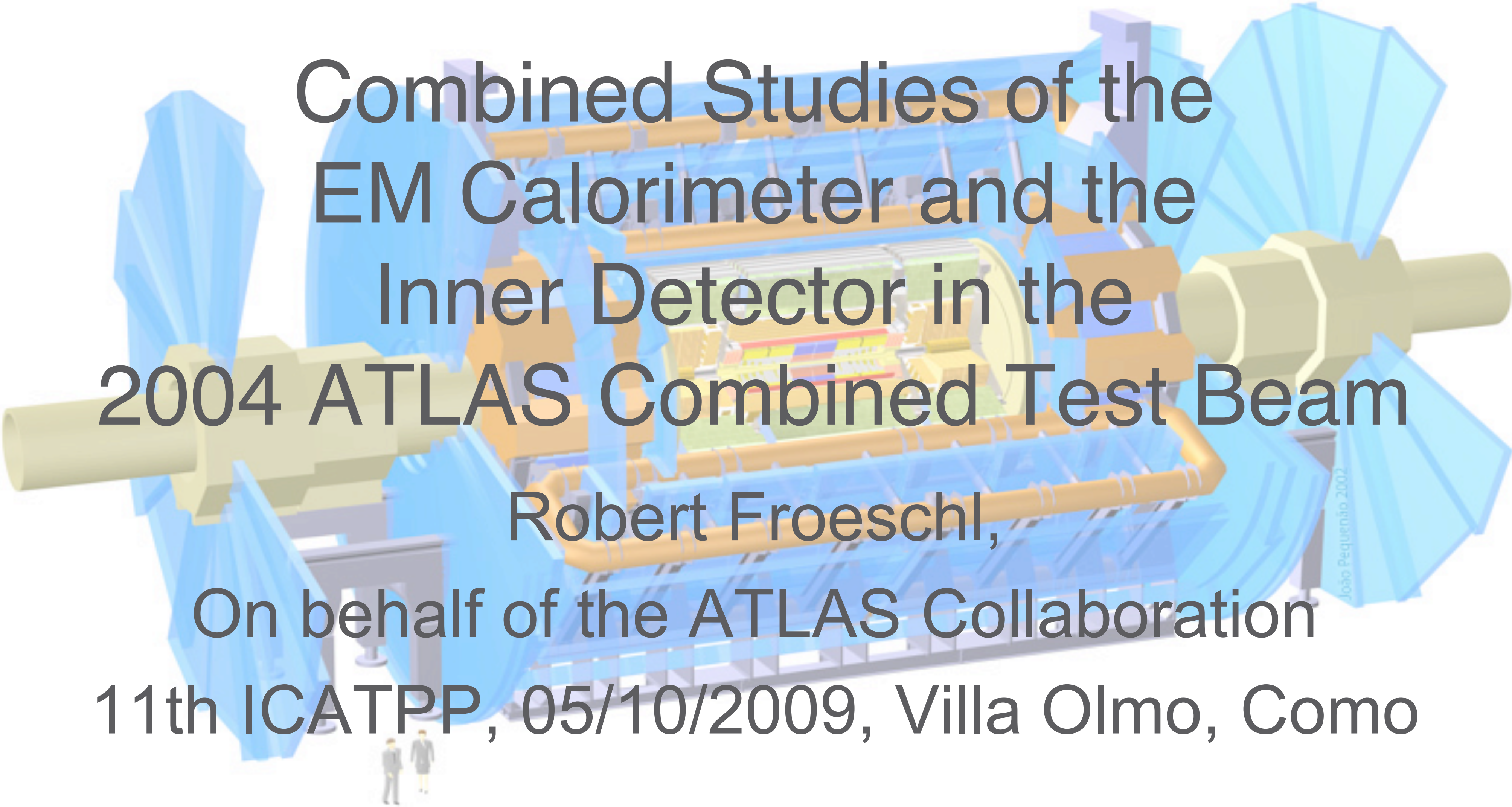


# Combined Studies of the EM Calorimeter and the Inner Detector in the 2004 ATLAS Combined Test Beam

Robert Froeschl,
On behalf of the ATLAS Collaboration

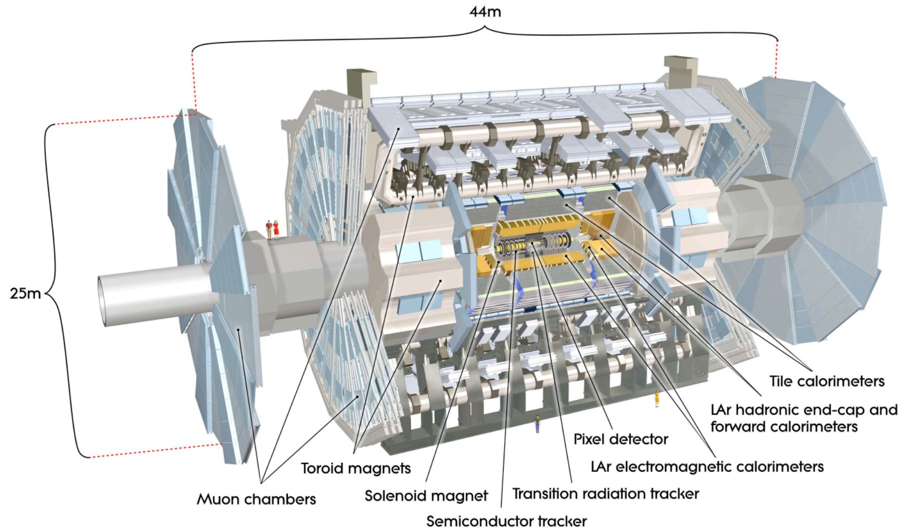
11th ICATPP, 05/10/2009, Villa Olmo, Como

# Outline

- Electron Calibration for the ATLAS electromagnetic calorimeter at the Combined Test Beam (CTB) 2004
- Intercalibration between the energy scale of the electromagnetic calorimeter and the momentum scale of the Inner Detector
- Bremsstrahlung recovery using the cluster position in the calorimeter

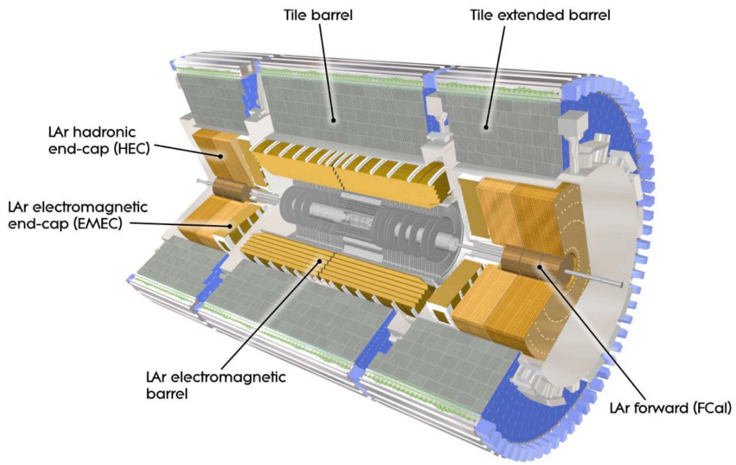
# ATLAS

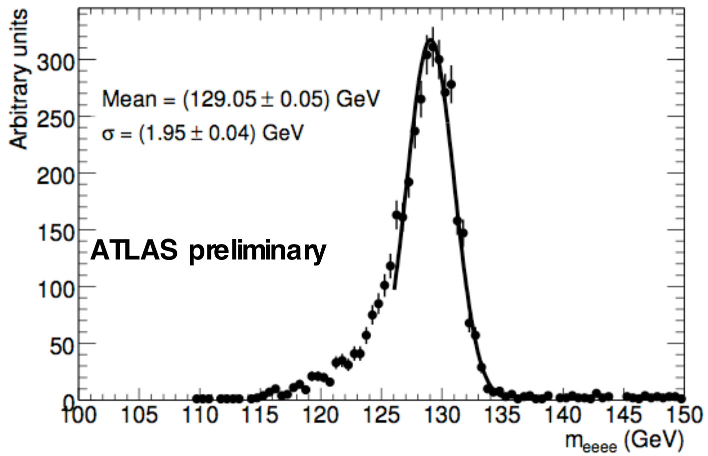
- General purpose experiment at the LHC (Large Hadron Collider at CERN)
- Experiment designed to discover new particles up to several TeV
  - Higgs Boson
  - Supersymmetry
  - Quark substructure
  - ?
- Precision measurements
  - W boson mass
  - Top quark



# Electromagnetic calorimeter

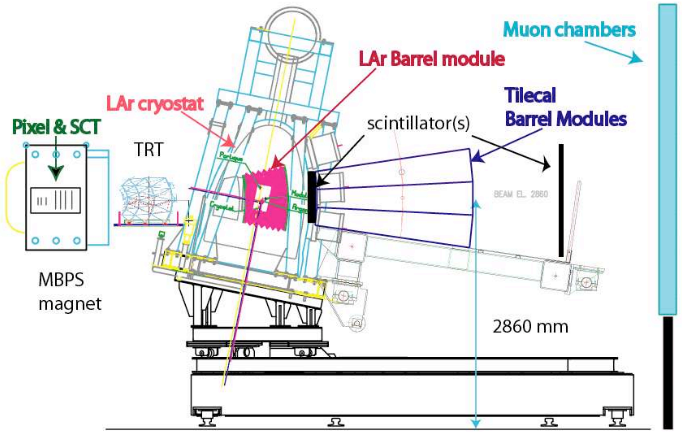
- Primary task
  - Energy measurement and identification for electrons and photons by absorption
- Lead-Liquid Argon sampling calorimeter
- Accordion geometry
  - Seamless azimuthal coverage
- Three longitudinal layers plus presampler
- Electron energy measurement important for many interesting physics channels
  - $H \rightarrow e^+e^-e^+e^-$

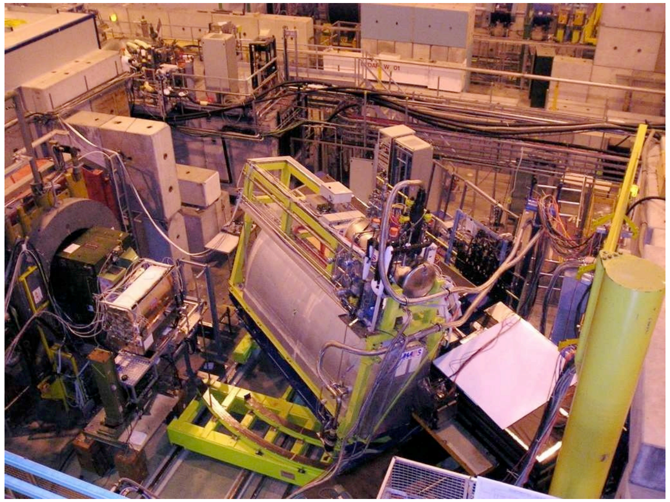


# Combined Test Beam 2004

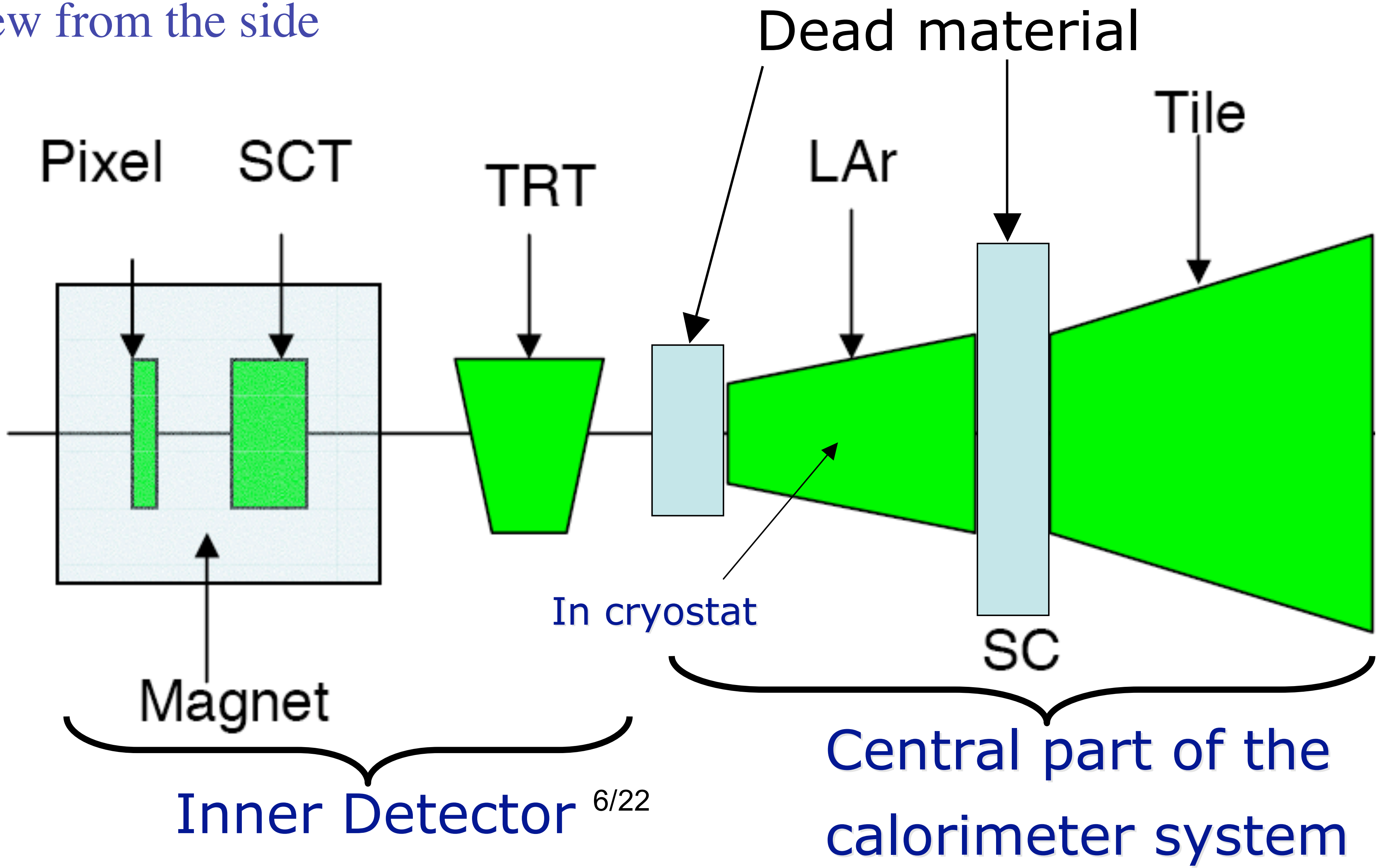
- Complete segment of the barrel part of ATLAS including components from all subdetectors exposed to electrons, pions, photons, muons and protons
- This talk is focused on electrons only



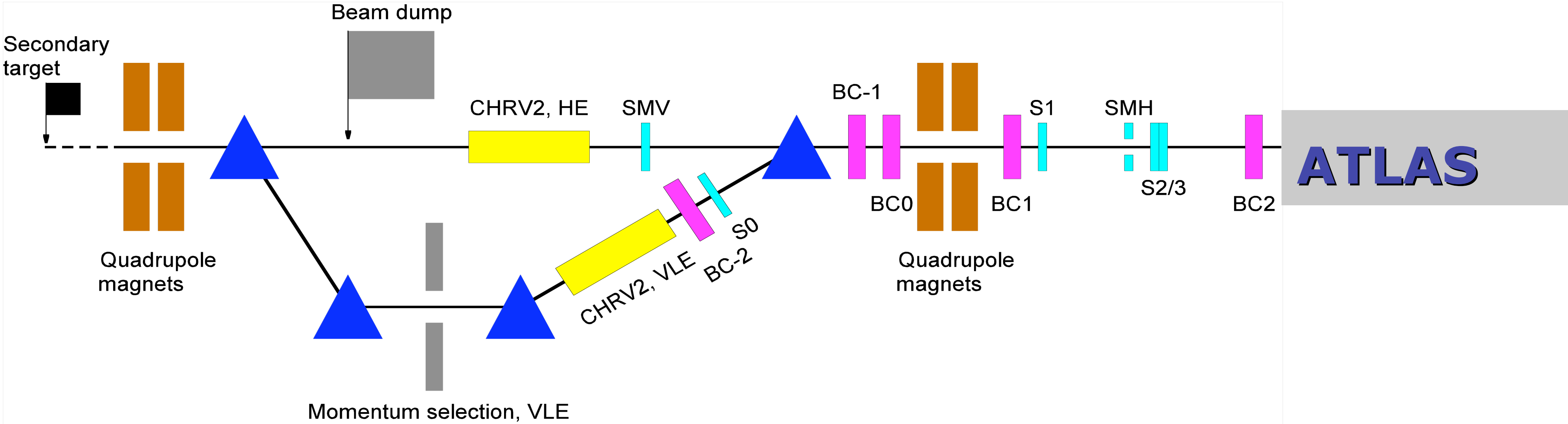
# Combined Test Beam 2004 Setup

View from the side



# Beam Line of the Combined Test Beam 2004

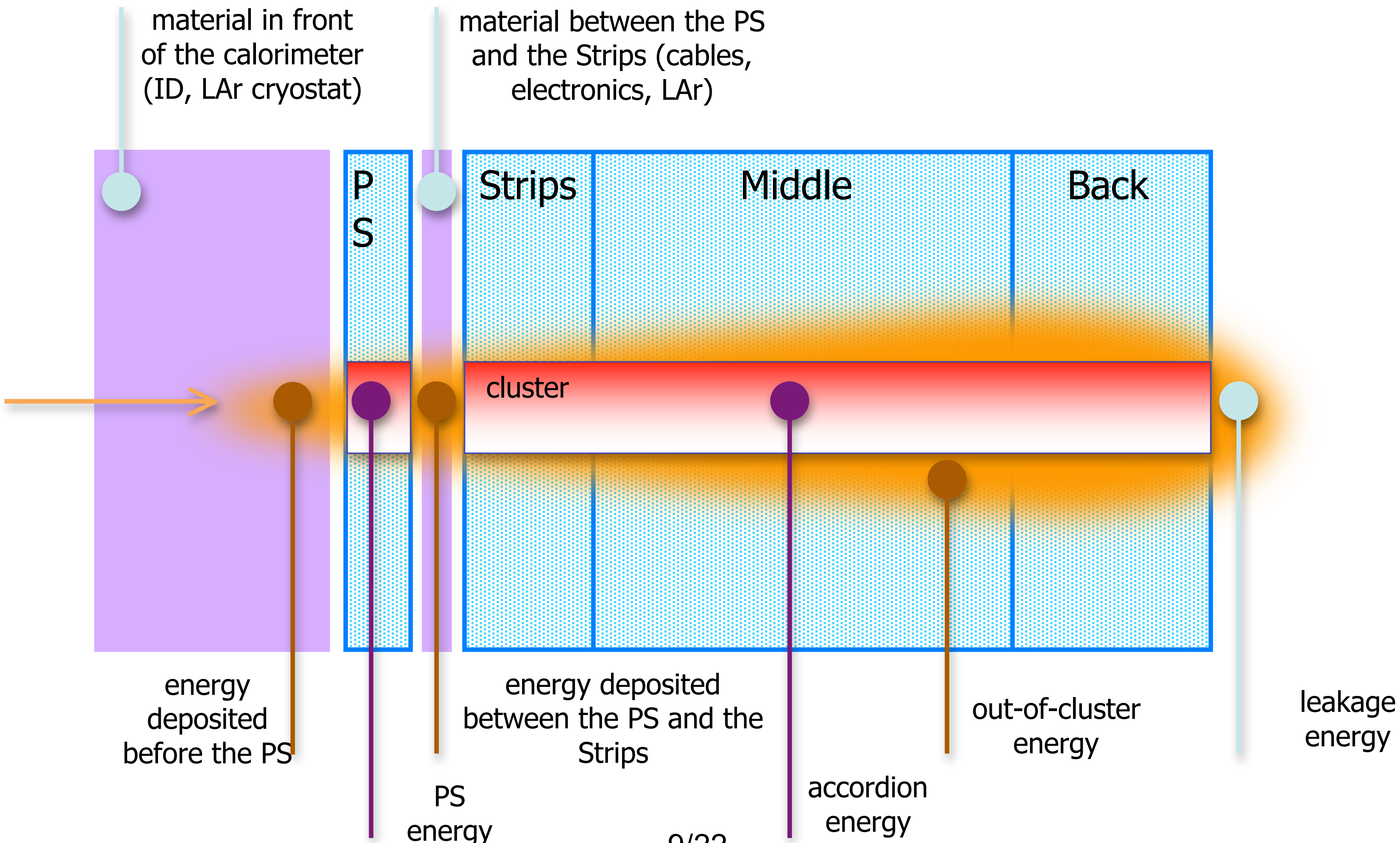
## View from the top



# Electron calibration
# Calibration Hits Method

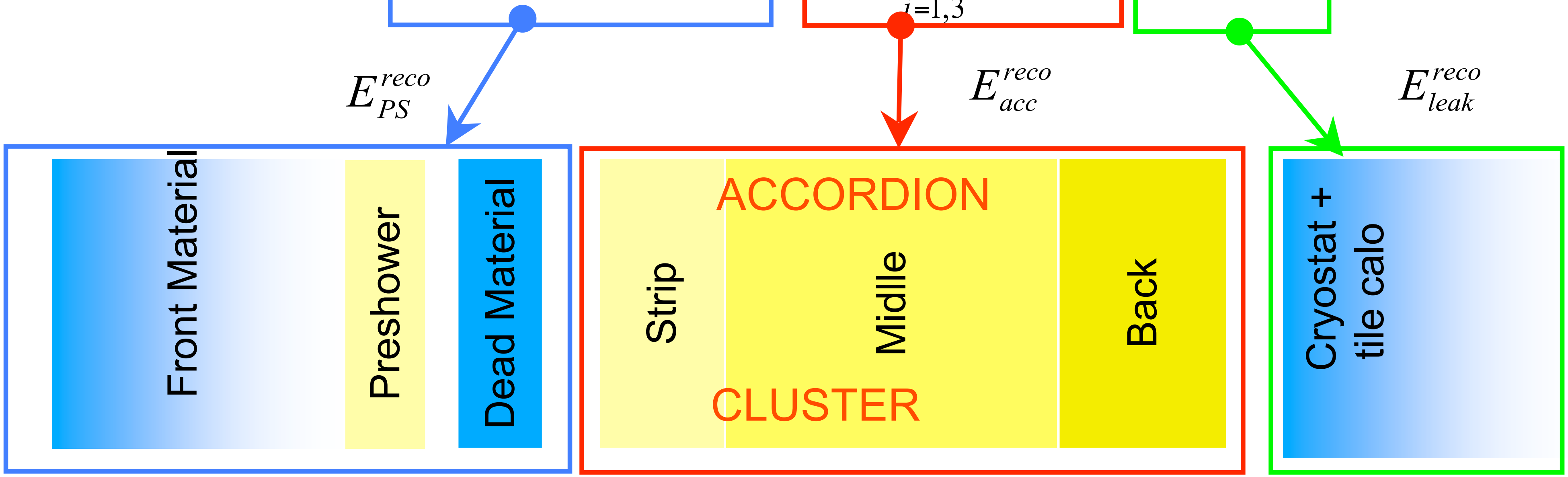
- Parameterizations of all energy deposits (Monte Carlo simulation) by measured quantities
- Apply these parameterizations to data
- Sufficiently good description of the data by the Monte Carlo simulation required
  - Material description of the detector in the Monte Carlo simulation
- Adjust absolute energy scale (correction on the percent level)
  - Known physics process, e.g. Z boson decay
  - Intercalibration with Inner Detector (E/p)

# Electron calibration
# Calibration Hits Method



# Electron calibration
# Calibration Hits Method

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

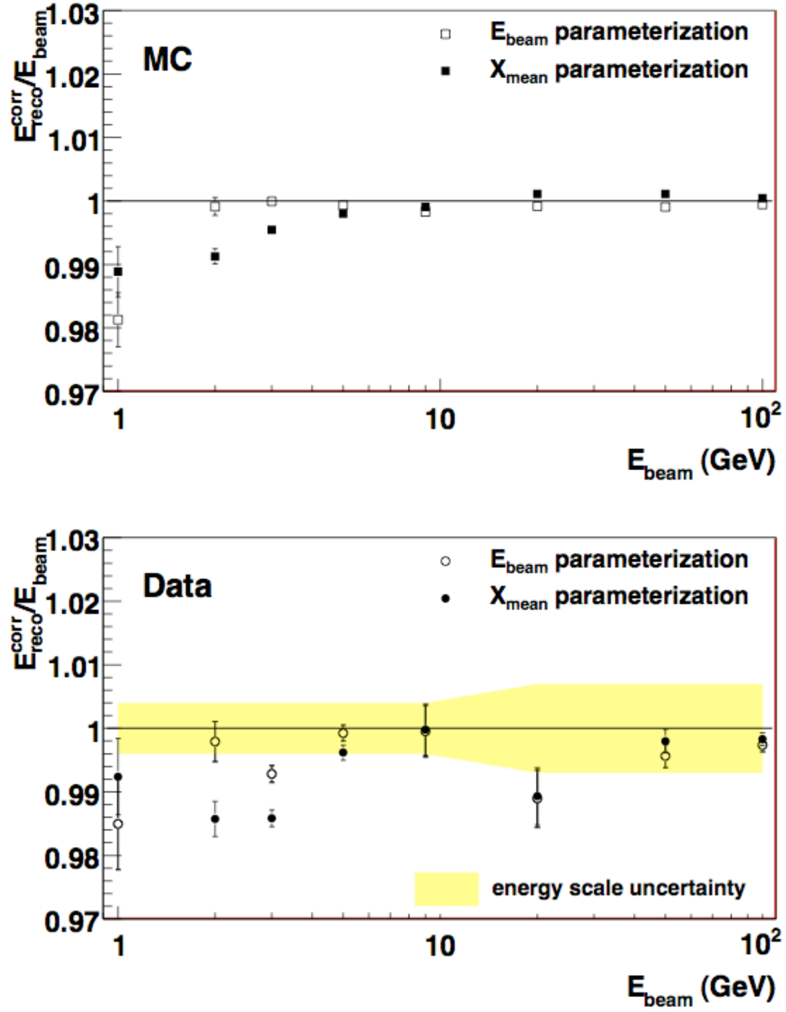



Shower depth

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

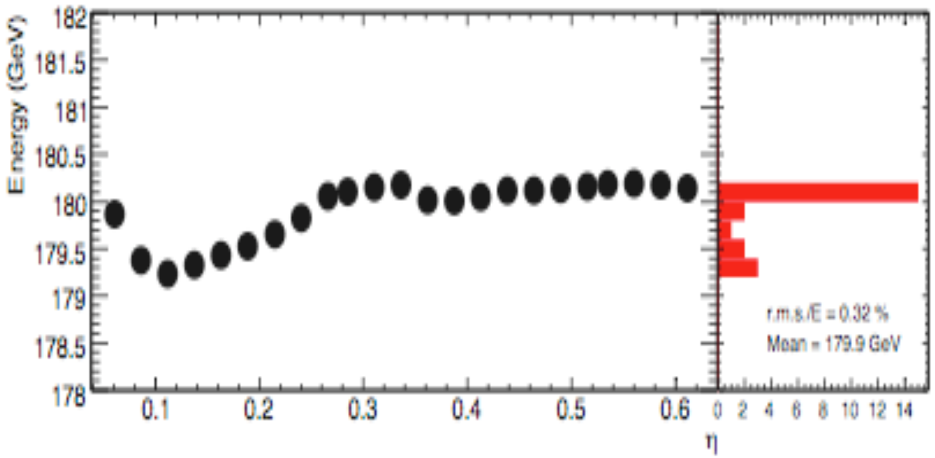
# Combined Test Beam 2004
# Linearity without magnetic field $\eta$=0.45

- Requirement
  - Linearity 0.5%
    - Linearity 0.02% around Z peak
- Monte Carlo simulation (consistency check)
  - Linearity 0.2% for 5-100 GeV/c
  - Linearity 0.5% for 1-100 GeV/c
- Data after scale adjustment
  - Linearity 0.5% for 1-100 GeV/c
  - Dominated by Data-MC agreement



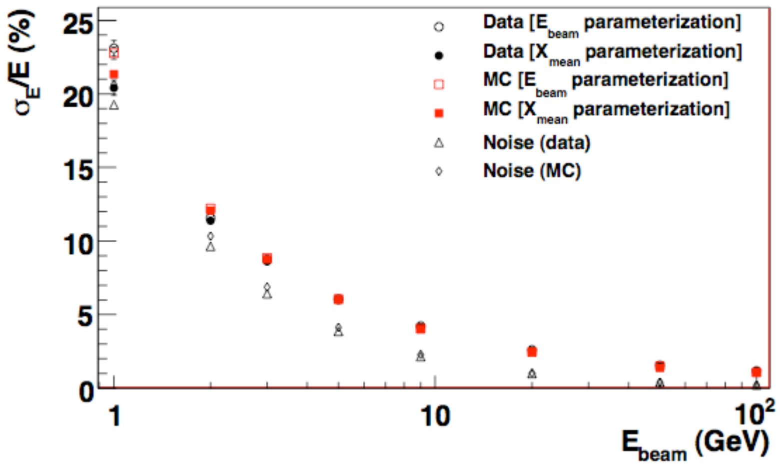
# Combined Test Beam 2004 Uniformity without magnetic field

- Uniformity investigated with 180 GeV/c electrons at different $\eta$ positions at $\varphi$=0 (middle of the module used in the CTB 2004)
- Obtained uniformity is 0.32%

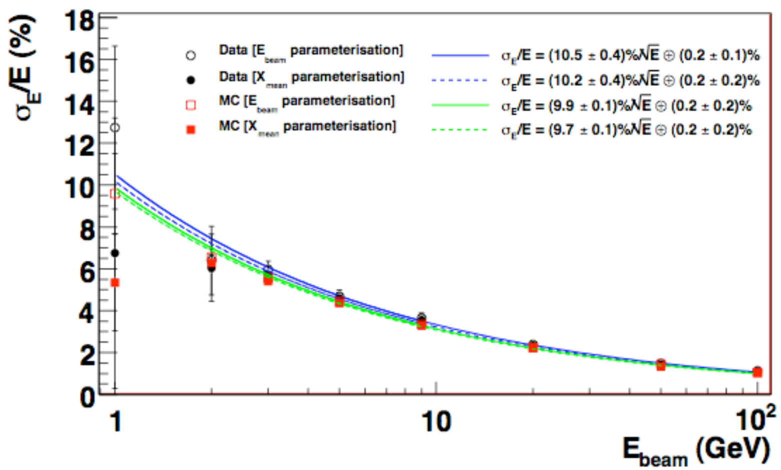


# Combined Test Beam 2004
# Resolution without magnetic field $\eta$=0.45

- Requirement after noise subtraction (193 MeV)
  - Stochastic term
    - 10%GeV$^{1/2}$/sqrt(E)
  - Local constant term
    - 0.2%
- MC simulation for 2-100 GeV/c
  - Stochastic term
    - (9.7±0.1)%GeV$^{1/2}$/sqrt(E)
  - Local constant term
    - (0.2 ± 0.2)%
- Data for 2-100 GeV/c
  - Stochastic term
    - (10.2±0.4)%GeV$^{1/2}$/sqrt(E)
  - Local constant term
    - (0.2 ± 0.1)%



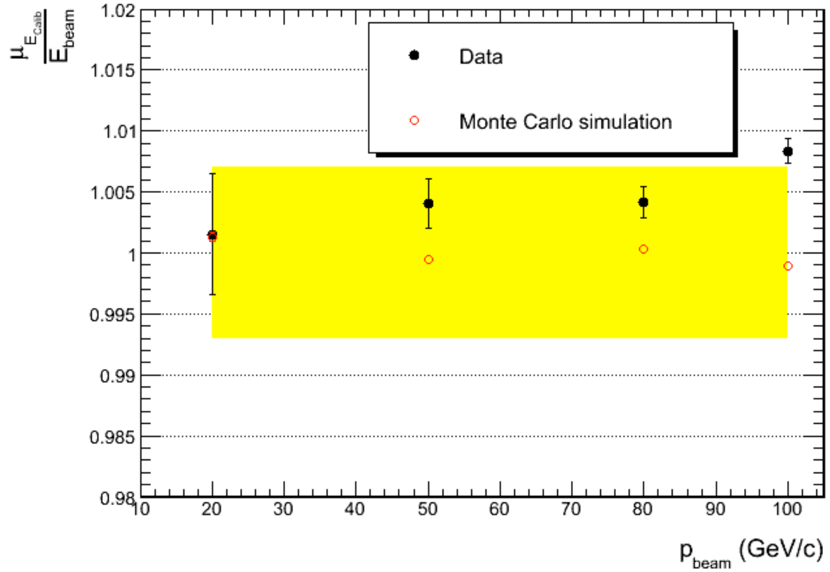

Noise included




Noise subtracted

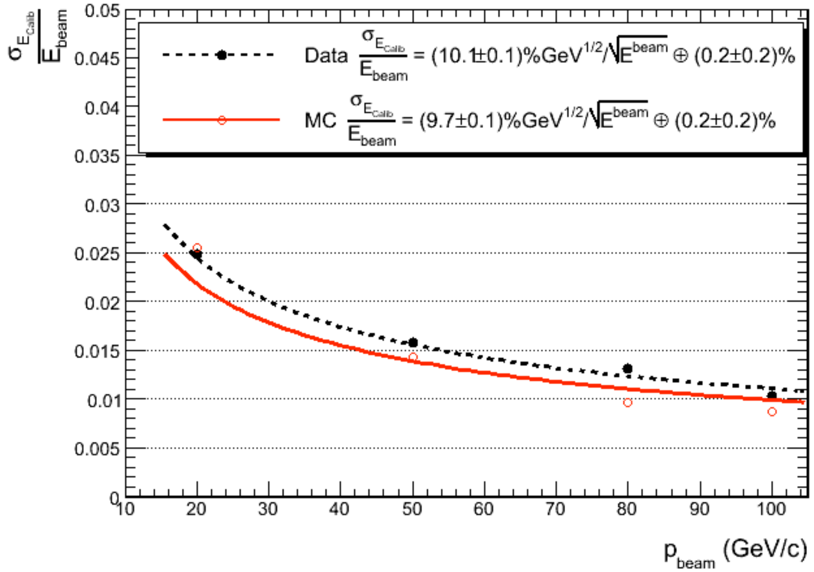
# Combined Test Beam 2004
# Linearity with magnetic field at $\eta$=0.45

- Requirement
  - Linearity 0.5%
- Monte Carlo simulation (consistency check)
  - Linearity 0.1% for 20-100 GeV/c
- Data after scale adjustment
  - Linearity 0.3% for 20-100 GeV/c



# Combined Test Beam 2004
# Resolution with magnetic field at $\eta$=0.45

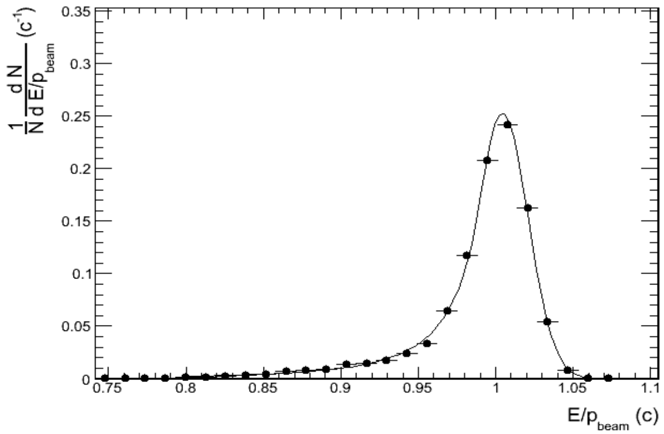
- Requirement after noise subtraction
  - Stochastic term
    - 10%GeV$^{1/2}$/sqrt(E)
  - Local constant term
    - 0.2%
- MC simulation for 20-100 GeV/c
  - Resolution too good for $p_{beam}$>50 GeV/c
  - Stochastic term
    - (9.7±0.1)%GeV$^{1/2}$/sqrt(E)
- Data for 20-100 GeV/c
  - Stochastic term
    - (10.1±0.1)%GeV$^{1/2}$/sqrt(E)
  - Local constant term
    - 0.2%

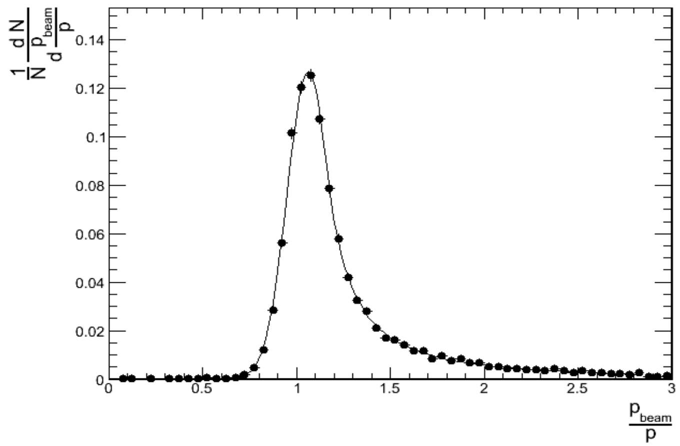


# Intercalibration with E/p Procedure

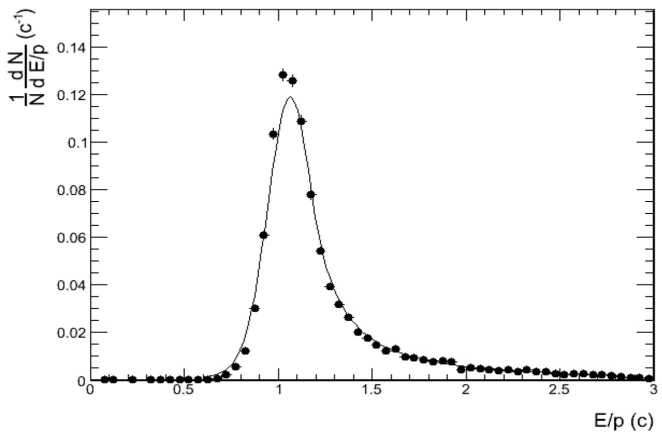
- Consider $E/p_{true}$ and $p_{true}/p$ as random variables
- Parameterize $E/p_{true}$ and $p_{true}/p$
- Parameterize E/p by an integral of the joint distribution of $E/p_{true}$ and $p_{true}/p$
  - Factor the joint distribution of $E/p_{true}$ and $p_{true}/p$ (Backup)
    - $E/p_{true}$
    - $p_{true}/p$
    - Correlation
- Compute correlation from MC and apply it to data
  - Knowledge of $p_{true}$ necessary
  - Material description important
- Fit E/p model to observed E/p distribution
  - Parameters in E/p model reflect the properties of $E/p_{true}$ and $p_{true}/p$ distributions
- Momentum scale of Inner Detector set by the magnetic field
  - Measured very precisely in-situ for ATLAS
  - Use relative scale between $E/p_{true}$ and $p_{true}/p$ distributions to translate momentum scale into energy scale of the calorimeter

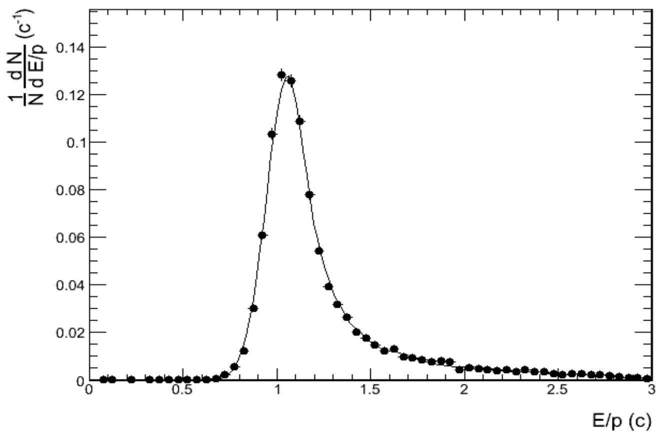
# $E/p_{beam}$, $p_{beam}/p$ and $E/p$ without /with correlation for CTB data 50 GeV/c




Without Correlation

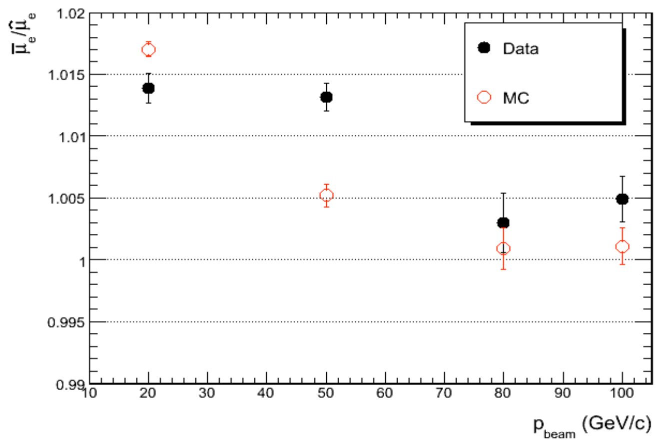


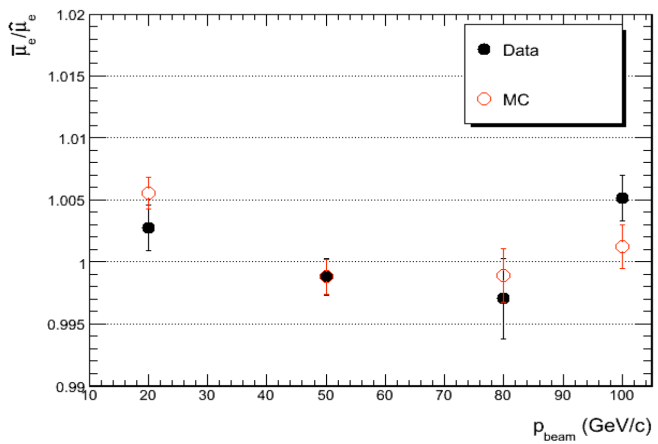

With Correlation from MC

# Intercalibration with E/p Combined Test Beam 2004

- Tested described method to extract the relative scale between the inner detector and the LAr calorimeter using E/p with data from the combined test beam
- With correlation btw. E and p relative scale factor can be extracted with a precision better than 0.5%
- Correlation absolutely needed for $p_{beam} \leq 50$ GeV/c
  - This is the most interesting range for W→eν
- Description of the correlation should be more difficult for the CTB 2004 than for ATLAS
  - Material in the beam line
  - Less compact geometry



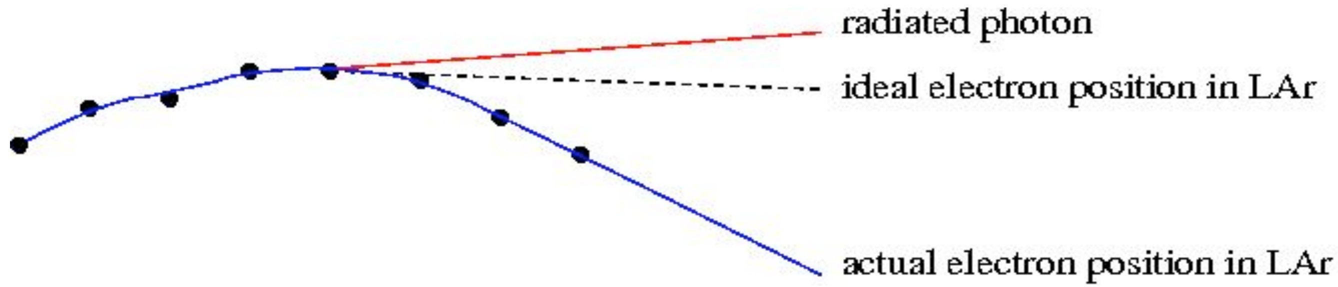

Without correlation




With correlation from MC

# Bremsstrahlung recovery

- Main idea
  - The barycenter of the electron and photon clusters, weighted with the respective transverse energy, should be the same as that of an electron without any bremsstrahlung activity



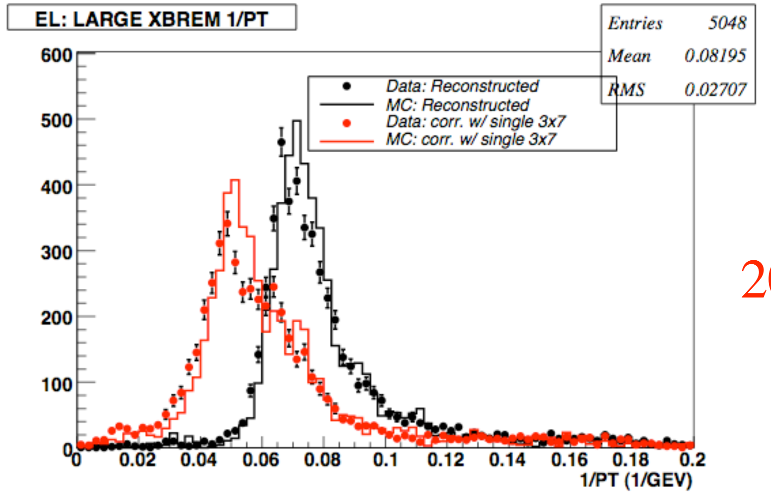

- Implementation
  - Dividing the (Silicon) track into two parts
  - Refitting only the part close to vertex together with the (3x7) LAr cluster position as an ordinary hit.

# Bremsstrahlung recovery

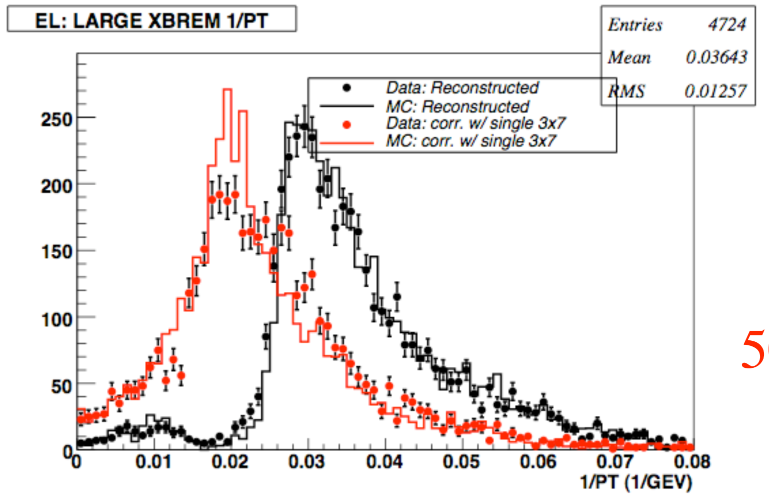
- Amount of Bremsstrahlung activity
  - Xbrem := Phi distance of the cluster to the extrapolation of the track to the calorimeter (Backup)
- Events with large Xbrem

  > 20 mrad (20 GeV)

  > 5 mrad (50 Gev)
- Even for events with heavy Bremsstrahlung activity, peak structure and position is recovered



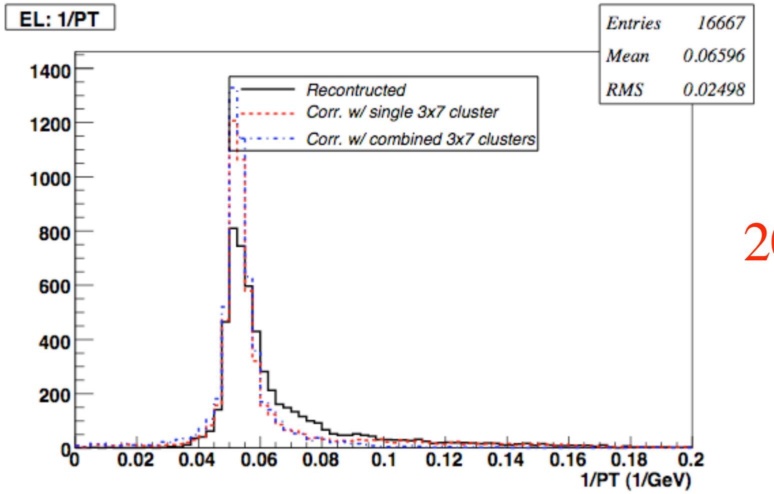

20 GeV/c



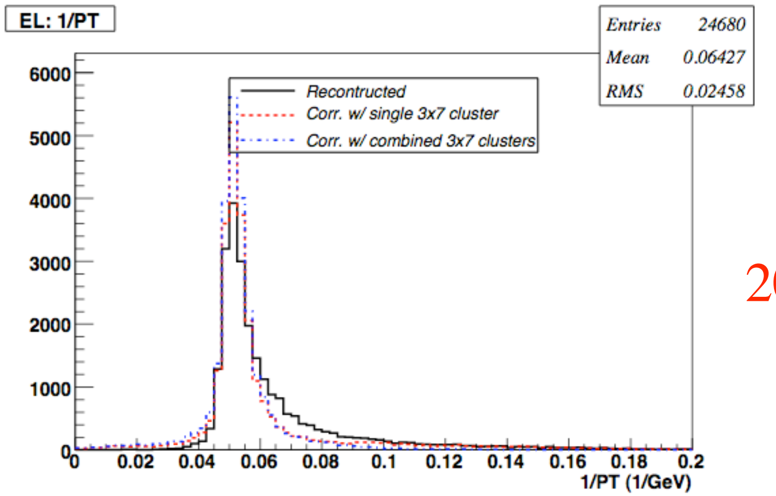

50 GeV/c

# Bremsstrahlung recovery

- Significant tail due to Bremsstrahlung
  - Removed by Bremsstrahlung recovery
- Peak structure and position is recovered




MC
20 GeV/c

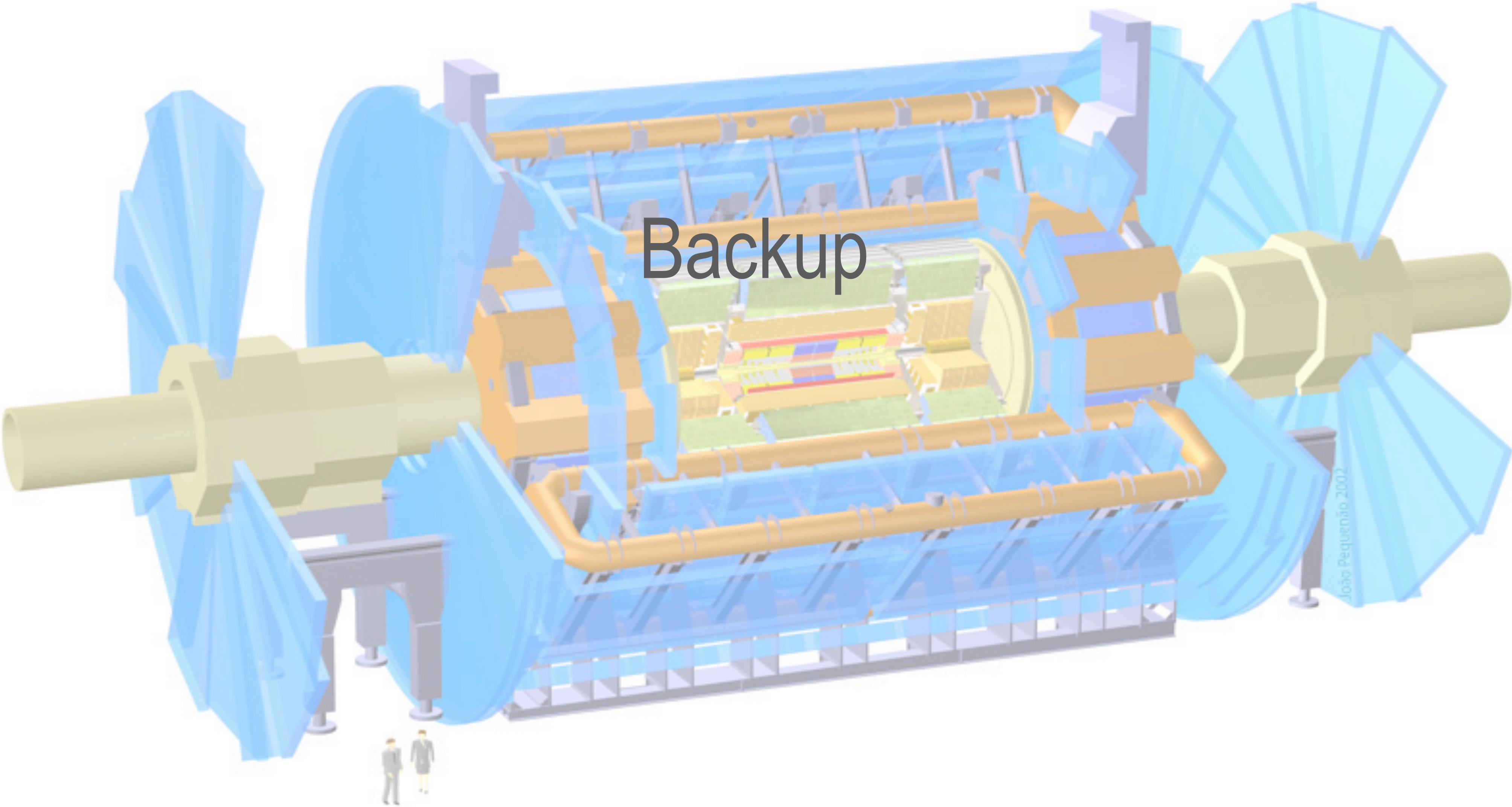



Data
20 GeV/c

# Conclusion

- Combined Test Beam 2004 showed that the Liquid Argon Barrel ($\eta$=0.45) calorimeter will work according to the requirements with realistic amounts of upstream material and a magnetic field
- Intercalibration with E/p validated at the Combined Test Beam 2004 with an obtained precision of 5‰
- Bremsstrahlung recovery can be used to recover the initial electron momentum even for events with heavy Bremsstrahlung activity

# Backup



# Modeling of E/p for the CTB 2004

- Random variables

$$e = E/p_{beam}$$

$$q = p_{beam}/p$$

$$r = e \cdot q$$

- Distribution for E/p

$$R(r) = \int_{-\infty}^{\infty} f_{(E,Q)}\left(\frac{r}{w}, w\right)\frac{1}{w}\, dw$$

$$R(r; \alpha_e, n_e, \mu_e, \sigma_e, \alpha_q, n_q, \mu_q, \sigma_q) = \int_{-\infty}^{\infty} E(\frac{r}{w}; \alpha_e, n_e, \mu_e, \sigma_e)\, Q(w; \alpha_q, n_q, \mu_q, \sigma_q)\, C(\frac{r}{w}, w)\frac{1}{w}\, dw$$

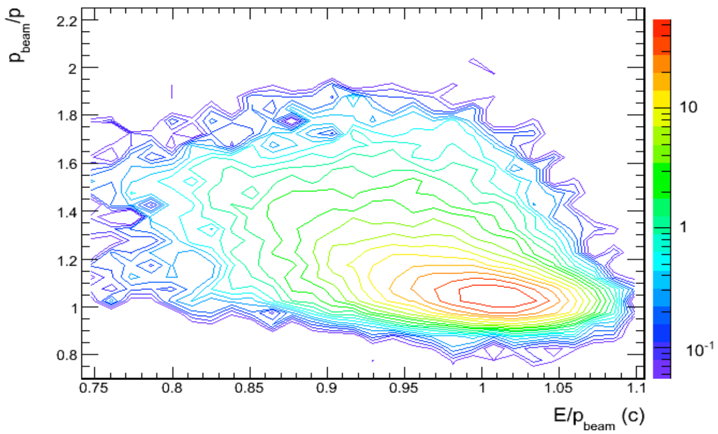
- Correlation

$$C(e,q) = \frac{f_{(E,Q)}(e,q)}{E(e)\, Q(q)}$$

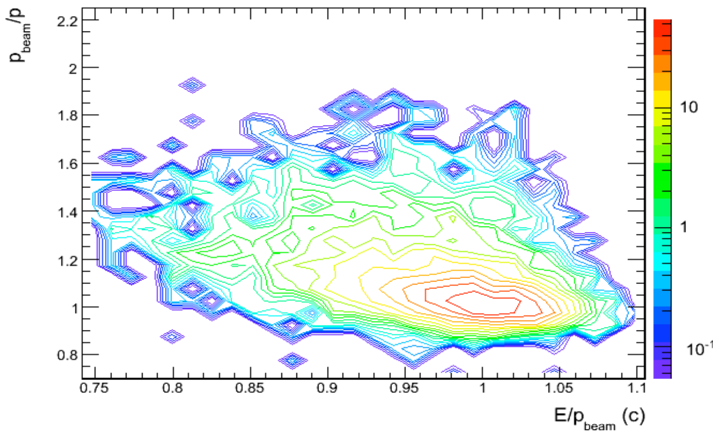
computed bin-wise

# Joint distribution (MC and data) and correlation (MC) for 20 GeV/c

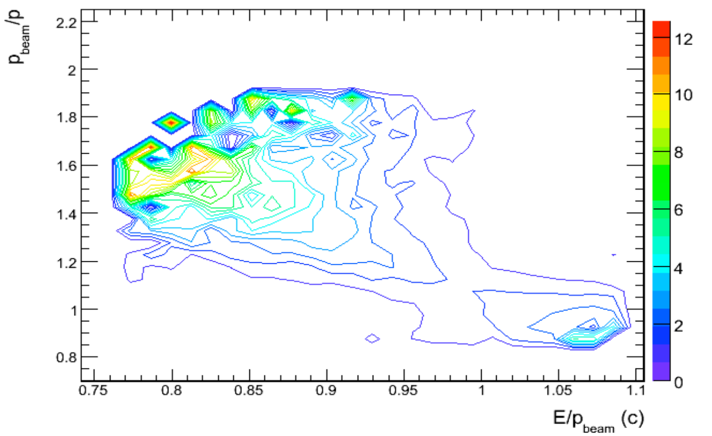
$f_{EQ}(e,q)$
MC



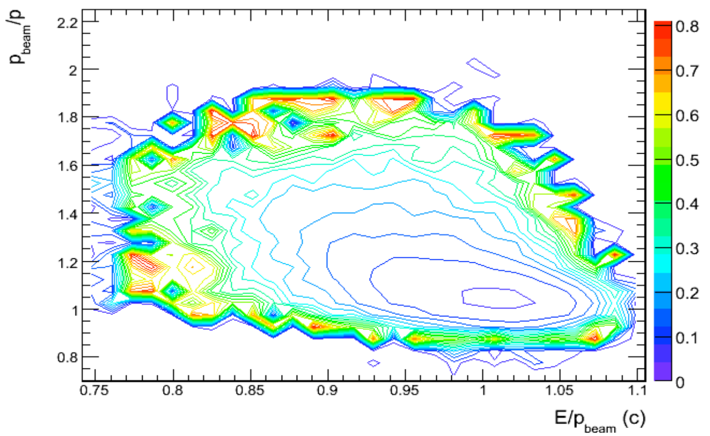

$f_{EQ}(e,q)$
data




C(e,q)
MC

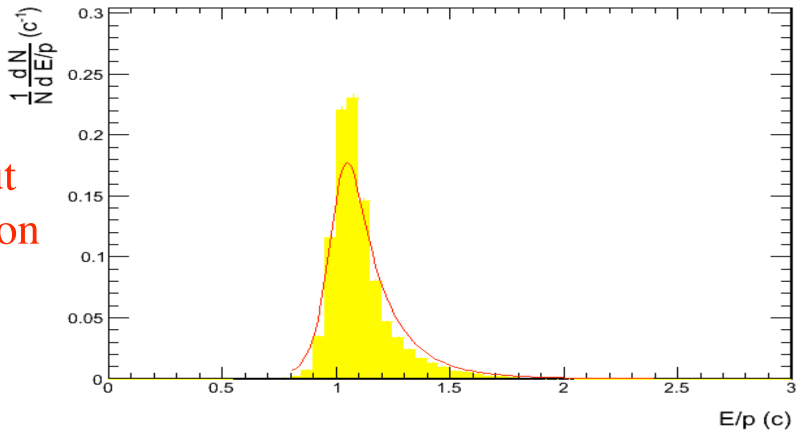


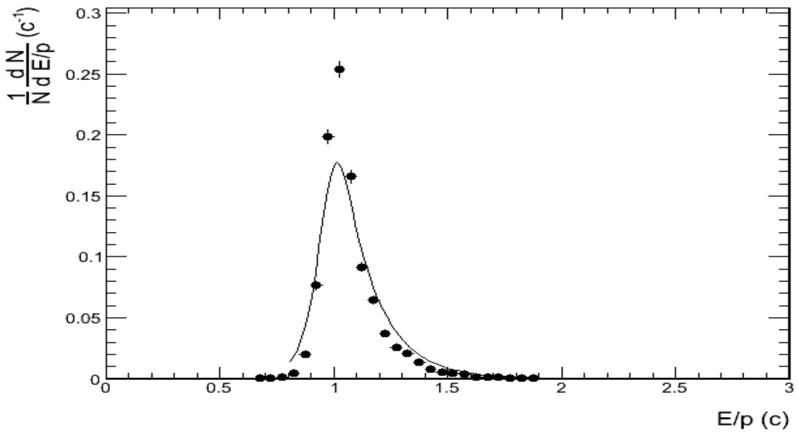

C(e,q) MC
relative
error



# E/p without /with correlation for MC/Data 20 GeV/c

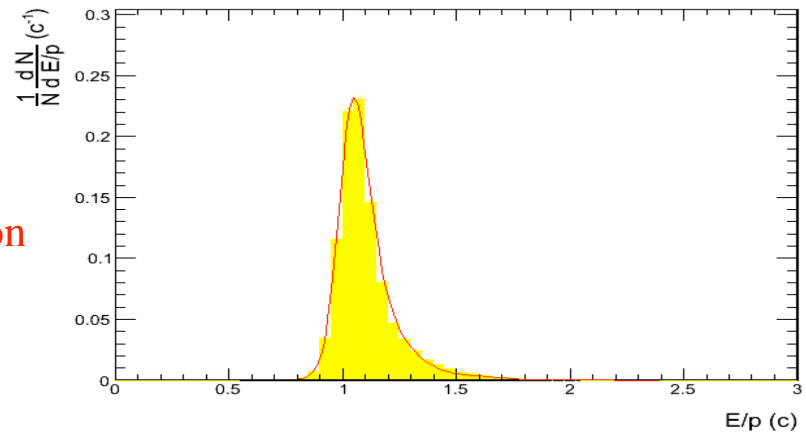
Without correlation

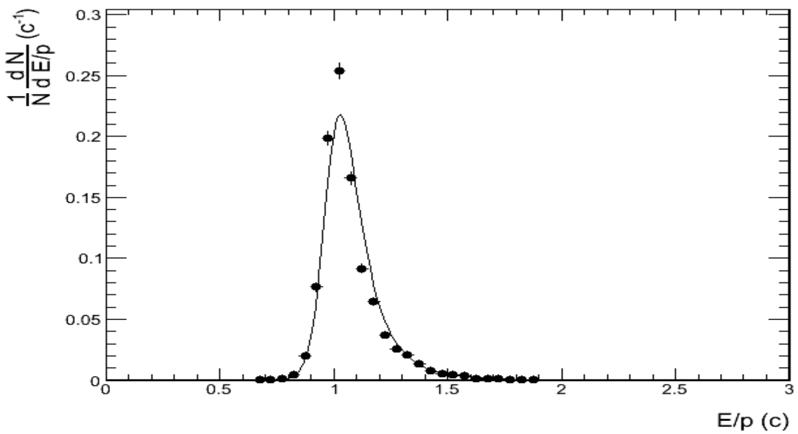



Without correlation

With correlation

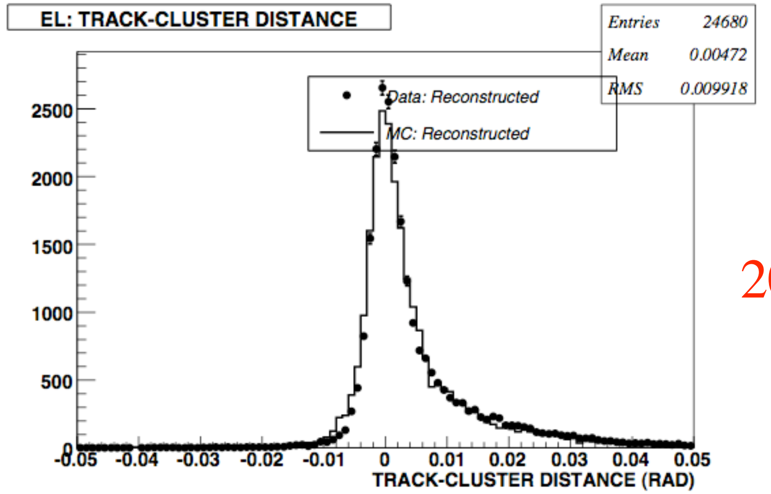


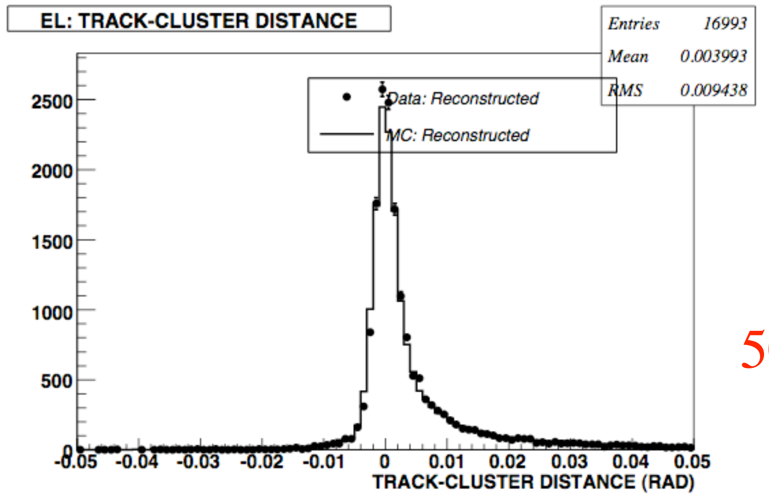

With correlation from MC

# Bremsstrahlung recovery

- Amount of Bremsstrahlung activity
  - Xbrem := Phi distance of the cluster to the extrapolation of the track to the calorimeter




20 GeV/c




50 GeV/c