Fast Shower Simulation in ATLAS Calorimeter

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On behalf of the Atlas-Calorimeter and
Atlas-Fast-Parameterisation Groups

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- Introduction
- Acceleration Strategies
    - Fast shower parameterisation
    - Frozen shower library
- Performance

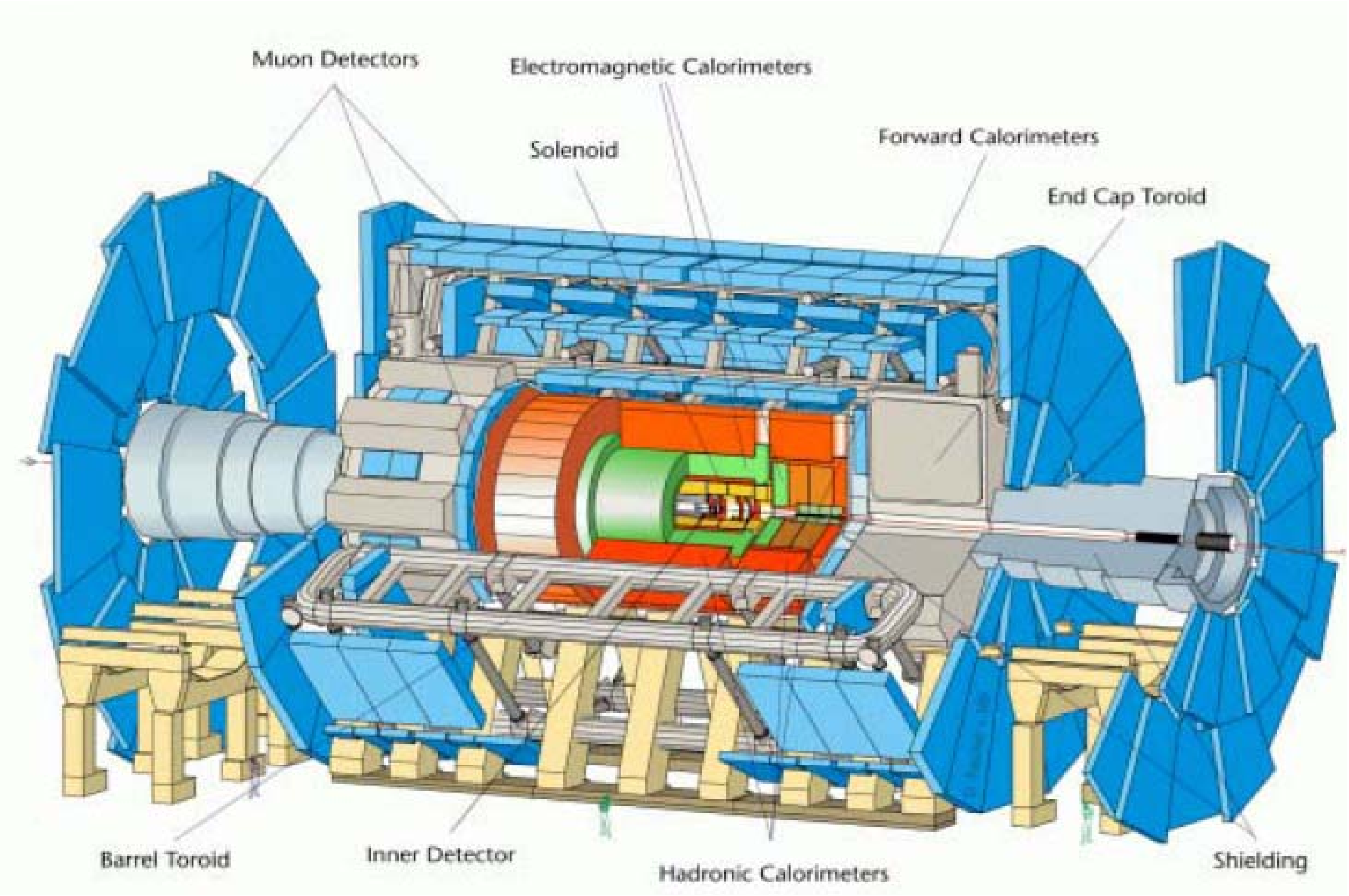
Introduction

Sample	Z -> e+e-	di-jets	SUSY
Subsystem	Time/Event [%]		
Tracker	3,7	3,8	4,4
Calo - barrel	5,9	7,3	11,0
Calo - endcap	32,0	46,1	33,9
Calo - forward	33,4	14,5	20,6
Calo - hadronic	3,0	6,6	4,7
Muon	5,7	6,4	8,0
Other	9,8	9,0	9,7
Dead	6,5	6,3	7,7
Event	7,7 min	13,6 min	12,8 min

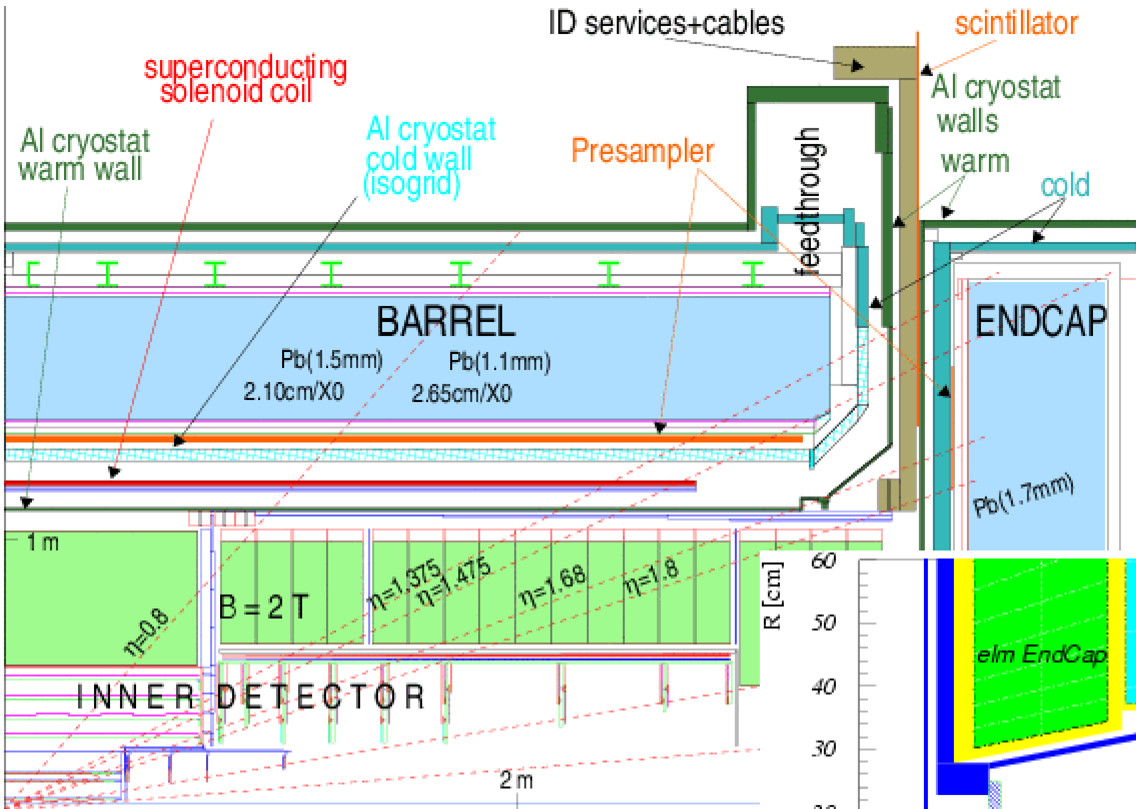
- **Simulating the ATLAS detector in Geant4 takes around 10 minutes for an average physics event (not including digitization)**
- **Interaction rate for average physics processes (jets, W->lv, Z->ll, $t\bar{t}$) is between 10 to 1000 Hz**
- **Main time is spend in the calorimeter system**

Improve time consumption of EM shower simulation in order to reduce overall simulation time and increase Monte Carlo data sample

The ATLAS Detector



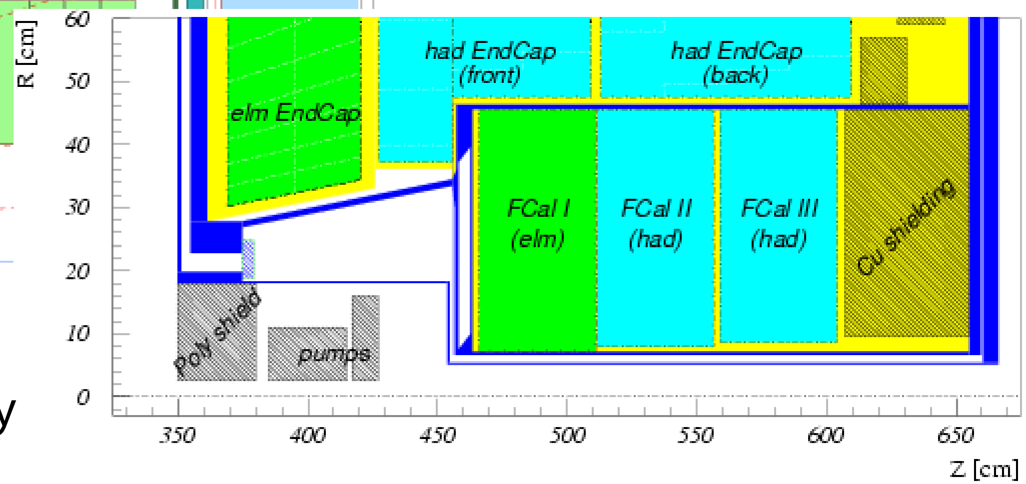
The ATLAS Calorimeter



4 calorimeters use Liquid Argon technology:

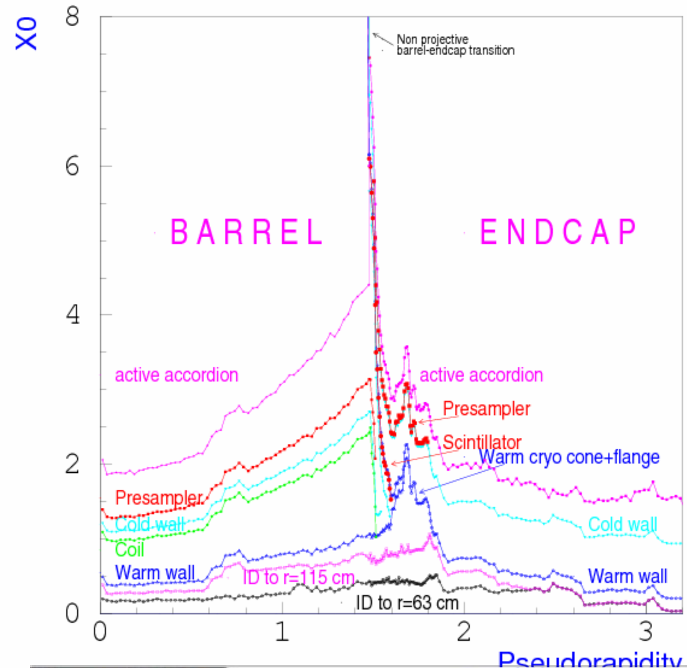
Barrel, Endcap, Forward and Hadronic Endcap

LAr used for radiation hardness and speed



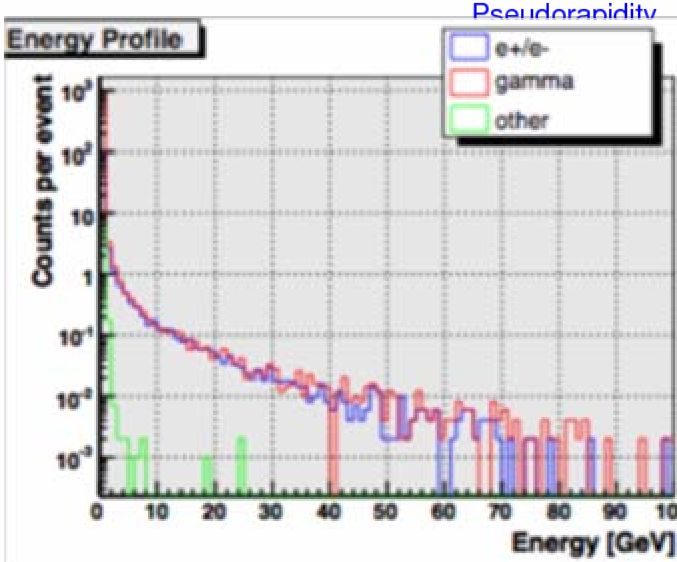
Barrel and Endcap:
Accordion structure for ϕ uniformity

Accelerating Simulation



Three different approaches:

- **High energy electrons (> ~1 GeV): fast shower parameterisation**
  - Describe longitudinal and transverse shower profile by functions
- **Low energy electrons (< ~1 GeV): frozen shower library**
  - Describe shower by pre-stored hits (frozen shower)
- **Very low energy electrons (< ~10 MeV): one spot model**
  - Substitute very low energy electrons by one energy deposit
- **Photons are electrons (pair production)**



These techniques are implemented into the ATLAS Geant4 detector simulation deriving from GFlashShowerModel (Geant4).

Fast Shower Parameterisation Technique

A treatment for showering electrons on a sound mathematical footing is available for electrons:

- Grindhammer, Peters - hep-ex/0001020
- Grindhammer, Rudowicz, Peters - NIMA290:469(1990)

- Describe longitudinal and transverse shower profile by functions

- Estimate parameters from fully simulated showers (Geant4) as a function of a few kinematic quantities
  1. Longitudinal profile (Γ function)
  2. Transverse profile (rational function)
- At simulation time substitute an EM shower by random hits sampled from functions for the transfers and longitudinal shower profile at steps of 1/100 X0.

- Approach valid for energies above ~GeV and homogeneous calorimeter

Fast Shower Parameterisation Technique

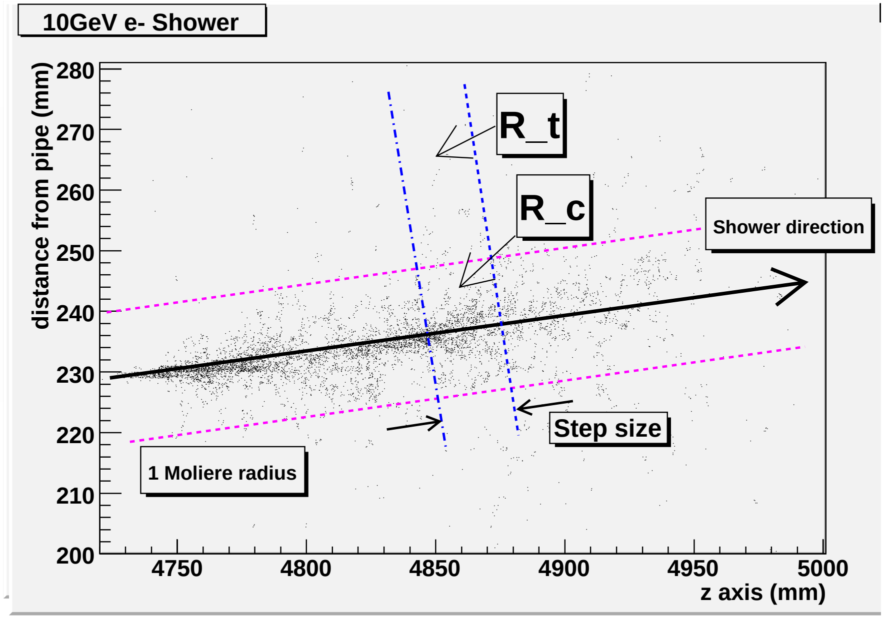
- **Longitudinal shower profile:**

$$< \frac{1}{E}\frac{dE(t)}{dt} >= \frac{(\beta t)^{\alpha-1}\beta exp(-\beta t)}{\Gamma(\alpha)}$$

t =longitudinal depth into shower

α =shape parameter

β =scaling parameter



- **Transverse shower profile:**

$$< \frac{1}{E(t)}\frac{dE(t,r)}{dt} >= p\frac{2rR_C^2}{(r^2+R_C^2)^2} + (1-p)\frac{2rR_T^2}{(r^2+R_T^2)^2}$$

$R_C(t)$ =the median of the energy distribution of the core of the shower

$R_T(t)$ =the median of the energy distribution of the tail of the shower

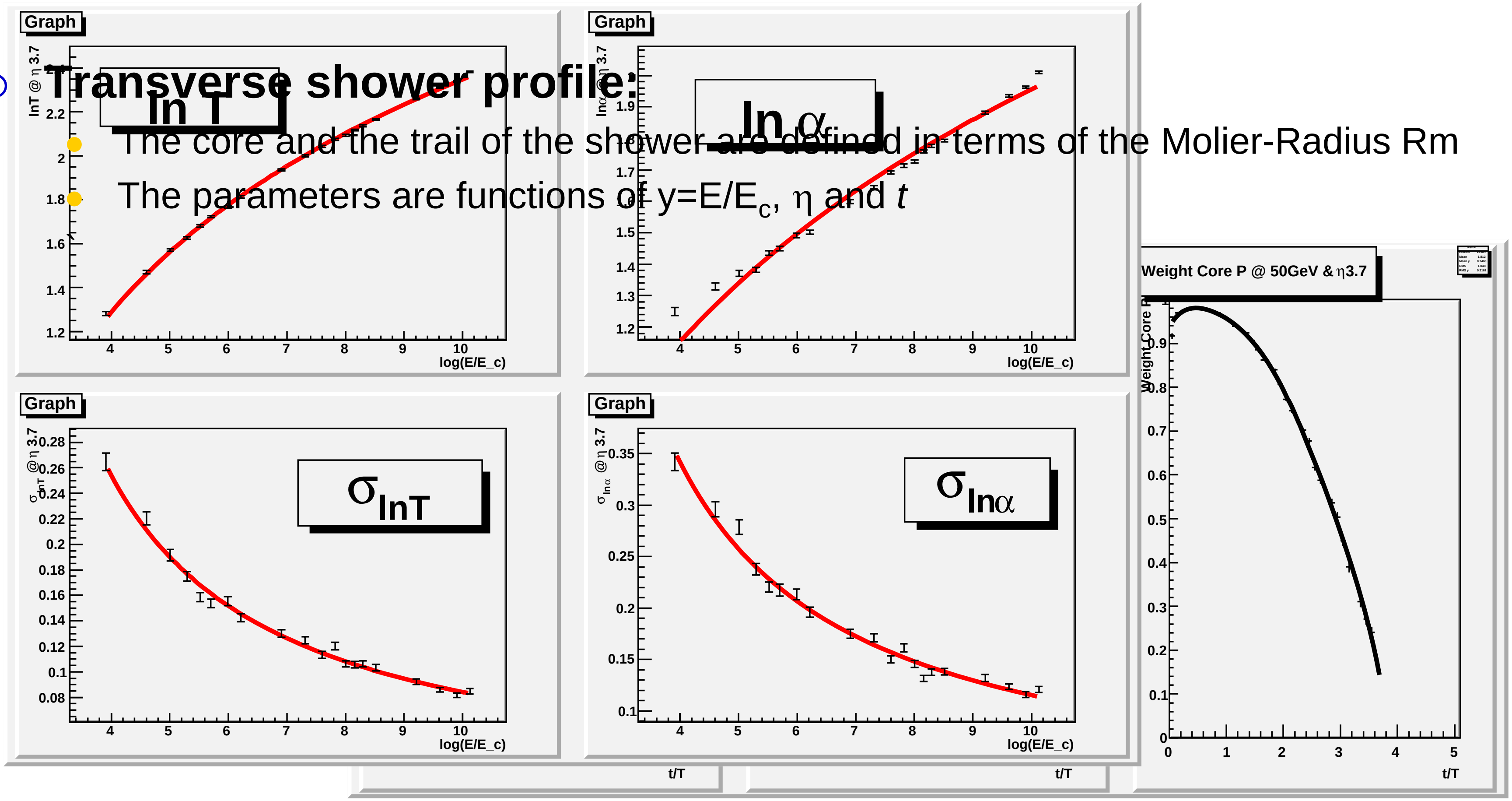
p is a weighting function

$$p(t) = E_{core}(t)/E_{tail}(t)$$

Parameter Extraction: Forward Calo

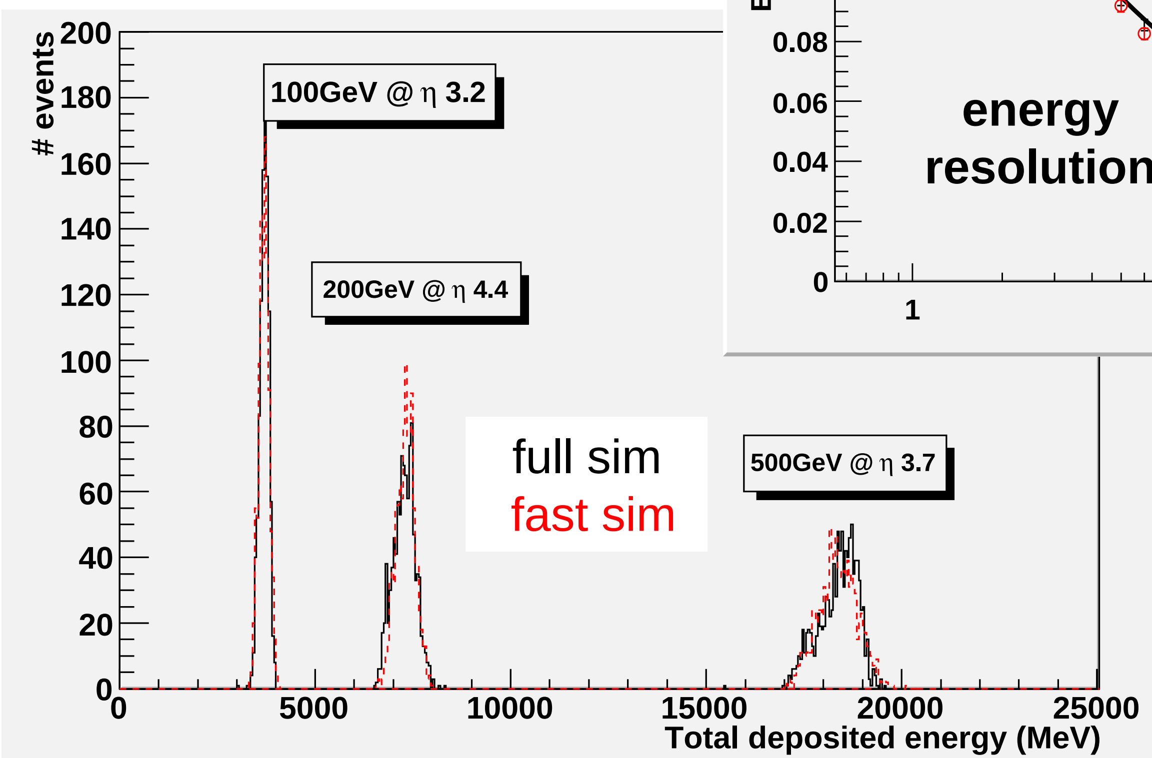
- **Longitudinal shower profile:**
  - $T = (\alpha-1)/\beta$ and α are functions of $y=E/E_c$ and η
  - T and α are related to moments of the profile

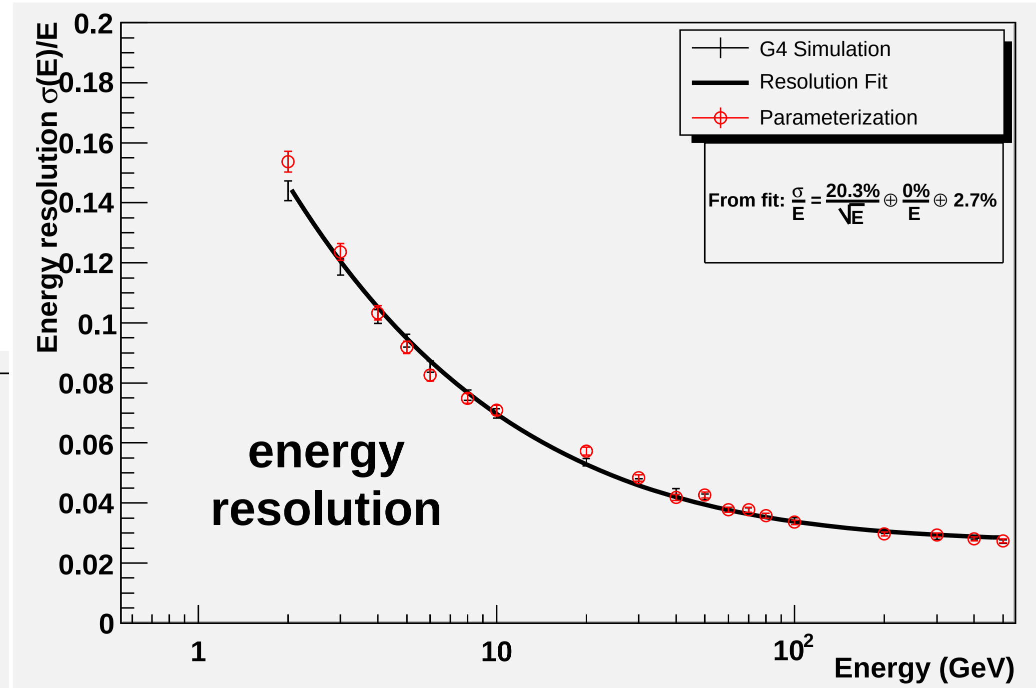
- **Transverse shower profile:**
  - The core and the trail of the shower are defined in terms of the Molier-Radius Rm
  - The parameters are functions of $y=E/E_c$, η and t



Performance in Forward Calorimeter

Energy deposition from electrons





- **Parameter extraction complex**
- **Approach valid for high energies**

Good description of full and fast simulation!

Frozen Shower Technique

- **In short:**
  At simulation time substitute electron shower below an energy cut-off using pre-stored hits.
  (Similar approach as for minimum bias events or in computer games, where small parts are produced by pre-stored animations.)

- **Idea:**
  - Store only showers for a few discrete Energies and η values (bins) in a library
  - Substitute incoming electron below energy cut-off by one shower from the library (get shower from library, interpolate E and η, transform coordinates)
  - Reuse showers from library many times

- **Design goals:**
  - Significant speed up
  - Good agreement with full simulation
  - Reasonable resource consumption (disk/memory)

Frozen Shower Technique - Details

Frozen Shower generation:

- Simulate electrons starting from the front of the calorimeter with fixed Energy, η, ϕ
- Store only energy deposits in the sensitive detector (including sampling fluctuations and response)
- Use local coordinate system (along particle direction) for hit position
- Compress energy deposits

- Create library with many showers

Simulation time:

- If incoming electron is in correct energy range substitute it with a frozen shower
- Pick shower randomly from adjacent Energy and η bins
- Interpolate energy and η
- Transform position of energy deposits into global coordinate system
- Put energy deposits back into simulation using dedicated sensitive detector

- For different electrons cycle through the frozen shower library in η and *E* bins

Reduction of Frozen Shower Size

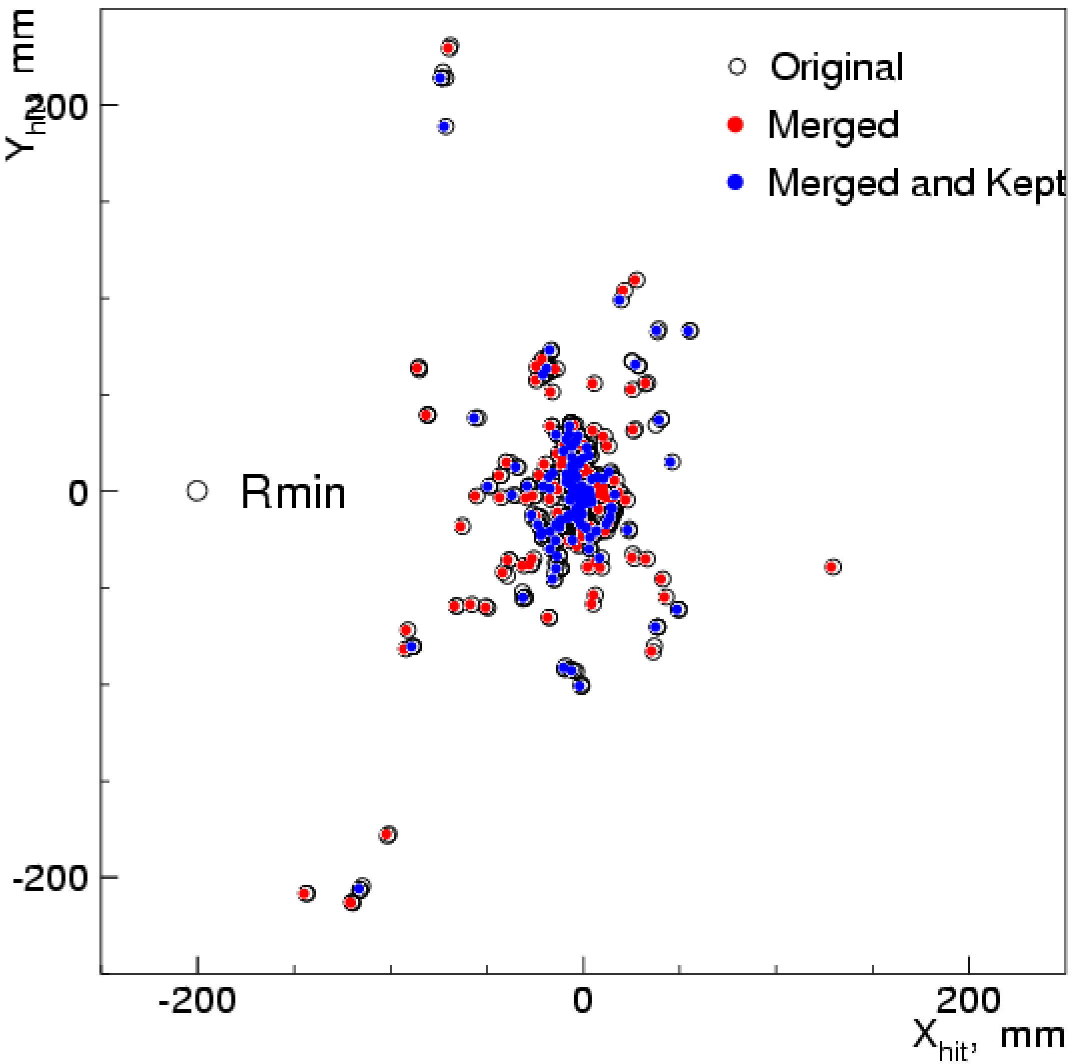
Clustering:
- Find a pair of energy deposits with the smallest spacial separation R
- If $R < R_{min}$, replace the pair by one deposit at the center of energy
- Repeat first step

Truncation:
- Sort deposits following the energy
- Calculated running sum
- Keep deposits corresponding to fraction f of the total energy

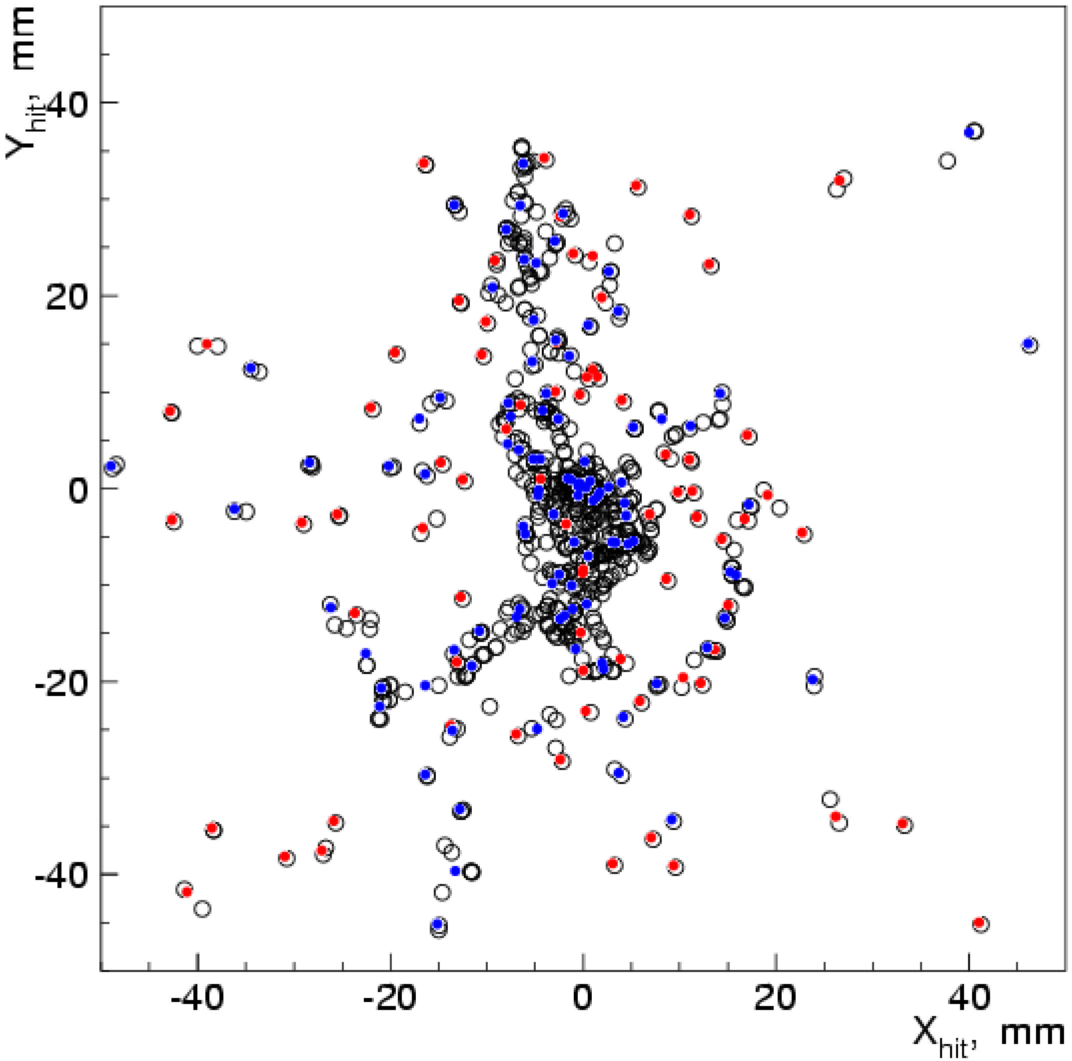
Rescaling:
- Rescale x_i-x_{ave}, y_i-y_{ave} for the remaining deposits such that the second momentum of the original shower is preserved

Use R_{min} = 5 mm and f = 95%.

Reduction of Frozen Shower Size

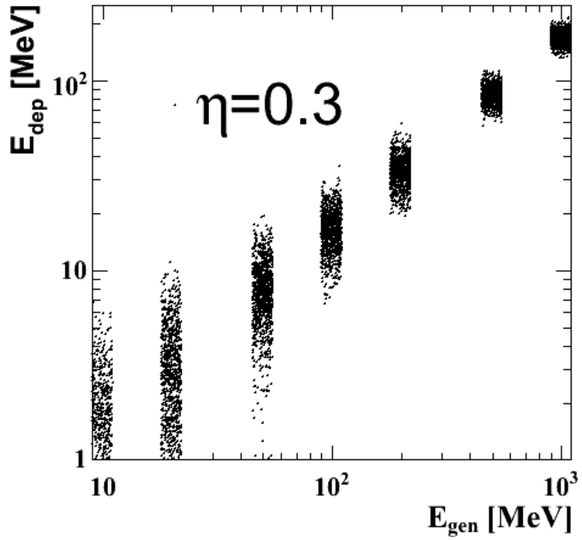


Reduction of Frozen Shower Size - Zoom



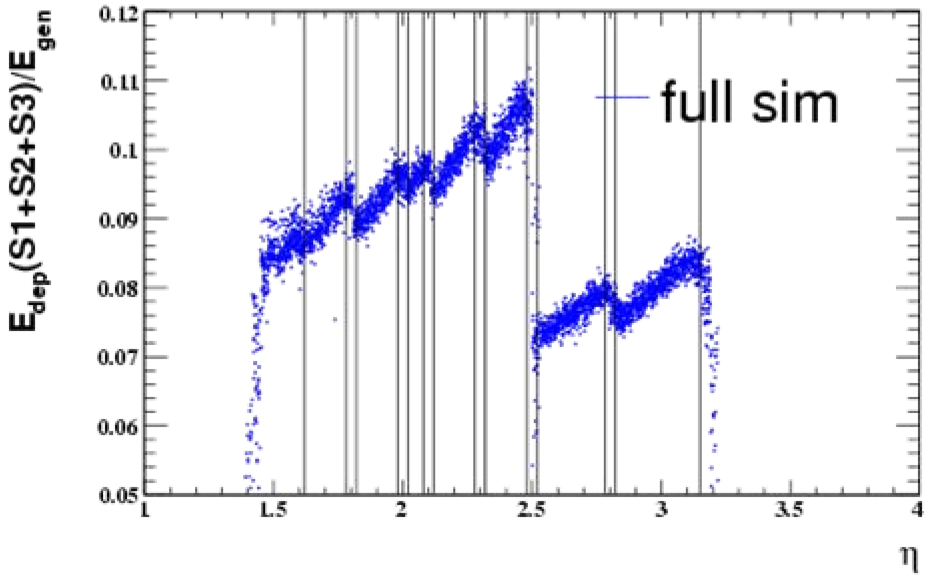
Optimization of Frozen Shower Library

- **Energy binning:**
  - 10, 20, 50, 100, 200, 500, 1000 MeV
  - ➢ smooth distribution of deposited energy over all bins

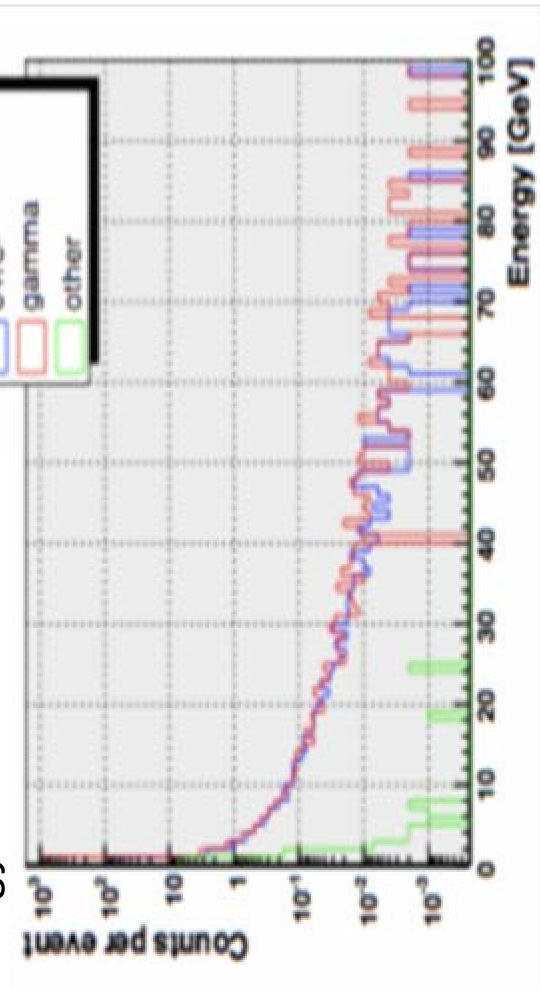


- **η binning:**

  Accordion structure is non-pointing
  - Effective sampling fraction varies with η
  - Compensation by change of absorber depth
    - Barrel: η=0.8
    - Endcap: η=2.5
  - Compensation by HV (Endcap)



Simulation Strategy



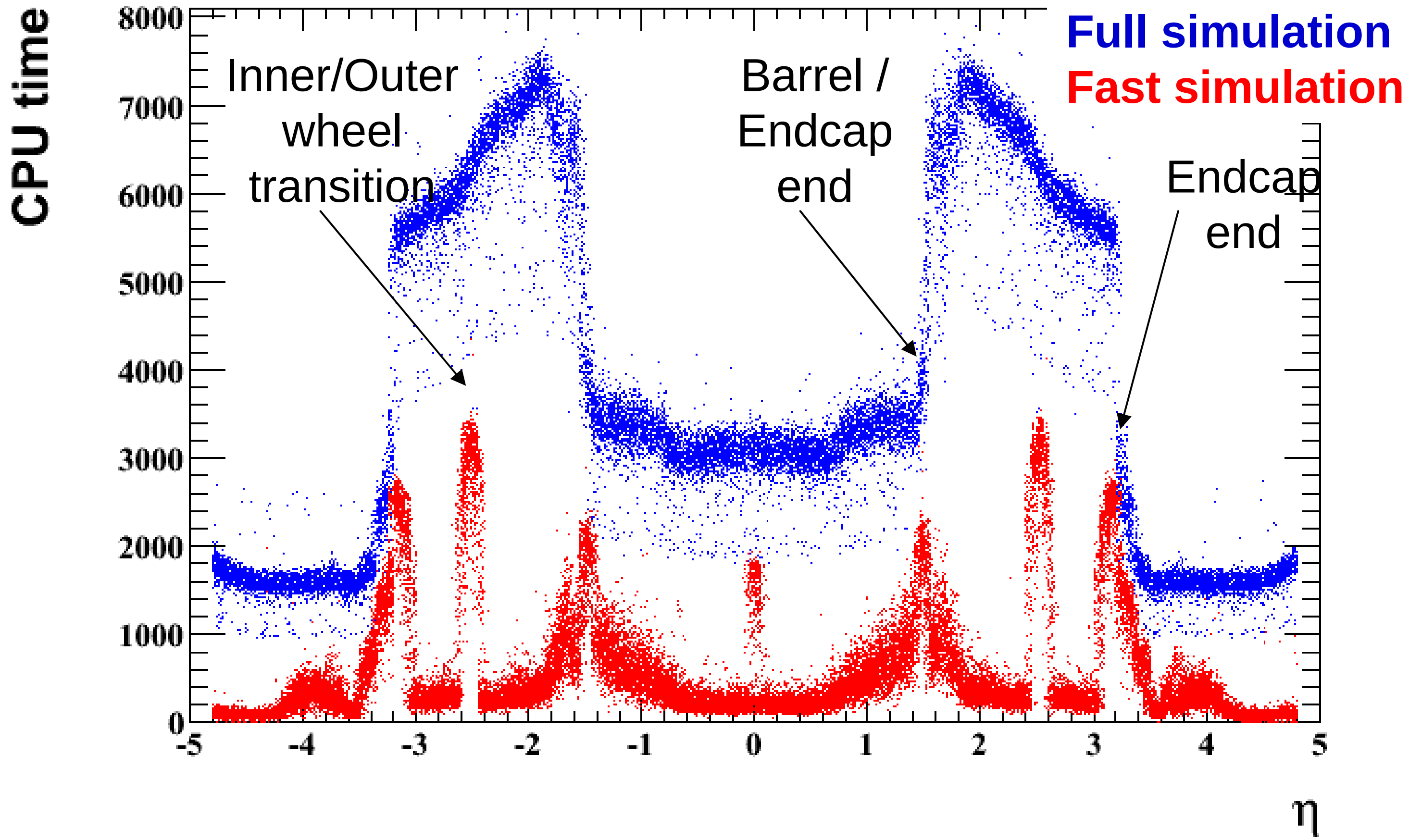
Energy Profile in Barrel

Barrel/Endcap		Forward
Full Simulation (Geant 4)	∞	Parameterisation
Frozen Showers	1 GeV	Full Simulation (Geant 4)
	0.5 GeV	
Killing	10 MeV	Killing

Results - Timing

Single electrons/positrons with E=50 GeV from IP:

- **average time gain of 10**
- **Cracks and intersections clearly visible**



Results - Timing of Physics Events

Single electrons/positrons

	full [s]	fast [s]	improvement
Barrel	2,3	0,7	3,3
Endcap	4,4	0,9	4,9
Forward	1,1	0,4	2,8

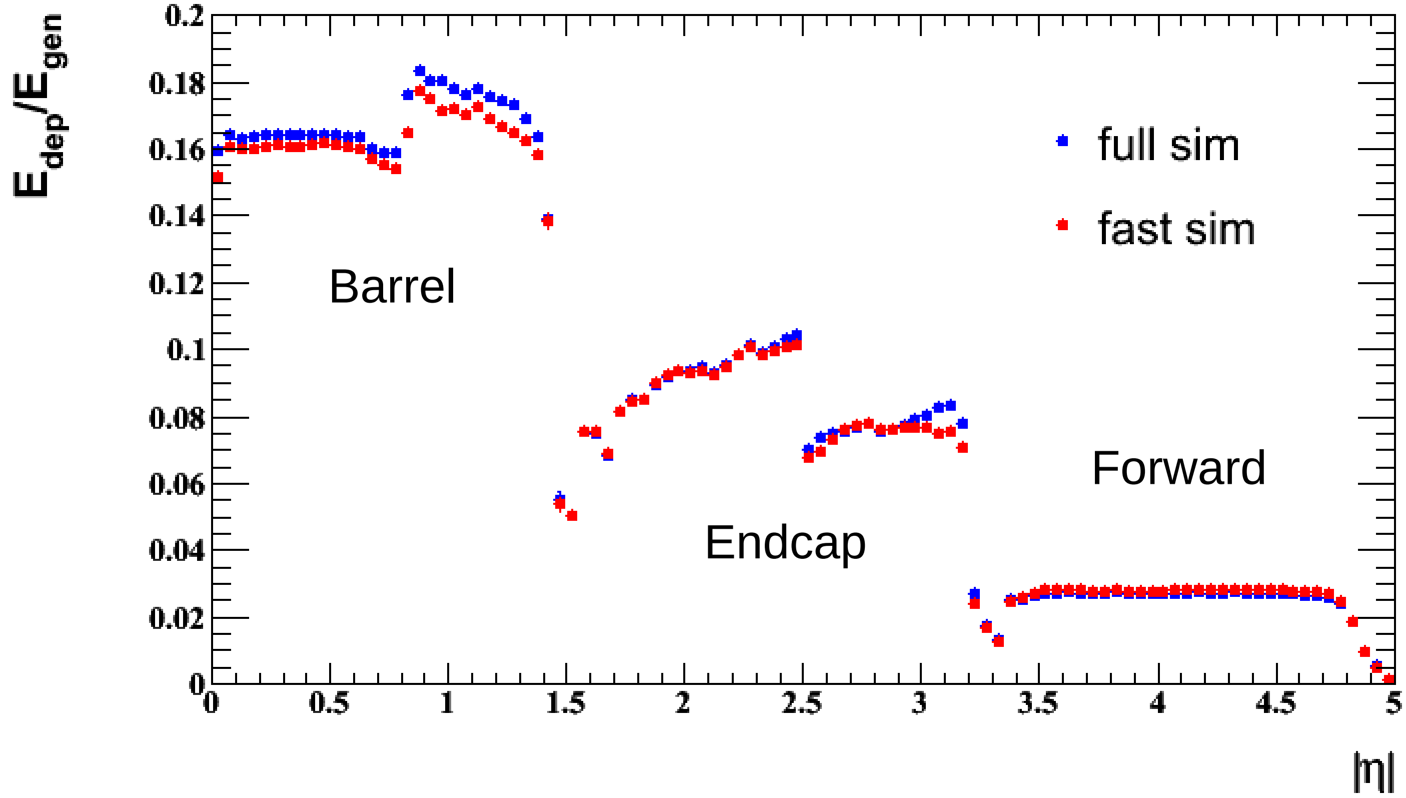
acceleration factor: ~2

Physics events

	Z -> e+e-		di-jets		SUSY	
	full	fast	full	fast	full	fast
Subsystem	Time/Event [%]					
Tracker	3,7	7,8	3,8	7,2	4,4	8,0
Calo - barrel	5,9	6,0	7,3	5,8	11,0	7,7
Calo - endcap	32,0	24,0	46,1	27,1	33,9	23,0
Calo - forward	33,4	19,0	14,5	10,9	20,6	12,1
Calo - hadronic	3,0	5,7	6,6	13,4	4,7	10,3
Muon	5,7	13,0	6,4	12,5	8,0	13,9
Other	9,8	11,7	9,0	12,0	9,7	12,3
Dead	6,5	12,7	6,3	11,1	7,7	12,7
Event	7,7 min	3,3 min	13,6 min	6,5 min	12,8 min	6,3 min

Results - Deposited Energy

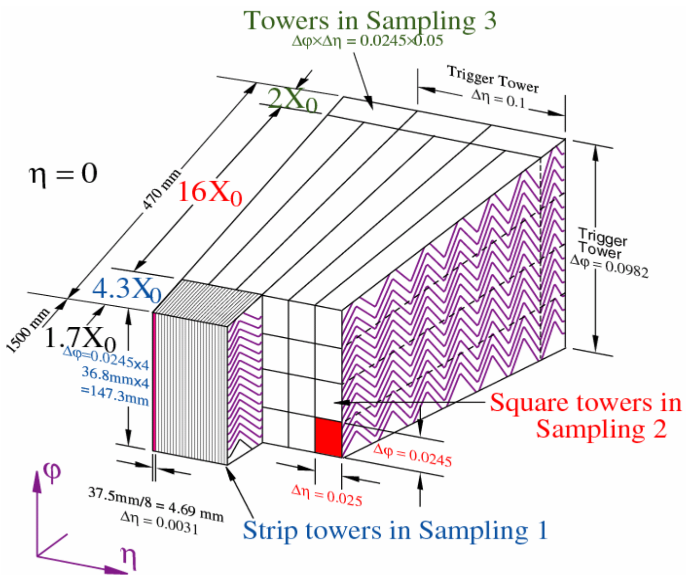
- **50 GeV Electrons/Positrons from IP, flat distribution in ϕ:**

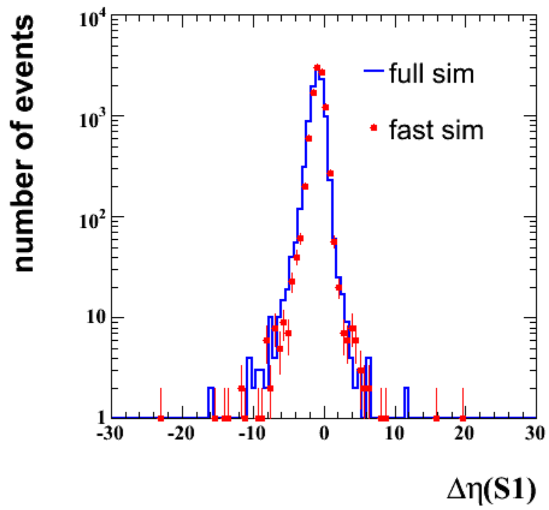


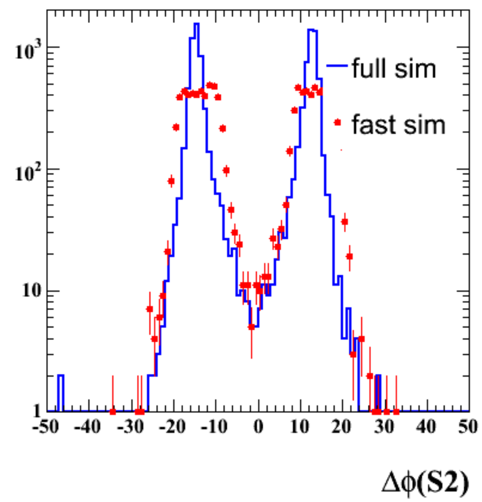
- Overall agreement is good
- Small, constant offset in barrel
- Some discrepancy around edges in endcap

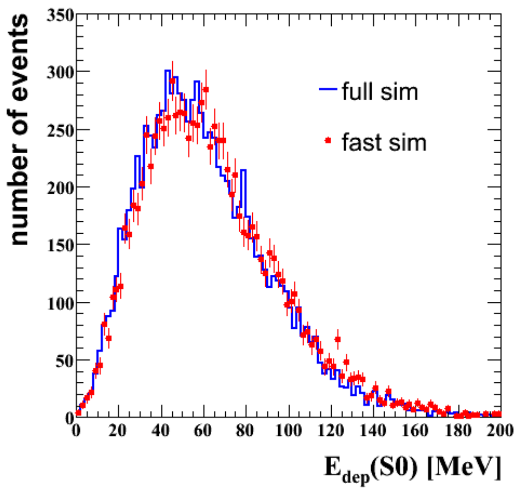
Other Quantities at Generated Level

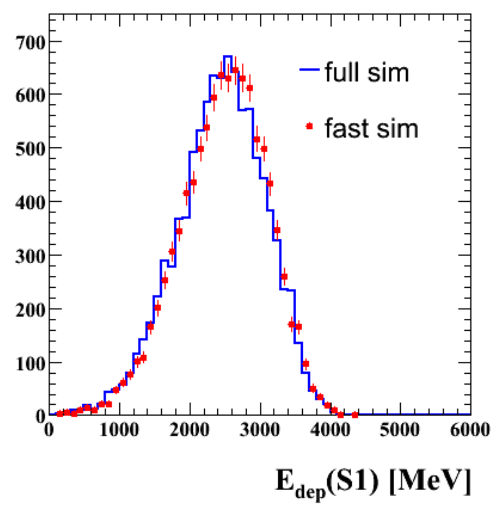
50 GeV e^+/e^- from IP, flat ϕ, η=0.25









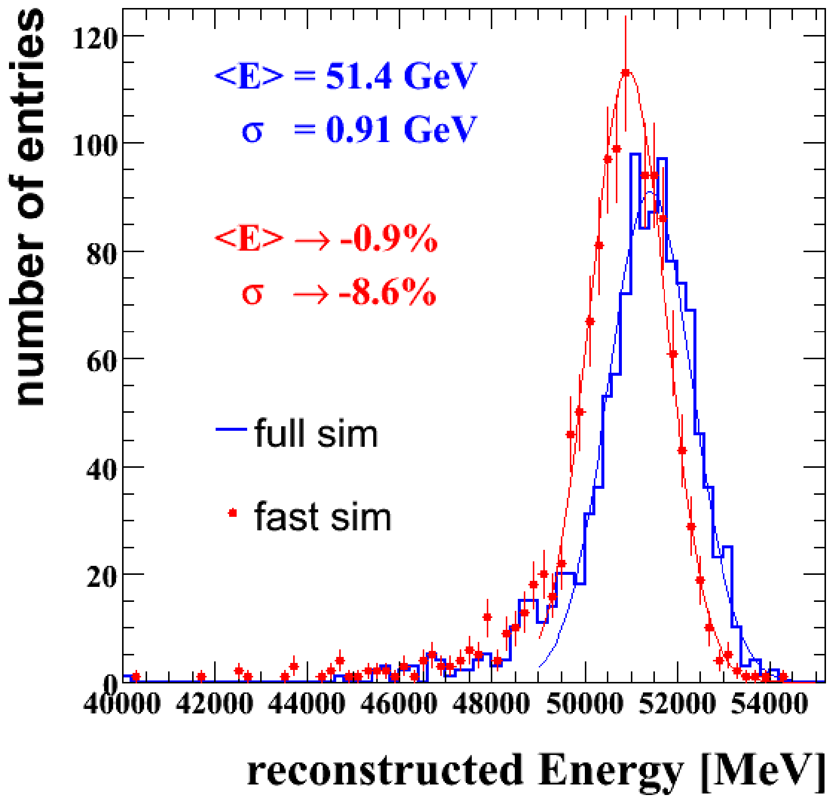


- **Overall agreement is good**
- **Small shift in deposited energy**
- **ϕ resolution in 2nd sampling needs better modeling**

Reconstructed Energy

- **Quantities at simulation level look good**
- **How about reconstruction level?**

50 GeV e^+/e^- from IP, flat ϕ, η=0.25



- **How good is this?**
  - For this first attempt: good
  - For SUSY searches: okay
  - For precision measurements: bad
- **Is the current implementation sufficient for analysis?**
- **This question should be motivated by physics and might not have one general solution**
- **Current goal:**
  - Try to understand which features are working and which not
  - Try to understand if they are needed
  - Fix it by first principal
  - Fix it by modeling it

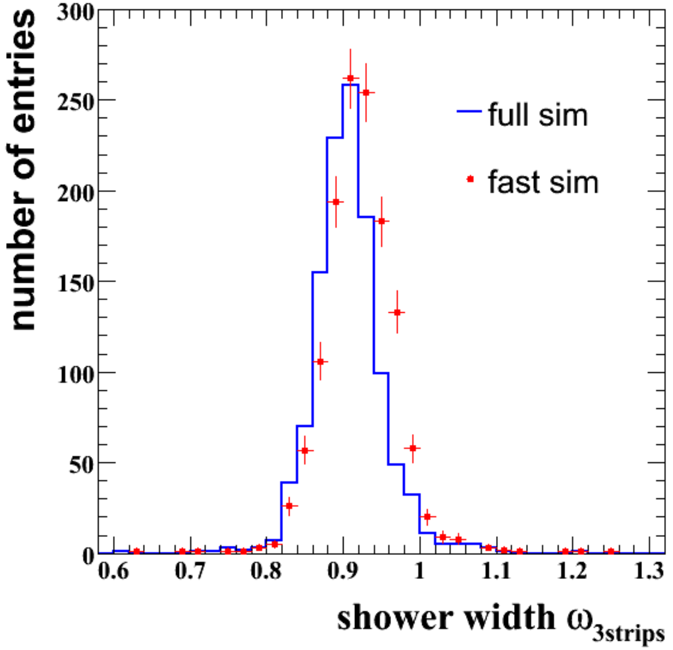
Reconstructed Shower Shapes

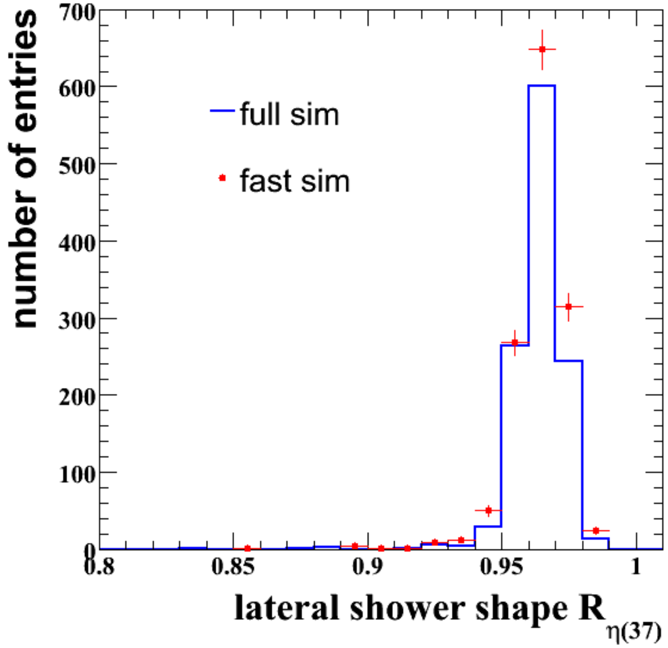
Checks on reconstructed electrons: quantities for e/γ ID

- **Shower width in 3 strips:**
  width in η calculated from three strips in 1st sampling
- **Lateral shower shape $R_{\eta(37)}$:**
  ratio of energy reconstructed in 2nd sampling
  in a 3x7 and 7x7 cluster (ηxϕ)

Agreement already quiet good.

Need study if e/γ ID is effected!





Summary

- **In order to produce a sufficiently large Monte Carlo dataset the Atlas detector simulation needs to be accelerated**
- **The calorimeters are the main time consumers**
- **Different acceleration techniques are possible:**
  - Fast shower parameterisation
  - Frozen Shower library
  - One spot model
- **All three methods have been implemented and tested within the Atlas detector simulation**
  - Factor 10 time gain for electrons and photons
  - Factor 2-3 time gain for average physics event
  - Main time gain comes from Frozen Showers
  - Fast shower parameterisation only good for high energy electrons
  - Good description of quantities at simulation and reconstruction level
- **Fast simulation approach is tested on the GRID right now**
- **Improve detector description**