Performance of the ATLAS LAr barrel calorimeter in the 2004 combined test beam

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ATLAS

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Outline

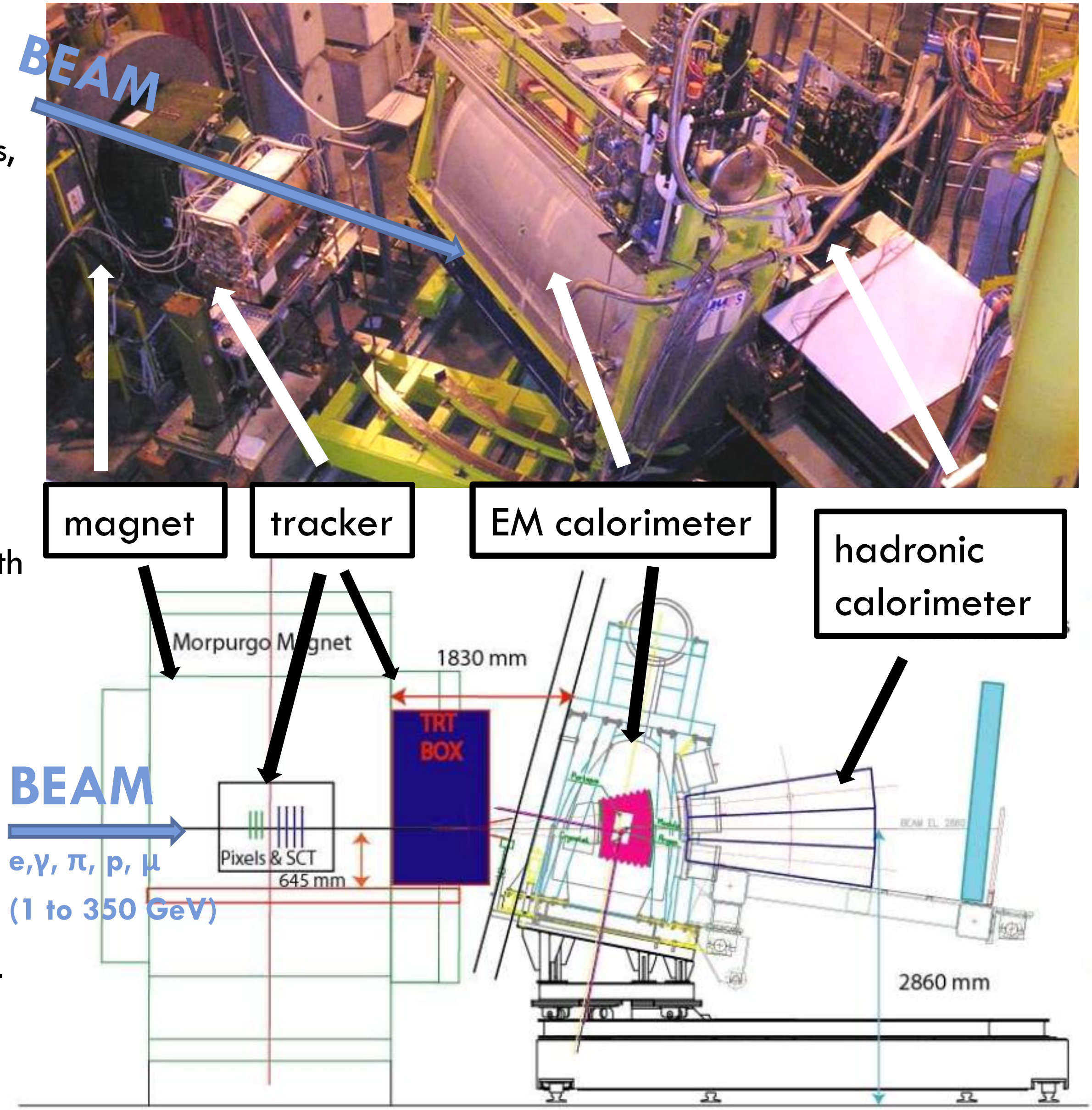
- The layout, goals and achievements of the 2004 combined testbeam of the ATLAS barrel section.

- Standalone performance of the liquid argon electromagnetic calorimeter
  - Results on energy response uniformity, linearity and resolution for various configurations with extra material added in front of the calorimeter.
  - Results on very low energy electrons.

- The combined performance of the ATLAS EM calorimeter and tracking detector (inner detector)
  - Beam acceptance and preliminary results on pT measurements with magnetic field
  - Preliminary results on E/p measurements
  - Preliminary results on Bremsstrahlung recovery using LAr information.

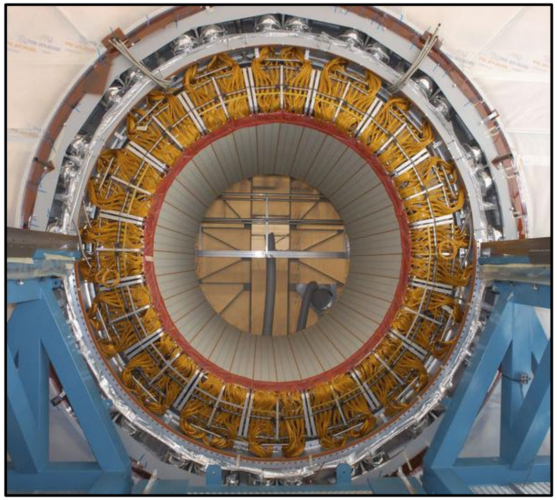
The 2004 Combined Testbeam (CTB)

- Full slice of the barrel detector
  - Magnet with horizontal field (1.4 T)
  - Inner detector, tracker (silicium pixels, scilicium strips planes, Transition radiation detector)
  - LAr electromagnetic calorimeter
  - Hadronic calorimeter (Tiles)
  - Muon chambers
- Main goals of the CTB
  - Test the detector performances with final or close to final electronics equipment, TDAQ infrastructure and reconstruction software.
  - Validate the description of the data by MonteCarlo simulations down to energies of 1GeV to prepare the simulation of ATLAS data.
  - Perform combined studies in a set-up very close to ATLAS (e.g. combined calorimetry, and ID-calorimetry).



The LAr EM calorimeter & energy reconstruction

The ATLAS half barrel and cryostat



calorimeter module

calorimeter module in cryostat (testbeam)

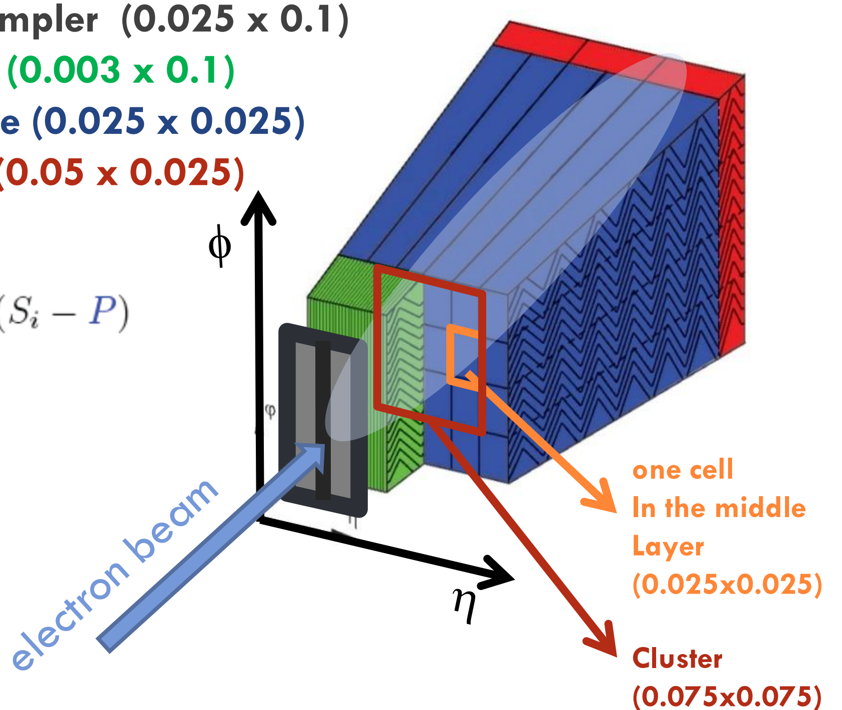
Layers and granularity ($\Delta\eta$x$\Delta\phi$):

Presampler (0.025 x 0.1)

Strips (0.003 x 0.1)

Middle (0.025 x 0.025)

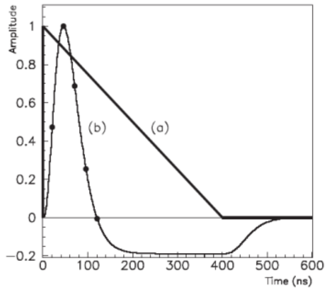
Back (0.05 x 0.025)



- LAr energy reconstruction:
  - Cell energy:

$$E(GeV) = f_{DAC\to\mu A} \times f_{\mu A\to GeV} \times \frac{M_{cali}}{M_{phys}} \times g_{ADC\to DAC} \sum_{i=1}^{n} a_i(S_i - P)$$

  - Electronic calibration constants:
    p = pedestal
    a = optimal filtering
    f,g = ADC → GeV

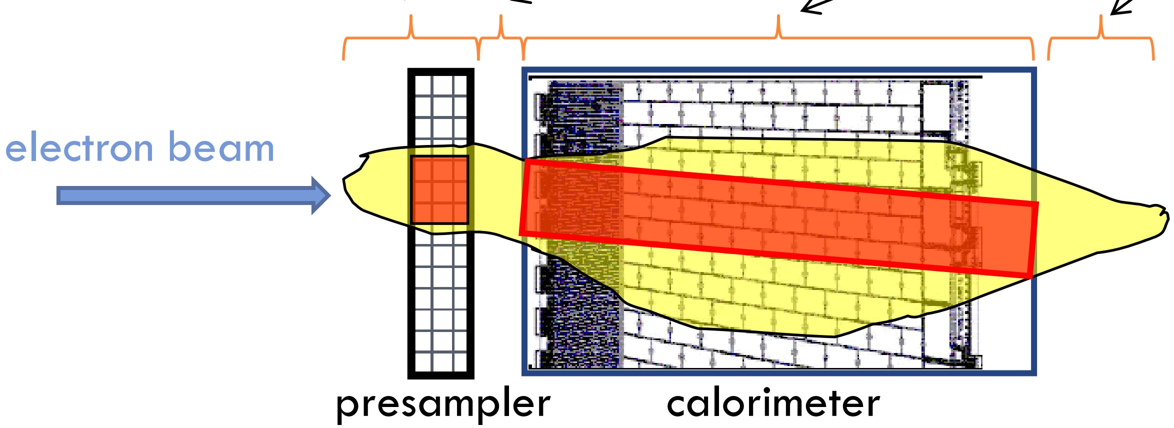


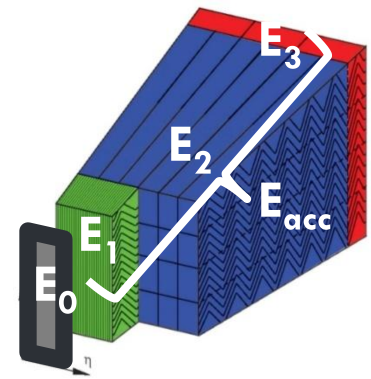
- Cluster: sum of cell energies in 0.075x0.075 over all layers

Electron energy calibration

- Energy parameterisation:

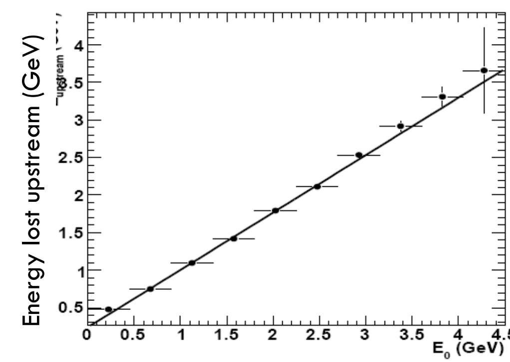
$$E_{electron} = \text{offset} + W_0 E_0 + W_{01}\sqrt{E_0 E_1} + \lambda E_{acc} + W_3 E_3$$

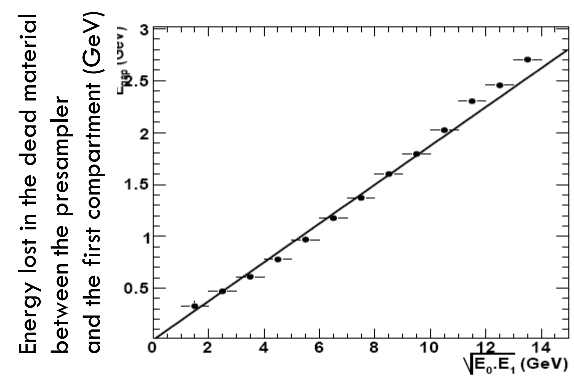




- Offset: energy lost by ionisation in the dead material in front of the calorimeter.
- W_0: correcting for energy lost in front of calorimeter by pre-showering electrons.
- W_{01}: empirical correction for the energy lost

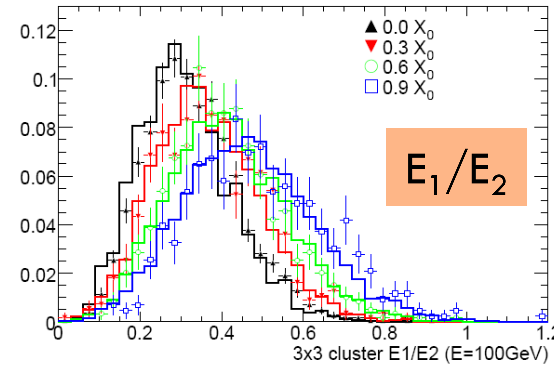
  in the dead material between the presampler and the first compartment.
- λ: out of cluster correction and sampling fraction
- W_3: correcting for the energy leakage at the back of the calorimeter

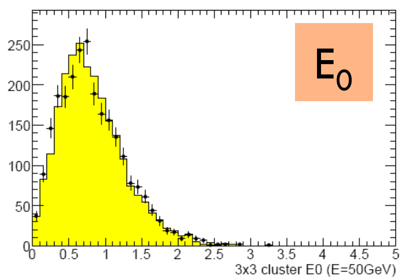


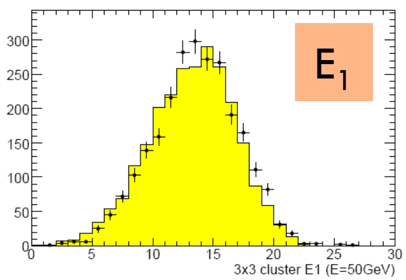


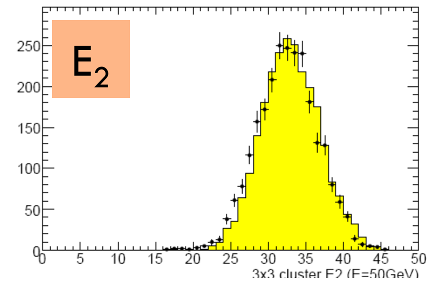
Data/MC comparisons

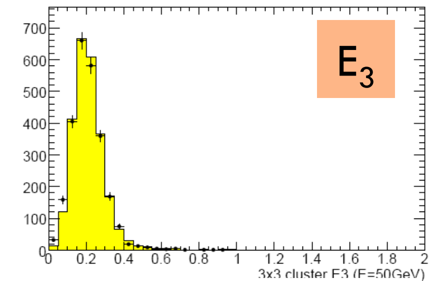
- The energy calibration strategy of the LAr calorimeter relies on the simulation of the experimental set-up and the exact description of the detector response
- A high level of agreement between data and MC is therefore crucial for the performance of the detector.
- In the CTB a big emphasis was given to a careful data-MC comparison.





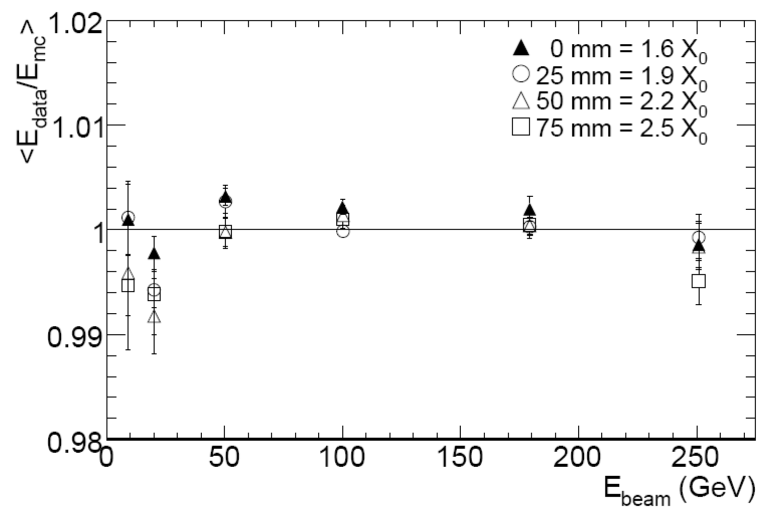






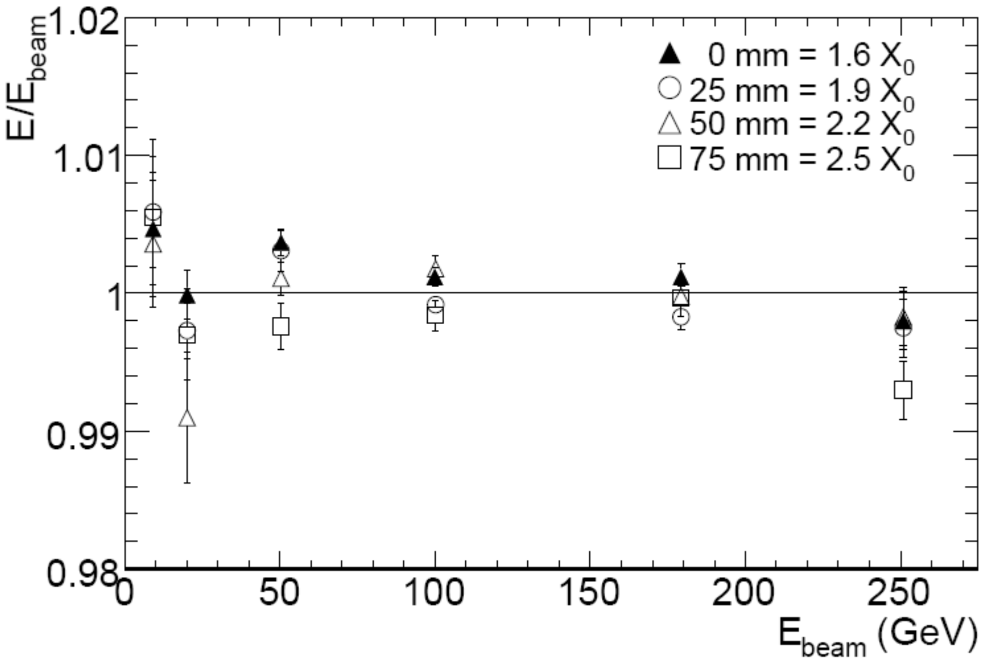
- Percentage mean energy difference between data and MC simulation for all energies and all material configurations

  Considering all systematic errors, the level of agreement between the MC and the data was estimated to be of order 0.4%



Results on energy linearity for electrons (9-250 GeV)

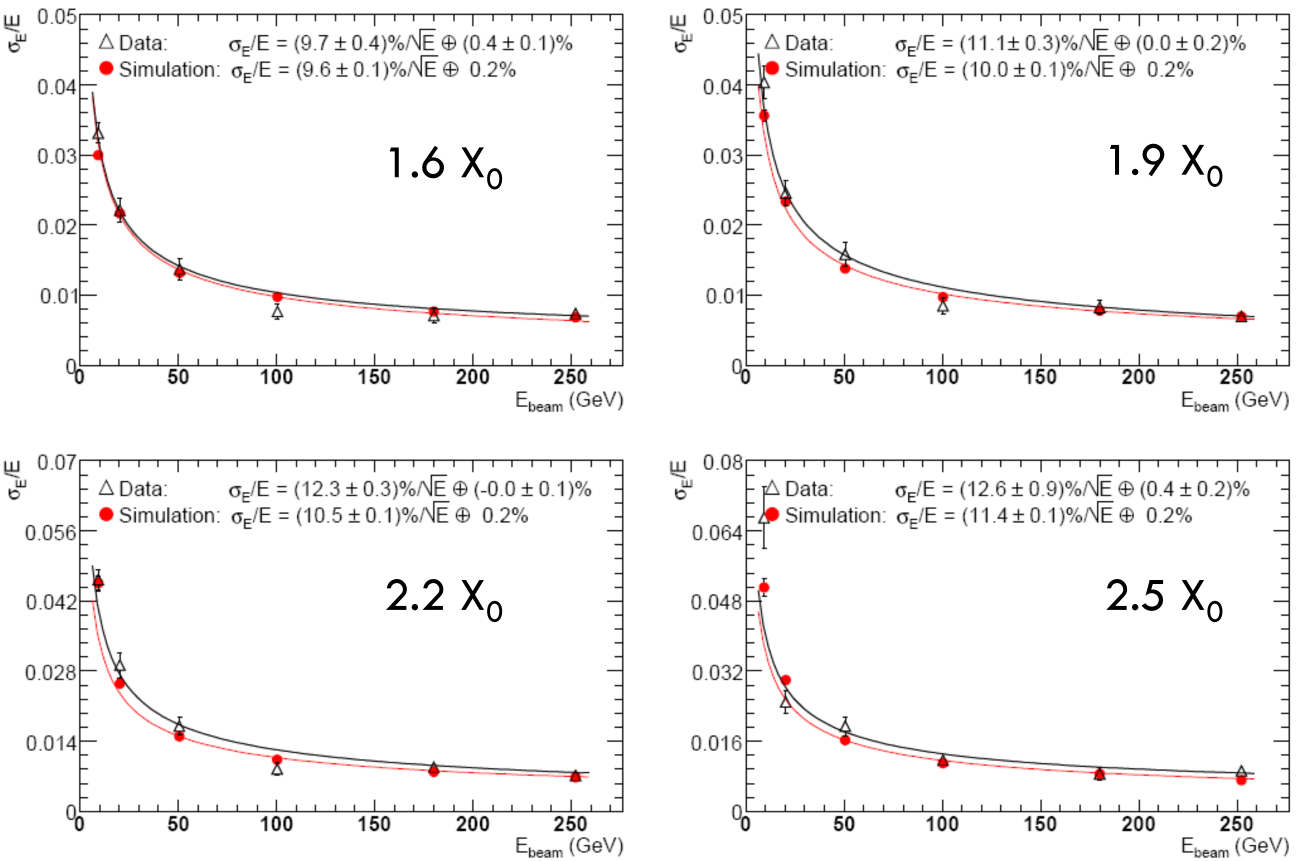
- The energy linearity obtained after application of the longitudinal weights to the cluster sampling energies for 4 different material configurations in front of the calorimeter cryostat: no material, 25, 50 and 75mm of Aluminum.
- These configurations correspond to the amount of material in ATLAS in different eta-regions.
- A 0.5% non-linearity is observed



- Remark: spread of the data-points at the level of 0.2% or less is seen for fixed beam energy. The variations from one energy point to another can be attributed to the systematics of the CTB setup itself. In particular, changes to beam conditions (collimator openings, beam-optics magnetic fields) seem to have large effects in the relative beam energy (systematics of beam line included in the error bars).

Energy resolution results for electrons (9-250 GeV)

- Energy resolution for 4 different material configurations comparing MC and data after the applying longitudinal weights.

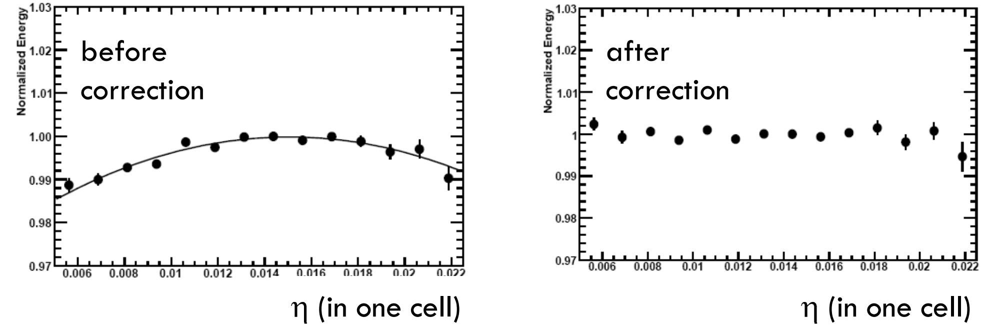


- Remark: The resolution worsens at the approximate rate of $0.5\%/\sqrt{E}$ per $30\% X_0$ increment of the material in front of the calorimeter.

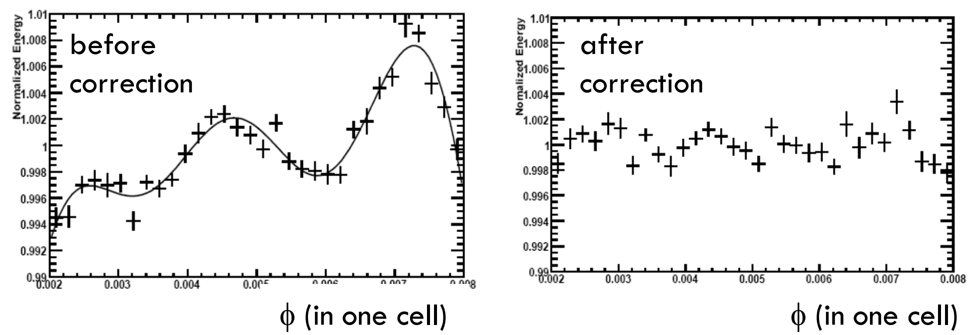
HV Corrections, Cluster corrections and uniformity

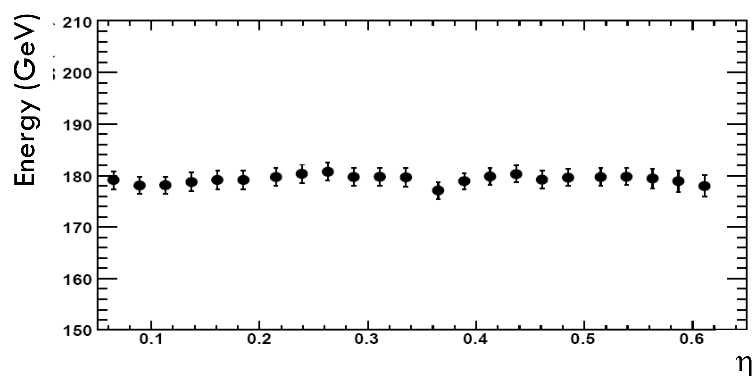
- Cell level
  - HV corrections
    (lower HV, dead HV cells)
  - Correction applied event by event using the shower shape
- Cluster level
  - S shape in the middle layer
  - S shape in the strips
  - Energy modulation along:
    - Phi
    - Eta
- Spatial scans, in the pseudo-rapidity region 0.−0.6375 and the median plane of each cell ($\phi \simeq 0$), were made with electrons at 180 GeV. The energy in each η bin is corrected according to the described calibration scheme.
- A non-uniformity of 0.5% is observed which is in agreement to measurements performed in earlier testbeams

η modulations



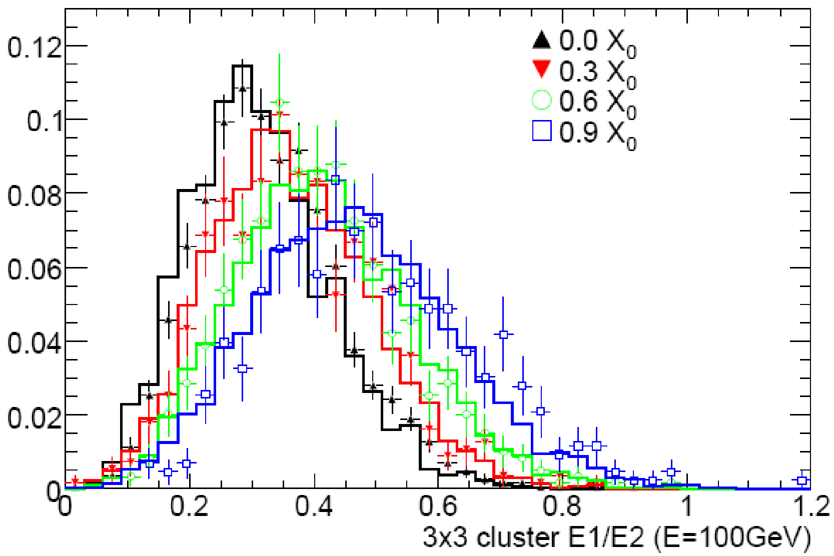
ϕ modulations

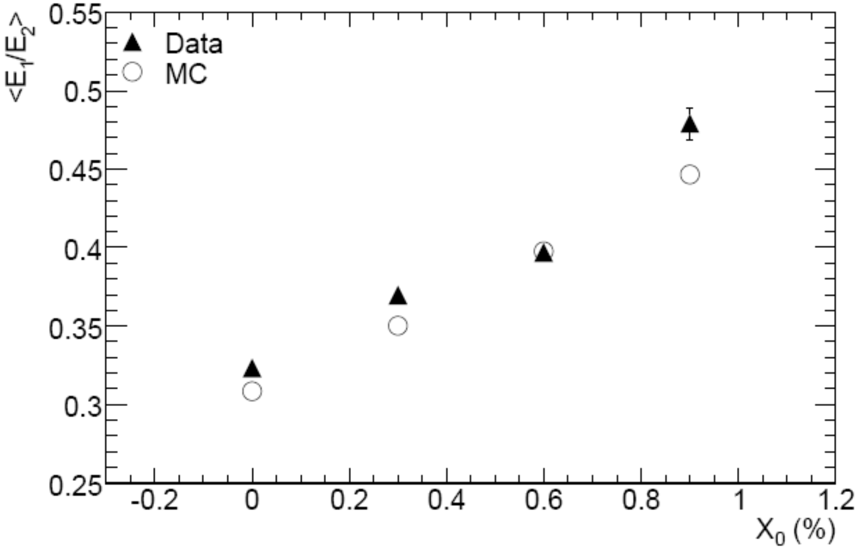




Material dependence of E1/E2 and implications for ATLAS

- E1/E2 is sensitive to the material distribution in front of the LAr calorimeter. The increase in the mean of the data distributions by 20-25% for $0.3X_0$ is well reproduced by the MC.



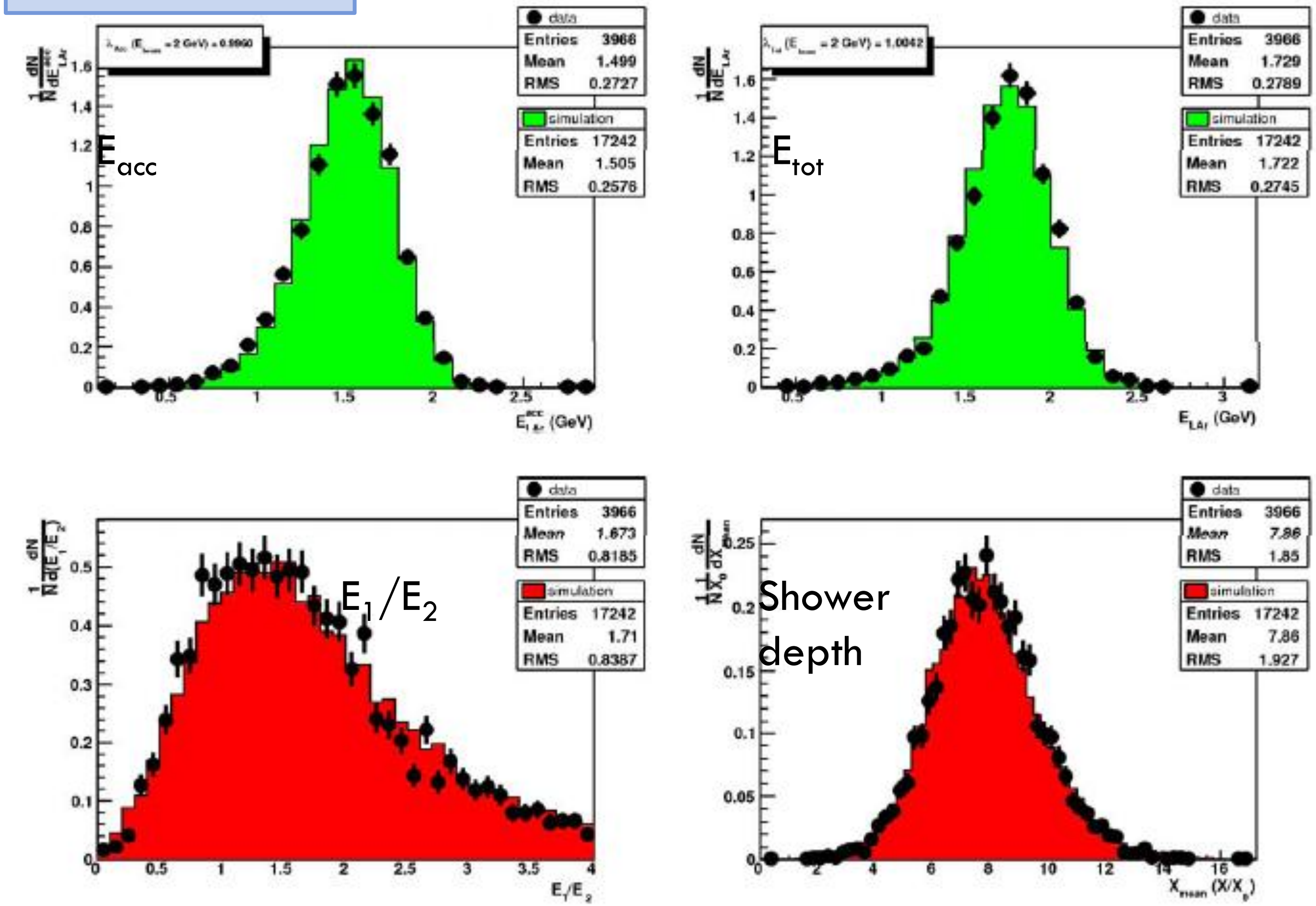


- This dependence can be used in ATLAS to develop a calibration procedure where the longitudinal weights will be varied in accordance to the change in E1/E2.

Very Low Energy electrons (1-9 GeV)

- DATA/MC comparisons for very low energy electrons

2 GeV electrons

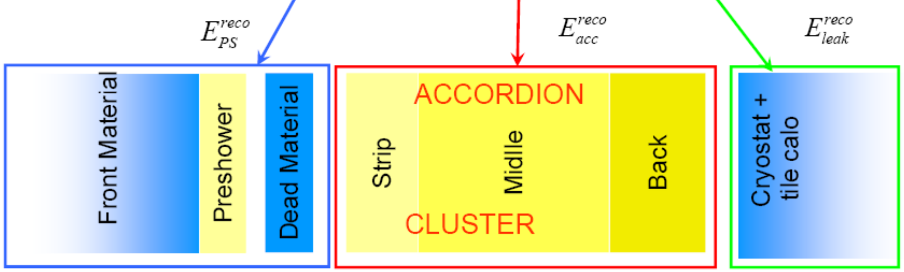


- The VLE data is very well described by the MC simulation

Very Low Energy electrons (1-9 GeV)

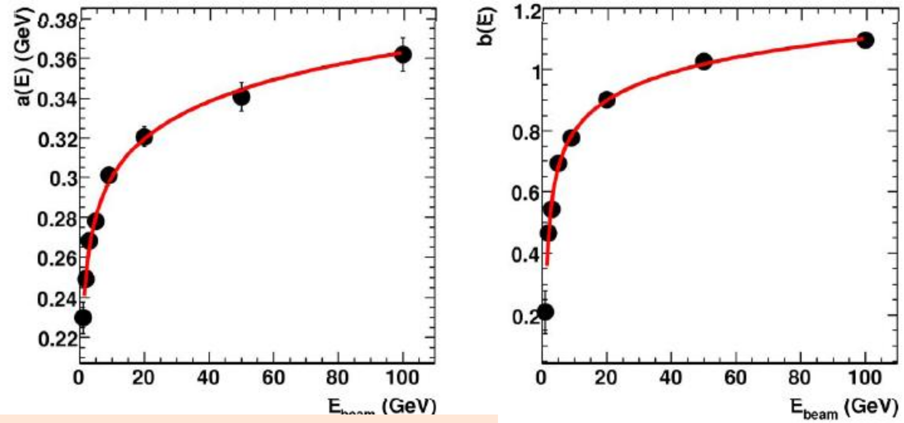
- Calibration strategy:

$$E^{reco} = \boxed{a(E) + b(E)E_{ps}^{cl\_lAr}} + \boxed{S_{acc}(\sum_{i=1,3} E_i^{cl\_lAr})} \cdot \boxed{(1 + f_{leak})}$$

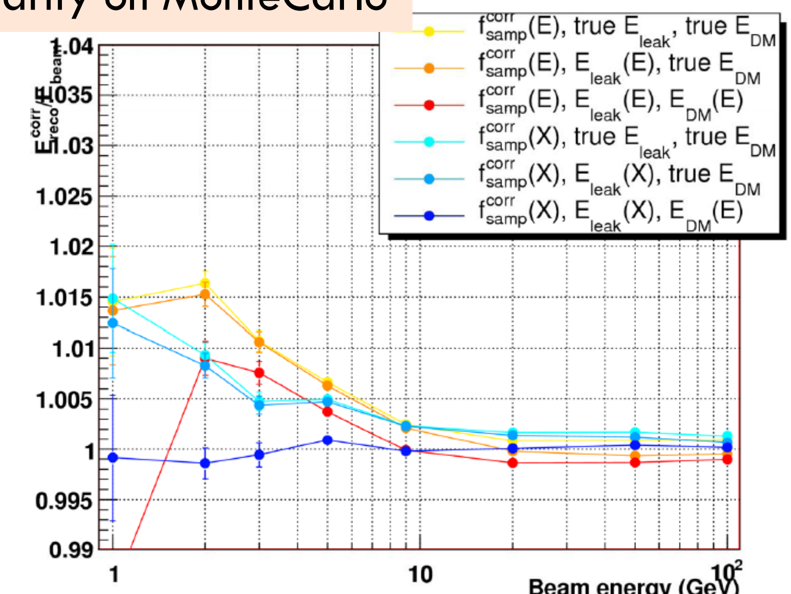


Shower depth $X = \frac{\sum_{i=1}^{4} E_i^{LAr} X_i}{\sum_{i=1}^{4} E_i^{LAr}}$

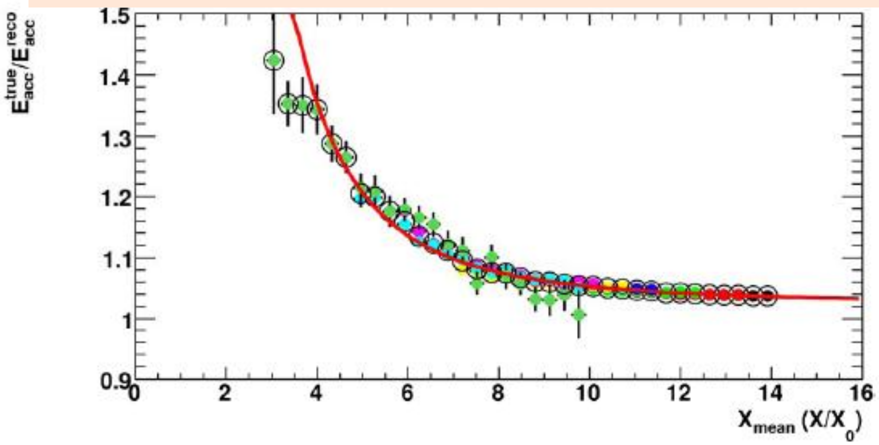
Dead material correction



Linearity on MonteCarlo



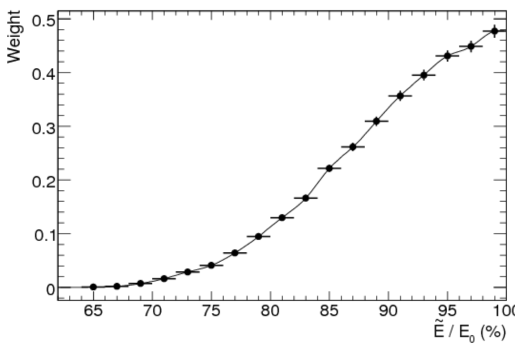
Sampling fraction correction vs shower depth



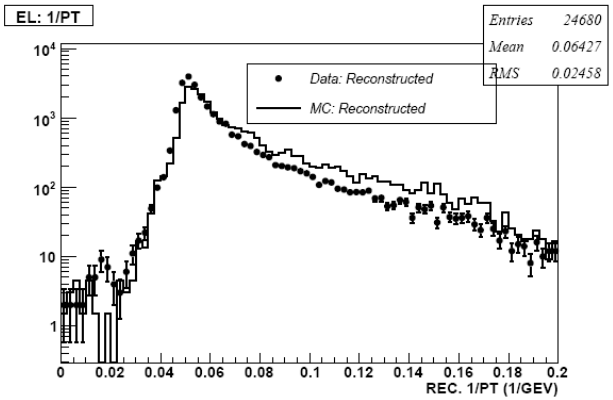
For high energy electrons, X_{mean} has mainly high values and the assumption of a constant sampling fraction is valid. For low energy electrons the sampling fraction is shower depth dependent.

Combined Studies (EM calorimeter & Inner detector)

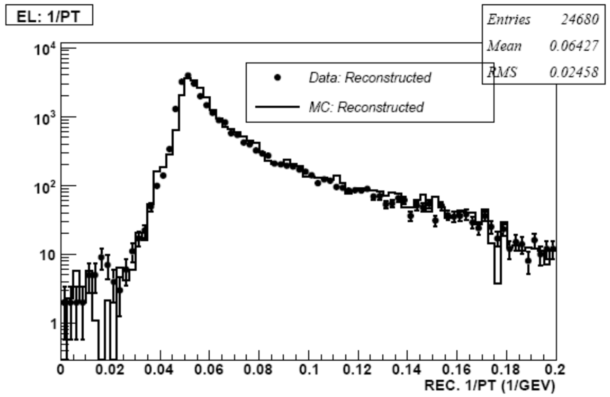
- Beam acceptance
  - In the 400 meters between momentum selection and the experimental setup, the beam particles traverse 15 % of a radiation length X_0. In these 400 meters, many elements that have been tuned for the nominal energy will have different effects for particles that lost part of their energy by Bremstrahlung.
  - In order to account for this effect an acceptance curve as a function of the remaining particle energy was calculated by tracking particles through the beam line and counting with which probability they would hit the trigger scintillator.



Calculated weights as a function of the particle energy (percent of the nominal beam energy)



1/pT for 20 GeV electrons without acceptance correction



1/pT for 20 GeV electrons with acceptance correction

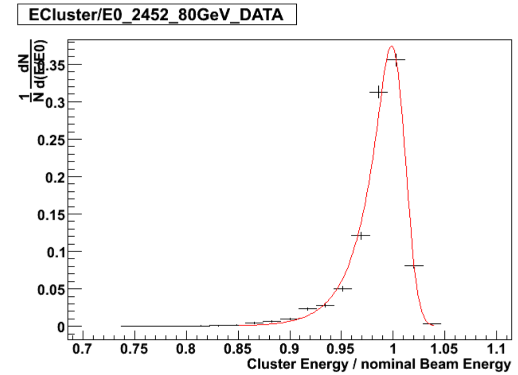
  - It can be seen that the data fit substantially better to the simulation that takes into account the beam line acceptance by applying the weights.

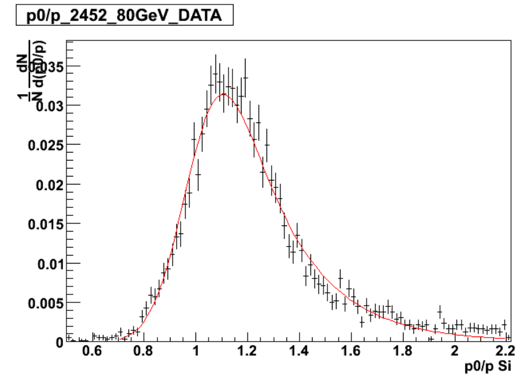
E/p measurements and modeling

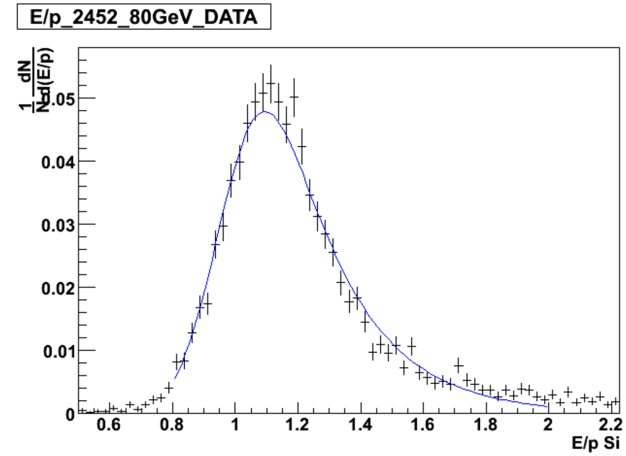
- In the CTB, the inner detector setup was located inside a magnet
- Combined (ID&LAr&TileCal) data recorded with magnetic field switched on
- Good MC-data agreement for the runs with magnetic field
- Empirical functions found that describe very well the energy and 1/p distributions
- Convolution of these two functions (as for the product of two random distributions) describes well the measured E/p distribution (blue plot)

  (>20GeV, below strong correlation between the two distributions)
- It is shown that it is possible to extract the correct scale E0 from the E/p distribution.
- Precision of 0.5% achieved with ~5000 events (after all cuts)
- This concept will also be used in ATLAS to compare the ID scale with the scale of the LAr EM calorimeter.

Parameter	E and 1/p fit resp.	E/p fit
E0	1.0092(4)	1.0138(43)

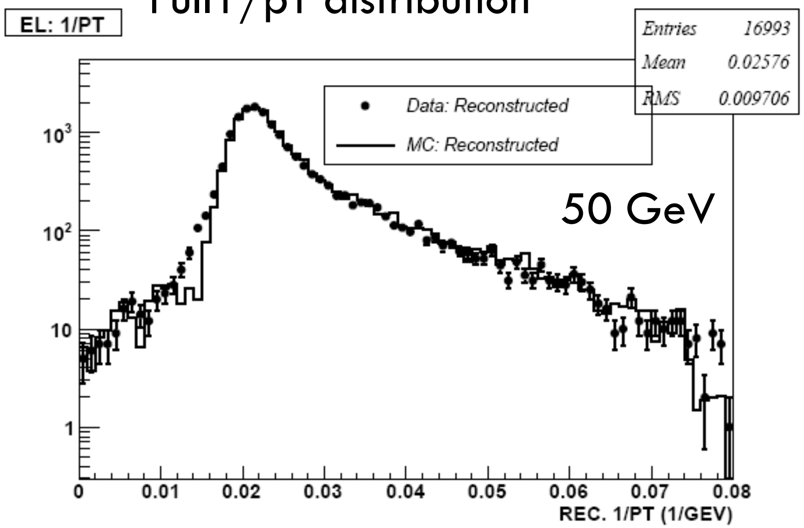




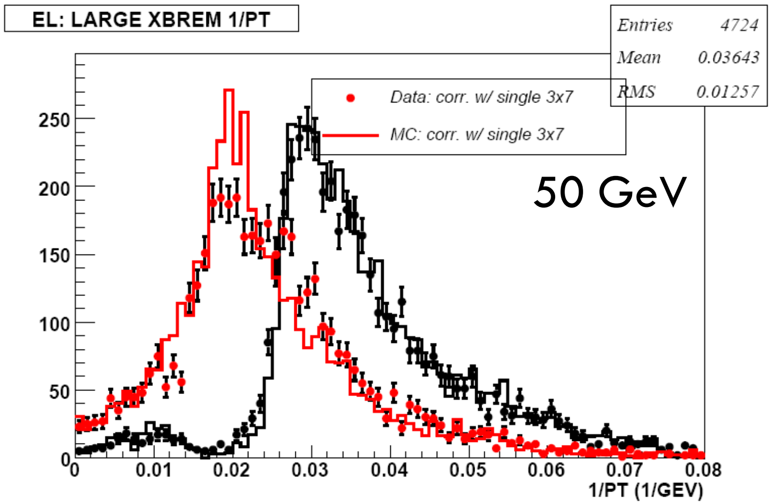


Bremsstrahlung recovery

Full1/pT distribution

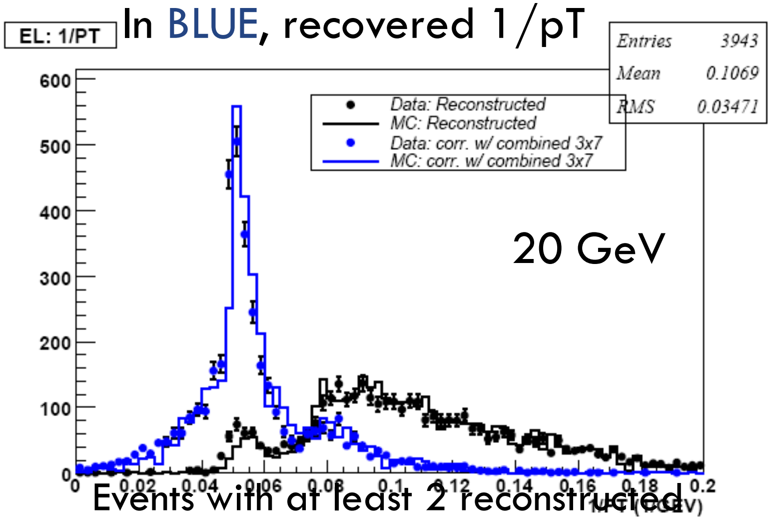


In RED, recovered 1/pT



Large XBrem events (greater than 5 mrad)

In BLUE, recovered 1/pT



Events with at least 2 reconstructed 3×7 clusters : 20 GeV

The implementation of the algorithm consists of dividing the (Silicon) track into two parts, and refitting only the part close to the vertex together with the (3x7) LAr cluster position as an ordinary hit.

Conclusion and further Studies

- Final results have been presented for uniformity, linearity and resolution of the LAr electromagnetic calorimeter.
- Ongoing and promising studies on the very low energy electrons have been shown.
- The standalone studies have considerably increased our understanding of the individual detectors and the MC description of the CTB set-up. Many combined algorithms (Bremsstrahlung recovery, E/p) have been developed and tested in the CTB, and are now ready for the first ATLAS data.
- Other studies comprise:
  - Study of converted/non-converted photons.