Commissioning and Performance of the ATLAS Transition Radiation Tracker with First High Energy pp and Pb-Pb collisions at LHC

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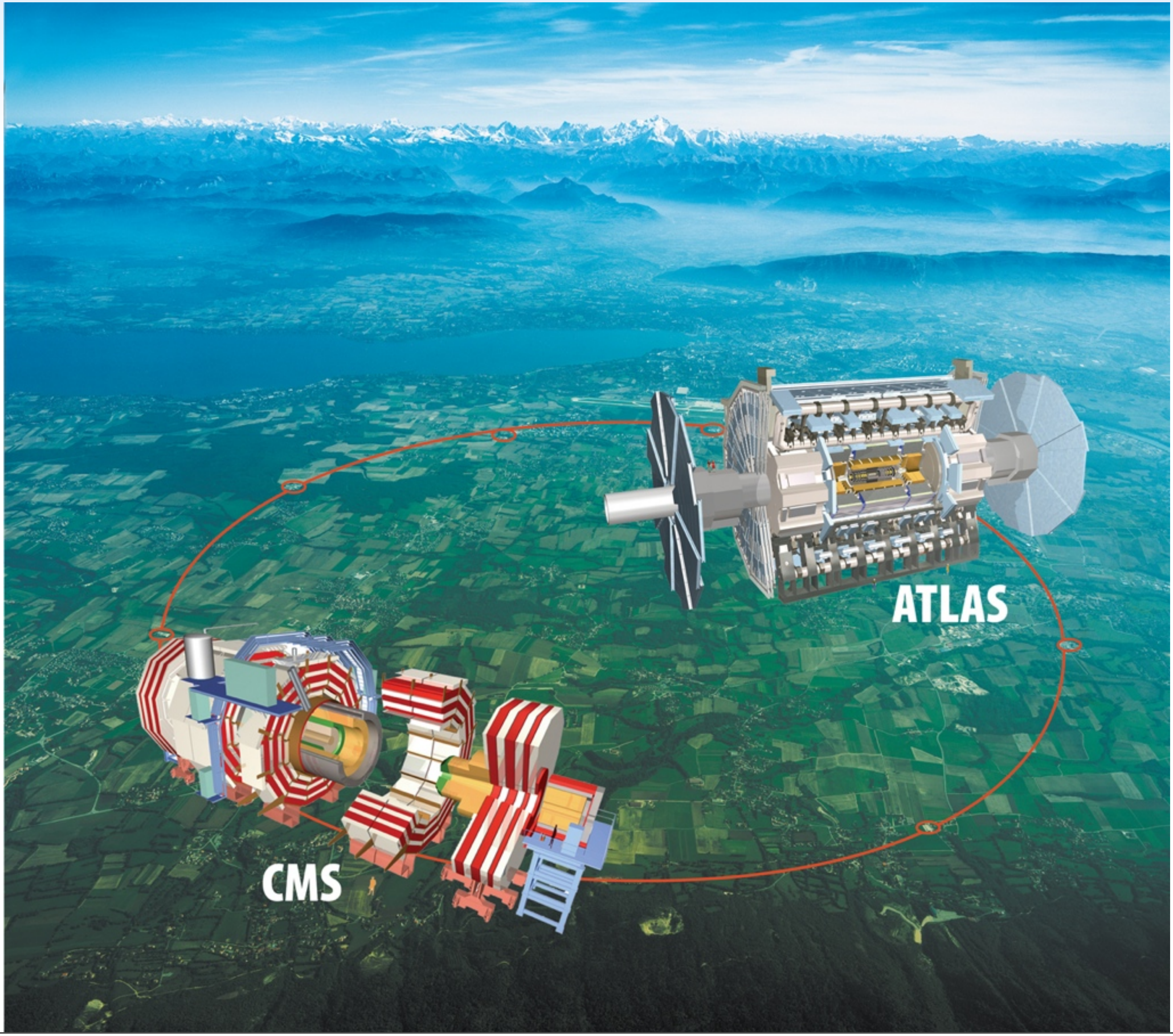
Outline

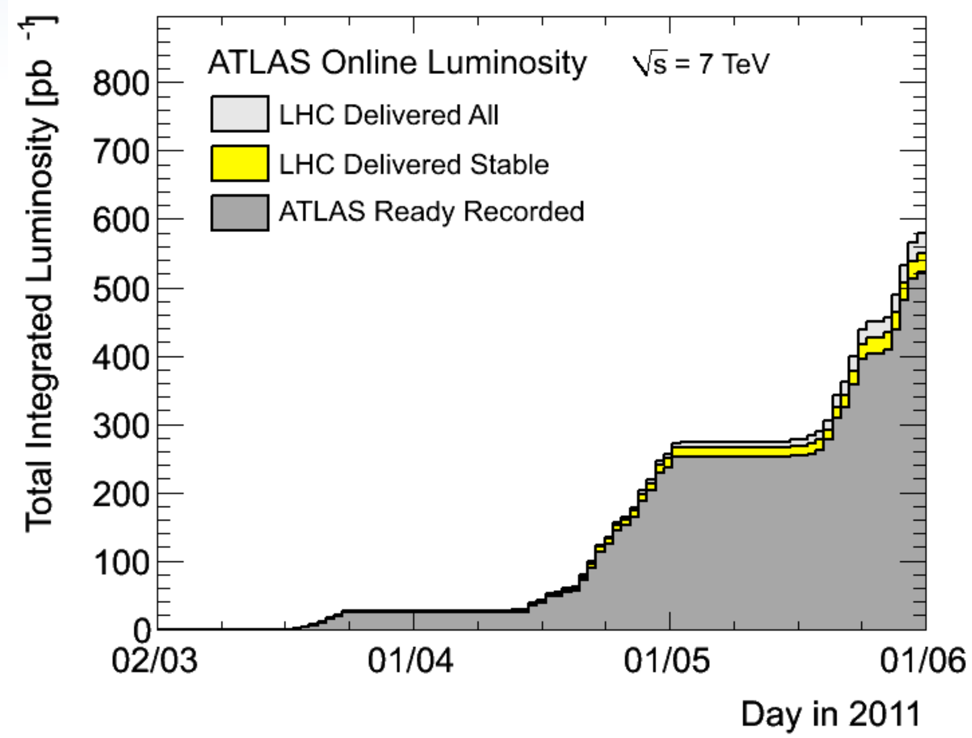
- ATLAS and the LHC
- The Transition Radiation Tracker (**TRT**):
    - Design
    - Operation
    - Calibration
    - Performance
- Summary

The LHC

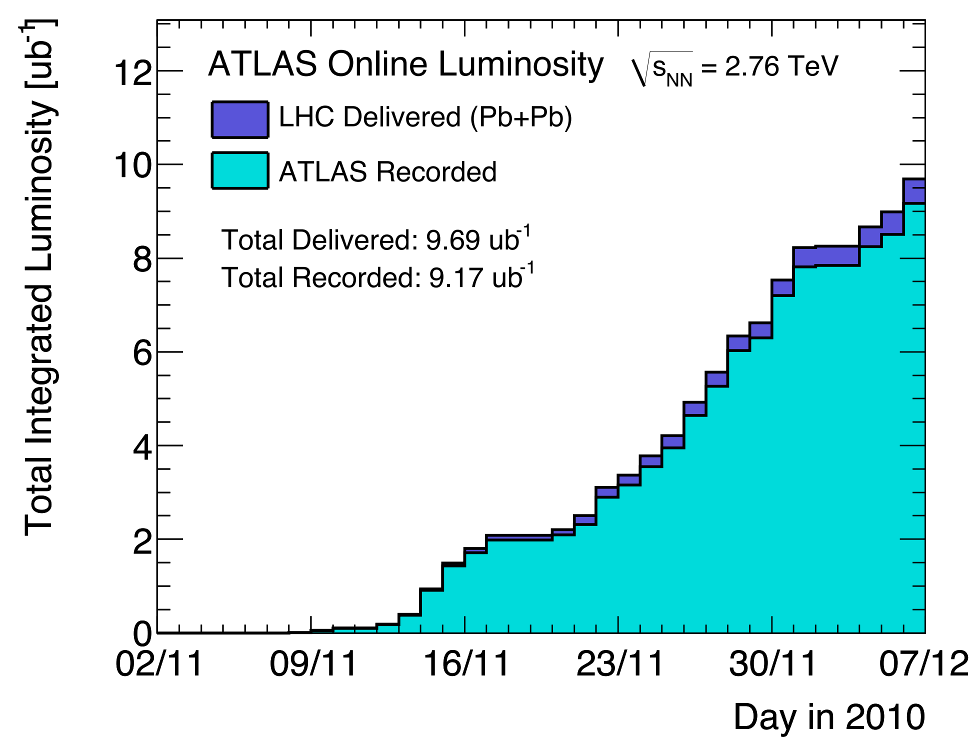


Status of the LHC

- Synchronous collider of protons (40 MHz, 25 ns bunch spacing) and Pb ions
- First collisions in Nov. 2009, stable running in 2010, continuing to run in 2011
- Design instantaneous luminosity of **10^{34} cm^{-2}s^{-1}** with energy of **7 TeV** per proton beam; currently running at ~**10^{33} cm^{-2}s^{-1}** (setting world records!) with **3.5 TeV** per beam and 50 ns bunch spacing
- Delivered **48 pb^{-1}** of proton-proton collisions and **10 μb^{-1}** of Pb-Pb collisions in 2010
- Already delivered over **500 pb^{-1}** of pp collisions in 2011!

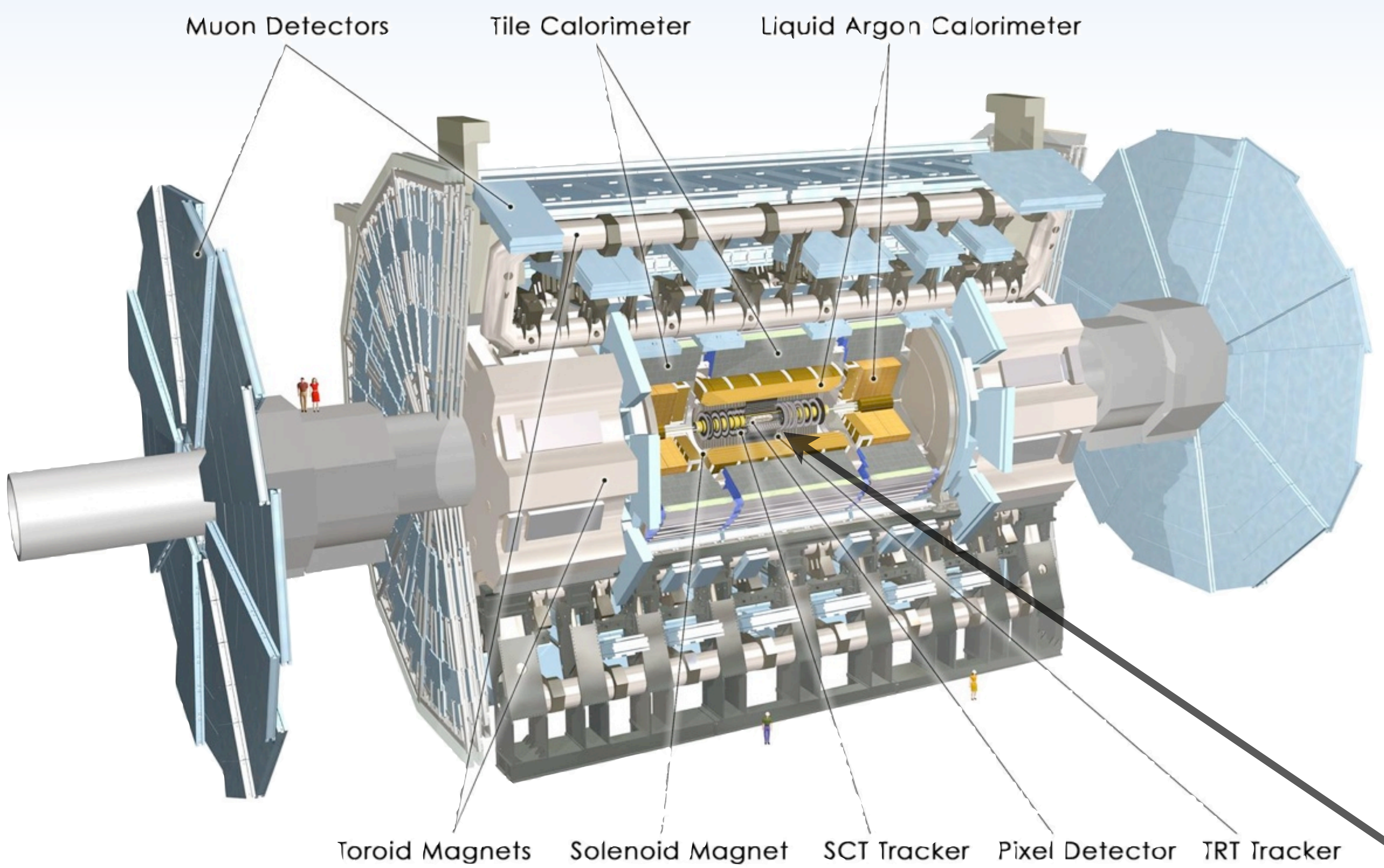


pp integrated luminosity



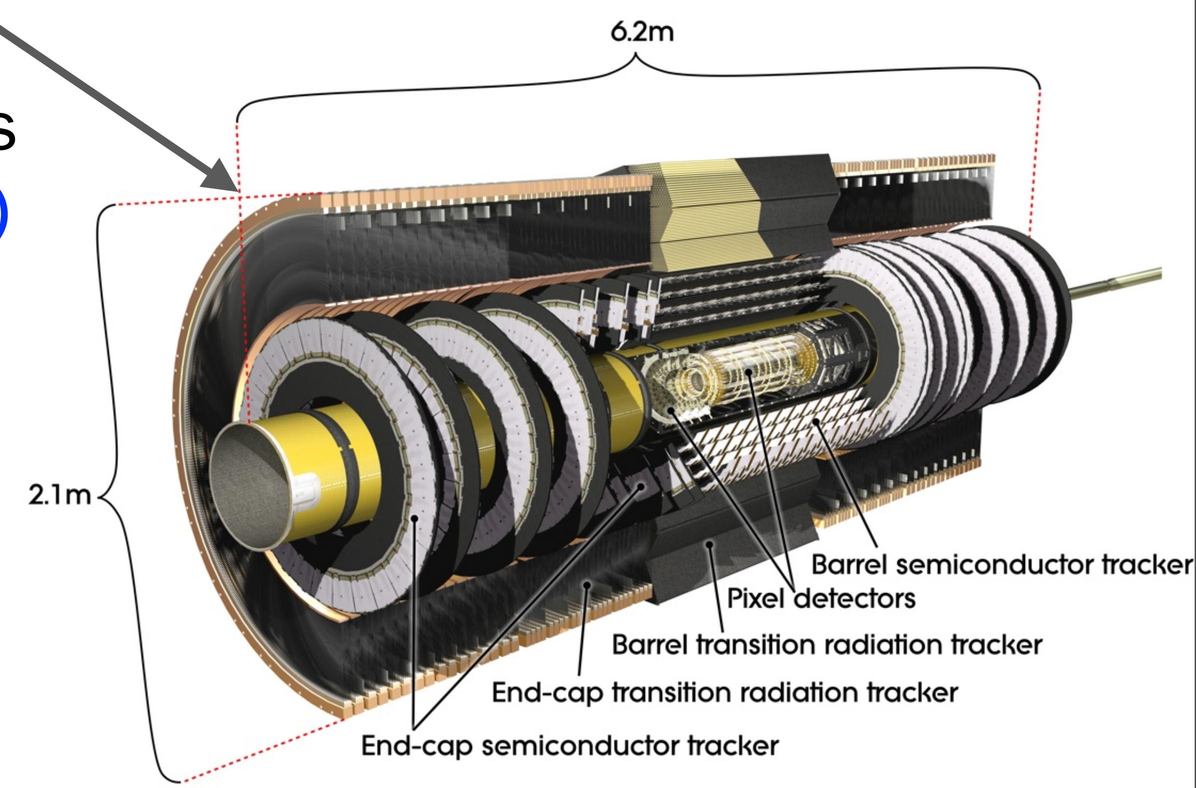
PbPb integrated luminosity

ATLAS



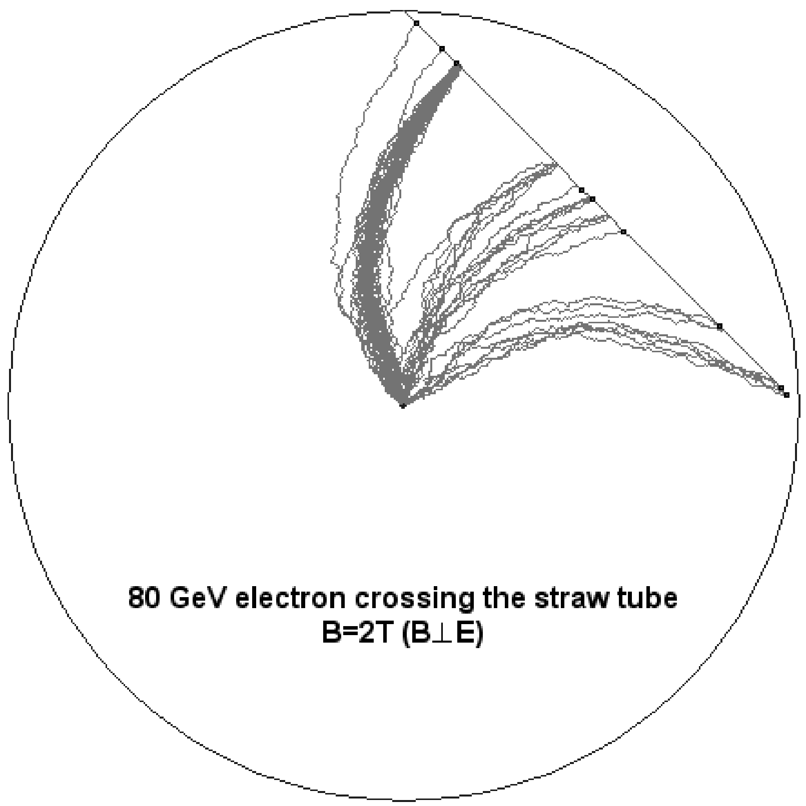
- Large multi-purpose particle detector
- Consists of several sub-detectors:
  - Muon Spectrometer (MS)
  - Liquid Argon and Scintillator Tile Calorimeters
  - Inner Detector (ID)
- Toroid magnets supply ~1.4 T field and ID solenoid provides 2 T field

- Inner Detector composed of two silicon trackers (Pixel & SCT) surrounded by **straw tracker (TRT)**
- ID provides tracking for charged particles with $p_T > 0.1$ GeV within $|\eta| < 2.5$; $\eta \equiv -\ln(\tan(\theta/2))$
- 6.2 million channels in the SCT and more than 80 million channels in the Pixels

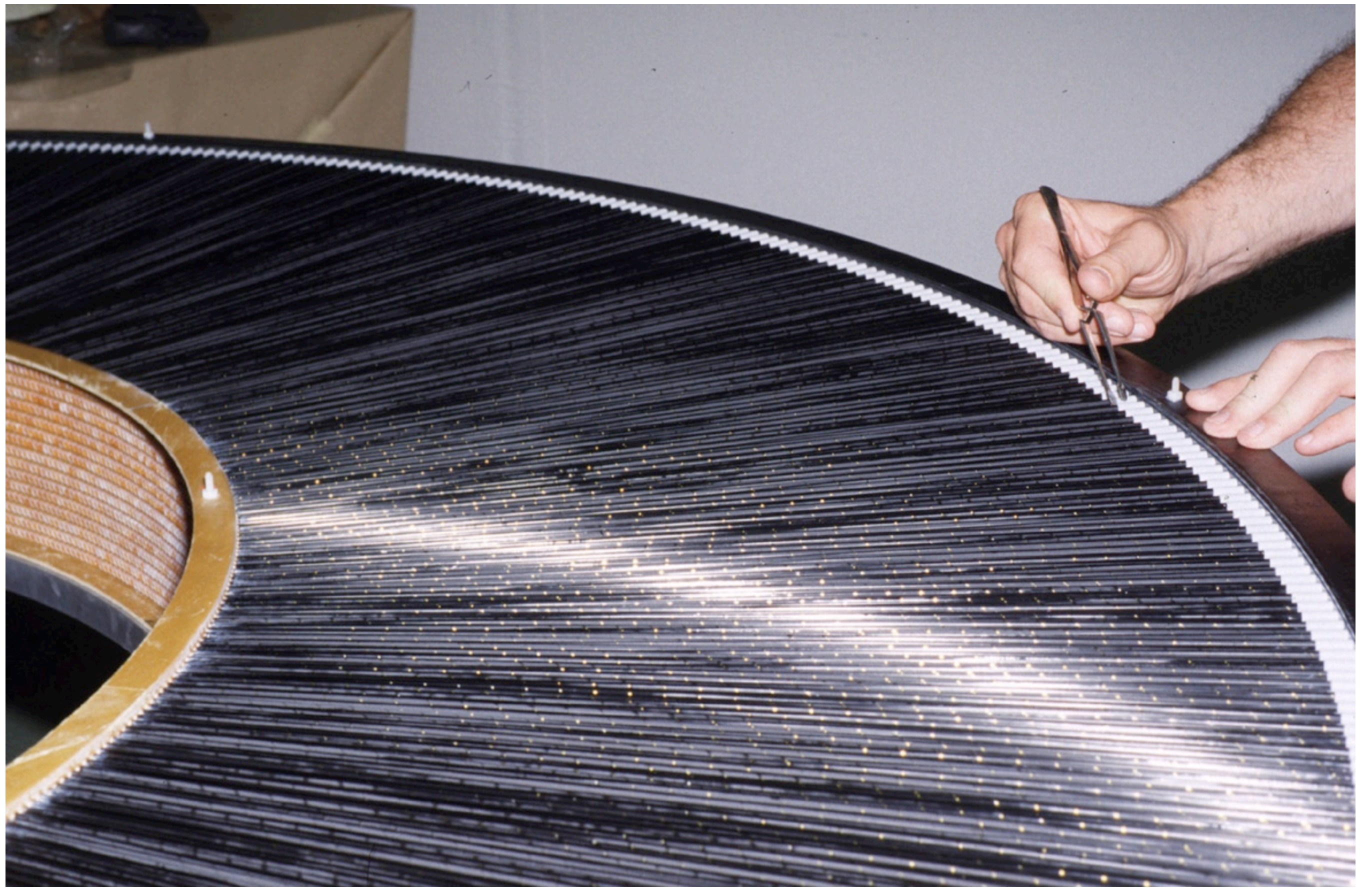


TRT Design: The Straw

- Kapton straw (d = 4 mm) strung with gold plated tungsten anode wire (d = 31 μm)
- Reinforced with carbon-fiber for mechanical strength and thermal conductivity



- Filled with gas mixture of $Xe/CO_2/O_2$ (70%/27%/3%) chosen for **stability** and **transition radiation** absorption
- Works in proportional mode with the straw wall being held at -1.5 kV (wire at ground)

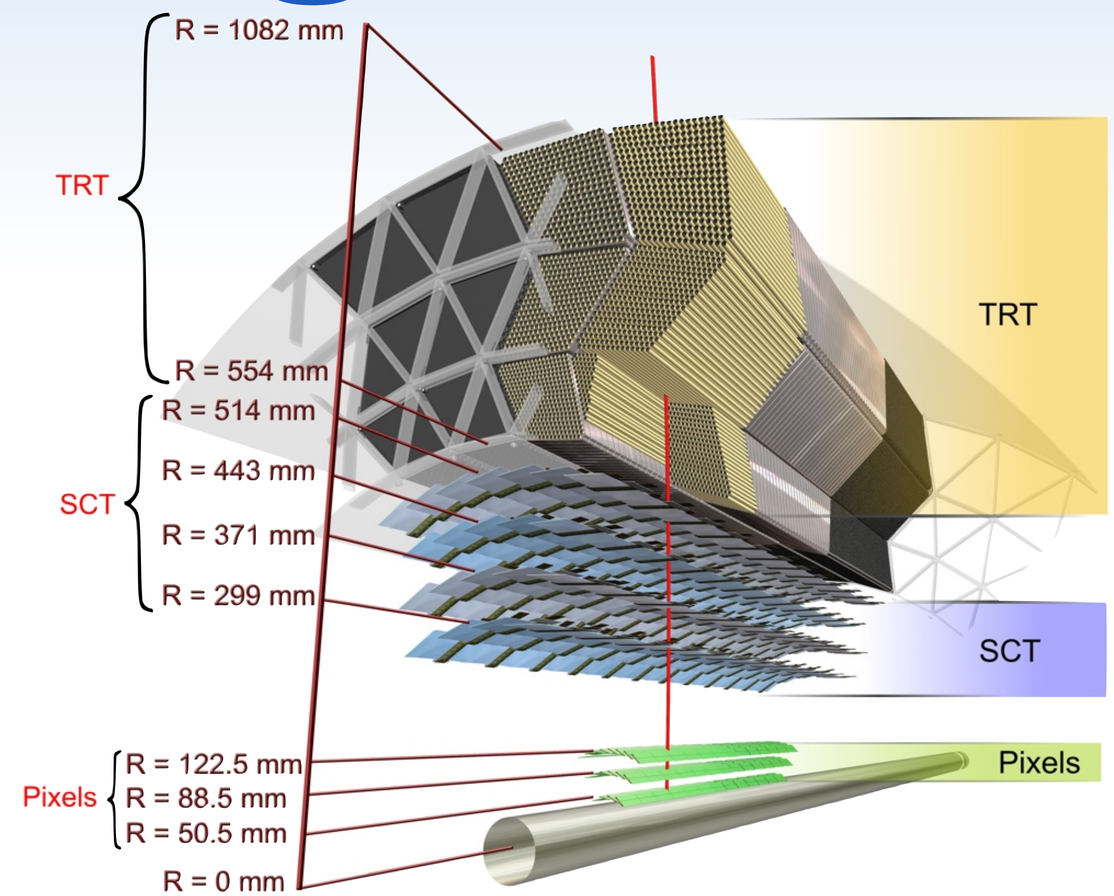


Straws in a prototype end-cap wheel

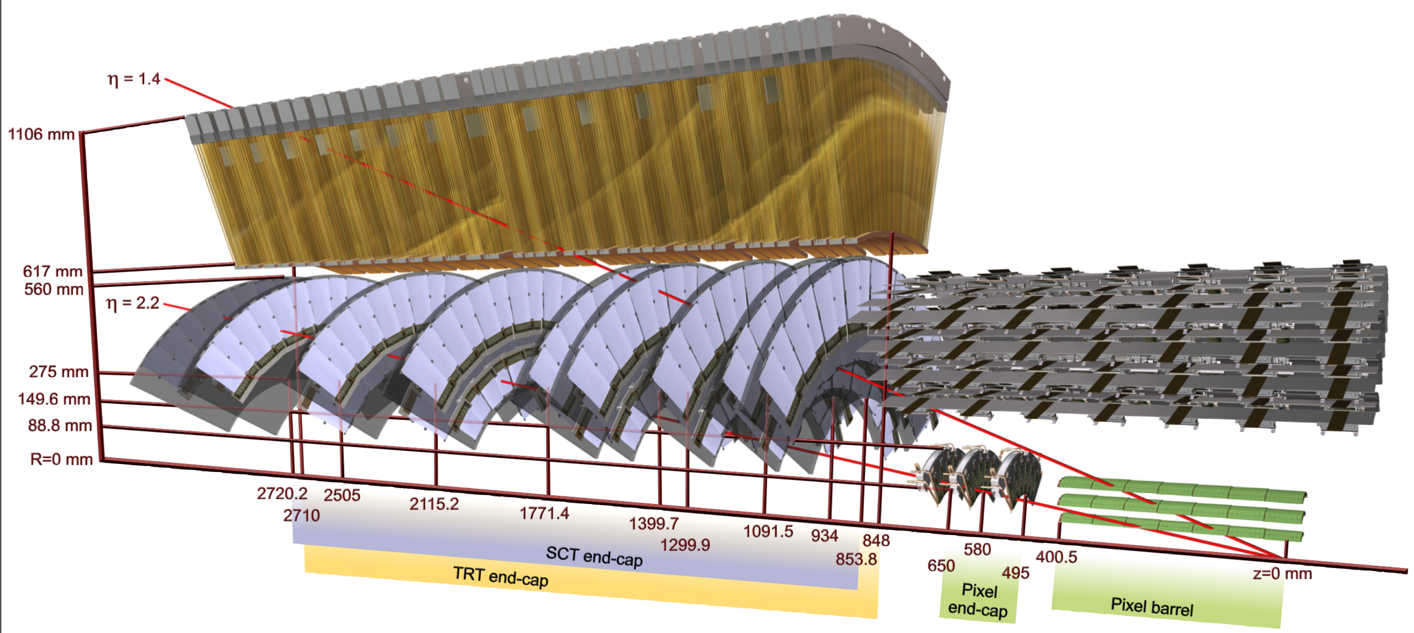
TRT Design

TRT Barrel

- ~53k 1.44 m straws arranged parallel to beam pipe covering $|\eta| < 1.0$
- Wire segmented in middle by glass bead to create a total of **106k readout channels** (innermost straws have two beads with dead region in between to reduce occupancy)
- Polypropylene foam for transition radiation



Inner Detector barrel



Inner Detector end-cap (+ Si barrel)

TRT End-cap

- 39 cm straws arranged radially in 20 wheels (8 straw layers per wheel) covering $0.7 < |\eta| < 2.0$
- ~**120k readout channels** per end-cap, one end-cap on each side of the barrel
- Polypropylene foils between wheels for transition radiation

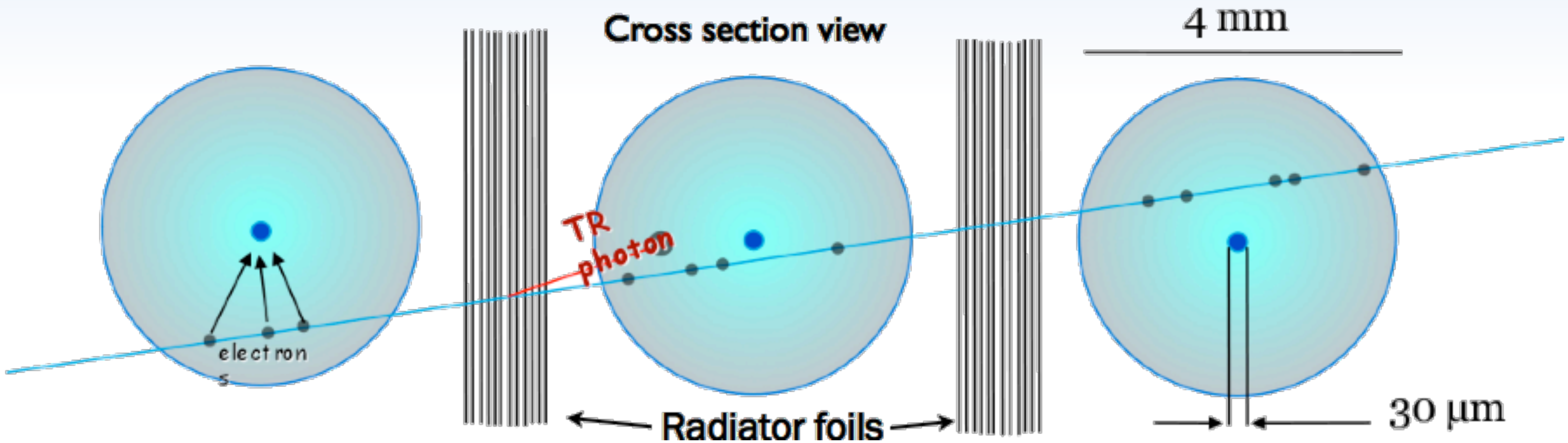
TRT Operations

- For the 2010 run, the TRT provided good quality data with **100% efficiency** during LHC stable beams - one of two ATLAS sub-detectors!
- Due to:
  - Much work by TRT experts to keep the detector running smoothly
  - Automated processes to correct readout problems at runtime
  - Ability to run with nominal high voltage regardless of beam conditions
- Note: **98%** of the installed detector is currently being read out

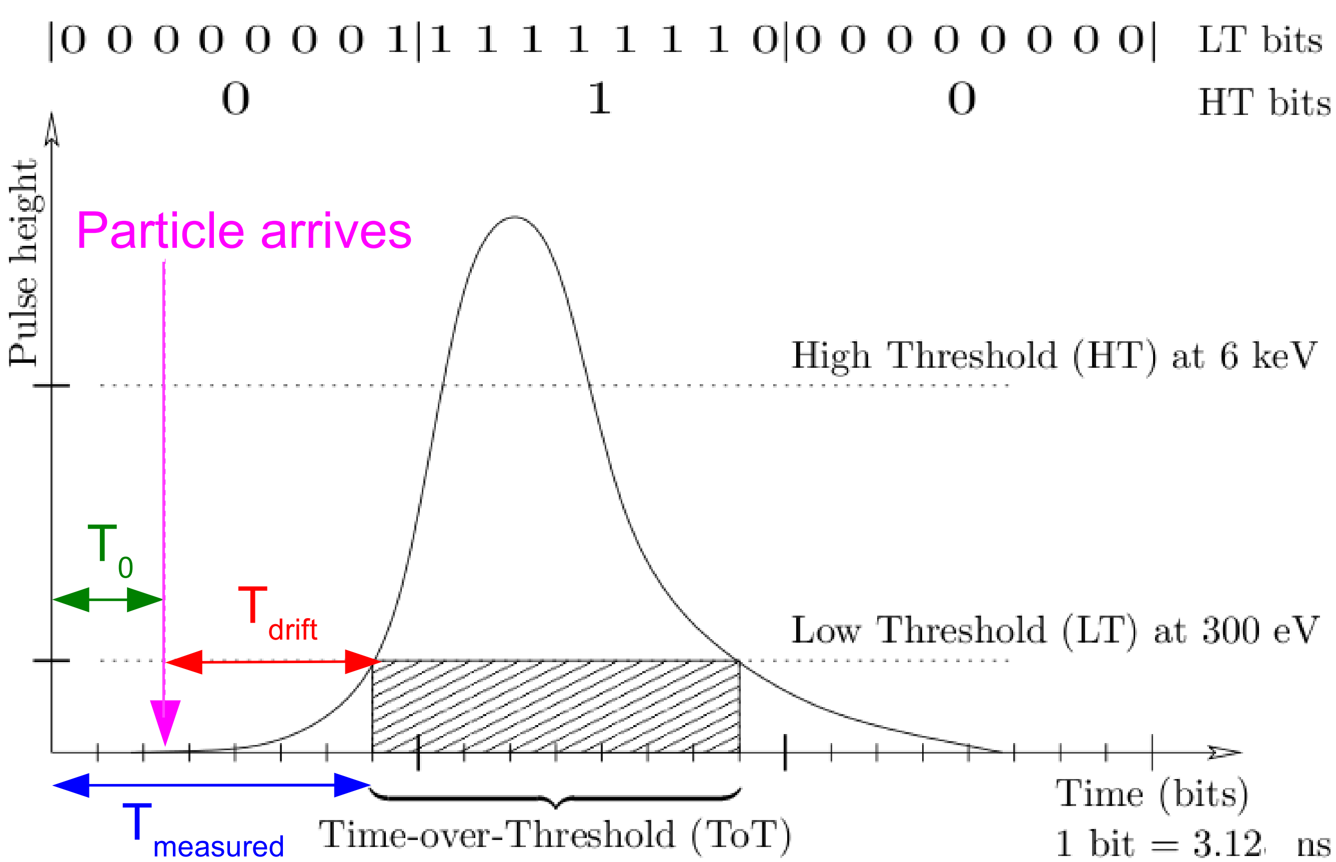
Inner Tracking Detectors			Calorimeters				Muon Detectors			
Pixel	SCT	TRT	LAr EM	LAr HAD	LAr FWD	Tile	MDT	RPC	CSC	TGC
99.1	99.9	100	90.7	96.6	97.8	100	99.9	99.8	96.2	99.8

Luminosity weighted relative detector uptime and good quality data delivery during 2010 stable beams in pp collisions at $\sqrt{s}$=7 TeV between March 30th and October 31st (in %). The inefficiencies in the LAr calorimeter will partially be recovered in the future.

Particle Detection

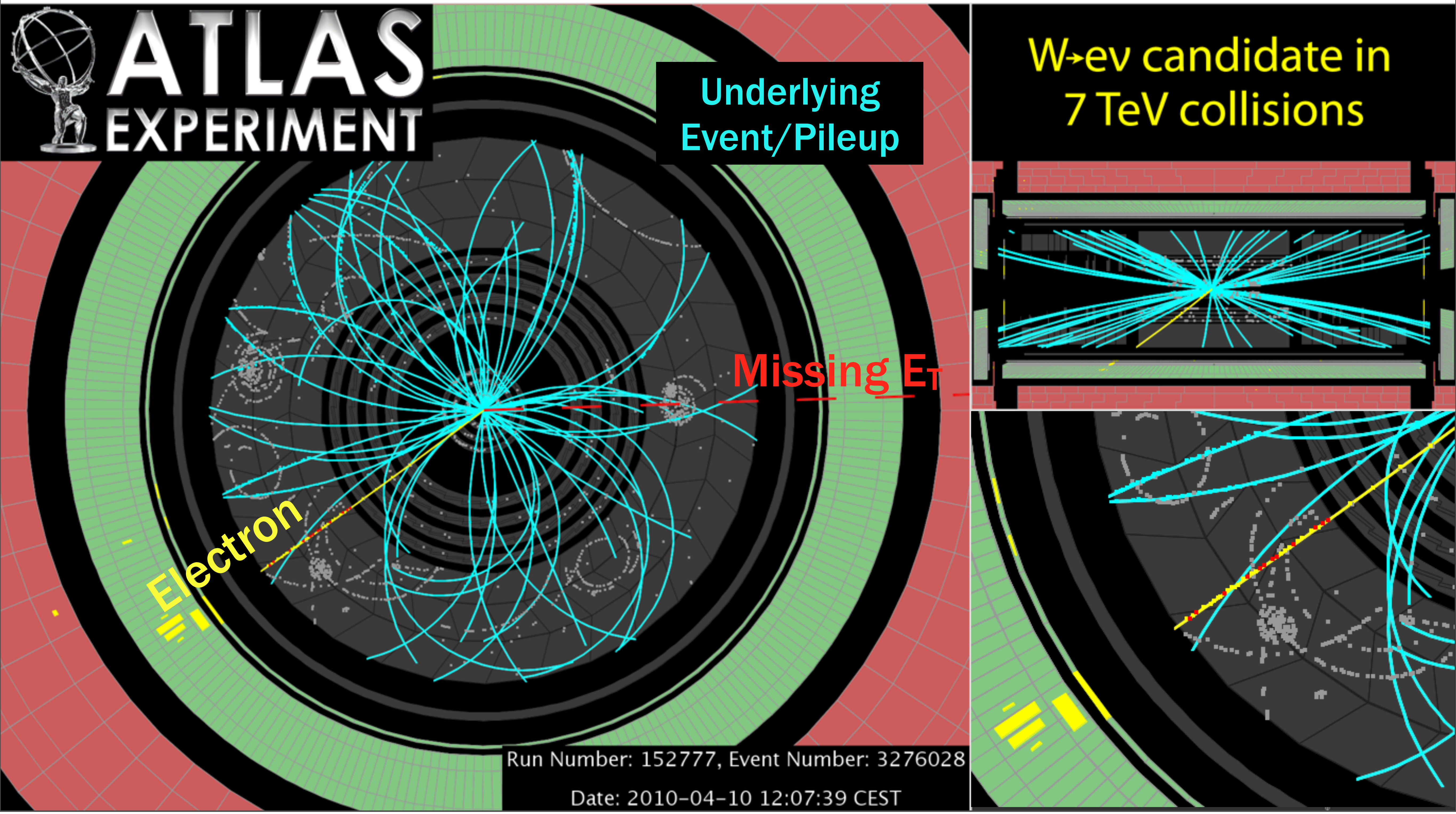


- Charged particle ionizes gas, closest ionization determines T_{Drift}
- Readout granularity of 3.119 ns (8 bins per bunch crossing), trigger reads out 3 bunch crossings (~75 ns)
- **Low threshold** - particle tracking
- **High threshold** - particle identification using transition radiation photons



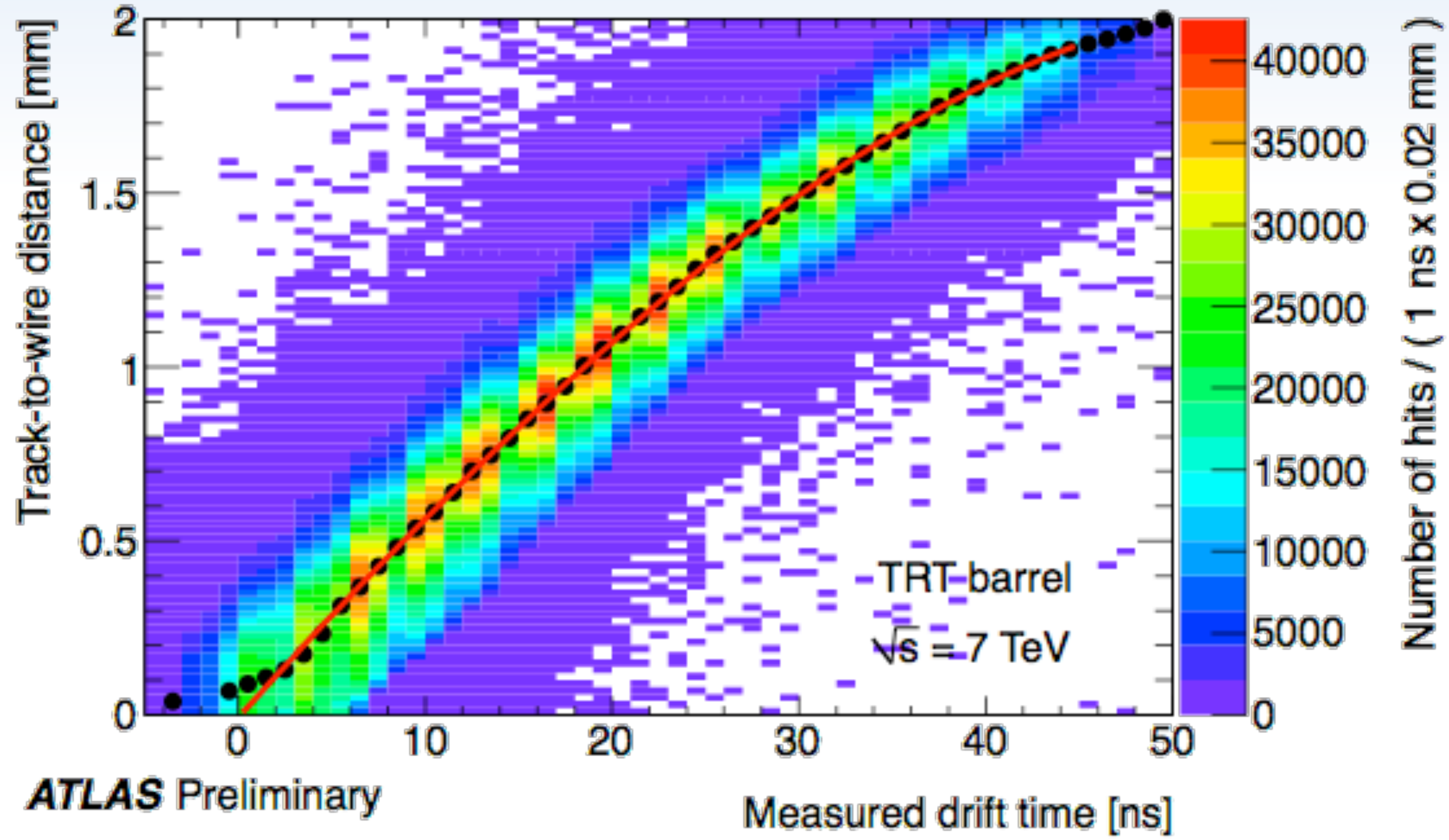
W→eν Candidate

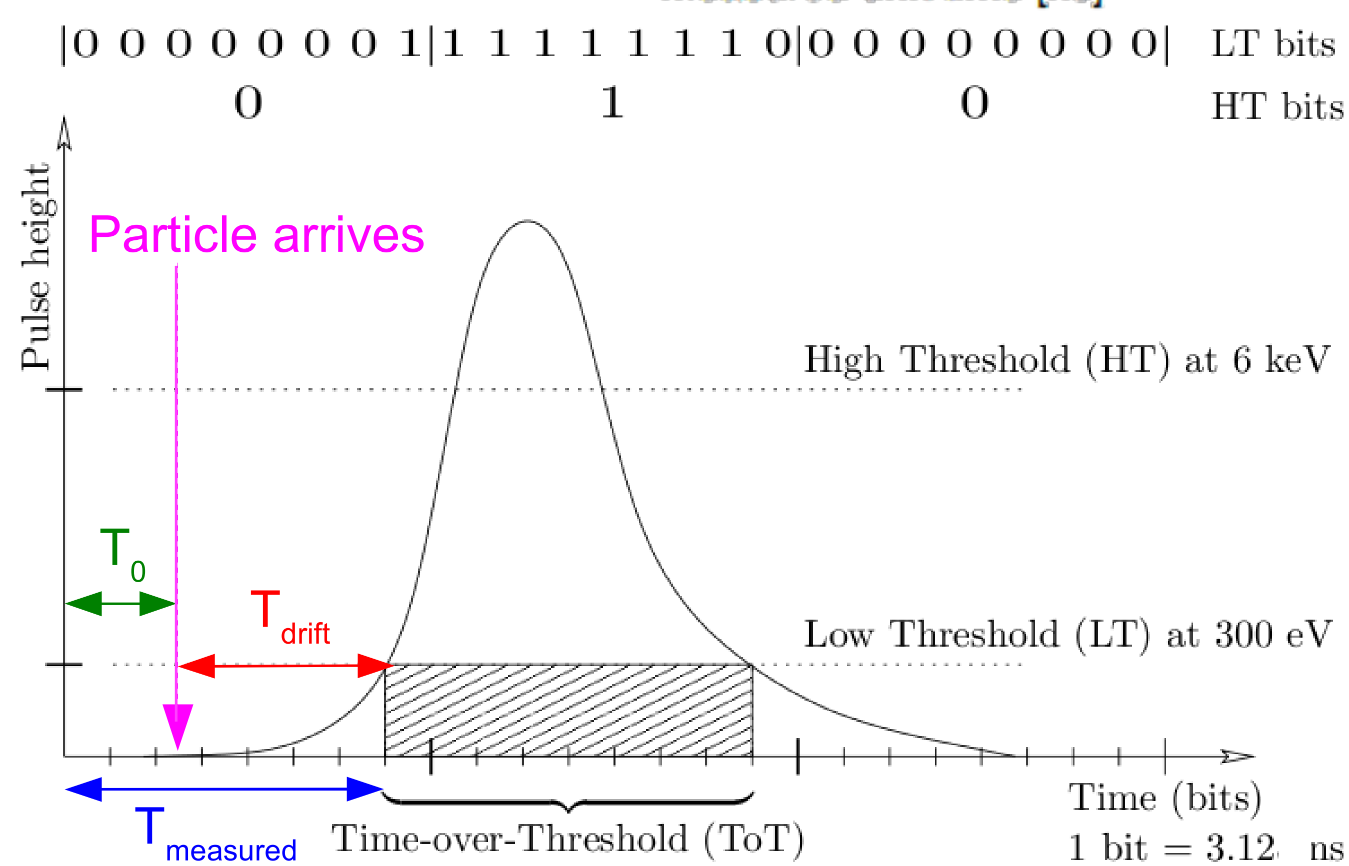
electron p_T = 23 GeV E_T^{miss} = 31 GeV



Calibration

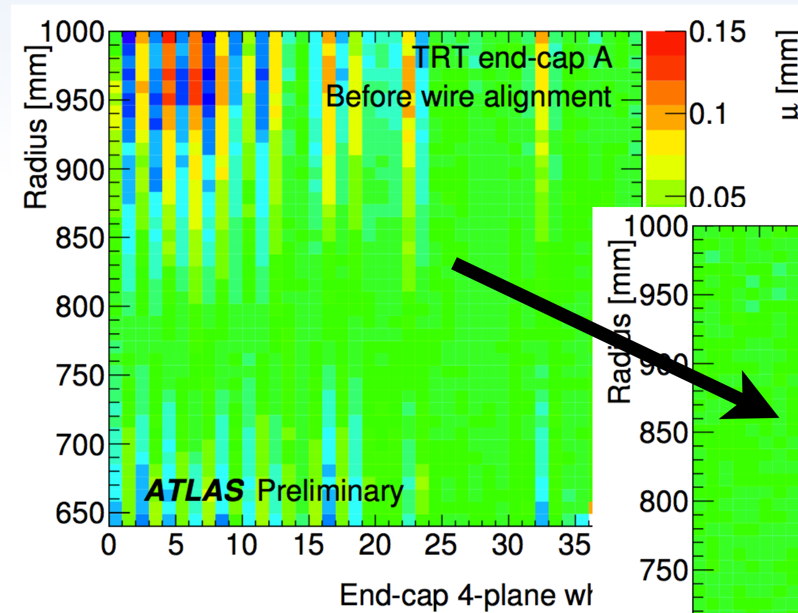
- **Thresholds:**
  - Low thresholds equalized to 2% noise occupancy
  - High thresholds equalized for uniform response to electrons
- **Calibration (every 24 hours):**
- **“R-t” relation** converts T_{drift} to a measured drift radius
  - Depends on gas composition, temperature, magnetic field
  - **Uniform, stable detector response:** two R-t relations for barrel, one for each end-cap
- **“T_0”** calibration (front end chip level)
  - Accounts for time of flight of particle, electronics delays, etc.

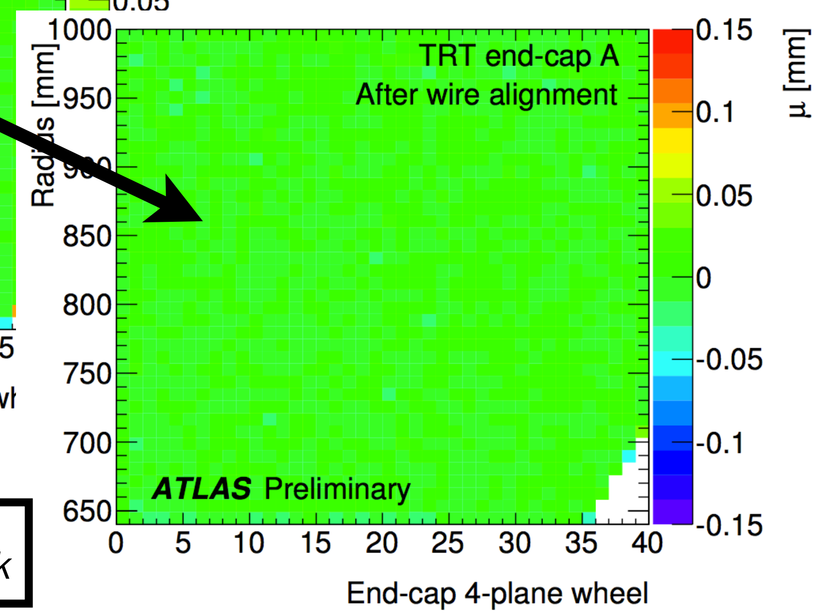




Position Resolution

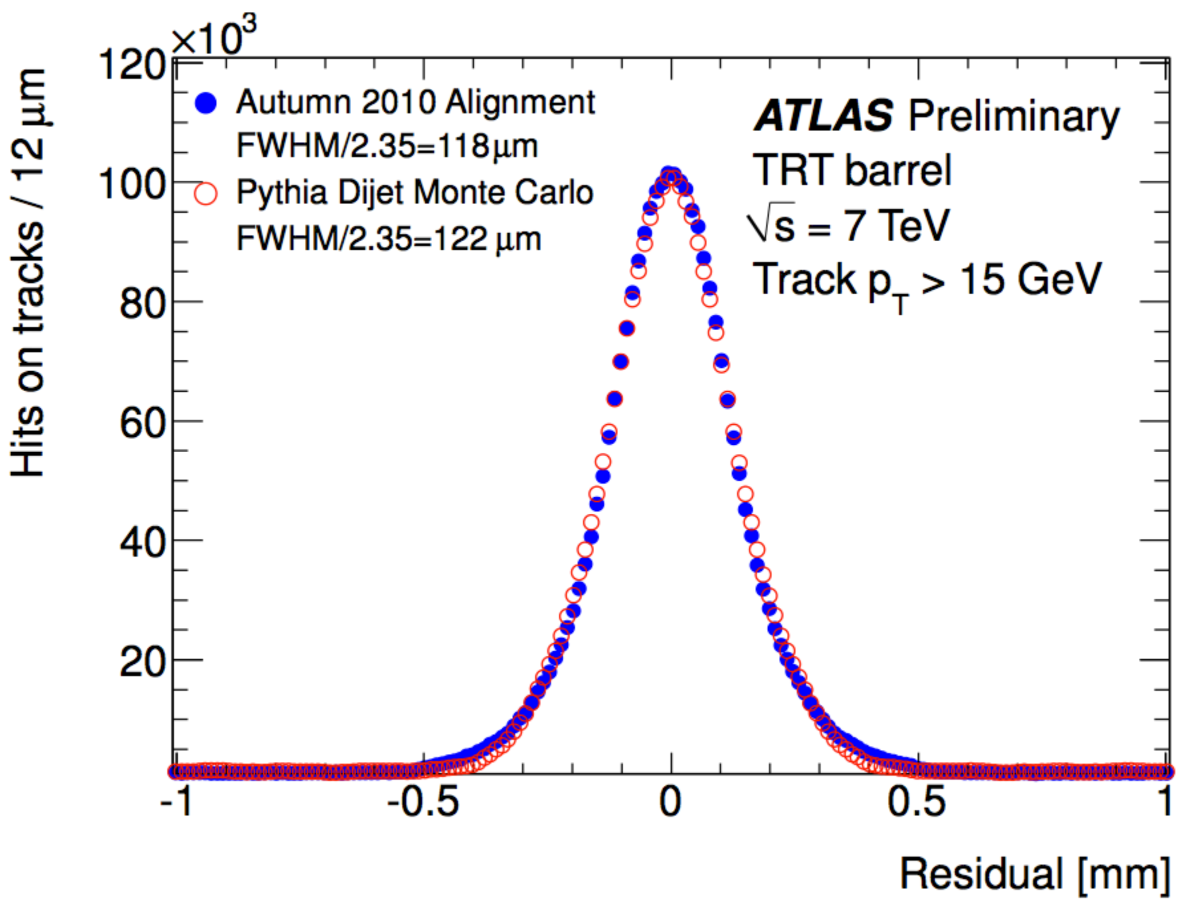
- TRT provides on average **30 position measurements** with **118 (132) μm** resolution in the barrel (end-cap)
- Due to:
  - Alignment work, including a wire by wire alignment of the entire TRT (over 700k DoF!)
  - Calibration improvements, including drift time corrections for signal size

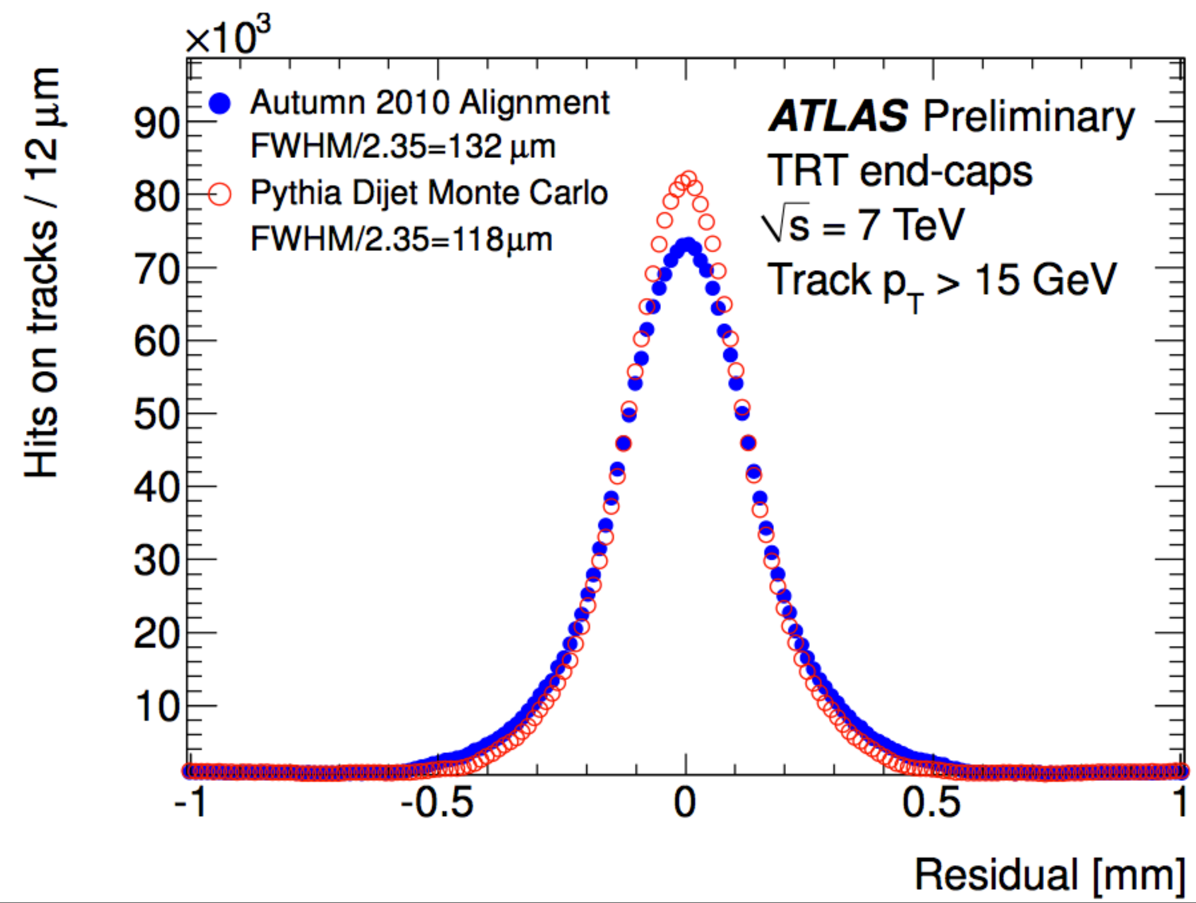




Mean Position Residual
Red/Blue == Misaligned!

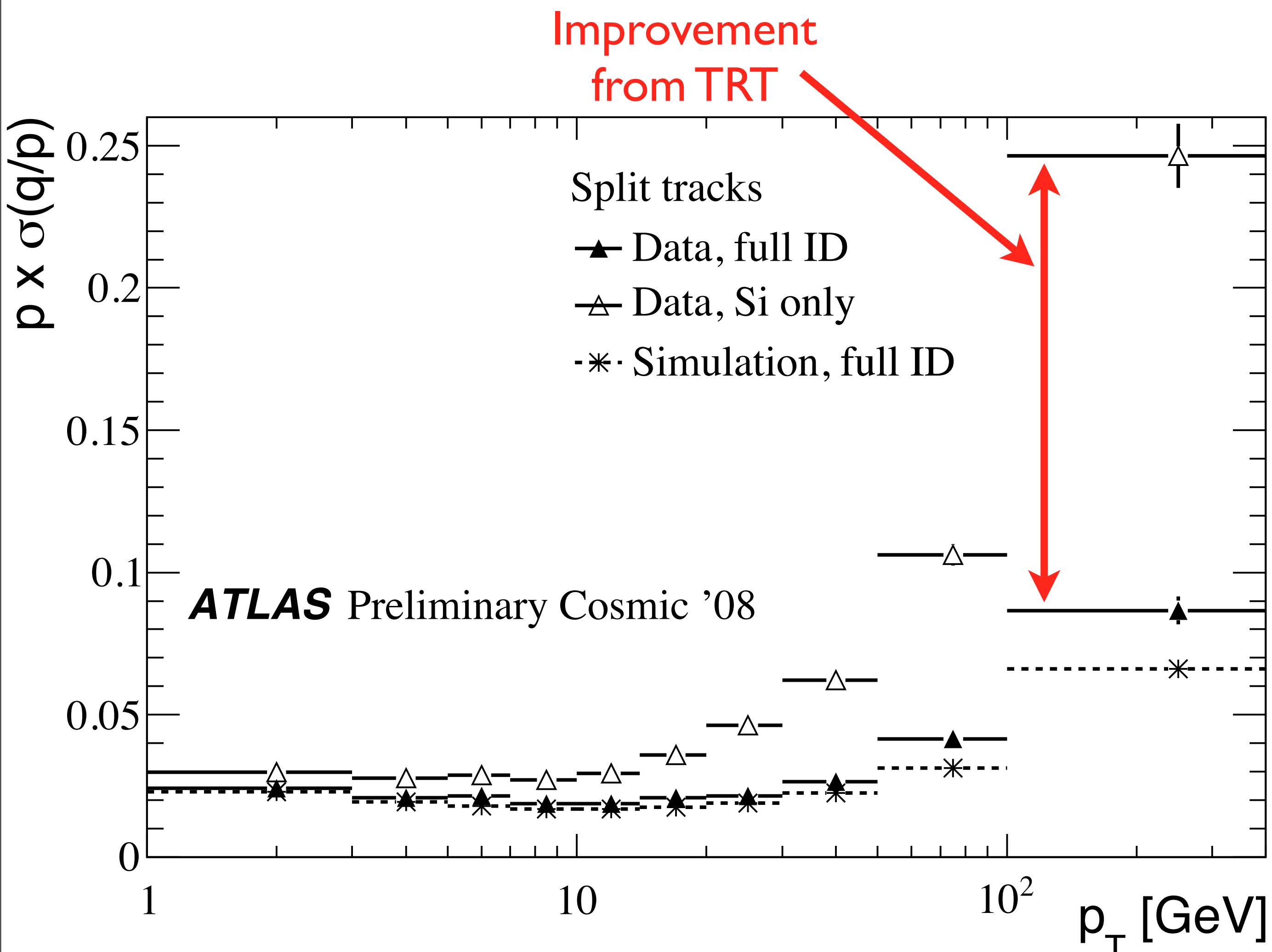
Residual ≡ $R_{Drift} - R_{Track}$

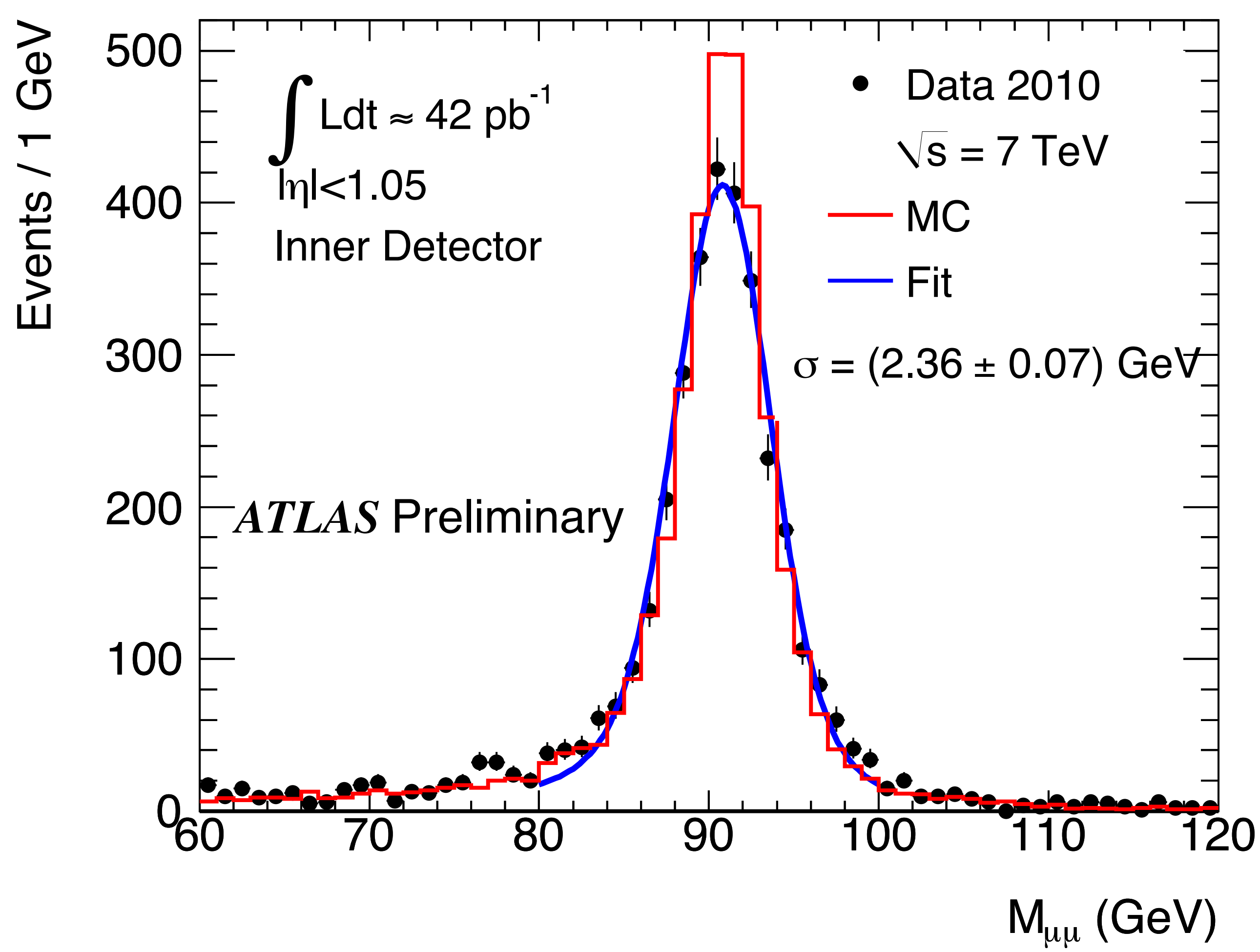




Momentum Resolution

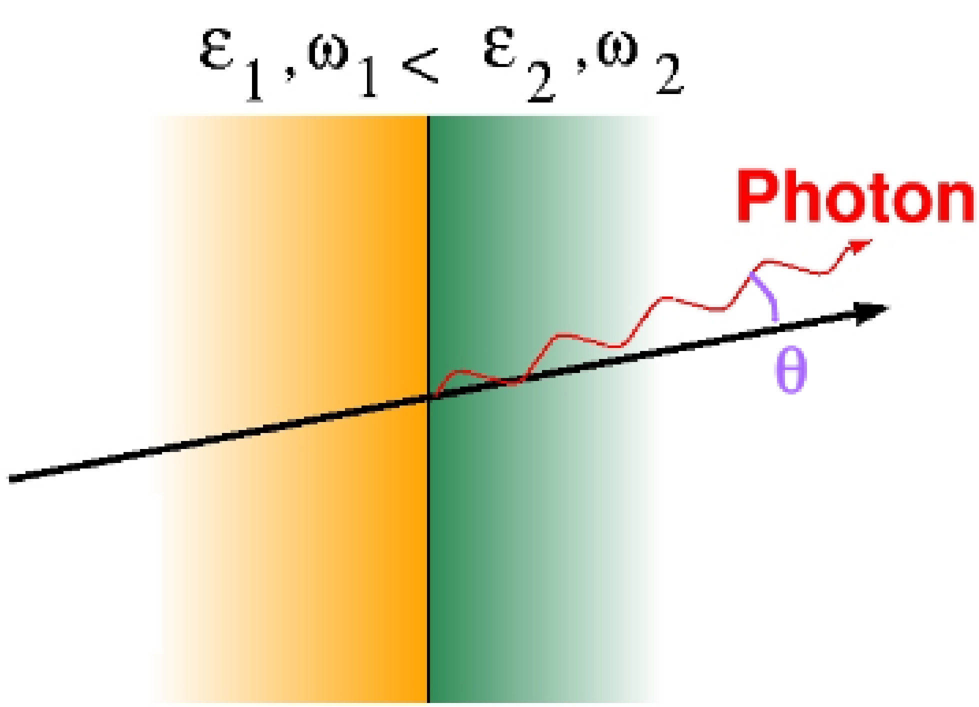
- **Significant improvement** in momentum resolution in the Inner Detector due to large number of hits and longer "lever arm"
- Z mass resolution in the Inner Detector also shows good performance, approaching that of the "ideal" Monte Carlo





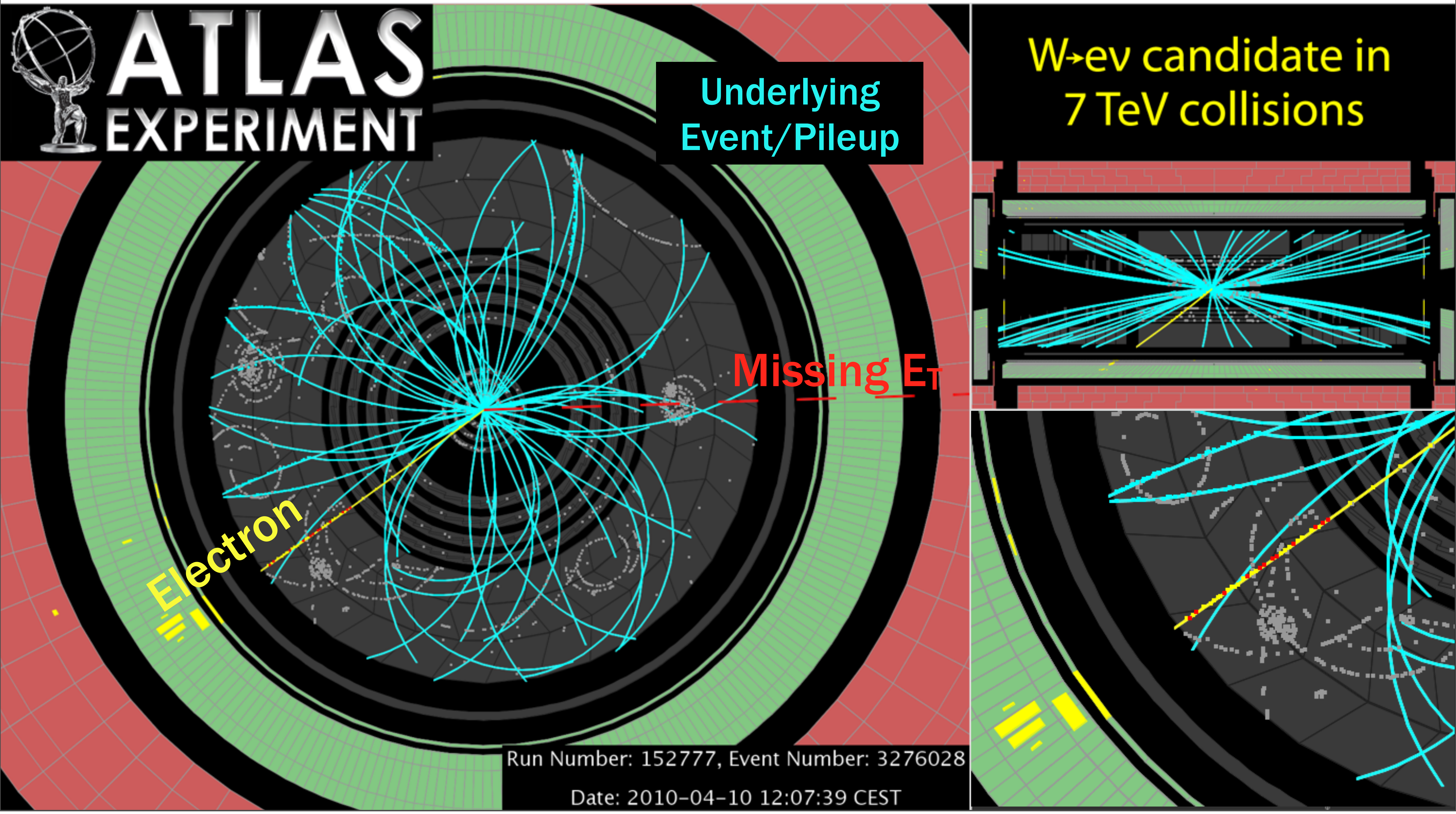
Transition Radiation

- **Transition radiation:** photon emitted by a charged particle when traversing the boundary between materials with different dielectric constants (ε_1,ε_2)
- Intensity of emission is a function of $\gamma = E/m$, $\theta \propto 1/\gamma$
  - Low photon emission probability per transition ⇒ many transitions needed
    - Intensity eventually limited by saturation effects
  - Emitted energy $\propto$ (ε_1 - ε_2)
    - Gas and plastic give photon energies of 5 to 30 keV
- Gas with high photon absorption (high Z) required - **Xenon**
- Discriminate electrons from hadrons based on number of **High Threshold** (HT) hits on a track

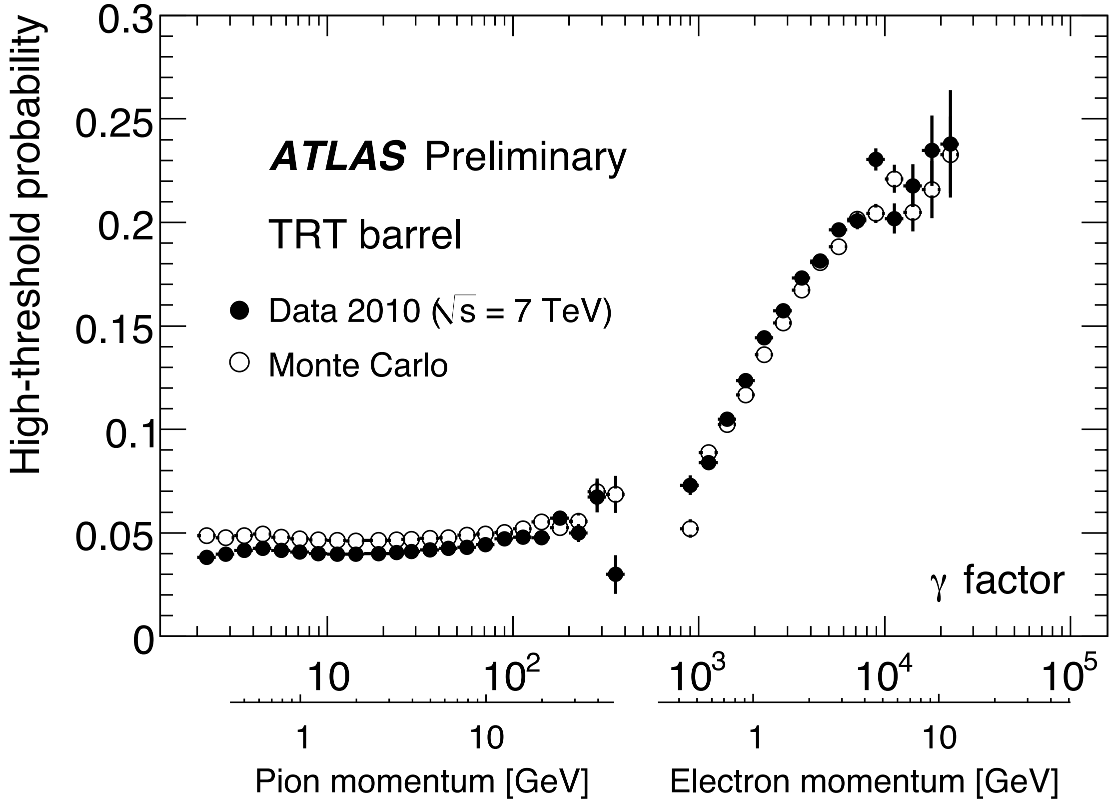


W→eν Candidate

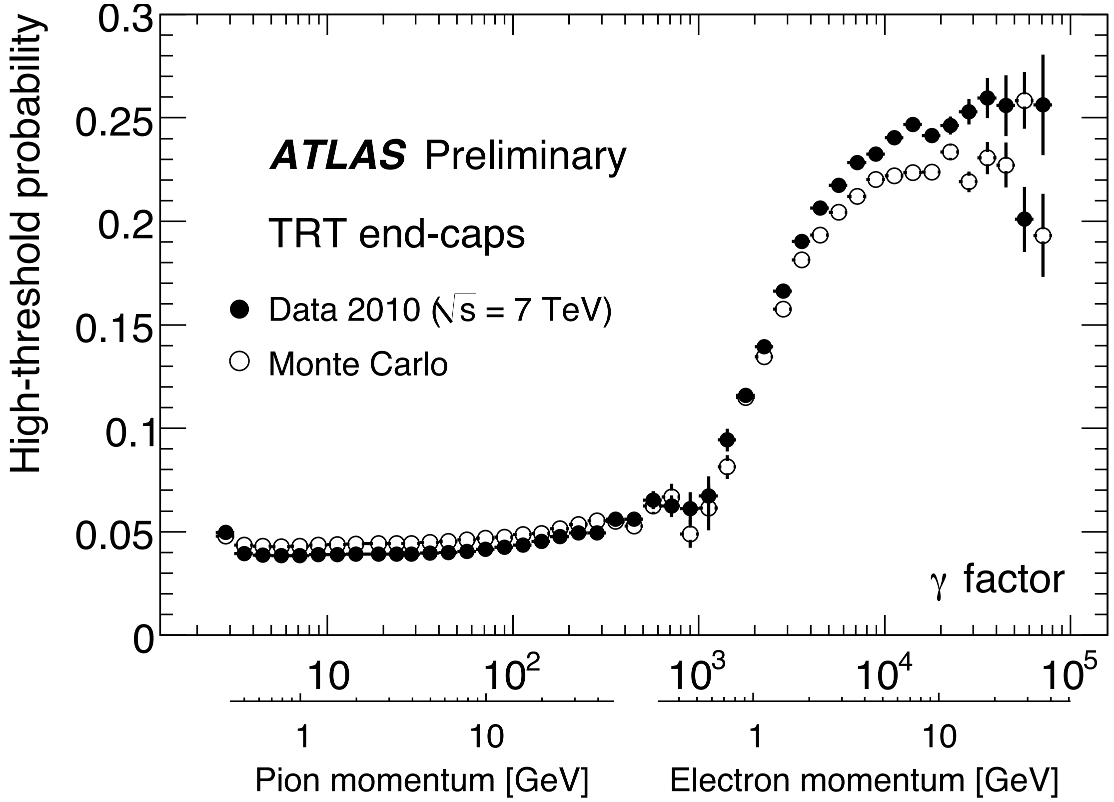
TRT high threshold hits on track marked in red

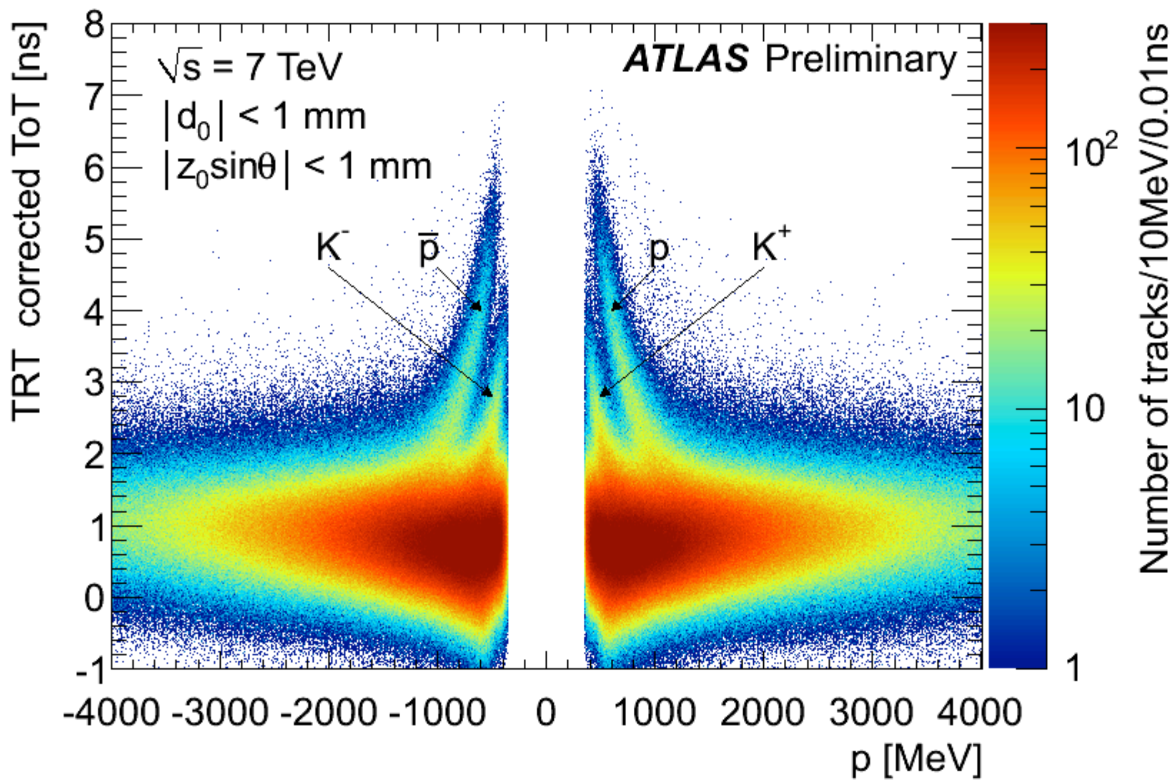


Particle Identification



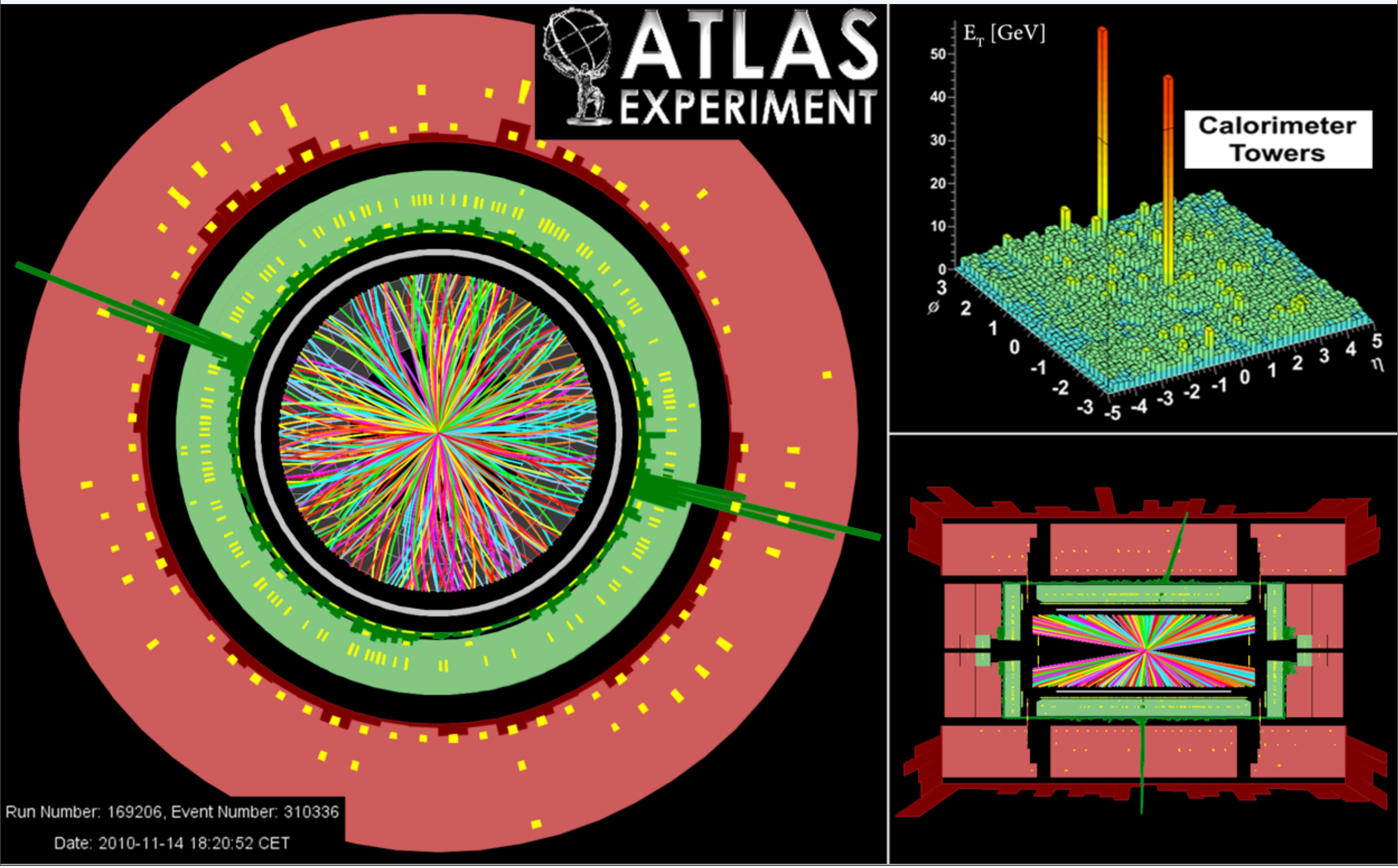
- TRT **High Threshold hit fraction** provides electron/hadron discrimination from transition radiation for energies < 150 GeV
- End-caps provide better HT fraction discrimination due to regular spacing of the radiator foils and also having more radiator
- **Time over threshold** is sensitive to ∂E/∂X of charged particle, providing particle identification for momentum < 10 GeV





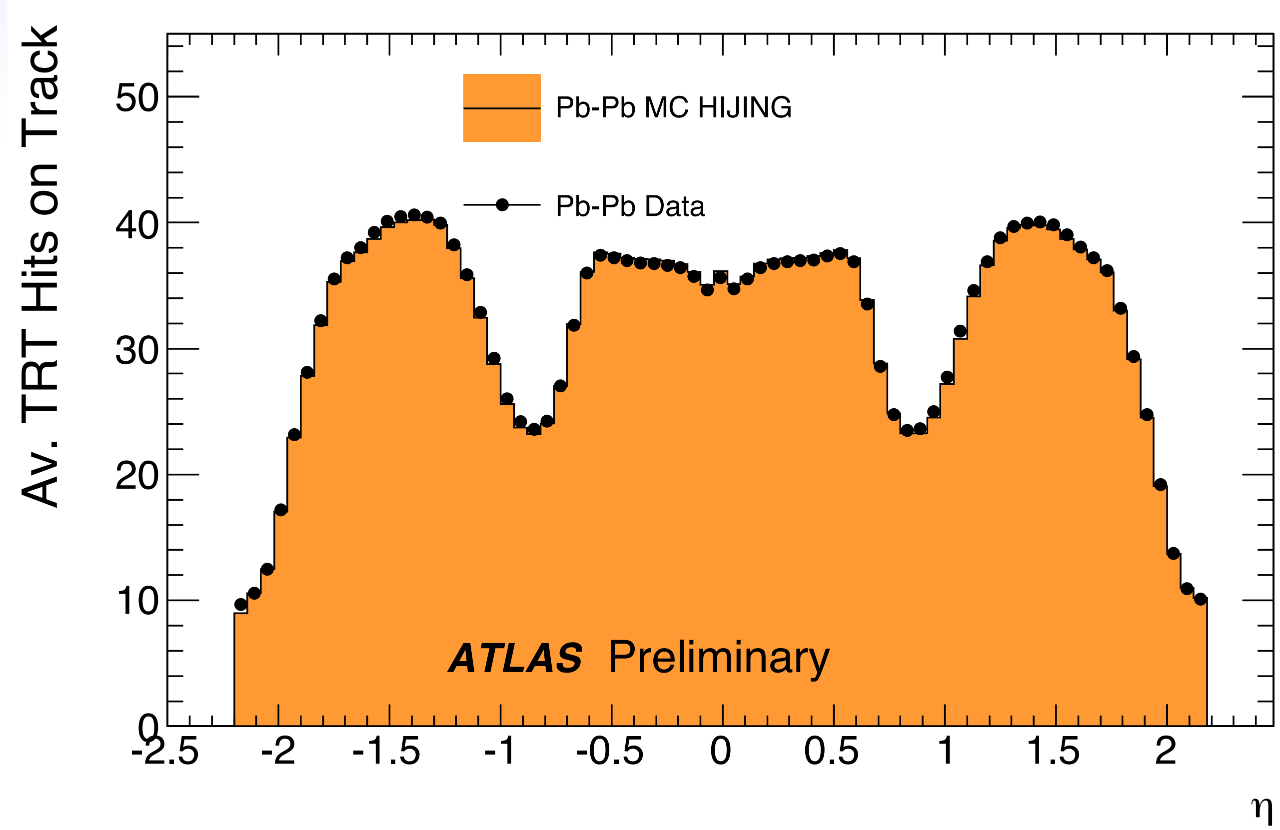
Heavy Ion Performance

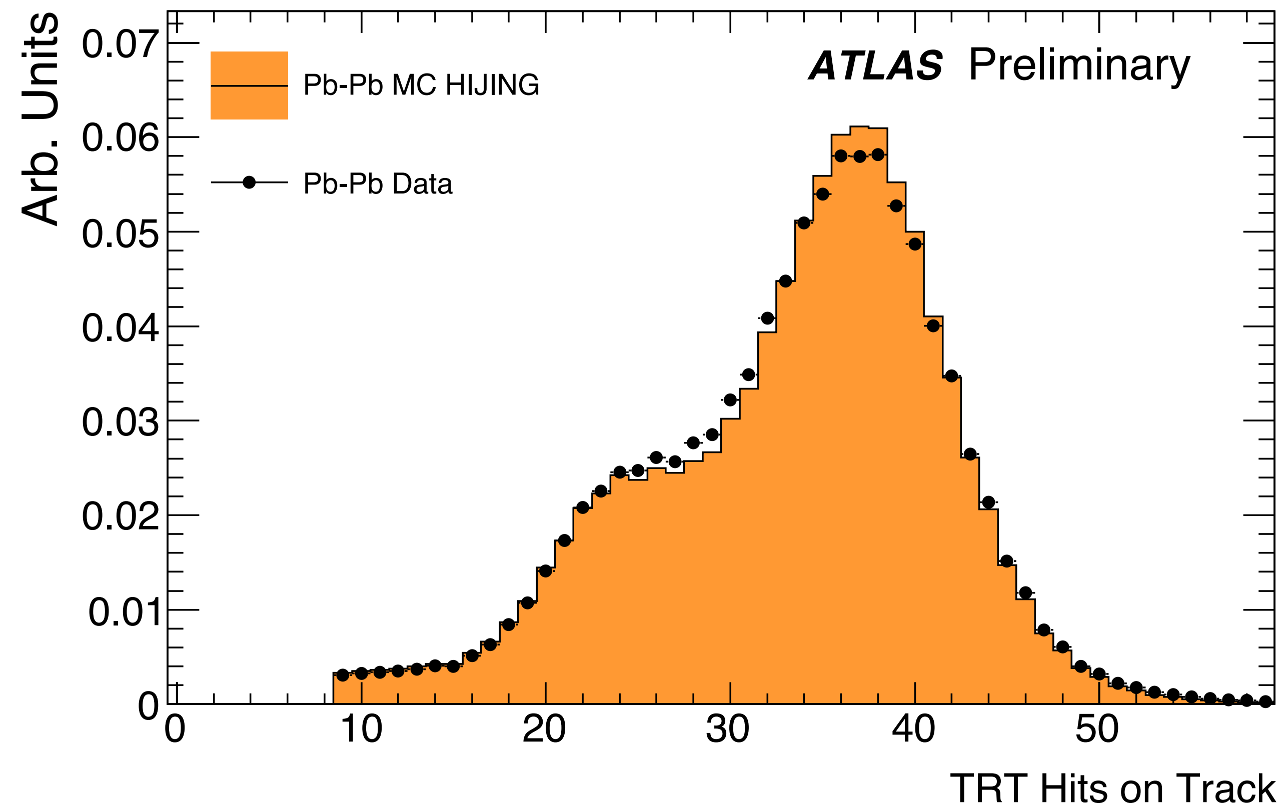
$Z \rightarrow e^+e^-$ candidate in Pb-Pb collisions



Heavy Ion Performance

- Provide a challenge for the TRT as detector occupancies for the most central collisions are **> 90%**
- Readout performed well due to lossless data compression and lower collision rate
- Allowed studies to optimize tracking in high occupancy environments
- Even in high occupancy events, TRT contributes to particle tracking





Summary

- The **TRT**:
  - A straw tracker in the ATLAS Inner Detector which provides charged particle **tracking** and **identification**
  - Smooth running with **100% data taking efficiency** during LHC stable beams in 2010 and 2011
  - Alignment and calibration procedures implemented and producing **118 (132) μm** hit resolution in barrel (end-cap)
  - Tracking improves momentum resolution and transition radiation detection improves electron identification
  - Heavy ion collisions demonstrate readout and tracking capability in high occupancy environments

Backup

Hit Efficiency

- Hit Efficiency ≡ $\dfrac{\text{\#of hits on track}}{\text{\# of straws passed by track}}$

  (excluding first and last hit on track)

- Achieved a "plateau" hit efficiency of **94%** in the central (± 1.3 mm) region of the straw
- Inefficiency at outer straw radius due to reconstruction effects and smaller signal size
- Excludes 2% of straws which are known to be inactive