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Commissioning and performance of the ATLAS Transition Radiation Tracker with cosmic rays and first high energy collisions

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ABSTRACT

The Transition Radiation Tracker 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 recent commissioning progress and the performance achieved in preparation for first collisions at the LHC.

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 solenoid 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. 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 ~ 50 ns. The length of the straws has been chosen such that the counting rate per wire is not more than ~ 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% CO_2, 3% O_2). To minimize the number of radiation lengths only light materials were used throughout the detector.

When a charged particle traverses a straw it typically loses a few 100 eV 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 25 000. This signal is modified with an analog Amplifier Shaper Discriminator Baseline Restorer ("ASDBLR") where it is discriminated on a ~ 300 eV threshold. To permit a hit resolution of 130 μm, the signal is then recorded in a digital pipeline of 3.125 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 5).

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" of 300 eV. The trailing edge of the discriminated signal from a particle is caused by the latest electrons in the avalanche that come from close to the straw wall. The timing of the trailing edge can be tuned in groups of ~ 200 straws on the front-end boards such that all readout signals fit well within the 75 ns readout window. Fig. 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 in the barrel has been measured to be within 1 ns for more than 97% of the readout channels. The outliers in these histograms have already been adjusted as of this writing.

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Note that timing variations are corrected on a finer granularity separately in calibrations for offline 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. Fig. 2 shows, using LHC collision data, the drift distance calculated from each reconstructed track as a function of the drift time measured in the front end electronics ("RT relation"), for all straws in the barrel. The solid line is a fit to this data and matches well with a fit to cosmics data (dashed). This parametrization is used to convert drift time to drift distance as input to track reconstruction algorithms.

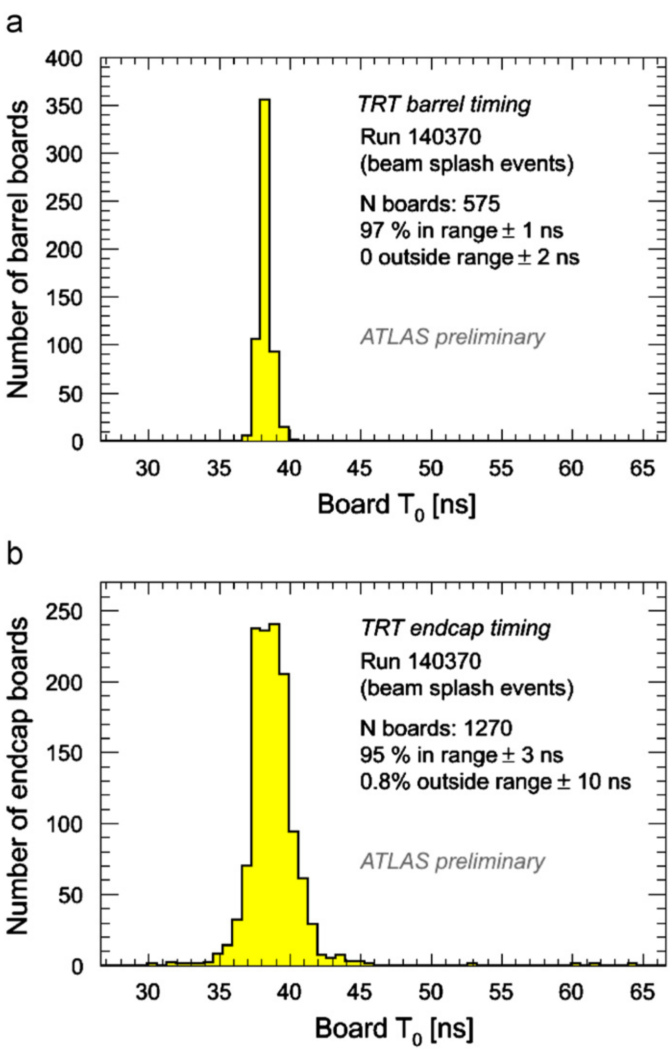

Fig. 1. The TRT readout timing measured in 2009 beam splash data for the barrel (a) and end-caps (b).

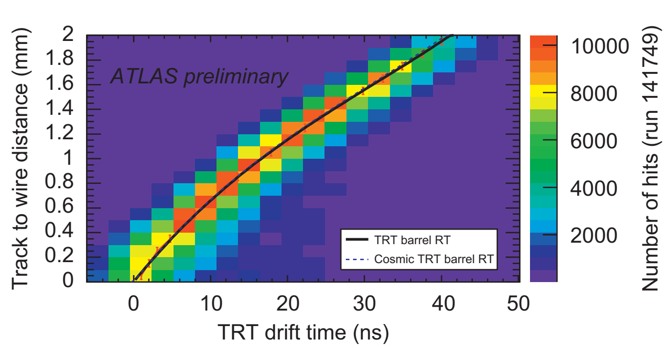

Fig. 2. The RT dependency for the barrel from LHC collision events. The dashed line shows a fit to the RT dependency from cosmics data, and matches with a fit (solid) to the collision data.

3. Active readout fraction

An estimate of the active readout fraction can be obtained from noise data. Results from test beam measurements indicate [3] that a straw noise occupancy of 2% is equivalent to a tracking threshold of $\sim 250\,\text{eV}$. Fig. 3 shows the noise occupancy for all readout channels after the tracking thresholds have been equalized to this level. While the majority of readout channels shows a good uniformity at 2% occupancy, outlier channels with more ("noisy") or less ("dead") occupancy are used to determine the fraction of channels that is unusable for track reconstruction to $\sim 2\%$ with approximately the same fraction for barrel and both end-caps together. About 85% of the unusable barrel channels were already found before the detector was installed in the ATLAS cavern.

4. Transition radiation

The TRT permits the discrimination of electrons from charged hadrons using transition radiation (TR). As the barrel straws are immersed in polypropylene fibers (interleaved foils in the end-caps), TR photons with an energy of more than 5 keV can be produced when a charged particle with a Lorentz factor $\gamma > 1000$ crosses the ~ 30 boundaries between the fibers and the active gas in the straw. Xe active gas has been chosen for its short absorption length for photons of this energy. As at this energy the photoelectric effect dominates, the energy of one absorbed TR photon is contained in a single straw. The front end electronics can separate straw signals from these high energy deposits and regular tracking hits using a separate "high threshold" (HT) discriminator set at $\sim 6\,\text{keV}$. Fig. 4a shows the probability that the HT is crossed per straw as a function of γ for end-cap tracks from collision events. Clearly visible is the TR onset at $\gamma > 1000$. The non-zero fraction for charged tracks comes from the probability to have a dE/dx above the HT. The electrons in this sample have been selected from photons that convert before they enter the TRT, as shown in an example event in Fig. 4b. One of the tracks is required to pass tight electron selection criteria while the

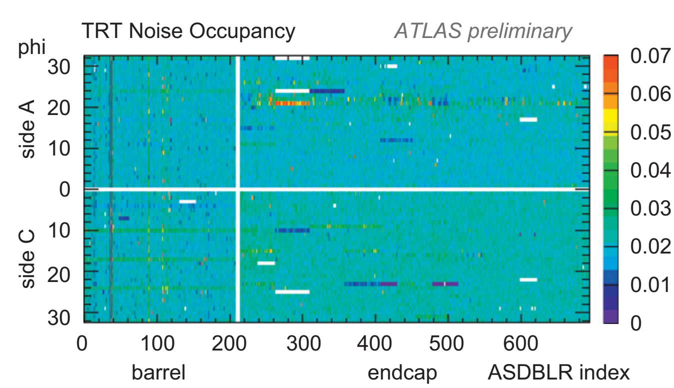

Fig. 3. The noise occupancy for barrel and both end-caps for groups of eight straws ("ASDBLR index"). While the plot shows a good uniformity at 2%, outliers are used to determine the fraction of readout channels that is unusable for track reconstruction to $\sim 2\%$.

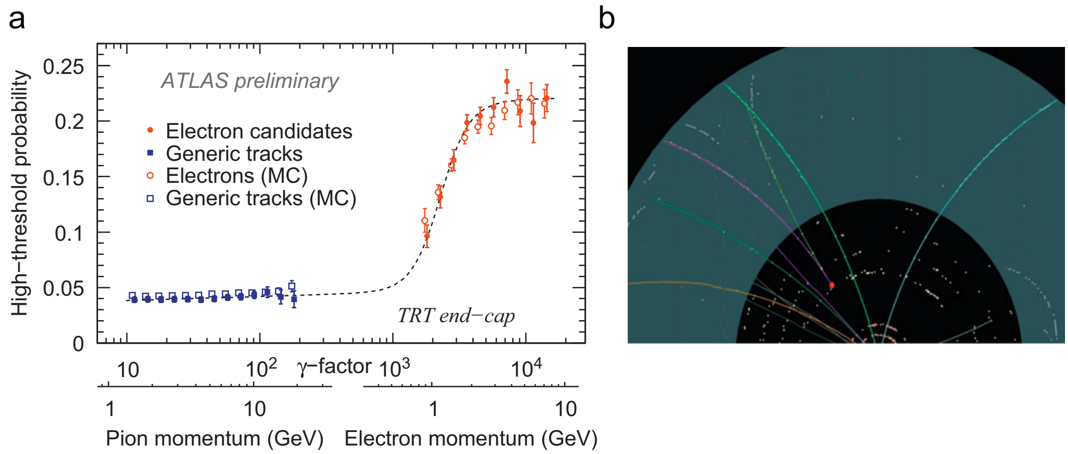

Fig. 4. (a) Fraction of straw hits on track that have a HT signal as a function of $\gamma = E/m$ for the TRT end-caps as measured in collision events from December 2009. The electrons have been selected from photon conversion as shown in an example event display in (b) where the photon converts in the Silicon Semiconductor Tracker (SCT).

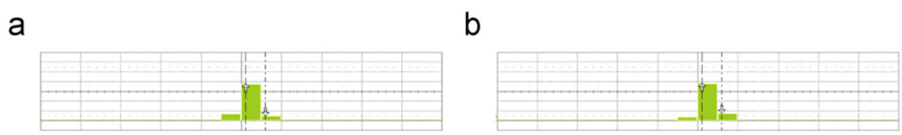

Fig. 5. The jitter of trigger pulses from the A side of the TRT in (a) for tracks that crossed both barrel sides, with the trigger pulse from the C side as a reference point at 0 (centered). (b) The same for barrel C side with the A side as a reference. The histogram shows the distribution of the pulses, accumulated over 1000 triggers in units of ATLAS clock cycles (25 ns). The granularity of the grid is 200 entries per division in y, and 25 ns per division in x. The jitter is estimated to be 8.75 ns. See Ref. [4] for more details.

HT probability is measured on the other. The HT is calibrated such that it is accurate to 1.2% to optimize pion–electron separation. The current precision is close to this value.

5. Front end electronics and TRT fast-OR trigger

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

A "Fast-OR" circuit on the DTMROC [4] permits sending a trigger signal to the TTC board if it receives a discriminated straw signal from any of the 16 associated readout channels. The TTC back-end receives trigger signals from groups of 10–15 DTMROCs over a communication line usually used for configuration and sense data transmission. Independent logic circuits on each of the 16 TTC boards in the barrel system can generate a trigger signal if the number of communication lines that carry a signal within a clock cycle (25 ns) exceeds a configurable number.

To ensure a high fraction of hits on track (~ a third) 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. Each TTC board was configured to send a trigger signal if at least four communication lines carry a signal. As a minor disadvantage, this configuration makes TR calibration difficult and is not compatible with configuration or sense data transmission. Fig. 5 shows the trigger jitter from cosmic tracks that traverse the barrel. As more than 90% of the triggers arrive in one clock cycle, the TRT Fast-OR soon became a reference for the timing-in of other ATLAS triggers. It helped improve the muon system (RPC) trigger timing as well as

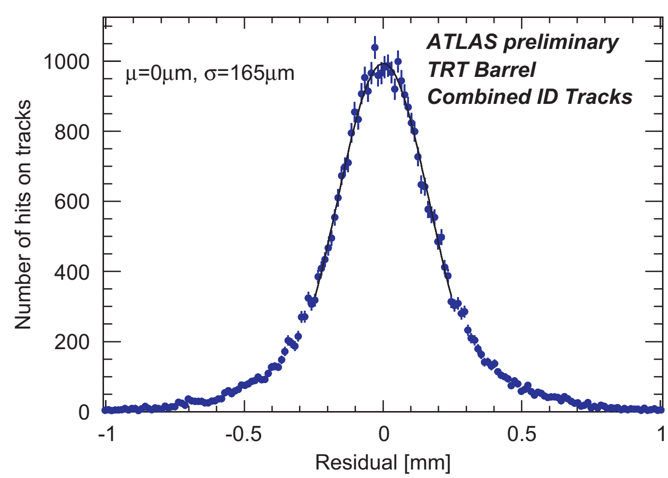

Fig. 6. The position resolution in the barrel using tracks from collision events taken in December 2009. The resolution of 165 μm is in agreement with the technical design report.

inner detector readout timing. The trigger rate is ~10 Hz and the efficiency of collecting cosmics tracks is ~75%.

6. Position resolution

A good position resolution for tracks that traverse the full inner detector is important for a good transverse momentum measurement of the track. Fig. 6 shows the resolution for barrel tracks from collision events of December 2009, after the data has been calibrated for alignment, RT relation and readout timing. The resolution of 165 μm, a value similar to what has been produced on cosmics data, is in agreement with the technical design report [2].

7. Conclusion

The TRT commissioning process with cosmics and first collisions has been very successful. Trigger capabilities that were not part of the original design have been implemented and used throughout the commissioning process to calibrate both the TRT and other ATLAS subsystems. The TRT performance in the barrel is within the expectations of the technical design report. While many analyses, such as a material mapping of the inner detector, already make use of TRT data, the TRT is in an excellent shape to produce more collision data in the coming months.

References

[1] E. Abat, et al., The ATLAS TRT Collaboration, J. Instr. 3 (2008) P06007; E. Abat, et al., The ATLAS TRT Collaboration, J. Instr. 3 (2008) P02014; E. Abat, et al., The ATLAS TRT Collaboration, J. Instr. 3 (2008) P10003.
[2] The ATLAS Collaboration, J. Instr. 3 (2008) S08003.
[3] P. Cwetanski, Straw performance studies and quality assurance for the ATLAS Transition Radiation Tracker, CERN-THESIS-2006-025, 2006.
[4] S. Fratina, et al., The TRT fast-OR trigger, ATL-INDET-PUB-2009-002, 2009.