dE/dx and Time-over-Threshold with the ATLAS Transition Radiation Tracker

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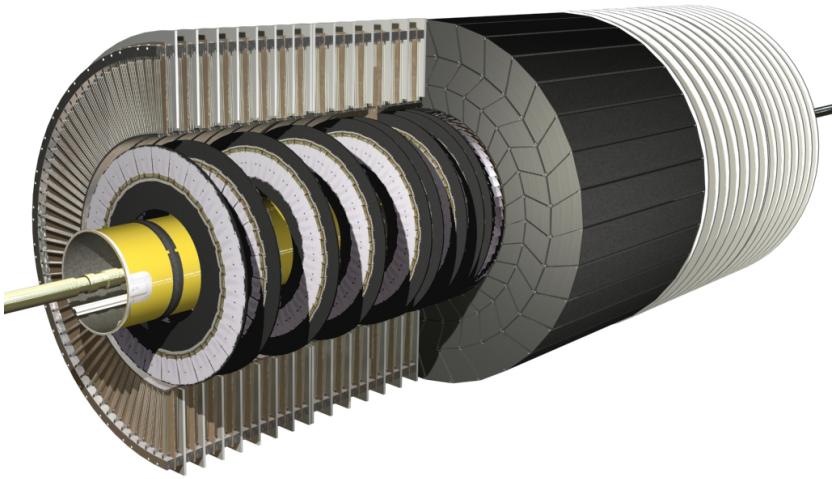
Outline

1. The Transition Radiation Tracker
2. dE/dx and Time-over-Threshold
3. Analysis of Test Beam Data & Simulation
4. Summary and Conclusion

The Transition Radiation Tracker

High-granularity MWPC with transition radiation detection

- $\sim$350000 thin drift tubes $\Rightarrow$ straws with $\varnothing$ 4 mm and 30 μm tungsten wire
- Barrel straws ($\sim$50000) parallel to beam axis, perpendicular and radial in end-cap
- TR for particles with $\gamma \gtrsim 1000 \Rightarrow$ electrons...
- Radiator foils/foam alternated with straws $\Rightarrow$ TR
- TR photons absorbed in Xe(70)/CO_2(27)/O_2(3) gas $\Rightarrow$ larger signal for electrons



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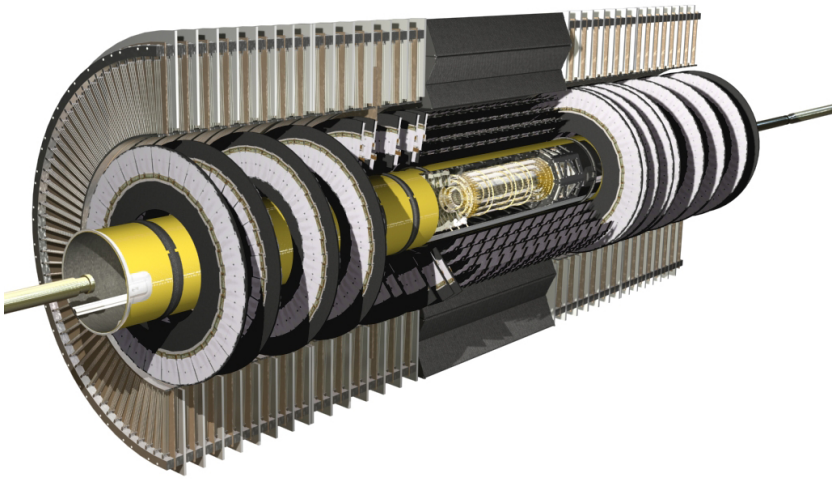
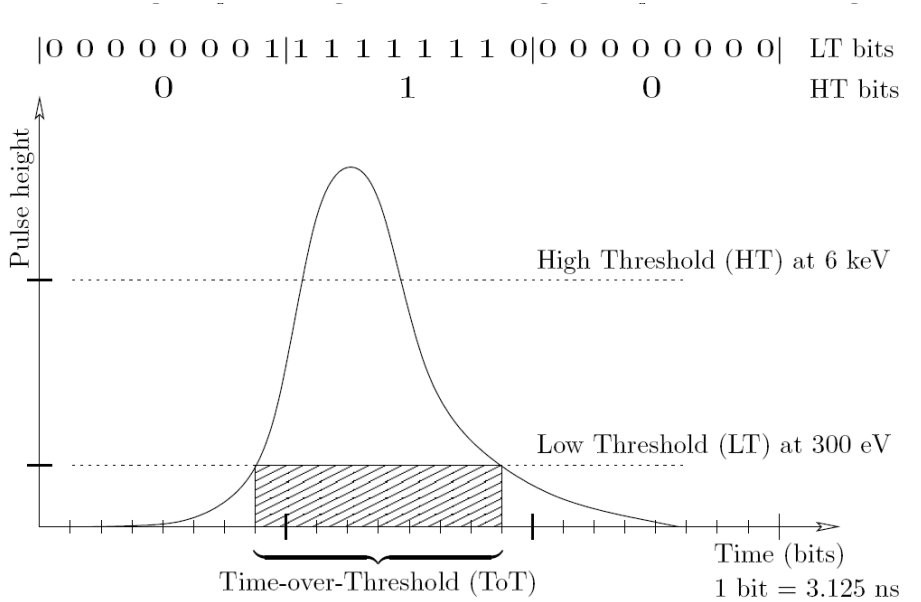


TRT tresholds & Time-over-Threshold

2 thresholds:

- LT(∼300 eV): tracking, Time-over-Threshold
- HT(∼6 keV): transition radiation, e^- – ID



(drawing: S. Mehlhase)

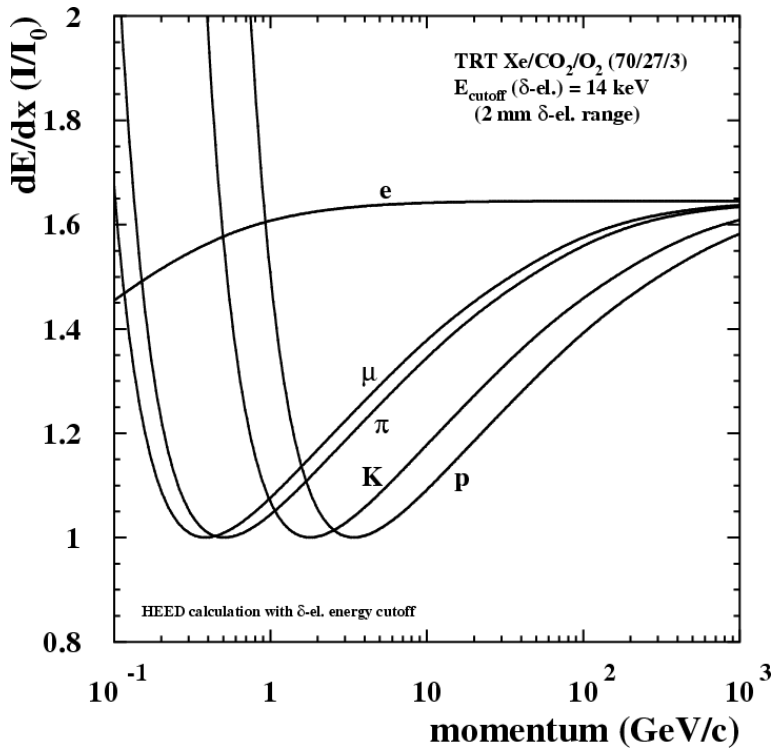
- 24 low-threshold bits × 3.125 ns ⇒ 75 ns total (= 3 BC)
- 3 high-threshold bits for 25 ns each

⇒ ToT corresponds to signal width
pulse height is not recorded!

dE/dx and Time-over-Threshold

- Motivation: enhance ATLAS PID abilities, hips (like stable staus)
- dE/dx usually obtained by pulse height $\Leftrightarrow$ integrated charge relationship
- instead, use relationship ToT $\Leftrightarrow$ pulse height $\Leftrightarrow$ dE

plot: Michael Hauschild



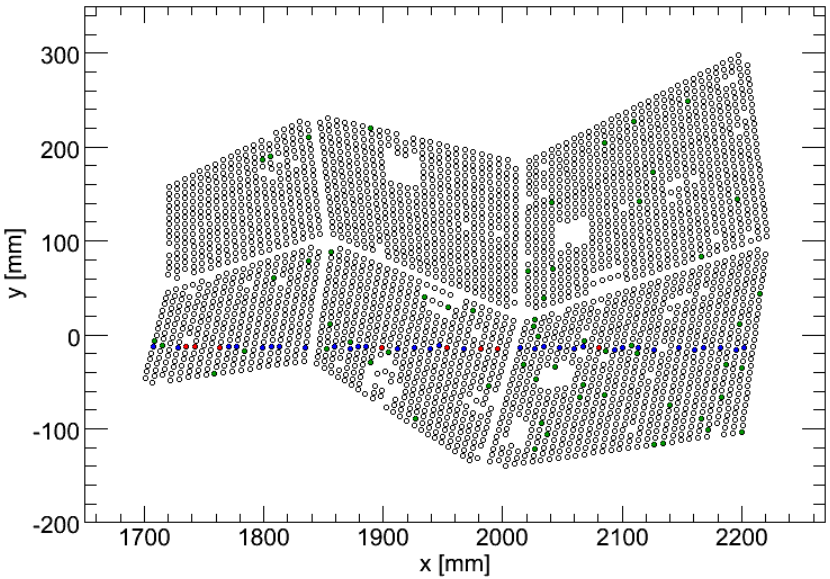
ideal case:

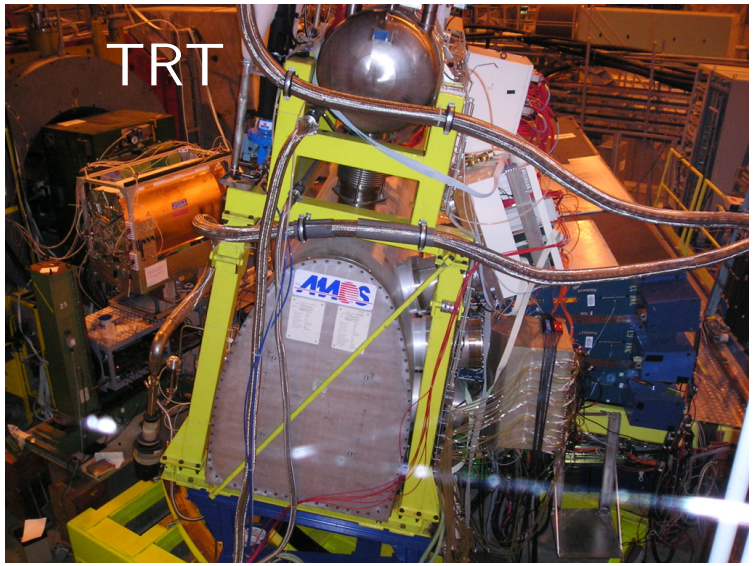
ToT $\sim$ pulse height $\sim$ energy loss

$\Rightarrow$ but non-linearities must be expected

ATLAS Combined Test Beam 2004

- Combined test of all ATLAS sub-detectors, barrel ϕ-slice
- Energies: 1-350 GeV, π, e, μ, B-field and no B-field
- additional PID by Čerenkov, scintillators (muon tag)
- CTB real data and MC reconstruction finished (with T. Petersen, S. Mehlhase). PID with ECAL, HCAL, Cher and muon tag.

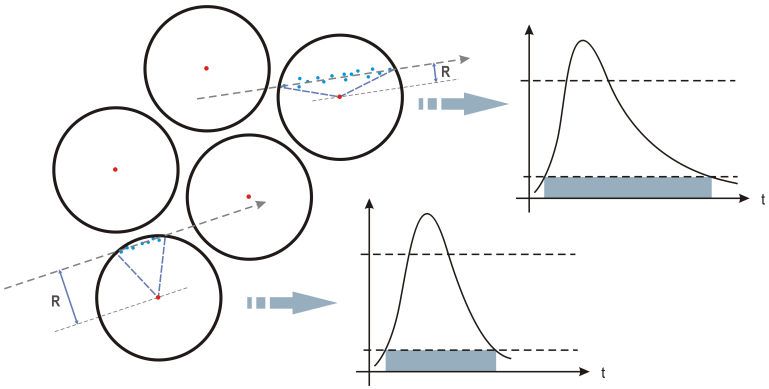




Geometry Dependence of the ToT

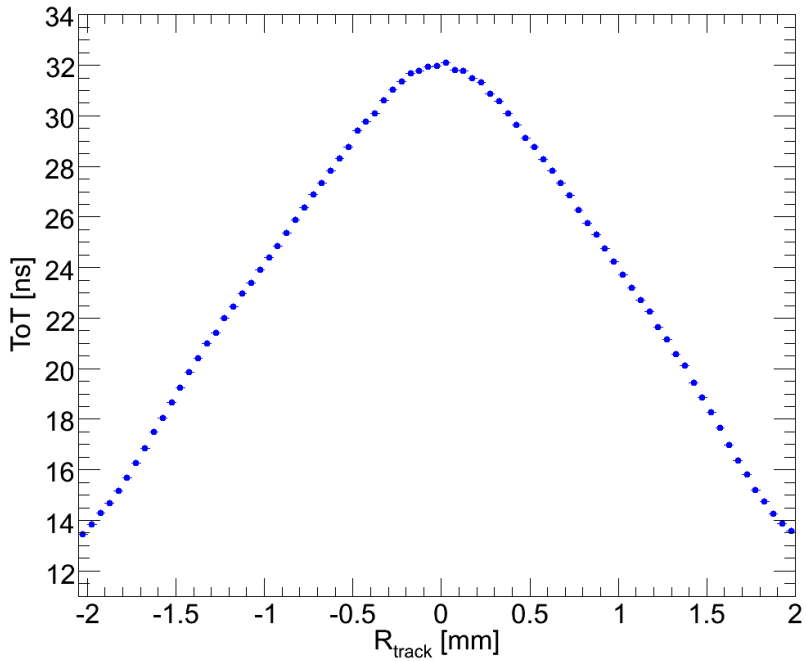
ToT depends on distance from the wire:

- If $\langle \text{ToT} \rangle \sim \langle dE \rangle$, then also $\langle \text{ToT} \rangle \sim L$
  $\Rightarrow$ at least correction $\langle \text{ToT} \rangle / L$, but this is not enough!



$\Rightarrow$ clusters with different drift distances

$\Rightarrow$ arrive shifted in time for large R $\Rightarrow$ broader pulse



$\langle \text{ToT} \rangle$ vs. R_{track}, 9 GeV pions

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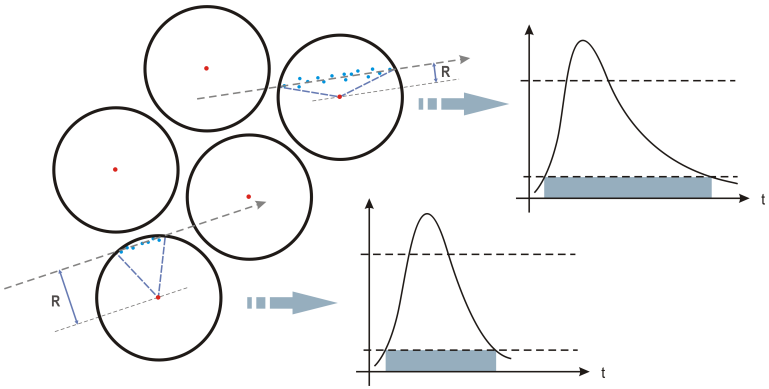

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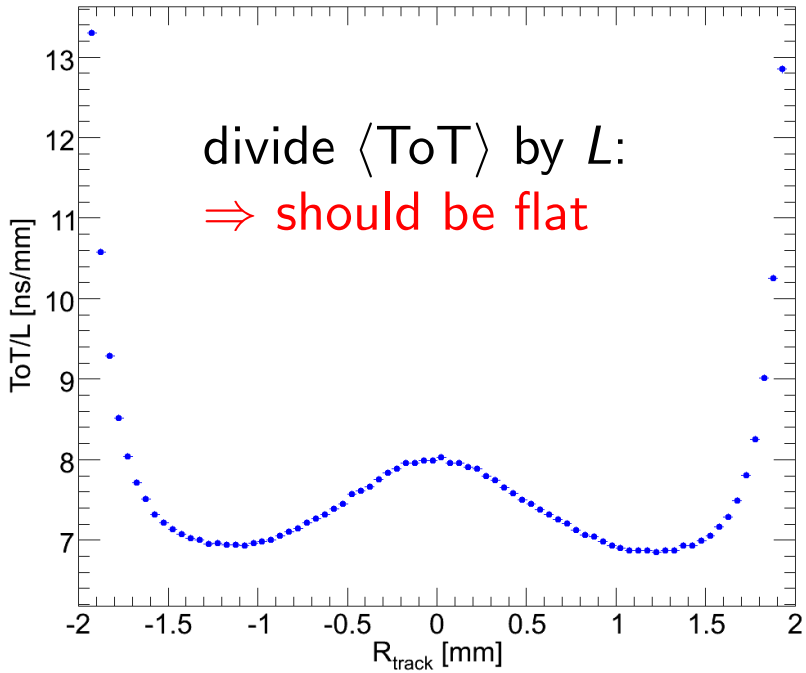
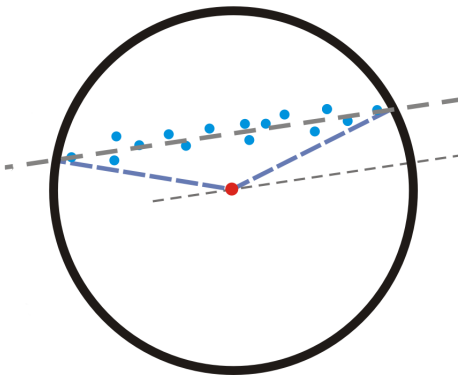


$\langle \text{ToT} \rangle / L$ vs. R_{track}, 9 GeV pions

ToT Studies on Digitisation Level

Essential: $dE \Leftrightarrow$ ToT Relationship. Is $dE \sim L$ correct?

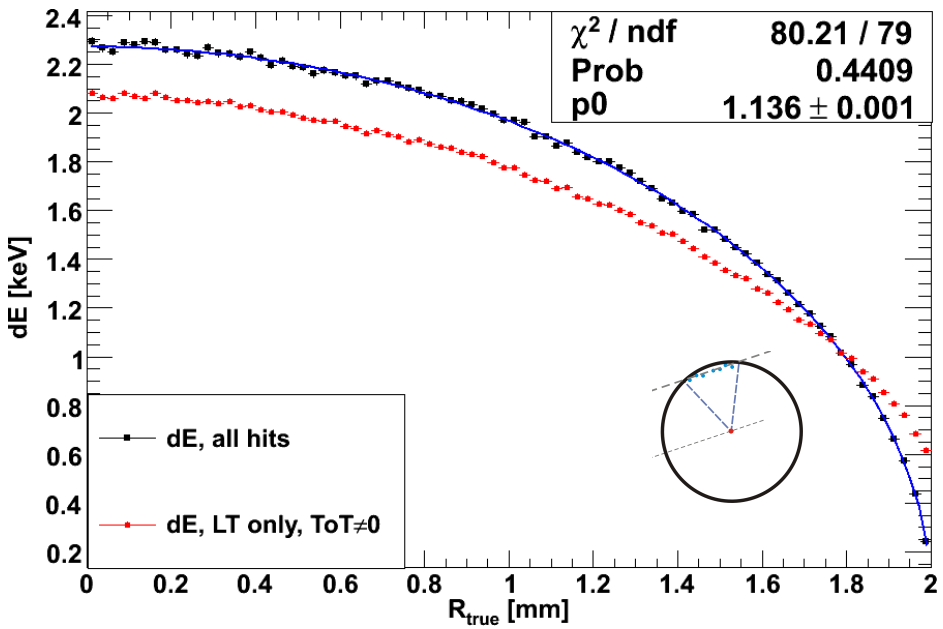
- dE information (and other truth info) cannot be obtained from CTB Monte Carlo ntuples
  $\Rightarrow$ need different approach



- Full TRT simulation was used to create independent straw crossings (no tracks) at different γ for uniformly distributed R_{true}, no TR simulated
- generated ntuples contain ToT, dE, R_{true} etc.
  $\Rightarrow$ digitisation information but no tracking applied

Energy Loss Distribution

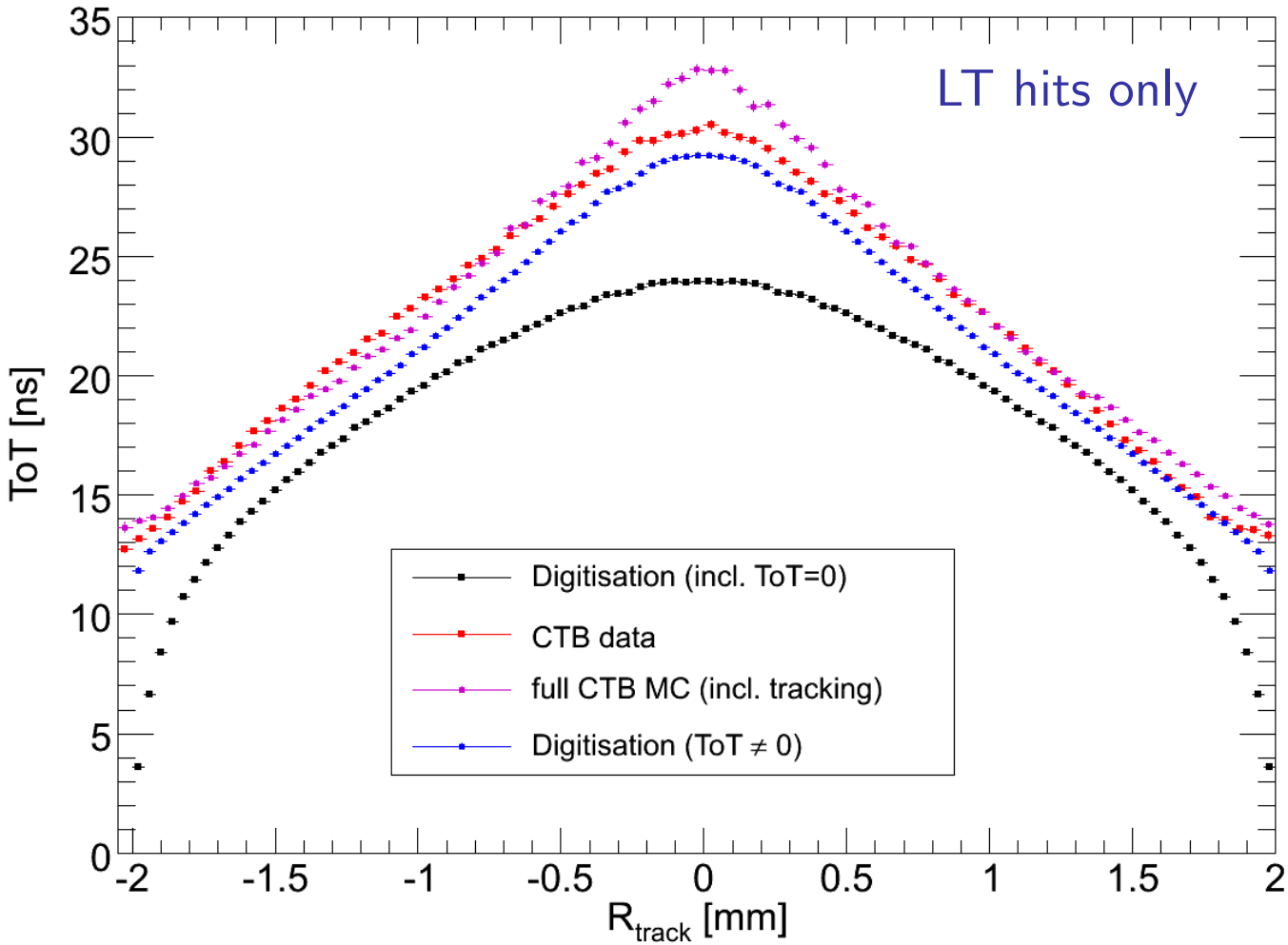
- $dE \sim L \sim \sqrt{R_{straw}^2 - R_{true}^2}$ as expected, if straws with $ToT \neq 0$ and HT-hits (from dE/dx) are included:



$dE(R_{true})$ profiles for pions at 20 GeV

- But: different shape if cut on $ToT > 0$ and LT hits only
- Hits with low dE have higher probability not to cause a signal
  $\Rightarrow$ offset for large R_{true}
- Same effect causes offset of $\langle \text{ToT} \rangle (R_{true})$ distribution

⟨ToT⟩ Distributions



⟨ToT⟩ ($R_{true/track}$) profiles for digitisation stage, MC and data, pions 20 GeV

ToT Geometry Correction

Back to test beam data...

- ToT has to be corrected for geometry, simple approach $ToT \sim L$ proves to be insufficient

$$\langle ToT \rangle \sim \left\langle \frac{dE}{dx} \right\rangle \cdot L(R) \cdot \; g(R) \;\leftarrow \text{some extra function} \neq 1$$

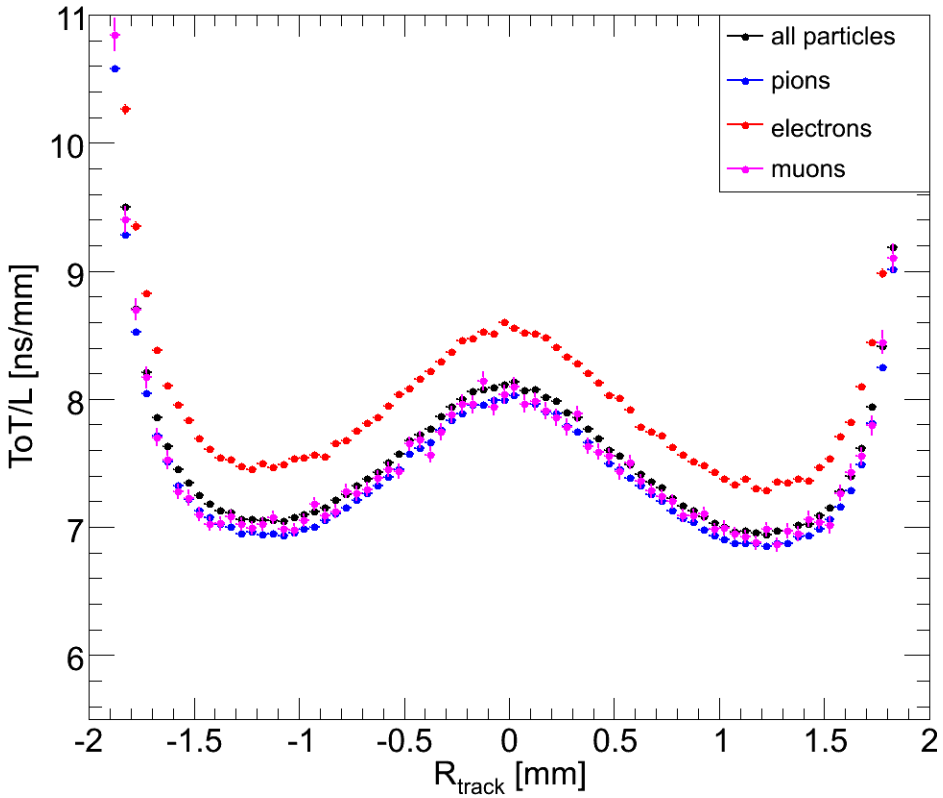
- $\langle ToT \rangle$ can be obtained from data, length $L(R)$ and $\left\langle \frac{dE}{dx} \right\rangle$ are known

$$\Rightarrow g(R) \sim \frac{ToT}{L \left\langle \frac{dE}{dx} \right\rangle}$$

- for different particle types at given E, ToT/L should only be multiplied by a constant corresponding to dE/dx

ToT/L for different particle types

- Curves have a similar shape and are separated, electron above pions, pions near muons, as expected
- But: there are run-by-run variations (probably gas gain)



ToT/L profiles, 9 GeV

- The curves should merge for high Energy (same dE/dx)
  Result: overall tendency ok but some energies/ runs seem problematic
  e.g. still a large $e - \pi$ gap at 180 GeV
- maybe due to proton impurities at $E \geq 20$ GeV
- and: remaining TR for e^-

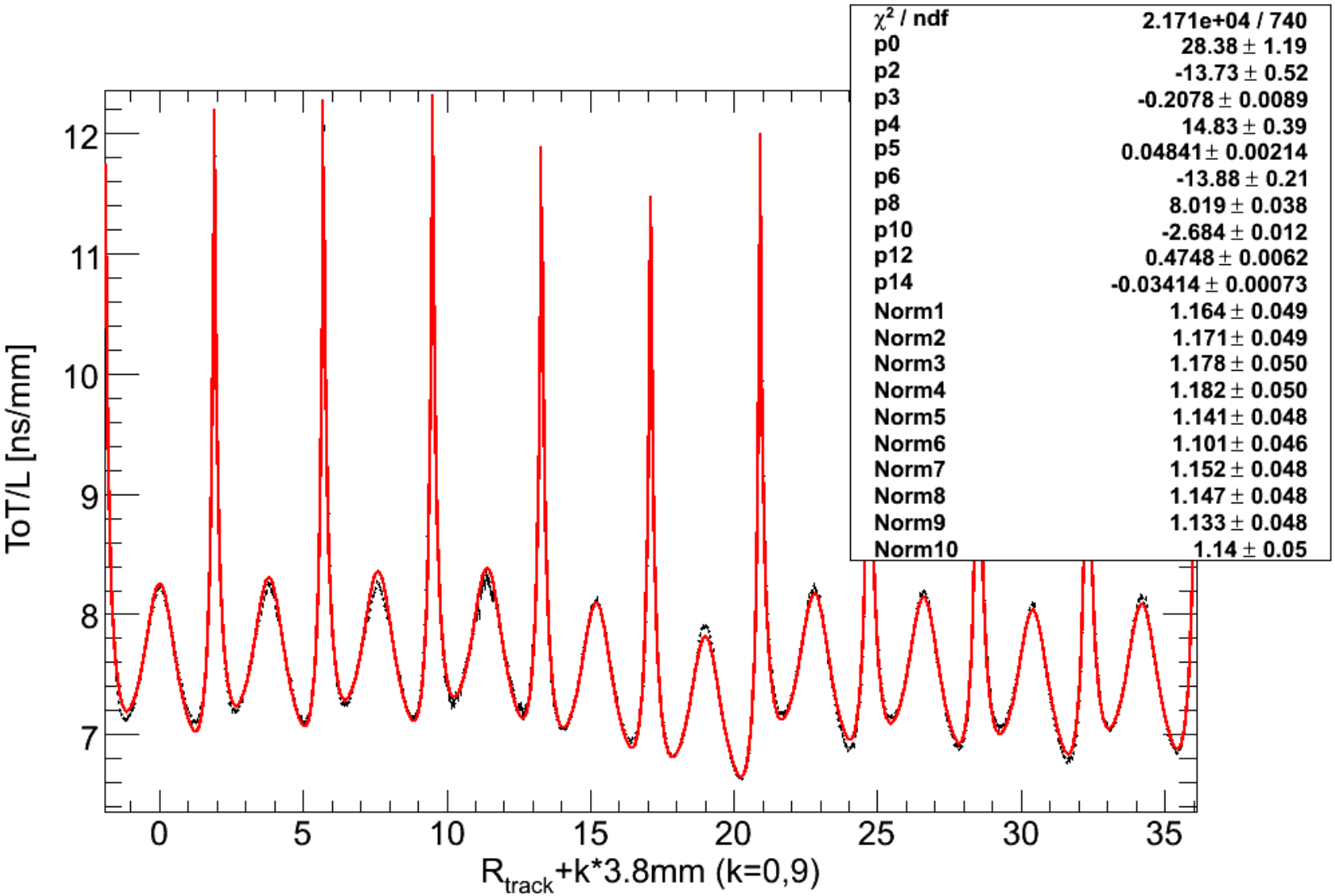
Geometry Correction

- Perform simultaneous fit of ToT/L distributions at all k energies, but allow the curves to be individually scaled (this is the dE/dx part)

$$g_i(R) = n_i \left(p_0 + p_1 R + \ldots + p_j R^j\right) \quad i = 1, \ldots, k$$

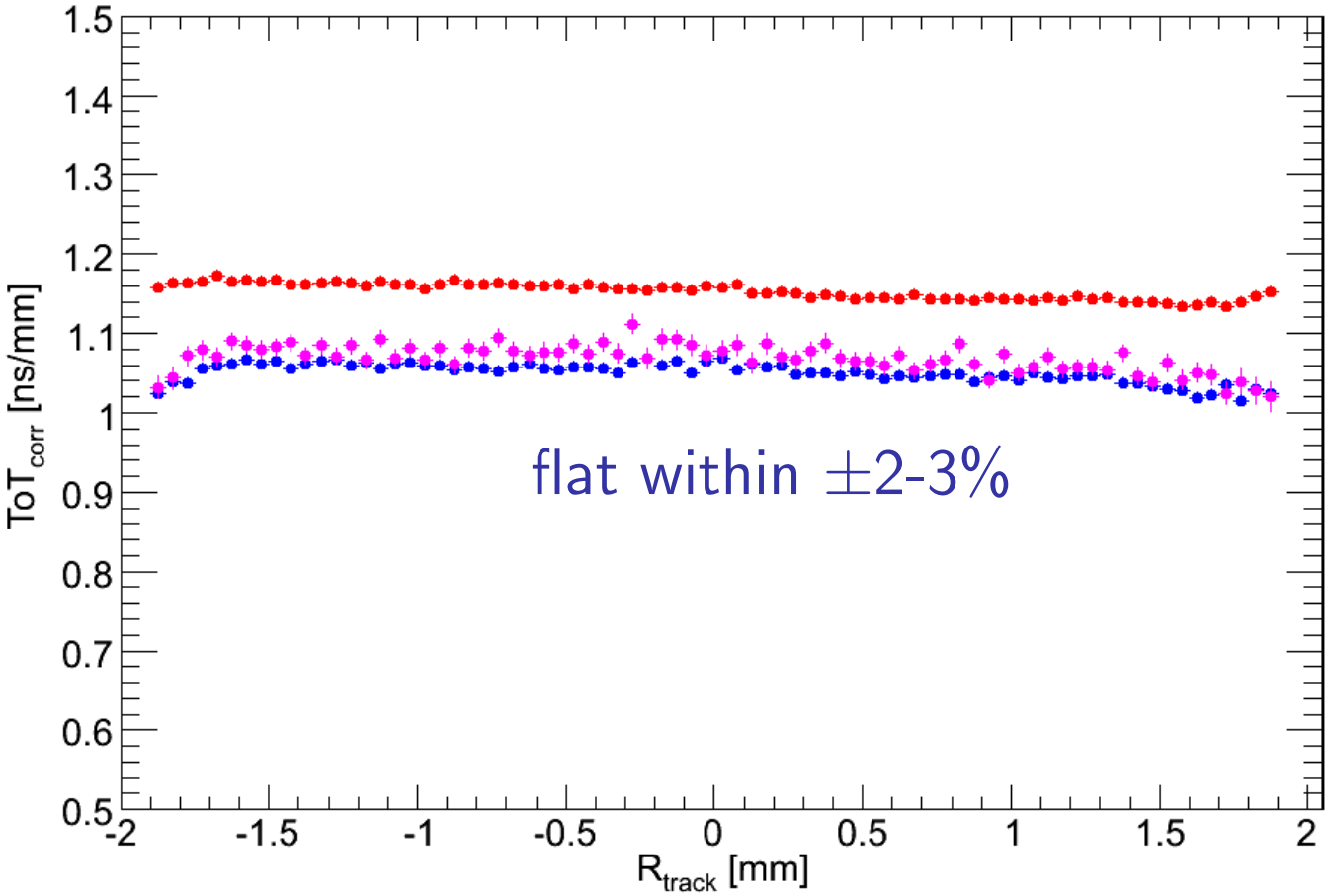
- k normalisation factors, j parameters (the same for all i)
- polynomial order j chosen 14, skipping powers: 7,9,11,13 $\Rightarrow$ 11 parameters for shape
- Fit for profiles filled with all particle types

Simultaneous Fit

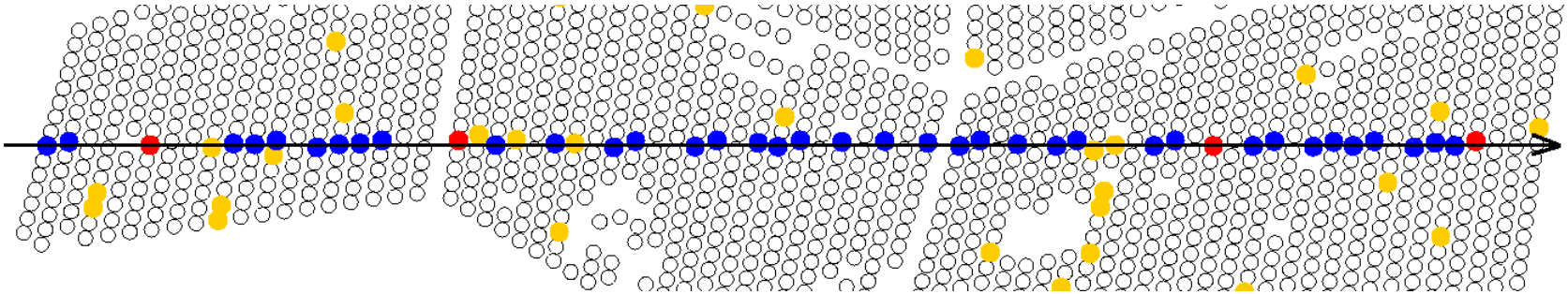


Corrected Time-over-Threshold

Result looks quite good:



Building a dE/dx variable



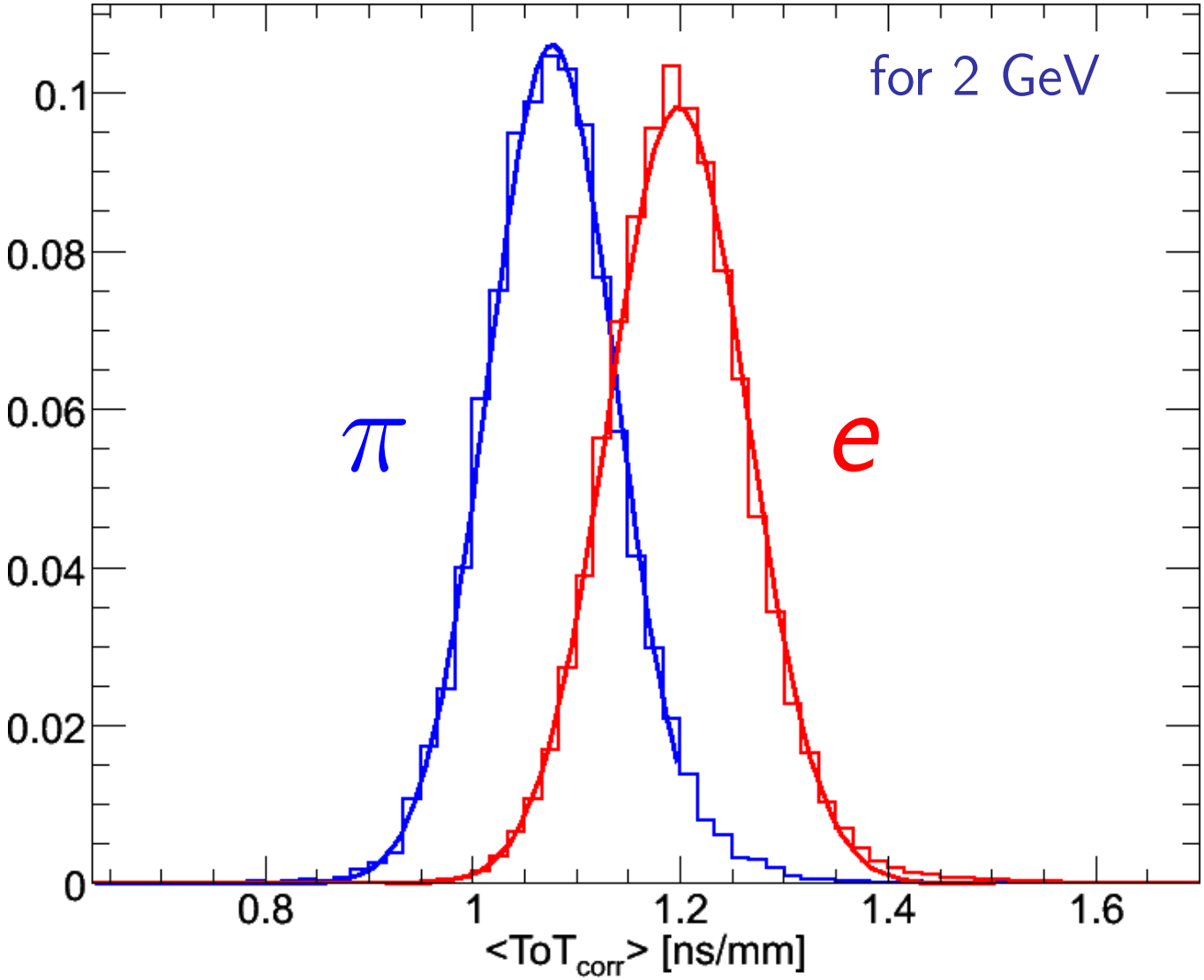
- $\langle dE/dx \rangle$ is a track variable $\Rightarrow$ combine hits on track
- correct single hits for distance from the wire:

$$\mathrm{ToT}_{corr} = \frac{\mathrm{ToT}}{L\, g(R_{track})}$$

- calculate mean and RMS of N ToT_{corr} values:

$$\langle \mathrm{ToT} \rangle_{corr} = \frac{1}{N} \sum_{i=1}^{N} ToT_{corr,i}$$

Separation Power



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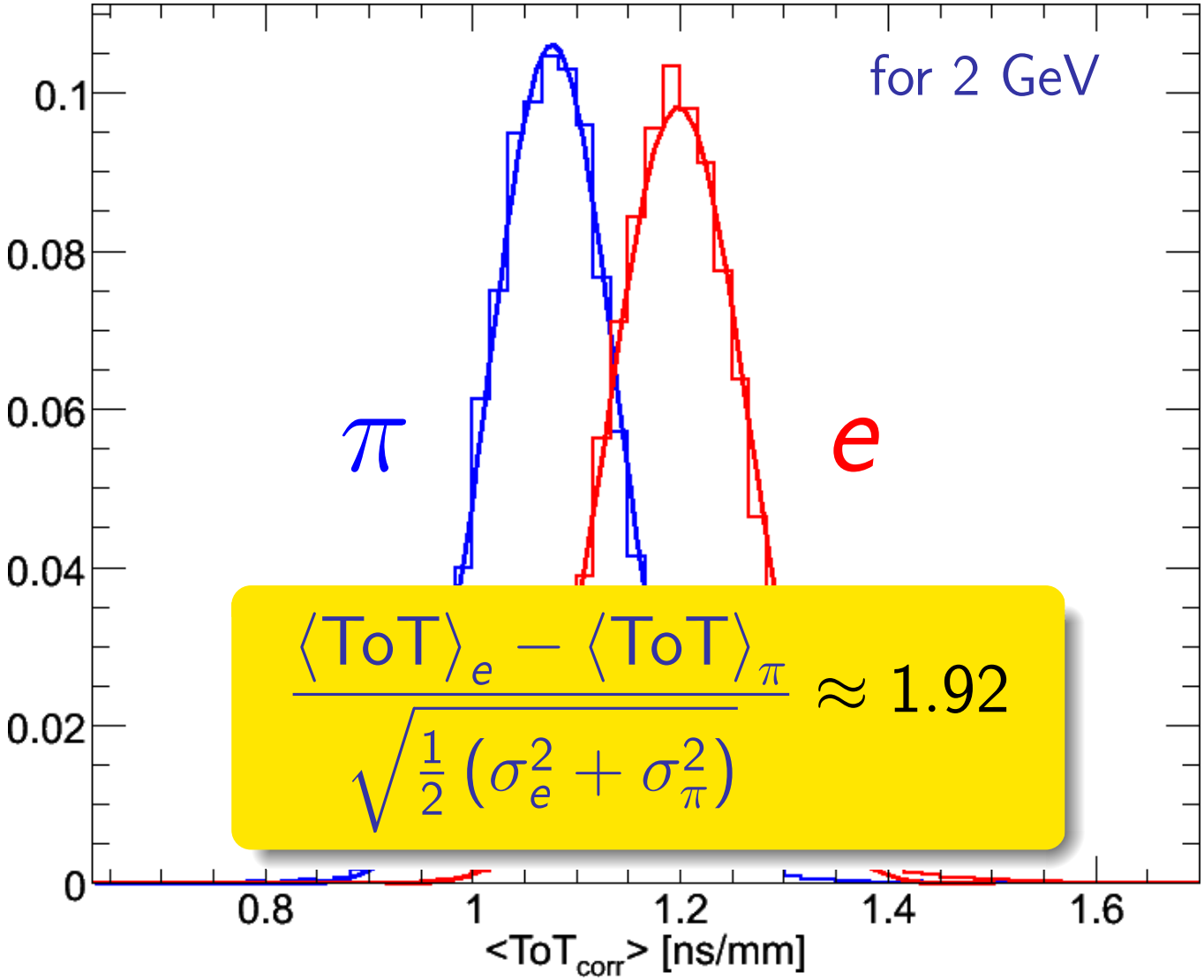
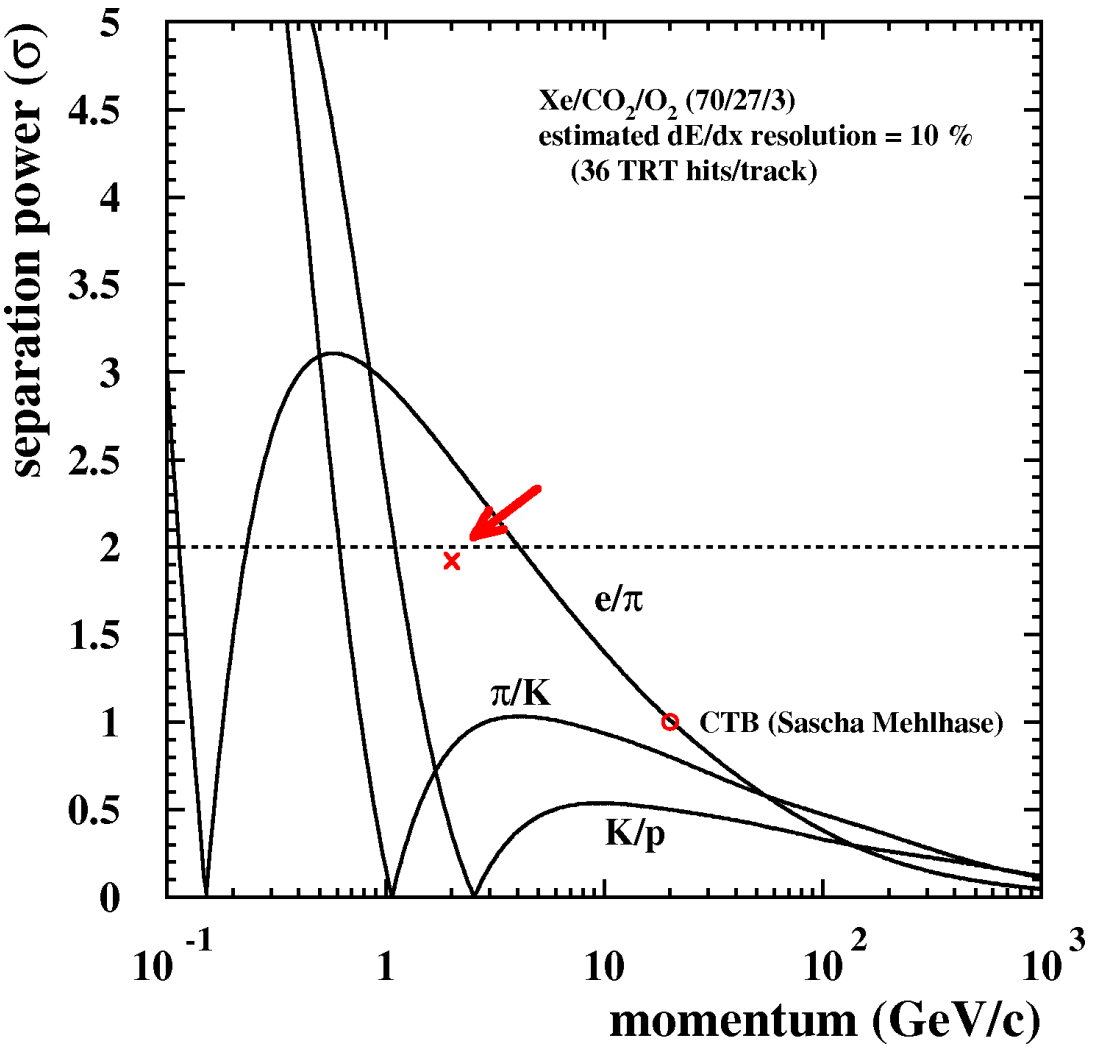


$$\frac{\langle \mathrm{ToT} \rangle_e - \langle \mathrm{ToT} \rangle_\pi}{\sqrt{\frac{1}{2}\left(\sigma_e^2 + \sigma_\pi^2\right)}} \approx 1.92$$

Separation Power



(plot: Michael Hauschild)

- Result for 2 GeV not bad but below prediction
- separation for other energies in principle there $\Rightarrow$ Thesis
- improvements possible, tails for high energy electrons etc.

Summary & Conclusion

What has been done...

- CTB data Reconstruction incl. PID finished
- Learned a lot by digitisation stand-alone simulation
- A couple of systematics studied for test beam data, only few shown here, a lot more to learn
- geometry correction works fine so far, however, still inclusive method, no real model
- Finally: There is quite some separation by dE/dx

To be done...

- Separation powers at all energies $\Rightarrow$ have to finish Thesis...
- Improvements: likelihood(?), get rid of tails, what about HT-hits? Gas gain stability.