The ATLAS TRT and its Performance at LHC

Ahmet BİNGÜL

University of Gaziantep

On Behalf of ATLAS TRT Collaboration

ICPP-II, Istanbul, TURKEY

20-25 June 2011

Outline

- Introduction (LHC status)

- The ATLAS TRT

- Operation of the TRT

- Calibration of the TRT

- Particle Identification with TRT

- Performance of the TRT (*pp and Heavy Ion collisions*)

- Summary
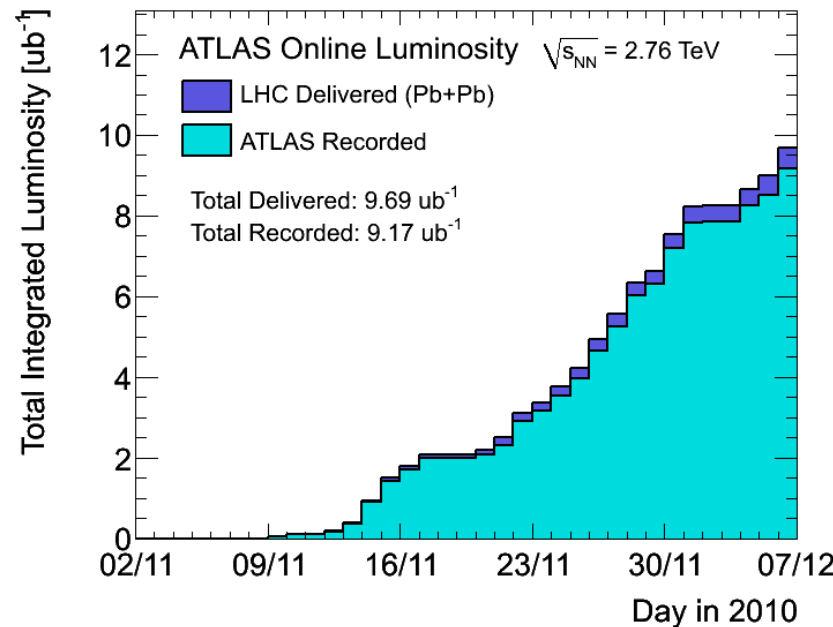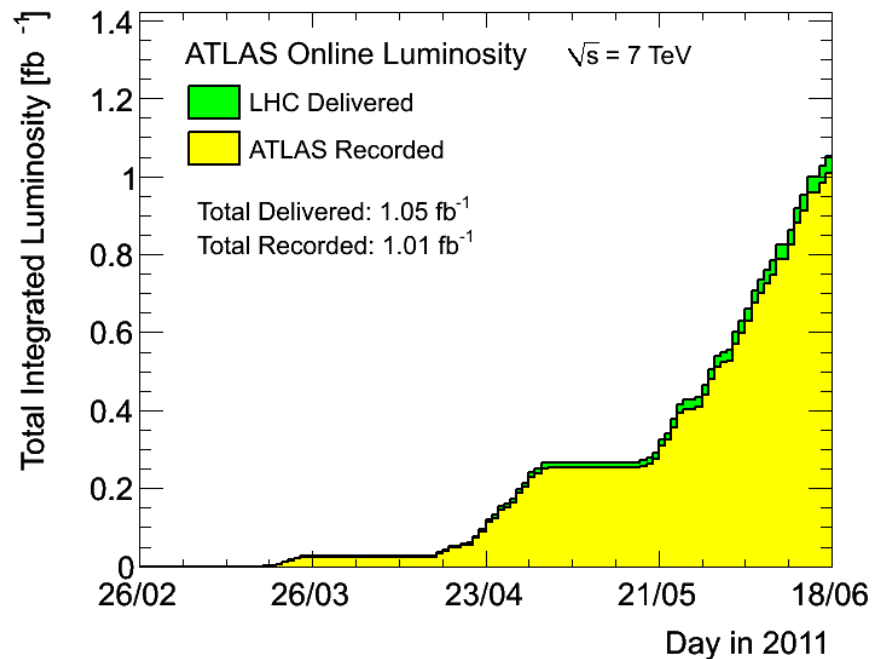
LHC Status

- **Design (for p-p collisions)**
  - E_{CM} = 14 TeV
  - Interaction rate f = 40 MHz
    (T = 1/f = 25 ns bunch spacing)
  - Luminosity L = 10^{34} cm^{-2}s^{-1}

- **Currently**
  - running at L = 10^{33} cm^{-2}s^{-1}
  - E_{CM} = 7 TeV
  - T = 50 ns bunch spacing
  - Delivered >1 fb^{-1} of p-p collisions and 10 μb^{-1} of Pb-Pb collisions
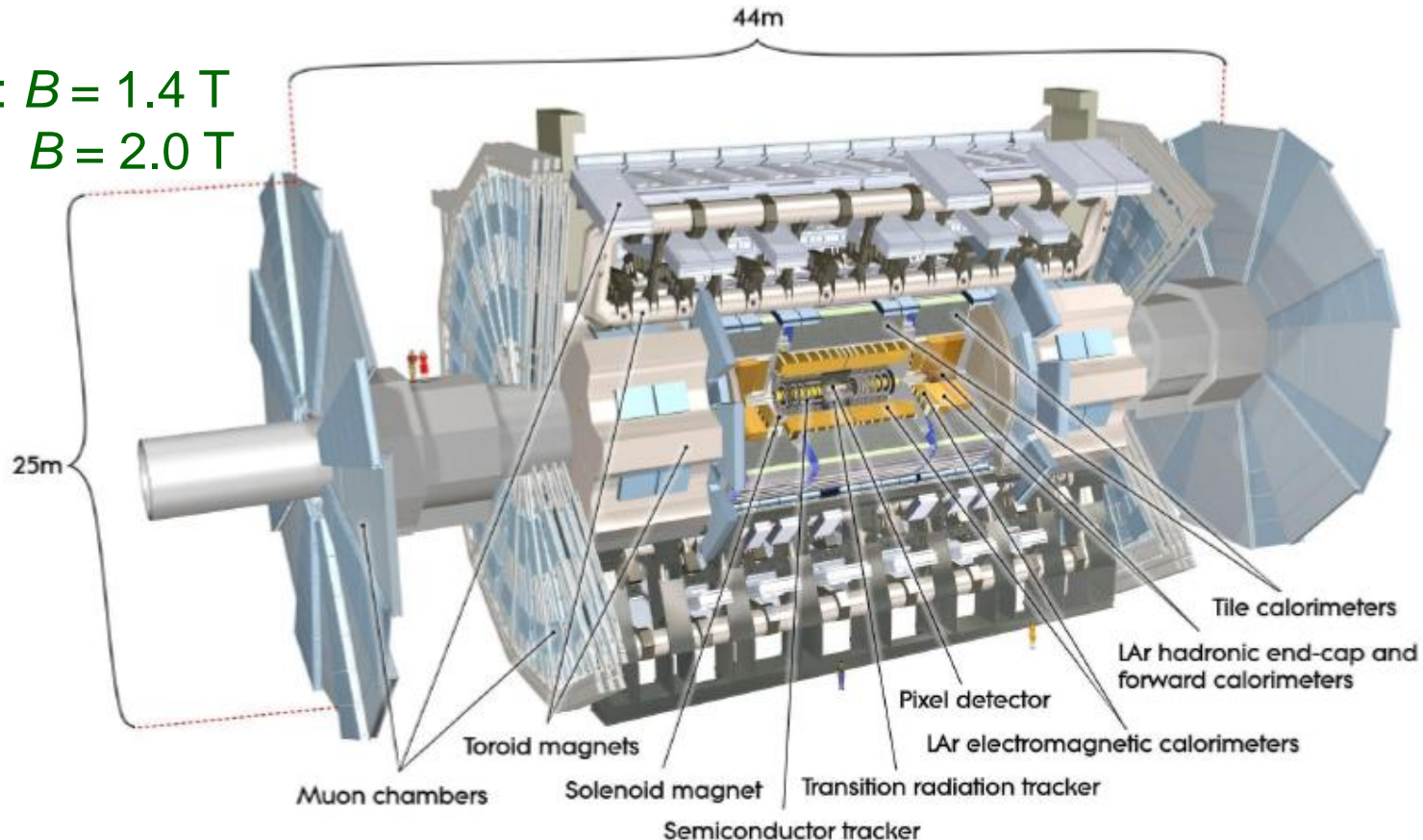
- **Physics**
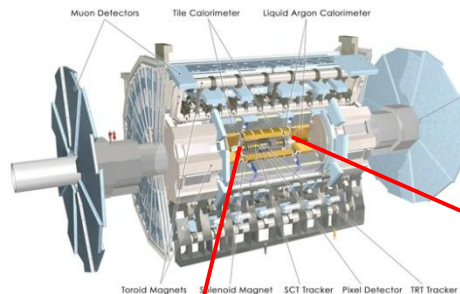 - *Standard Model has already been rediscovered*

ATLAS

- Large multi-purpose particle detector consisting of several sub-detectors:
  - *Muon Spectrometer*
  - *Liquid Argon and Scintillator Tile Calorimeters*
  - *Inner Detector (ID) (for charged particle tracking and identification)*

Toroid magnets: B = 1.4 T
ID solenoid: B = 2.0 T
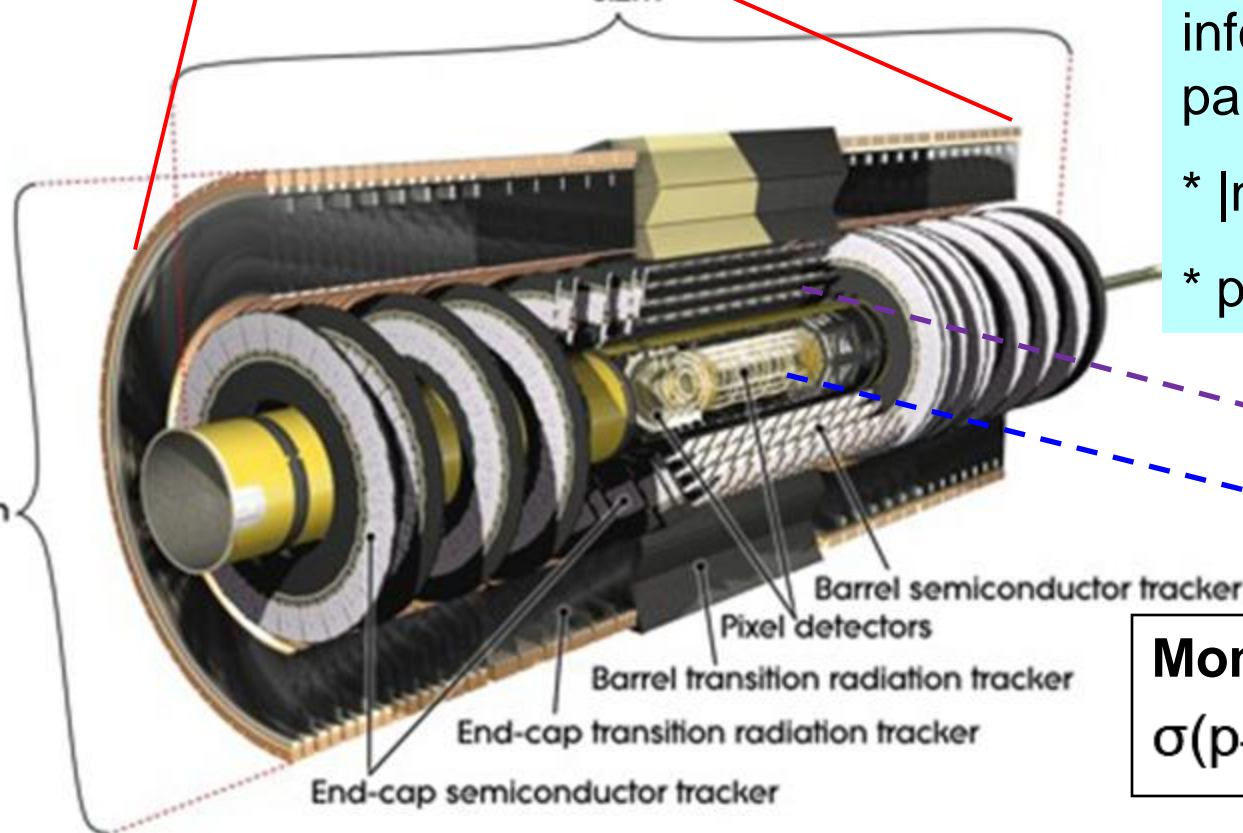
ATLAS Inner Detector

ID is composed of

* two silicon trackers (Pixel & SCT)

* Transition Radiation Tracker (TRT)

Provides tracking information for charged particles with:

* |η|<2.5

* p_T > 0.5 GeV

6.2m

2.1m

SCT: 6.2 M channels

Pixel: 80 M channels

Barrel semiconductor tracker

Pixel detectors

Barrel transition radiation tracker

End-cap transition radiation tracker

End-cap semiconductor tracker

Momentum Resolution:

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

ATLAS TRT

Physical Properties of TRT:

- is a gaseous detector.

- consists of straw tubes (d = 4 mm) reinforced with carbon fibers and containing a d = 31 μm gold plated tungsten wire in the center.

- The straw wall is at –1.5 kV while the wire is kept at ground.

- Filled with gas mixture of $Xe/CO_2/O_2$ (70%/27%/3%) chosen for stability and transition radiation performance
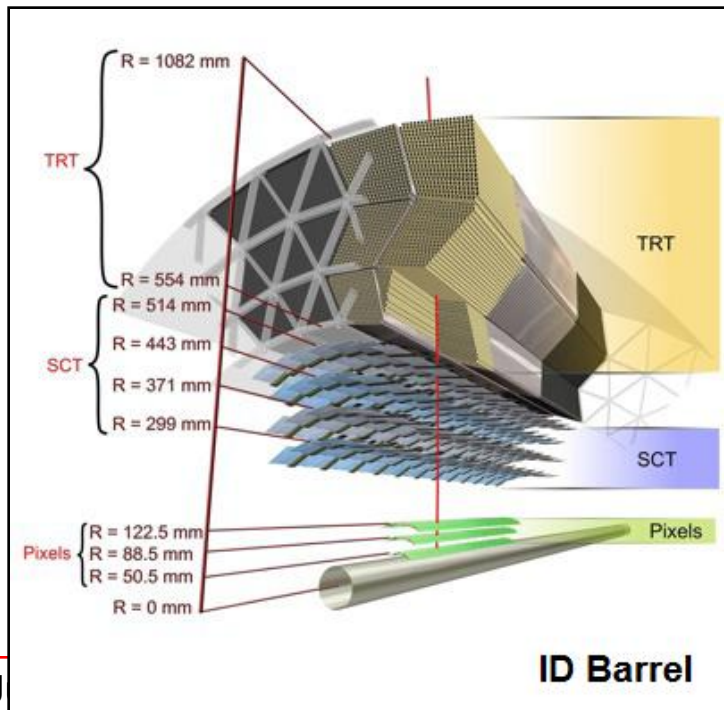
TRT provides:

- p_T measurement over wide range

- electron identification

- long lever arm for continuous tracking (~30 hits per track)

- hit precision of ~130 μm

Particle

anode wire

80 GeV electron crossing the straw tube
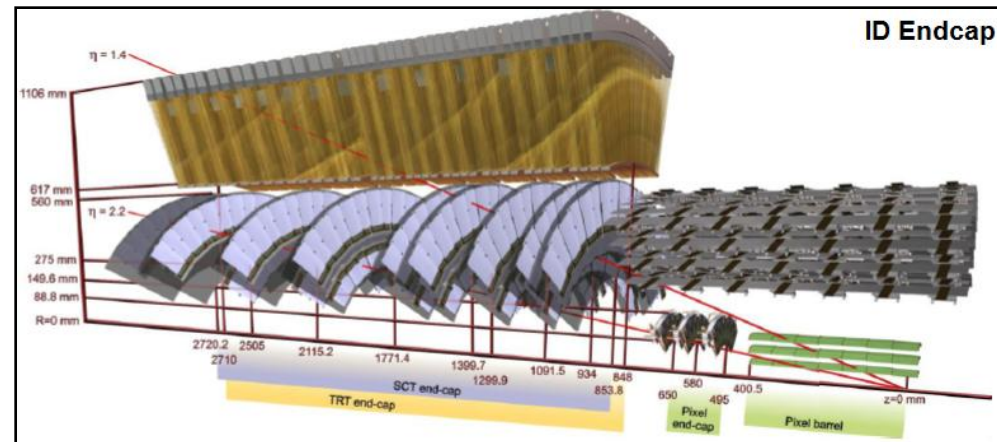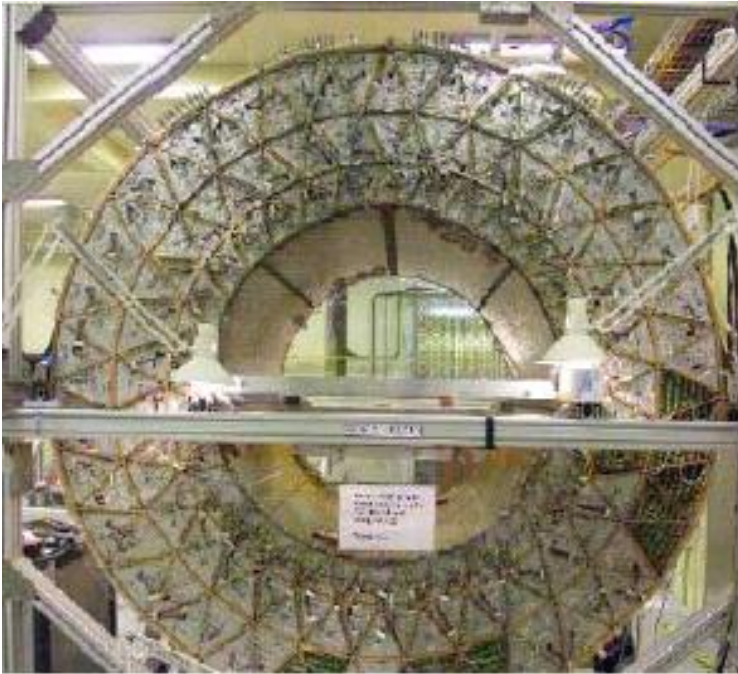B=2T (B⊥E)
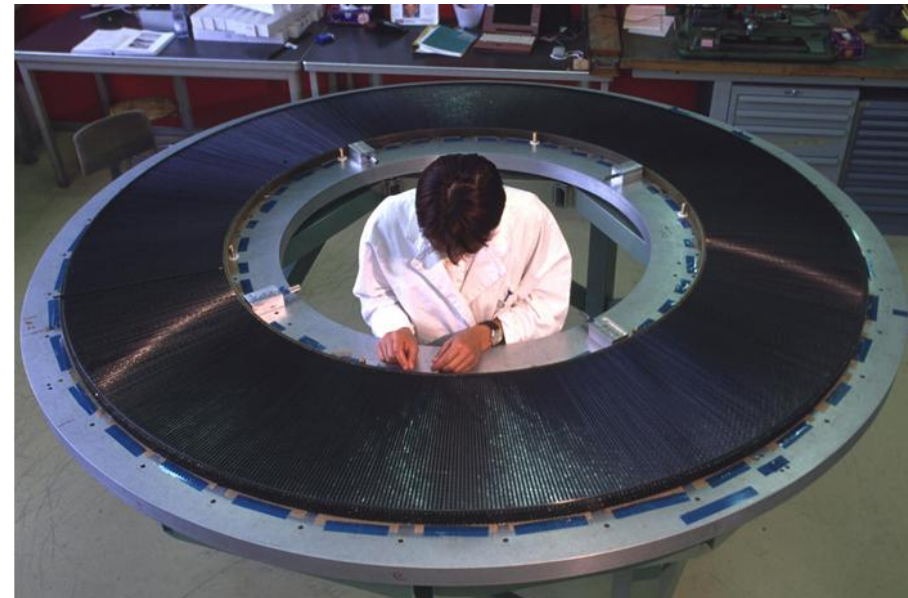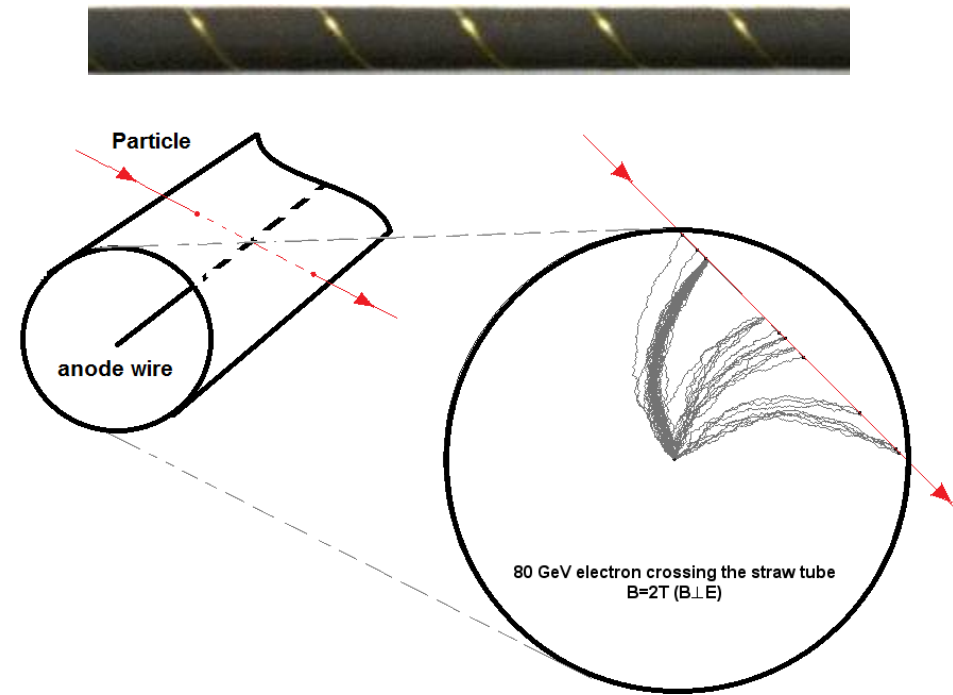
ATLAS TRT

TRT Barrel

- 105088 readout channels
- 144 cm straws arranged parallel to beam pipe
- covers $|\eta| < 1.0$

2 TRT End-caps

- 245760 readout channels
- 39 cm straws arranged radially in 20 wheels
- covers $0.7 < |\eta| < 2.0$

TRT Barrel   TRT End-caps
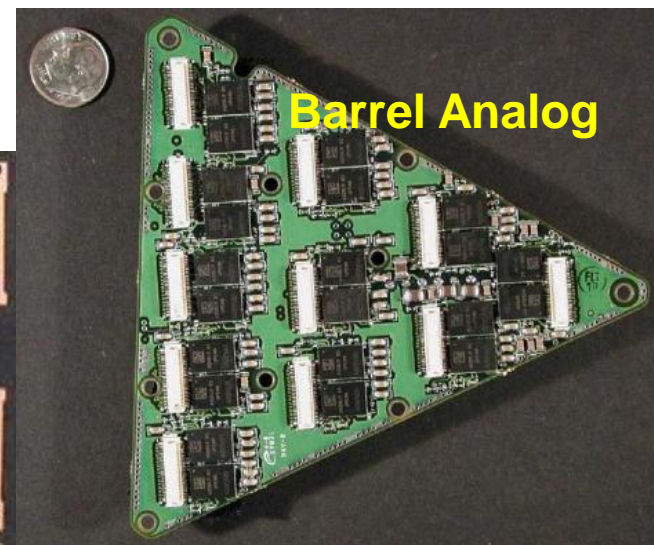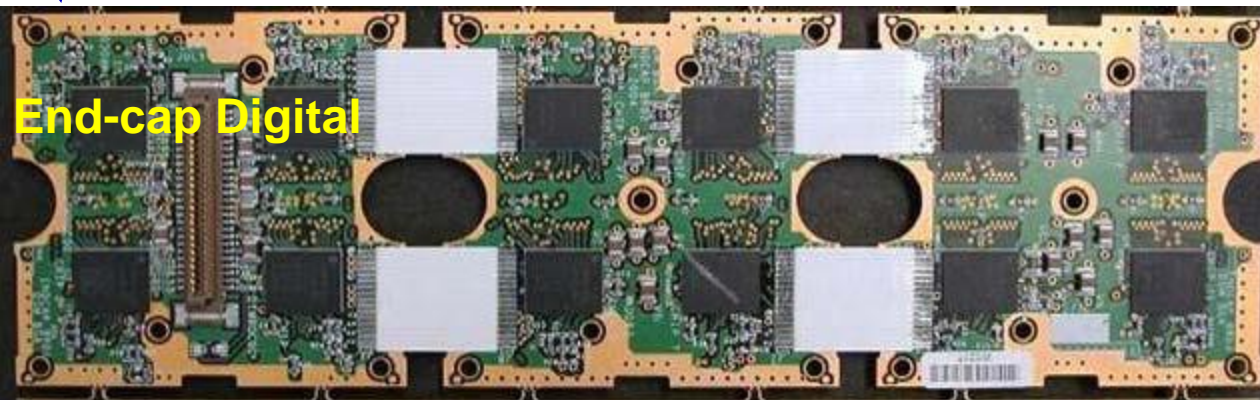
ATLAS TRT Electronics

*** *The TRT front-end electronics uses two thresholds*

- a low threshold (300 eV) for registering the passage of minimum ionizing particles

- a high threshold (6 keV) to flag the absorption of transition radiation X-rays.

*** *Front-End electronics consists of*:

- ASDBLR – Amplifier Shaper Discriminator Baseline Restorer

  => analog integrated circuit

- DTMROC – Digital Time Measurement Readout Chip
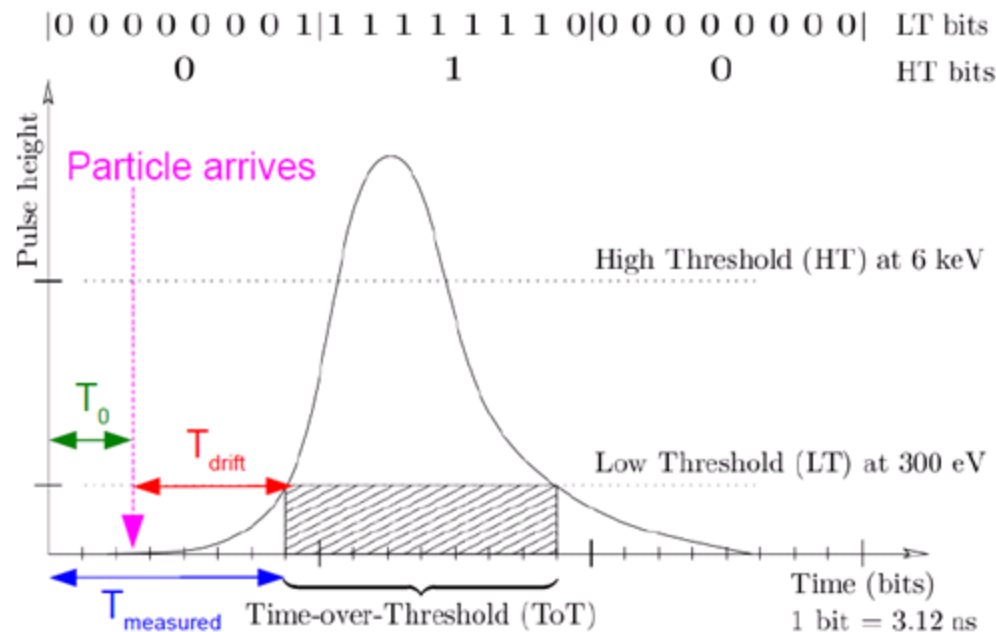
  => digital integrated circuit

  Total number of readout channels: 350848

End-cap Digital

Barrel Analog

Particle Detection

Cross section view

4 mm

Radiator foils

30 μm
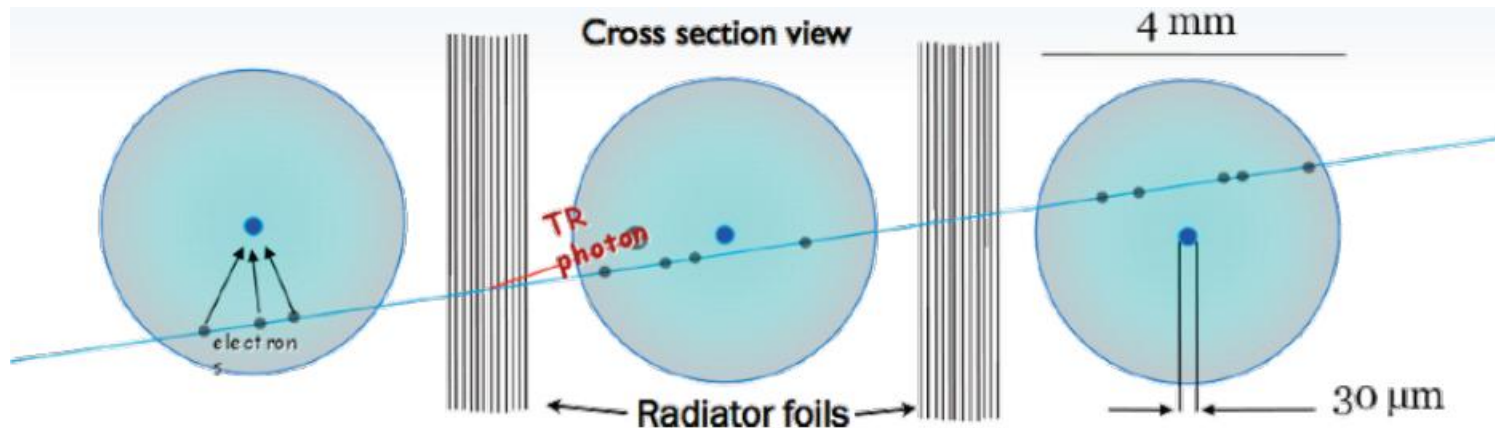
- A charged particle ionizes gas
- Electrons drift to wire to produce signal (a few hundred of eV)
- LT: for particle tracking
- HT: for particle id
- ToT: for particle id

- Time resolution: 3.12 ns
- 8 bins per bunch crossing
- 75 ns read out per event

|0 0 0 0 0 0 1|1 1 1 1 1 1 0|0 0 0 0 0 0 0| LT bits

0   1   0   HT bits

Pulse height

Particle arrives

High Threshold (HT) at 6 keV

T_0

T_{drift}

Low Threshold (LT) at 300 eV

$T_{measured}$ Time-over-Threshold (ToT)

Time (bits)
1 bit = 3.12 ns

Transition Radiation (TR)

TR: photon (soft X-ray) emitted by a charged particle
when traversing the boundary between materials
with different dielectric constants (ε_1, ε_2)

$$\varepsilon_1, \omega_1 < \varepsilon_2, \omega_2$$

- ➤ Intensity   : $I \propto \gamma = E/m$
- ➤ Emission angle: $\theta \propto 1/\gamma$
- ➤ Emitted Energy: $E_{TR} \propto (\varepsilon_1 - \varepsilon_2)$
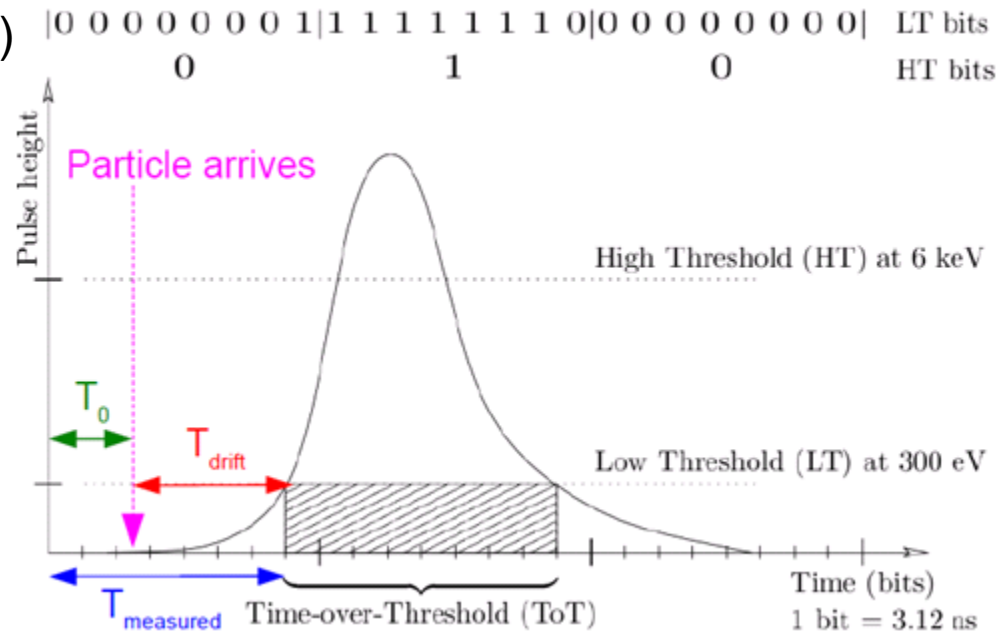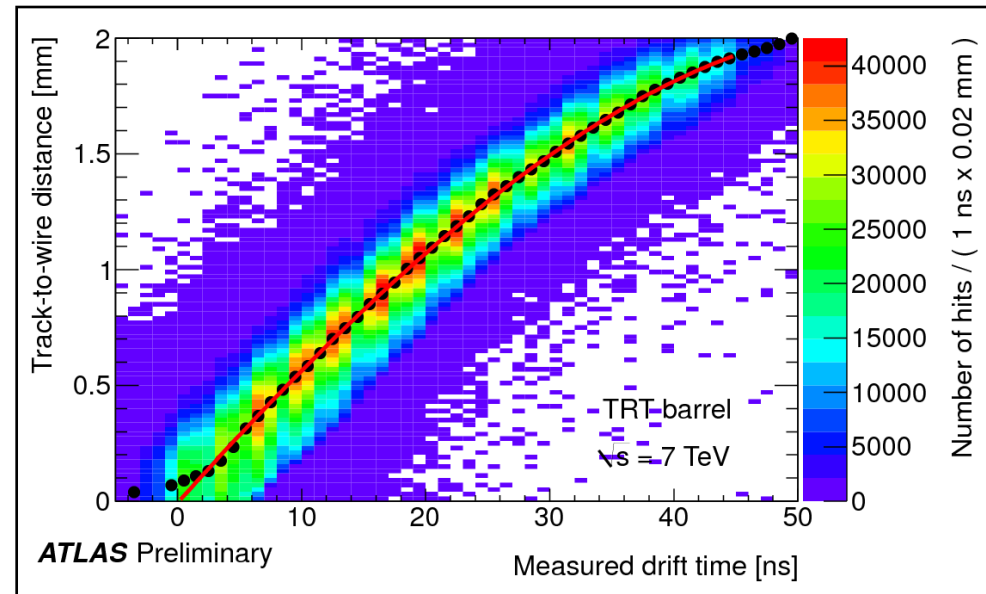
Photon

θ

- Low photon emission probability
  per transition.
   => *Many transitions needed*

- Gas and plastic give photon energies 5 – 30 keV

- Gas with high photon absorption (high Z) required
   => *Xenon based mixture*

- Discriminate <u>electrons</u> from <u>hadrons</u> based on
  number of HT hits on a track
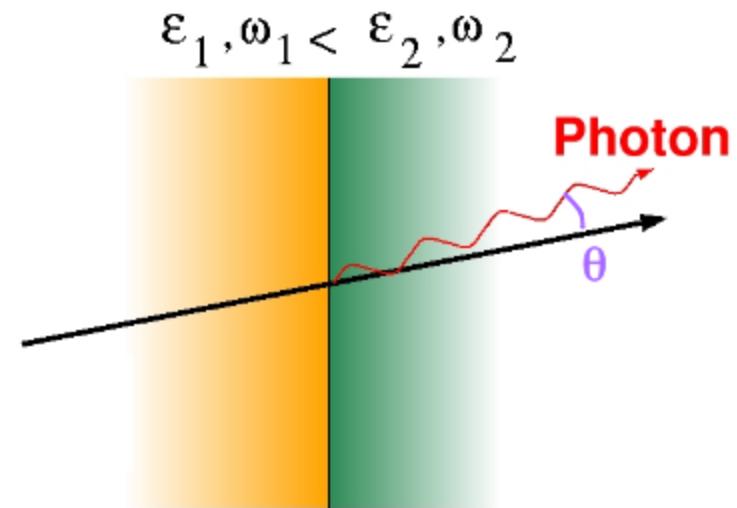
Calibration

- By design each straw measures a time which has to be converted into spatial coordinates.

- **R-t relation** converts T_{drift} to a measured drift radius
  - Depends on external effects (*Magnetic Field, Temperature,...*)
  - *For all TRT straws, One R-t relation is used for Barrel and one for end-cap*
  - *R-t calibration is performed regularly (every ~24h).*

- **T_0 calibration** (Hardware level) depends on ToF, cable lengths, electronics delays.

R-t relation curve

ATLAS Preliminary
TRT barrel
$\sqrt{s} = 7$ TeV

|0 0 0 0 0 0 1|1 1 1 1 1 1 0|0 0 0 0 0 0 0| LT bits
      0   1   0   HT bits

Particle arrives
High Threshold (HT) at 6 keV
Low Threshold (LT) at 300 eV
T_0
T_{drift}
$T_{measured}$
Time-over-Threshold (ToT)
Time (bits)
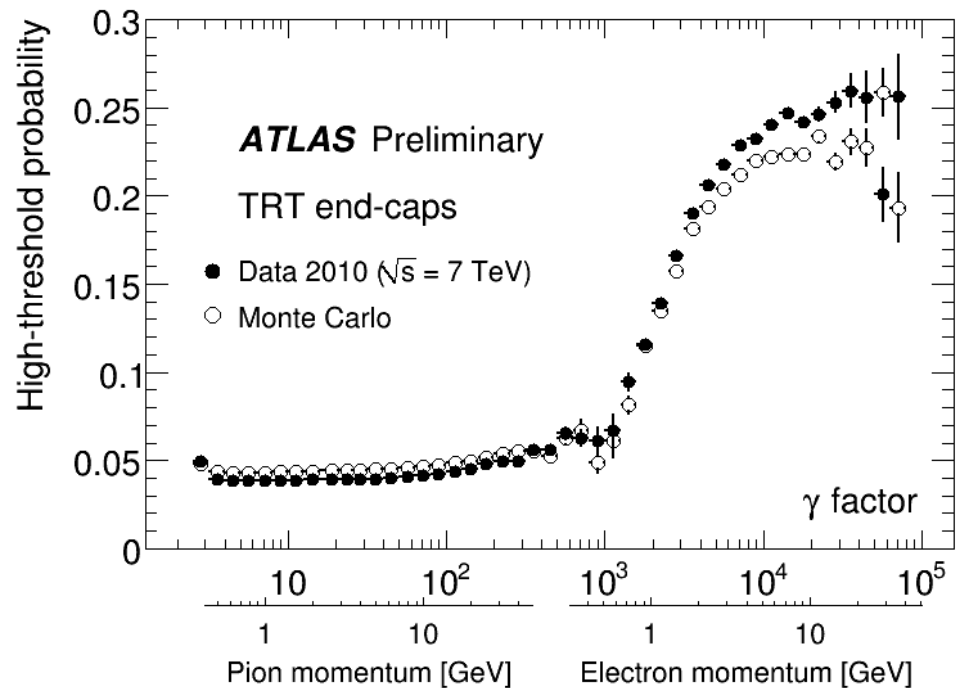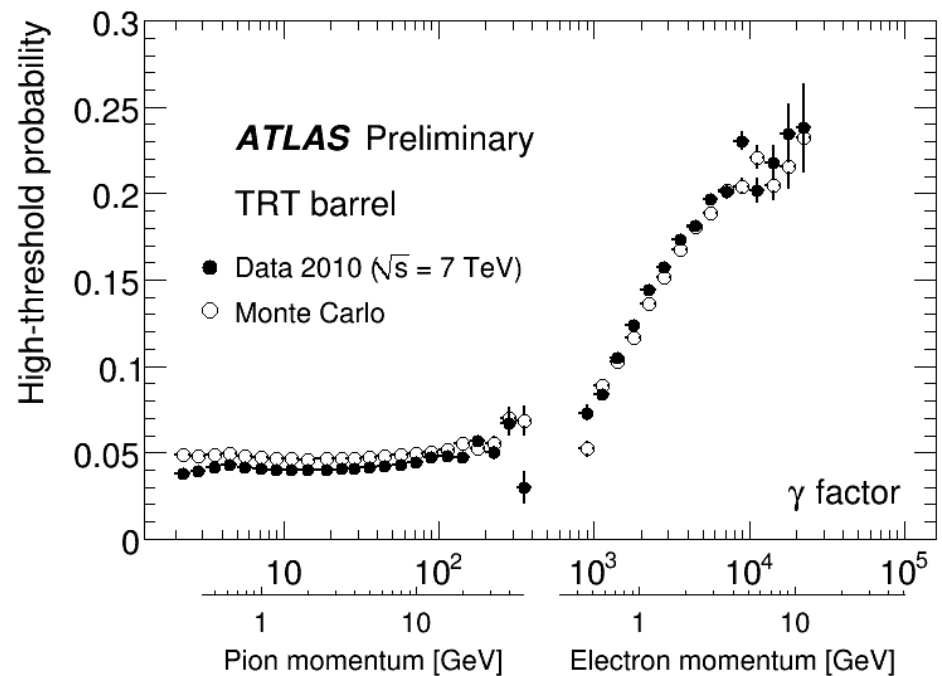1 bit = 3.12 ns
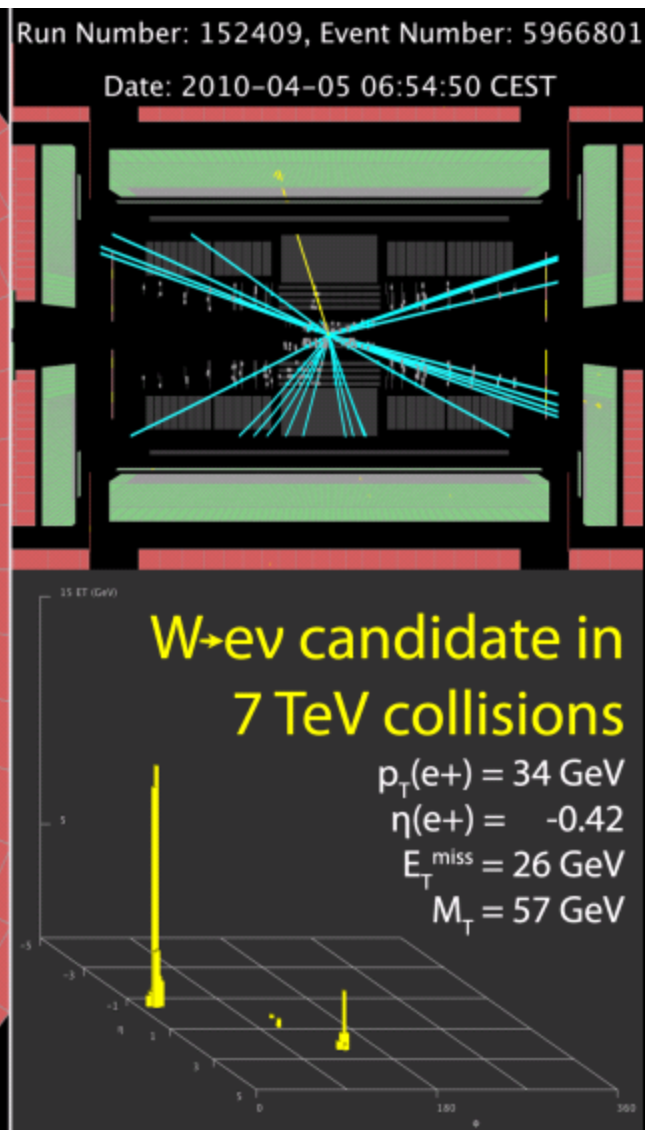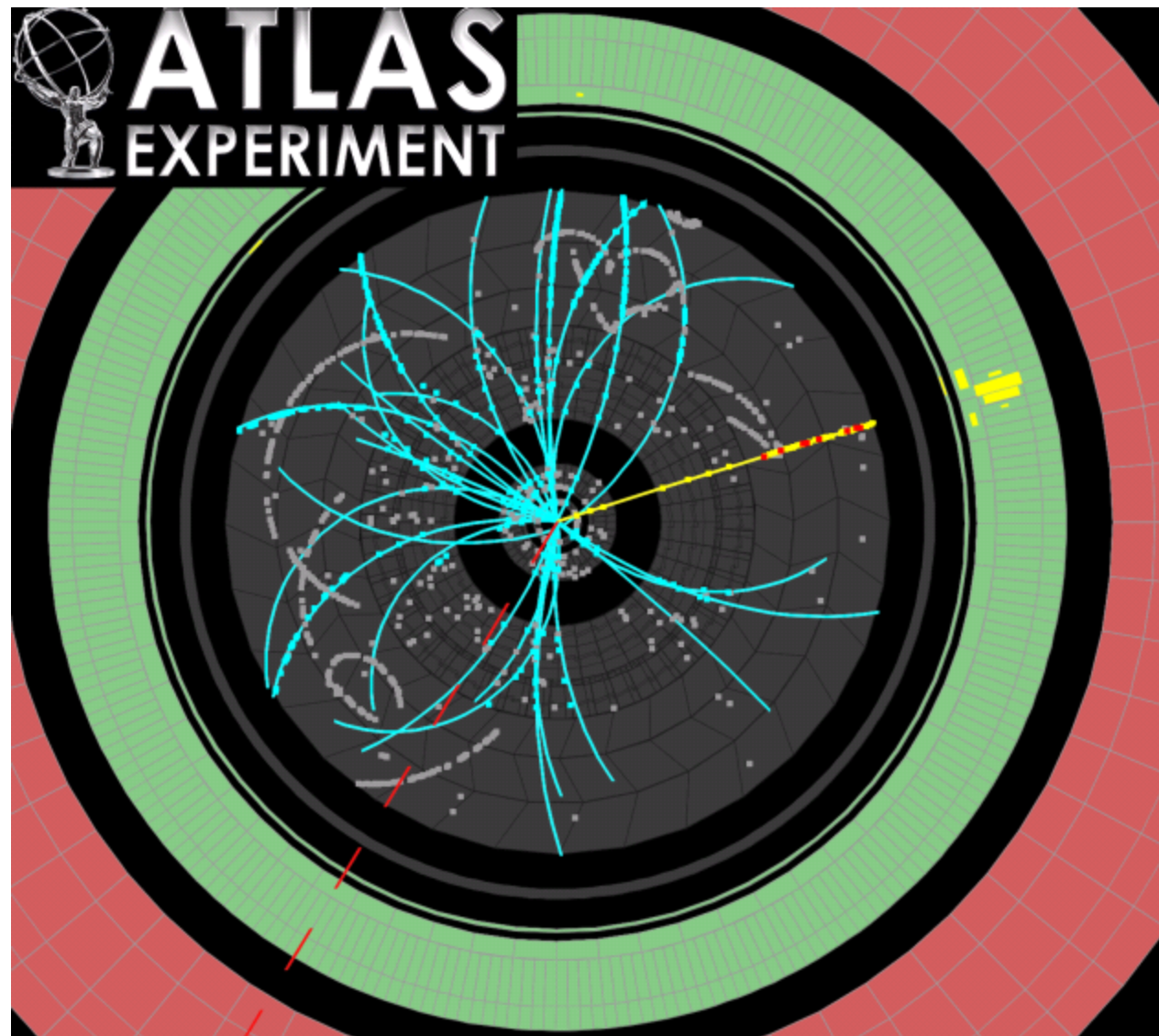
ATLAS TRT Performance

Particle Identification

- TRT High Threshold hit fraction defined by:

$$p \equiv \frac{\text{\# of HT hits on tracks}}{\text{\# of LT hits on tracks}}$$

  provides electron/hadron discrimination
 *over the momentum range between 1 and 150 GeV/c*

- Different number of radiators are used for barrel and end-cap

Run Number: 152409, Event Number: 5966801

Date: 2010-04-05 06:54:50 CEST

W→ev candidate in
7 TeV collisions

$p_T(e+) = 34$ GeV
$\eta(e+) = -0.42$
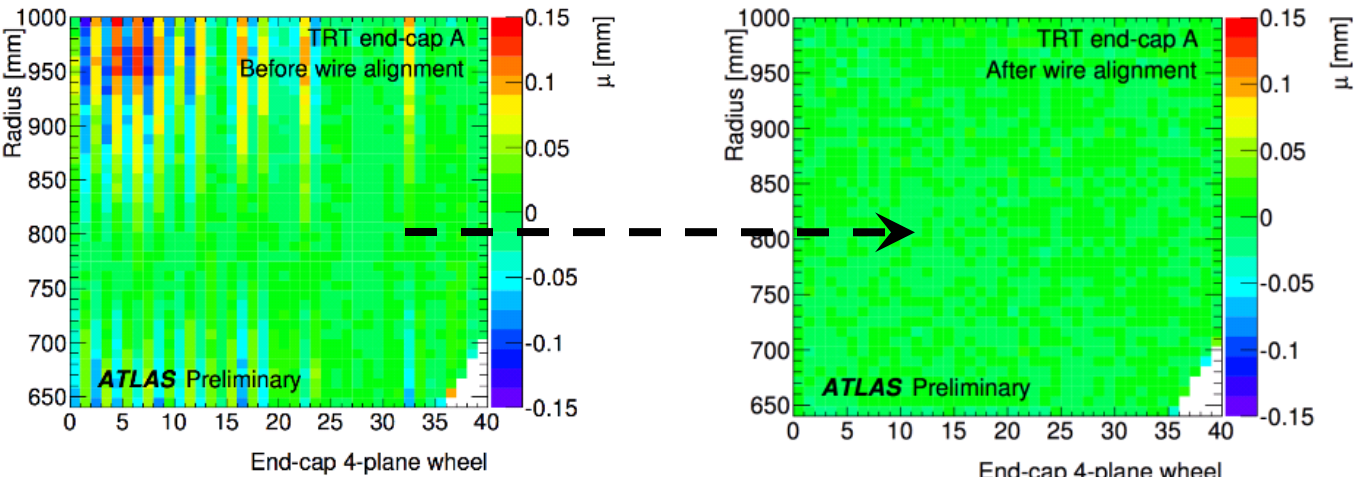$E_T^{miss} = 26$ GeV
$M_T = 57$ GeV

Particle Identification

- Time Over Threshold (ToT) is sensitive to dE/dx of charged particle, allowing an independent method of particle identification.
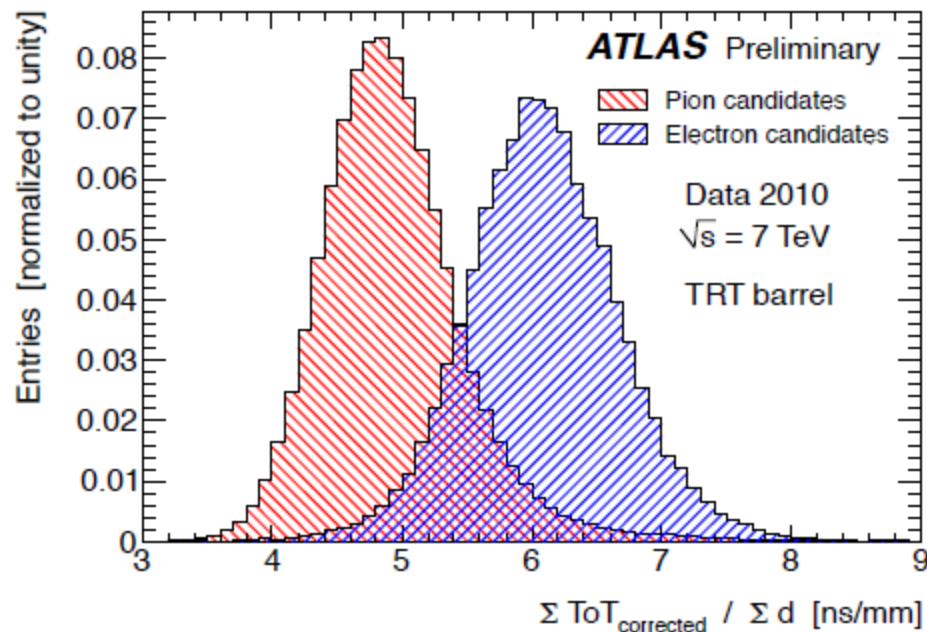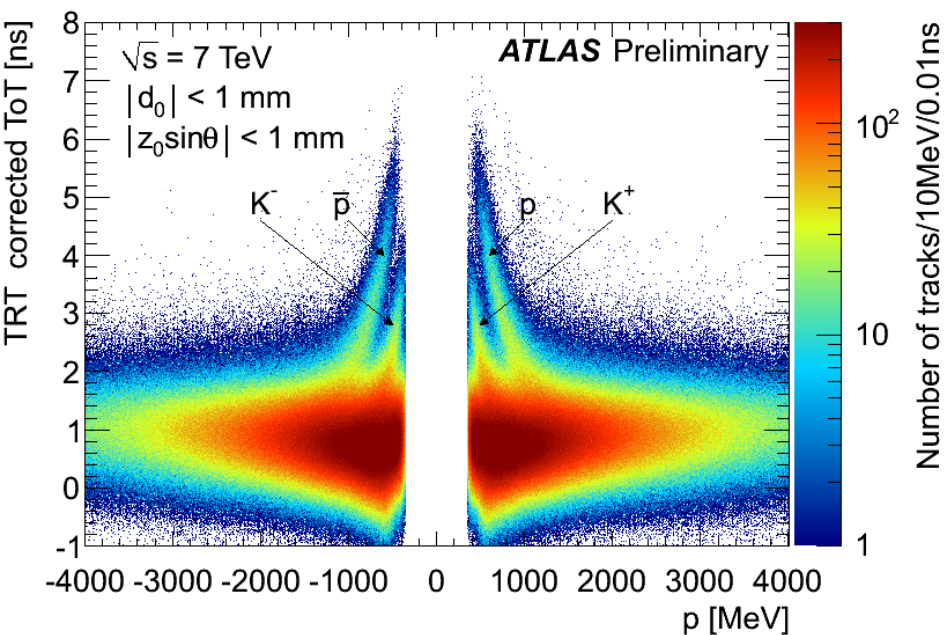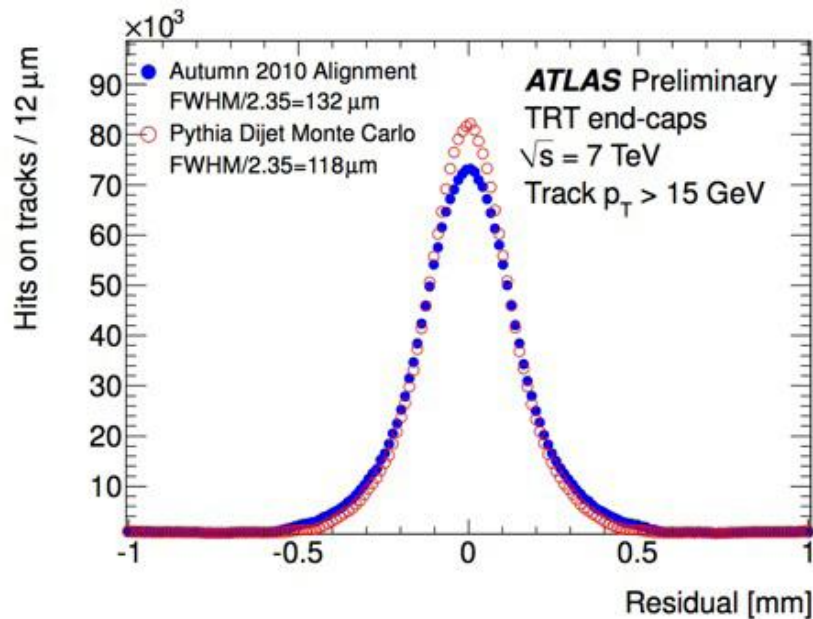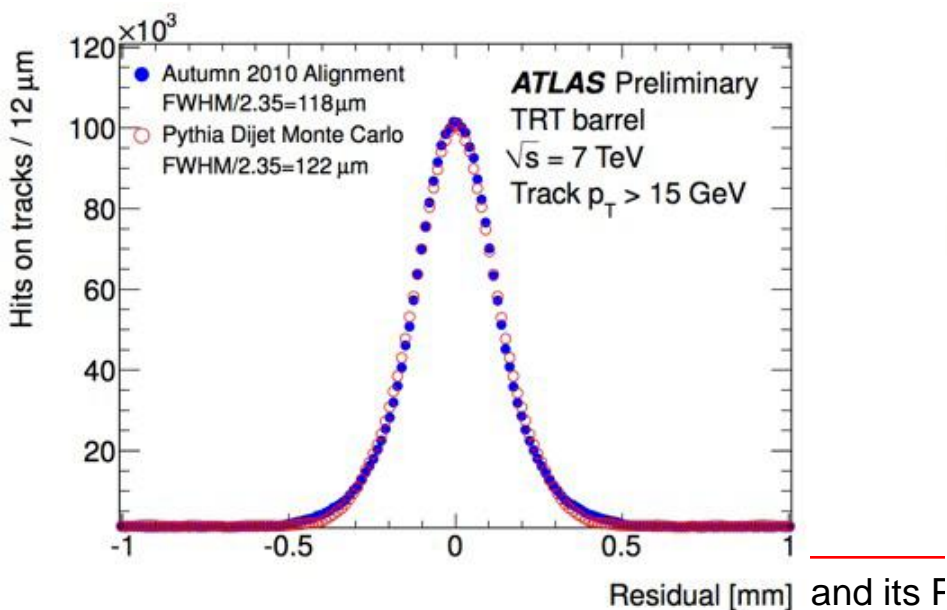
Position Resolution

- TRT provides on average 30 position measurements with ~120(130) μm resolution in the Barrel(End-cap), surpassing design resolution!

Good alignment work, including a wire by wire alignment is done (700k DoF!)
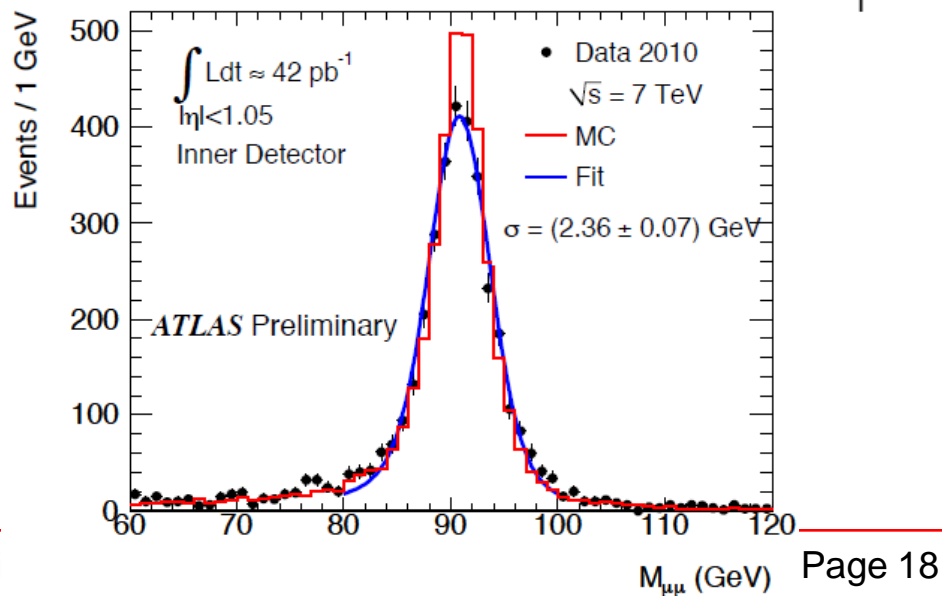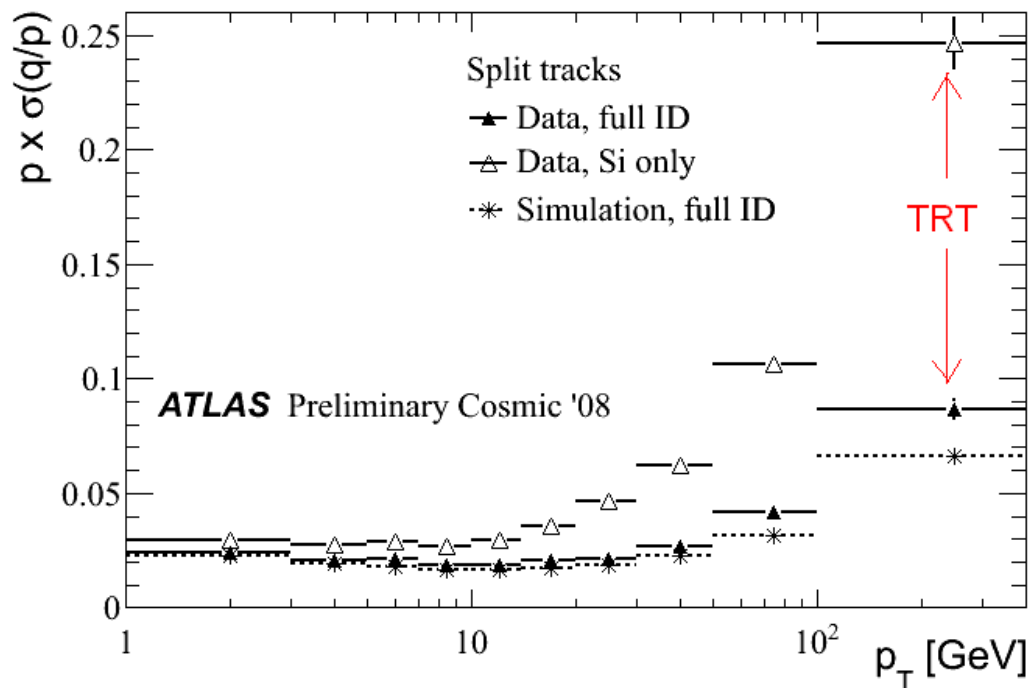

and its F

Momentum Resolution

- With its long lever arm, the TRT significantly improves the momentum resolution compared to tracks reconstructed with silicon hits only.
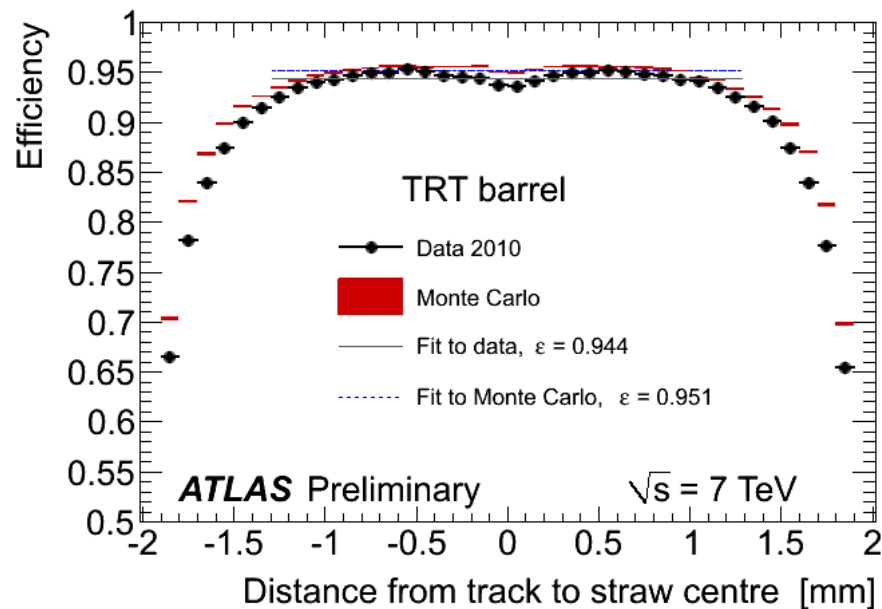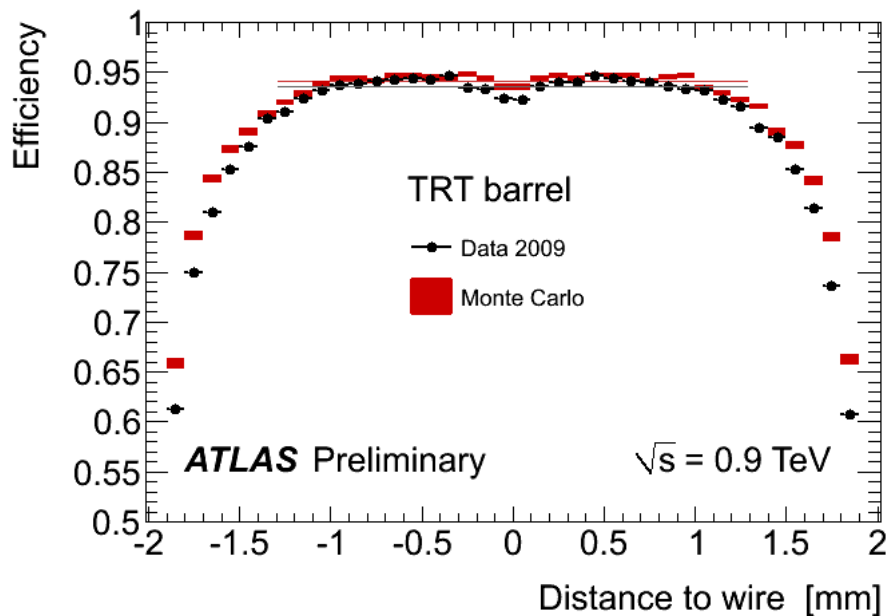
also

- Z mass resolution in the ID shows good performance

- Good agreement data/MC

Straw Hit Efficiency

- TRT hit efficiency ~ 94% in the central region (1.3 mm) of the straw

- Dead channels excluded (~2%)

- Inefficiency at outer straw radius due to reconstruction effects and smaller signal size

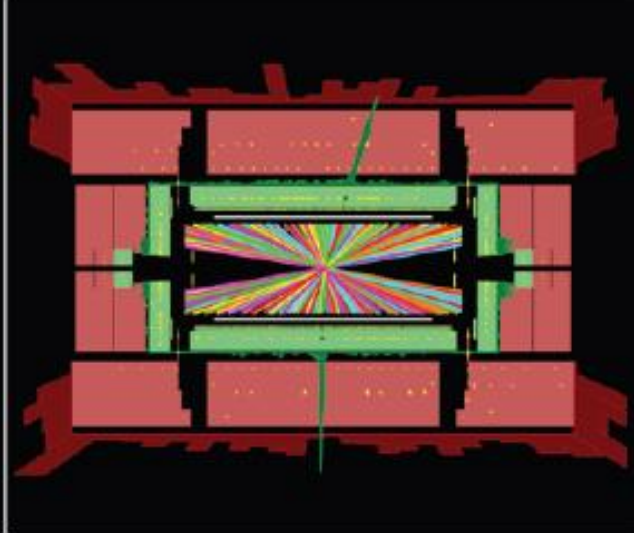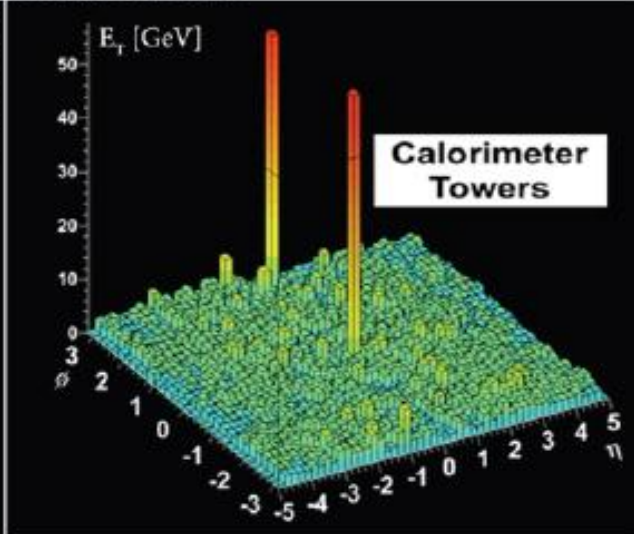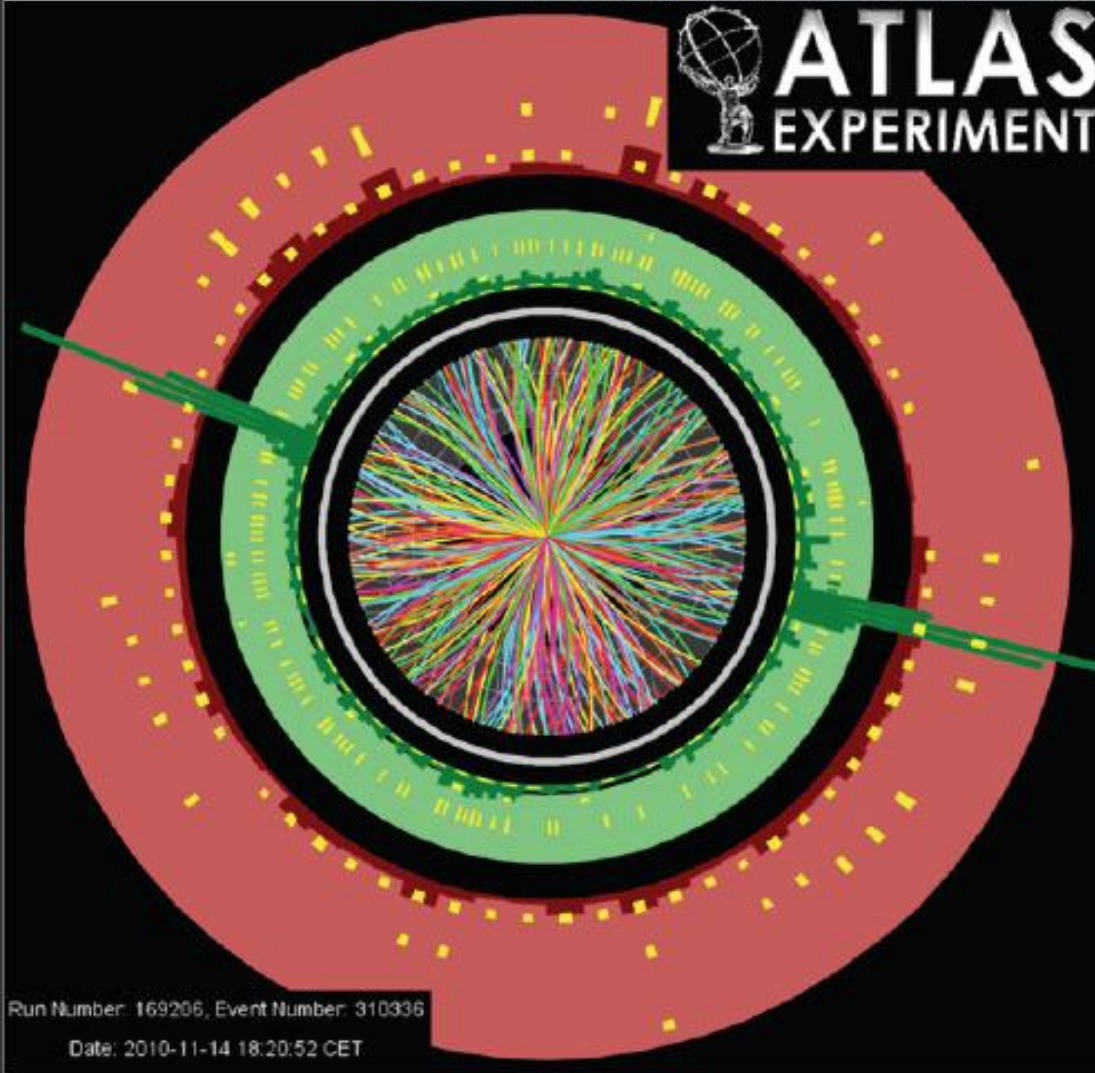- MC was tuned to 900 GeV agrees well with 7 TeV data

Heavy Ion Performance

- Several weeks of Heavy Ion running at the end of 2010

- Very challenging environment: occupancy > 90% (several thousands of tracks per event)

- Even in high occupancy, TRT provides useful tracking information
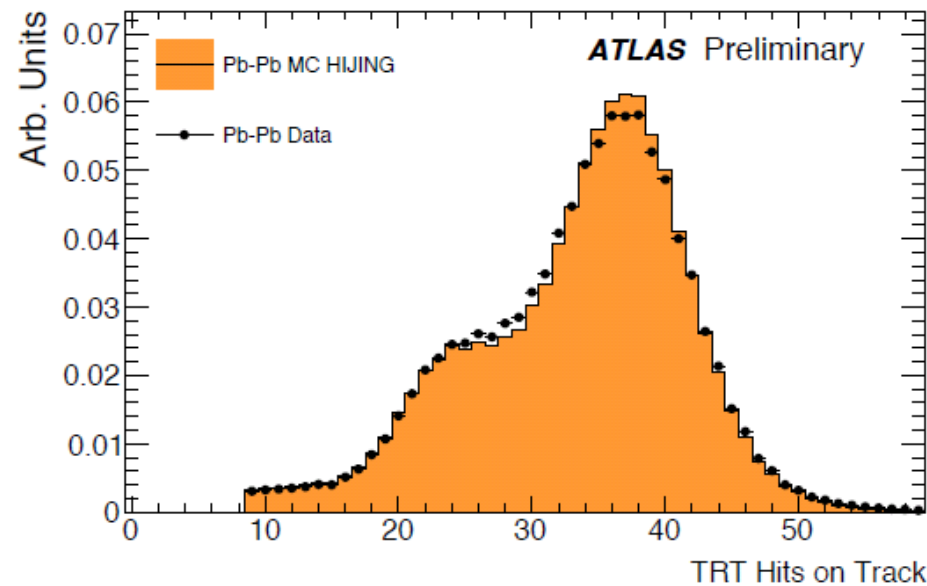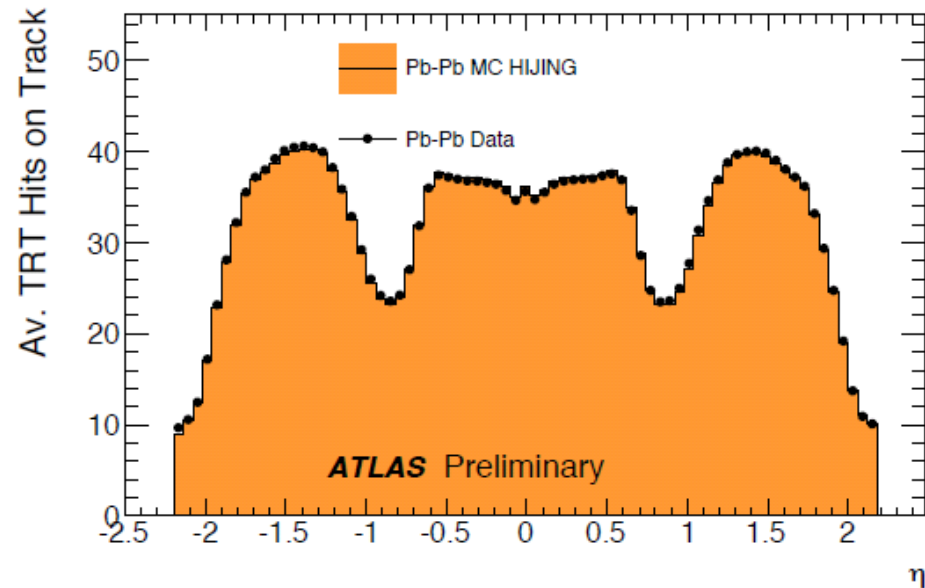
Z→e⁺e⁻ candidate in Pb-Pb collisions

Summary

The TRT

- is an excellent detector improving ATLAS tracking with its long lever arm and the high number of hits per track

- provides particle identification

- runs with 100% data taking efficiency during LHC stable beams in 2010 and 2011

- alignment and calibration results in ~120(130) μm hit resolution in Barrel(End-cap) which is better than the design expectations.

- improves the tracking measurements in HI collisions as well

- is ready for at least ten more years of LHC running

ACKNOWLEDGMENT

- Thanks to the many devoted TRT workers making the detector perfect.

References

[1]. ATL-INDET-PROC-2011-001   *S. Schaepe*

[2]. ATL-COM-INDET-2011-016   *J. Stahlman*

[3]. ATL-INDET-PROC-2010-040   *J. D. Degenhardt*

[4]. ATL-INDET-PROC-2010-043   *R. Mashinistov*

[5]. ATL-INDET-SLIDE-2010-280   *S. Smirnov*

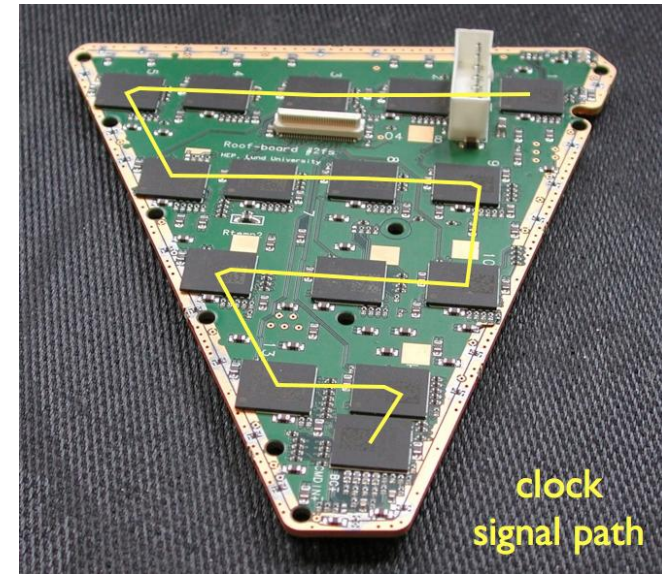[6]. ATL-INDET-SLIDE-2011-200   *S. Schaepe*
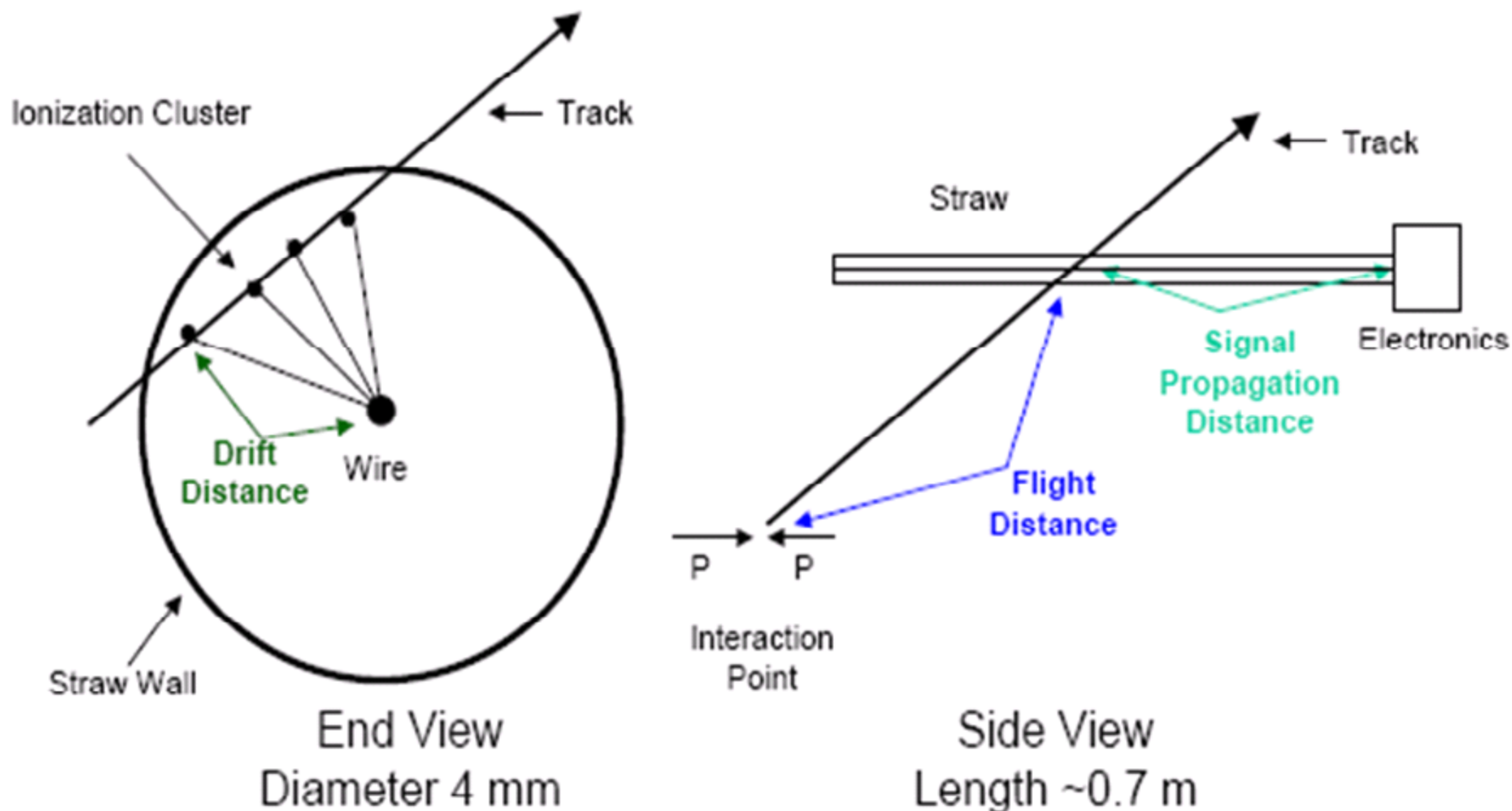
Backup Slides

A - T0 calibration

B - Particle ID and binomial distribution

A - T0 Calibration

In hardware, the timing of the readout window can only be tuned for single readout boards in fixed steps of 0.5 ns. Within a given board there is still a timing spread of up to 3 ns. For the desired resolution however a precision in the order of 100 ps has to be achieved. One of the main effects requiring offline calibration is illustrated in Fig. The timing signal is distributed to the different DTMROCs on a readout board serially resulting in a small offset between neighboring chips. Routinely the offset is measured for every straw in each run and a calibration is run on the level of single chips. Straws connected to one chip were found to show no major variations in timing. Experience shows that calibration constants have to be updated every few weeks. The main reasons for such frequent updates are linked to the slow drifts of the time reference provided by the LHC and replacements of single hardware components in the readout or triggering chain.

clock signal path

How a Straw Tube Measures Time

Ionization Cluster

← Track

Drift Distance

Wire

Straw Wall

End View
Diameter 4 mm

← Track

Straw

Signal Propagation Distance

Electronics

Flight Distance

P → ← P

Interaction Point

Side View
Length ~0.7 m

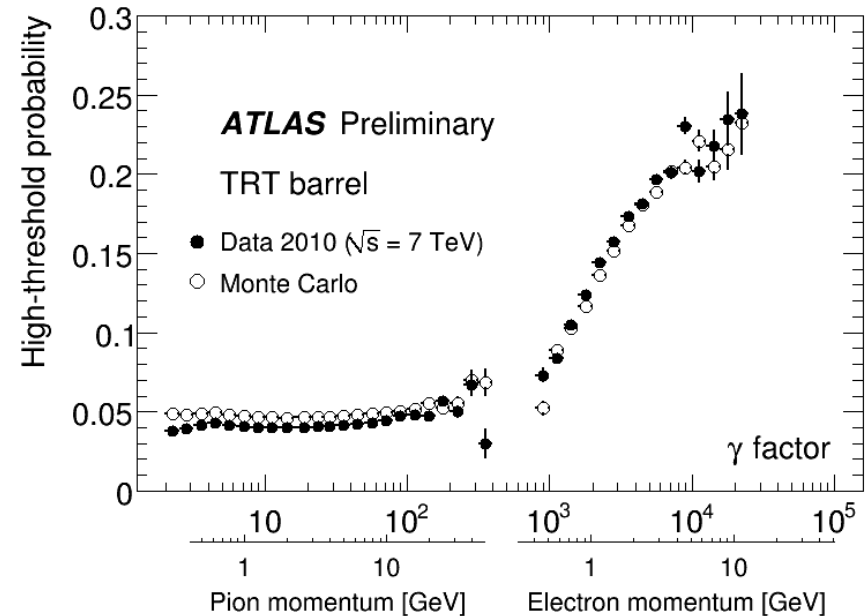**Cluster Arrival Time = Flight Time + Drift Time + Propagation Time**

B - Particle Identification and Bin. Dist.

The use of HT is a statistical

process **>> binomial distribution**

For N = 30 straws and **p = 1 GeV/c**
   P(e) = 12% => <nHT> = 3.6 hits
   P(π) = 4% => <nHT> = 1.2 hits

For N = 30 straws and **p = 10 GeV/c**
   P(e) = 20% => <nHT> = 6.0 hits
   P(π) = 4% => <nHT> = 1.2 hits

For N = 30 straws and **p = 150 GeV/c**
   P(e) = 20% => <nHT> = 6.0 hits
   P(π) = 10% => <nHT> = 3.0 hits

Toy Simulation Results for N = 30 straw hits:

p = 1 GeV/c

e ->

π ->

p = 10 GeV/c

e ->

π ->

p = 150 GeV/c

e ->

π ->
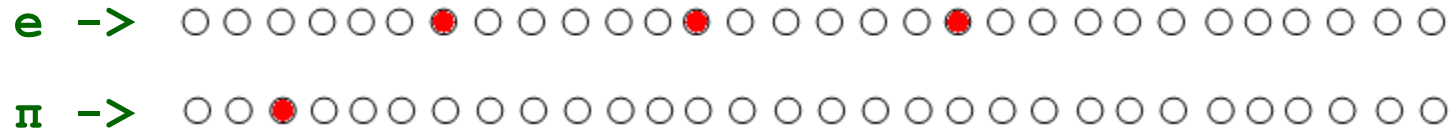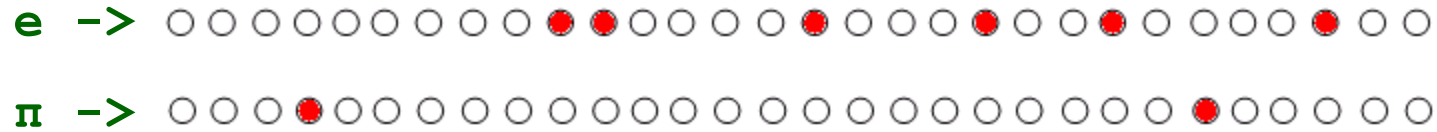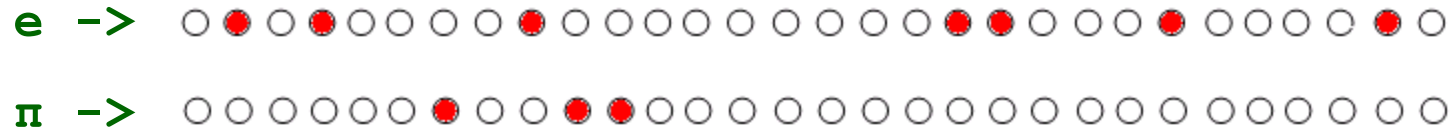
- Test Beam vs
  2010 Data and MC