ATLAS Note

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TRT dE/dx optimization

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A general TRT variable to measure dE/dx using Time-Over-Threshold has been optimized for different gas mixtures. Two definitions of Time-Over-Threshold were introduced for high occupancies. Tools data base was expanded in three times to store Xe/Ar/Kr corrections separately for data and Monte Carlo. New ToT scale function to the Xenon values was developed. TRT dE/dx ATHENA tool have been updated and successfully integrated to the 21st release.

Contents

1 Introduction

In the design of the Transition Radiation Tracker (TRT) two concepts were combined: A tracking measurement via hit position information and particle identification via effects of transition radiation. Many in-depth studies have been performed to determine a measure for the specific energy loss per track length (dE/dx) of a particle traversing the detector using TRT Time-Over-Threshold measurements (see [1], [2] and [3]). Finally a general TRT variable to measure dE/dx using Time-Over-Threshold was been developed in 2012 and implemented in the Athena package called TRT_ToT_Tools. A complete description of this tool could be found in [4].

During Run 2 the TRT gas geometry has been changed. Several Barrel layers and Endcap wheels have been filled by an Argon-based gas mixture. As well, switching to the new gas mixtures is expected for other TRT detector layers in the future. TRT dE/dx tools need to be developed to take into consideration the different ToT for the new gas mixture, as well as supporting various Xe/Ar/Kr gas geometries. More over, LHC is going to have higher luminosity. This is additional challenge for TRT dE/dx tools.

This paper is organized as follows.
Section 2 contains data and event selection used for this studies. The TRT dE/dx estimator quality overview for low $<\mu>$ for previous version is shown in Section 3 concepts of new corrections are introduced to fix TRT gas geometry evolution issue. Section 4 contains description of TRT dE/dx tools optimization. New Time-Over-Threshold versions are discussed in Section 5 and validation of new TRT_ToT_Tools tag is presented in Section 6.

2 Data and event selection

Due to the unavailability of Minimum Bias samples and low $<\mu>$ and with large enough statistics, instead xAOD samples with $Z \to ee$ and $Z \to \mu\mu$ trigger selection for Data and $Z \to \mu\mu$ trigger selection for MC was used in this study. It contains approximately 500k events for Data and 8M events for MC. In order to analyse the data samples properly preliminary event selection should be applied at the event level.

Only events with $<\mu> < 20$ were considered, but for several study stages this interval has been sliced. Standard minimum bias track selection has been used, which demands:

- $p_{\mathrm{T}} > 0.5$
- $N_{PixelHits} > 2$
- $N_{SCTHits} > 5$
- $N_{IBLHits} + N_{BLayHits} > 0$
- $|\eta| > 2.5$
- $|d_0| < 1.5$mm
- $|z_0 \sin(\theta)| < 1.5$mm

In addition, a minimum number good TRT hits

- $N_{GoodHits} > 4$

is required in our track selection. These hits have to pass the hit quality cuts

- no tube hits
- $0.01 < r_{track} < 1.9$mm

These dE/dx studies were performed with a standalone RootCore-based package which was created during this qualification task specifically for standalone dE/dx studies. It allows us to test new features, implements additional calibrations and so on without disturbing the current version of Athena-based dE/dx tool. This package can be found in the public Git repository [5].

3 Old TRT_ToT_Tools tag status

The dE/dx estimator as a function of η, φ and the number of hits used in the calculation of dE/dx presented for the old TRT_TOT_Tools-01-00-09 tag for Run 2 is shown in Figure 1. A good variable for dE/dx should be a flat line plotted against these variables. For plots versus φ and number of used hits ((c) - (f)) it is true and the estimator state is satisfactory. But for plots versus η ((a) and (b)) the dE/dx estimator varies signficantly in both Data and Monte Carlo which are also in poor agreement with each other. Reasons for the variability in the Data is that during Run 2 there was gas replacement in certain parts of the TRT detector (see 4), as well as the general degradation of r-S calibrations during the TRT working period; calibration corrections were last updated in 2013.

As introduced in [4], by default r-S calibration parameters are mean values of ToT for each part of TRT detector as a function of drift radius (r). In this case plots 1(a) and 1(b) strongly suggest that work needs to be done on calibration.

In this study, r-S corrections for Argon are prepared including scales to normalize the average Argon dE/dx to the average value seen for Xenon in each TRT region. The problem of how to calculate the ToT estimator per track, which contains hits of different gas mixtures, is addressed by implementing a number of algorithms in TRT_ToT_Tools with a switch to leave the opportunity to select the best one later.

//But since scripts for r-S calibrations extraction and update were lost, as well as the TRT group was close to final 21^{st} //ATHENA release freeze-out and had no time to redevelop it, the group decided to implement

4 New gas geometry

At the end of 2015, the TRT had two Endcap wheels and innermost Barrel layer filled by Argon gas mixture as it shown at Figure 2. In the future there are plans to fill other parts of TRT with Argon and possibly with Krypton. Because of the definition, the TRT dE/dx estimator is very sensitive to r-S corrections (see more in [4]). For this reason it is necessary to inspect the mean ToT in Xenon and Argon in detector regions, investigate differences and implement such a solution that can easily deal with changes in TRT gas configurations during the detector's lifetime.

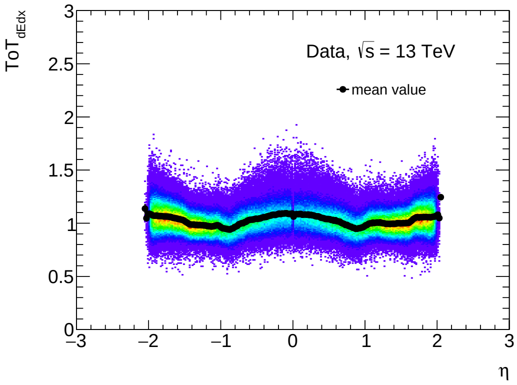
It is well known that the mean ToT value has strong drift radius dependency. A first check of the Barrel and Endcap TRT regions provided results shown in Figure 3(a) for Barrel and Figure 3(b) for Endcaps. Different coloured dots represent ToT distributions for Xenon and Argon gas mixtures, as well as different straw types. Black dots correspond to the ToT distribution in the whole Barrel or Endcap TRT region. In the Barrel, the mean ToT value for Argon gas is higher than for Xenon for long straws and smaller for short straws. In the Endcap the mean ToT value for Argon is significantly smaller than for Xenon. These difference illustrate the requirement for geometry-dependent ToT corrections or recalculation of r-S corrections especially for Argon-based straws. Both corrections have been implemented in the TRT dE/dX tool.

Another sensitive distribution is the relative deviation of the measured ToT from the mean value. This is shown in the R,Z-plane before the corrections in Figure 4(a). The Argon region in the Endcaps layers and innermost Barrel layer are clearly seen.

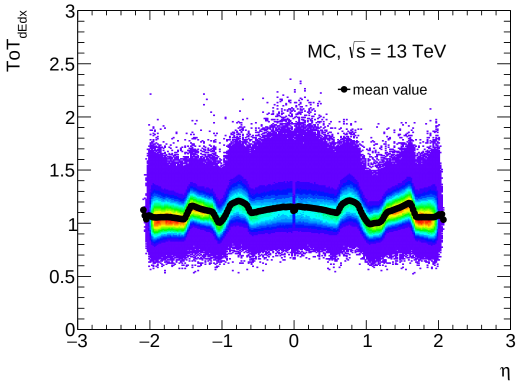
4.1 Normalization of Argon

Since ToT has strong drift radius dependency, it was decided to develop corrections as a function of drift radius (r) as well. For this, the ToT mean values in Argon and Xenon gases need to be parametrized as function of r. Argon ToT values are normalized by calculating correction factors that scale the mean Argon ToT values to those of Xenon in each region of the TRT.

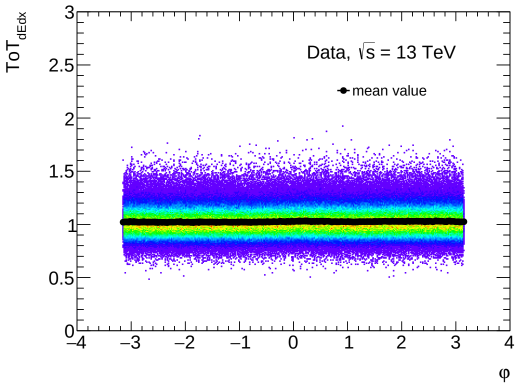
Distributions of Time-Over-Threshold as a function of drift radius are shown on plots 5(a) for Xenon and 5(b) for Argon. They were prepared with the same granularity as r-S corrections.



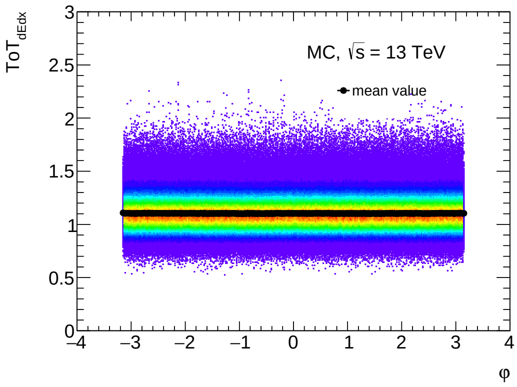
(a) dE/dx^{TOT} vs ϕ in Data.



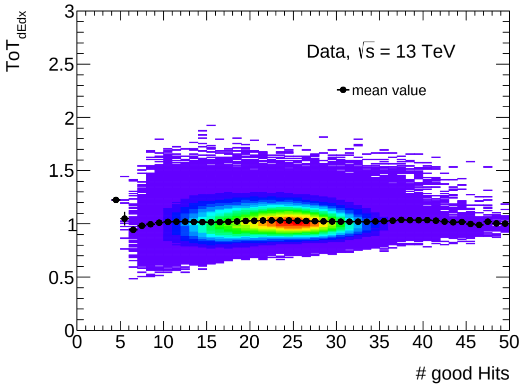
(b) dE/dx^{TOT} vs ϕ in MC.



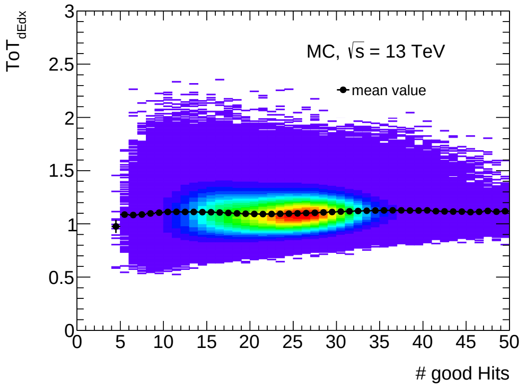
(c) dE/dx^{TOT} vs φ in Data.



(d) dE/dx^{TOT} vs φ in MC.



(e) dE/dx^{TOT} vs N^{hits} in Data.



(f) dE/dx^{TOT} vs N^{hits} in MC.

Figure 1: dE/dx for TRT_ToT_Tools-01-00-09 after all applied corrections plotted against the track η ((a) and (b)), φ ((c) and (d)) and the number of hits used in the calculation of dE/dx ((e) and (f)). The black dots represent the average dE/dx in the corresponding bin.

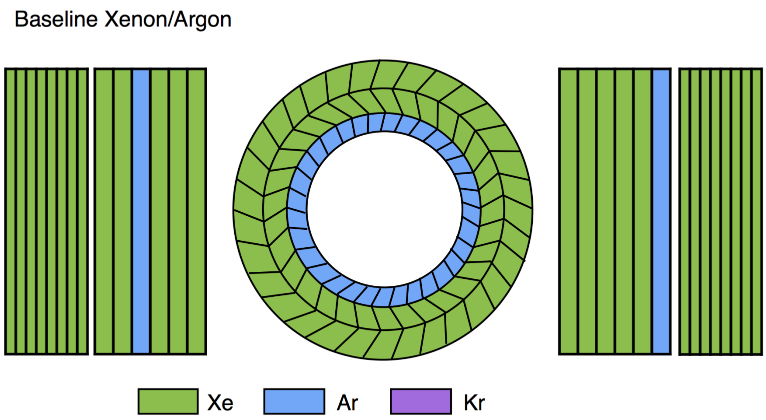
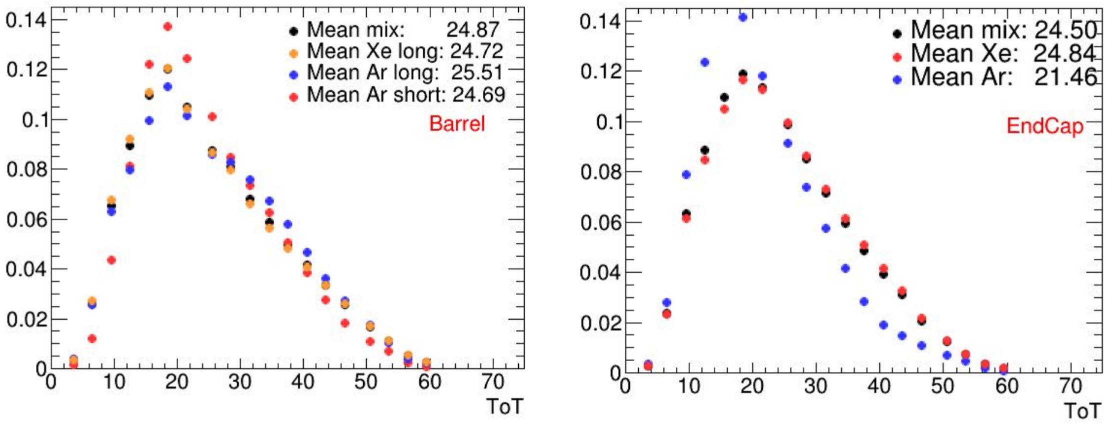


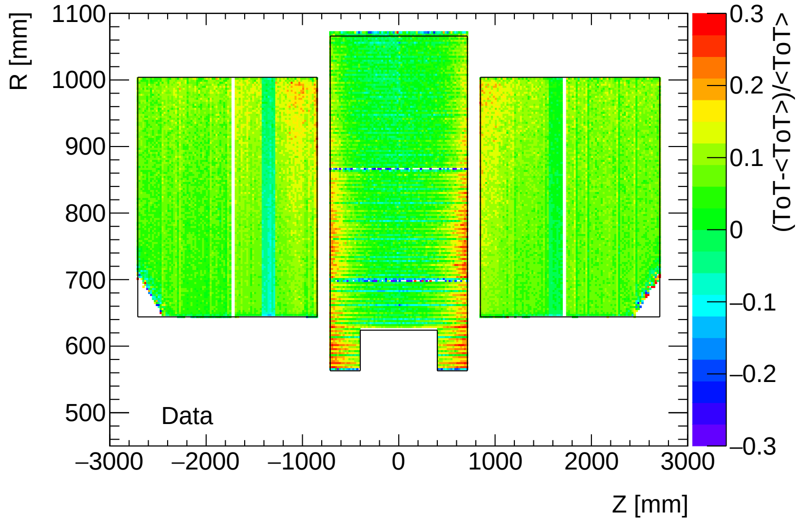
Figure 2: Used during 2015 proton proton data taking, Barrel layer 0 (B0), Endcap side C wheel 3 (EC3), and Endcap side A wheel 5 (EA5) are filled by Argon gas mixture.



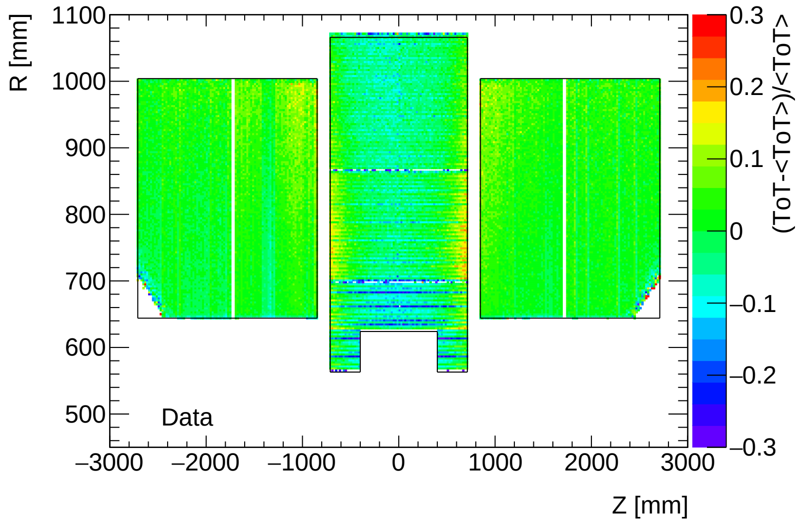
(a) TRT Barrel

(b) TRT Endcap

Figure 3: Time-Over-Threshold distributions calculated by LargerIsland ToT definition for data samples in the TRT Barrel (a) and Endcaps (b). Different gas mixtures and straw types are presented by coloured dots. Black dots represents mean value over hole detectors part.

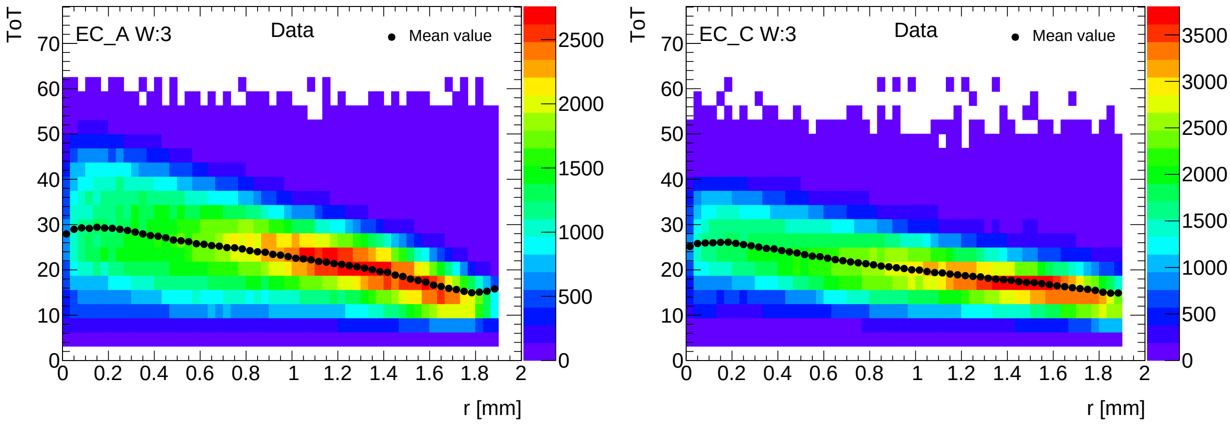


(a) Before correction



(b) After correction

Figure 4: Relative deviation of measured ToT from the mean value before mimic to Xenon correction (a) and after (b) shown in the R,Z-plane.



(a) Xenon

(b) Argon

Figure 5: ToT distributions versus drift radius for Xenon (a) and Argon (b) Endcaps opposite layers. The black dots represent the average ToT in the corresponding bin.

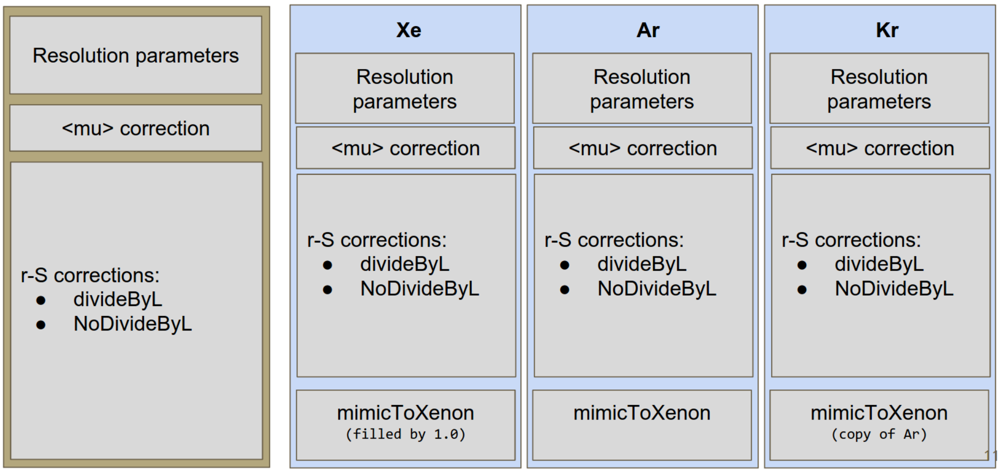
To calculate the normalisation correction factors, wheels from the opposite sides of TRT with different gas mixtures are taken (see Figure 2). For the Barrel, the innermost layer was compared with the middle one. At the beginning a 5th degree polynomial function to parametrize Ar/Xe mean values ratio have been used. This approach in principle is able to reduce the number of correction parameters needed to be uploaded to the database, but tool stress testing shows increasing of the execution time per event. Another approach has been chosen; distributions are sliced into 20 pieces along r from 0 to 2 mm and for each piece the mean ToT value was determined by a Gaussian fit. After that, the ratio of these mean values was calculated and as a result there are 20 correction parameters for each detector part. The ToT Tool database was expanded to store all of these parameters. The result of correction procedure is shown in Figure 4(b). Difference between relative deviation of measured ToT from the mean value before mimic to Xenon correction and after for Endcap layers with Argon is $\sim 8\%$.

4.2 Database

The most technically difficult part from the software point is to deal with gas geometry evolution during the detectors life time. It has been decided to expand the TRT_ToT_Tool database and store r-S corrections and Argon normalization corrections for each gas type independently. Thus the default TRT_ToT_Tools database is increased in size by a factor of three to have access to all necessary parameters for Xenon, Argon and Krypton. This approach allows to use this tool for dE/dx calculations even after applying new TRT gas geometry without a code update. A schematic presentation of the old and new database structures is depicted in Figure 6. For new unknown gas layers tool will take preloaded parameters. Here, parameters are copies of known correction parameters from neighbour TRT parts where the gas already have been changed. However, future developers should keep in mind, that the database should be updated as soon as a new TRT gas geometry will be applied and new data samples will be available.

For Xenon old r-S corrections and resolution parameters have been applied. For Argon normalization, in the case of Xenon hit gas type, all correction values are initialized to be equal 1 to prevent any possibility of an error. All Xenon database parameters were copied to Argon and Krypton database parts. The feature was integrated for database debugging, and it was implemented in the TRT dE/dx tool in the ATHENA. To do so, the header file should be updated and database usage should be switched off. Argon normalization correction parameters are uploaded to the Argon database part and this full Argon database snapshot has been copied to Krypton one. Finally it needs to be mention that new TRT_ToT_Tools version still has backward compatibility with the old database version.

There is a special feature integrated to the TRT_ToT_Tools for database debugging in the TRT dE/dx tool in the ATHENA. To do so, the tool header file should be updated with new database parameters and direct ATHENA database usage should be switched off in the code.



(a) TRT_ToT_Tools-01-00-09 (b) TRT_ToT_Tools-02-00-17

Figure 6: Schematic presentation of database structure related to the TRT_ToT_Tools ATHENA package. Scheme (a) describes database structure for tag 01-00-09 and older versions. Scheme (b) shows how default database have been expanded to deal with different gas geometries.

4.3 Scenarios for TRT_ToT_Tools

The standard TRT dE/dx estimator calculation approach is introduced in [4]. The TRT detector was full with Xenon gas mixture and it was clear how to calculate dE/dx variable for each track. But now it is a normal situation if track has different gas mixture hits. That leads to the question of what is correct way to calculate the dE/dx estimator if track pass several gases. Some ideas have been implemented to the TRT dE/dx tool with a switch to turn the algorithm on:

- Standard dE/dx estimator calculation algorithm: the tool calculates ToT for each hit on track with r-S correction, calculates the number of hits on track, truncates one hit with the largest ToT and returns the ratio $\frac{\sum ToT_{corrected}}{n_{hits}}$ after an additional $<\mu>$ correction. In the TRT_ToT_Tools, the *kAlgStandard* switch turns this algorithm on.
- Same as the previous algrithm, but with a normalization of the mean ToT for Argon or Krypton (see 4.1). In this case, after normalization, we consider Argon or Krypton hit as Xenon and apply corresponding r-S correction. There is also the possibility to turn on this script for all other scenarios additionally using the switch *kAlgScalingToXe*.

- Weighted average algorithm: the tool calculates a dE/dx estimator for each gas track part and then calculates a union estimator. The algorithm removes the highest ToT hit for each gas part of track. The switch is *kAlgReweight*.
- Same as mentioned above, but it removes only one hit on track with the highest ToT even if the track passes more than one gas. The swtich is *kAlgReweightTrunkOne*.

The performance of each algorithm will be studied in the future. A Python job options file have been implemented for the ToT tool. In TRT_ToT_Tools-02-00-20, *kAlgReweightTrunkOne* is set as the default algorithm with additional ToT normalization.

5 Versions of Time-Over-Threshold

The extraction of a Time-Over-Threshold measurement from the low threshold bit pattern can be defined in various ways. In [4] four of them were under consideration and the **TOTLargerIsland** definition was chosen. High $<\mu>$ runs provide a new challenge for TRT dE/dx tools. Due to high occupancy we have a higher probability that more than one particle will pass a given straw during a single event; this distorts the bit pattern. Also, the probability to have holes in the central bit pattern part is smaller in this case. Also it's important to keep in mind that for the high $<\mu>$ runs, the TRT TDAQ introduced a new compression scheme to reduce event size and fix problem with low S-Link bandwidth.
There were suggestions for several new schemes for the Time-Over-Threshold estimators for high $<\mu>$. The TRT dE/dx tool implements the following schemes:

- **TOTLargerIsland** – same as it was done in previous tag. This scheme defines the length of the largest signal island in the bit pattern as the Time-Over-Threshold. This is illustrated in Figure 7(a).
- **TOTHighOccupancy** – this scheme is used as a standard in detector operation today, counts all bits between the first bit that is set (leading edge) and the last bit set (trailing edge), but for leading edge and trailing edge gates are defnied in the bit pattern: For leading edge it is required to find a 0 to 1 transition in the range from second bit to the 18'th, while search is going from the beginning. For trailing edge the gate is installed from the 20'th to the 9'th bit and the search starts from the end of bit pattern. This is depicted in Figure 7(b).
- **TOTHighOccupancySmart** – same scheme as above, but the search for second trailing edge have been added. This scheme is illustrated in Figure 7(c).

Based on a comparison of dE/dx separation power for high $<\mu>$ events, final Time-Over-Threshold scheme should be selected.

6 Validation of the new TRT_ToT_Tool tag

The TRT_ToT_Tool code has been significantly updated; results of validation checks are given below.

TRT dE/dx^{TOT} estimator stability as a function of η, φ and the number of hits used in the calculation of dE/dx have been checked first. Results are presented on Figure 8. Calculations are performed for the tool configurated as close to old tag as possible using the switches *kAlgReweightTrunkOne* and **TOTLargerIsland**. The Azimuthal distribution is seen to improve (Figure 1(a)). Unfortunately there

High threshold	0								0								0							
Low threshold	0	0	1	1	1	1	1	1	1	1	1	1	0	0	1	1	0	0	1	1	1	1	0	0
Time bins	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

(a) TOTLargerIsland

High threshold	0								0								0							
Low threshold	0	0	1	1	1	1	1	1	1	1	1	1	0	0	1	1	0	0	1	1	1	1	0	0
Time bins	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

(b) TOTHighOccupancy

High threshold	0								0								0							
Low threshold	0	0	1	1	1	1	1	1	1	1	1	1	0	0	1	1	0	0	1	1	1	1	0	0
Time bins	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

(c) TOTHighOccupancySmart

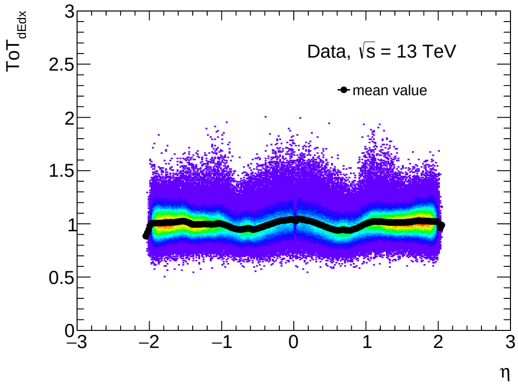
Figure 7: Illustration of the tree different definitions of ToT. The red regions indicate the number of bits counted for the Time-Over-Threshold. For further details see explanation in text.

were problems with hit R,Z-positioning for MC in the TRTxAOD data samples and it wasn't possible to get same distributions for MC.

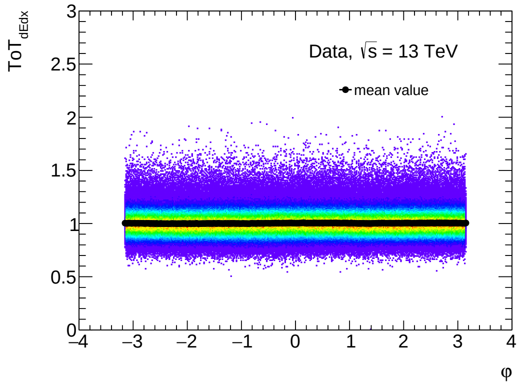
Also an assessment has been made to check how the dE/dx estimator distribution profile has changed after the tool update. Figure 9 compares the new tag 02-00-06 to the old 01-00-09. Some changes are seen due to Argon ToT normalization in the new tag.

7 Conclusion

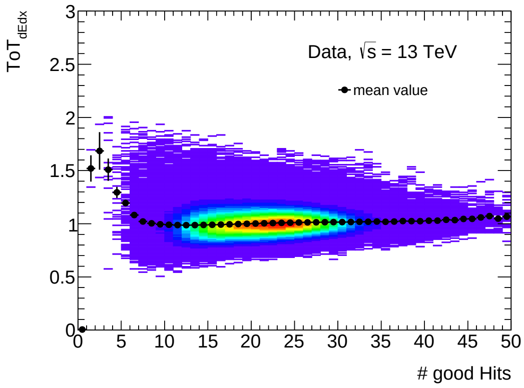
The TRT dE/dx estimator is studied for mixed Xe and Ar tracks and a comparison between data and simulation is made. Based on this, ToT normalization calibration procedure for Argon have been developed and validated. The TRT ToT Tool database has been reorganized and expanded with the possibility to have access to the all gas types correction parameters. Two new definitions of the Time-Over-Threshold estimation from the TRT bit pattern have been introduced for high <μ> events. Special job options files based on Python have been prepared for easier tool control without recompilation. The option to calculate dE/dx estimators using 4 different scenarios is implemented. The tool has been significantly updated in a short time, and successfully passed all required tests and has been integrated to the 21$^{\text{st}}$ ATHENA release as TRT_ToT_Tools-02-00-06.



(a) dE/dx^{TOT} vs η.



(b) dE/dx^{TOT} vs φ.



(c) dE/dx^{TOT} vs N^{hits}.

Figure 8: dE/dx for TRT_ToT_Tools-02-00-06 after all applied corrections plotted against the track η (a), φ (b) and the number of hits used in the calculation of dE/dx (c). The black dots represent the average dE/dx in the corresponding bin.

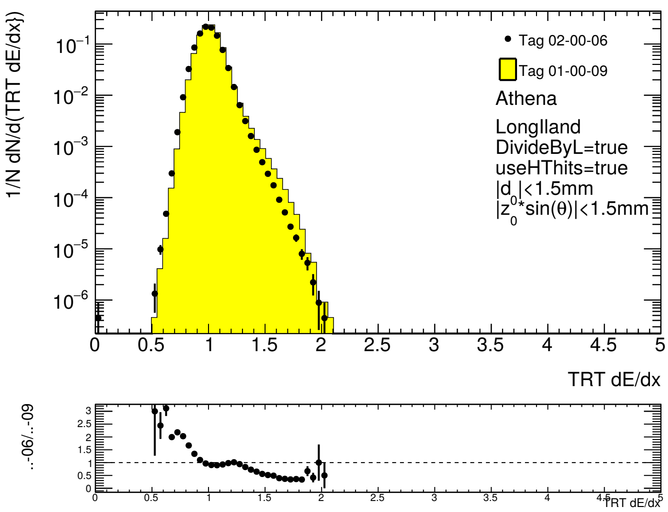


Figure 9: TRT dE/dx^{TOT} estimator distributions for old tag 01-00-09 and new one.

References

[1] C Marino et al., 'Specific Energy Loss Estimators using the ATLAS TRT', tech. rep. ATL-COM-INDET-2010-150, CERN, 2010, URL: https://cds.cern.ch/record/1306792.

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[5] 'Git repository for RootCore-based dE/dx validation package', https://gitlab.cern.ch/dponomar/DEDX_DxAOD_STUDIES.