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Performance of the ATLAS Transition Radiation Tracker read-out with cosmic rays and first high energy collisions at the LHC

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ABSTRACT: The Transition Radiation Tracker (TRT) is the outermost of the three subsystems in the ATLAS Inner Detector. It contributes significantly to the precision of the momentum measurement of charged particles and to the identification of electrons. This note reports about the commissioning and performance of the TRT with cosmic rays and the first high energy collisions at the LHC.

KEYWORDS: Gaseous detectors; Particle tracking detectors; Transition radiation detectors.

Contents

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1. Introduction and Design

The Transition Radiation Tracker (TRT) [1] is the outermost subsystem of the inner detector at ATLAS [2] which is immersed in a 2 T solenoidal magnetic field. The TRT is a straw drift-tube detector operated in proportional mode with a total of 350,848 readout channels. It contributes significantly to the precision of the momentum measurement of charged particles and to the identification of electrons. As a continuous tracker it provides a large number (30) of measurement points ("straw hits") on track, with a hit resolution of 130 μm for charged particles with $p_T > 0.5$ GeV/c, and it covers the pseudorapidity range $|\eta| < 2$.

The straw drift tubes are made of thin Kapton-based multilayer material. They have a diameter of 4 mm and contain a 30 μm diameter, gold-plated tungsten anode wire in the center. The small tube radius limits the maximum drift time to $\sim$50 ns. The length of the straws has been chosen such that the counting rate per wire is not more than $\sim$20 MHz at LHC design luminosity. The straw wall, which lies at a potential of -1.5 kV relative to the wire, provides a separation between the transition radiation medium and the active gas (70% Xe, 27% CO2, 3% O2). To minimize the number of radiation lengths only light materials were used throughout the detector.

The TRT consists of three parts, a barrel [3] and two endcaps [4]. The barrel covers $|\eta| < 1$ and is made of 52,544 straws 144 cm in length electrically split in the middle, with independent readout at both ends. The straws are oriented parallel to the beam and they are arranged in 3 modules of up to 32 straw layers each. The transition radiator material which completely surrounds the straws inside each module consists of polypropylene-polyethylene fiber matting. The two endcaps each contain 122,880 straws 37 cm in length radially aligned to the beam axis. They cover the region $1 < |\eta| < 2$. The TRT endcap radiators are disk-shaped stacks of alternating layers of thin plastic film and sheets of a spacer fabric.

1.1 Readout and Electronics

When a charged particle traverses a straw it typically loses a few hundred eV of energy to ionization clusters of electrons and ions in the gas. The liberated electrons drift towards the wire, where the high electric field leads to secondary ionizations in the gas with an average gain of 25000. This signal is modified with an analog Amplifier Shaper Discriminator Baseline Restorer (ASDBLR) [5] where it is discriminated on 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. The DTMROC can further (a) configure the ASDBLR to inject a test pulse used to estimate the effects of radiation damage, (b) sense the low voltage applied to both ASDBLR and DTMROC, (c) transmit configuration and sense data to the Trigger, Timing and Control (TTC) back-end during data taking used for e.g. single event upset recovery, and (d) transmit a trigger signal to the TTC back-end (see Section 4).

For the TRT back-end electronics, clock, trigger, and command signals are sent to the front-end boards by TRT-TTC boards, 9U VME modules housed in the counting room. After each trigger, data is read out via the ReadOut Driver (ROD) boards, also 9U VME modules in the counting room. Signals between the front-end and back-end are repeated at TTC and ROD patch panels located in the ATLAS toroid volume.

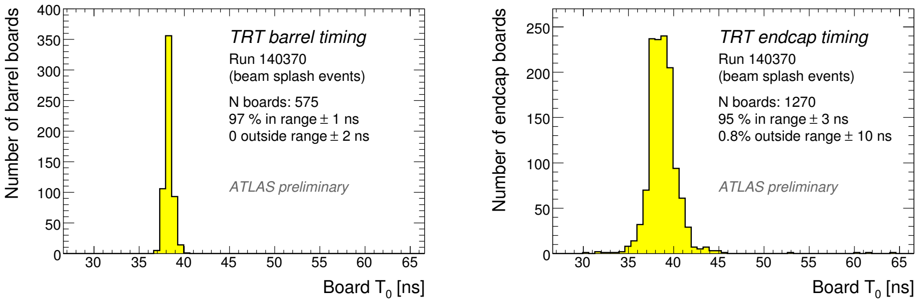
2. Tracking

The recorded signals from the anode wires provide information about both the particle tracks and the synchronization in time of the various readout channels. To discriminate between noise and straw signals from particles, the energy deposited in the straw is required to be higher than a tracking threshold (low threshold or LT) of 300 eV. The readout timing can be tuned in groups at the level of front-end boards ($\sim$200 straws) such that all readout signals fit well within the 75 ns readout window. Figure 1 shows the relative readout timing (t_0) distribution of all barrel and endcap boards separately, using data from fall 2009 where single LHC beam bunches were shot at closed LHC collimators 140 m upstream of ATLAS ("beam splashes"). The timing spread was already within ±1 ns in the barrel and ±3 ns in the endcaps, and the outliers in these histograms have been adjusted as of this writing. Offline, timing variations are corrected on a finer granularity to improve track reconstruction.

The leading edge of the straw signal comes from avalanche electrons closest to the wire and is correlated to the distance that these electrons drift from track to wire, and hence to the track to wire distance. This so-called R-T relation, determined from fits to data, is used to convert measured drift time into a distance for the track reconstruction algorithms.

3. Particle Identification

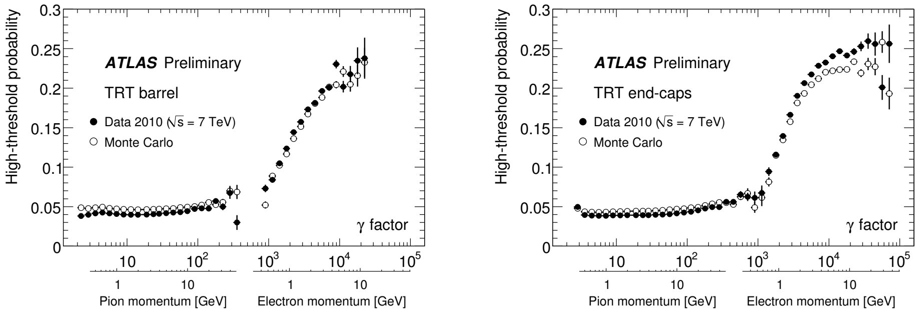
The TRT is able to discriminate electrons from other charged particles using transition radiation (TR), which consists of soft x-ray photons emitted by charged particles traversing the boundary between materials with different dielectric constants. The photons are produced with an angle of the order $1/\gamma$ relative to the track, where $\gamma = E/mc^2$, and the number of TR photons produced depends on γ and the number of boundaries crossed. TR photons have energies in the range of



(a) (b)

Figure 1. Relative hardware timing for front-end boards, as measured in 2009 beam splash events, for the barrel (a) and endcaps (b). The hardware timing settings are adjusted on the granularity of front-end boards, and the outliers have been subsequently corrected.

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 2 (a)) and the endcaps (Figure 2 (b)) give different onset curve shapes. Not shown in the endcap plot is the different TR onset curve for the A and B wheels, arising from different spacing of radiator layers. The Monte Carlo simulation is being tuned using this 7 TeV collision data to match the TR performance.



(a) (b)

Figure 2. Probability of a TRT high-threshold (HT) hit as a function of the Lorentz factor, $\gamma = E/mc^2$, for the TRT barrel (a) and endcaps (b) regions. A pure electron sample was selected in data using photon conversions.

4. Fast-OR Cosmics Trigger

When the LHC incident in Sept. 2008 promised an extension of the commissioning period using cosmics, the decision was made to finalize the implementation of a TRT cosmics trigger [6]. It allowed the TRT to collect cosmics tracks independently of other subsystems, with rates in both barrel and endcap that were significantly higher than what other triggers had been able to produce. 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. As a minor disadvantage, this configuration makes TR calibration difficult and is not compatible with configuration or sense data transmission. 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%. The granularity of the trigger is too coarse to make it useful in busier collision events, however.

5. Performance

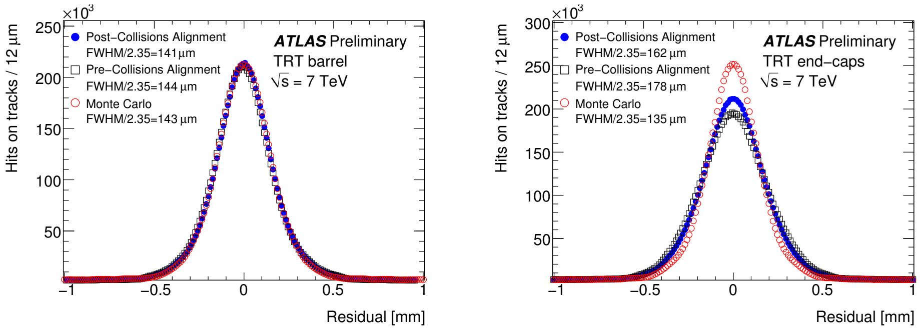
Many studies have been done using cosmic rays and first collisions data to understand the detector response and maximize the TRT performance. One critical aspect of the TRT performance is, naturally, its availability for physics runs. The TRT has been active and providing good quality data in 100% of LHC physics runs in 2009 and 2010, the highest among all ATLAS subdetectors. In addition to lots of hard work by the TRT operations team, automated procedures to recover from common readout problems contribute to this efficiency.

To provide good momentum resolution, good position resolution is required. Figure 3 (a) shows the spatial residual for the barrel and Figure 3 (b) the endcaps. The residuals are unbiased, i.e. the hit measurement from the straw whose residual is calculated is not used in the track fit. The tracks in the sample are from particles of relatively low momentum (a cut $p_T > 2$ GeV was used). Multiple scattering effects are therefore important and lead to residuals larger than the intrinsic resolution. The barrel performance is already close to expected from Monte Carlo, while the endcaps show a slightly worse resolution. Unlike in the barrel, the rate of tracks in cosmic runs is very small in the endcaps for geometric reasons, hence detailed studies with cosmic ray data were not feasible. More recently, improvements in calibration, tracking, and especially alignment have improved these residuals so that both the barrel and endcaps are approaching the design resolution of 130 μm.

The number of hits on a track is important for the momentum measurement, so hit reconstruction efficiency is an important parameter. The TRT hit efficiency is defined as the number of straws with a hit on the track divided by the number of straws crossed by the track, and is shown versus track-to-wire distance in Figure 4. The efficiency in the plateau region of ±1.3 mm is 95%. Known dead channels (2% of total) are removed from this plot.

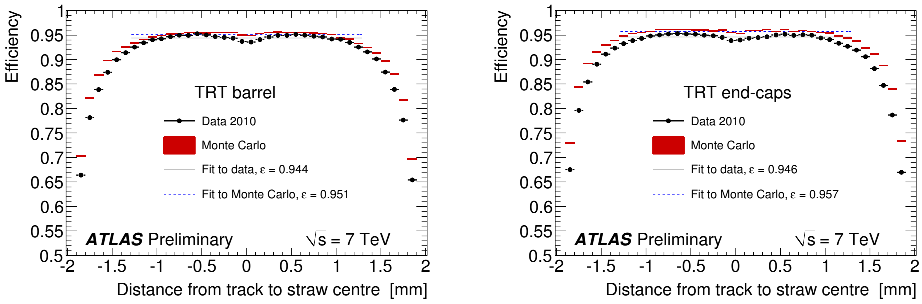
6. Conclusion

The TRT has performed well thus far in the first year of LHC physics running, in operations, track-



(a) (b)

Figure 3. TRT unbiased position residuals, for the barrel (a) and endcaps (b).



(a) (b)

Figure 4. Hit efficiency versus track-to-wire distance, for the barrel (a) and endcaps (b).

ing, and particle identification. The performance is already approaching design in some respects, with ongoing studies to further improve this, and many ATLAS physics analyses are already making use of the excellent TRT performance.

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