Using Time over Threshold in conjunction with Transition Radiation to improve Particle Identification in the ATLAS Transition Radiation Detector

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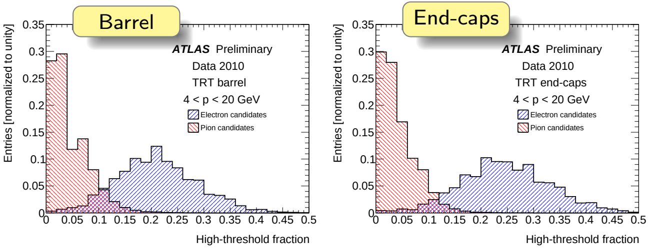
on behalf of the ATLAS collaboration

TRDs for the third millenium - 16/09/2011

Introduction

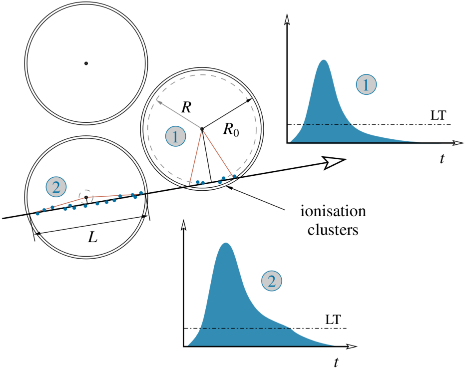
- Particle Identification capability of the ATLAS TRT detector already shown (E. Hines) using Transition Radiation information only. Reminder :



- Aim of this presentation is to show what we can gain using **Time over Threshold** in conjunction with **Transition radiation**

- This presentation mainly focuses on electron-pion separation

ToT and dE/dx



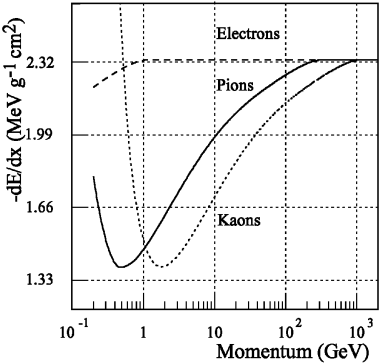
- Measured ToT correlated with the sum of the energy depositions of primary ionization electrons

$$\text{ToT} \propto dE/dx$$

- ToT also dependent on track-to-wire distance, will discuss that later...

ToT and dE/dx

Bethe-Bloch curves for various particles in the ATLAS TRT gas mixture, *from "Particle identification using time-over-threshold method in the ATLAS TRT" T. Akesson et al., Nuclear Instruments and Methods in Physics Research A 474 (2001) 172-187.*



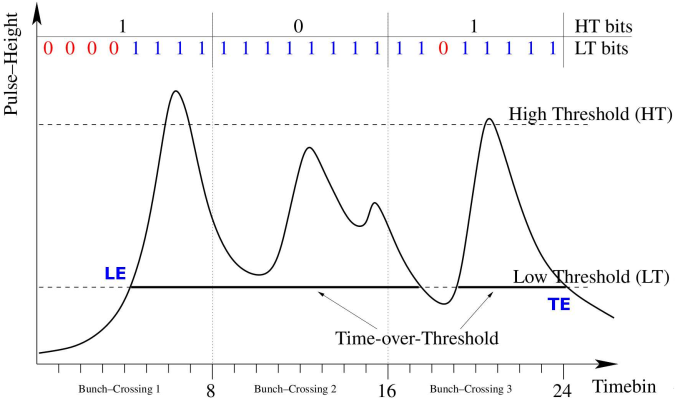
→ In this plot : $70\%\ Xe + 20\%\ CF_4 + 10\%\ CO_2$

→ Currently used : $70\%\ Xe + 27\%\ CO_2 + 3\%\ O_2$

- In ATLAS TRT : Large magnitude of the relativistic rise thanks to the use of Xe
- Measured ToT can be used to better distinguish between electrons and pions based on their expected dE/dx

Time over Threshold (ToT) definition used

- In the following slides :
  ToT is defined as the **number of bits above threshold in the largest single group** of bits above threshold, multiplied by the bin width (14×3.12ns in this example)
  - Similar performance to a method that uses the number of bits above threshold
  - Better performance than a method that uses
    $\text{ToT} = t_{\text{Trailing Edge}} - t_{\text{Leading Edge}}$



ToT and correction

ToT subject to several systematic effects

- track to wire distance (due to drift-time, limited number of ionization clusters)
- signal attenuation
- signal reflection from the end of the wire that is not read out
- signal delay due to the propagation along the wire
- signal shaping

$\longrightarrow$ These effects are taken into account by **corrections** to the ToT at the hit level

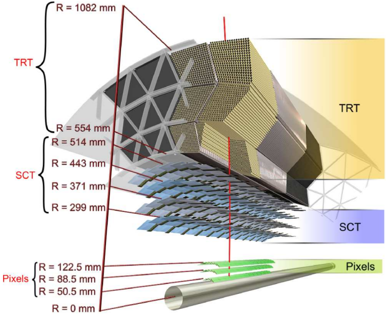
Quite challenging since we have in the ATLAS TRT :

	$\lvert z \rvert_{min}$ (mm)	$\lvert z \rvert_{max}$ (mm)	R_{min} (mm)	R_{max} (mm)	Number of modules	Number of layers	Straws per module
Barrel (both sides)	**0**	**780**	**554**	**1082**	**96**	**73**	**52544**
Type-1 module (inner)	400	712.1	563	624	32	9	329
Type-1 module (outer)	7.5	712.1	625	694		10	
Type-2 module	7.5	712.1	697	860	32	24	520
Type-3 module	7.5	712.1	863	1066	32	30	793
End-cap (one side)	**827**	**2744**	**615**	**1106**	**20**	**160**	**122880**
Type-A wheels	848	1705	644	1004	12	8	6144
Type-B wheels	1740	2710	644	1004	8	8	6144

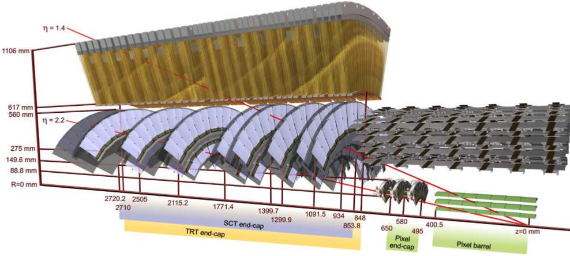
Corrections applied

- **Corrections for** z **dependence in barrel,** R **dependence in end-caps** are applied to ToT at the hit level

Barrel : Straws parallel to the beam axis



End-caps : Straws perpendicular to the beam axis



- To take into account the track to wire distance dependence, the average corrected ToT is divided by the average track-to-wire distance

$$\text{ToT-based variable} = \frac{\sum_{\text{hits on track}} \text{ToT}}{\sum_{\text{hits on track}} \text{d}}$$

Particle candidates selection

- **Electron candidates from photon conversions**
  - 2 tracks with $\left\{ \begin{array}{l} \geq 20 \text{ TRT hits} \\ \geq 4 \text{ Si (SCT and Pixel) hits} \end{array} \right.$
  - conversion vertex required to be well reconstructed (χ^2 cut) and to be ≥ 60 mm away from the primary vertex in the radial direction
  - tag and probe method used :
    $\left\{ \begin{array}{l} \text{tag with HT hit fraction } \geq 0.12 \\ \text{the 2 tracks are treated independently} \\ \text{if both tracks pass the tag requirement, each is also used as a probe} \end{array} \right.$

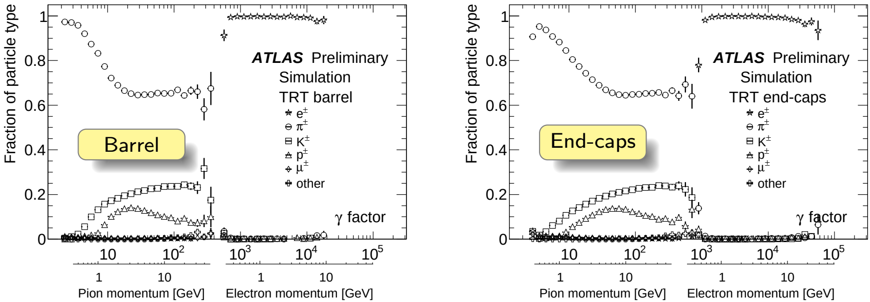
- **Pion candidates from remaining tracks**
  - tracks with $\left\{ \begin{array}{l} \geq 20 \text{ TRT hits} \\ \geq 4 \text{ Si hits} \end{array} \right.$
  - exclude tracks with no innermost Pixel layer
  - exclude tracks which are part of a conversion candidate
  - $dE/dx < 1.6$ g^{-1}cm^2 in the Pixel detector to reduce contamination from protons at low p

Particle candidates selection

- **Purity of the electron candidates sample**

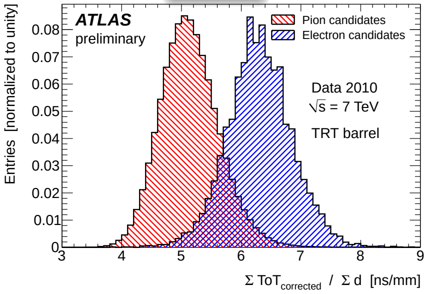
  Contamination from π and other particles :
  - Barrel : 1% for $\gamma < 10^4$, and increases to $\approx 2\%$ at higher γ
  - End-caps : from $< 1\%$ for $\gamma \leq 2 \cdot 10^4$ to 5% at $\gamma \approx 4 \cdot 10^4$

- **Purity of the pion candidates sample**
  - Lower purity but has almost no effect
  - Combining barrel and end-caps : 84% pions, 10% kaons, 5% of protons, $< 0.5\%$ electrons



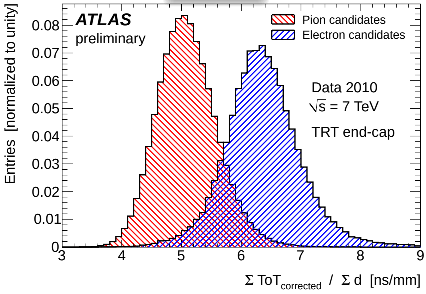
ToT distributions

Barrel



$\langle p \rangle_{\text{electrons}} = 1.8\text{GeV}$
$\langle p \rangle_{\text{pions}} = 1.6\text{GeV}$

End-caps



$\langle p \rangle_{\text{electrons}} = 2.8\text{GeV}$
$\langle p \rangle_{\text{pions}} = 2.2\text{GeV}$

- Arbitrary values for $\sum \text{ToT}/\sum d$, no normalization applied
- We can get further discrimination between electrons and pions using the ToT-based variable
- The TR-based electron-pion separation can be further enhanced through measurements of the ToT, which vary as a function of energy deposition (dE/dx) in the straws

Combining HT and ToT measurements

- 2 likelihood functions are computed from signal and background PDFs :
  - one for HT, L_{HT}
  - one for ToT, L_{ToT}

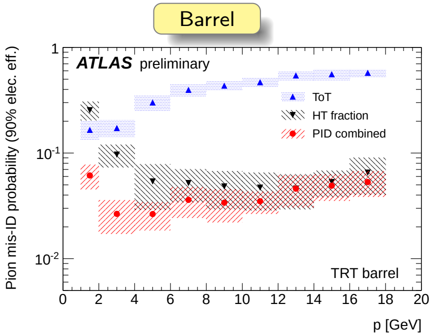
- HT hits are not used to compute ToT based variable

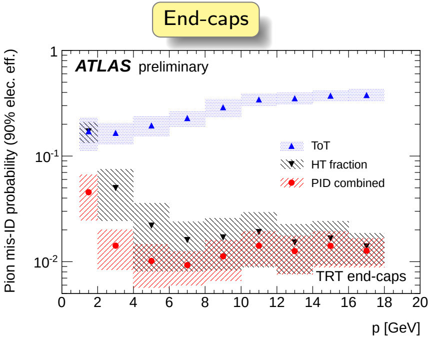
  $\rightarrow$ 2 likelihoods are assumed to be **independent**, so that we can combine them

- **Combined likelihood** :

$$\mathrm{L}_{\mathrm{combined}} = \frac{\prod\limits_{\mathrm{HT,\ ToT}} \mathrm{L}_i}{\prod\limits_{\mathrm{HT,\ ToT}} \mathrm{L}_i + \prod\limits_{\mathrm{HT,\ ToT}} (1 - \mathrm{L}_i)}$$

Results



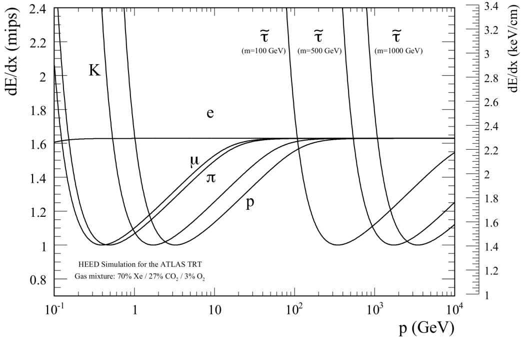


- Uncertainties estimated by varying the selection criteria such that the electron efficiency changed by $\pm 2\%$
- Any contamination of the pion sample with electrons above the TR threshold will systematically bias the estimate of the pion rejection factor by roughly the same amount

ToT-based variable significantly improves the pion rejection at $p < 10$GeV

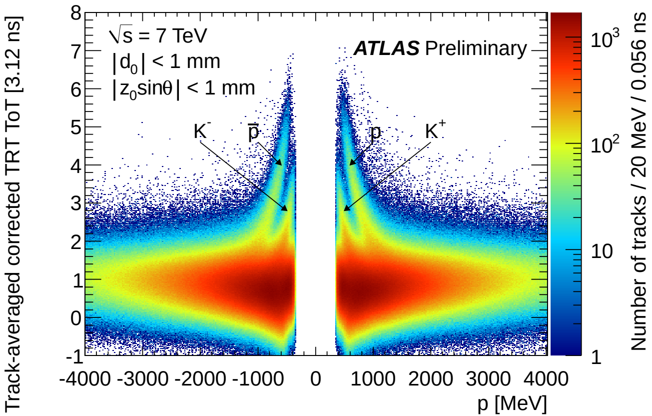
- Use of ToT for $e - \pi$ separation was presented, but...
- This estimator for energy loss based on the ToT can also be used for the identification of highly ionizing stable massive particles

Mean energy loss by ionization of the $Xe - CO_2 - O_2$ gas mixture used inside the ATLAS TRT



ToT and highly ionizing particles

- ToT-based estimator as a function of the track momentum



- The estimator is offset to be equal to 1 for minimum ionizing particles
- The ToT measurement was used for one of the background estimation cross-checks in the ATLAS heavy ionizing stable massive particle search with 2010 data

Search for stable hadronising squarks and gluinos with the ATLAS experiment at the LHC, Phys. Lett. B 701, 1-19 (2011).

Conclusions

- ToT varies as a function of energy deposition (dE/dx) in the straw
- The TR-based $e - \pi$ separation can be further enhanced at momenta $p < 10$ GeV through measurements of the ToT
- Pion mis-ID probability reduced by a factor of up to 4 combining ToT and TR information
- ToT corrected to take into account systematic effects