The ATLAS TRT performance in proton-proton and ion-ion collisions at the LHC

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On behalf of the ATLAS Collaboration

"Physics of fundamental interactions"

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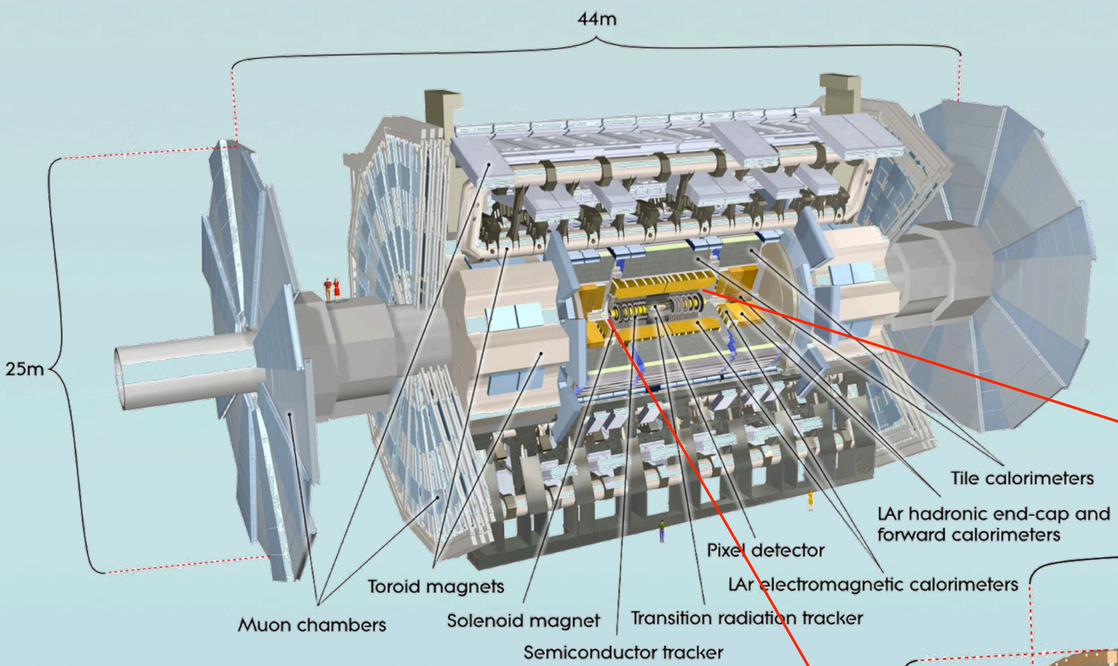
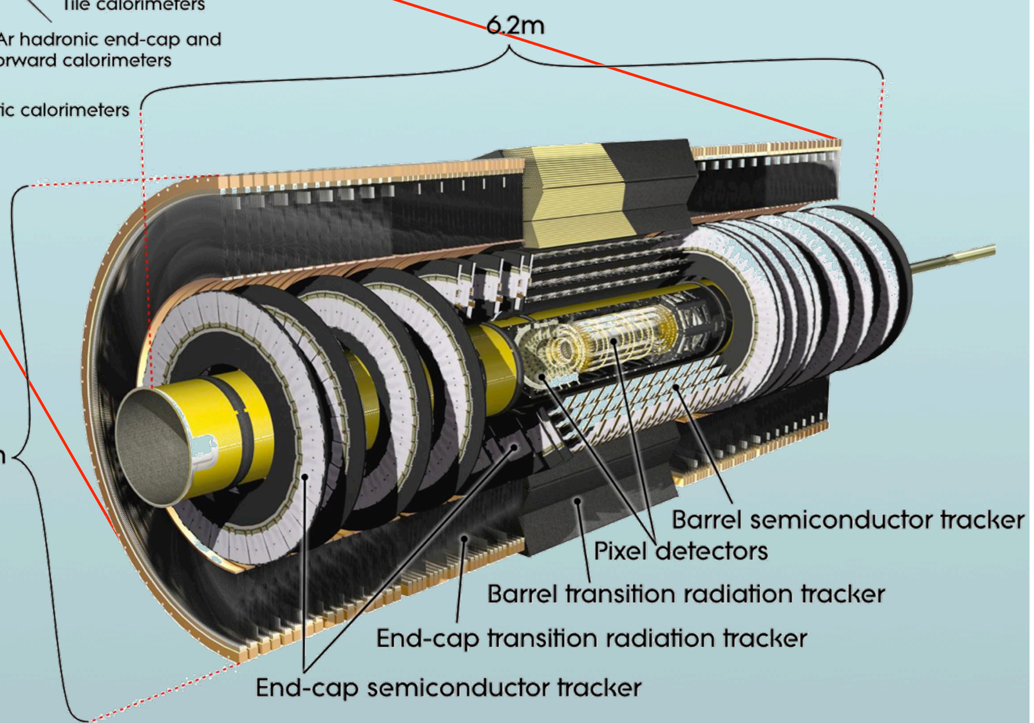
Outline

- ATLAS Inner Detector
- Transition Radiation Tracker
- TRT design requirements
- Timeline
- Principles of Operation
- TRT Electronics
- Fast-OR Cosmics trigger
- TRT Performance (pp and Pb-Pb collisions)
- TRT Physics Tasks
- Summary

ATLAS Inner Detector



The ATLAS Transition Radiation Tracker (TRT) is the outermost part of the Inner Detector system enclosing also the silicon strip and pixel detectors (SCT + Pixels). The whole ID is immersed in a 2 T magnetic field



<u>TRT goals:</u>

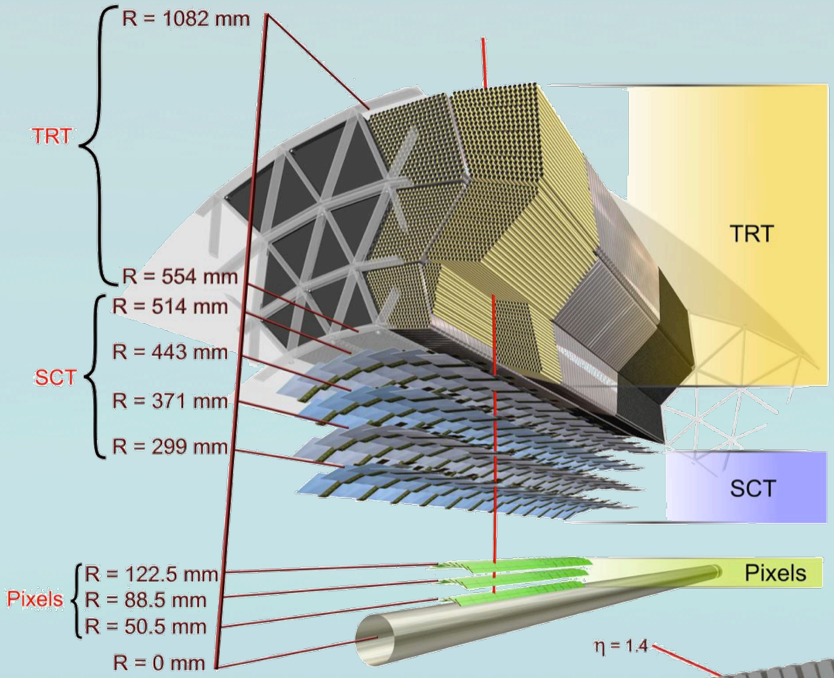
Momentum resolution for charged particle tracks above 0.5 GeV, $|\eta|<2$

- $\sigma(p_T)/p_T = 0.05\% p_T \oplus 1\%$

Electron identification

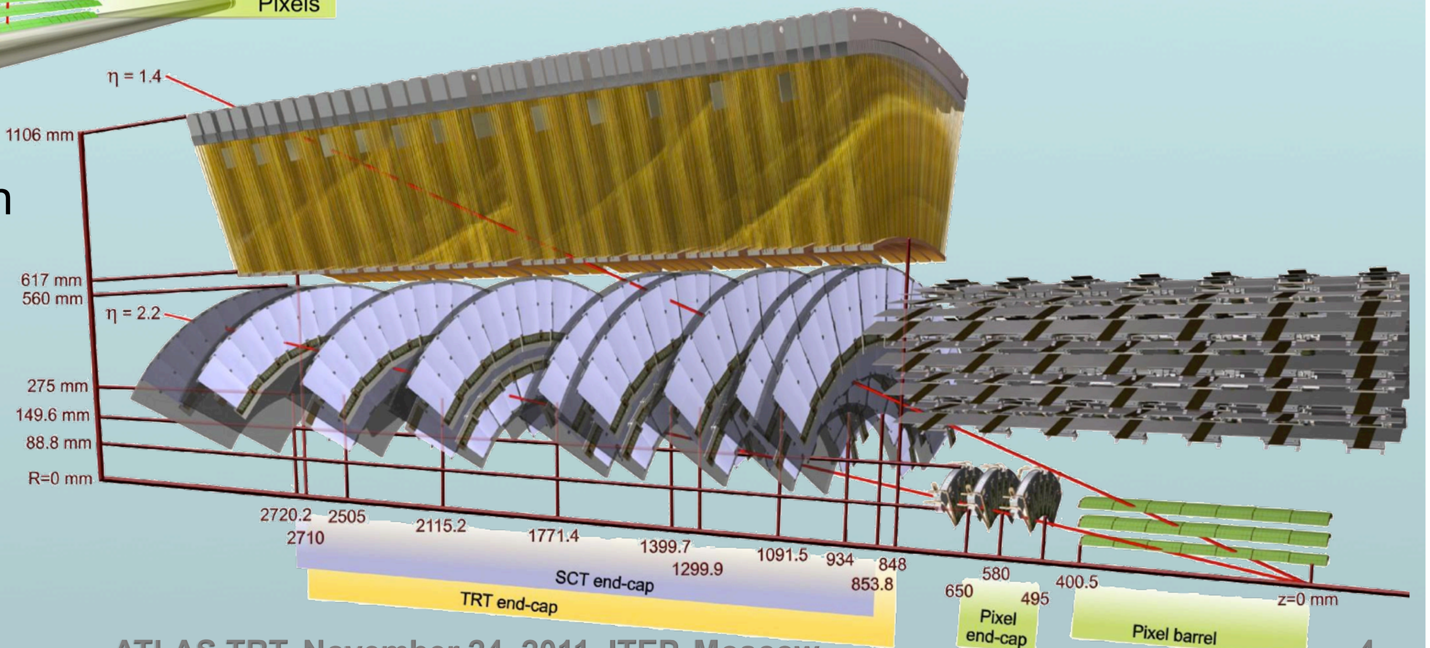
- $|\eta|<2$
- 1 GeV < p < 150 GeV

ATLAS Transition Radiation Tracker



<u>TRT Barrel:</u>
- 3 module types in R * 32 φ modules
- 1.44 m long straws parallel to beam axis
- wires electrically split in the middle to reduce occupancy (1.5 cm inactive region)
- each straw has an independent readout on both ends
- 105088 readout channels

2 <u>TRT end-caps</u>, each with:
- 20 wheels with 8 straw layers
- 39 cm long radial straws
- 122880 readout channels



TRT Design Requirements

- Accurate p_T measurement in conjunction with the Si tracking detectors:
  - long lever arm needed
  - many hits (30-40 TRT hits per track)
- Provide Electron Identification
- Reliable and efficient operation with high occupancy
  - up to 30%
- Operation in high counting rate environment
  - up to 20 MHz/straw
  - time between bunch crossings: 25 ns
- Minimal amount of material (in radiation lengths)
- Harsh radiation environment
  - ~10 MRad
  - ~10^{14} n/cm^2 year
- Minimal detector ageing effects
  - fast and chemically neutral active gas
- Chemically resistant straw materials
- Extremely precise and robust mechanical structure
  - tolerances <30 μm
- Maintenance of temperature stability
  - cooling of both straws and electronics is required

TRT: Timeline

1988: Initial paper published on TRT concept
1989: R&D for the TRT begins (1990: RD6)
1994: LHC machine approved. First full-size TRT prototype completed (10'000 channels for end-cap wheel)
1996-1998: Major Technical Design Reports for ATLAS construction approved
1998: ISTC project #441
2000: Assembly of Barrel modules and end-cap wheels starts
Front-end electronics specified and vendor chosen
2001: ISTC project #1800p
2006: First cosmic track recorded
2006: Installation of Barrel ID in ATLAS cavern
2007: Installation of ID end-caps in the cavern
2008: TRT routinely operated
Various Milestones Cosmic runs
September 10^{th}: first LHC beam seen (beam splashes)
2009: Stable operation
Spring/Summer Cosmic Combined runs
October ATLAS 24/7 operation first collisions at $\sqrt{s}$=900 GeV
2010: Stable 24/7 operation
first high energy proton collisions $\sqrt{s}$=7 TeV

TRT: Timeline

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CERN 88-02
22 April 1988

ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

THE FEASIBILITY OF
EXPERIMENTS AT HIGH LUMINOSITY
AT THE LARGE HADRON COLLIDER

Report of the High-Luminosity Study Group
to the CERN Long-Range Planning Committee

Edited by J.H. Mulvey

GENEVA
1988

ESTIMATE OF A TRANSITION RADIATION DETECTOR'S PERFORMANCE AS PART OF AN ELECTRON IDENTIFICATION SCHEME

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In this discussion of electron identification, it will be assumed that the starting point is an electron candidate, i.e. an electromagnetic (e.m.) shower seen in a calorimeter, and an interaction position; this could be known either through a vertex detector or by the calorimeter's capability of pointing the e.m. shower to the beam line. If the centroid of the e.m. shower is determined with a 1 mm precision in two layers separated by 100 mm, a sufficiently narrow road could be defined. The capacity of the calorimeter alone to identify electrons will not be discussed here. It has been demonstrated [1] that a hadron rejection of 10^2 to 10^3 can be achieved, with a 95% electron efficiency, by requirements on longitudinal and lateral shower development. In this note improvements are studied which can be achieved by equipping the region between the calorimeter and the interaction region.

Ideally, this region should be equipped with a tracking detector having a spatial resolution equal to the width of the path defined by the shower and vertex position, which is about a millimetre. In addition, this tracking detector should be as efficient as possible for electrons and as inefficient as possible for hadrons, e.g. a transition radiation detector (TRD). Here it is important to bear in mind that the role of the TRD is to reject hadrons that are in another momentum range than that of the electrons, since the predominant background is an e.m. shower from an energetic π^0 in spatial coincidence with low-energy charged hadrons. Consequently, the optimization of the TRD depends more on these low-energy hadrons than on the energy range of the electrons to be measured. The TRD can thus be made compact.

Transition radiation detectors can be operated in two different modes [2]: i) total ionization measurement, and ii) cluster counting. In the first method the total combined signal of ionization and X-rays is measured in the X-ray absorption gap. The background here comes from the Landau-distributed fluctuations in dE/dx. In the second method the number of energy deposits above a given threshold, i.e. the number of TRD quanta, is counted. Here the background is the Poisson-distributed number of δ-rays. The second method provides somewhat better hadron rejection, and more importantly uses simpler electronics and lends itself to fast-trigger applications.

In this discussion we will consider the cluster-counting method in a TRD of the type described in Ref. [2]. This detector, shown in Fig. 1, consists of a large number of radiator-proportional chamber (PC) sets. Each radiator is about 1 cm thick and consists of 40 polypropylene foils, each foil being 18 μm thick. The PC is 3 mm thick and has a wire spacing of 2 mm. The chamber gas is a mixture of xenon (60%) and helium (35%), with methane (5%) as the quencher.

The single-particle response of such a TRD is shown in Figs. 2 and 3. Figure 2 shows the rejection, $R = \epsilon_\pi/\epsilon_e$, as a function of the detector length for 50 GeV particles and a requirement of 90% electron efficiency. The rejection varies strongly with the length of the TRD, and we have taken 40 cm (5% of a radiation length) as a figure for the further discussion. This choice is not completely *ad hoc*, since our background will be of a combinatorial nature, and we will

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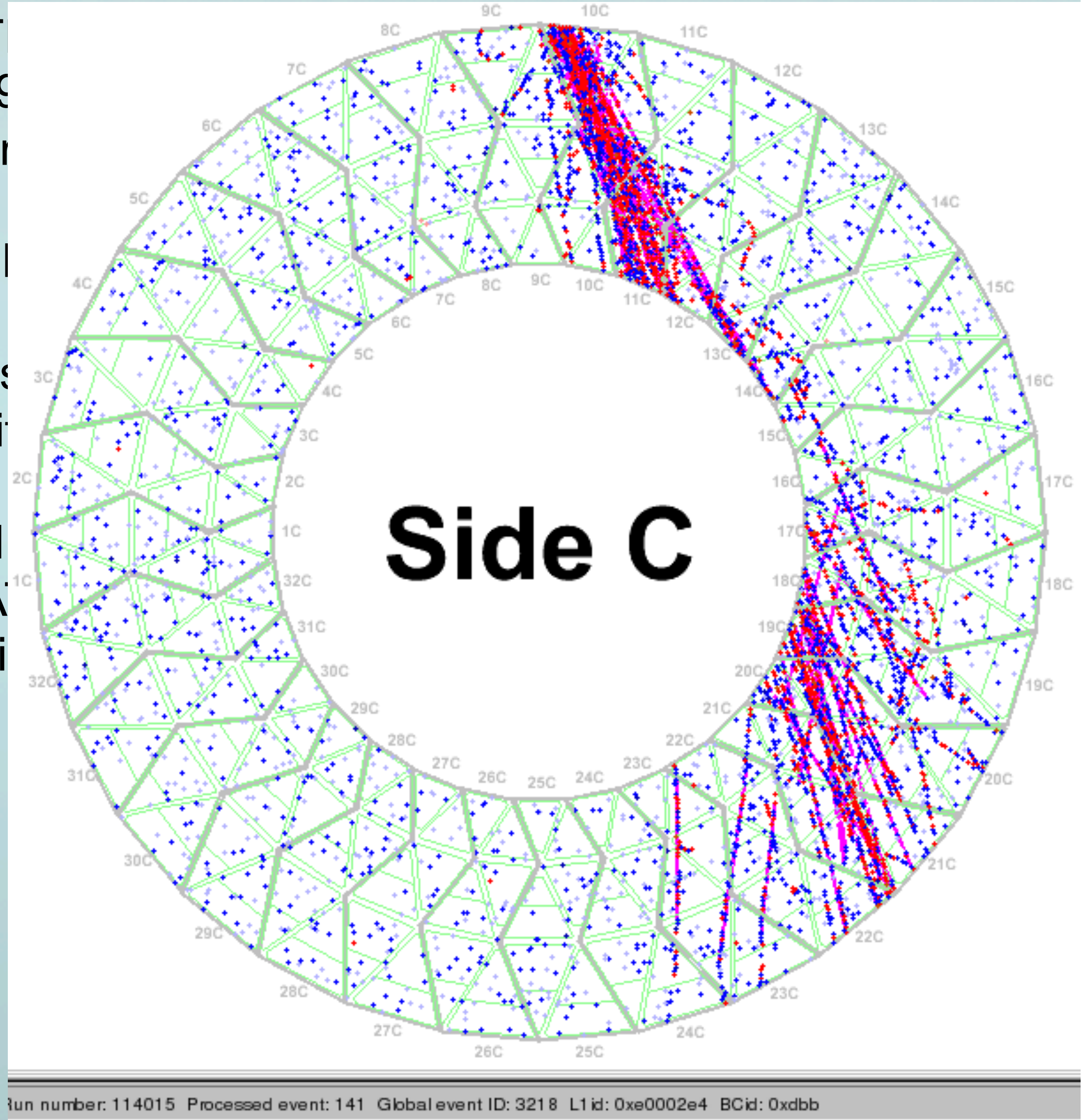

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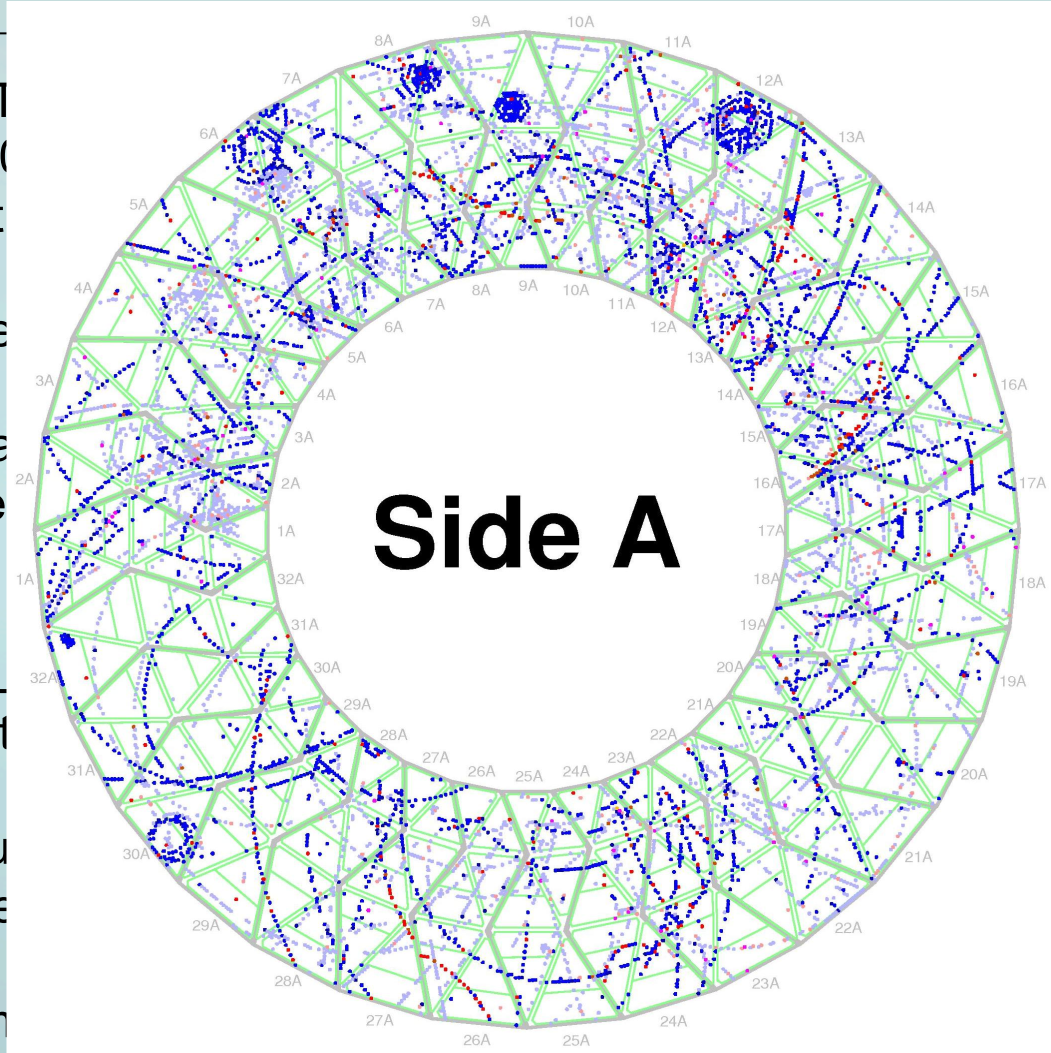
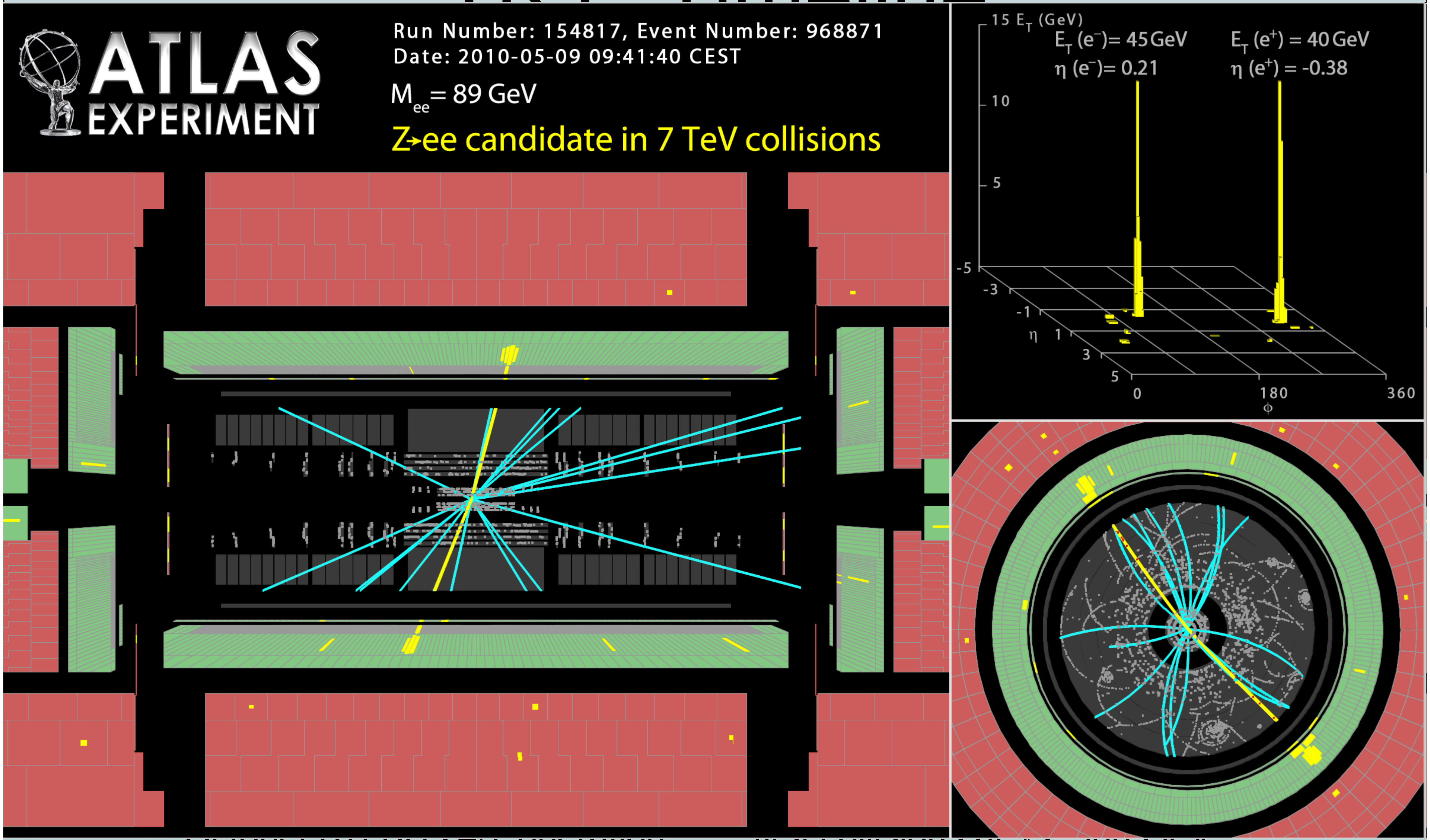
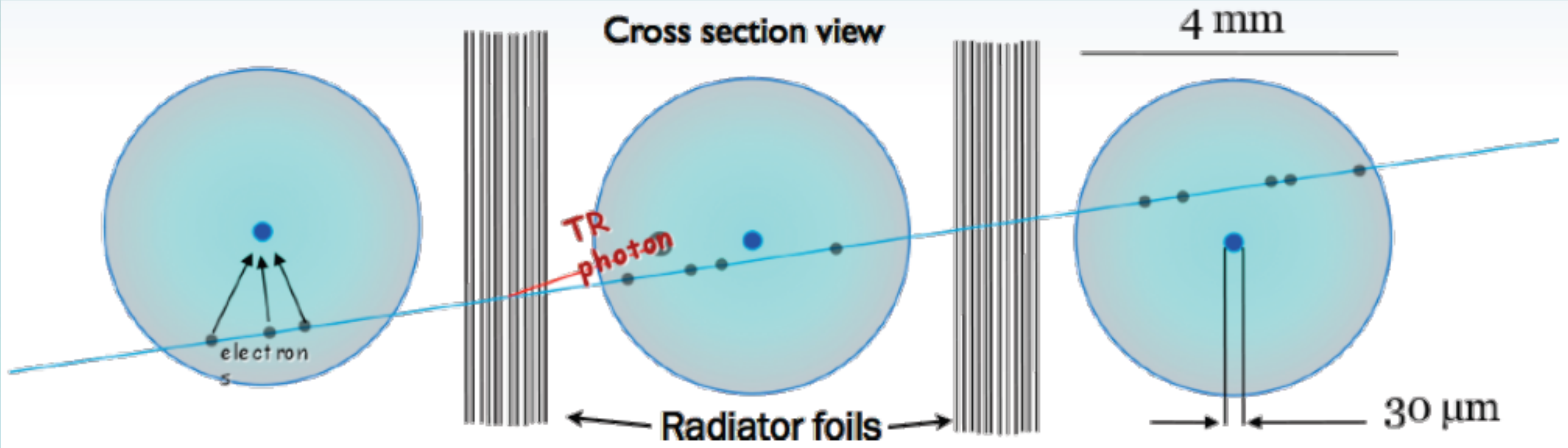


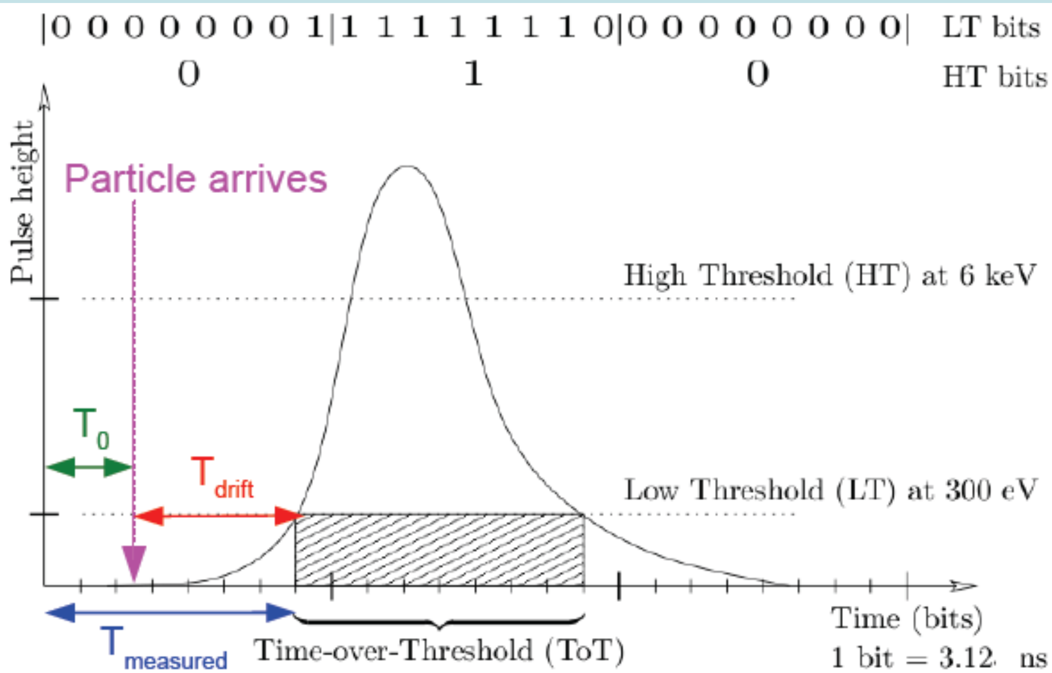
TRT: Timeline



2010: Stable 24/7 operation
<u>high energy proton collisions √s=7 TeV</u>

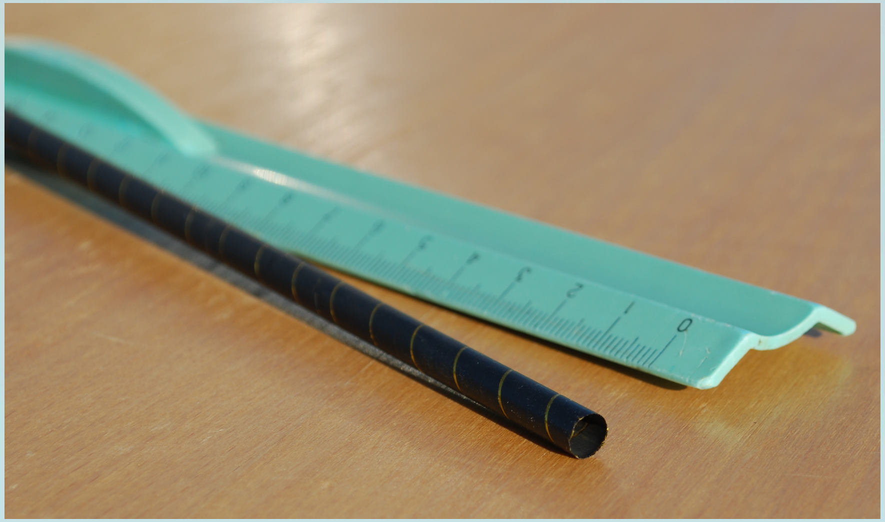
TRT: Principles of Operation

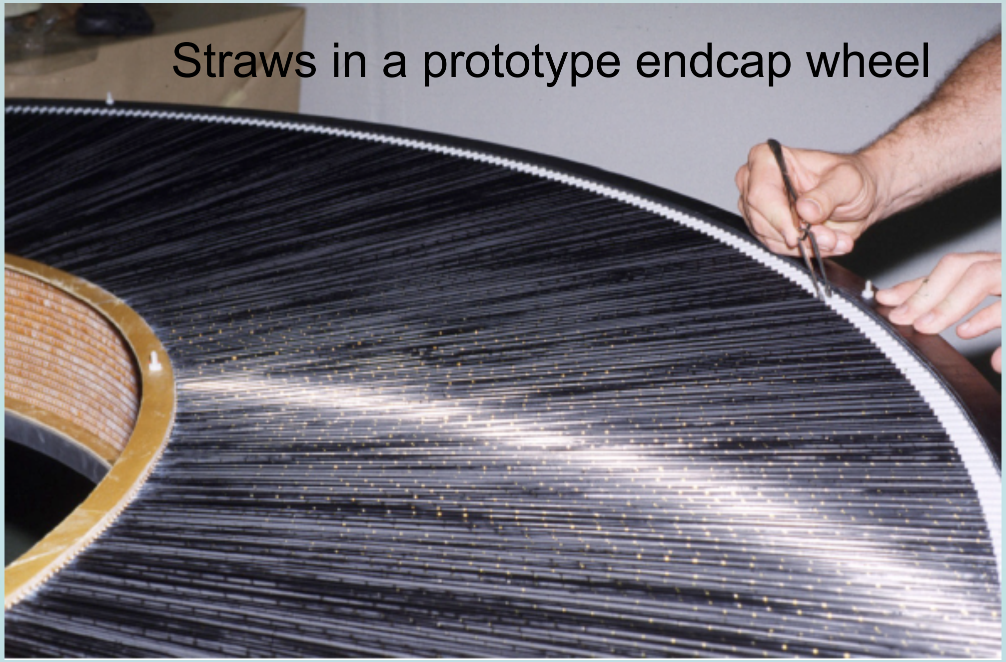


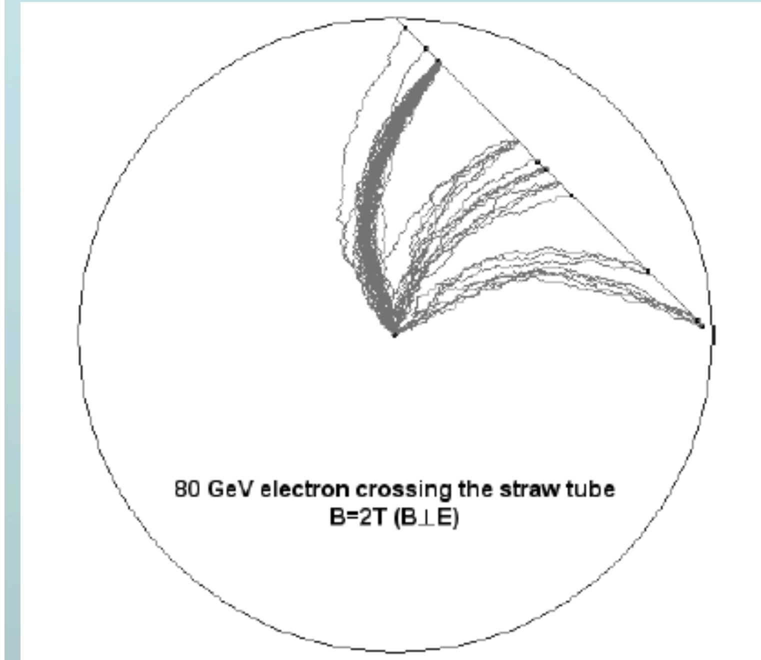


- Thin-walled tubes (straws) with drift time (T_{drift}) measurements for increased spatial resolution
- T_0 depends on ToF, cable lengths, electronics delays, trigger conditions etc.
  - Different for each straw
  - May change from run to run
    → calibrated every 36 h

TRT Design: The Straw





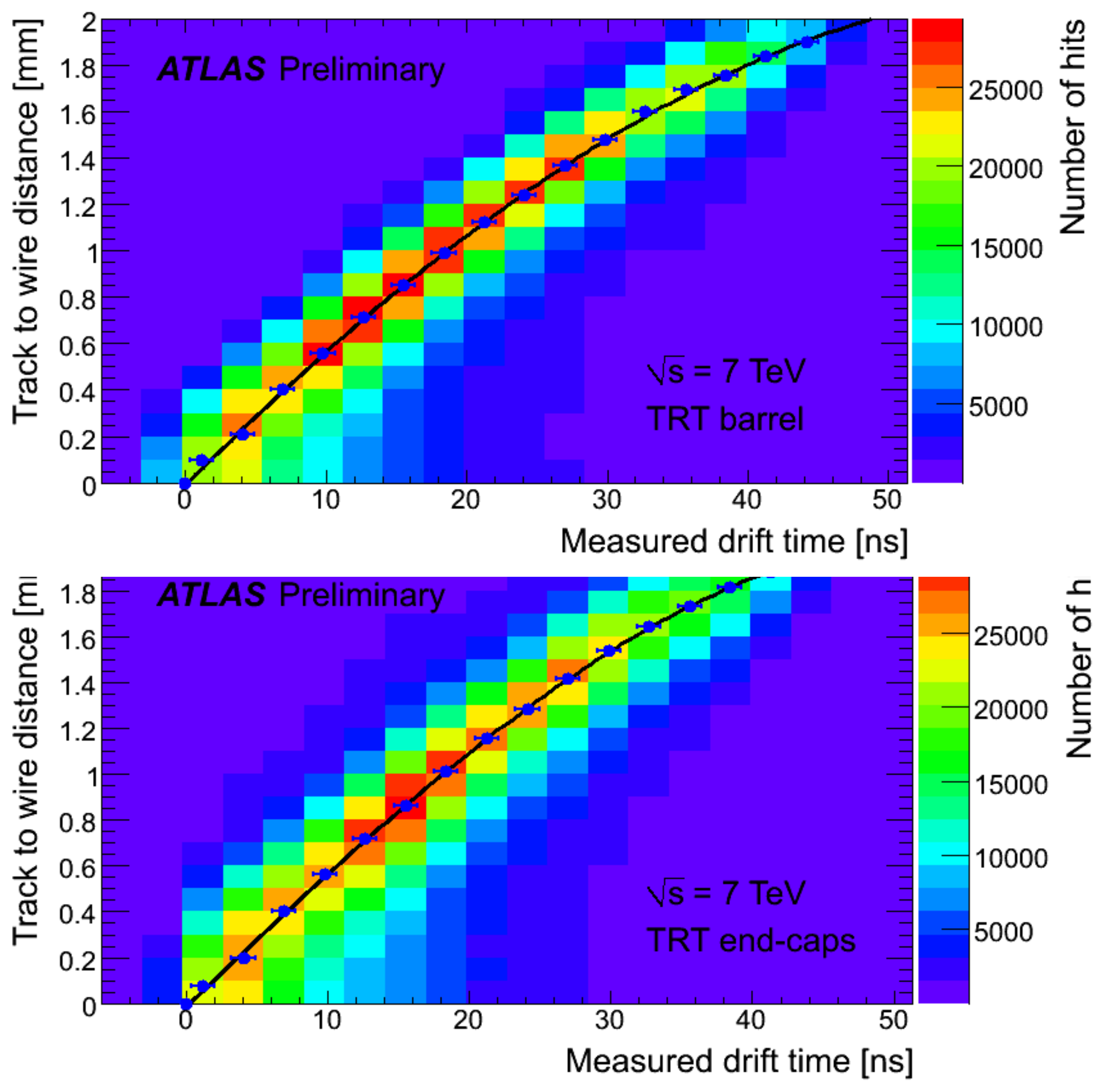


- Kapton straw (d = 4 mm) strung with gold plated tungsten anode wire (d = 31 μm)
- Reinforced with carbon-fiber for mechanical strength and thermal conductivity
- Filled with gas mixture of $Xe/CO_2/O_2$ (70%/27%/3%) chosen for stability and transition radiation absorption)
- Works in proportional mode with the straw wall being held at -1.5 kV (wire at ground)

TRT: R-t dependence

- Converts T_{drift} to drift radius used in tracking
- Gas composition, gas conditions and magnetic field dependent
- Calibrated every 36 hours
  - proved to be very stable
  - same performance 900GeV/ 7TeV

→ One R-t fit is used for <u>all</u> straws in <u>all</u> TRT partitions: BarrelA, BarrelC, EndcapA, EndcapC



TRT: Electronics

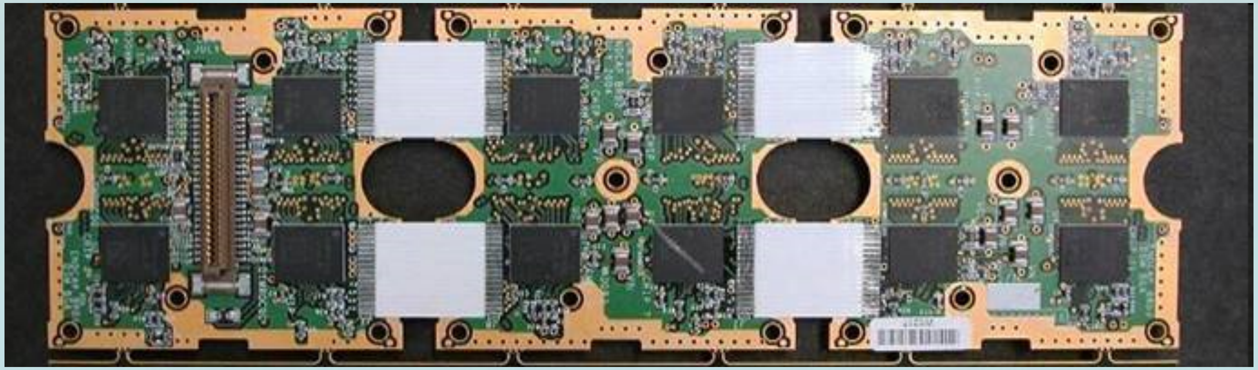
The custom made radiation-hard TRT front-end electronics implements two threshold algorithm to discriminate the signals: a low threshold (>300 eV) for registering the passage of minimum ionizing particles, and a high threshold (>6 keV) to flag the absorption of transition radiation X-rays.

It consists of analog and digital chips, mounted in Barrel on the opposite sides of PCB and in End-caps – on separate PCBs located on top of each other.

TRT readout chipset:

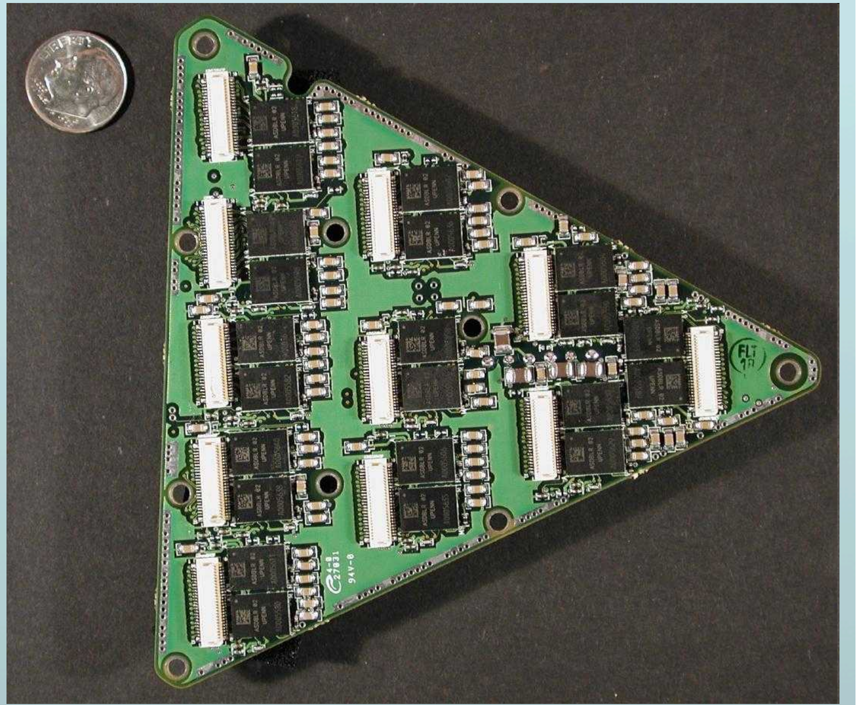
• ASDBLR – “Amplifier Shaper Discriminator Baseline Restorer” – analog integrated circuit

• DTMROC – ”Digital Time Measurement Readout Chip” – digital integrated circuit



↑ End-cap digital

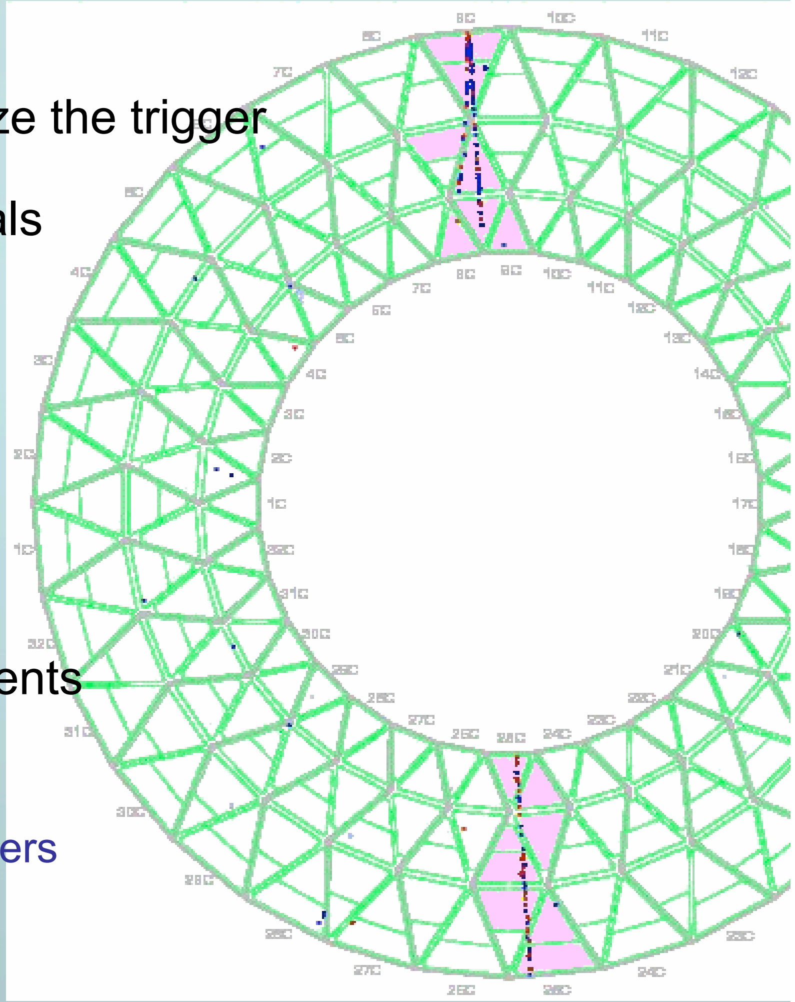
Barrel analog ↓



Total number of readout channels: 350848

TRT: Fast-OR Cosmics Trigger

- Motivation:
  - High good-track rate in standalone and combined running
  - Enhance track rate in the end-cap region
  - Independence from other systems
- After Sept.2008 LHC incident → decision to finalize the trigger

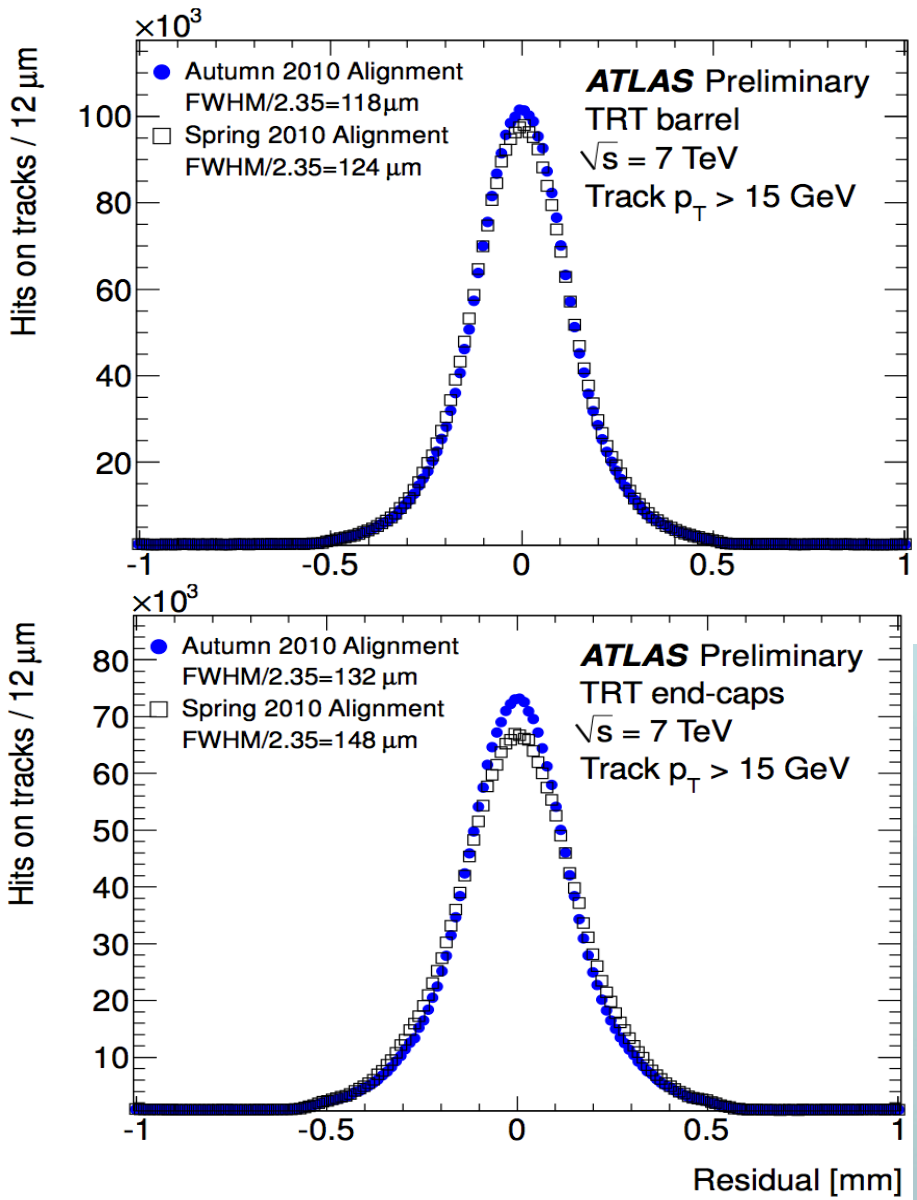


- Configuration: use DTMROC high threshold signals lowered to MIP levels
- Implementation was quick: first tracks – end Oct. 2008, timing-in completed May 2009
- The number of recorded cosmic muons tracks was doubled in just a week

- Very good trigger timing jitter of 9 ns
- Trigger rate ~10 Hz with a high purity of >90% events with tracks
- Became a major player in ATLAS commissioning:
  - reference trigger for timing-in of other ATLAS triggers

TRT Performance: Resolution

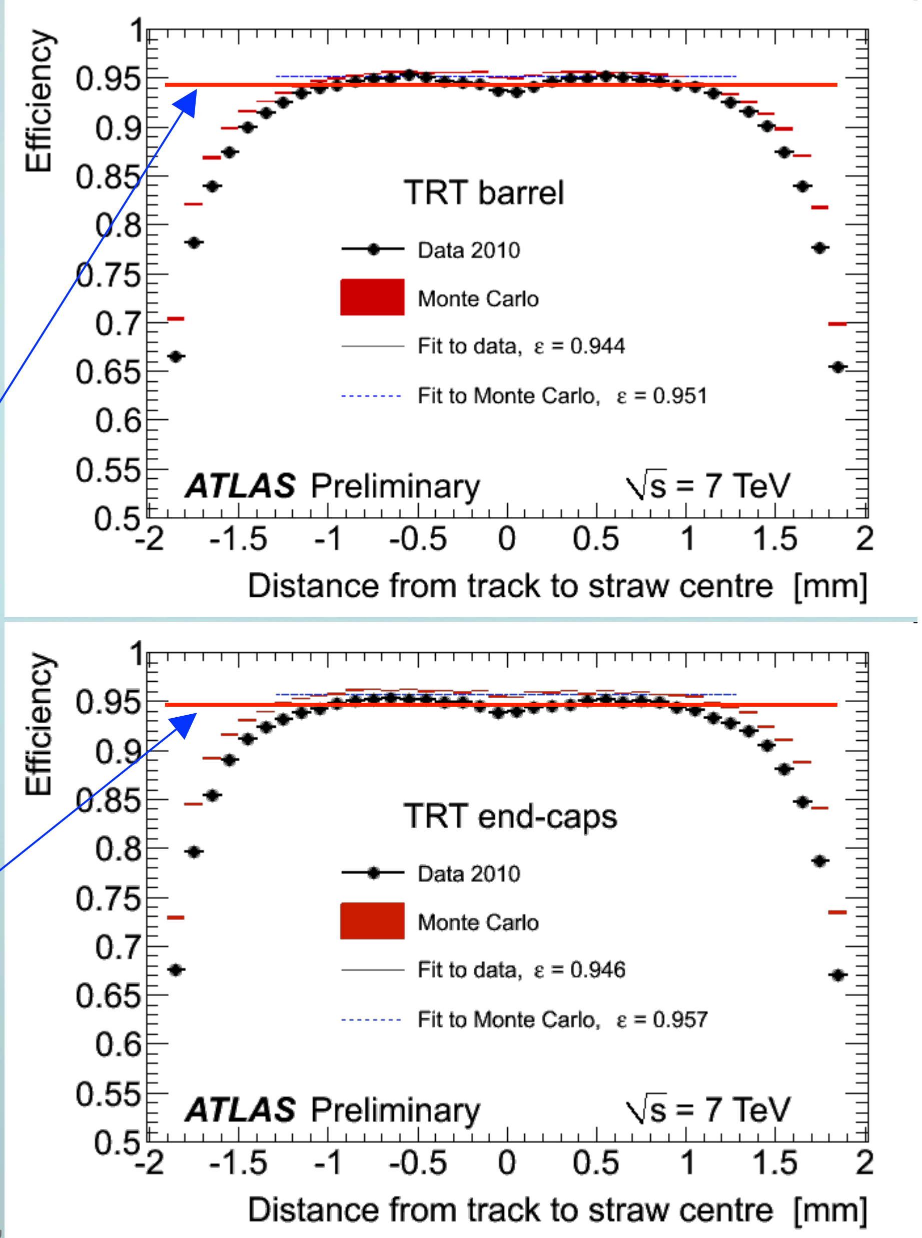
- Residual distributions show the difference between the fit and measured track position for each hit. They show the spatial resolution of the TRT straws
- Resolution improved in 7 TeV running to 118 μm (barrel) and 132 μm (end-caps) for tracks not suffering multiple scattering
- Much of the improvement is from careful alignment
- Design resolution was exceeded in the barrel
- Barrel benefits more from one extra year of cosmic running
- Physical limit nearly achieved



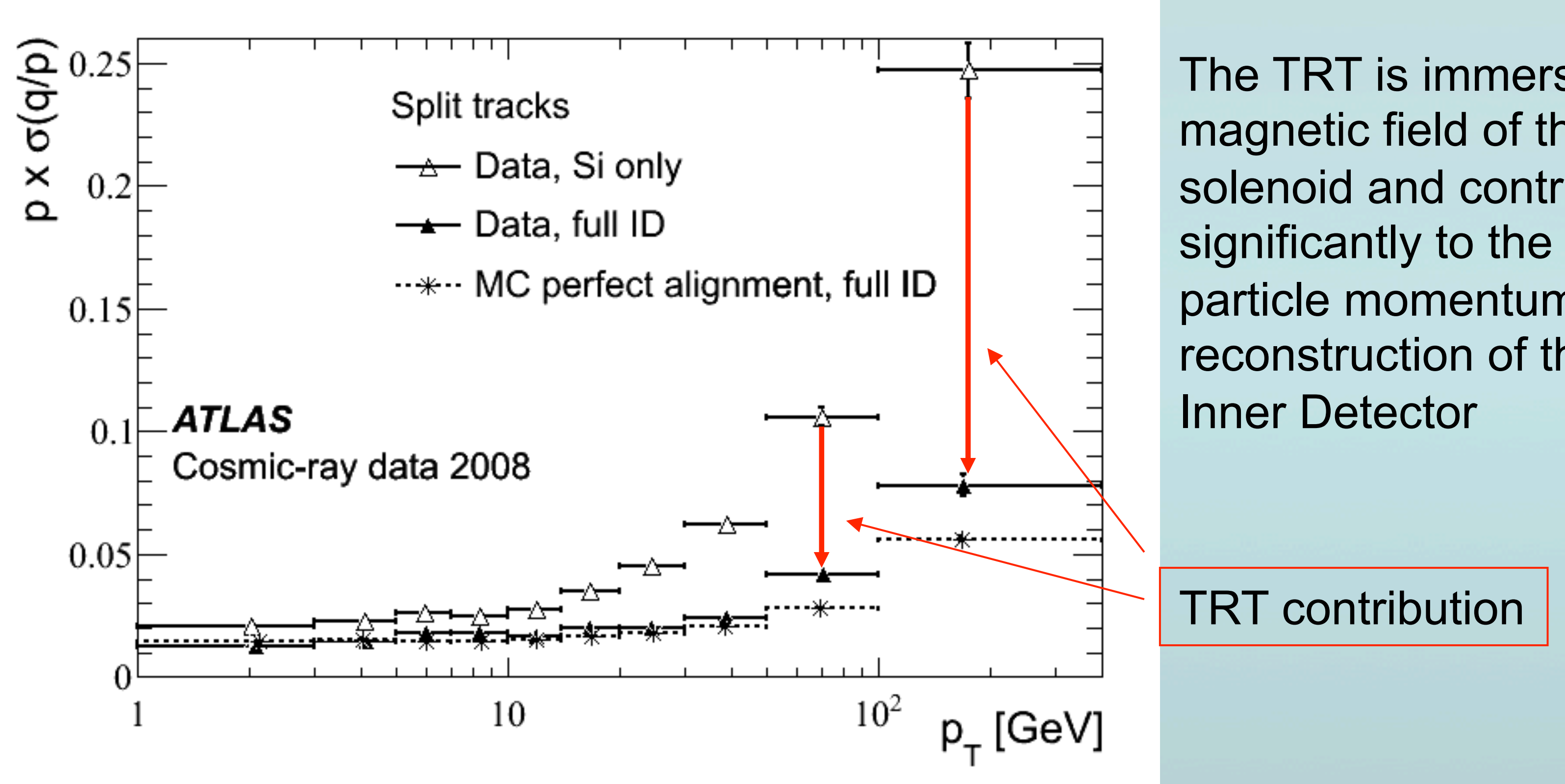
TRT Performance: Efficiency

- Number of straws with a hit on track divided by the number of straws crossed by track
- The 2% of known non-functioning straws are excluded from this study
- Same performance 900GeV/7TeV
- The track selection:
  - ❑ Pixel hits > 0
  - ❑ SCT hits > 5
  - ❑ TRT hits > 14
  - ❑ $p_T > 0.5$ GeV
  - ❑ $|d_0| < 10$ mm
  - ❑ $|z_0| < 300$ mm

Straw efficiency in Barrel ε = 94.4%
in Endcaps ε = 94.6%



TRT Performance: Momentum Resolution



The TRT is immersed in a 2 T magnetic field of the central solenoid and contributes significantly to the charged particle momentum reconstruction of the ATLAS Inner Detector

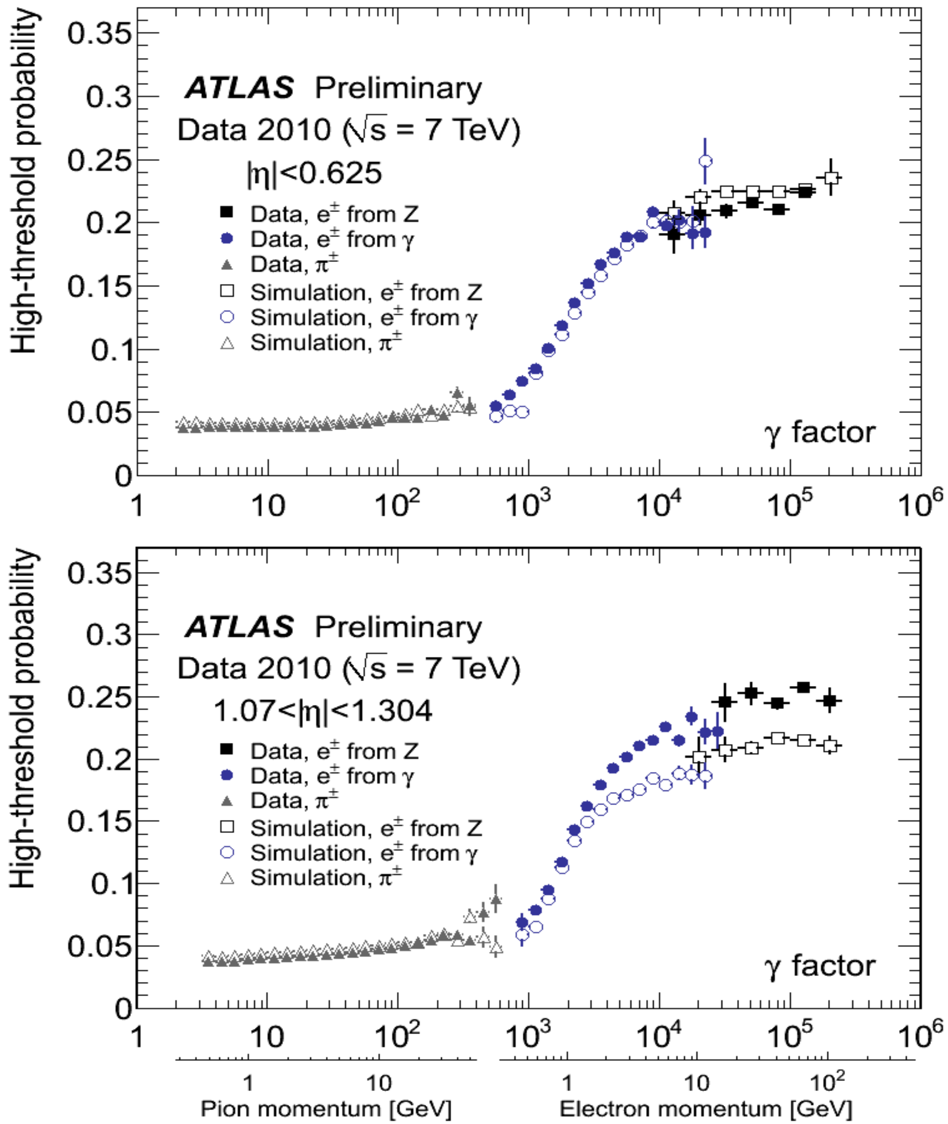
TRT Performance: Particle Identification with TR

Transition Radiation (TR):

- photons emitted by a charged particles when traversing a boundary between material with different dielectric constants ε_1, ε_2
- Intensity $I \sim \gamma = E/m$, $\theta \sim 1/\gamma$
- Emitted photons per transition $\sim O(\alpha_{EM}\gamma)$
  → Many transitions needed
- Emitted energy $\sim(\varepsilon_1 - \varepsilon_2)$
  → gas and light plastic, photon energies 5 – 30 keV
- Gas with high photon absorption required – Xe based mixture

TRT is able to separate electrons from pior over a momentum range between 1 and 15 GeV

- Requirement for the electron candidate selecti high-threshold probability on track > 12%



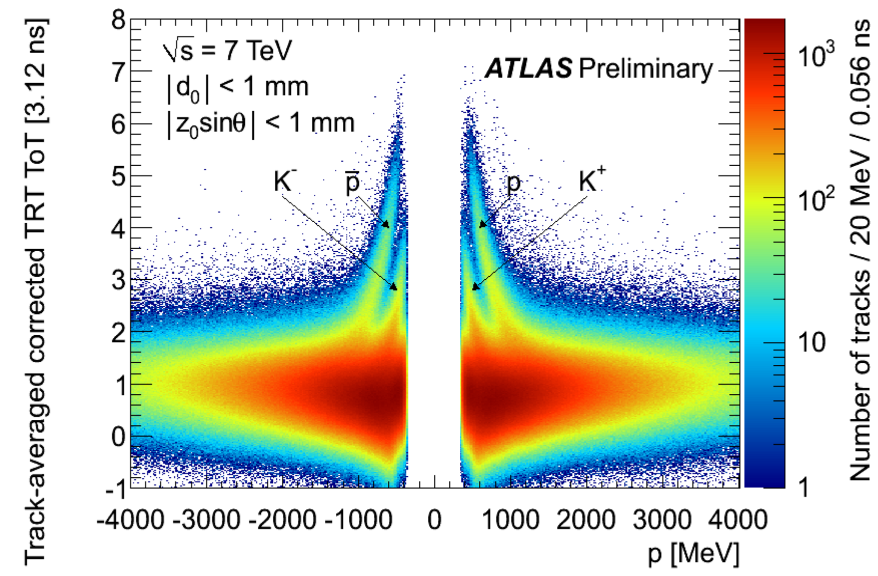
TRT Performance: Particle Identification with ToT

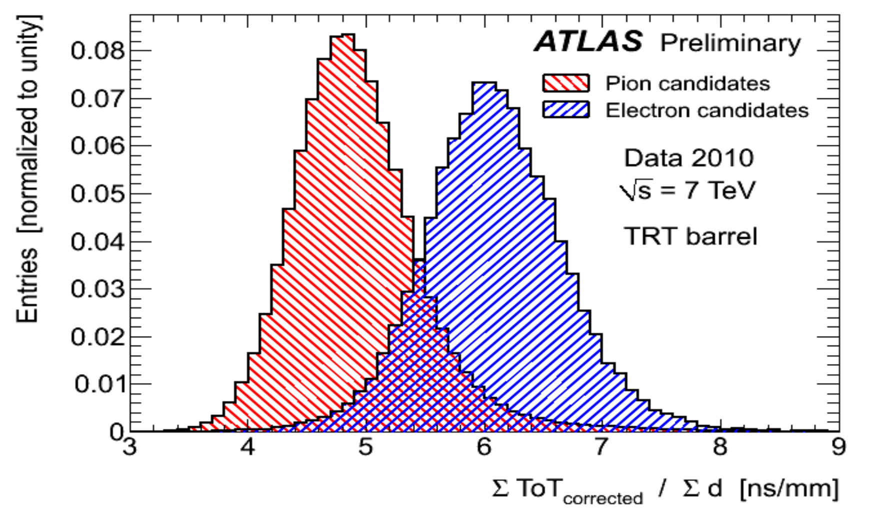
Time over (low) threshold (ToT)

- is sensitive to dE/dx of charged particle identification for momentum < 10 GeV
- depends on β (Bethe-Bloch)
- normalized to transverse path length of track in the straw
- corrected for hit position along the straw

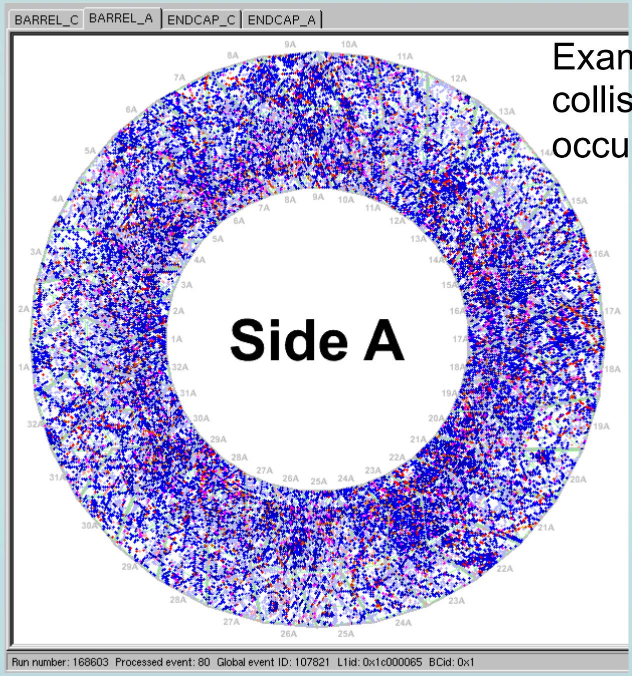
Combining TR and ToT technique

- yields additional information to improve the particle identification (pion mis-id ~10^{-2} at 90% electron efficiency)

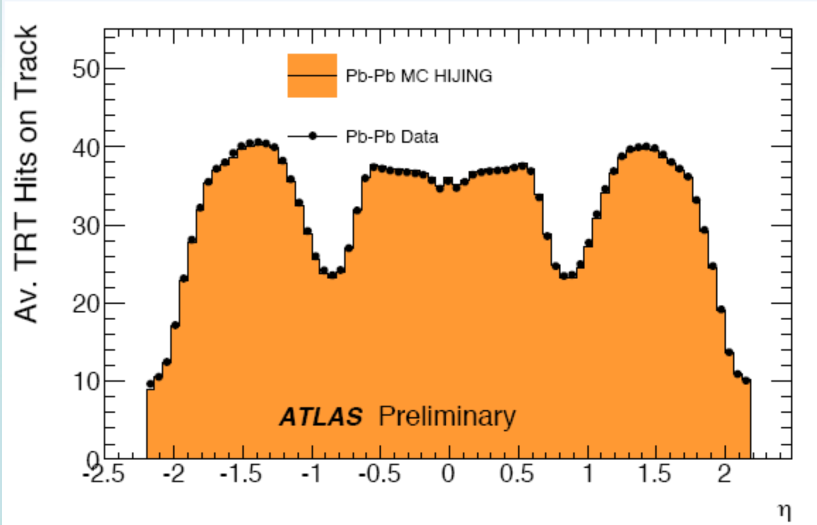


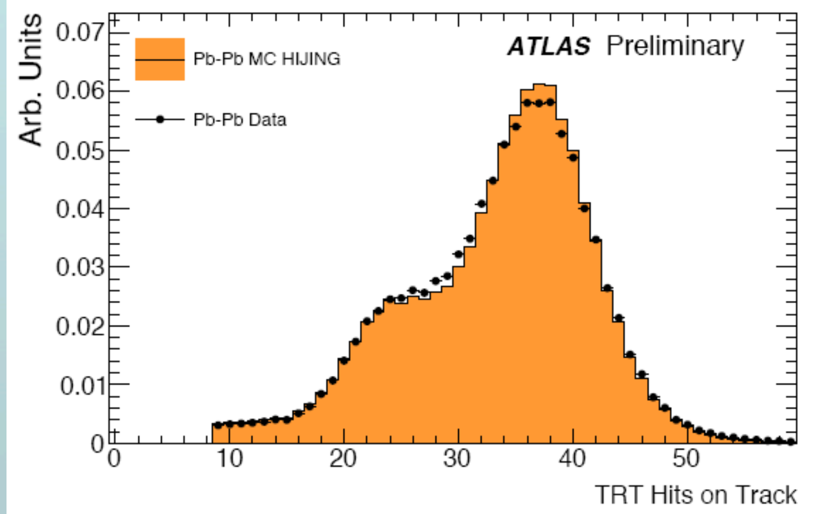


TRT Performance: Heavy Ions



Example of Lead-lead collision with TRT occupancy ~40%





- A real challenge for the TRT as detector occupancies for the most central collisions are close to 90%
- The readout performs well due to lossless data compression and lower collision rate
- New studies to optimize tracking in high occupancy environments
- Even in high occupancy events, the TRT contributes to particle tracking

Physics with the TRT at the LHC

- Tracking
  - continuous tracking and accurate p_T measurement for charged particles above 0.5 GeV/c and $|\eta|<2$
- TR (particle identification)
  - electrons in cosmic rays
  - electrons in photon conversions
  - Standard Model electro-weak measurements (W, Z, Wγ, Zγ, $t\bar{t}$ ...). Particle identification by TRT is used to minimize the background from fake electrons
  - SUSY searches (those including leptons)
  - searches for exotic stable heavy particles
  - Higgs searches ($H\to\gamma\gamma$, $H\to WW^{(*)}\to l\nu l\nu$, $H\to\tau\tau$)
  - measurement of inclusive electron spectrum at the LHC

Summary

- The Transition Radiation Tracker in the ATLAS Inner Detector (ID) provides charged particle **tracking** and **identification**
- With the latest alignment and calibration constants spatial residuals of **118 μm (barrel)** and **132 μm (end-caps)** can be achieved
- TRT tracking improves overall **momentum resolution** of the ATLAS ID, transition radiation improves **electron identification**
- TRT plays important role in many ATLAS physics tasks
- Heavy-ion collisions show that the TRT is ready for high occupancies at the LHC ever-increasing luminosities