The ATLAS Transition Radiation Tracker

Straw Tube Gaseous Detectors at High Rates

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on behalf of the ATLAS Collaboration

Outline

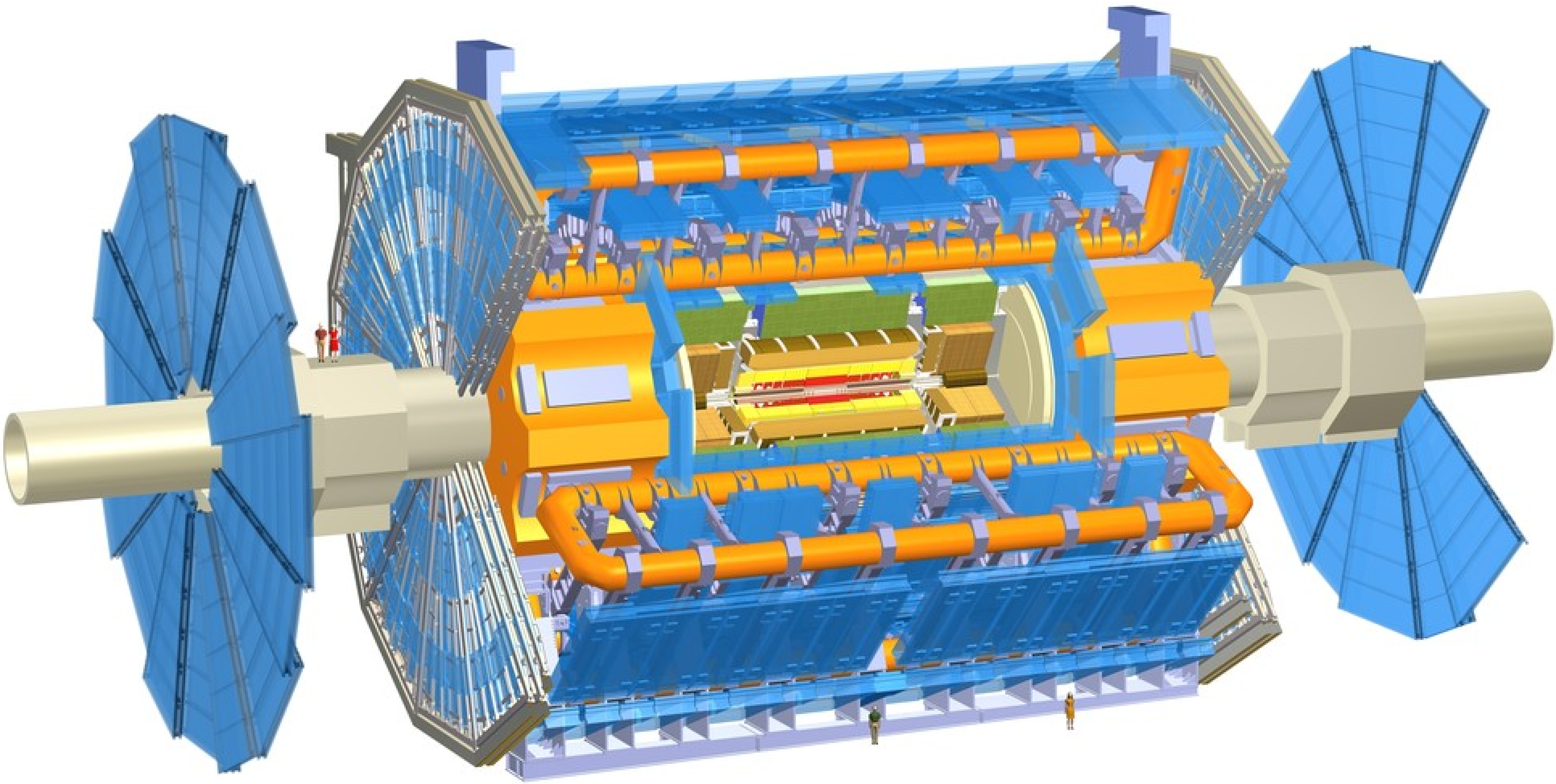
- Introduction
- Design

- Luminosity and Pile-Up
- Hit Occupancies

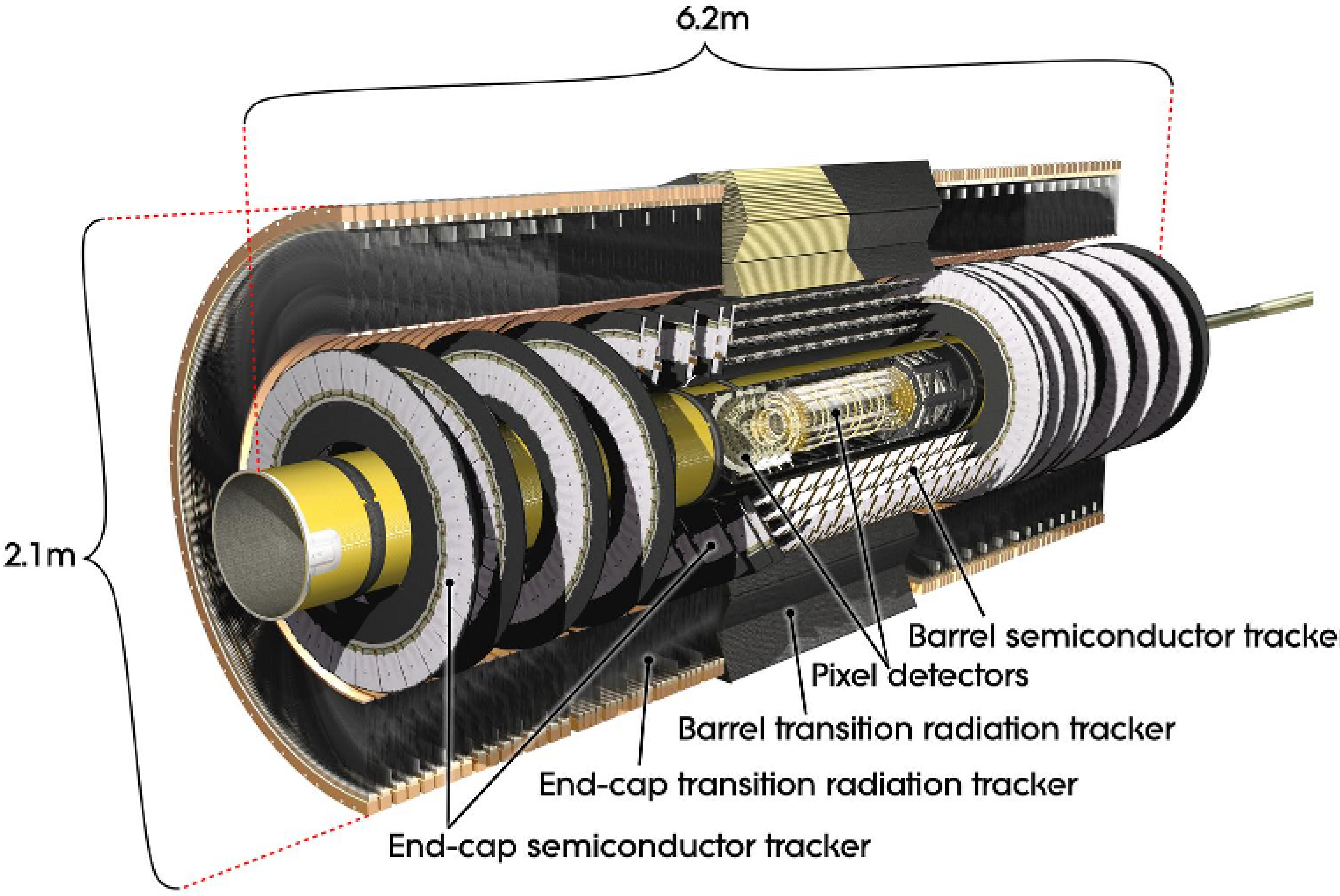
- Tracking Performance
- Particle Identification Performance

- Summary

ATLAS at the LHC, CERN



The ATLAS Inner Detector



Three Parts of the ATLAS ID

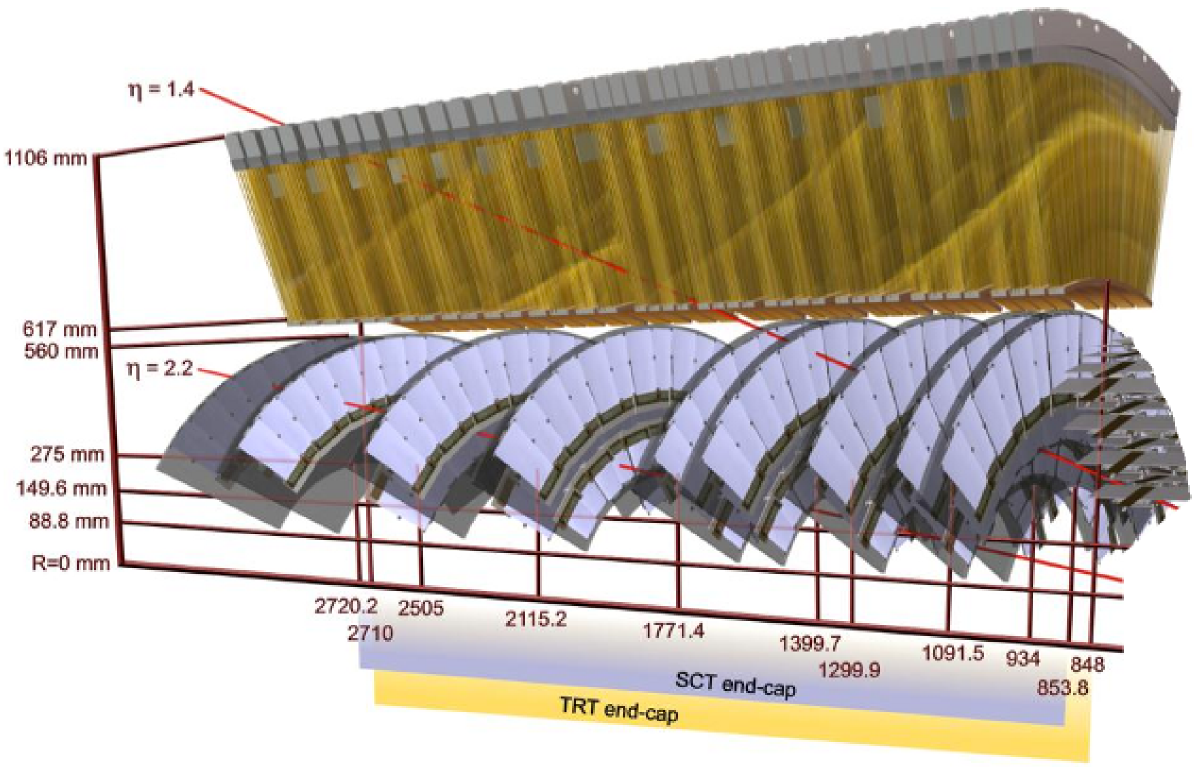
Pixel: silicon pixels

SCT: silicon stereo-strips

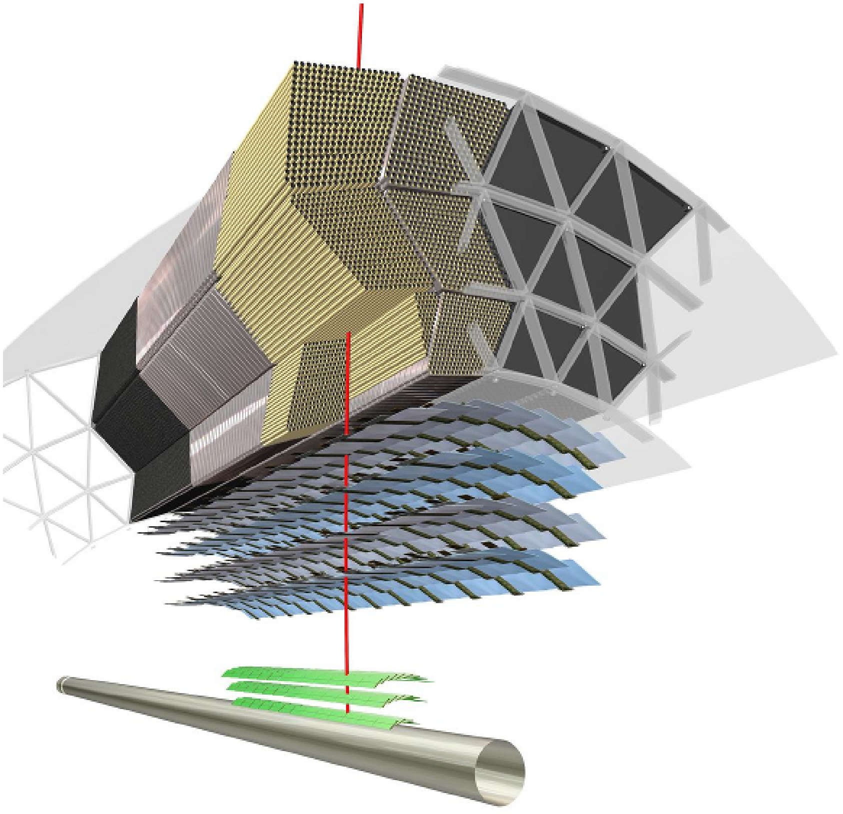
TRT: straw-tube tracker

- drift tubes (4 mm diameter) with central wire
- good single-point resolution around 120 µm (intrinsic value at low luminosity/occupancy)
- timing information on the nanosecond level
- long lever arm for wide-range p_T measurement
- continuous tracking (typically > 30 hits per track)
- high tolerance against radiation doses
- extra feature: electron identification

TRT Geometry — View



Endcap



Barrel

TRT Geometry — Numbers

TRT Barrel

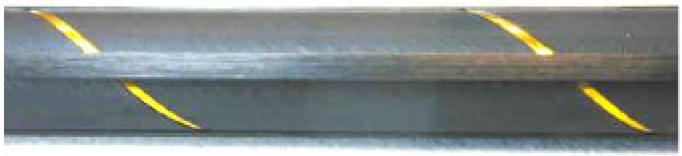
- **longitudinal** straws (along the beam axis) of 1.5 m length
- three layers of 32 modules each, **50 000** straws
- wires electrically split, read out on both sides
- ranging from $r = 0.5$ m to $r = 1.1$ m, covering $|\eta| < 1$

TRT Endcap A and C

- **radial** straws (perpendicular to the beam axis) of 0.4 m length
- 8 inner wheels, 12 outer wheels per side, **120 000** straws
- wires read out at their outer end
- ranging from $|z| = 0.8$ m to $|z| = 2.7$ m, covering $1 < |\eta| < 2$

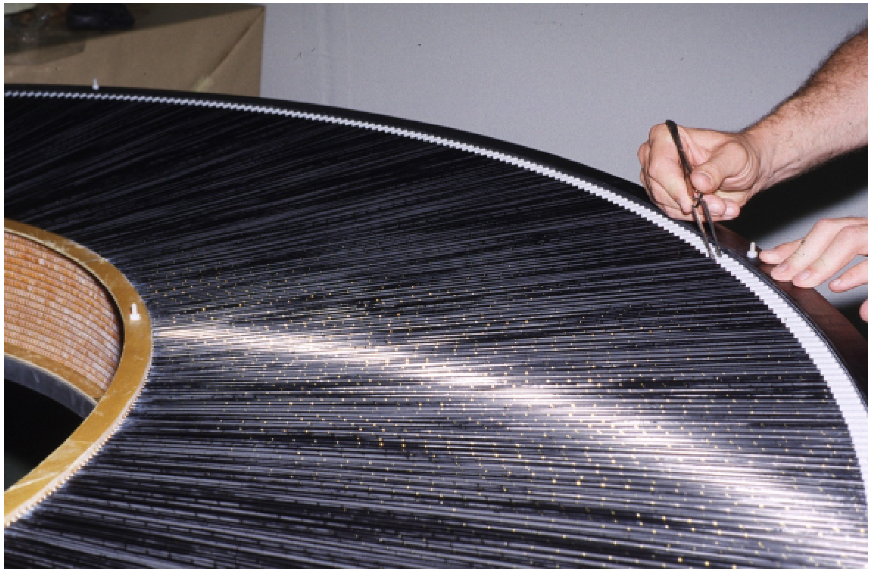
TRT Straws

Structure



- wound Kapton tube (d = 4 mm) with glued carbon fibre reinforcement
- gold-plated tungsten wire (d = 31 μm)

Electrical supply



- straw wall at −1530 V
- central wire at ground
- proportional counter mode

Gas filling

- Xe-CO_2-O_2 mixture (70 : 27 : 3)
- X-ray absorber plus quenchers

Particle Detection

Signal formation

- charged particles ionize the gas
- electrons drift towards the wire
- gas amplification avalanche
- first arrival determines drift time

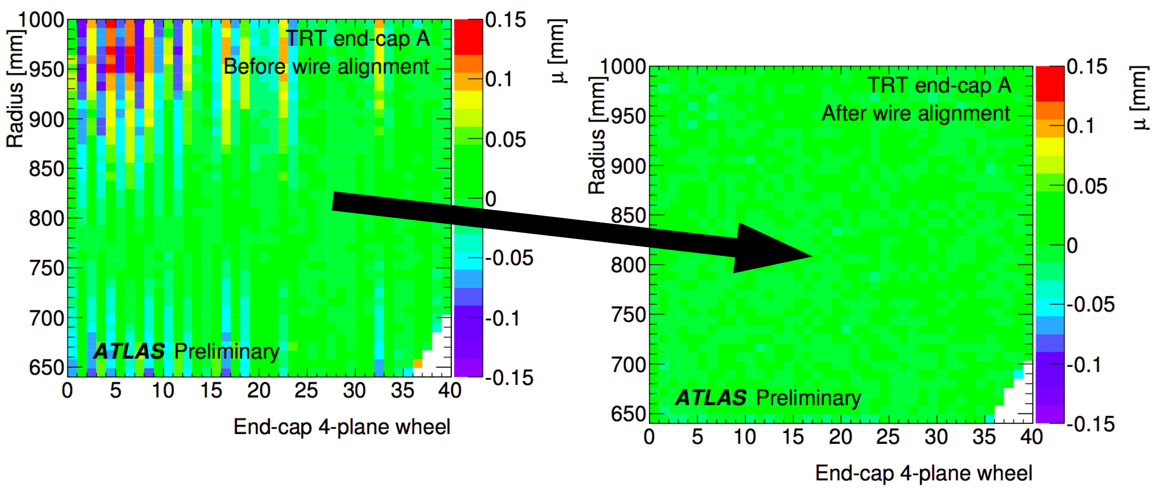
Signal readout

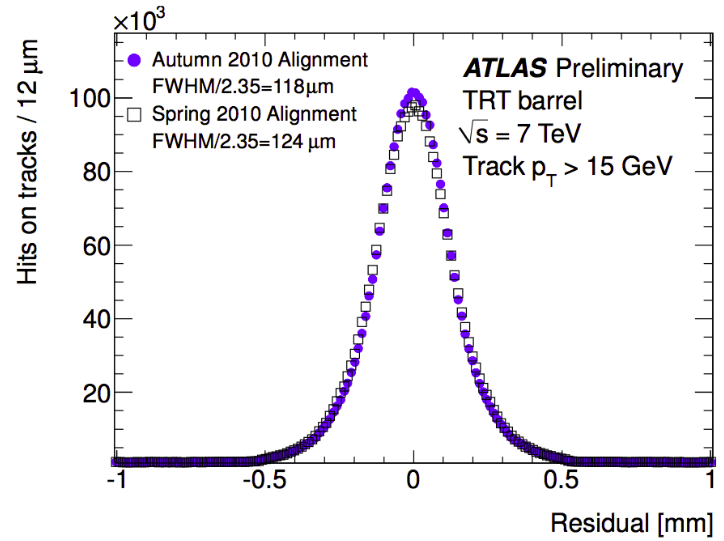
- signal gets amplified
- sampled in 24 time bins of 3.12 ns
- each time bin compared against threshold (300 eV): 24-bit pattern
- buffered in 6-µs readout pipeline
- passed on to central DAQ at up to 80 kHz

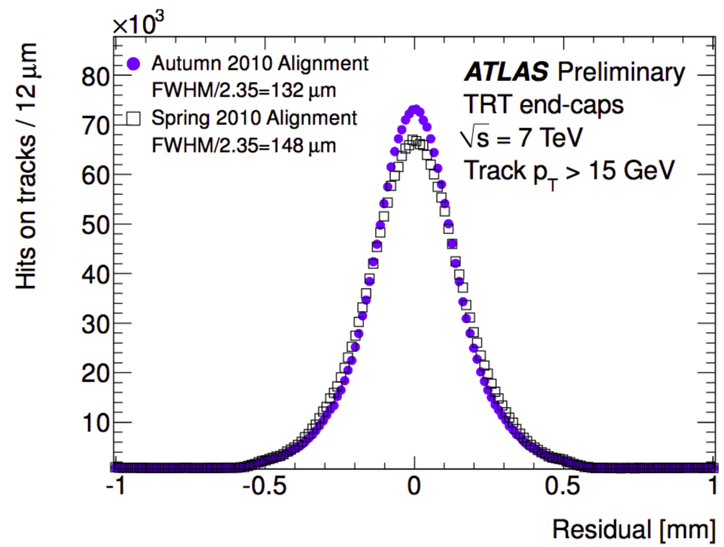
Position Resolution

TRT yields avg. of 30 position measurements for each track

- **barrel: 118 µm** residual
- **endcaps: 132 µm** residual
- additional improvements from wire-by-wire **alignment** with 700 000 degrees of freedom



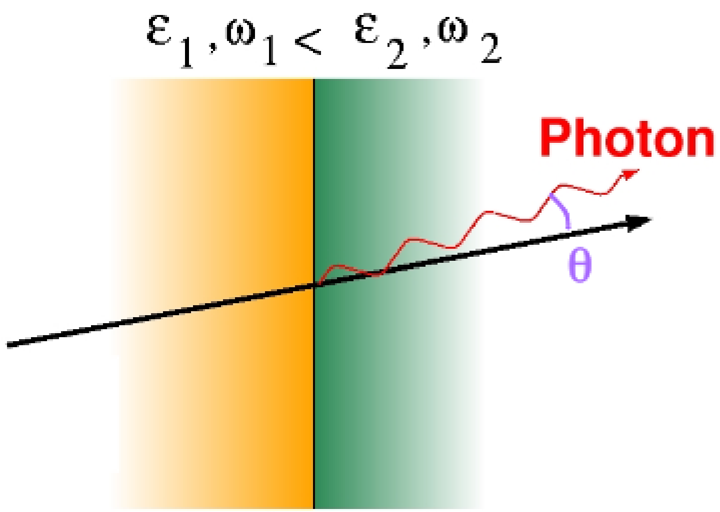




Transition Radiation

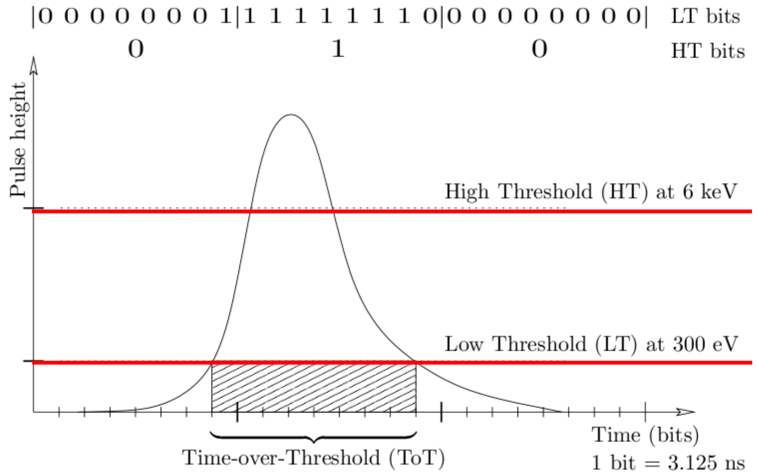
What is it?

- charged particles can emit photons at **material boundaries** ($\varepsilon_1 \neq \varepsilon_2$)
- effect depends on **$\gamma = E / m$**, useful for particle identification
- typical photon energies 5–30 keV



How do we use it?

- many thin **radiator** fibres/foils increase emission probability
- xenon gas acts as X-ray **absorber**
- **ternary** readout electronics register high-threshold hits (6 keV) sampled in 25-ns time bins



Luminosity and Pile-Up

Instantaneous luminosity

- figure of merit for physics
- around 6 to 8 · 10^{33} cm^{-2} s^{-1} in 2012

Events per BX ("μ")

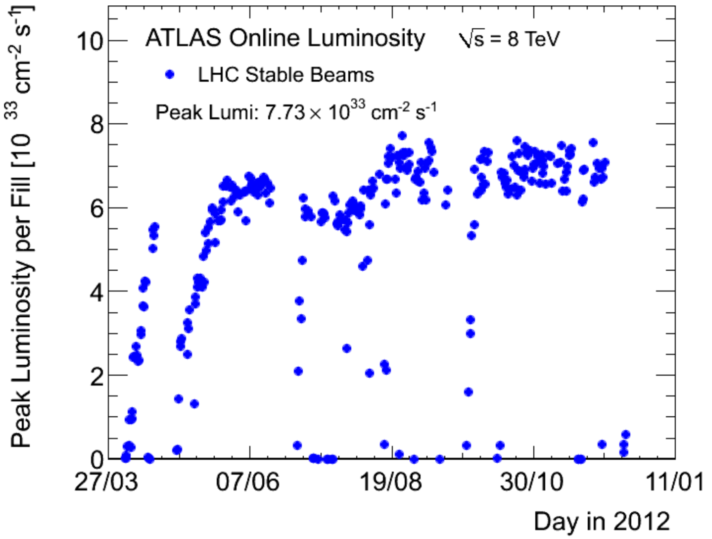
- determines in-time pile-up
- ranging from 25 to 35 in 2012

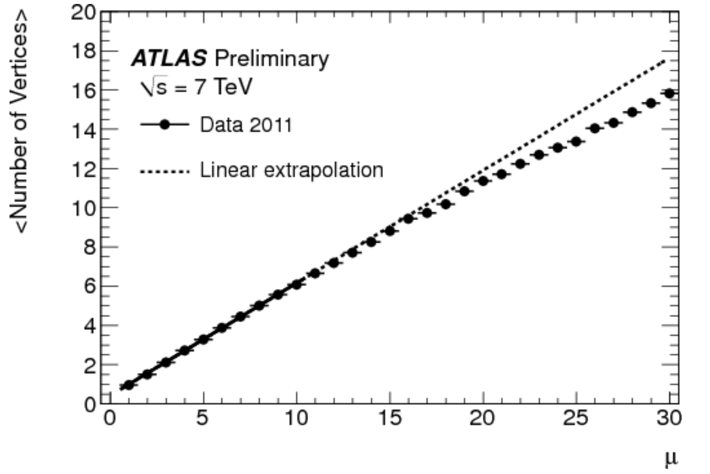
Number of vertices per BX

- result after reconstruction

Bunch spacing

- influences out-of-time pile-up
- 50 ns in 2012, 25 ns in 2015?





Occupancy at High Rates

Low-threshold hits

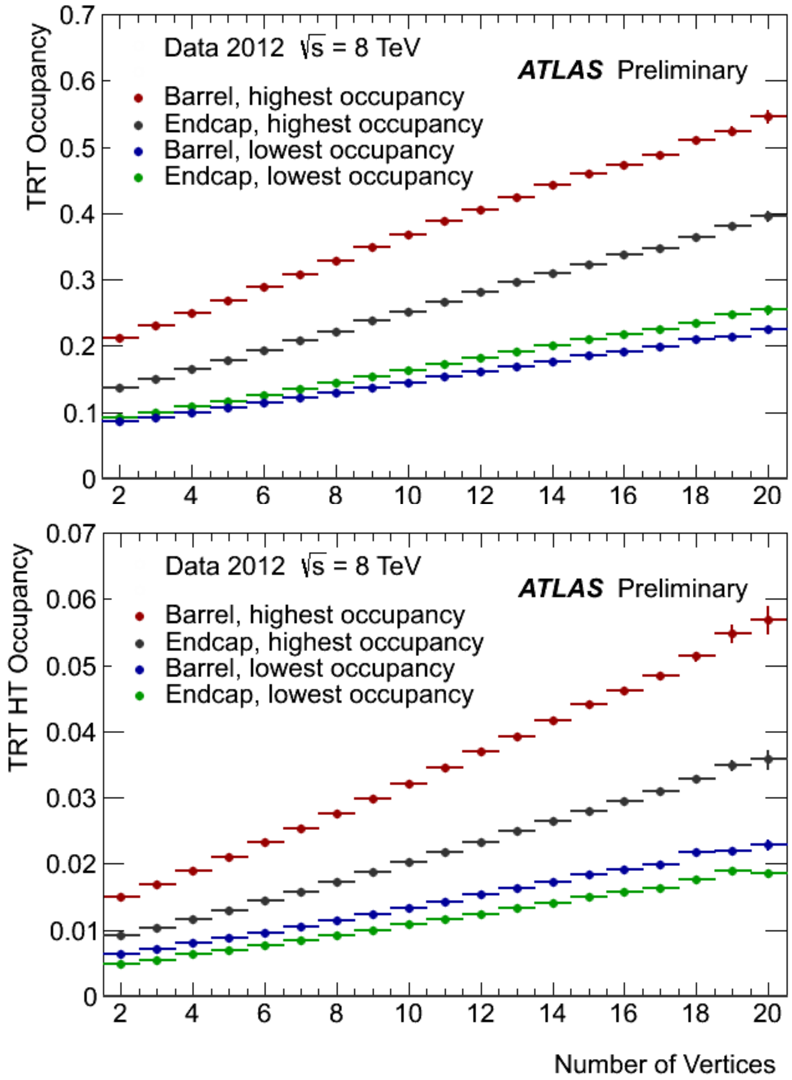
- raw occupancy 10–60%
- increases linearly with N_{vtx}
- strongly depends on region

High-threshold hits

- occupancy is O(10) lower

This looks scary, but …

- you can still reject out-of-time pile-up (not yet applied here)
- you have drift time information (at least for most of the hits): match within ±3 ns of 75 ns



TRT Hits in Tracking

Precision hits

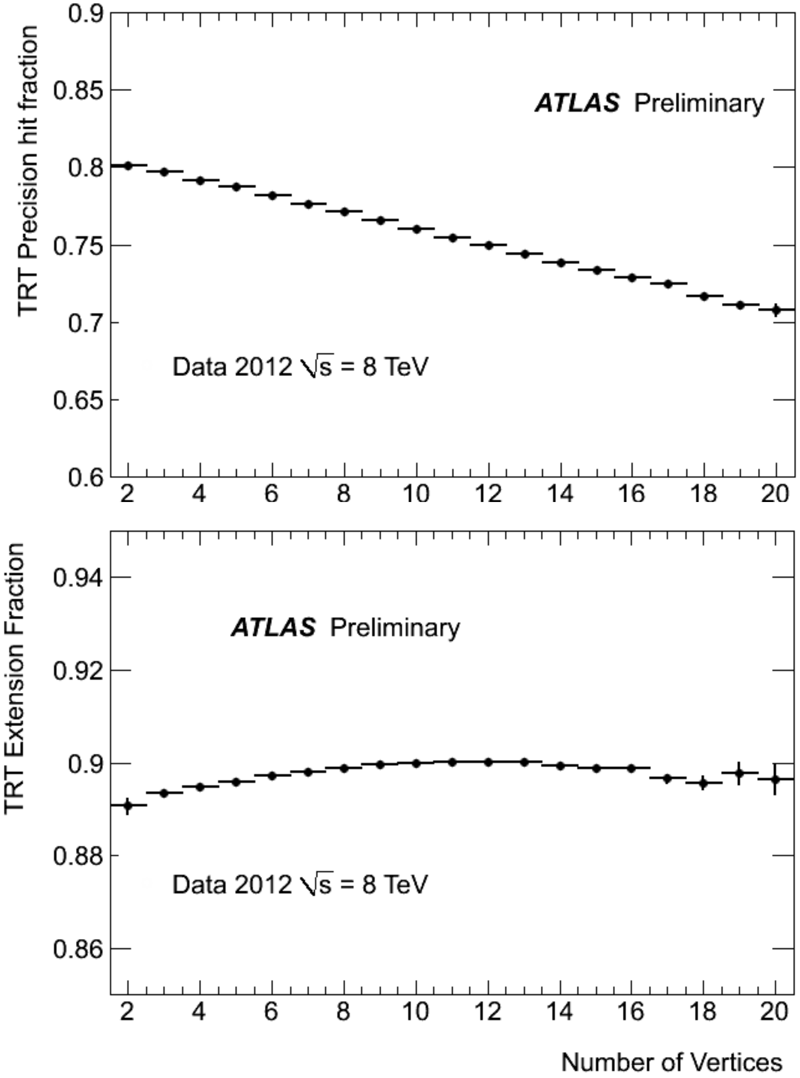
- have good drift time information
- are the most useful for tracking
- depend moderately on pile-up

Non-precision hits

- caused by overlapping tracks, poor drift time measurement, out-of-time pile-up, δ-electrons, …

Track extensions

- of Si-seeded tracks into the TRT
- 9 TRT hits or more, 50% precision
- hardly depend on pile-up – good!



TRT Resolution with Pile-Up

Resolution **depends on pile-up …**

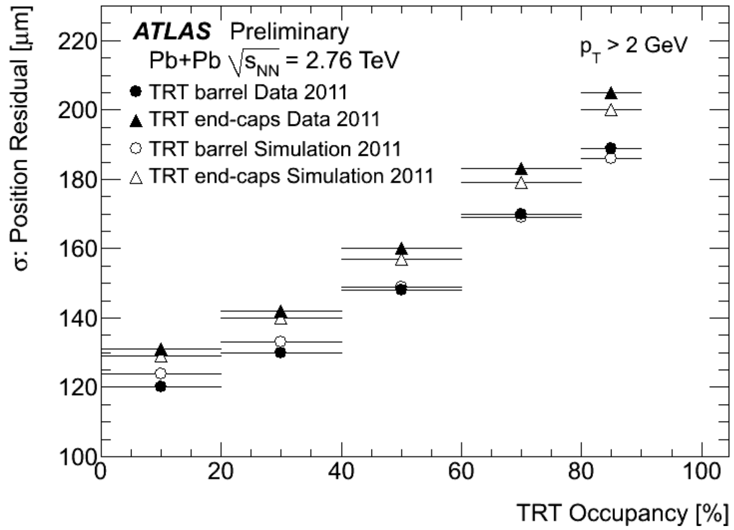
- less hits with good time information
- overlapping tracks compete with each other: the earlier one wins

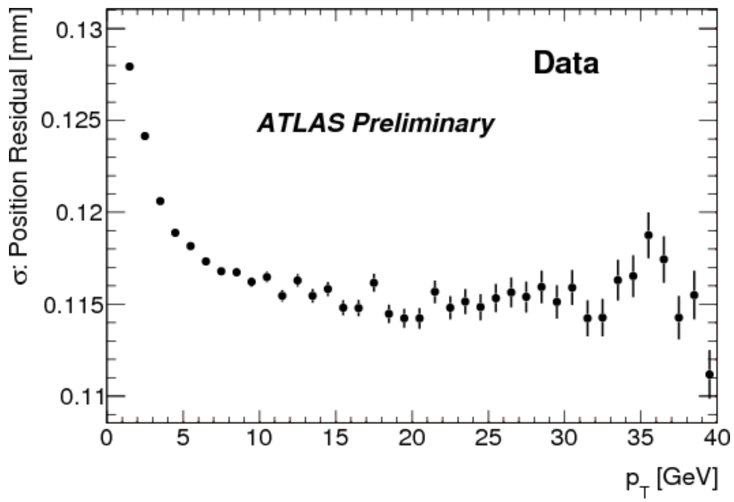
… but only moderately

- Pb-Pb collision events may reach occupancies up to 80%
- residuals stay around 200 µm even in this extreme case
- still useful for tracking!

Influence of **momentum** is weak

- except for tracks with very low p_T





ID Tracking with Pile-Up

ID tracking **is not easy …**

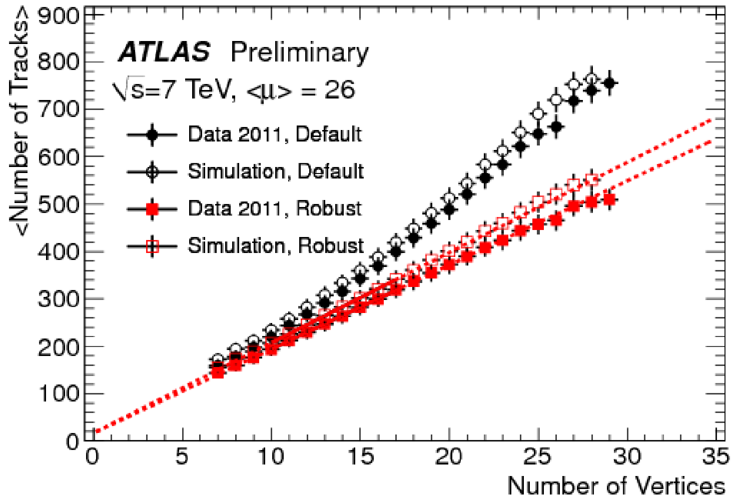
- default track requirements yield fake vertices and tracks
- 7 Si hits, not more than 2 holes (i. e. hits expected but not found)

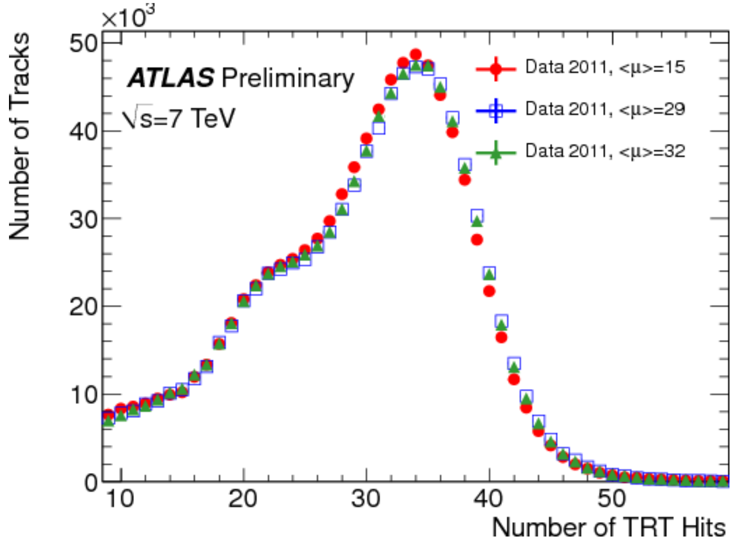
… but it works (if done right)

- robust track requirements are much safer against pile-up
- 9 Si hits, no holes allowed

TRT is important for tracking

- contributes around 30–40 hits
- this hardly depends on pile-up

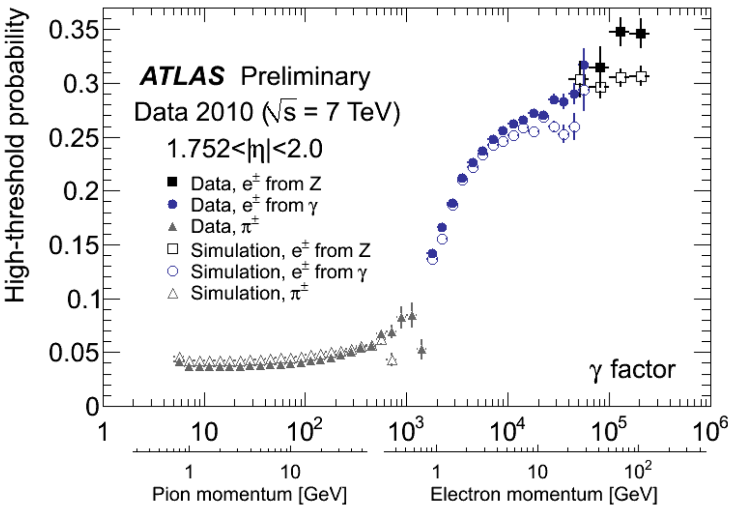




Particle Identification

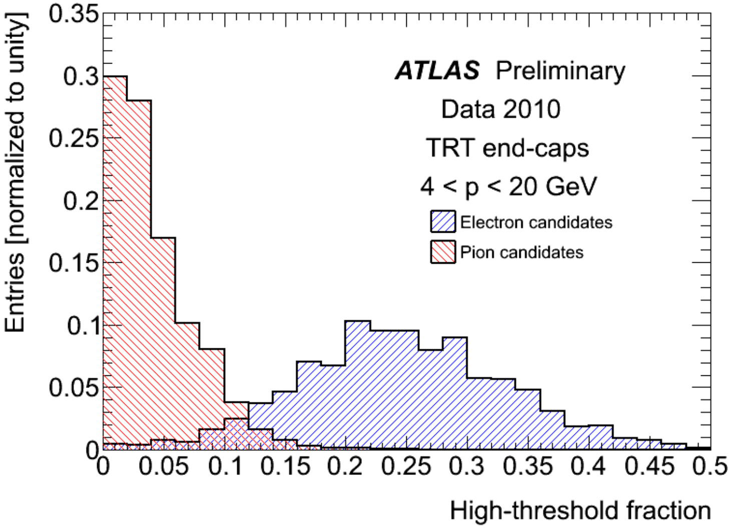
High-threshold probability

- electron–hadron discrimination using transition radiation (up to energies of 150 GeV)
- works best in the endcaps (endcaps have more radiators that are more regularly spaced)



High-threshold fraction

- fraction of HT hits per track
- electrons from conversions
- momentum range 4–20 GeV

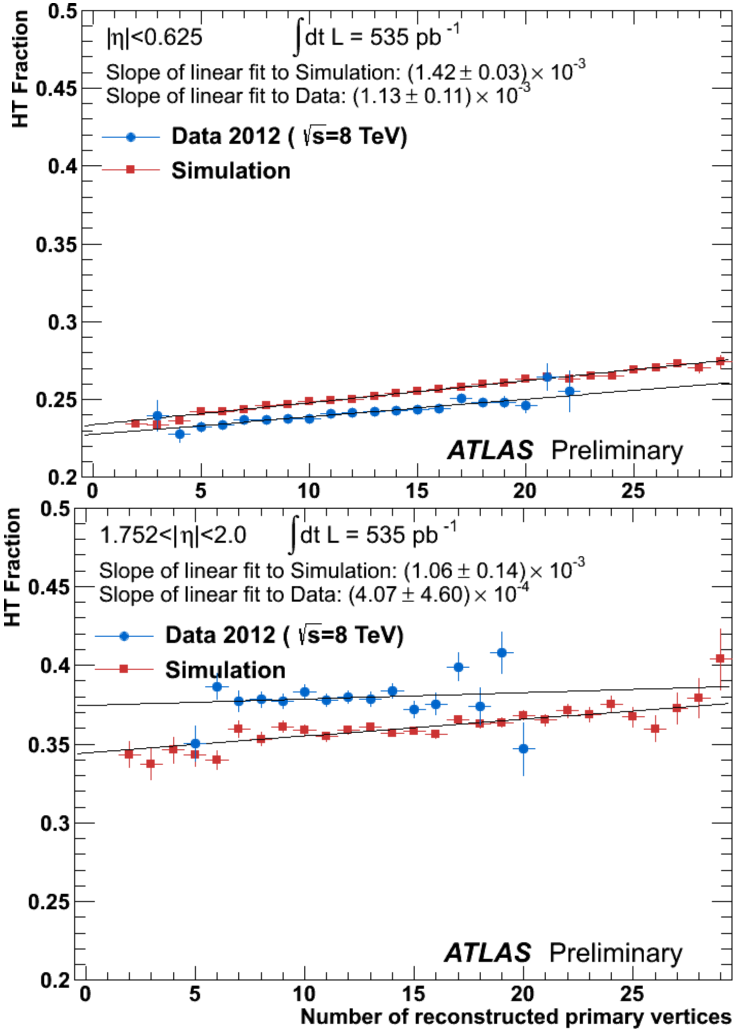


Particle ID with Pile-Up

HT fraction is still usable

- look at electron candidates with tag-and-probe at Z peak
- yields 25% HT hits in the barrel, 35% in the endcap (for largest η)
- depends only weakly on pile-up

Electrons can still be found



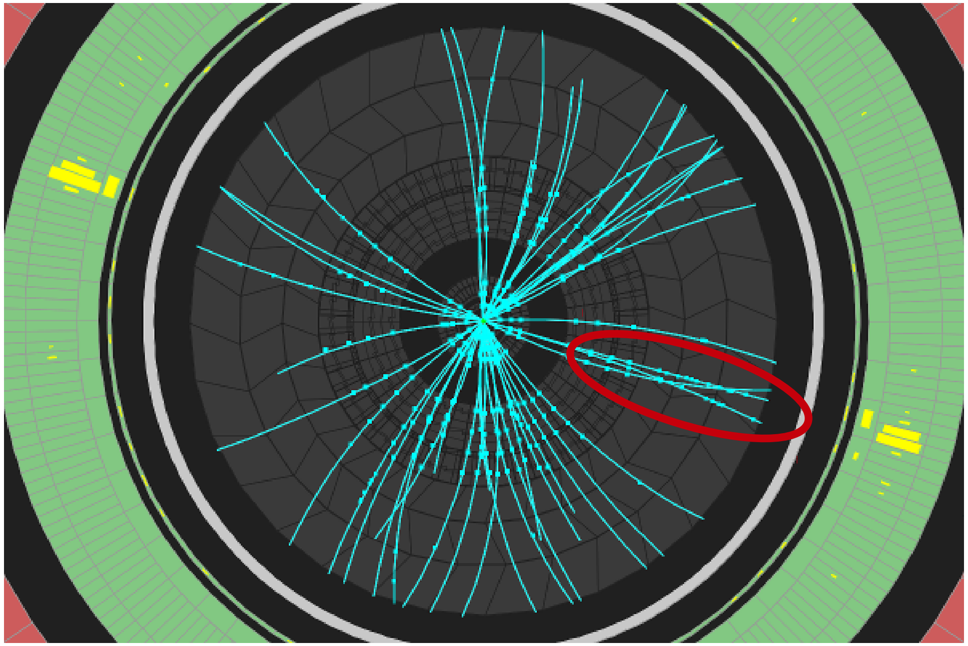
Physics with the TRT

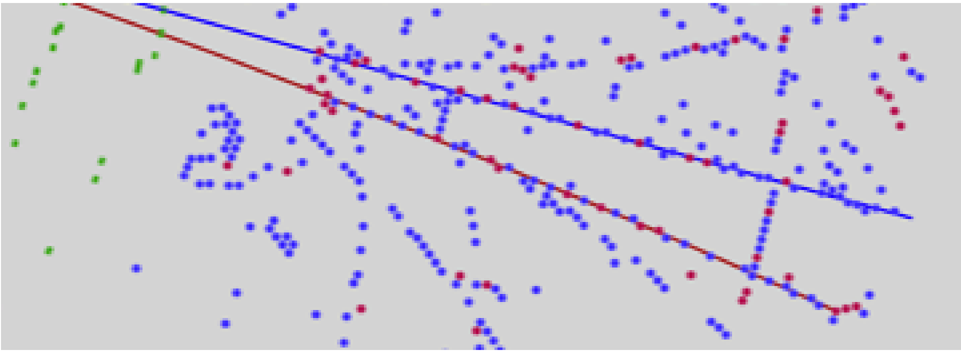
The TRT is needed for:

- anything with **electrons**, including **γ conversions**
- example on the right: **H → γγ** with **γ → e⁺e⁻**

The TRT may also find particles with unusual properties (**dE / dx**):

- stable massive particles with electric charge?
- magnetic monopoles?
- unexpected things?





Summary

The ATLAS TRT provides **tracking** and **identification** of charged particles.

It is susceptible to **in-time pile-up** and **out-of-time pile-up** (for bunch spacings of 50 ns and less).

Some areas see **occupancies well above 50%**, but:

Tracking works – most hits provide useful drift time information, most tracks can be extended into the TRT.

Particle ID works – high-threshold hits from transition radiation can be used to identify electron tracks.

References

Images and plots:

- atlas.ch Multimedia (slide 2, 3, 4, 6, 8)
- ATLAS Data Summary (slide 12)
- TRTPublicResults TWiki (slide 15, 18)
- EventDisplaysFromHiggsSearches TWiki (slide 19)
- ATLAS-CONF-2011-012 (slide 10)
- ATLAS-CONF-2011-128 (slide 17)
- ATLAS-CONF-2012-042 (slide 12, 16)
- ATL-COM-PHYS-2012-468 (slide 13, 14)

Related presentations:

- ATL-INDET-SLIDE-2011-254
- ATL-INDET-SLIDE-2011-621