

# DRIFT CIRCLE ERROR CALIBRATION IN THE TRT DETECTOR\*

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The Transition Radiation Tracker (TRT) is the outermost part of the ATLAS Inner Detector and its main purpose is improving momentum resolution of charged particles by providing measurements at large radial distances. In the TRT, the particle position is inferred from the time at which the ionisation signal reaches the wire located at the centre of the straw. This drift time measurement is translated into a one-dimensional spatial constraint — a circle around the wire, referred to as the drift circle. The uncertainty of the drift circle measurement (*drift circle error*) is determined from the distribution of unbiased residuals, which depends on the drift time and on the position of the straw within the detector, and must be periodically updated to account for changing detector conditions. This work presents the latest Run 3 calibration performed using 2024 data with muon tracks at low pile-up, as well as the evaluation of the detector performance after the calibration. The results show an improvement in the region of high local detector occupancy.

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## 1. Introduction

The Transition Radiation Tracker (TRT) is one of the sub-systems of the ATLAS Inner Detector (ID) responsible for the reconstruction of charged-particle trajectories [1]. Starting from the interaction point, the Inner Detector is composed of the silicon Pixel Detector, followed by the silicon strip Semiconductor Tracker, and complemented by the gaseous TRT detector.

The TRT consists of 298,304 straw tubes filled with a xenon- or argon-based gas mixture [2]. In the central barrel region, the straws are aligned parallel to the beam axis and form three concentric layers (figure 1) on both the positive and negative pseudorapidity sides. Further from the centre

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along the beam direction, the straws are oriented perpendicular to the beam and point radially outward. These straws are grouped into 14 endcap wheels on each side of the detector: the positive pseudorapidity side (side A) and the negative pseudorapidity side (side C). Figure 1 additionally shows the active gas mixtures used in different parts of the detector and their evolution between Run 2 and Run 3.

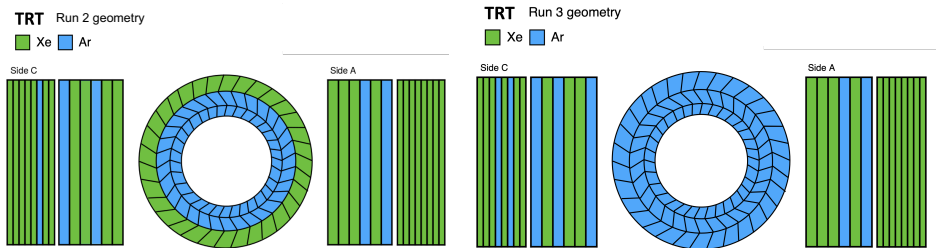


Fig. 1. TRT gas configuration during Run 2 (left) and Run 3 (right) LHC data-taking. The central rings represent the barrel, while the stripes represent the endcaps. The green layers are the layers filled with a xenon-based mixture and the blue layers are filled with an argon-based mixture.

Each TRT straw operates as a drift chamber. When a charged particle traverses the detector, it ionises the gas inside the straw and the resulting electrons drift towards the wire located at the centre of the straw. The particle position is determined from the arrival time of the ionisation signal at the central wire. This drift time is converted into a radial distance from the wire, defining the radius of the so-called *drift circle*, which represents a single hit in the TRT detector (figure 2) [3]. The reconstruction of charged-particle trajectories begins with measurements in the silicon detectors and, when possible, the tracks are extended into the TRT. Including TRT information improves the resolution of the transverse momentum,  $p_T$ , measurement [4]. Reliable TRT track extensions require that at least 30% of the associated hits are classified as *precision hits*. As illustrated in figure 2, a precision hit is defined as a hit for which the distance between the reconstructed track trajectory and the drift circle is within  $\pm 1.75$  times the corresponding drift circle uncertainty (drift circle error).

The drift circle measurement uncertainties are determined from the width of the distribution of unbiased residuals, defined as the distance between the reconstructed track position and the drift circle measurement, where *unbiased* indicates that the considered hit is excluded from the track fit. The drift circle errors are evaluated separately for different detector elements (barrel modules and endcap wheels) and for several drift-time intervals, reflecting the dependence of the timing resolution on drift time [2]. As detector

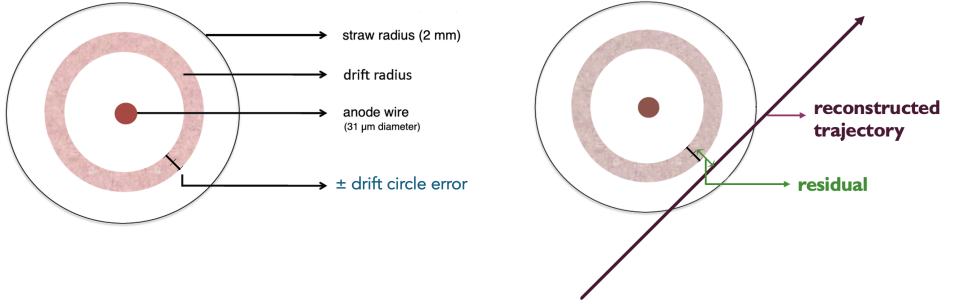


Fig. 2. Geometry of the straw in the TRT detector. The small red circle in the middle represents the anode wire that collects the drifting electrons produced during ionisation in the straw. The light red ring represents the drift circle together with its uncertainty (error). The radius of the circle corresponds to the distance travelled by the electrons. The residual is the distance between the drift circle and the reconstructed trajectory.

conditions evolve, these uncertainties must be regularly updated to ensure an accurate description of the measurement response. This work presents the calibration procedure and its impact on the detector performance.

## 2. Drift circle error calibration

During Run 3, the Large Hadron Collider operates at increased collision energy and luminosity compared to previous runs, enabling both precision measurements of Standard Model processes and searches for New Physics phenomena. The average number of interactions per bunch crossing,  $\langle\mu\rangle$ , is typically in the range of 40–60, corresponding to a high occupancy in the TRT detector that can lead to artificially broadened residual distributions.

The drift circle error calibration is therefore performed using a data sample with a low average number of proton–proton interactions per bunch crossing. This sample is obtained from the so-called *pp reference* data recorded for heavy-ion studies at a centre-of-mass energy of  $\sqrt{s} = 5.36$  TeV. To select a sample of well-measured tracks, the tag-and-probe method is employed using muon pairs originating from the  $Z \rightarrow \mu^- \mu^+$  decays. Tight identification criteria are applied to the tag muons, while probe tracks are selected by requiring that the tag–probe pair forms an invariant mass consistent with the  $Z$  boson resonance.

For the calibration, the detector is divided into 34 layers (3 barrel layers and 14 endcap layers on each side as shown in figure 1) and 18 drift time bins. For each layer and drift time bin, the residual distribution is obtained

and then fitted with a Gaussian function, using the iterative algorithm. The width ( $\sigma$ ) of the distribution gives the drift circle error. The procedure is repeated for every layer and every drift time bin to create a “map” of drift circle error values. Figure 3 presents the visualisation of such a map as well as the example residual distribution with a Gaussian fit function, obtained in the  $\sqrt{s} = 13.6$  TeV  $pp$  data.

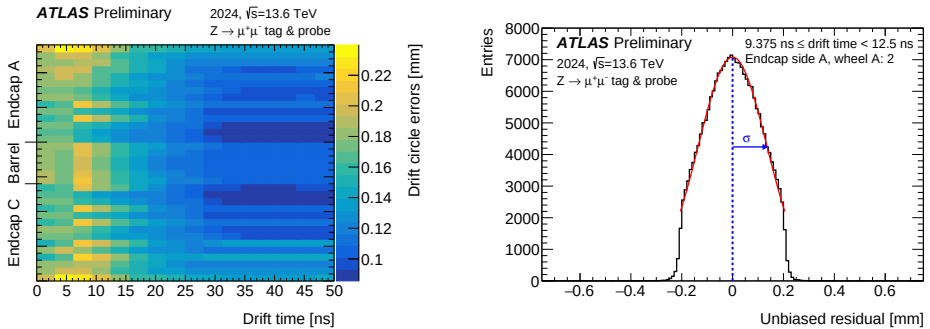


Fig. 3. TRT drift circle measurement uncertainty distribution for the data divided into detector layers and drift time bins (left) and the example of the drift circle unbiased residual distribution for one of the endcap layers and one of the drift time bins with a Gaussian fit function (right). The  $\sigma$  of the Gaussian fit represents the drift circle uncertainty.

### 3. Detector performance

The performance of the detector after the drift circle errors calibration was evaluated on a sample recorded during beam condition of typical proton–proton collisions (high  $\langle\mu\rangle$ ).

The 2024 data sample recorded at  $\sqrt{s} = 13.6$  TeV in 2024 and corresponding to  $6.1 \text{ fb}^{-1}$  was used. The muon tracks originating from the  $Z \rightarrow \mu^- \mu^+$  decays were again selected using tag-and-probe method, with additional  $p_T \geq 20$  GeV requirement. The sample was first processed with Run 2 uncertainties and later with Run 3 uncertainties applied.

The Run 3 drift circle errors result in the general increase in the  $\sigma$  of the unbiased residual distribution, which is presented as a function of  $p_T$  and track occupancy in figure 4. The track occupancy is a variable used to measure the local detector occupancy and is defined as a fraction of the straws with a valid drift time measurement in the detector modules surrounding the track. It is highly correlated with the number of proton–proton interactions. Regions with high track occupancy characterize with a high percentage of TRT straws recording signal, making the trajectory

reconstruction more difficult. This results in a decrease of the quality of the hits, which is represented by the fraction of precision hits on a trajectory (*precision hit fraction*). Following the calibration, the precision hit fraction shows a small increase, especially in the region of high track occupancy (figure 5).

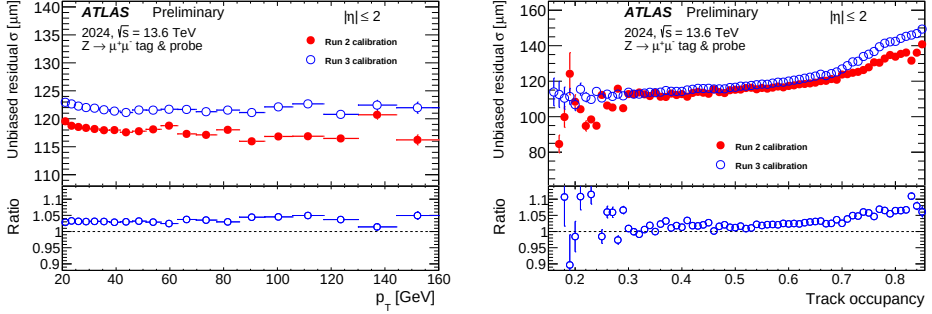


Fig. 4. The  $\sigma$  of the Gaussian fit function of drift circle unbiased residual distribution as a function of  $p_T$  (left) and local detector occupancy around the track (*track occupancy*) (right).

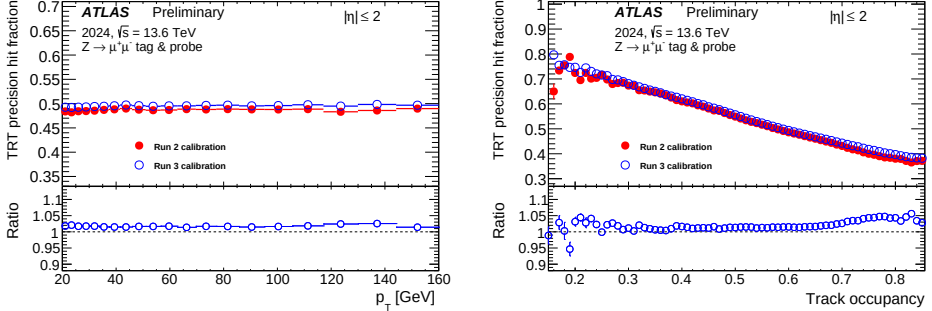


Fig. 5. The TRT precision hit fraction as a function of  $p_T$  (left) and local detector occupancy around the track (*track occupancy*) (right).

Higher number of precision hits leads to more tracks being extended in the TRT, which is represented by the TRT track extension fraction. It is calculated as the ratio of the tracks that have been successfully provided with the TRT extension to all the tracks. The results presented in figure 6 show that Run 3 calibration improved the track extension fraction for the particles in the whole examined  $p_T$  range. Similarly to the precision hit fraction, the change is the most prominent in the region of high local detector occupancy around the track.

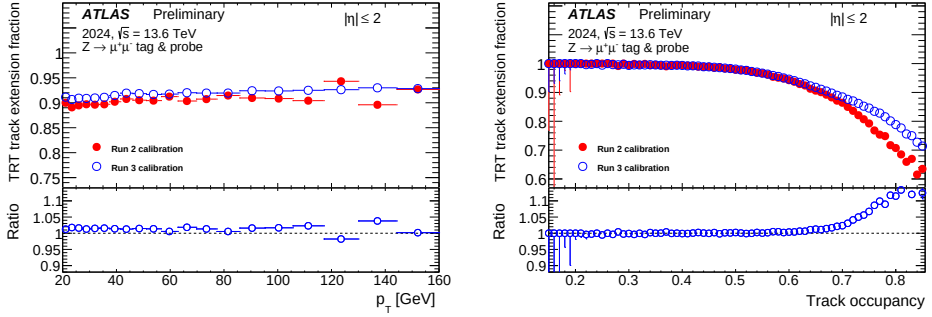


Fig. 6. The TRT track extension fraction as a function of  $p_T$  (left) and local detector occupancy around the track (*track occupancy*) (right).

#### 4. Summary

The Transition Radiation Tracker provides the extension to the reconstructed trajectories, which improve the transverse momentum measurements. The drift circle is the figure representing the position measurement in the TRT detector. The uncertainties of the measurement (drift circle errors) determine which TRT hits are classified as precision hits and result in the track extension.

The calibration of the drift circle errors was performed using Run 3 data with muon tracks originating from  $Z$ -boson decays in a low number of proton–proton collisions per bunch crossing. Subsequently, the detector performance in the standard proton–proton collisions was evaluated. The calibration caused the increase of the drift circle residuals, comparing to the Run 2 uncertainties. This results in an increase in both the precision hit fraction and the track extension fraction, especially in regions of high track occupancy.

#### REFERENCES

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