ATLAS Transition Radiation Tracker (TRT): Straw Tubes for Tracking and Particle Identification at the Large Hadron Collider

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Abstract

The ATLAS Transition Radiation Tracker (TRT) is the outermost of the three inner detector tracking subsystems and consists of ~300000 thin-walled drift tubes ("straw tubes") that are 4 mm in diameter. The TRT system provides ~30 space points with ~130 micron resolution for charged tracks with $|\eta| < 2$ and $p_T > 0.5$ GeV/c. The TRT also provides electron identification capability by detecting transition radiation (TR) X-ray photons in an Xe-based working gas mixture.

Compared to Run 1, the LHC beams now provide a higher centre of mass energy (13 TeV), more bunches with a reduced spacing (25 ns), and more particles in each bunch leading to very challenging, higher occupancies in the TRT. We will present the TRT modifications made for Run 2: to improve response to the expected much higher rate of hits and to mitigate leaks of the Xe-based active gas mixture. The higher rates required changes to the data acquisition system and introduction of validity gate to reject out-of-time hits. Radiation-induced gain changes in the front-end electronics were studied. Many gas leaks were repaired and the gas system was modified to use a cheaper Ar-based gas mixture (or even a Kr-based mixture which is under study) in some channels. A likelihood method was introduced to optimize the TRT electron identification.

LHC after 2013-15 upgrade

The LHC parameters for **Run 2**.

Machine param.	Run 1	Run 2	Unit
CM energy $\sqrt{s}$	7	13	TeV
Peak luminosity	7×10^{33}	2×10^{34}	$cm^{-2}s^{-1}$
Average pileup	~21	~30	events
Bunch separation	50	25	ns
L1 input rate	20	40	MHz

All detectors and the LHC underwent **significant upgrades** during the Long Shutdown 1 (LS1) period.
Beam energy almost doubled bringing the possibility to explore of the Standard Model in an energy range never achieved previously.
Almost doubling the beam luminosity allows to precisely study the Standard Model and especially the **Higgs boson**.
Doubling the number of LHC bunches and much higher pileup results in **new challenges** in the detector data acquisition system and for trigger performance.

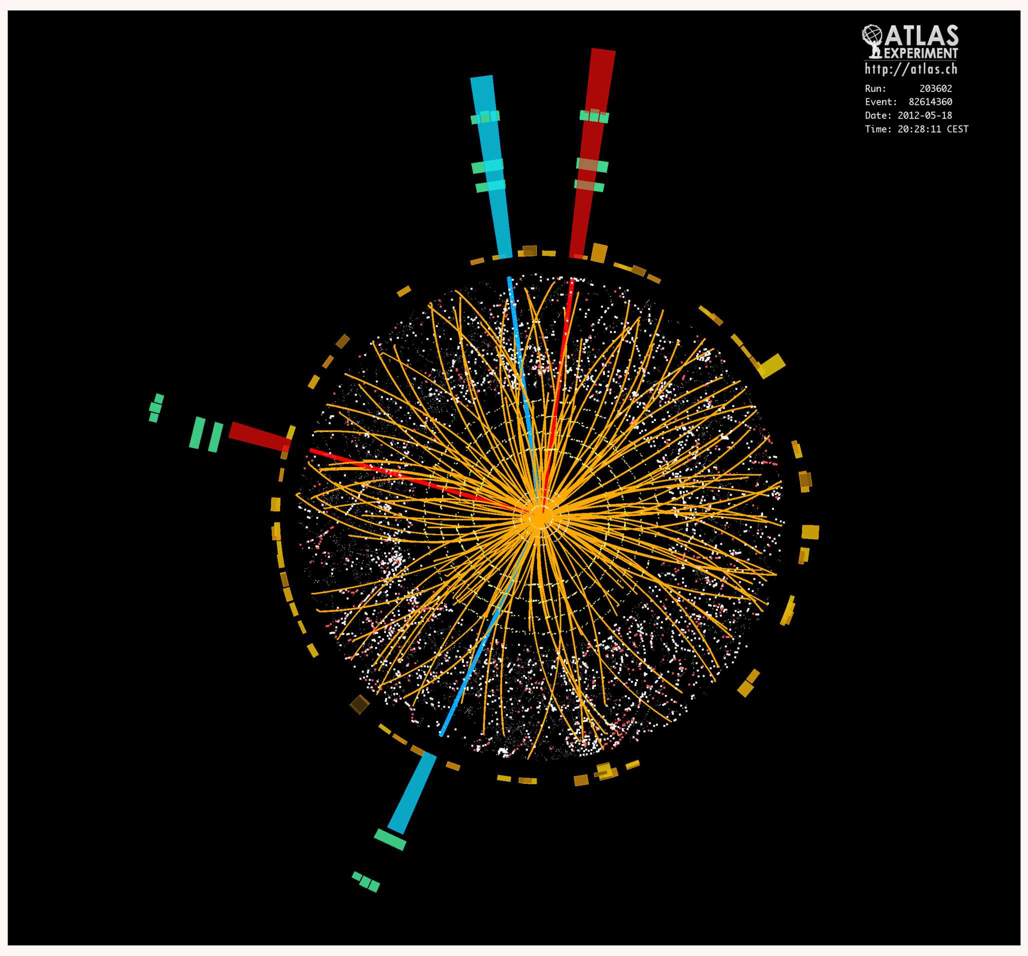

Fig. 1. Event display of $H \rightarrow ZZ \rightarrow 4e$ candidate with m(4l) = 124.5 GeV from proton-proton collisions at a collision energy of 13 TeV.

ATLAS – Inner Detector & TRT

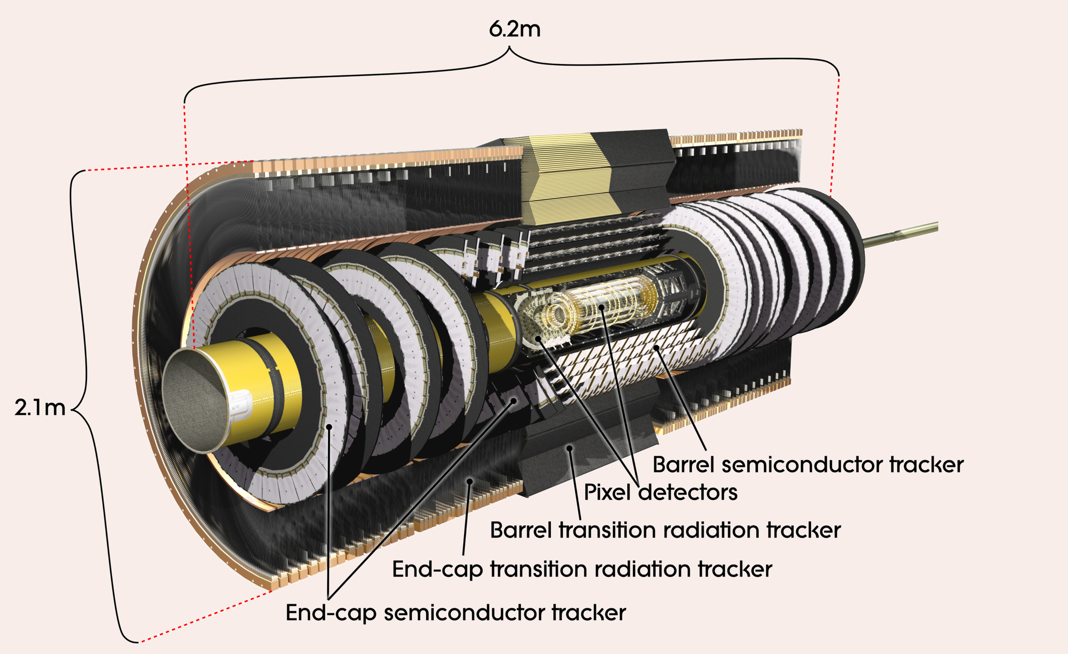

Fig. 2. The ATLAS Inner Detector.

ATLAS – "A Toroidal LHC ApparatuS" is along with CMS, one of the two general purpose detectors at LHC that discovered the long-sought Higgs boson.
Inner Detector (ID) – the very high precision tracking system surrounding the interaction point where LHC beams collides to detect and identify charged particles. The ID consists of silicon pixels (PIX), silicon strips (SCT) and gaseous proportional tubes (TRT).
Transition Radiation Tracker (TRT) – the outermost part of the Inner Detector, based on small diameter straw tubes. TRT exploits a novel and unique design which combines continuous tracking capability with particle identification (PID) based on transition radiation (TR).

Performance at High Pileup and High Occupancy

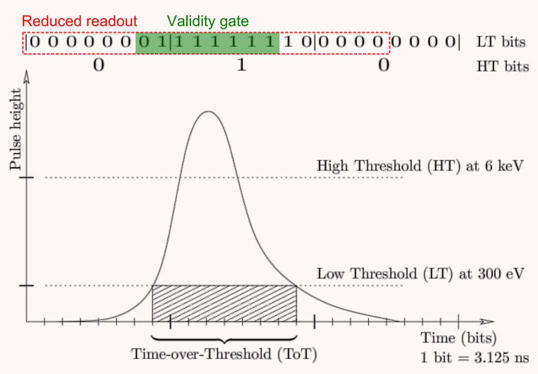

Fig. 3. The digitization of the TRT LT and HT signals from a single straw.

Signal digitization
A **low threshold (LT)** is readout in 24 time bins (3.125 ns each) to record tracking information.
Ternary readout electronics provide **high threshold (HT)** hits (~6 keV) in 3 time bins (25 ns each) to identify electrons.

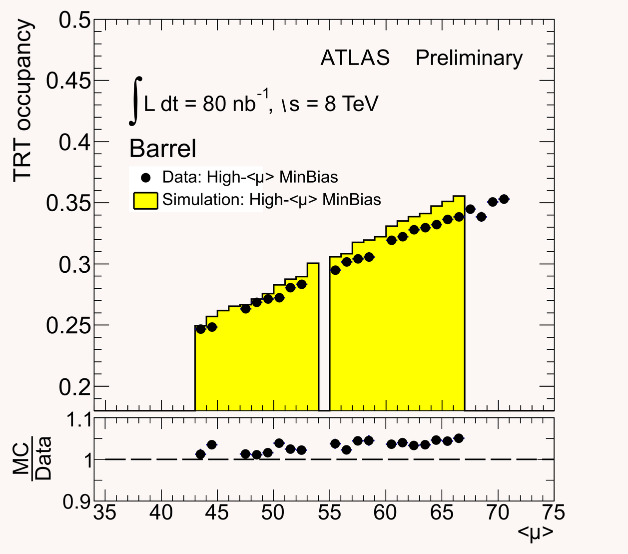

Fig. 4. TRT straw occupancy as a function of $<\mu>$.

Zero suppression both online and offline uses tunable validity gates with tunable width. Using only middle HT bit rejects out-of-time background.
The TRT readout employs a **Huffman lossless** compression algorithm.

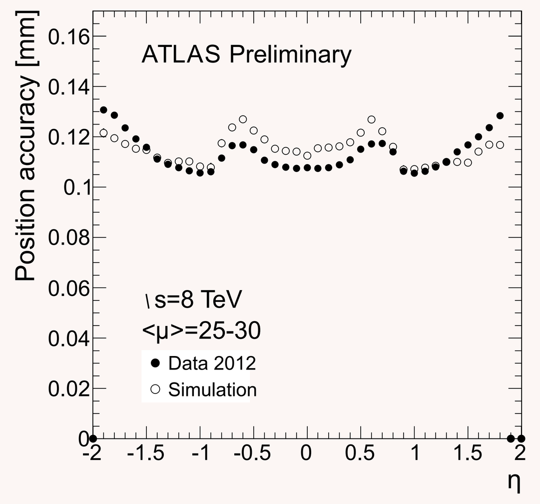

Fig. 5. Track position measurement accuracy in the straw as a function of η for muons $p_T > 30$ GeV.

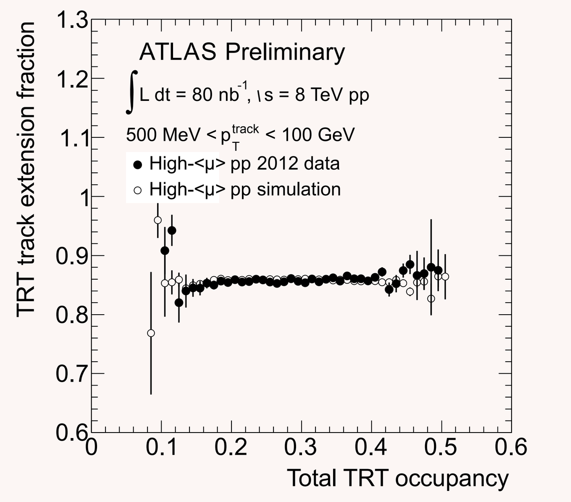

Fig. 6. TRT track extension (from PIX & SCT) fraction as a function of total TRT occupancy for minimum bias events.

Data acquisition and tracking conditions become very challenging when the detector runs at high occupancy levels (due to the luminosity increase and the reduction in bunch spacing) The TRT tracking is performing very well under the extreme conditions providing **high-precision spatial measurements**.

Active Gas Mixture Leaks

Due to the leaks, parts of the **TRT gas system** have been filled with Ar-based gas mixture.
It has been decided to use Ar-based gas mixture in places where the Xe losses are unaffordable (significant reduction of costs – Xe leaks at ~150 l/day with ~15 CHF/l). The **affected parts** of the TRT detector are: The innermost barrel layer – **M0** (1/3 of the barrel), end-cap A wheel **A6** and end-cap C wheel **A4** (2 out off 28 end-cap wheels). However, this configuration may change during the Run 2 if new leaks develop.
In the meantime, testbeam studies are ongoing to investigate the possibility of using a Kr-based gas mixture, which has better (than Ar) X-ray absorption coefficient with more reasonable price (than Xe).

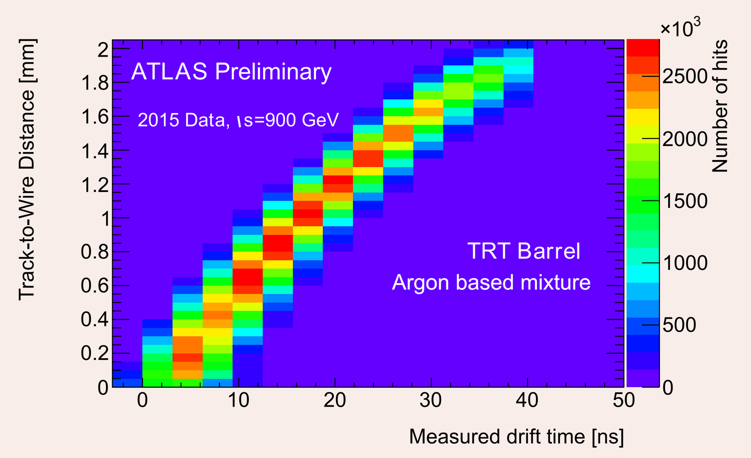

Fig. 7. The R-T dependency for the barrel with all TRT straws filled with Ar-based gas mixture.

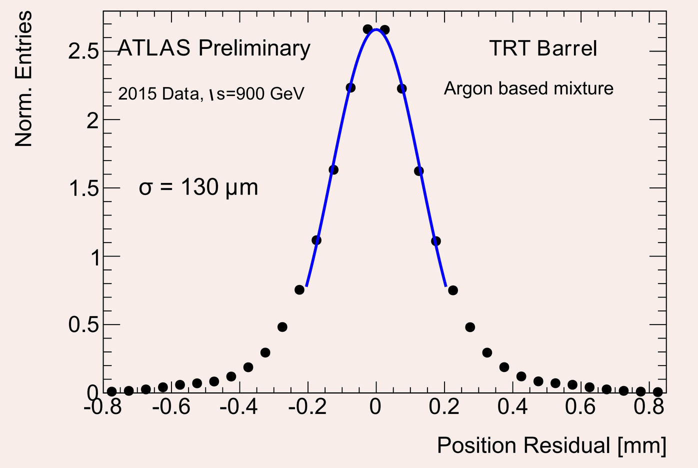

Fig. 8. The hit residual distribution for the barrel for tracks of $p_T > 0.5$ GeV with at least one SCT hit and at least 10 TRT hits.

The **Run 2 Baseline Scenario** of the TRT active gas fill configuration was optimized to minimize the impact of running the TRT parts with Ar-mixture (which has ~5× lower TR absorption probability) on PID performance. The **tracking accuracy** is not affected by Ar-based gas mixture.

Particle Identification

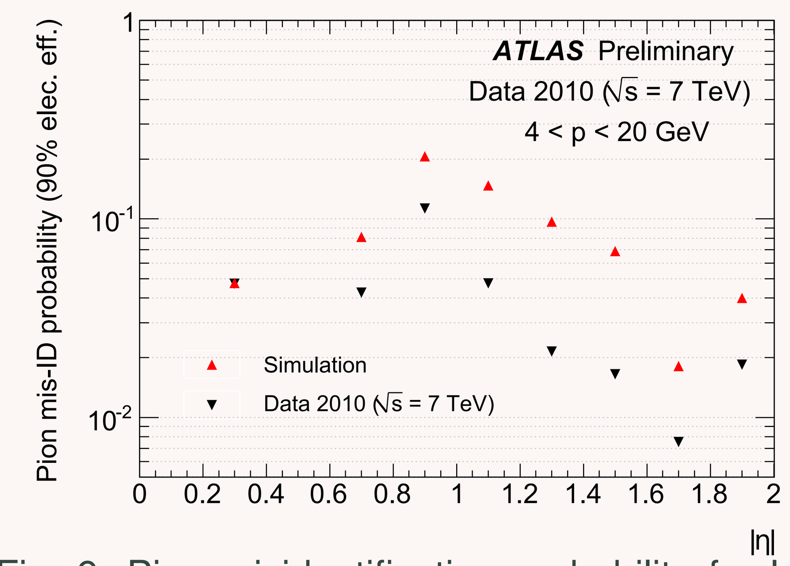

Fig. 9. Pion misidentification probability for HT fraction criteria that gives 90% electron efficiency in bins of η.

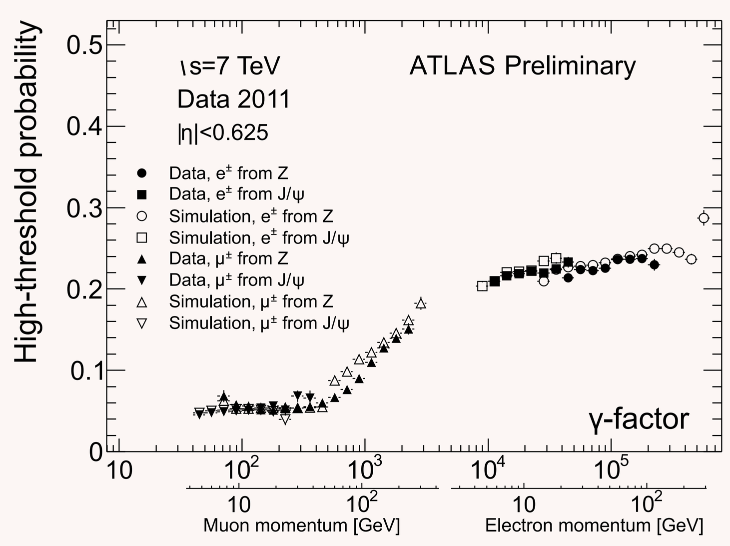

Fig. 10. The HT probability for electrons and muons as a function of Lorentz γ-factor in the TRT barrel.

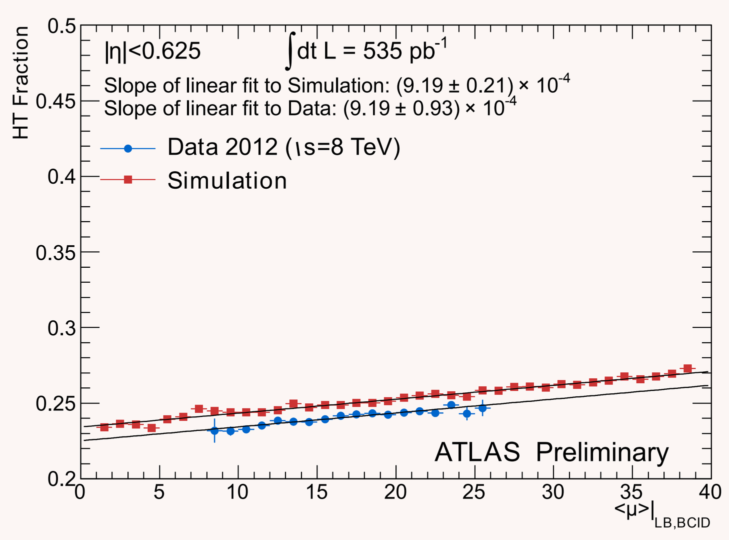

Fig. 11. The HT probability as a function of average number of interactions per bunch crossing for electrons.

The HT probability **varies significantly** across the TRT detector due to the use of different radiators, detector geometry and two gas mixtures. The higher luminosity in Run 2 greatly increases occupancy leading to **increased HT probability**.
PID based on a **likelihood method** which accounts for these various effects has been proposed in the following form:

$$\mathcal{L}^{e,\mu} = \prod_{\text{TRT hits}} \begin{cases} p^{e,\mu}_{HT} & \text{if HT hit} \\ 1 - p^{e,\mu}_{HT} & \text{else} \end{cases} ;\ p^e = \frac{\mathcal{L}^e}{\mathcal{L}^e + \mathcal{L}^\mu},\ p_{HT} \text{ – probability to produce a HT hit, } p^e \text{ – electron probability.}$$

Summary

The TRT detector **performs very well** despite high pileup, extreme occupancy, problems with gas leaks (mixed Ar/Xe gas operation mode) and significantly contributes to tracking and electron identification.

References

[1] The ATLAS Collaboration, *Physics Letters B*, 716, 1, (2012).
[2] The ATLAS Collaboration, *Atlas Note*, ATL-INDET-PUB-2014-001.
[3] *https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TRTPublicResults.*

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