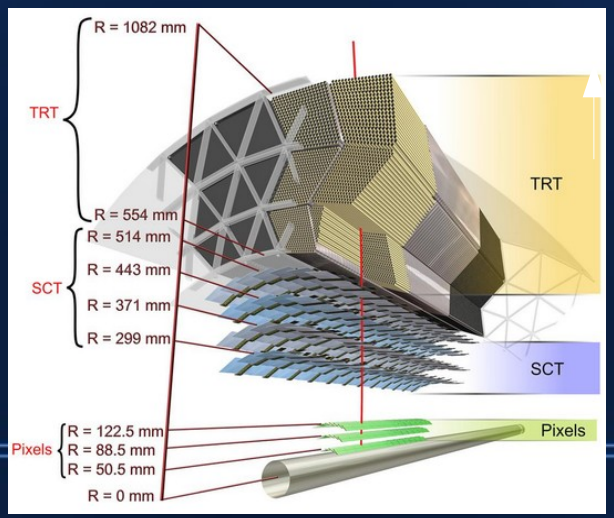
Simulation of Transition Radiation and Electron Identification Ability of the ATLAS TRT

Esben Klinkby
Niels Bohr Institute,

TRDs for the third Millennium
Bari Sep. 14-16 2011



Simulation of Transition Radiation and Electron Identification Ability of the ATLAS TRT

Outline

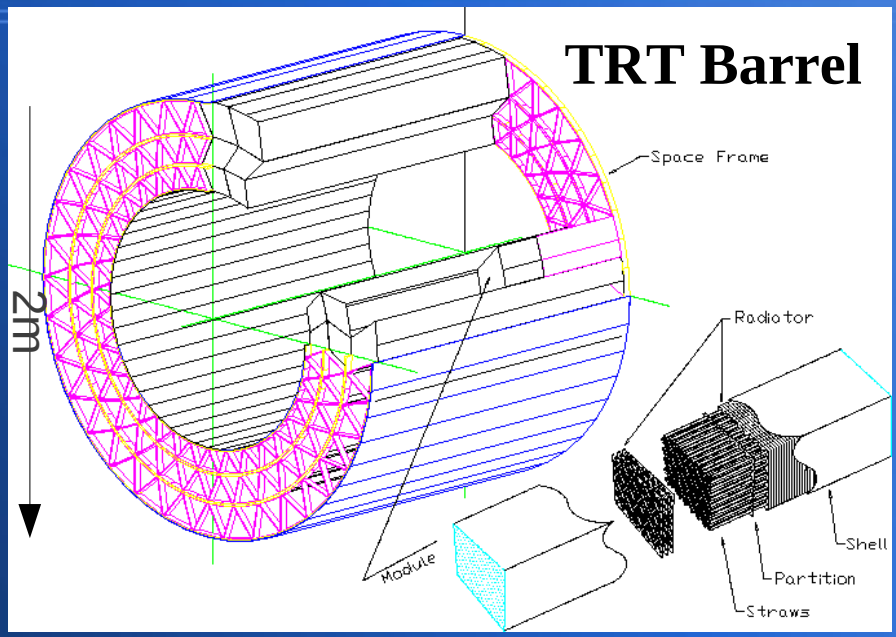
- TR in ATLAS & TRT basics
- Implementation in the simulation
- Tuning to test beam & collision data
- Electron ID with the TRT
- Using TRT PID in physics analysis

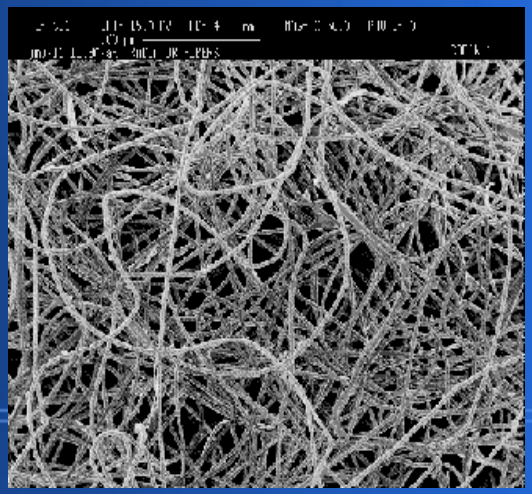
TR in ATLAS and TRT basics: why TR?

- Transition radiation is used in the ATLAS TRT detector to assist in particle identification (PID)
- In particular, TR significantly improves overall separation of electrons from pions in the energy/momentum region 1-200 GeV
- Specially useful at low pT (1 –10 GeV) where backgrounds from charged-hadrons are particularly severe

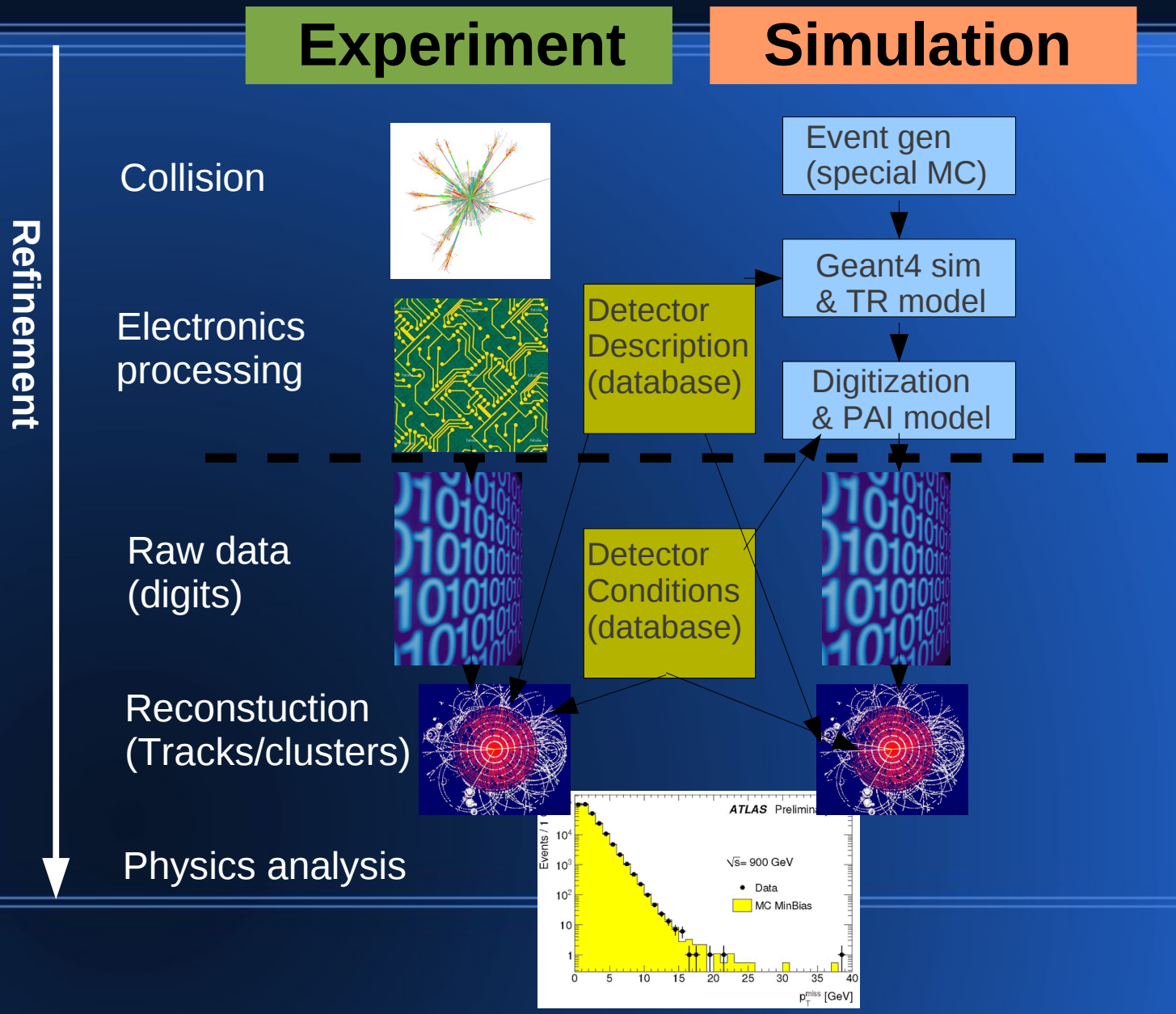
TR in ATLAS and TRT basics:
The detector

- Modular drifttube assembly.
- Polyethelene fiber/foils interspaced
- Active gas Xenon (70%)
- The TR energy is a few keV
- MIP *dE/dx* loss in a straw ~2keV
- High threshold trigger ~6 keV. Hits passing this are called HT hits.
- Fraction of HT hits to all hits, is the measure used for PID





ATLAS software overview



Implementation in the simulation

Based on P. Nevski (NIMA, 522,116 (2004))
Total energy radiated by a charged particle passing from vacuum to a foil:

$$E_{rad} = \frac{1}{3}\alpha\gamma\hbar\omega_p$$

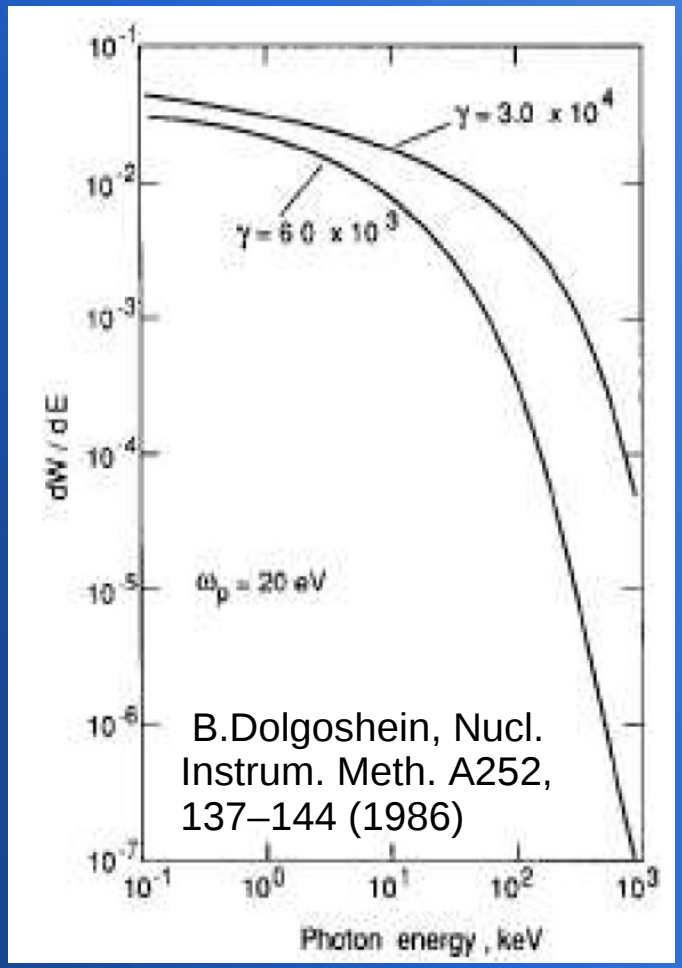
where

$$\hbar\omega_p = \frac{\sqrt{4\pi N_e r_e^3} m_e c^2}{\alpha}$$

Number of photons is Poisson dist with mean:

$$N_\gamma = \frac{\alpha}{\pi}\left(\ln\frac{\omega\gamma}{E_{cutoff}}(\ln\frac{\omega\gamma}{E_{cutoff}} - 2) + \frac{\pi^2}{12} + 1\right)$$

This number is low: ~$\alpha/2$ → many foils/fibers



The radiated TR spectrum from a polyethylene surface.

Implementation in the simulation

Simulation step

- In Geant4 PhysicsList:
  - Add discrete process: TRTTransitionRadiation
- Method TRTTransitionRadiation (action is in PostStepDoIt):
  - If inside radiator: get appropriate geometry (fibre/gap thickness)
  - Calculate photon spectrum for these parameters (γ, geometry, …)
  - Generate discrete photons and hand them over to Geant4

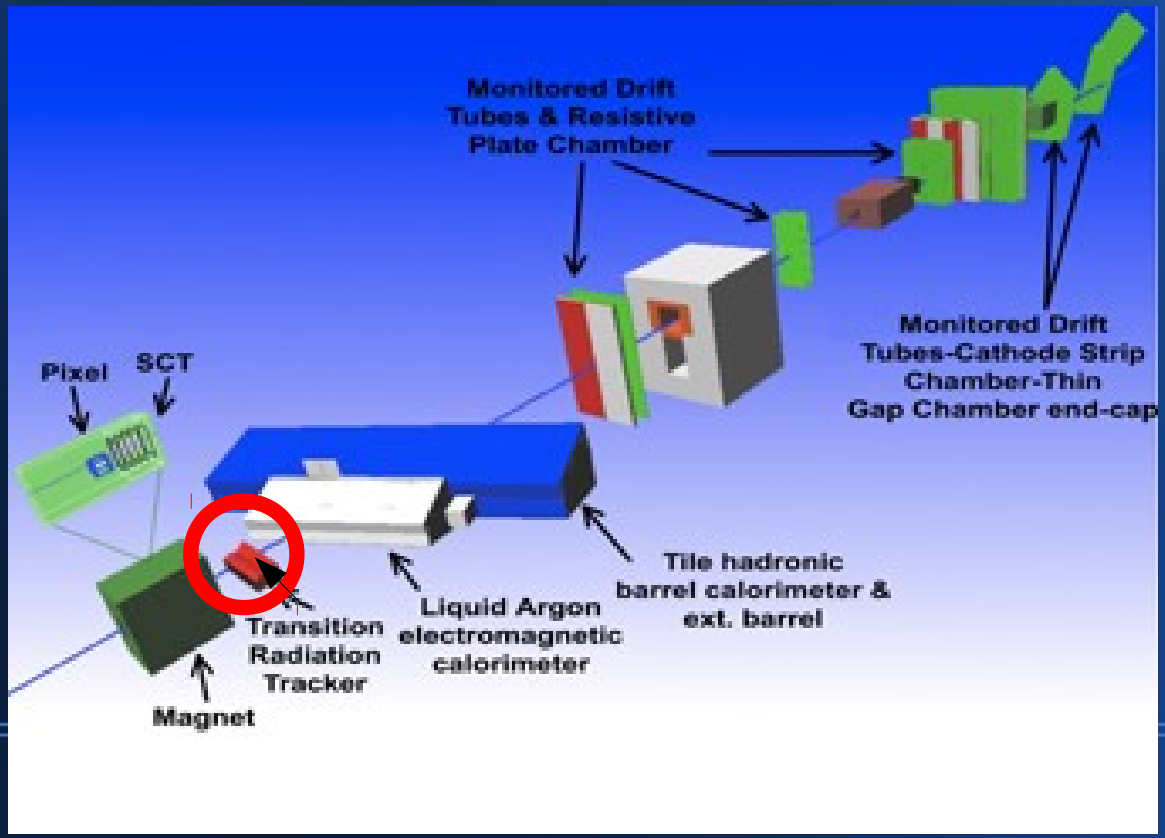
Simulation output: $E_{deposited}$, time, position

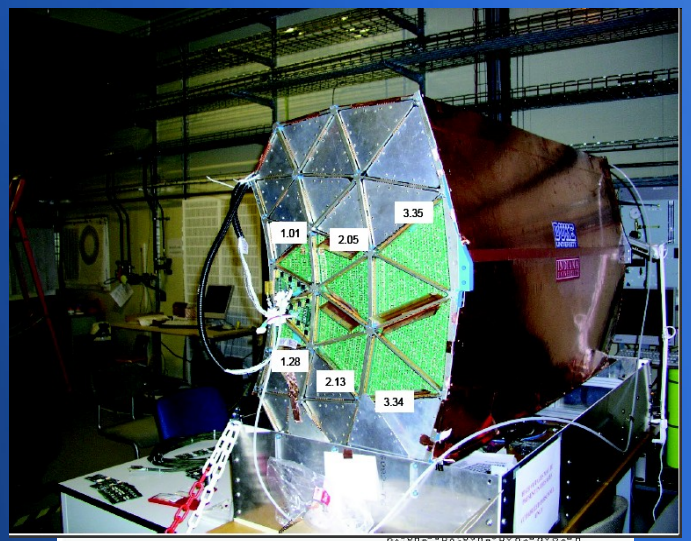
Digi step

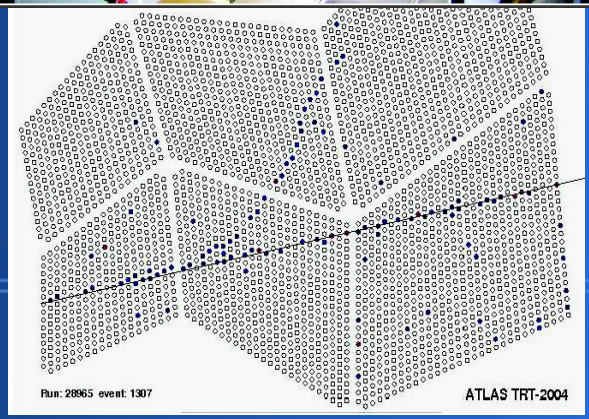
- Convert $E_{deposited}$ to a number of freed electrons
- Drift electrons to anode wire under influence of:
  - ***E*** & ***B*** fields, reattachment, gain
- Propagate signal to electronics under influence of attenuation.
- After signal shaping, discriminate the signals against thresholds: low (~300 eV) and high (~6 keV)

Tuning to test beam data

- Combined testbeam carried out to test the combined performance of a full slice of the barrel part of the ATLAS detector
- Beam constituents known (measurable) → very useful setup to test TR performance.



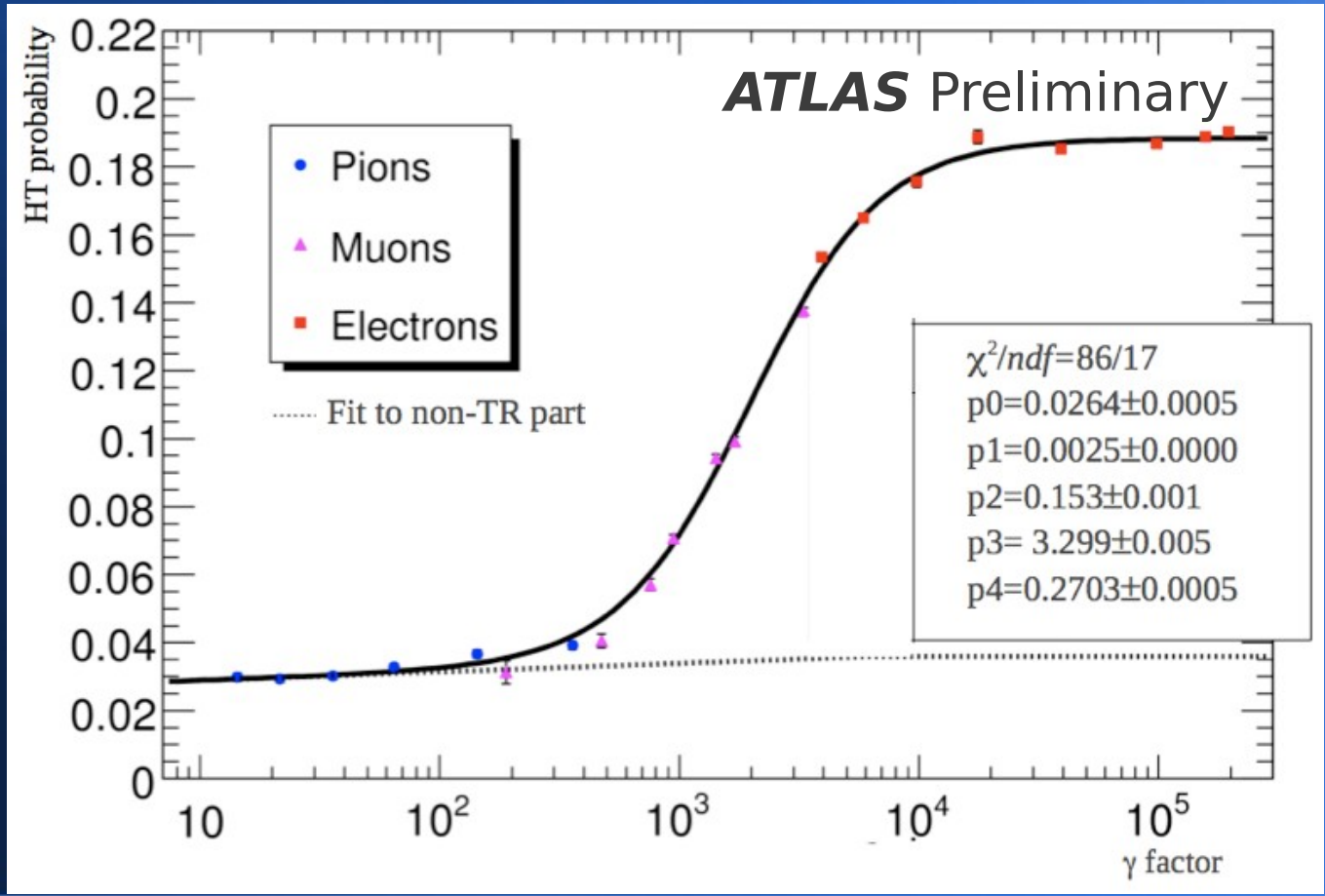




Tuning to test beam data

HT probability data is fitted by the generic onset curve :

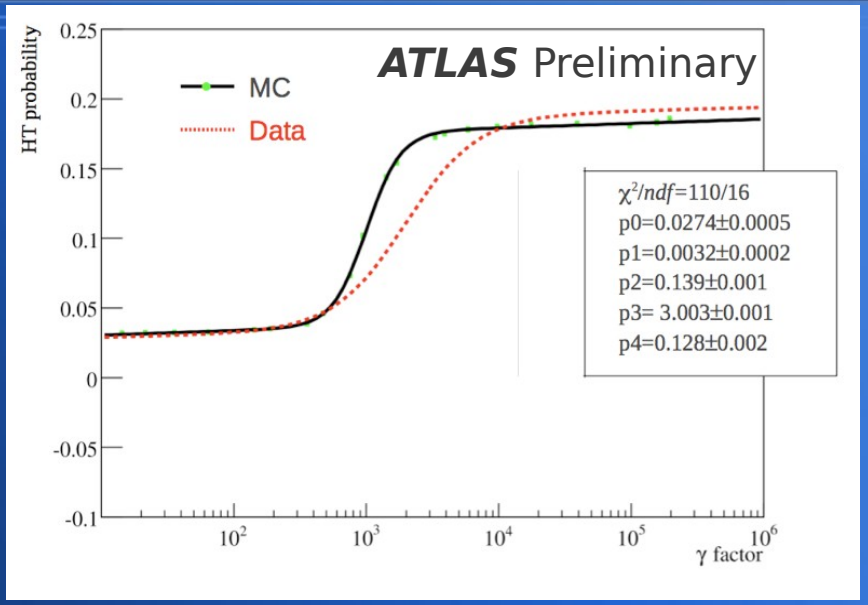
$$p_{HT}(\gamma) = p_0 + p_1 \log_{10}(\gamma) + \frac{p_2}{1+\exp(-(\log_{10}(\gamma) - p_3)/p_4)}$$



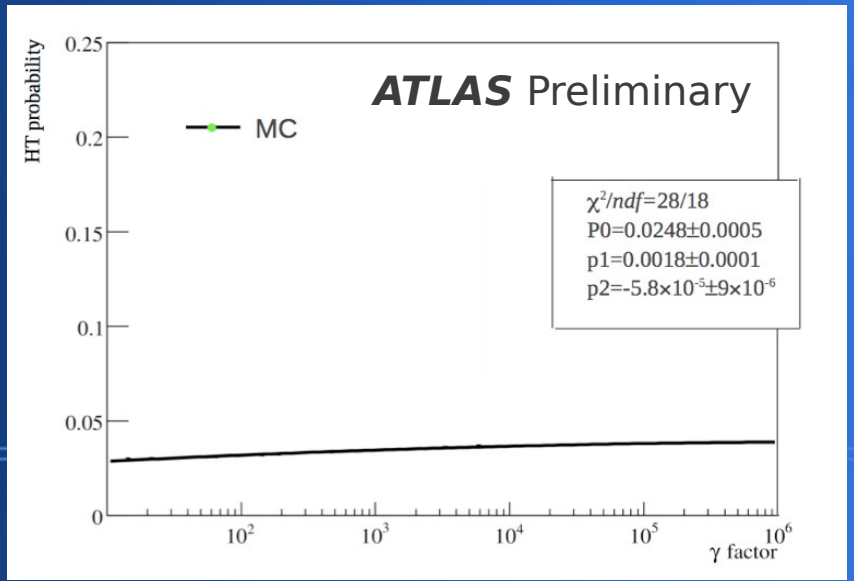
High threshold probabilities for different particles in test-beam data as a function of Lorentz gamma factor.

Tuning to test beam data

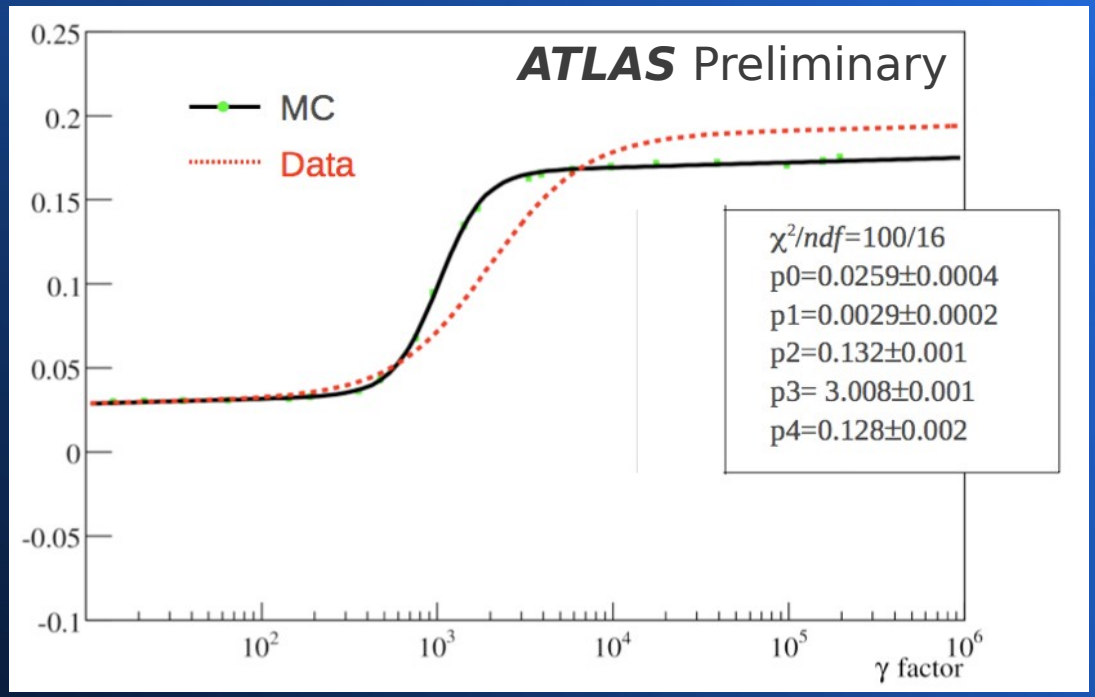
- Comparison of barrel high threshold probability between testbeam data and pre-tuned simulation.
- Note that barrel simulation assumes foils, whereas fibers are used.
- Discrepancies observed:
  - Pion plateau (step 1)
  - Onset (step 2)
  - Electron plateau (step 3)



- Simulated *dE/dx* curve after tuning the low-energy tail to data using the high threshold parameter
- Obtained by switching off transition radiation in the Monte Carlo simulation.

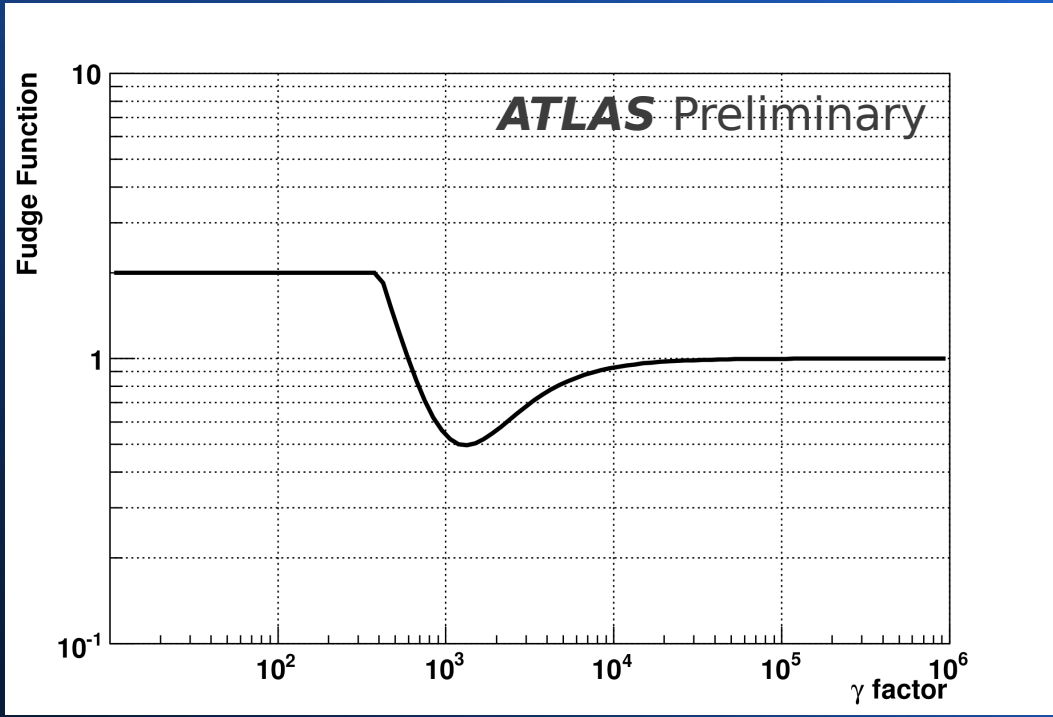


Tuning to test beam data – after “step 1”



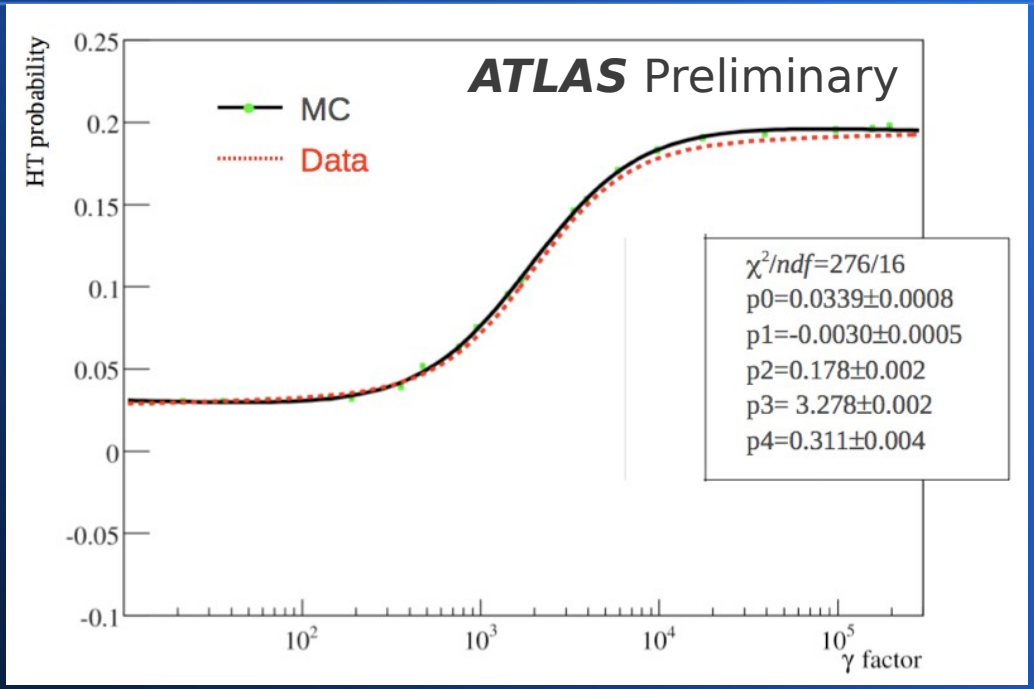
Comparison of barrel high threshold probability between testbeam data and simulation. The simulation is the pre-tuned transition radiation model with a high threshold setting of 6.25 keV. i.e. after “step 1”

Tuning to test beam data



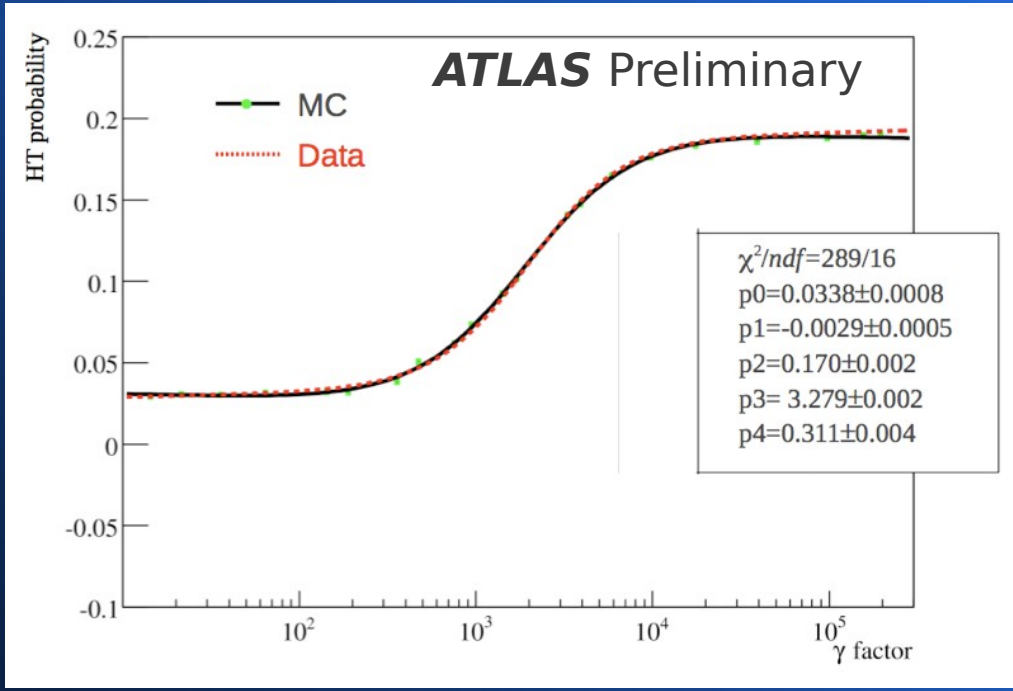
Fudge function that scales the number of photons in Monte Carlo simulation to reproduce the TR onset curve of data. The maximal allowed value of the fudge function is 2.

Tuning to test beam data– after “step 2”



Comparison of barrel high threshold probability between test-beam data and simulation. The simulation is the tuned TR model (“step 2”) with a high threshold setting of 6.25keV (“step 1”)

Tuning to test beam data– after “step 3”

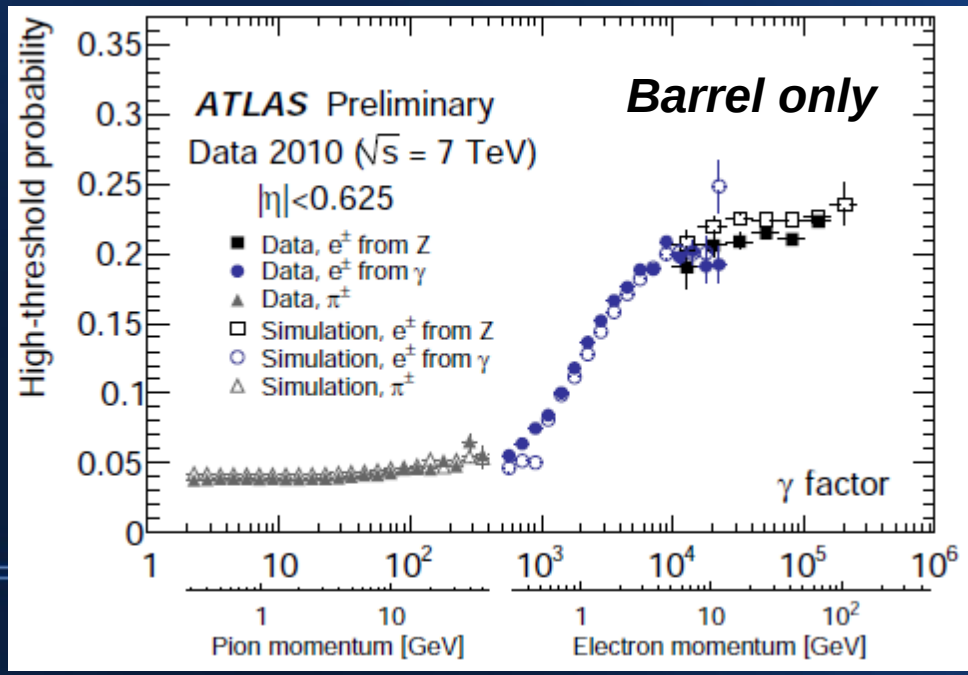


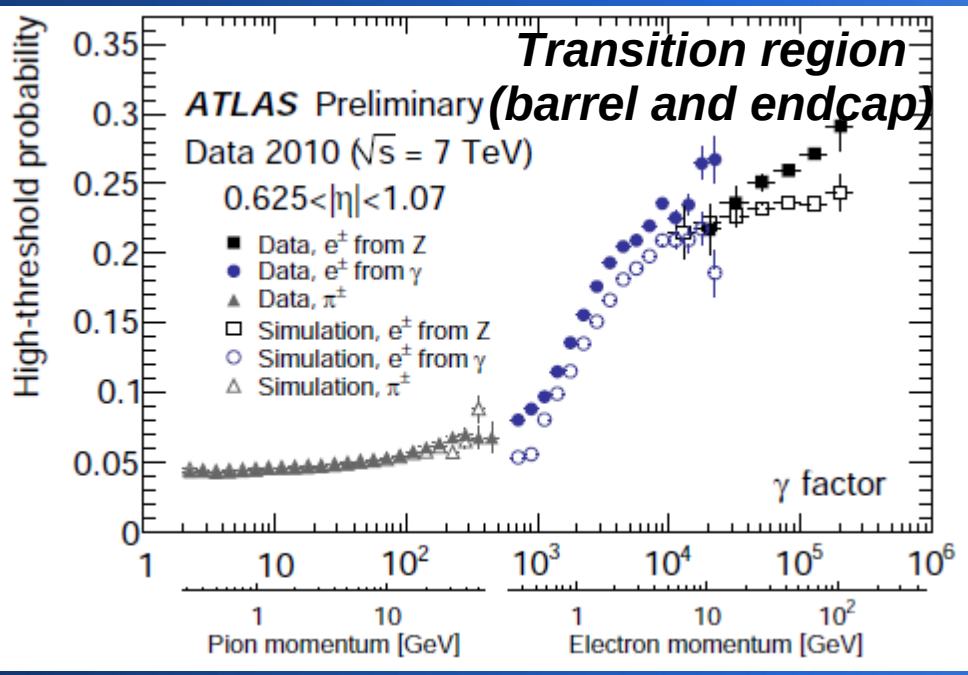
Comparison of barrel high threshold probability between test-beam data and simulation. The simulation is the tuned TR model with a high threshold setting of 6.25keV and a TR efficiency reduced to 95% (was 100% on all previous plots)

The tune is ported back into the official simulation

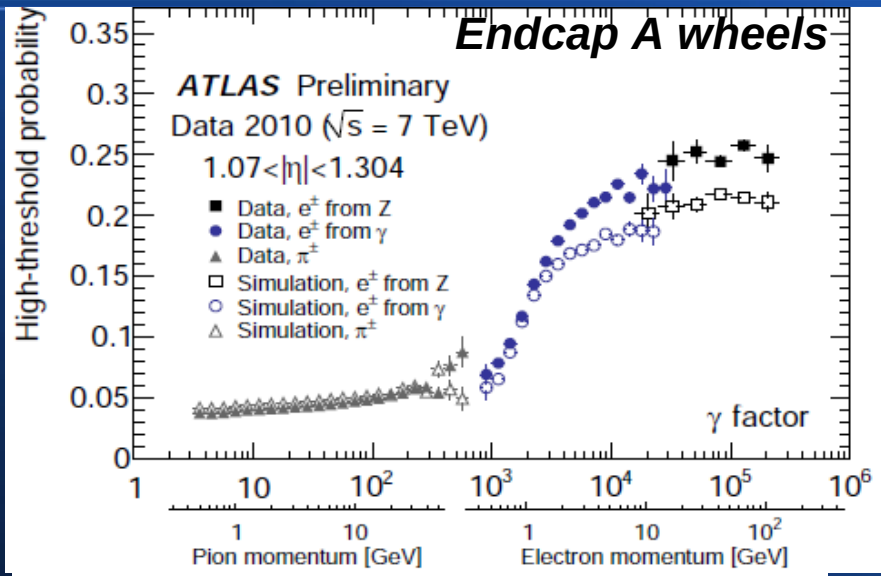
Tuning to collision data

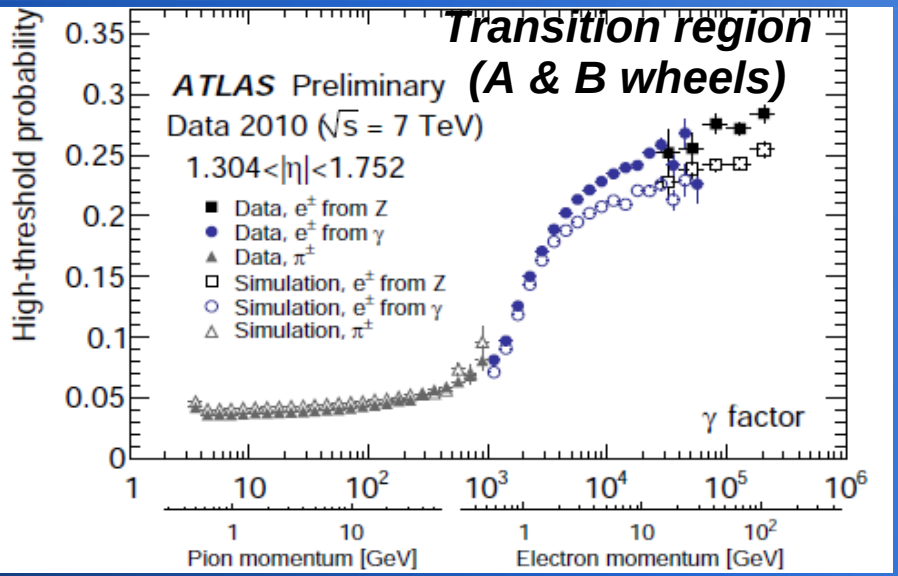
- Good agreement in barrel
- First collision data allows tune of TR responses in the the endcaps
- Turn around time is long, and simulation including the tune is not yet available, so shown here are pre-tuned results in η-bins

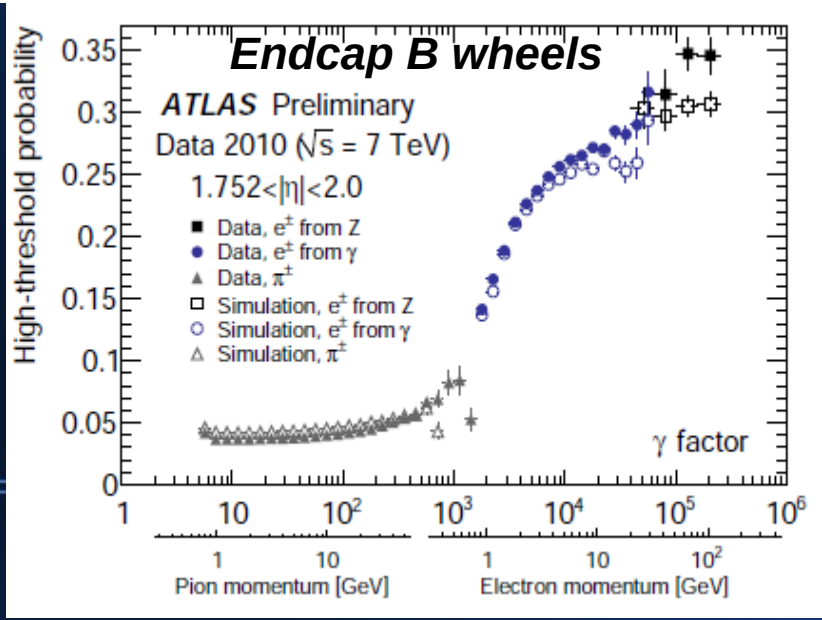




Tuning to collision data



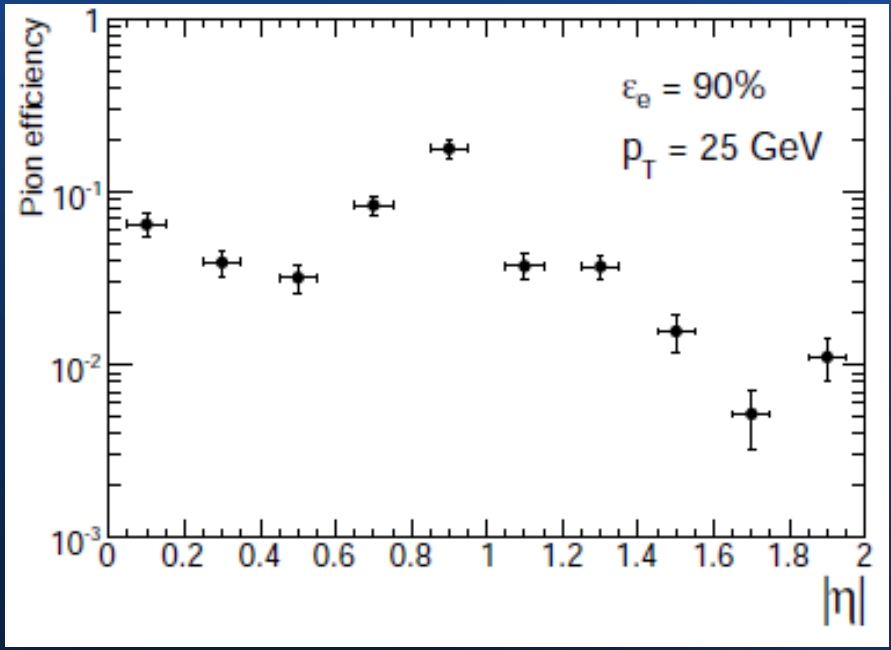




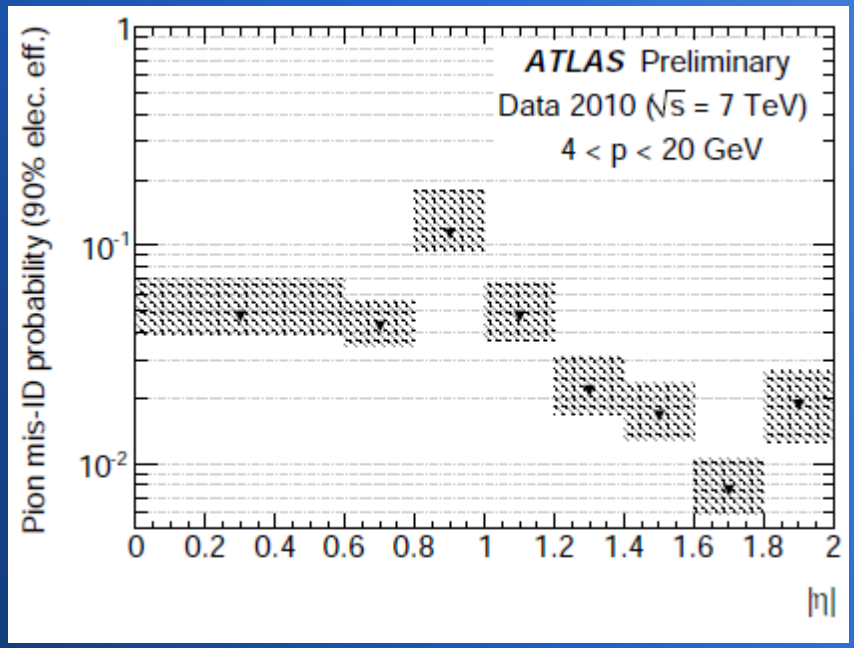
- B-type wheels have extra radiator filled spacing compared to A-type → expect more TR
- Pre-tuned simulation underestimates the TR in the A-type wheels. Fixed in simulation running now

Electron ID with the TRT

See E. Hines talk from yesterday for details



Pre-data taking expectations of pion mis-ID probability in different |η|-bins

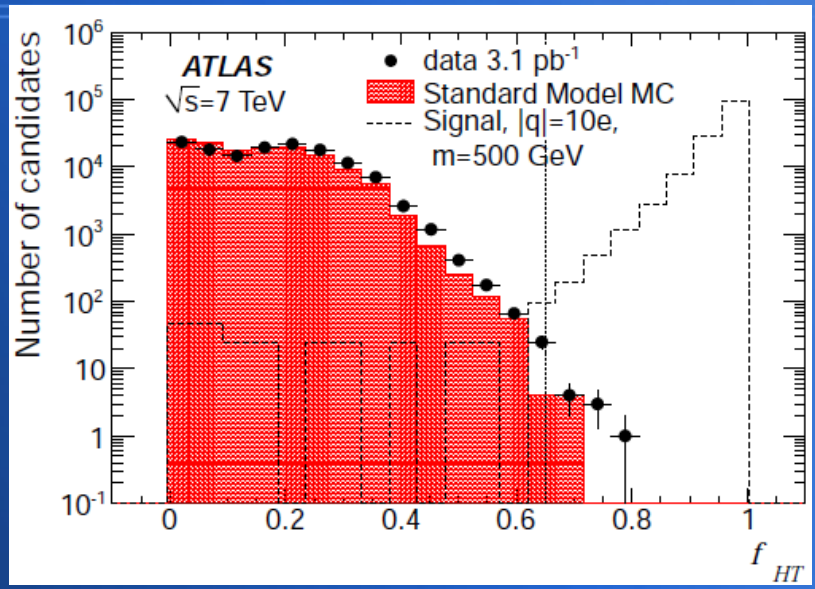


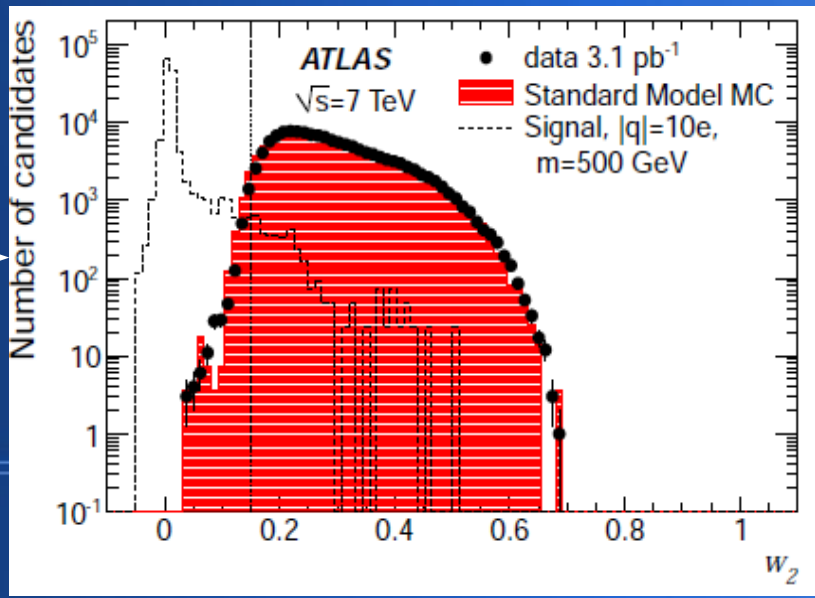
Observed pion mis-ID probability in different |η|-bins

- Note: Different pT ranges!

Example of usage:
Search for highly ionizing particles

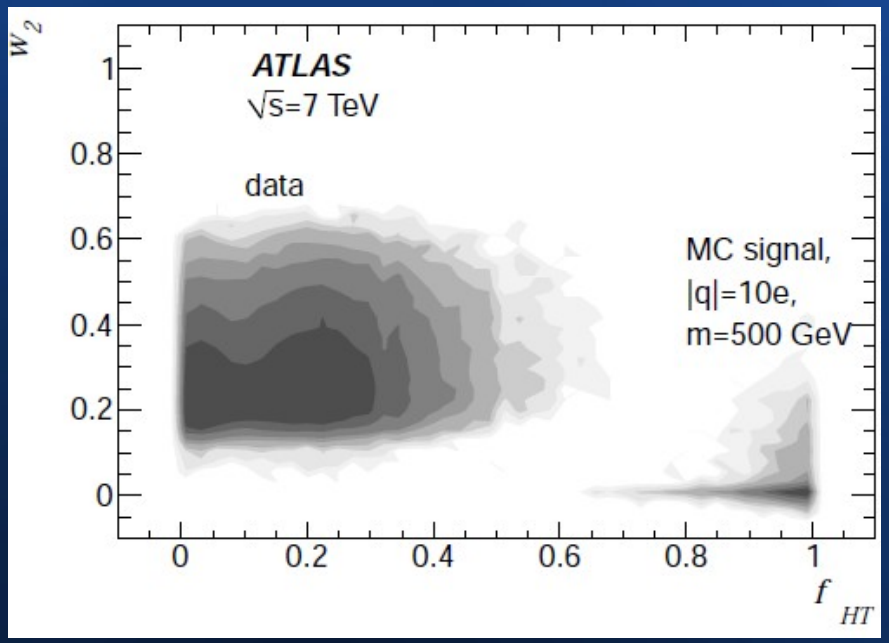
- Increased E_{CM} → production cross-section for highly ionizing particles could be passed
- Predicted (monopoles, Qballs, black holes), but searched for independently:
- Abnormal high ionization:
  - → abnormal fraction of HighThreshold TRT hits
  - → abnormal energy distributions within the cells of ab Electromagnetic cluster





Example of usage:

Search for highly ionizing particles



- Limits on HIPs in fiducial ranges of (η, E_{kin}) (pb)

m [GeV]	$\|q\| = 6e$	$\|q\| = 10e$	$\|q\| = 17e$
200	1.4	1.2	2.1
500	1.2	1.2	1.6
1000	2.2	1.2	1.5

- Limits on Drell-Yan fermion pair production (pb)

m [GeV]	$\|q\| = 6e$	$\|q\| = 10e$	$\|q\| = 17e$
200	11.5	5.9	9.1
500	7.2	4.3	5.3
1000	9.3	3.4	4.3

- Further reading: Phys.Lett. B698: 353-370. 2011

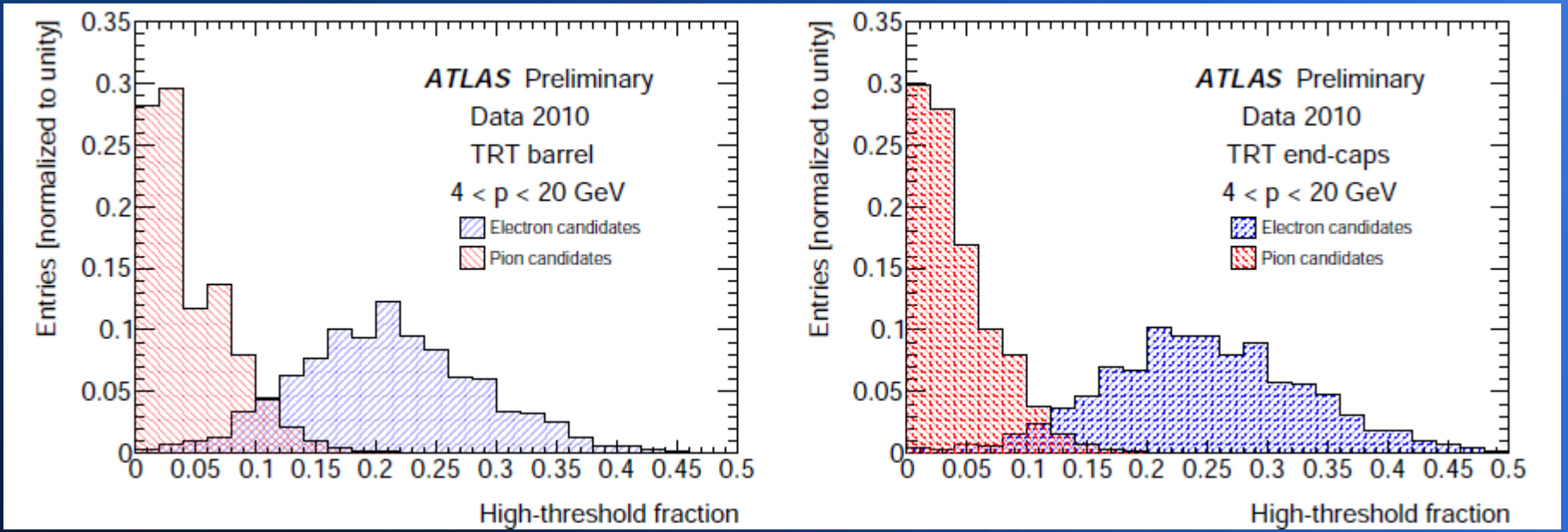
Summary

- The performance exceeds that expected from early simulation, based on Nevski (2004)
- The simulation of both barrel (testbeam) and endcap (collision) was tuned to accurately match the observations in data
- The transition radiation detector at ATLAS is a great success
  - At 90% electron efficiency, pion rejection of 10-100 obtained
- High threshold fraction has proved very useful in physics analyses both for those depending on electron ID and for searches for new physics

Backup slides

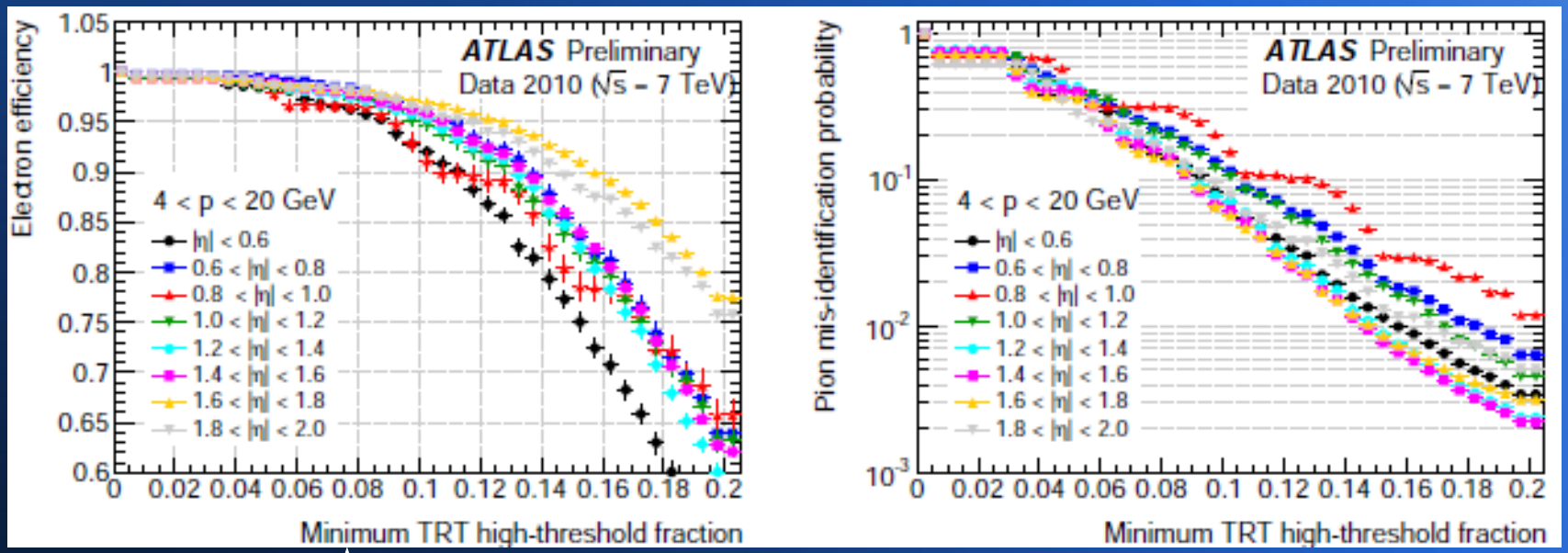
Electron ID with the TRT

Covered by E. Hines yesterday – a few highlights repeated here



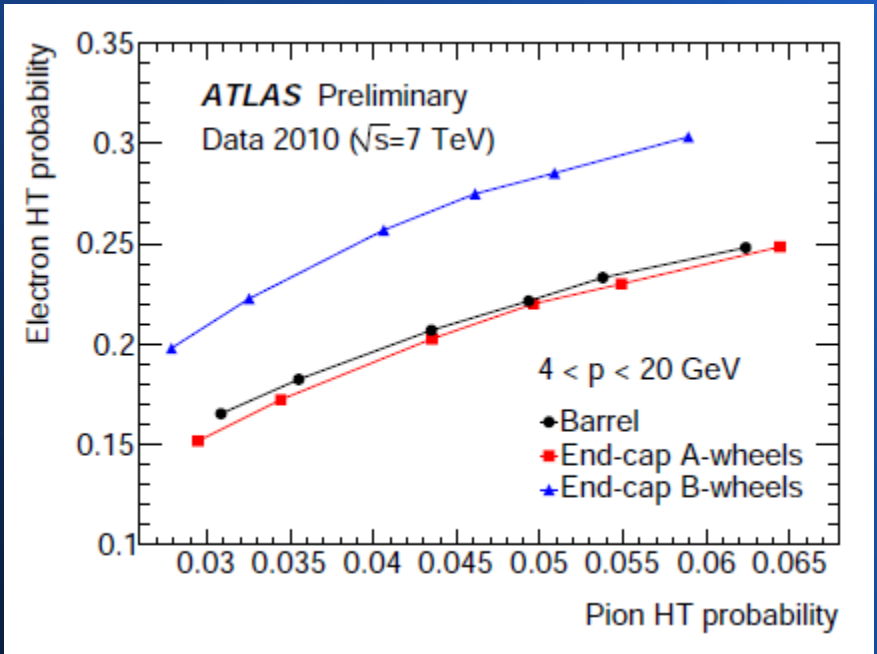
HT fraction for electrons (from photon conversions) and pion candidates

Electron ID with the TRT



Fraction of electron and pion candidates that pass a given high threshold cut

Electron ID with the TRT



HT probability for electrons vs. the HT probability for pions