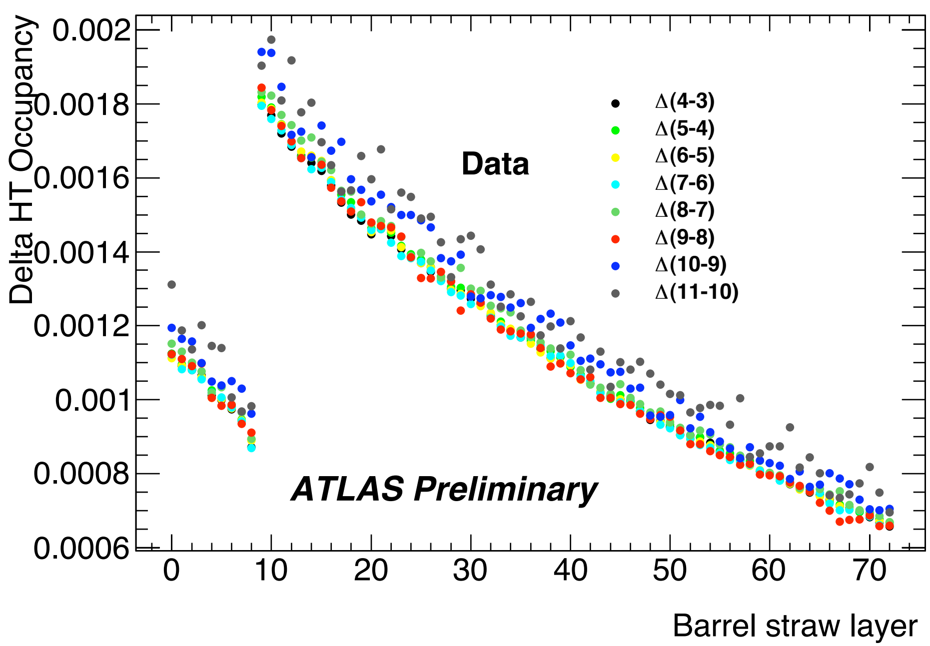
Delta occupancy

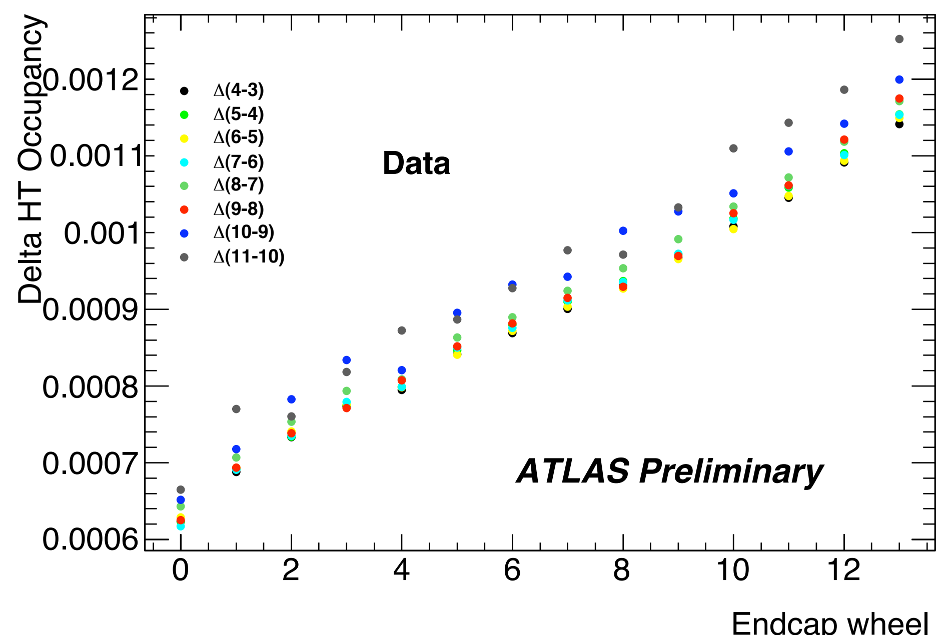
Look at how the occupancy changes as an additional reconstructed primary vertex is found in the event. Should be a measure of the additional in-time occupancy from every minimum bias interaction.

Delta occupancy





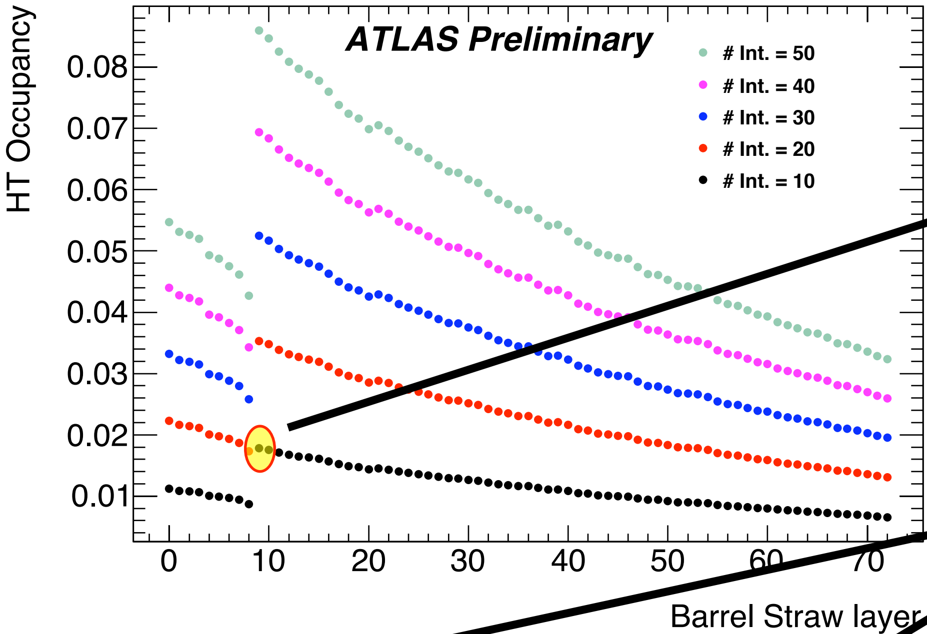


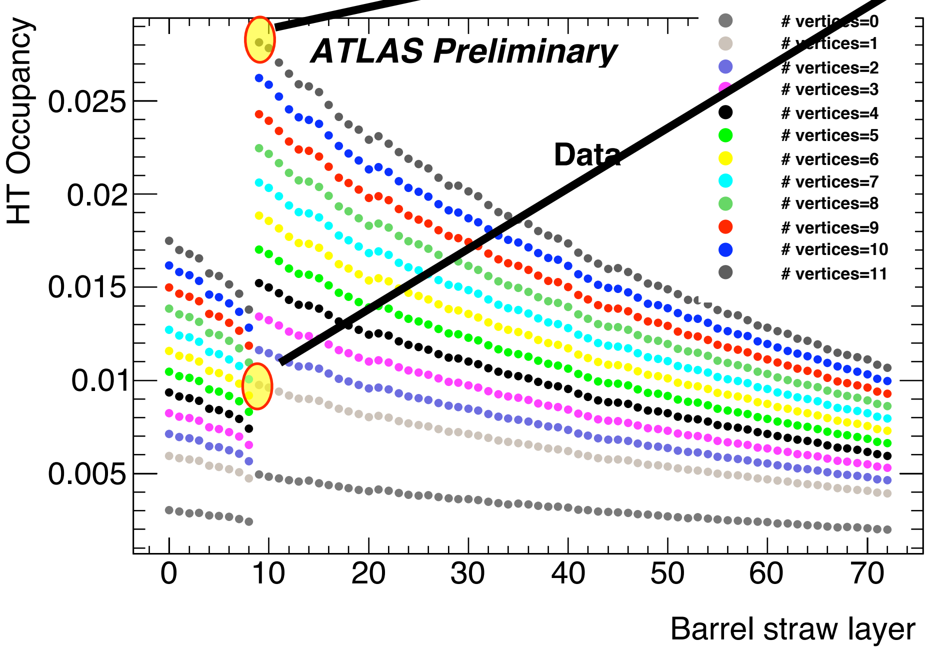


Using delta occupancy

- Do we have lots of overlapping low-energy particles contributing to occupancy at high N interactions?
- P(hit) = x
- P(nohit) = 1-x
- P(nohit) for N interactions = $(1-x)^N$
- P (at least one hit) = 1-P(nohit) = $1-(1-x)^N$
- This probability can be compared to the measured occupancy in data. Look at occupancy for N+1 interactions and subtract occupancy at 1 interaction (this removes the extra dependency on the hard scattering physics process)

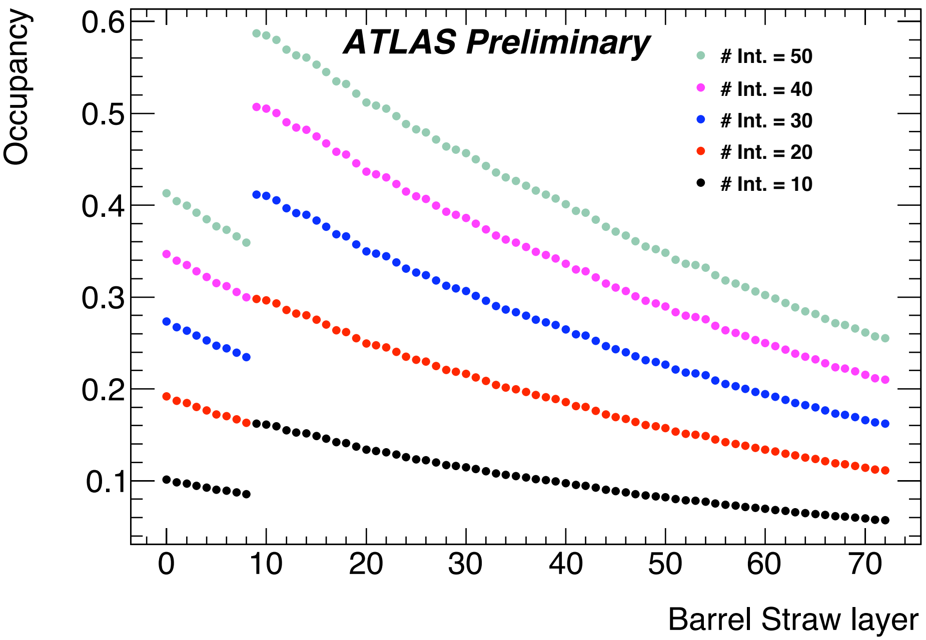
Comparing HT prediction to observation

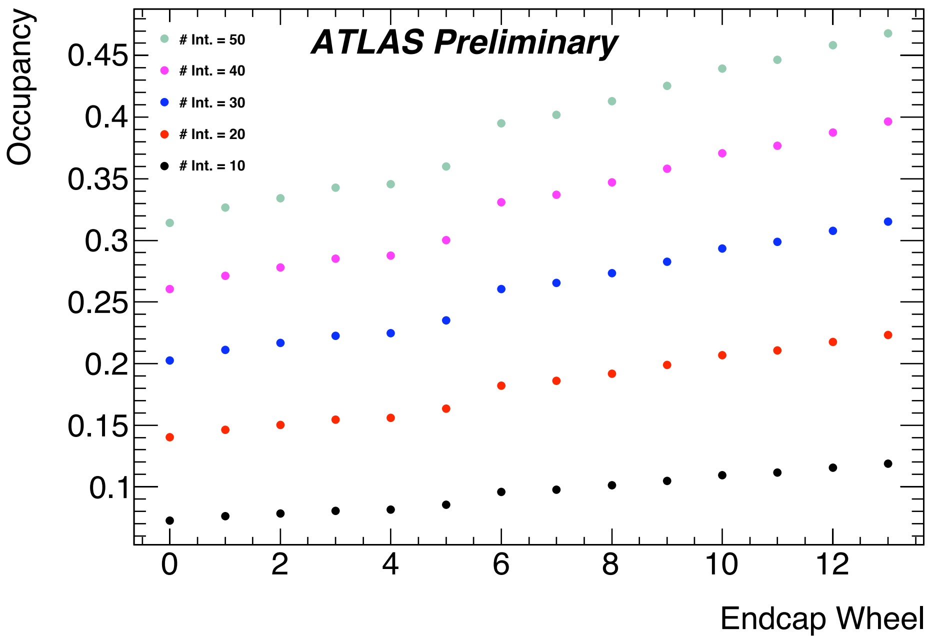




- At 10 interactions, predict 1.8% HT occupancy at straw layer 10
- We observe 2.8%-1.0-% = 1.8%.
- Results agree

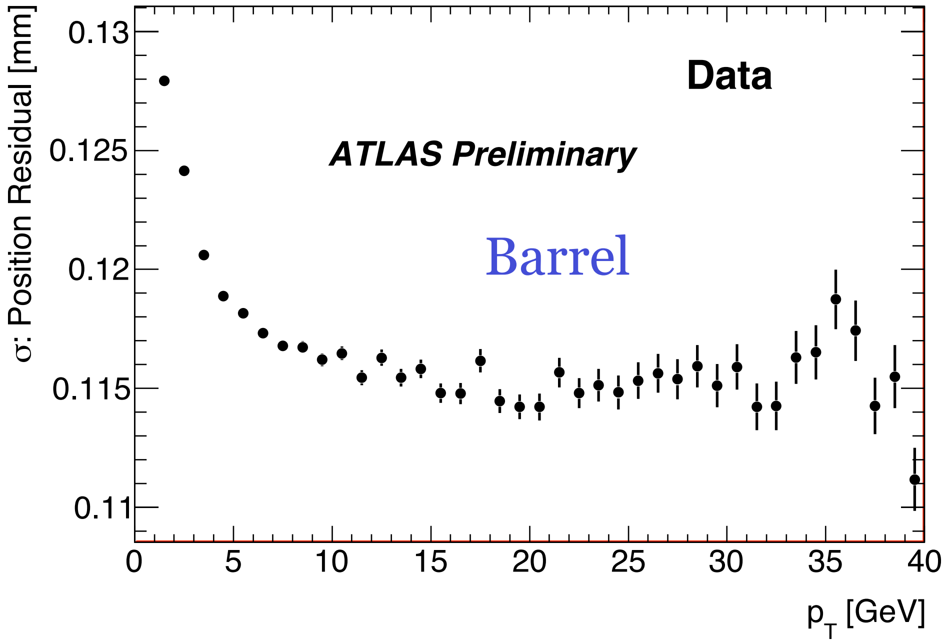
Predicted tracking occupancy



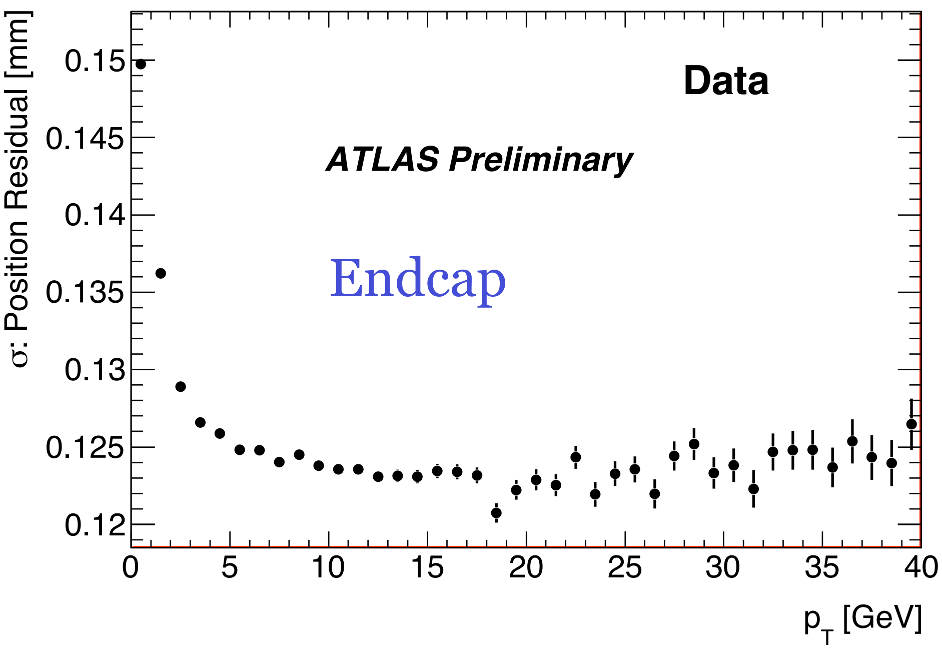


Region	Type	N=11 occupancy	N=1 occupancy	Observation	Prediction for N=10
Barrel Layer 10	LT	33	16	17	16
Barrel Layer 10	HT	2.8	1.0	1.8	1.8
Barrel Layer 72	LT	13	7	6	6
Barrel Layer 72	HT	1.1	0.4	0.7	0.7
Endcap Layer 0	LT	13	6	7	7
Endcap Layer 0	HT	0.9	0.3	0.6	0.6
Endcap Layer 159	LT	20	9	11	11
Endcap Layer 159	HT	1.8	0.6	1.2	1.2

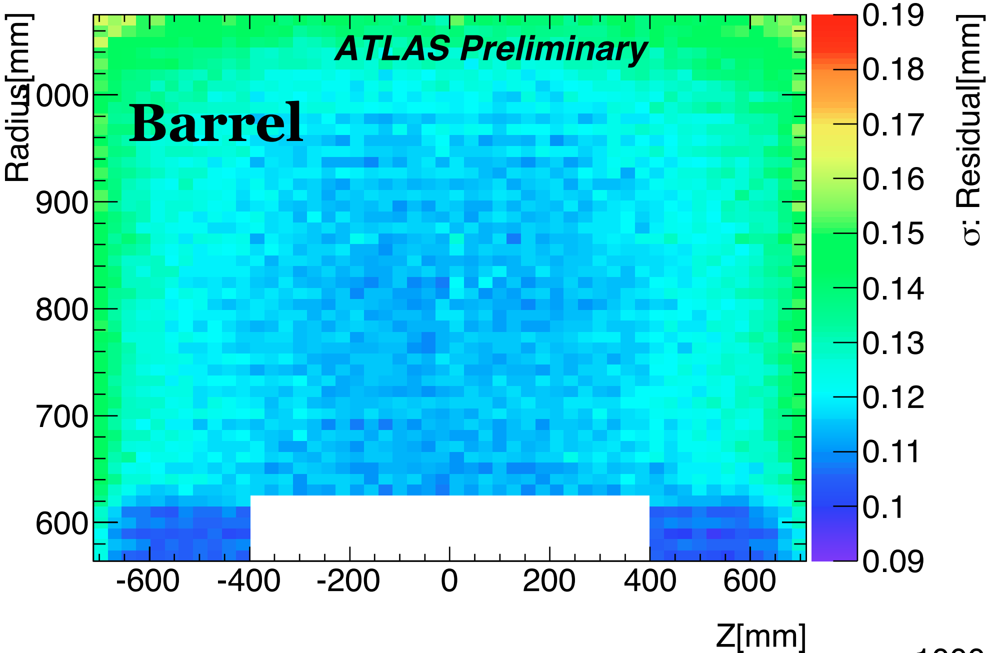
TRT Track Position residuals



Especially in the Endcap, scattering of track is important if $p_T <\sim 10$ GeV

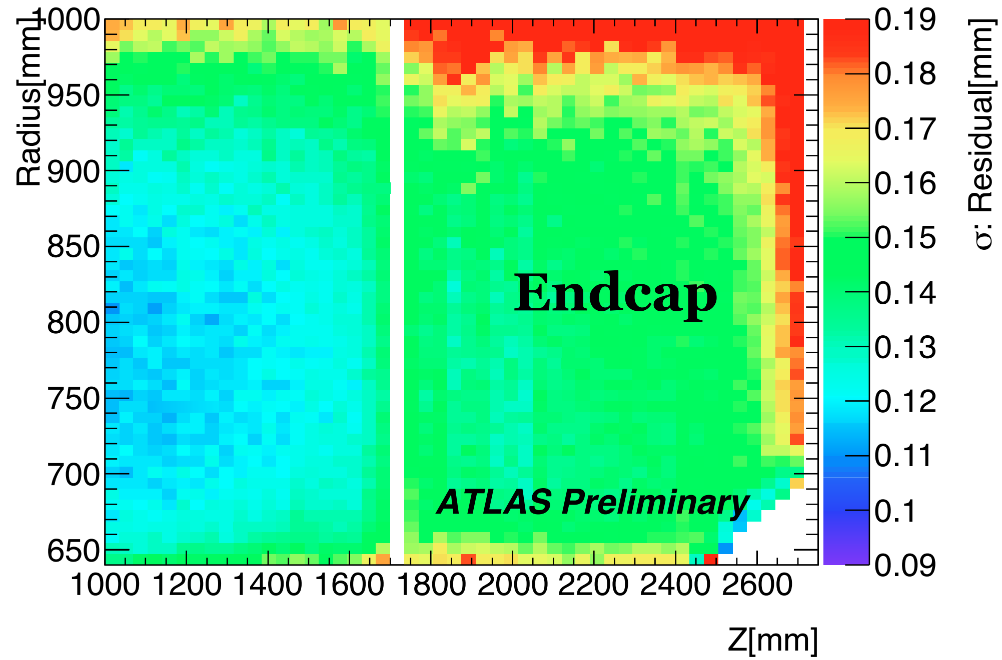


Residuals Maps

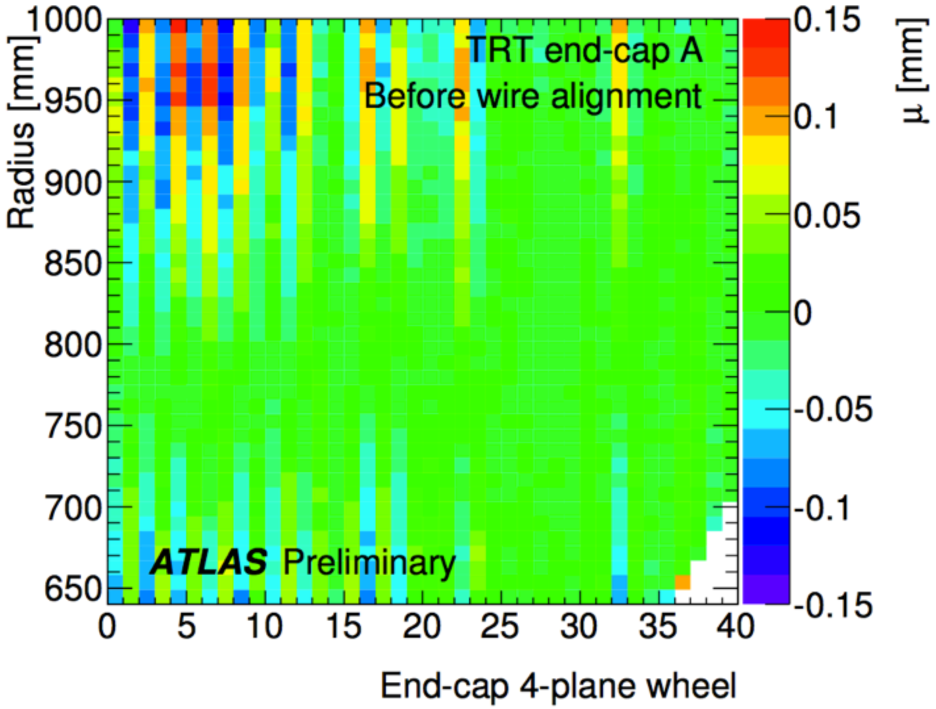


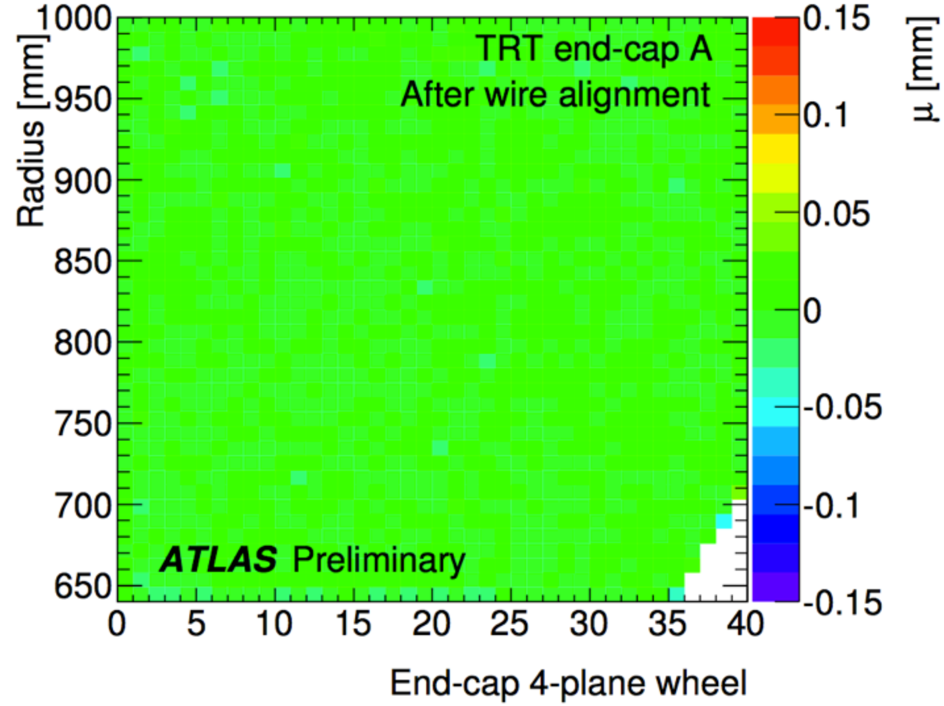
Position residual width as a function of R and Z in data for barrel (left) and endcap A (below). The widening of residuals at large Z and large radius is reproduced by the simulation

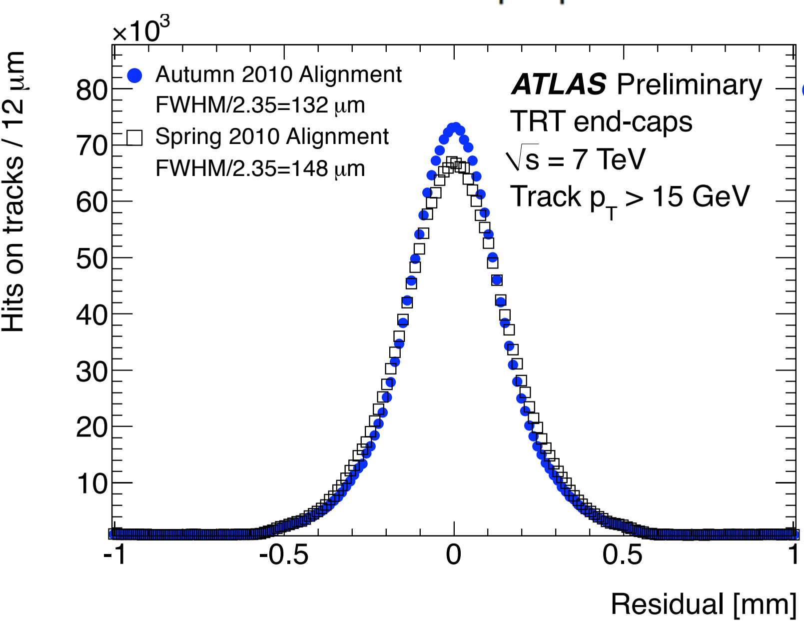
With high pt tracks, have <100 micron resolution in the short straws!



Importance of alignment



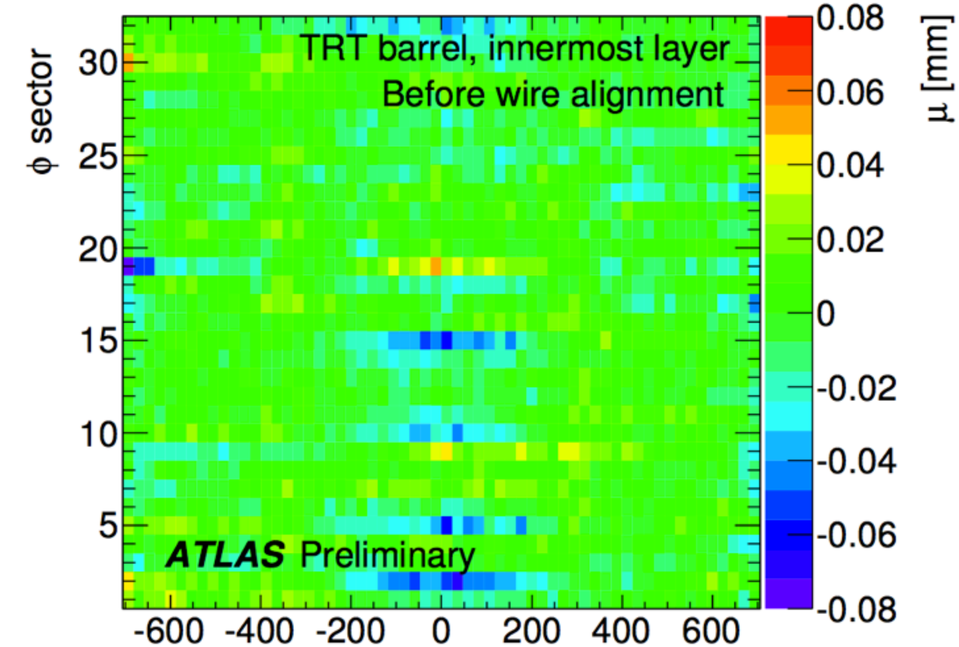


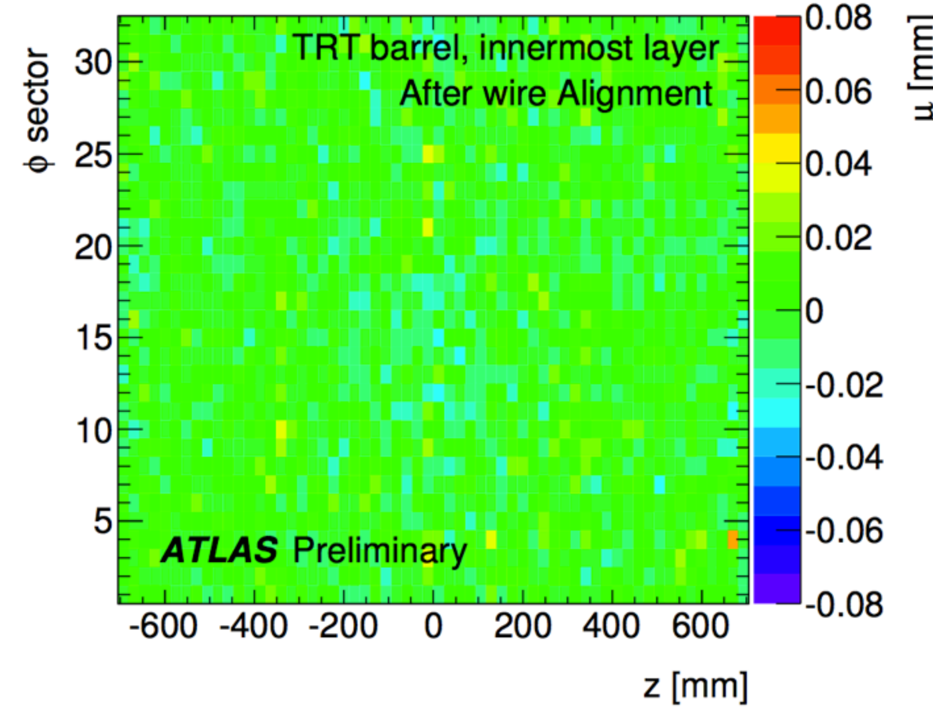


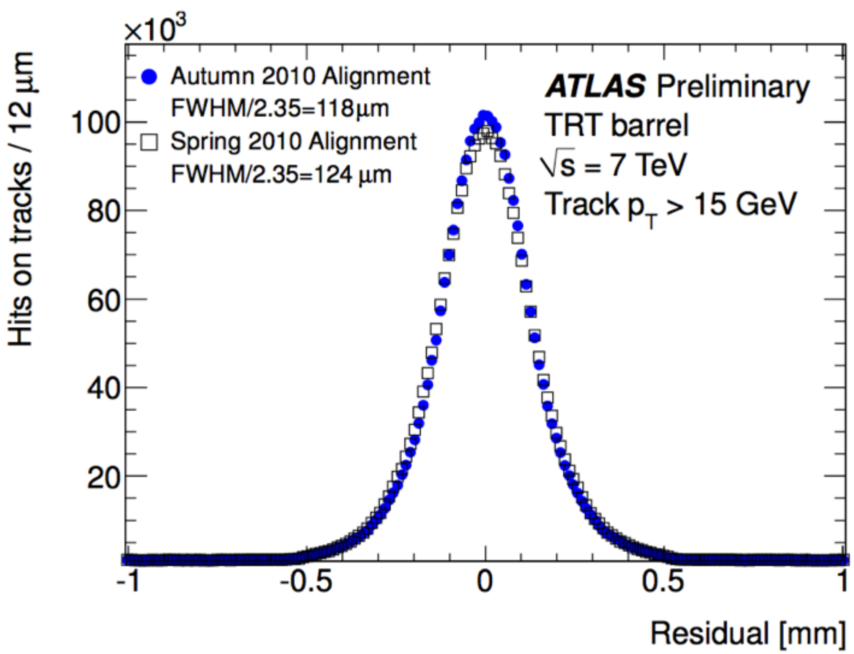
- ● After alignment
- □ Before alignment

Precision alignment of the straws is crucial to good tracking performance!

Importance of alignment





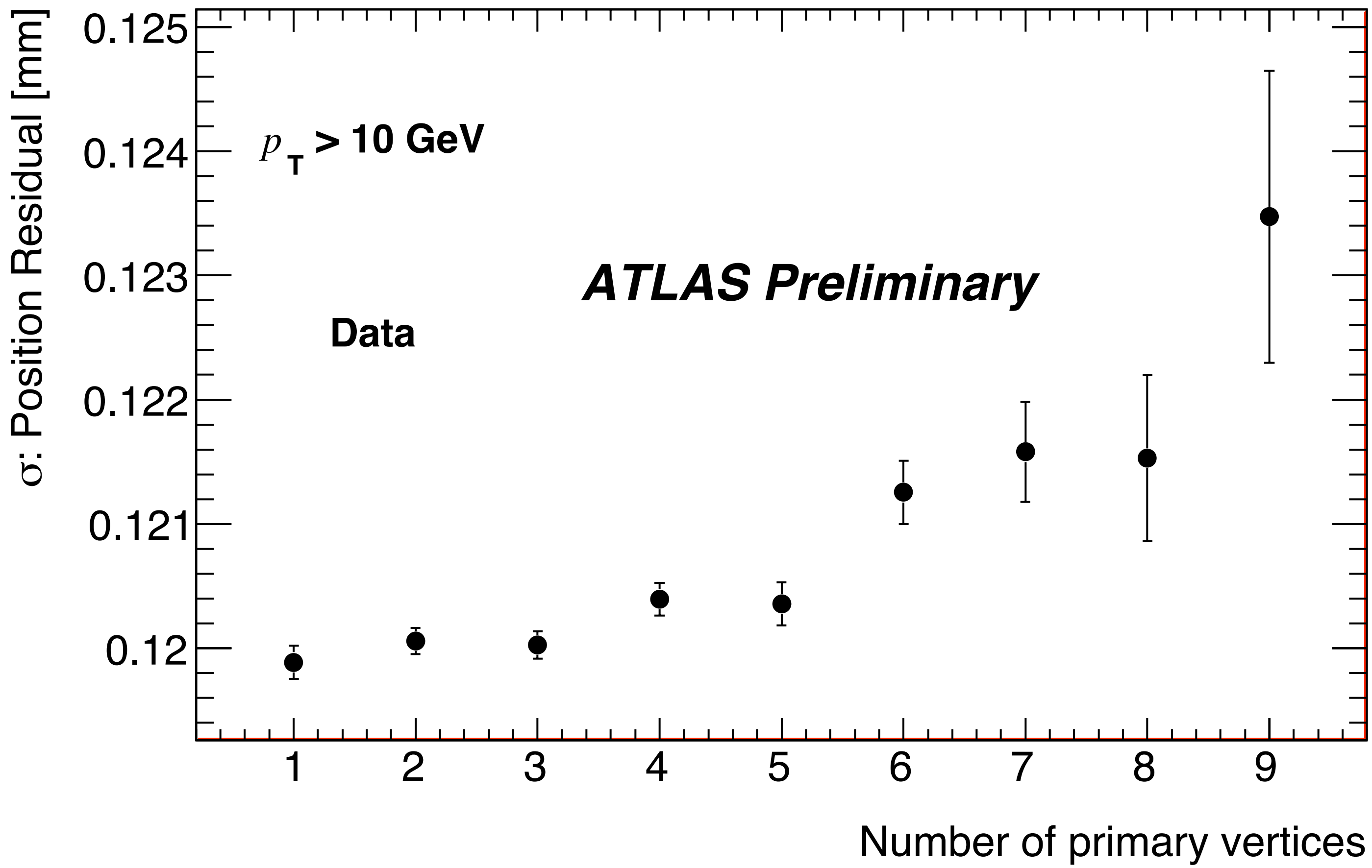


● After alignment

□ Before alignment

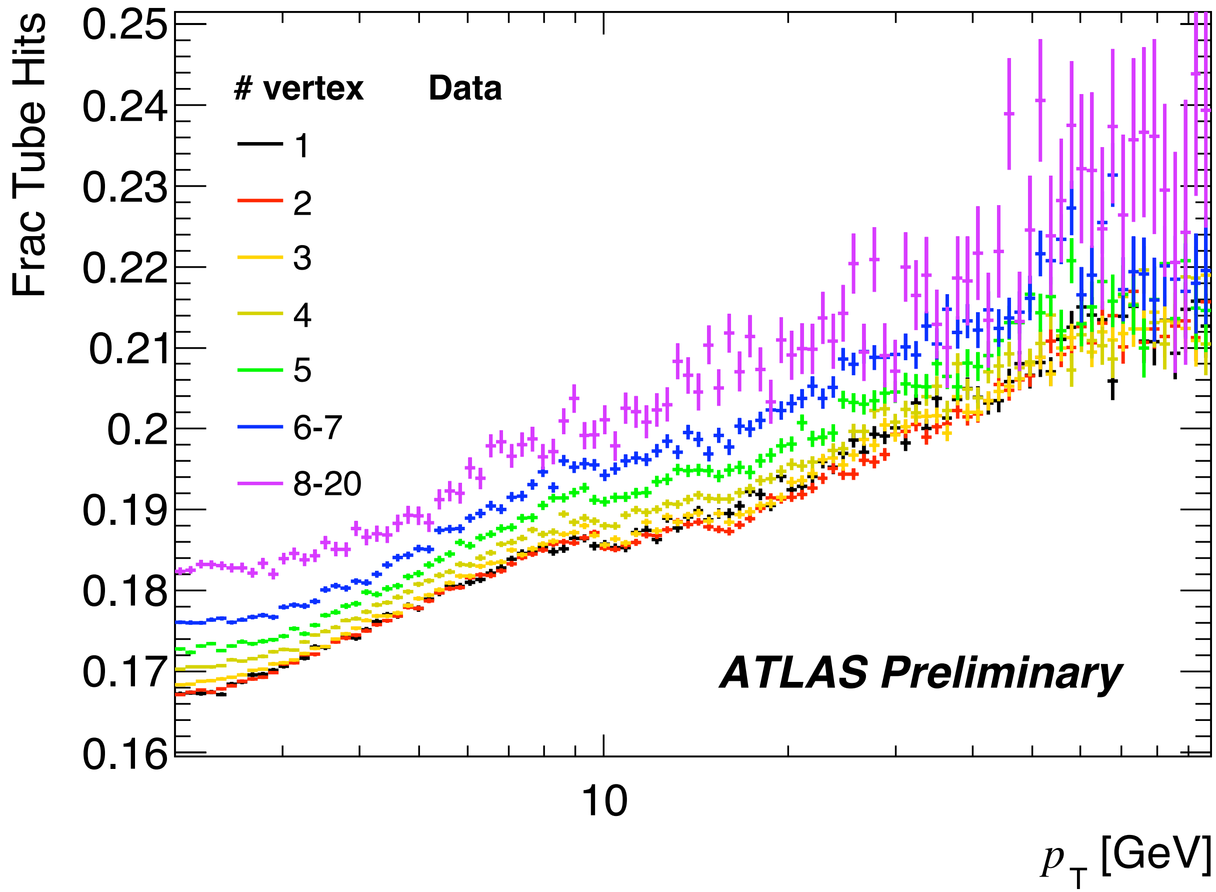
Precision alignment also important in the barrel

Residuals vs number of vertices



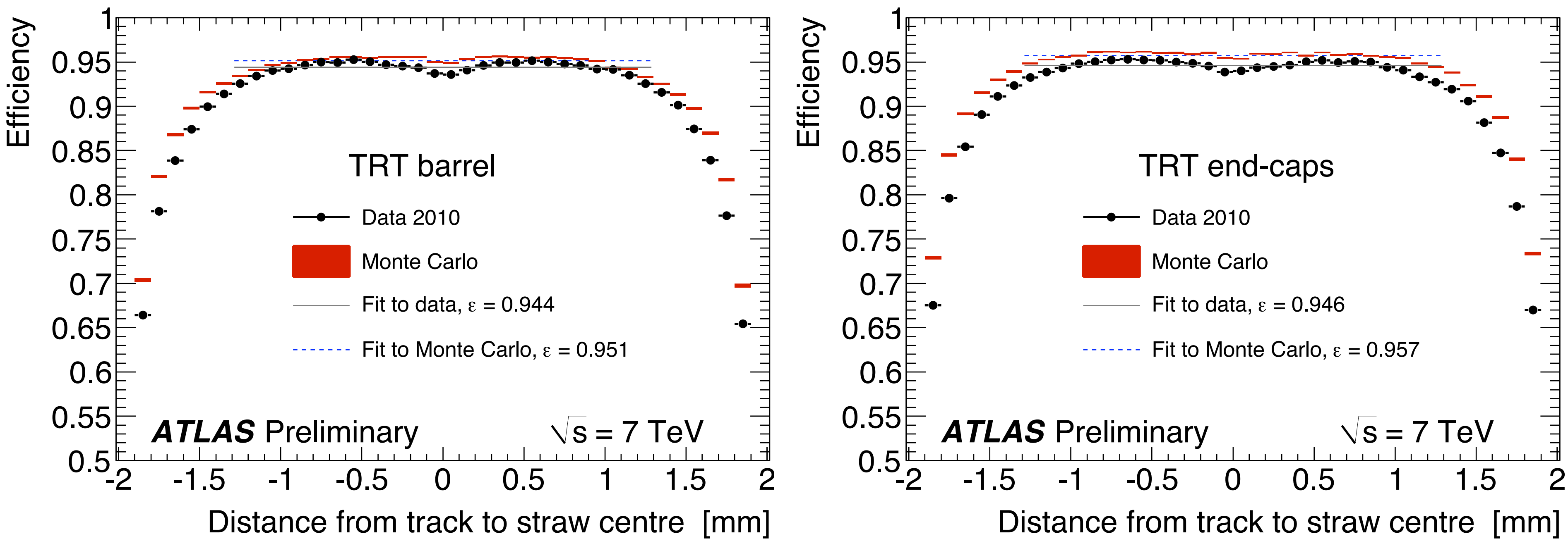
Position residual width (barrel+endcap) as a function of the number of reconstructed primary vertices found in the event

Tube hit fraction vs number of vertices



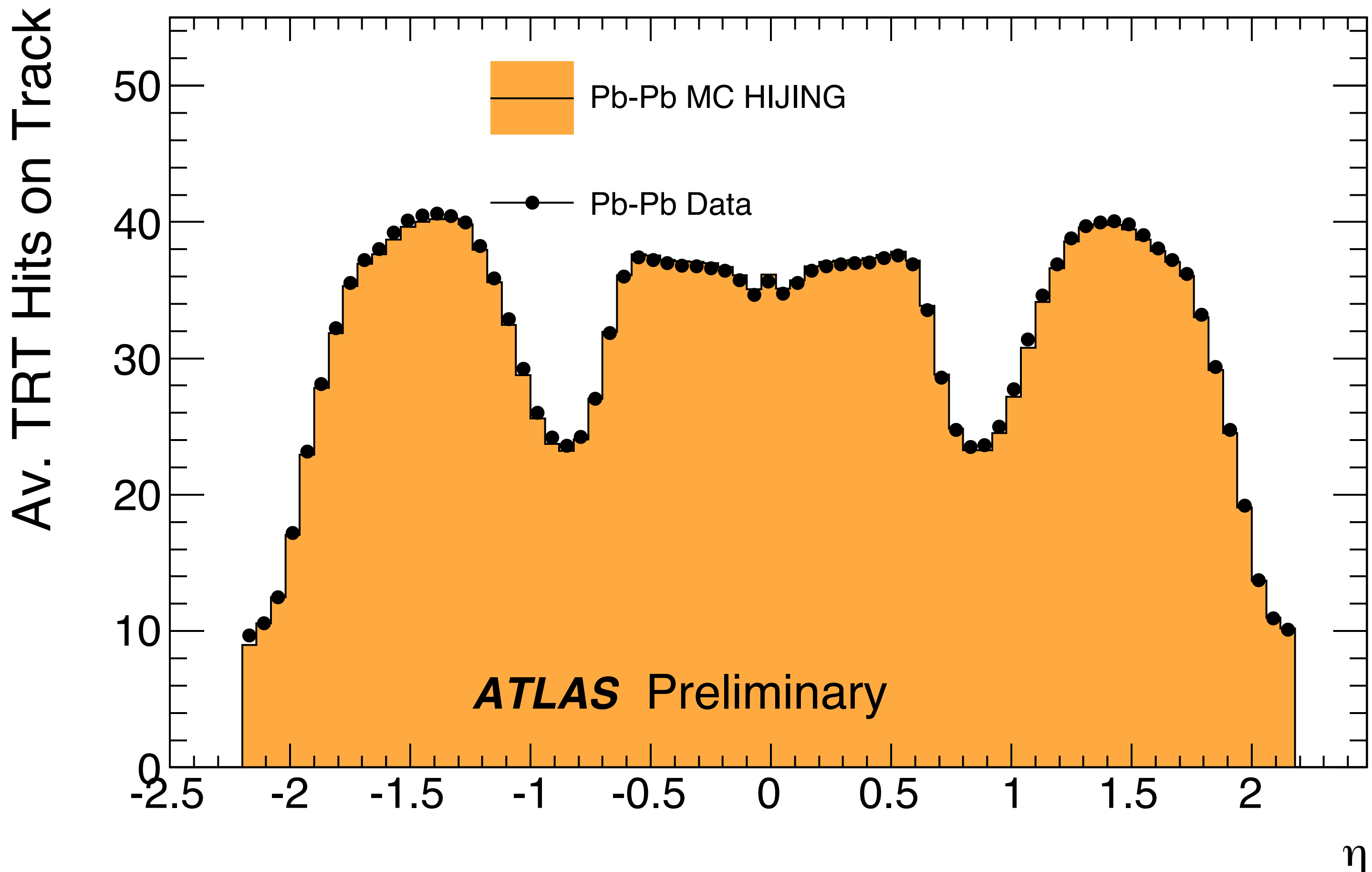
Fraction of TRT hits on track that are labeled as “non-precision hits” by the tracking software, as a function of track pt, shown for events with different numbers of reconstructed primary vertices

Efficiency



Track efficiency for hits on track, excluding 2% known non-functioning straws

Pb-Pb collisions



Studies indicate that TRT can contribute even in heavy ion collisions where occupancy can reach >90%

PID at high occupancy

- High level occupancy not yet affected significantly due to pileup, however at some point this will no longer be the case!
- What about 25 ns bunch spacing of LHC?
  - Recall: HL bits read out in OR of 3 windows 25 ns windows. Can use only middle window (keeps > 90% of transition radiation).
  - ToT for PID becomes harder to use, too
- PID in heavy ion collisions?
  - Studies underway

Very active area of study!

Conclusion

- The TRT is performing quite well and contributing significantly to tracking and to ATLAS PID
  - Precision alignment and calibration are important for optimal performance
- 50 ns bunch spacing is not much of an issue
  - Potential 25 ns bunch spacing next year will be doable as well
- No major degradation yet in terms of tracking/ PID performance at high pileup

Backup

Some other numbers on readout

- Rate/straw up to 20 MHz, 48 ns max. drift time
- Amplifier/shaper with ion tail cancellation and baseline restoration
- Two discriminators for each channel
- 200 - 300 eV (15% MIP) tracking threshold
- ~7 keV TR threshold
- Digital pipeline, 6 μs deep
- Tracking bit stored every 3.12 ns
- TR bit stored every 25 ns

Some other numbers

Counting Rate per wire	20 MHz
Ionization Current Density	0.15 µA/cm
Ionization Current per wire	10 µA
Power dissipated by ionization current per straw	15 mW
Total ionization current in detector volume	3 A
Total dissipated energy in the detector volume from ionizing particles	5 kW
Charge collected over 10 years of LHC operation	10 C/cm

Particle Flux at 1m from IP

Charged	10^5 hadrons/cm^2 sec
Photons	10^6 photons/cm^2 sec
Neutrons	10^6 n/cm^2 sec

Total Radiation Dose after 10 years

Neutrons	10^{14} n/cm^2
Charged Particles	10 MRad