Overview

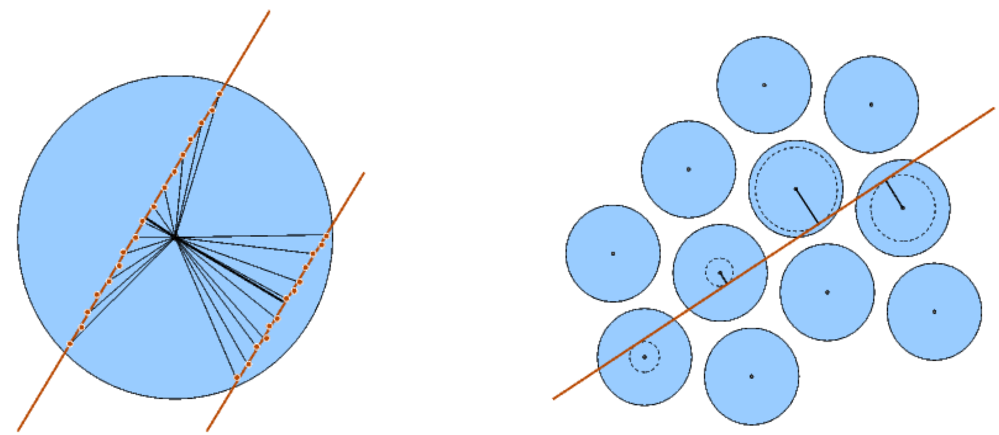
- Transition Radiation Tracker

- A Probability Based Approach to PID in the TRT
    - Goals / Figures of Merit / Monte Carlo Simulation
    - Data Sets
    - Data Quality Assurance
    - Non-TRT Particle ID Analysis
    - High Threshold (HT) Analysis / Time-over-Threshold (ToT) Analysis
    - Combining Variables
    - Results
    - Transition Radiation Onset Measurement

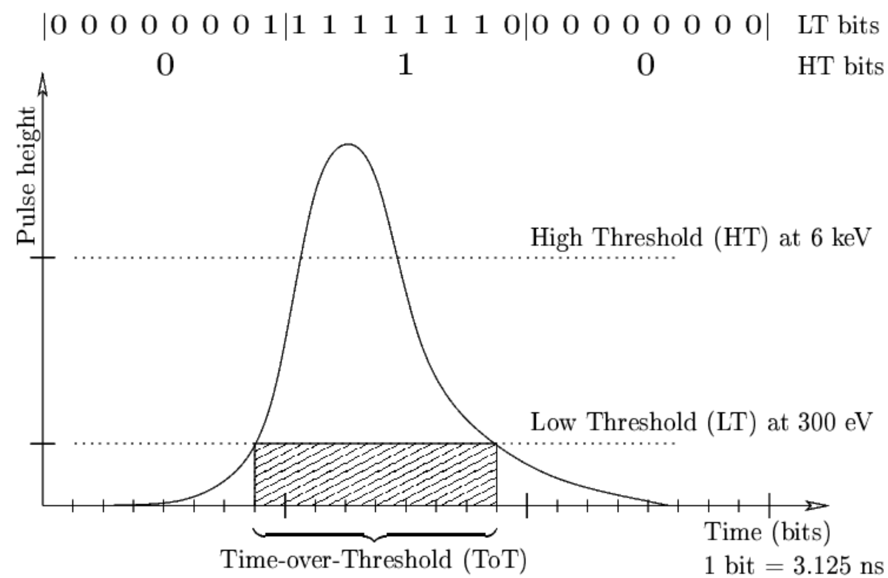
- ATLAS W Boson Mass Measurement Potential
    - Goal / Measurement Strategy (Ratio Method)
    - Overview on Systematic Uncertainties
    - Data Sets / Selection Criteria
    - Influence of Final State Radiation (FSR)

The Transition Radiation Tracker

- Design Concept
  - straw detector combined with transition-radiation detection
  - barrel-endcap structure
  - about 350000 straws
  - each channel provides a drift-time measurement (tracking) and two independent thresholds
    - LT: low-threshold/tracking hits
    - HT: high-threshold/particle identification hits (mainly caused by transition radiation)

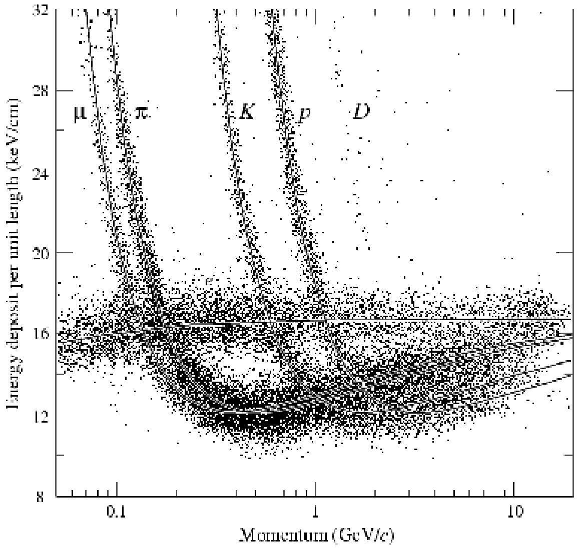


- Transition Radiation (TR)
  - essentially produced by electrons only, since a $\gamma = E/mc^2 > 1000$ is needed
    $\rightarrow$ allowing for particle identification



A Probability Based Approach to PID in the TRT

- Goals
  - optimal e/π separation
  - include time-over-threshold (dE/dx) information
  - determine separation's energy dependence
  - measure onset of transition radiation



- Figures of Merit
  - pion efficiency (ε^{π}) vs. electron efficiency (ε^{e})
    for method comparison at one energy
  - pion efficiency (ε^{π}) at 90% electron efficiency (ε^{e})
    for performance-over-energy comparison

- Monte Carlo Simulation !?!
  - not used, because
    - not reliable at this time (improvements in new ATLAS software releases)
    - additional systematic errors can be avoided
    - study can be done without it → non-TRT information
  - study can be used as input for tuning the simulation

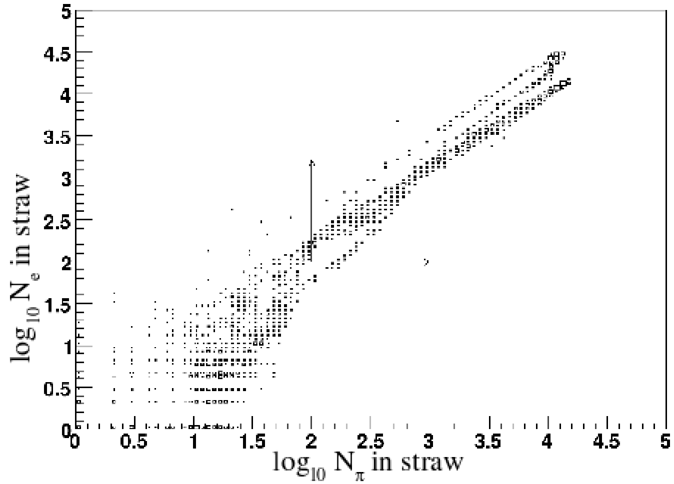
A Probability Based Approach to PID in the TRT

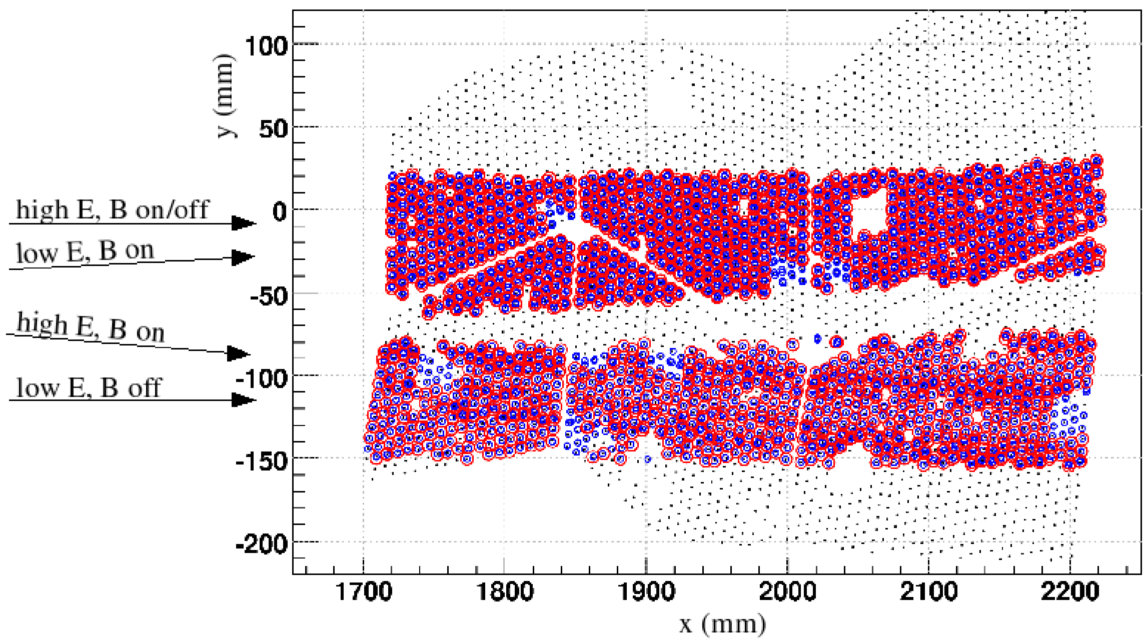
- Data from the Combined Testbeam Runs Autumn 2004
  - energies: 2, 3, 5, 9 (low E), 20, 50, 80, 100 and 180 GeV (high E)
  - different setups for each energy (B-field on/off and material in/out, except at 80 GeV)
  - in total 32 runs, each with about 50000 initial events
  - additional muon runs at 150, 180 and 350 GeV for cross checking and the transition radiation onset measurement

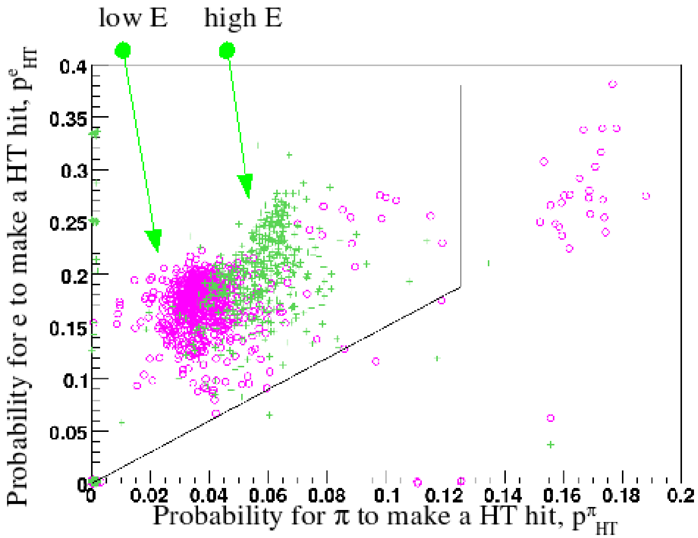
- Problems
  - efficiency problems in B-field runs due to errors in reconstruction code
    study done with ATLAS software version 11.0.42, recent versions (e.g. 12.0.4) contain bug fixes

A Probability Based Approach to PID in the TRT

- Data Quality Assurance
  - at least 100 electron and pion hits required for each straw
  - at least 50% higher probability for an electron to make a HT hit (p^{e}_{HT}) than for a pion (p^{π}_{HT}), with the latter one being below 12.5%
  - single quality TRT tracks *without* interference
    - only events with exactly one track
    - only track with 20 *quality* LT hits





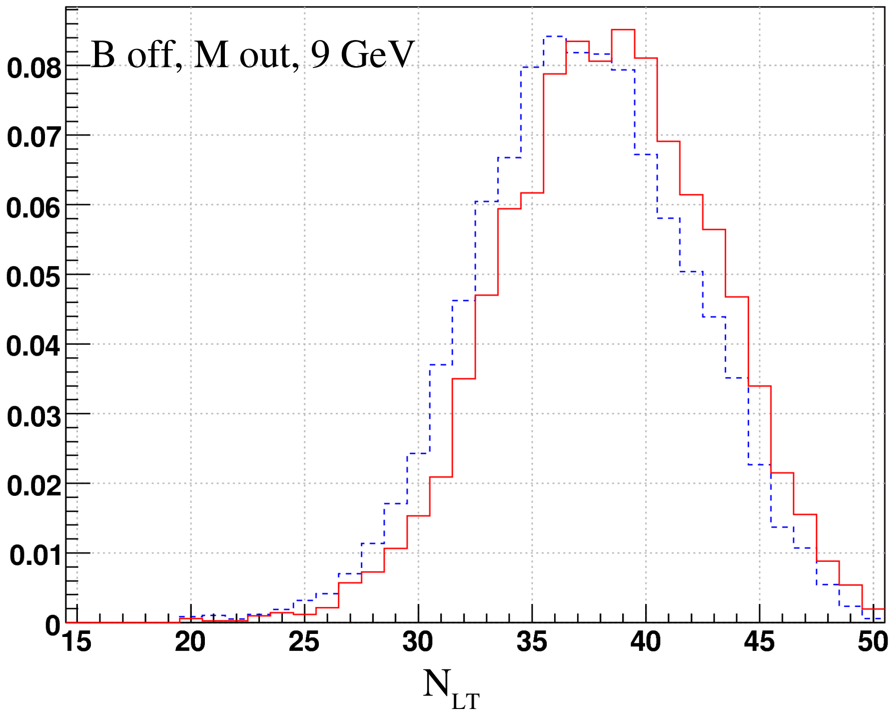


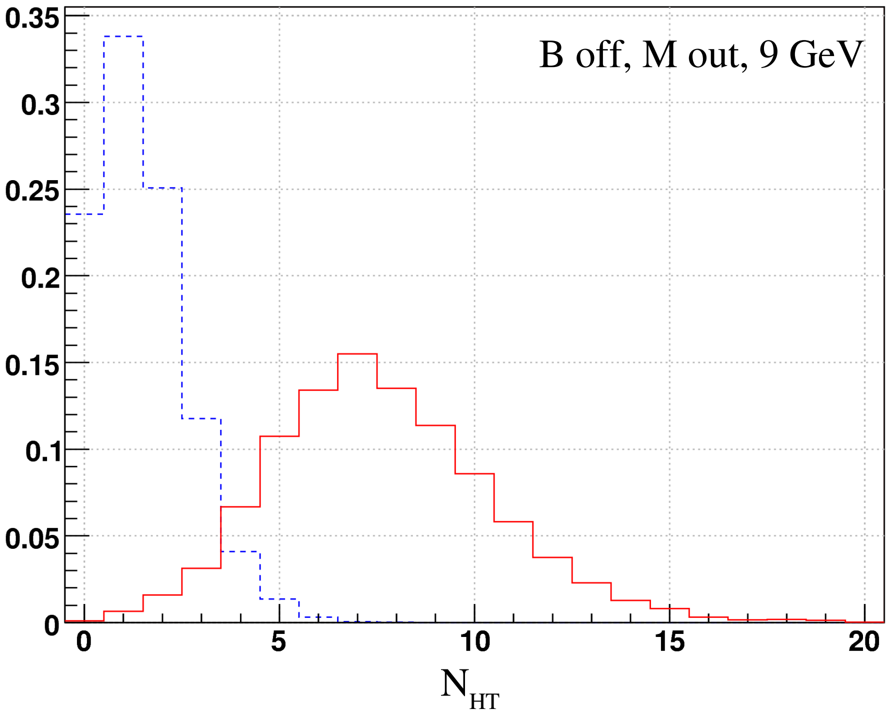
A Probability Based Approach to PID in the TRT

- Non-TRT Particle ID Analysis
  - pure samples of es, πs (and μs) obtained by using the other PID detectors
    electromagnetic calo. (EMF1, LArF), hadronic calo. (HadF), Cherenkov Counter (Cher), Muon-Tag
  - cuts for all variables optimised in an iterative procedure
    1. apply reasonable cuts on all but one variable for es and πs separately
    2. plot remaining variable for es and πs → obtain a good estimate of *true* distribution
    3. optimise cuts for this variable based on this plot
  - optimisation done at all energies separately
  - cut criteria represent an interplay between efficiency and purity
    (goal: samples with >1000 events and <0.2% contamination)
  - main muon separation given by Mu-Tag variable
  - essentially all cuts are more than 90% efficient
  - even with correlations, the overall contaminations are less than 0.2%

A Probability Based Approach to PID in the TRT

- High Threshold (HT) Analysis
  - cutting on the number of HT hits (N_{HT}) only has two shortcomings
    - each track does not hit the same number of straws
    - not all straws have the same HT probability

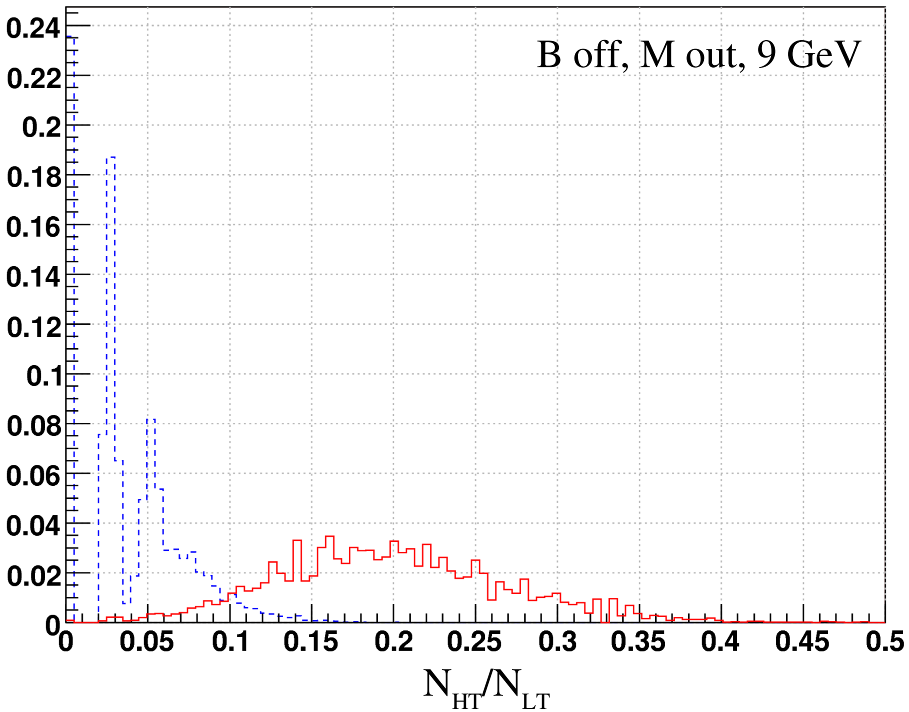


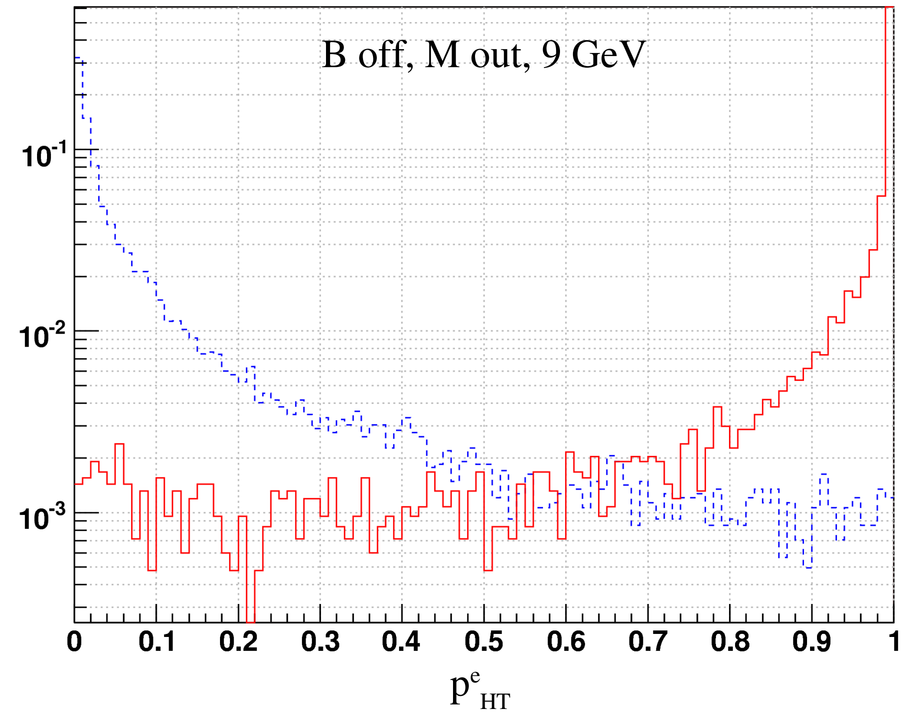


A Probability Based Approach to PID in the TRT

- High Threshold (HT) Analysis
  - cutting on the number of HT hits (N_{HT}) only has two shortcomings
    - each track does not hit the same number of straws
      can be solved, simply by normalising N_{HT} with N_{LT}
    - not all straws have the same HT probability
      can be solved by using a likelihood variable

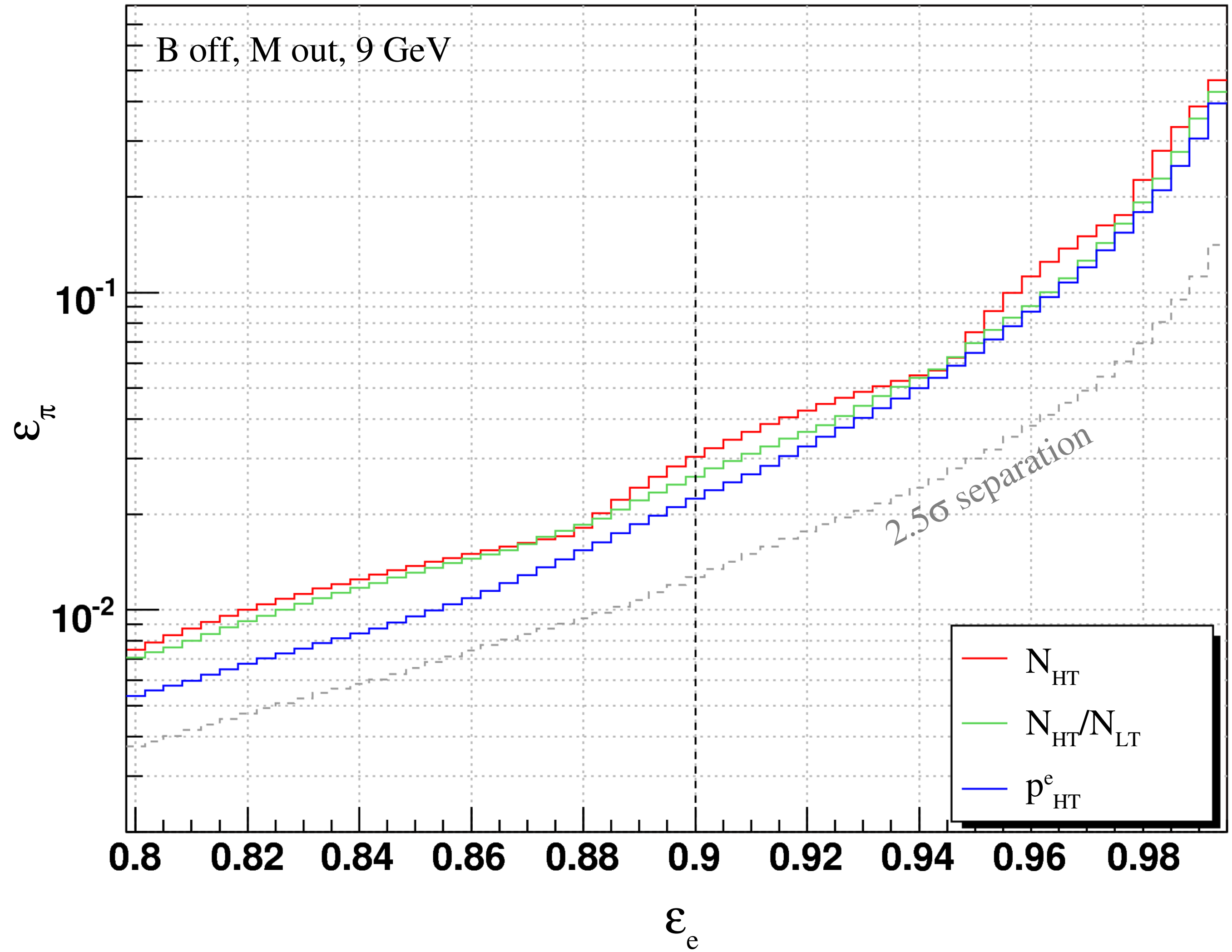
$$p^e_{HT} = \frac{\prod_i p^e_{HT,i}}{\sum_{j=e,\pi} \prod_i p^j_{HT,i}}$$





A Probability Based Approach to PID in the TRT

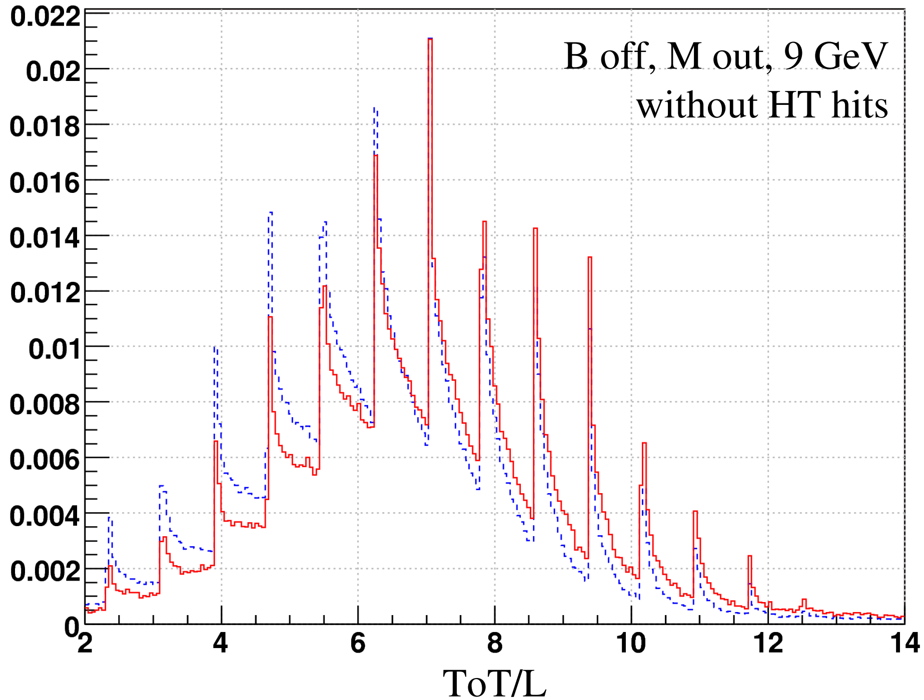
- High Threshold (HT) Analysis

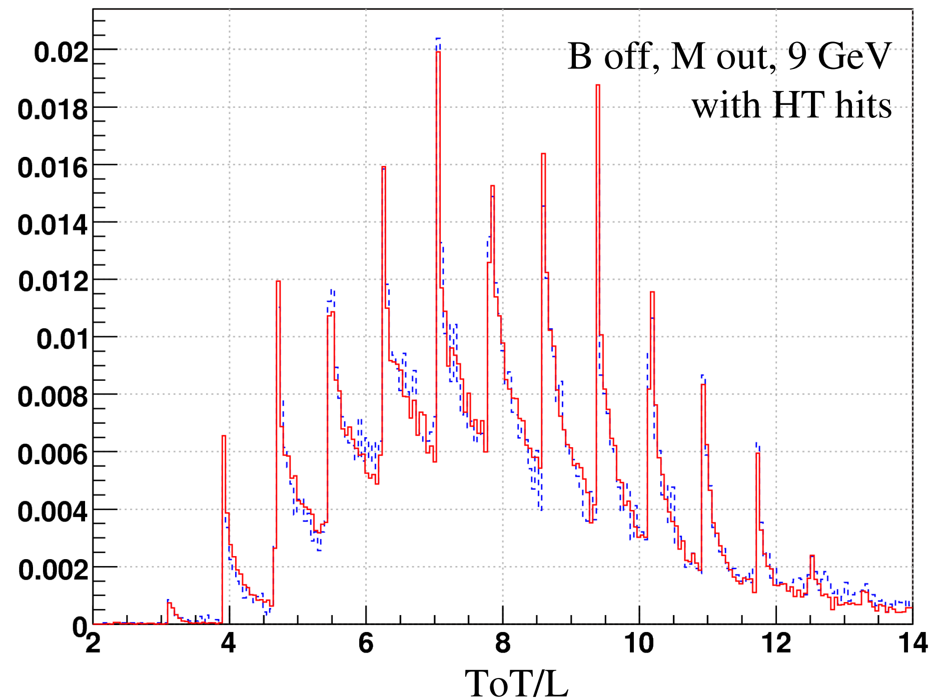


A Probability Based Approach to PID in the TRT

- Time-over-Threshold (ToT) Analysis
  - ToT is very dependent on track-to-anode distance
    - normalisation with track length in straw L → compensation of this geom. effect
  - a likelihood variable can be formed analog to the HT case
    - to avoid correlation with HT variable, the HT hits are omitted in the sum/product → little loss
    - with respect to ToT the straws are assumed to behave identically

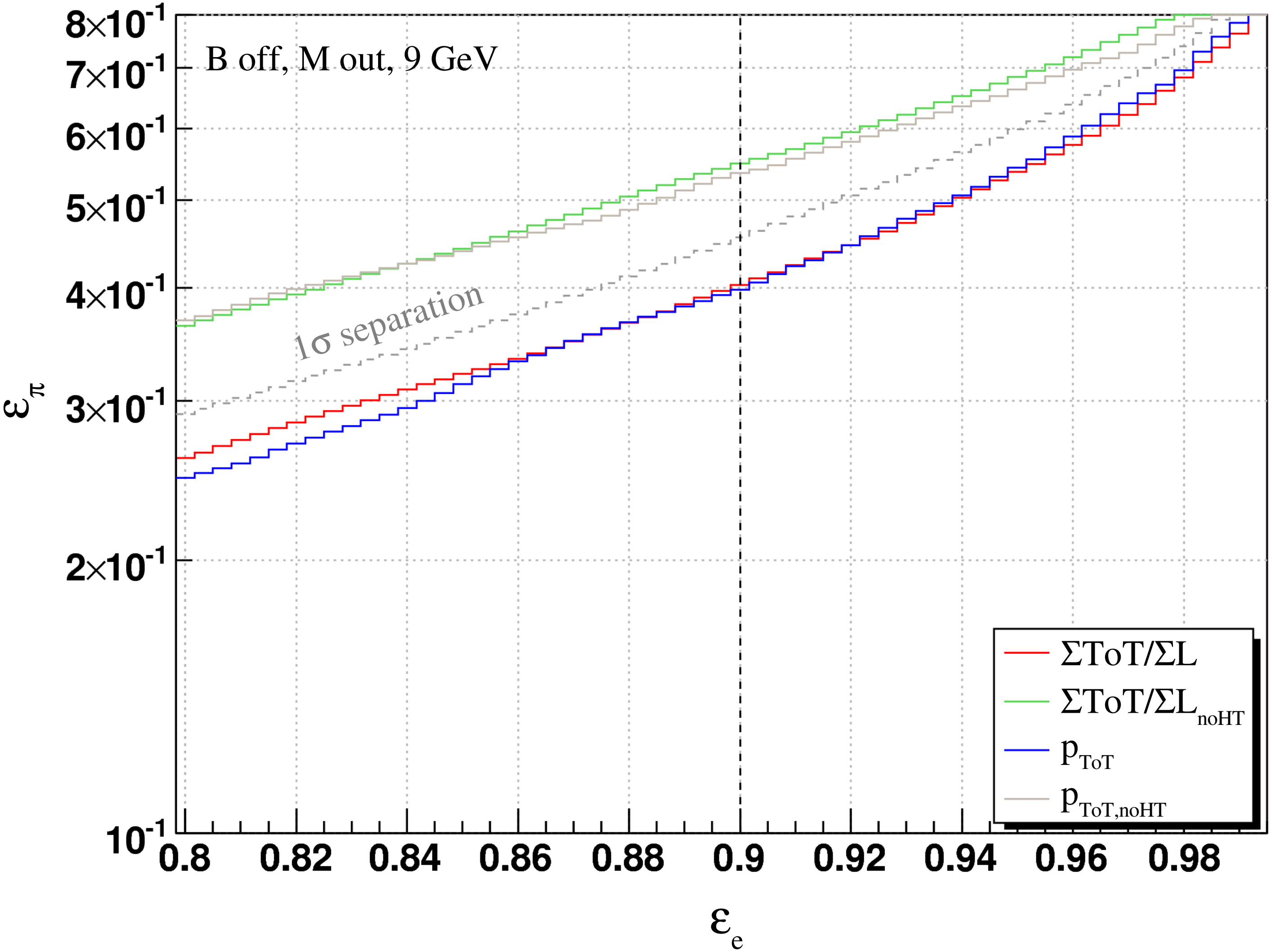
$$p^e_{ToT} = \frac{\prod_{i,noHT} p^e_{ToT,i}}{\sum_{j=e,\pi} \prod_{i,noHT} p^j_{ToT,i}}$$





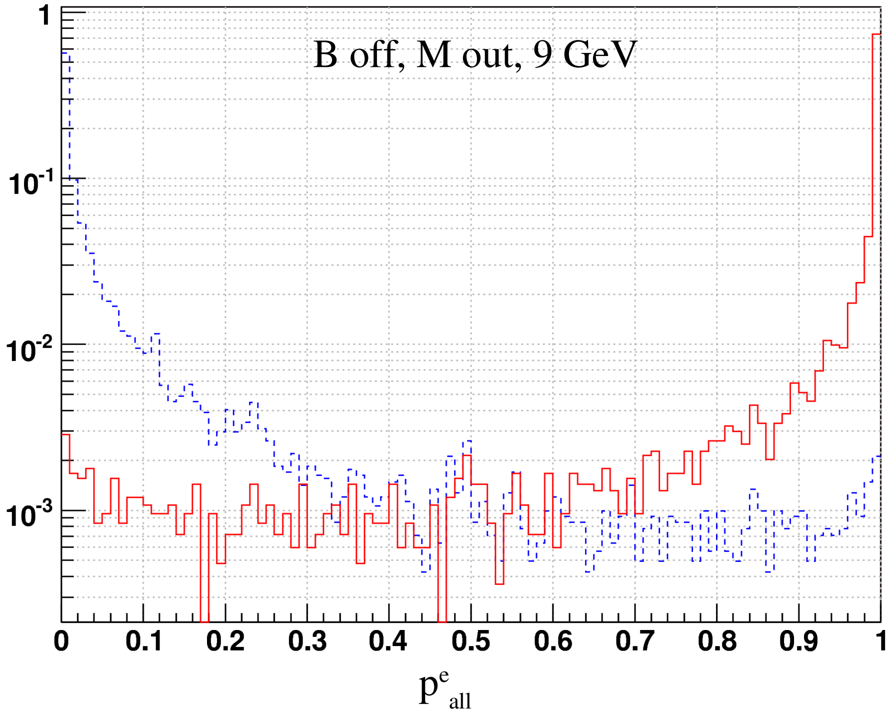
A Probability Based Approach to PID in the TRT

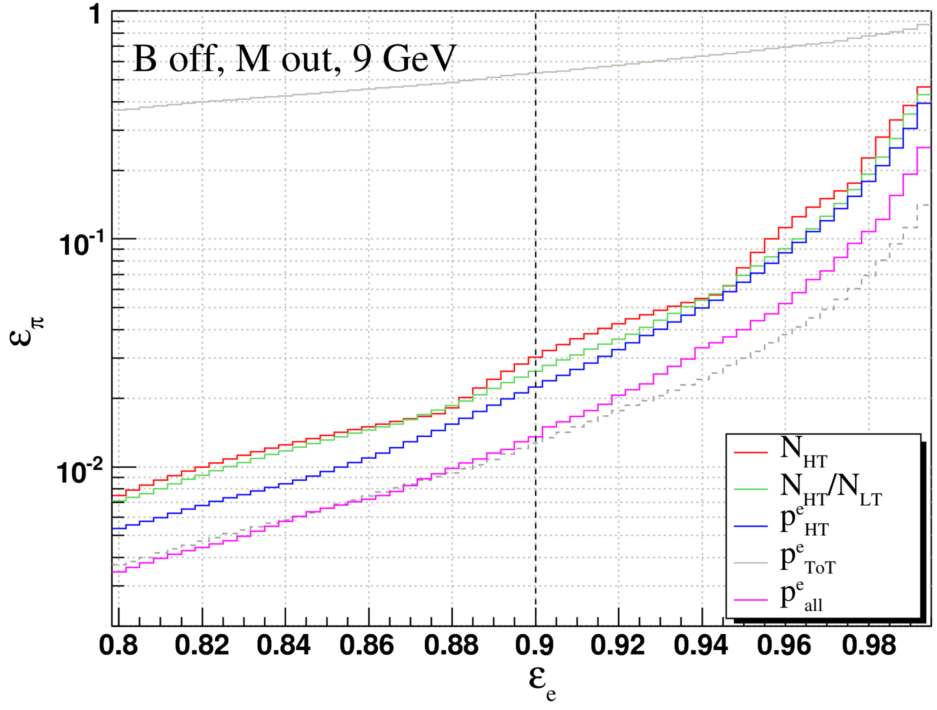
- Time-over-Threshold (ToT) Analysis



A Probability Based Approach to PID in the TRT

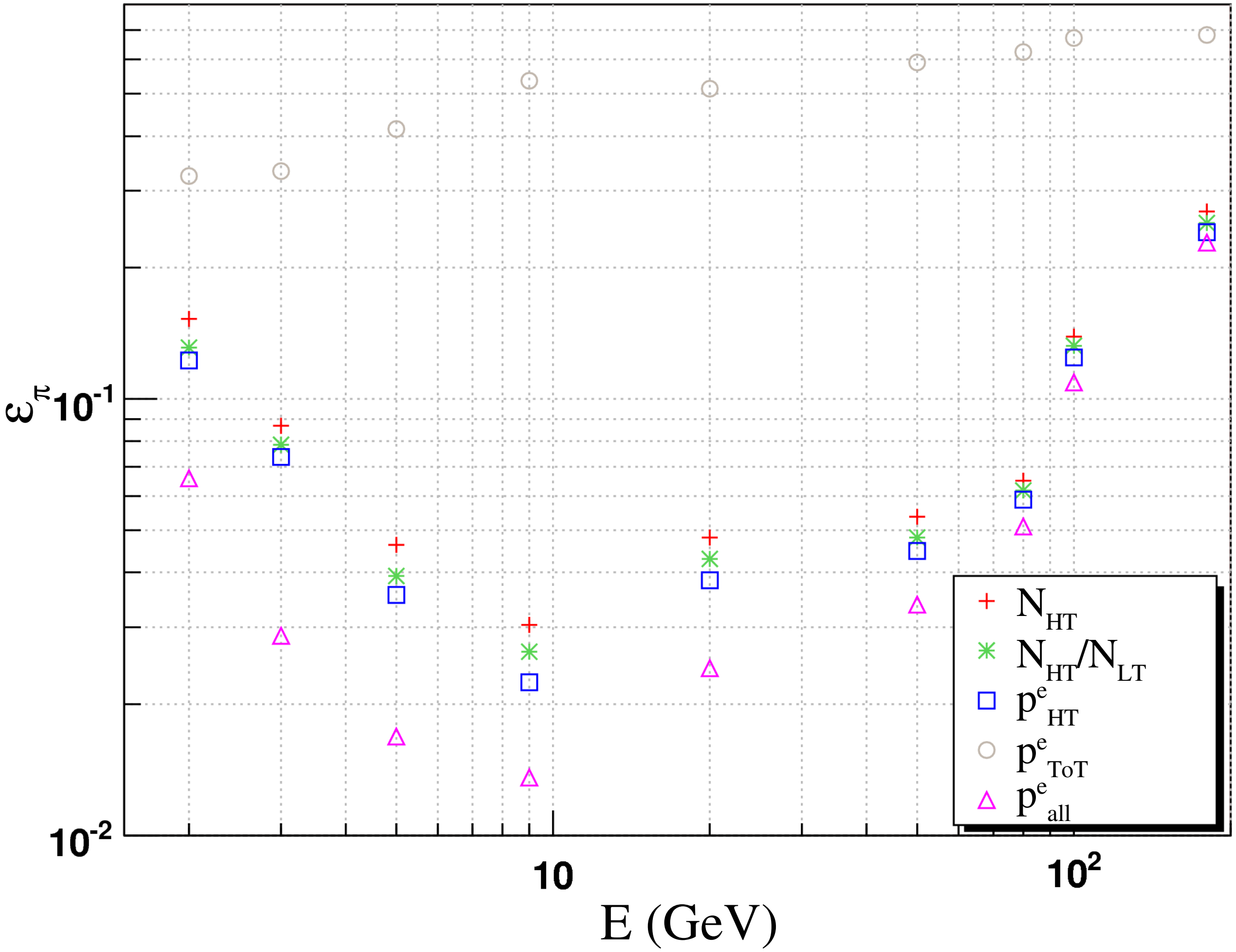
- Combining Variables
  - combining uncorrelated variables is done by $p^{e}_{all} = \frac{p^{e}_{HT}\, p^{e}_{ToT}}{\sum_{j=e,\pi} p^{j}_{HT}\, p^{j}_{ToT}}$
    - including HT hits in ToT variable gives sizable correlations
      → combination not possible
    - excluding HT hits in ToT variable, removes sizable correlation (ρ<0.3)
      → gives best result





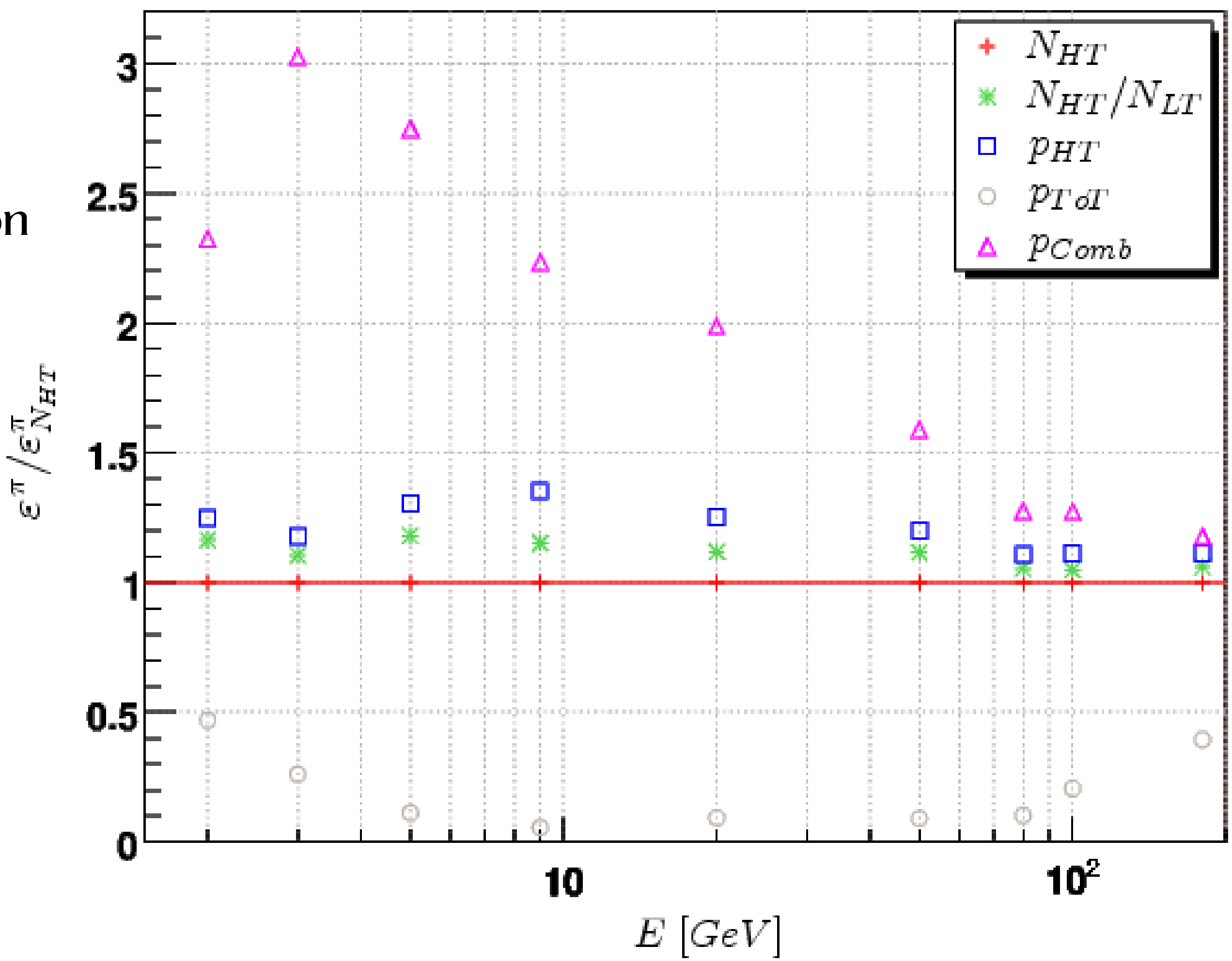
A Probability Based Approach to PID in the TRT

- Results on e/π separation
  - overall e/π separation varies with energy and is best around 10 GeV
  - pion rejection factor at 90% ε^{e} varies between 7 and 70



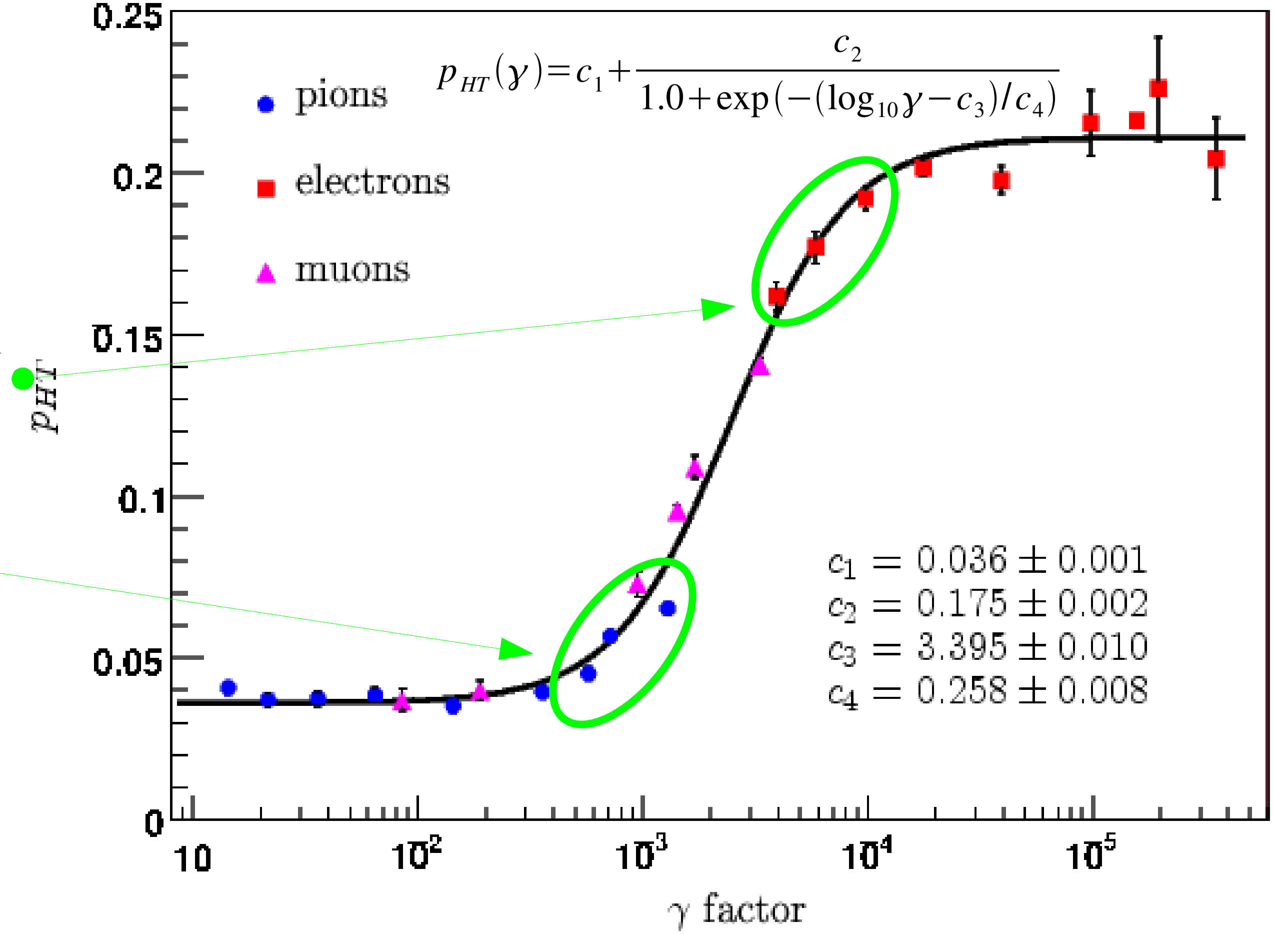
A Probability Based Approach to PID in the TRT

- Results on e/π separation – improvement over N_{HT}-method
  - relative improvement in terms of $\varepsilon_\pi/\varepsilon_\pi(N_H)$
  - normalising with N_{LT}
    5-20%
  - using HT likelihood
    10-40%
  - including ToT information
    30-50% (high E)
    80-300% (low E)
  - energy dependence of ToT separation as expected
    high at low energies,
    low at high energies



A Probability Based Approach to PID in the TRT

- Transition Radiation (TR) Onset
  - TR onset expected at γ~1000 (only calculated theoretically)
  - using given data along with muon runs on can measure $p^j_{HT}(E)$, j=e, π, μ
  - geometry change
    → low & high E slightly incomparable
    → correction applied
  - e onset seen at 2-5 GeV
    → bad for sep. at low E
  - onset seen at 180 GeV
  - simulation saturates at γ~2000 while data at γ~20000
    → tuning needed



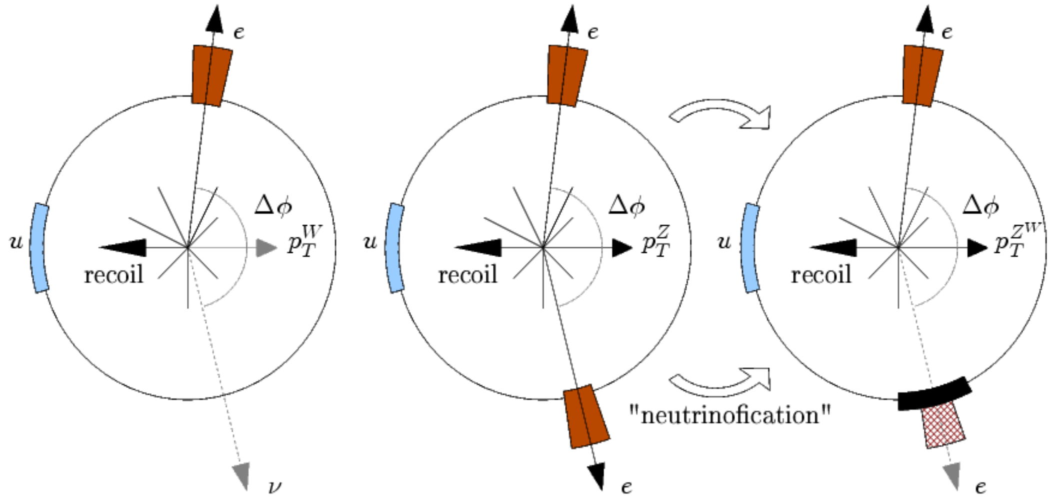
A Probability Based Approach to PID in the TRT

- Conclusions
  - using N_{HT}/N_{LT} improves separation (5-20%), still likelihood gives best results
  - e/π separation improves 40-300% (most at low energy)
  - pion rejection factors ($1/\varepsilon_\pi$) between 7 and 70
  - first TR onset measurement
    → results to be used as input for simulation

- Outlook
  - redo analysis with new software release (12.0.4/12.0.5)
    → all setups (B-field) can be used (big fixes in reconstruction software)
  - do Monte Carlo simulation of CTB runs (more stable/reliable with new releases)
    → compare real and simulated data
    → give input for simulation
  - do *reverse* analysis, yielding pion samples and electron rejection
    → can be used for tau identification/tagging
  - implementation of routines into the ATLAS software environment

ATLAS W Boson Mass Measurement Potential

- Goal
  - overall: measuring the W boson mass utilising the Z boson as a reference
  - this study: characterise the systematic error done by considering an incorrect theoretical model for the emission of real photons from the final state
- Measurement Strategy (Ratio Method)
  - W and Z events are very similar in their theoretical description
    → Z events can be treated as W events
    - involves treating one of the charged leptons as a neutrino → "neutrinofication"



- the W boson mass is extracted by fitting W distributions (preferentially m_T^W) to scaled distributions of the Z boson (scaling factor equals m_W/m_Z) and multiplying the scale factor, that optimises the fit, to the Z boson mass

ATLAS W Boson Mass Measurement Potential

- Systematic Uncertainties
  - the systematic error for the approximation of treating the Z as a W boson needs to be characterised
  - uncertainties mainly due to differences between the two bosons

Source	Effect	Impact on m_T^W	Impact on p_T^l
Production model	W width	1 MeV	1 MeV
	PDFs	. in progress, expected to be 4-8 MeV .	
	FSR, QED		
	Polarisation	. unknown, but considered very small .	
Lepton reconstruction	EM scale	4 MeV	5 MeV
	EM resolution	3 MeV	5 MeV
	EM linearity	4 MeV	5 MeV
	Lepton efficiency	.... in progress	
Recoil reconstruction	Recoil scale	5 MeV	—
	Recoil resolution	3 MeV	—
	Recoil linearity	in progress	—
	Lepton removal	in progress	—
Backgrounds	$W \to \tau\nu$	.... in progress, but small	
	$Z \to l(l)$	.... in progress, but small	
	QCD events	.... in progress, but small	
Statistics		1.8 MeV	3.2 MeV
Total		<15 MeV !?	< 15 MeV !?

  - while most systematics are reduced by increasing statistics, the PDF and QED/FSR uncertainties wont (or just slowly in case of PDFs)

ATLAS W Boson Mass Measurement Potential

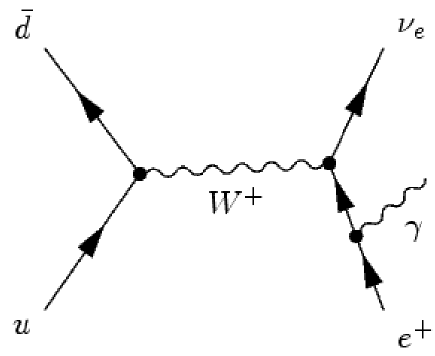
- Data Sets
  - essentially three samples
    1. fully simulated and reconstructed events from CSC11 sample (11.0.42) to get detector response
       (~17k Weν, ~280k Zee, ~19k Wμν, ~31k Zμμ)
    2. fast simulated events in different orders (0^{th}, 1^{st}, 2^{nd}, 4^{th}, exp)
       (100k for each type and order)
    3. ToyMC production (based on the two subsets above)

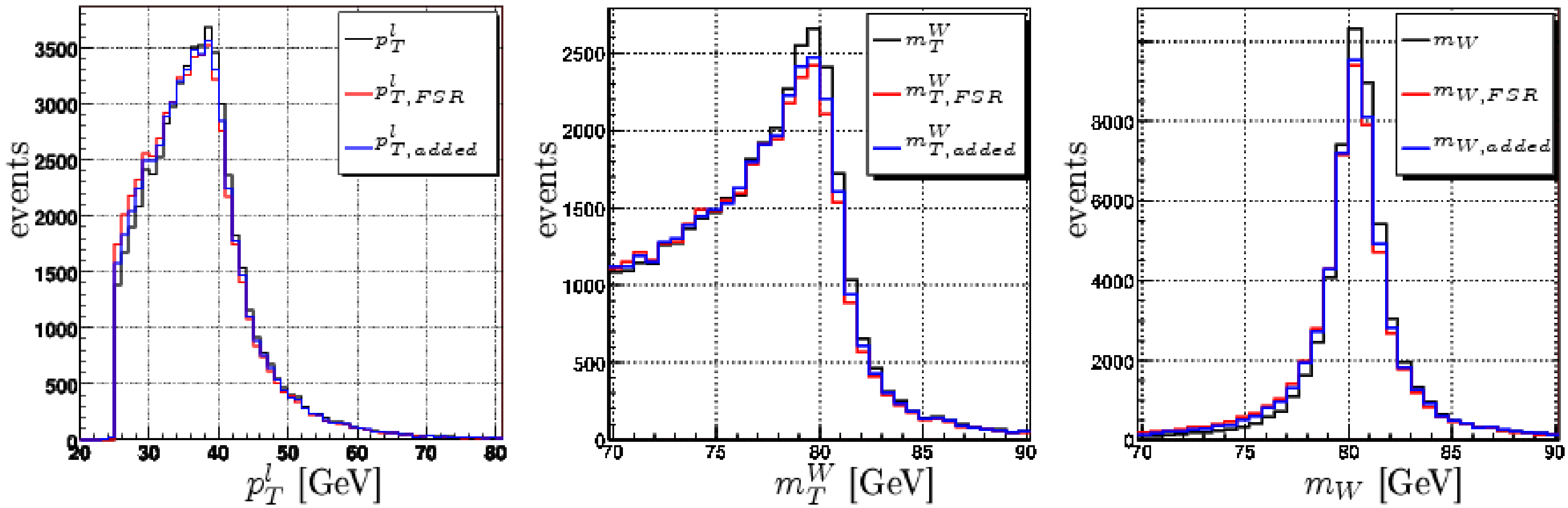
- Selection Criteria
  - W events without jets
    $p_T^l > 25$ GeV, $\eta < 2.4$ (excluding $1.3 < \eta < 1.6$)

- Evaluation of the Uncertainty
  - looking for the difference in the production model, with respect to FSR, between the two bosons
  - measure the stability of this against successive theory improvements (orders in QED)
  - yielding an uncertainty for considering an incorrect theoretical model for FSR when treating the Z boson as a W boson

ATLAS W Boson Mass Measurement Potential

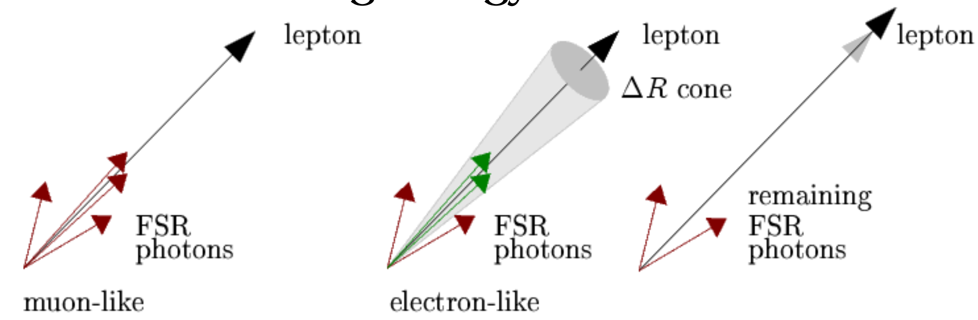
- Influence of Final State Radiation (FSR)
  - the emission of (real) FSR photons causes a drop in the energy of the leptons
    → and thereby a reduction of the
    - transverse lepton momentum
    - transverse mass of the boson
  - happens for both bosons
    → effect on m_W/m_Z is small



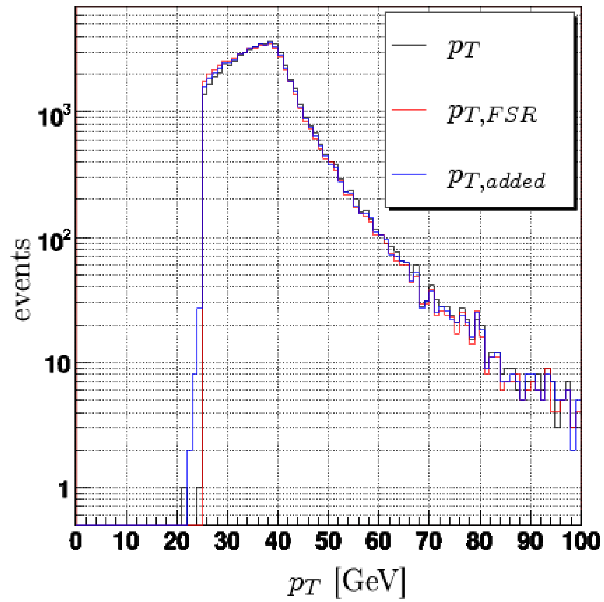


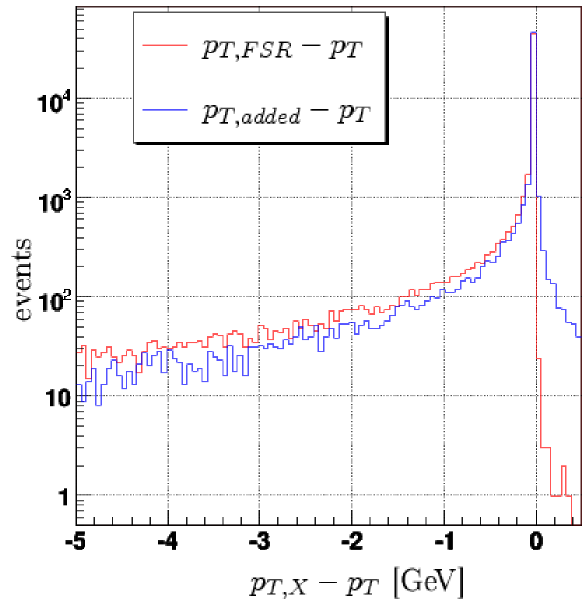
ATLAS W Boson Mass Measurement Potential

- Influence of Final State Radiation (FSR)
  - Generator level study (using FastSim data)
    - transverse momentum stored before (p_T) and after ($p_{T,FSR}$) FSR effects added
    - $p_{T,added}$ represents re-summing energy within a cone of $\Delta R=(\Delta\varphi^2+\Delta\eta^2)^{1/2}<0.07$



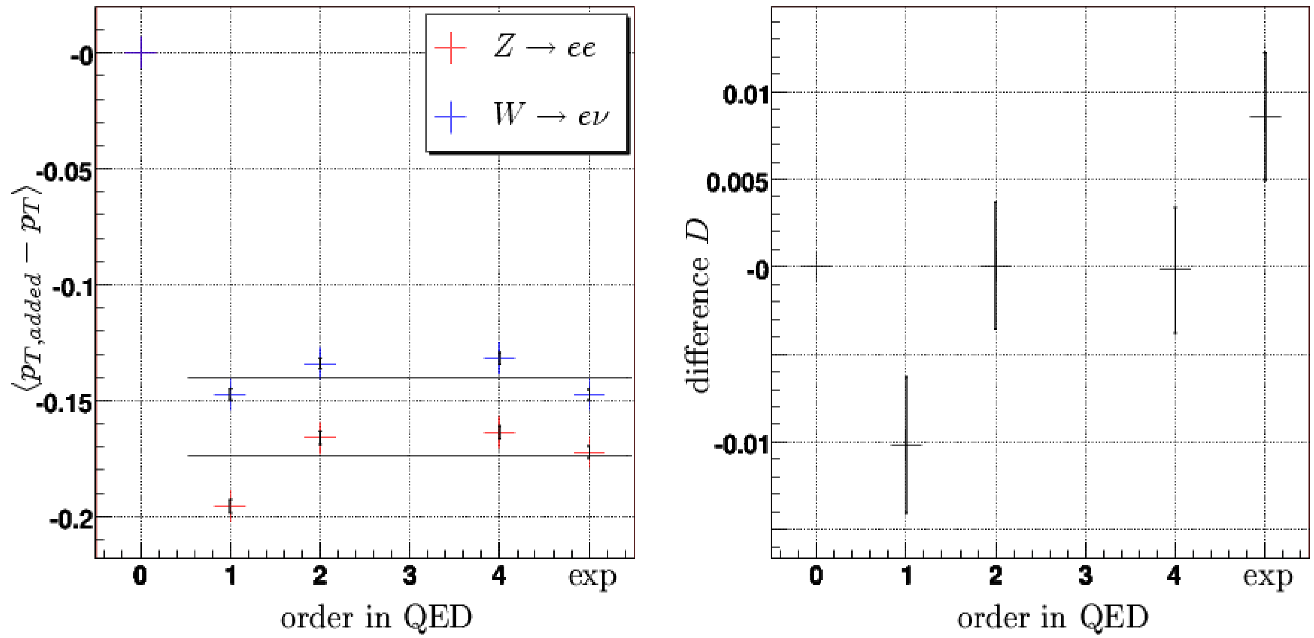
    - taking the residuals (e.g. $p_{T,FSR}-p_T$), the effect of FSR can be quantified





ATLAS W Boson Mass Measurement Potential

- Influence of Final State Radiation (FSR)
  - Generator level study
    - since only the difference between W and Z bosons is of interest, the two are subtracted: D(order) = X(Z,order) * weight – X(W,order)



- the RMS/stability of this difference over orders can be used as an estimate for the final systematic uncertainty on the transverse momentum and is measured to be about 3.8 MeV (2.4 MeV) for electrons (muons)
- at leading order, the effect on the W mass is twice the size, yielding 7.6 MeV (4.8 MeV) for electron (muons) as the final uncertainty for considering the wrong theoretical model for FSR

ATLAS W Boson Mass Measurement Potential

- Influence of Final State Radiation (FSR)
  - Detector level study
    - fully simulated and reconstructed data only available in exponentiated mode
    - to introduce differences with increasing orders, information from FullSim is combined with information from FastSim
      - FullSim is used to extract the effect of a certain number of FSR photons on the transverse momentum of the lepton
      - FastSim is used to get realistic fractions of events with a certain number of FSR photons for each order
    - combining this in a ToyMC, the same procedure as discusses before can be applied
    - due to the inclusion of detector effects (e.g. bremsstrahlung caused by material) the effects of FSR photons are essentially smeared out in the electron case
    - for muons (not suffering bremsstrahlung effects) the effect on the transverse momentum turns out to be 7.2 MeV, yielding 14.4 MeV for W boson mass
    - only a very rough upper estimate, since additional detector effects will cause a spread of the residuals and therefore make this value appear larger
  - due to this and the fact that the weakest point in the analysis is the connection between FullSim and FastSim, the values from the generator study are considered more trustworthy – 7.6 MeV (4.8 MeV) for electron (muons)

A Probability Based Approach to PID in the TRT