Performance of the ATLAS Transition Radiation Tracker with Cosmic Rays and First High Energy Collisions at LHC

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The ATLAS Transition Radiation Tracker (TRT) is the outermost of the three sub-systems of the ATLAS Inner Detector at the Large Hadron Collider (LHC) at CERN. It consists of close to 300000 thin-wall drift tubes (straws) providing on average 30 two-dimensional space points with 130 μm resolution for charged particle tracks with $|\eta| < 2$ and $pT > 0.5$ GeV/c. The TRT is immersed in a 2 T magnetic field generated by the central solenoid, significantly contributing together with the other two Inner Detector sub-systems to the particle momentum reconstruction. Along with continuous tracking, it provides particle identification capability through the detection of transition radiation X-ray photons. This talk will describe the operational experience gained with the ATLAS TRT detector during the commissioning with cosmic rays and operation with the first proton-proton collision data at 900 GeV and 7 TeV center-of-mass energy.

1. Introduction

The ATLAS Transition Radiation Tracker (TRT) is the outermost and largest of the three sub-systems of the ATLAS Inner Detector [1]. It is designed to operate in the 2T solenoidal magnetic field at the LHC design luminosity ($L = 10^{34} cm^2 s^{-1}$). The TRT is made of thin-walled straw drift tubes with a single hit design resolution of 130 μm. TRT detector geometry gives on average 30 two-dimensional spacepoints for charge particles with $|\eta| < 2$ and $pT > 0.5$ GeV/c. In addition to a significant contribution to the precision of the momentum measurement due to the track length measured, the TRT provides also particle identification.

The straw drift tubes were made by spirally winding and fusing 2 bands of aluminized kapton [2]. They are 4 mm diameter with a 31μm diameter gold plated tungsten anode wire in the center. The straws work in proportional mode with -1.5 kV potential in the straw wall with respect to the wire that is held at ground. The active gas used is a mixture of 70% Xe, 27% CO2, 3% O2.

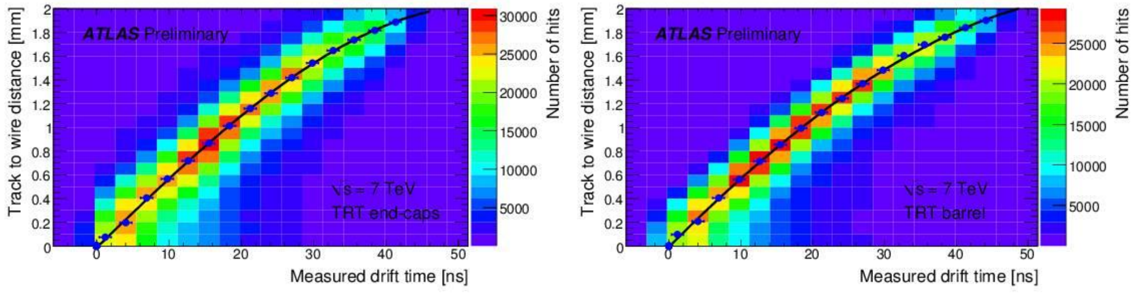
The TRT consists of three parts, a barrel [3] and two end-caps [4]. The barrel covers $|\eta| < 1$ and is made of 52544 straws 144 cm in length electrically split in the middle to reduce occupancy and with independent readout at both ends. The straws are oriented parallel to the beam and they are arranged in 3 layers of 32 modules each. The transition radiator material which completely surrounds the straws inside each module consists of polypropylene-polyethylene fiber matting. The two end-caps each contain 122880 straws 37 cm in length radially aligned to the beam axis and covering the region: $1 < |\eta| < 2$. The TRT end-cap radiators are disk-shaped stacks of alternating layers of thin plastic film and sheets of a spacer fabric. The TRT straw layout is designed so that charged particle tracks with transverse momentum pT > 0.5 GeV and with pseudorapidity |η| < 2 cross about 35 straws (except for the Barrel/End-cap transition region).

2. Tracking

When a charged particle traverses a straw, the gas is ionized creating clusters of electrons and ions along the particle path. The electrons drift towards the wire due to the 1.5 kV electric field and create secondary ionization with an average gain of 25000. A discriminator in the Front-End electronics yields a logical signal when the signal from the wire is above a programmable threshold. The discriminator output is recorded in 3.125 ns time bins and stored in a pipeline. Upon a level-1 trigger, a precisely selected sequence of 24 time bins (i.e. a window of 75 ns) is transferred from the pipeline to the off-detector electronics. The timing and width of this window are chosen to allow the recording of the trailing edge. The signals from particles associated with the trigger are fully readout, i.e. completely enclose the range, about 55 ns, of possible drift times. The discriminator thresholds are typically set to ~ 300 eV in order to limit the noise rate to less than 300 kHz.

For tracking, the drift time of the primary electron closest to the wire is important. In general the closest primary electron induces the first signal over the threshold but the measured time contains other effects such as the synchronization of the various readout channels, the TRT and LHC synchronization, signal propagation along the wire and the time of flight of the particle that need to be corrected. The correct timing for each TRT straw is calibrated in a 36 hour cycle.

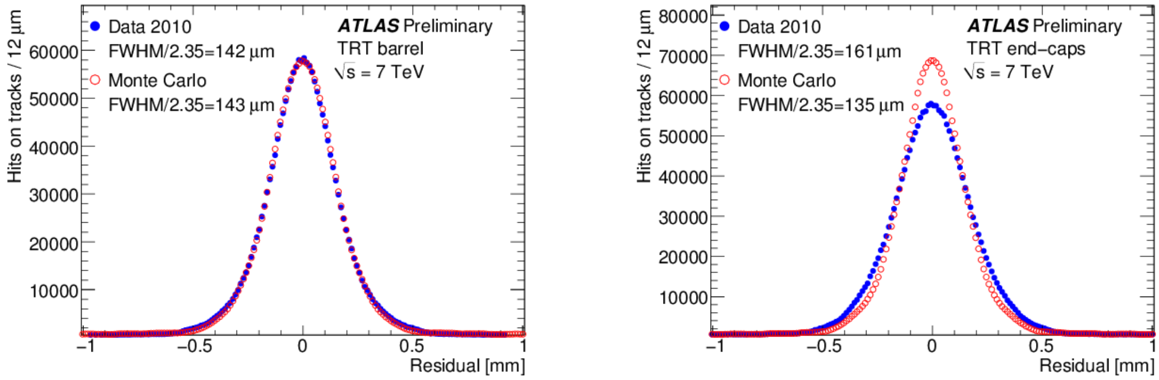
The plots on figure 1 show the TRT R-T dependency for the TRT barrel(a) and end-caps(b). This relation is used to infer track to wire distance, i.e., drift radius, based on measured drift time. To determine the R-T relation, the raw time measurement is first corrected with a T0 calibration constant. This way, different signal delays for different parts of the detector are taken into account. In the next step, the track to wire distance distribution is fit in bins of measured drift time. The peak position obtained with this fit is shown in blue points in the figures. The dependency of the peak position on measured drift time is described by a third order polynomial, shown in the black line. The R-T relation is calibrated every 24 hours and has shown to be very stable for cosmic data, 900 GeV and 7 TeV collisions.



(a) (b)

Figure 1. TRT R-T relation for 7 TeV for barrel (a) and end-caps (b)

Figure 2 shows the spatial residual for the barrel(a) and the end-caps(b). The barrel residual for data (142 μm) is in good agreement with Monte Carlo (143 μm) due to detailed studies done with cosmic data and first collisions. The end-cap residual for data (161 μm) is currently larger than for MC (135 μm) because more precise alignment corrections and better tracking algorithms are needed. Unlike in the barrel, detailed studies with cosmic ray data were not feasible.



(a) (b)

Figure 2. TRT spatial residual for 7 TeV for barrel (a) and end-caps (b)

3. Front End Electronics and TRT Fast-OR Trigger

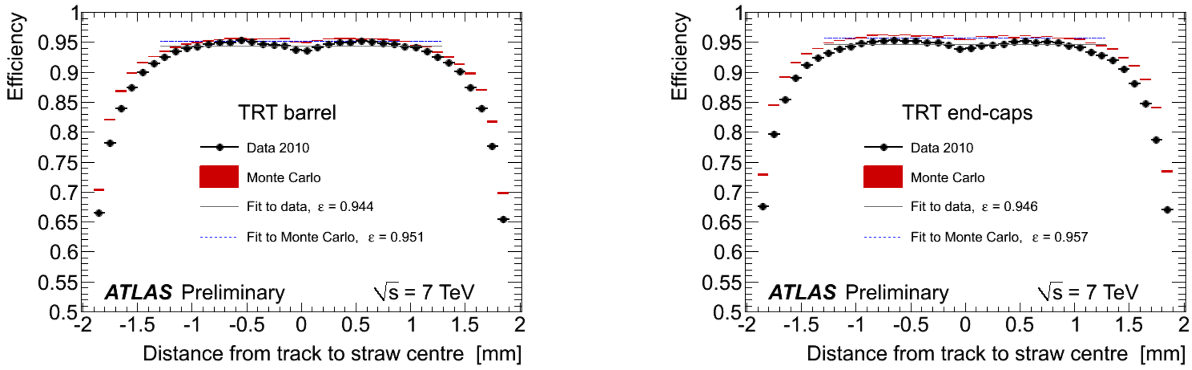
When the LHC incident in Sept. 2008 promised an extension of the commissioning period using cosmics, the decision has been taken to finalize the implementation of a TRT trigger [5]. It allowed the TRT to collect tracks from cosmics independent from other subsystems, with rates in both barrel and end-cap that were significantly higher than what other triggers had been able to produce.

The signal from a straw is amplified with an analog Amplifier Shaper Discriminator Baseline Restorer (ASDBLR) where it is discriminated with a 300 eV threshold. The signal is then recorded in a digital pipeline of 3.12 ns wide time bins in a Digital Time Measurement Read-Out Chip (DTMROC) before it is sent to the back-end electronics [6]. The trigger signal is generated by first OR-ing together all the discriminated channel outputs (either LT or HT) in a DTMROC, then OR-ing together all DTMROCs on a given front-end board.

To ensure a high fraction of hits on track (~30-50%) as well as very low noise, the trigger electronics on the DTMROC was configured to generate a signal from the high threshold that was lowered to minimum ionizing particle levels. More than 90% of the triggers arrive in one clock cycle, enabling the TRT Fast-OR to became a reference for the timing-in of other ATLAS triggers. It helped improve the barrel muon system trigger timing as well as inner detector readout timing, and provided a source of tracks for inner detector alignment. The barrel trigger rate is 10 Hz and the efficiency of collecting cosmics tracks is 75%.

4. Performance

Tracks cross on average ~35-40 straws but not all of them will record signals (hits). Figure 3 shows the hit reconstruction efficiency for 7 TeV collisions data (black) and Monte Carlo data (red). The hit reconstruction efficiency is defined as the number of straws with a hit on track divided by the number of straws crossed by the track. The 2% of known non-functioning straws are excluded from this study. The efficiency is dependent on the threshold setting. The MC threshold was tuned using 900 GeV data. This tune is in good agreement with the 7 TeV data as can be seen from efficiency plateaus for data (94%) and Monte Carlo (95%).



(a) (b)

Figure 3. Hit efficiency versus track-to-wire distance, for the barrel (a) and endcaps (b)

5. Particle Identification

The TRT is able to discriminate electrons from other charged particles using transition radiation (TR), which consists of soft x-ray photons emitted by charged particles traversing the boundary between materials with different dielectric constants. TR photons have energies in the range of 5-30 keV, and the TRT Xenon gas mixture was chosen to maximize the absorption probability for these. In order to identify hits with transition radiation, the TRT electronics has a second threshold (high threshold or HT) at ~6 keV. Figure 2 shows the probability of a TRT high-threshold hit as a function of γ. For charged particles with γ factors above 1000, the high threshold hit probability increases, allowing the TRT to identify electrons. The different radiators used in the barrel (Figure 4 (a)) and the end-caps (Figure 4 (b)) give different onset curve shapes. The Monte Carlo simulation is being tuned using this 7 TeV collision data to match the TR performance.

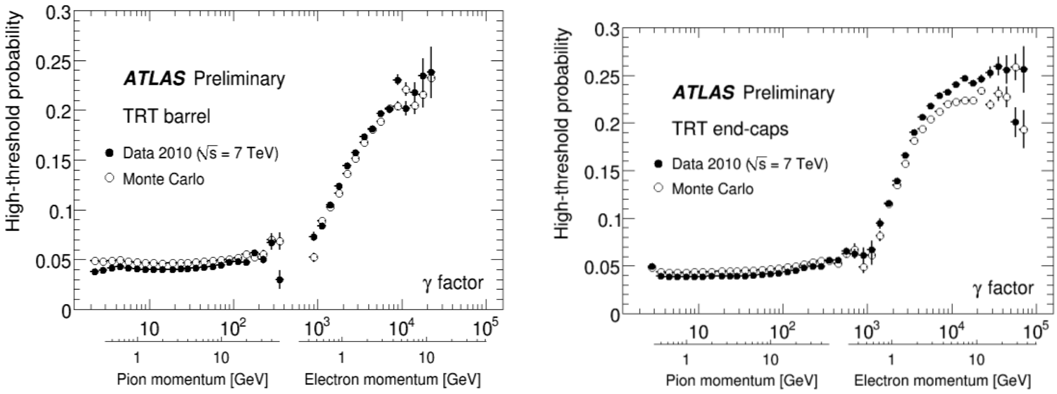


Figure 4. Probability of a TRT high-threshold hit as a function of the Lorentz γ factor as measured in 7 TeV LHC collision events for barrel (a) and end-caps (b)

Time over threshold (ToT) is a second method of particle identification. ToT is essentially the time between the first and the last electron arrival when a particle crosses a straw. ToT indicates a higher energy deposition in the straw. Figure 5 shows ToT distributions corrected for systematic variations along the z coordinate and divided by the transverse particle trajectory length for pion and electron candidates in 7 TeV collision data.

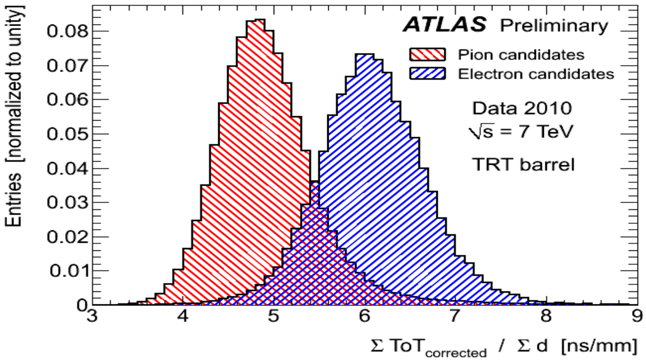


Figure 5. Time over Threshold (ToT) distributions for pion and electron candidates, as obtained from 7 TeV collision data.

6. Conclusion

The TRT commissioning process with cosmics and first collisions has been very successful. Trigger capabilities that have not been part of the original design have been implemented and used throughout the commissioning process to calibrate both the TRT and other ATLAS subsystems. TRT community has now achieved good understanding of the detector and is finding resolution, tracking efficiencies and PID properties very close to the MC expectations for both barrel and end-caps.

References

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