PERFORMANCE OF THE ATLAS TRANSITION RADIATION TRACKER WITH FIRST HIGH-ENERGY pp AND Pb-Pb COLLISIONS

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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 at CERN. It consists of close to 300000 thin-wall drift tubes (straws) providing on average 30 two-dimensional space points with 0.12–0.15 mm resolution for charged particle tracks with $|\eta| < 2$ and $p_T > 0.5\,\text{GeV}$. Along with continuous tracking, it provides particle identification capability through the detection of transition radiation X-ray photons generated by high-velocity particles in the many-polymer fibres or films that fill the spaces between the straws. Custom-built analog and digital electronics is optimised to operate as luminosity increases to the LHC design. In this article, a review of the commissioning and first operational experience of the TRT detector will be presented. Emphasis will be given to performance studies based on the reconstruction and analysis of LHC collisions. The first studies of the TRT detector response to the extremely high track density conditions during the November 2010 heavy-ion LHC running period will be presented. These studies give interesting insight to the expected performance of the TRT in future high-luminosity LHC proton-proton runs.

Keywords: ATLAS; Transition Radiation Tracker; TRT; Performance.

1. Introduction

The ATLAS experiment[1] is one of the four large particle detectors at the Large Hadron Collider (LHC) at CERN. It is a multi-purpose detector and consists of three main components: Inner Detector, calorimeters, and Muon Spectrometer. The Inner Detector in turn comprises three subsystems: the silicon Pixel detector, the Semiconductor Tracker (SCT), and the Transition Radiation Tracker (TRT). Immersed in a solenoidal magnetic field of 2 Tesla, the Inner Detector measures trajectories and momenta of charged particles with $p_T > 0.5\,\text{GeV}$ up to a pseudorapidity of $|\eta| = 2.5$.

2. Design of the TRT

The TRT is a straw-tube tracker. It consists of drift tubes with a diameter of 4 mm that are made from wound Kapton and reinforced with thin carbon fibres. In the centre of each tube there is a gold-plated tungsten wire of $31\,\mu$m diameter. With the wall kept at a voltage of -1.5 kV and the wire at ground potential, each tube acts as a small proportional counter. The tubes are filled with a gas mixture of 70 % Xe, 27 % CO_2, and 3 % O_2.

The TRT barrel region contains 52 544 straw tubes of 1.5 m length, parallel to the beam axis. They cover a radius from 0.5 m to 1.1 m and a pseudorapidity range of $|\eta| < 1$. The central wires are electrically split and read out at both ends of the straw. The endcaps contain radial 0.4 m long straws that are arranged perpendicular to the beam axis. Each side consists of 122 880 straws, covering the geometrical range $0.8\,\text{m} < |z| < 2.7\,\text{m}$ and $1 < |\eta| < 2$. The endcap straws are read out at their outer end.

When a charged particle traverses the TRT, it ionises the gas inside the straws. The resulting free electrons drift towards the wire where they are amplified and read out. The front-end electronics sample the incoming signal in 24 time bins of 3.12 ns and compare it against a threshold corresponding to 300 eV, resulting in a 24-bit pattern that gets buffered in a digital pipeline and then passed on to the central ATLAS data acquisition.

The spaces between the straws are filled with polymer fibres (barrel) and foils (endcaps) to create transition radiation, which may be emitted by highly relativistic charged particles as they traverse a material boundary. This effect depends on the relativistic factor $\gamma = E/m$ and is strongest for electrons. Typical photon energies are 5–30 keV. These soft X-rays can be absorbed by Xe atoms, depositing additional energy in the gas and leading to significantly higher readout signals. Such signals are detected by comparing them against an additional high threshold of 6 keV that is sampled in three 25-ns time bins alongside the pattern described before.

This design makes the TRT complementary to the silicon-based tracking devices: the single-point resolution of $120\,\mu$m is larger than that of the silicon trackers, but this is compensated by the large number of hits per track (typically more than 30) and the long lever arm.

3. Tracking Performance

The TRT readout data merely contains time information, which needs to be calibrated to be useful for tracking.[2] The first step is the T_0 calibration, defining the offset between the start of the readout and the arrival of par-

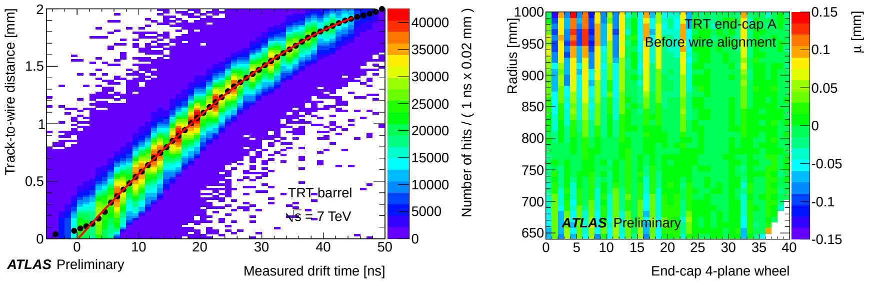

Fig. 1. Left: The $R(t)$ relation for the TRT barrel. The line shows the relation that is used to determine the drift distance based on the measured drift time. Right: Mean of a Gaussian fit to the TRT track residuals vs. radius and wheel before the wire-by-wire alignment.

ticles. It accounts for the time of flight, the signal propagation, and clock offsets. Its results are subject to small daily variations on the level of 100 ps, which are mainly caused by a drift of the central ATLAS clock.

The $R(t)$ calibration relates the measured drift time with a particle's distance of closest approach to the readout wire. It depends on the properties of the active gas (mixture, pressure, temperature), the voltage that is applied to the tube, and the magnetic field. The $R(t)$ relation is modelled by a third-order polynomial, as shown in Fig. 1, left. The resulting coefficients turn out to be very stable on the time scale of months. This is due to the TRT's "Gas Gain Stabilization System", which automatically adjusts the applied voltages to compensate for small variations of the other gas parameters, and also a precise monitoring of the composition of the gas mixture.

A key ingredient for maximum tracking performance is the alignment of all detector elements.[3] Figure 1, right, shows the spatial distribution of the Gaussian mean of the track residuals—the visible structures are apparently caused by a misalignment of some detector modules and a structure deformation. Such effects are cured by a track-based wire-by-wire alignment after which the distribution in Fig. 1, right, becomes nearly uniform.

This improvement is also reflected in Fig. 2: using the latest alignment data of autumn 2010, residual widths of 118 μm and 132 μm can be achieved for the barrel and endcap regions respectively, applying a cut of $p_T > 15\,\mathrm{GeV}$. Providing an average of 30 such position measurements, the TRT contributes significantly to the tracking performance of the Inner Detector as a whole, particularly at high p_T.

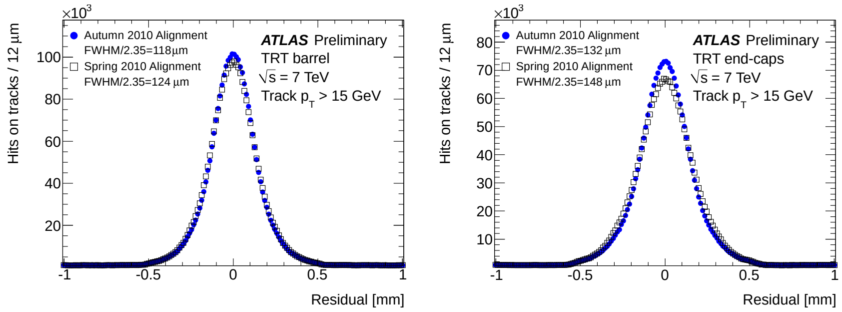

Fig. 2. Unbiased tracking residual distributions for the TRT barrel (left) and endcaps (right), comparing the alignment of spring 2010 (open squares) with that of autumn 2010 (solid circles).

4. Particle Identification Performance

The fact that the emission of transition radiation is much more likely for an electron than for a pion of the same momentum can be used to discriminate these particle types.[4] Figure 3, left, shows the high-threshold turn-on curve, i. e. the probability of getting a high-threshold hit as a function of a particle's relativistic γ factor. This probability is low for pions over a large momentum range (and almost entirely due to Landau fluctuations), but it rises quickly for electrons with momenta of only few GeV. This allows electron–hadron discrimination up to energies of 150 GeV.

Another source of information is the time over threshold (ToT), i. e. the number of time bins for which a readout signal exceeds the (low) threshold. This quantity depends on the particle's specific energy loss dE/dx, which in turn depends on the relativistic velocity β according to the Bethe–Bloch law. The combination of high-threshold and ToT information is shown in Fig. 3, right, which displays the pion misidentification probability as a function of momentum. One can see that the ToT is particularly helpful for low momenta, where the high-threshold turn-on curve is still rising.

5. Heavy-Ion Collisions

Heavy ions are a demanding challenge for the TRT: they yield thousands of tracks and average occupancies around 50 %, peaking at values up to 90 % for the most central collisions. The TRT readout electronics needed to employ lossless data compression to handle the enormous event data sizes, and the Inner Detector tracking and reconstruction software had to be adapted to cope with high-occupancy events.

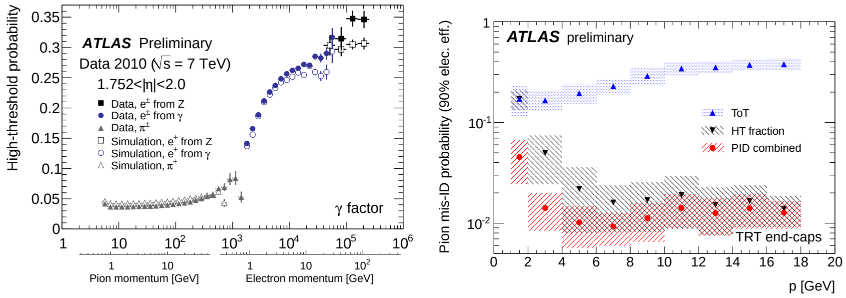

Fig. 3. Left: The high-threshold turn-on curve, shown for the outer endcap wheels. Right: The pion misidentification probability for selection criteria that give 90 % electron efficiency.

It turns out that the TRT is able to improve the track finding and the momentum resolution of the overall tracking system also for heavy-ion collisions: tracking studies show that the TRT still contributes an average of more than 30 hits per track over almost the entire covered η range. This is also a promising prospect for the conditions that will be encountered as the LHC delivers higher and higher luminosities in the future.

6. Summary

The ATLAS TRT provides tracking and identification of charged particles. With the latest alignment and calibration constants, spatial residuals of $118\,\mu$m (barrel) and $132\,\mu$m (endcaps) can be achieved. The TRT improves the overall momentum resolution of the Inner Detector, and by using its unique feature of transition radiation it contributes significantly to electron identification and background rejection. The experience gained from heavy-ion collisions shows that the TRT is ready for the high occupancies that have to be expected as the LHC's luminosity increases further.

References

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