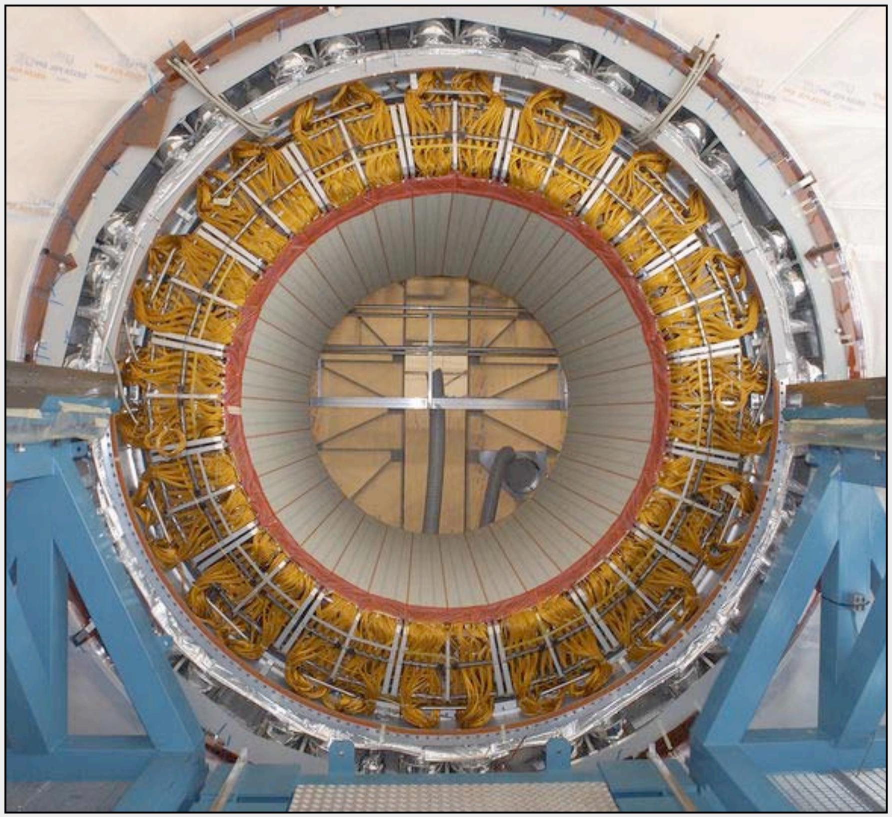
Studies of the Linearity of the ATLAS EM Barrel Calorimeter

Electron Beam Test Results from 2002 and 2004



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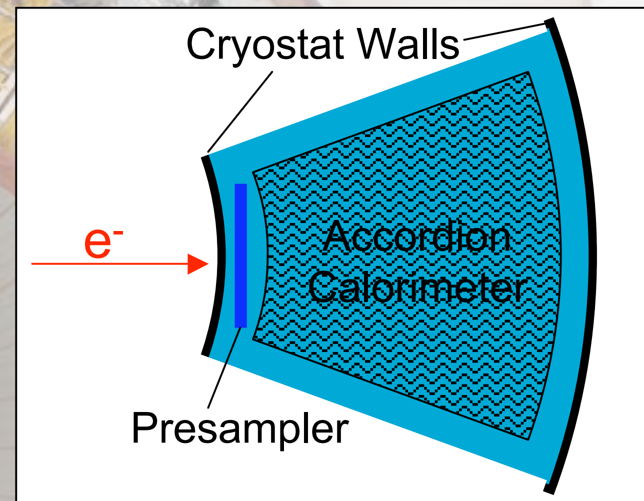
On behalf of the ATLAS Liquid Argon Calorimeter Collaboration

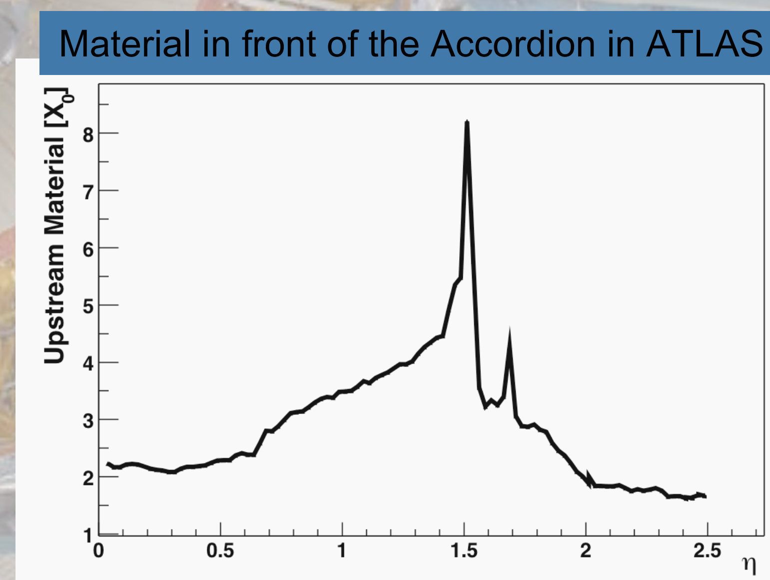
Structure of the LAr Calorimeter

(see talk by M. Aleksa for more details)

- Accordion Sampling Calorimeter
  - Segmentation in three longitudinal compartments
- Presampler
- (Significant) amount of dead material upstream (~2-3 X_0)
  - Cryostat wall, solenoid, …



- Calibration Strategy:
  - Use MC to understand effect of upstream material
  - Validate MC with testbeam data
  - Derive calibration constants from MC
  - Cross-check by applying calibration to testbeam.



Test Beam Setups

(See talks by M. Delmastro and I. Nikolic for more details)

Electron beams from the CERN SPS H8 beam line

2002 Standalone Run

- Precision Energy Scan
  - Exceptionally accurate determination of beam energy
    - Dedicated beam line instrumentation
    - σ_E=11 MeV + $3.4\cdot10^{-4}$ E
  - 15 Energy-Points in the range of 10 - 180 GeV
  - Impact point

    η=0.687, φ=0.282

2004 Combined Run

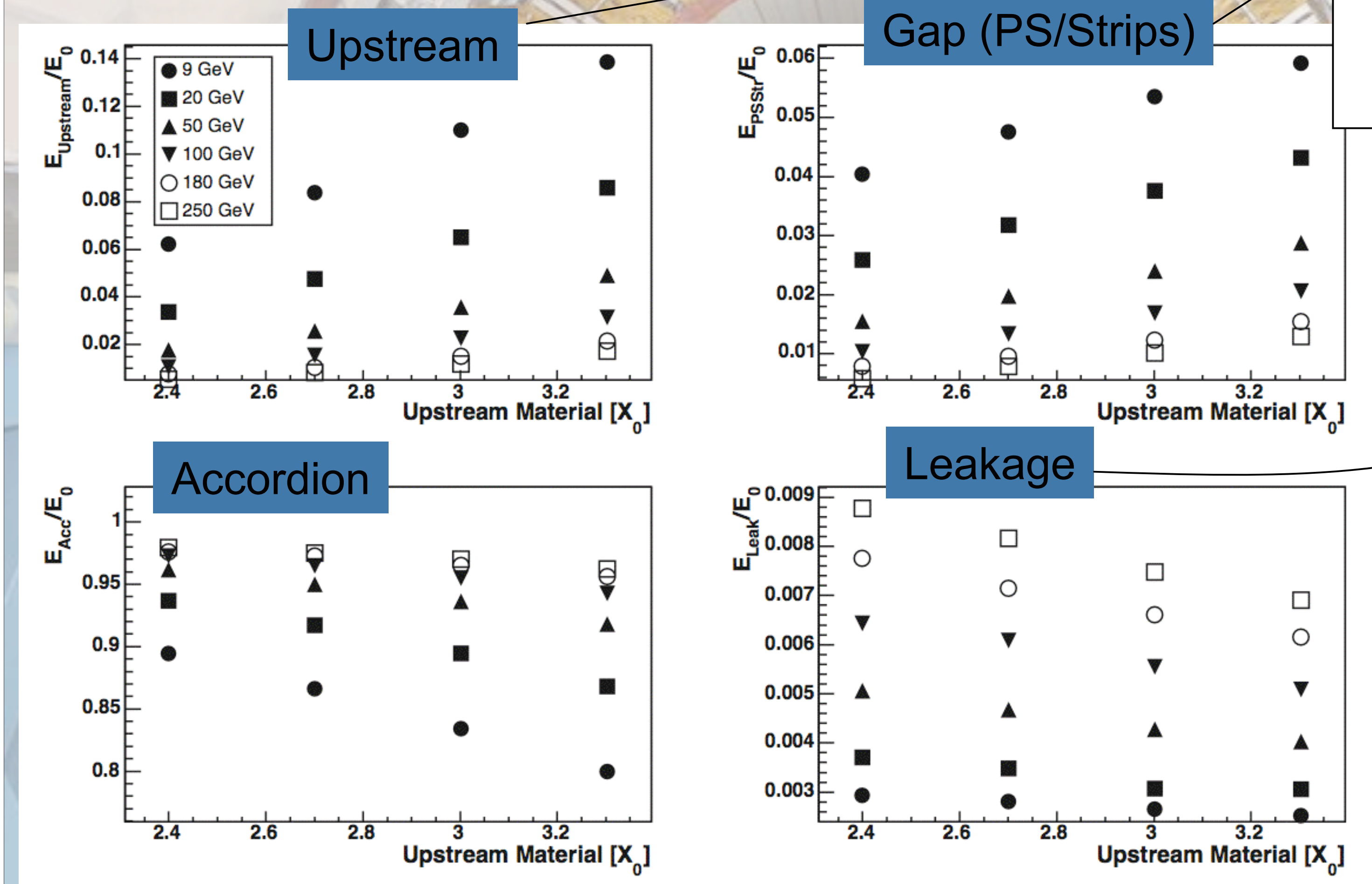
- Energy and Material Scan
  - Varied upstream material
    - 2.4, 2.7, 3.0, 3.3 X_0 realized by adding 25mm Al plates
  - 6 Energy points
    - 9,20,50,100,180,250 GeV
  - Impact point

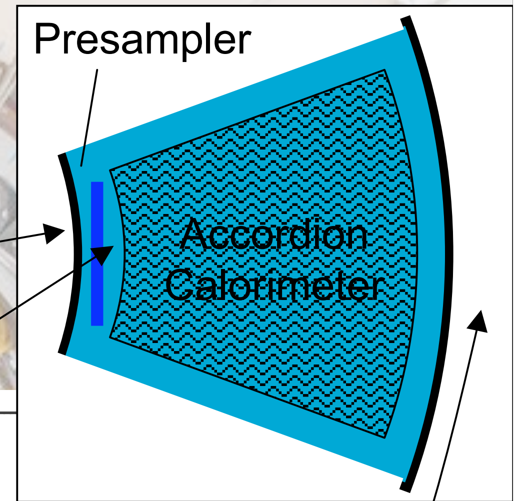
    η=0.4, φ=0
- Very low energy
  - Dedicated beam line modification
  - 1 to 9 GeV
  - No linearity results yet

We use a Geant4 based simulation of both setups.

Energy Deposit in the various regions

(Simulation of 2004 setup)



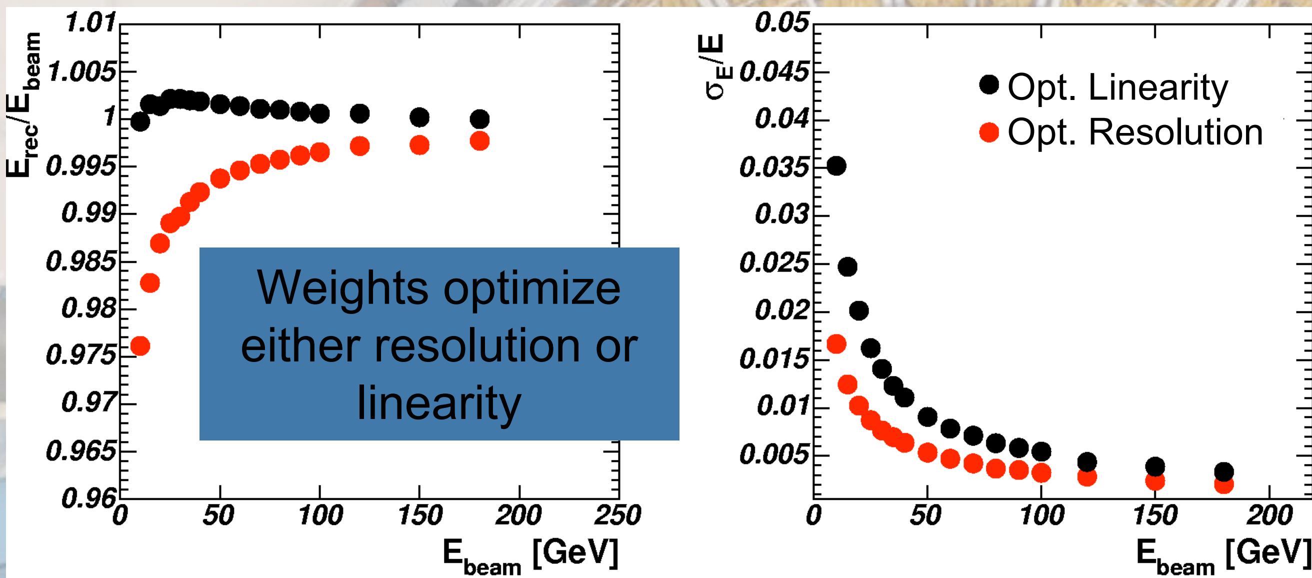


- Impact point:
  - η=0.4, φ=0
- Accordion:
  24.5 X_0 thick

Precise Calibration of the ATLAS EM Calorimeters

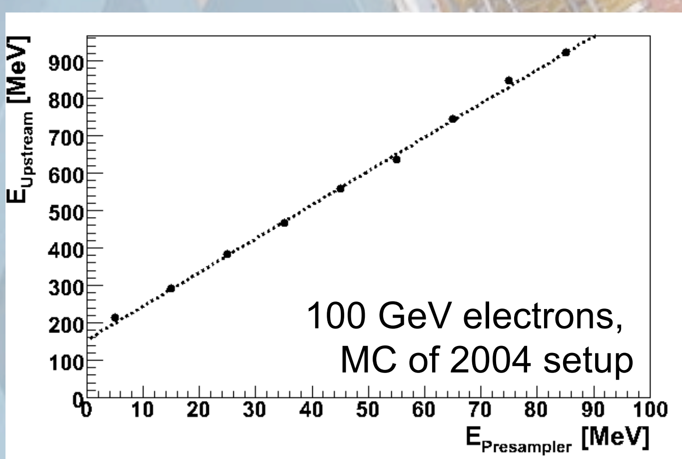
Correcting Upstream Energy Loss

What is the proper weight for the Presampler signal?



- A simple weight is not sufficient!
- Correlation plot of upstream energy deposit vs PS signal features an offset!

$$E_{Upstream} = a + b\,E_{PS}$$

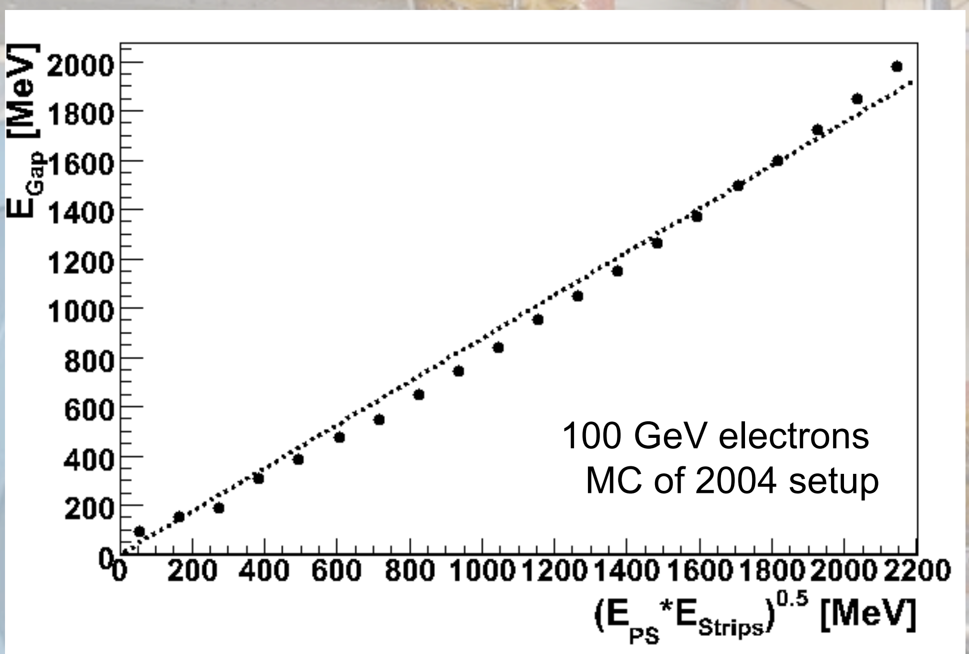


- Offset **a** accounts for energy loss by particles stopping before the presampler
  - Ionization energy loss (roughly energy independent)
  - Low-E bremsstrahlung photons that do not reach the Presampler (energy dependent)
  - Photo-nuclear interactions (energy dependent)
- Weight **b** accounts for ionization energy loss by particles traversing upstream matter and (part of) the presampler.

Precise Calibration of the ATLAS EM Calorimeter

Correcting for the Gap between PS and Accordion

- Significant amount of inactive material (~0.5 X_0)
  - Electronics boards and cables immersed in LAr
  - Dependence on impact point
- Shower already developed (about 2-3 X_0 before Accordion)



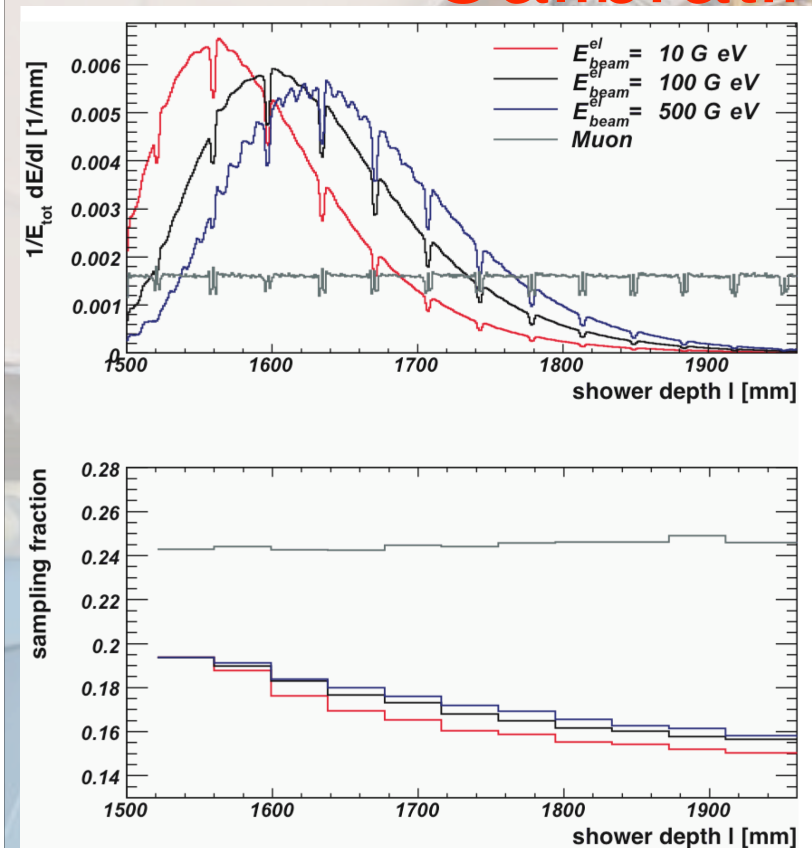
- Best correlation between measured quantities and energy deposit in the gap:

$$E_{Gap} = c \cdot \sqrt{E_{PS} \cdot E_1}$$

- Empirically found

Precise Calibration of the ATLAS EM Calorimeters

Calibrating the Accordion



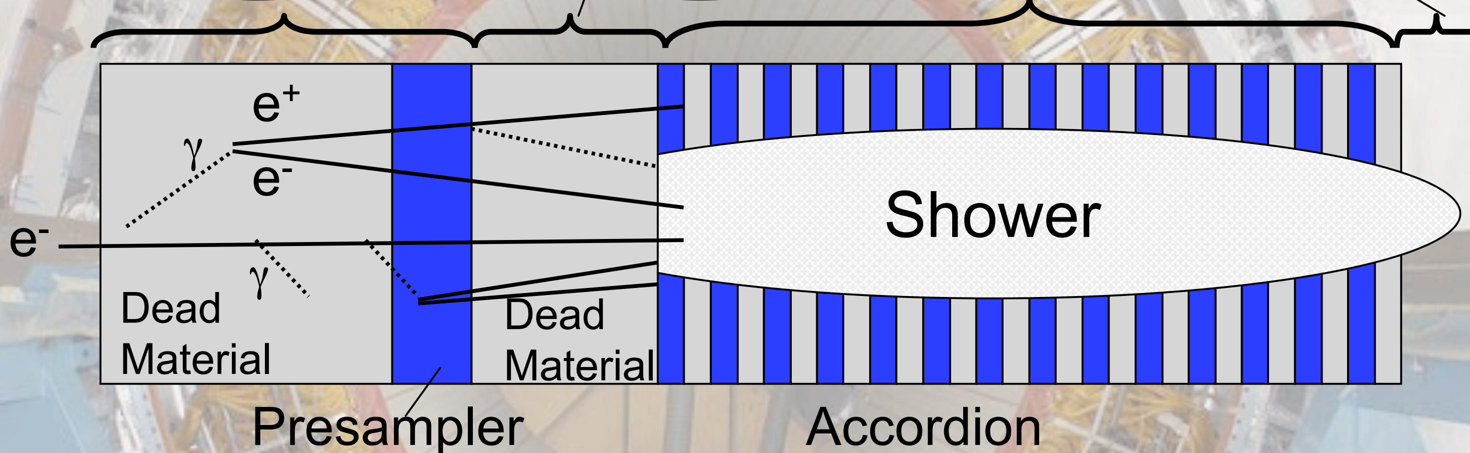
- Sampling Fraction (SF) not exactly constant!
  - Depends on shower composition.
    - Many short-ranged, low-energy particles are created and absorbed in the lead (much higher cross-section for photo-electric effect than argon)
    - Sampling Fraction decreases with depth and radius as such particles become more and more dominant.

- Use different SF for longitudinal compartments?
  - Compromises resolution and linearity since shower depth fluctuates.

Use same sampling fraction for all compartments and apply energy-dependent correction factor

Final Calibration Formula

$$E_{rec} = a + b\,E_{PS} + c\sqrt{E_{PS}\,E_{First}} + d\,E_{acc} + e\,E_{Back}$$

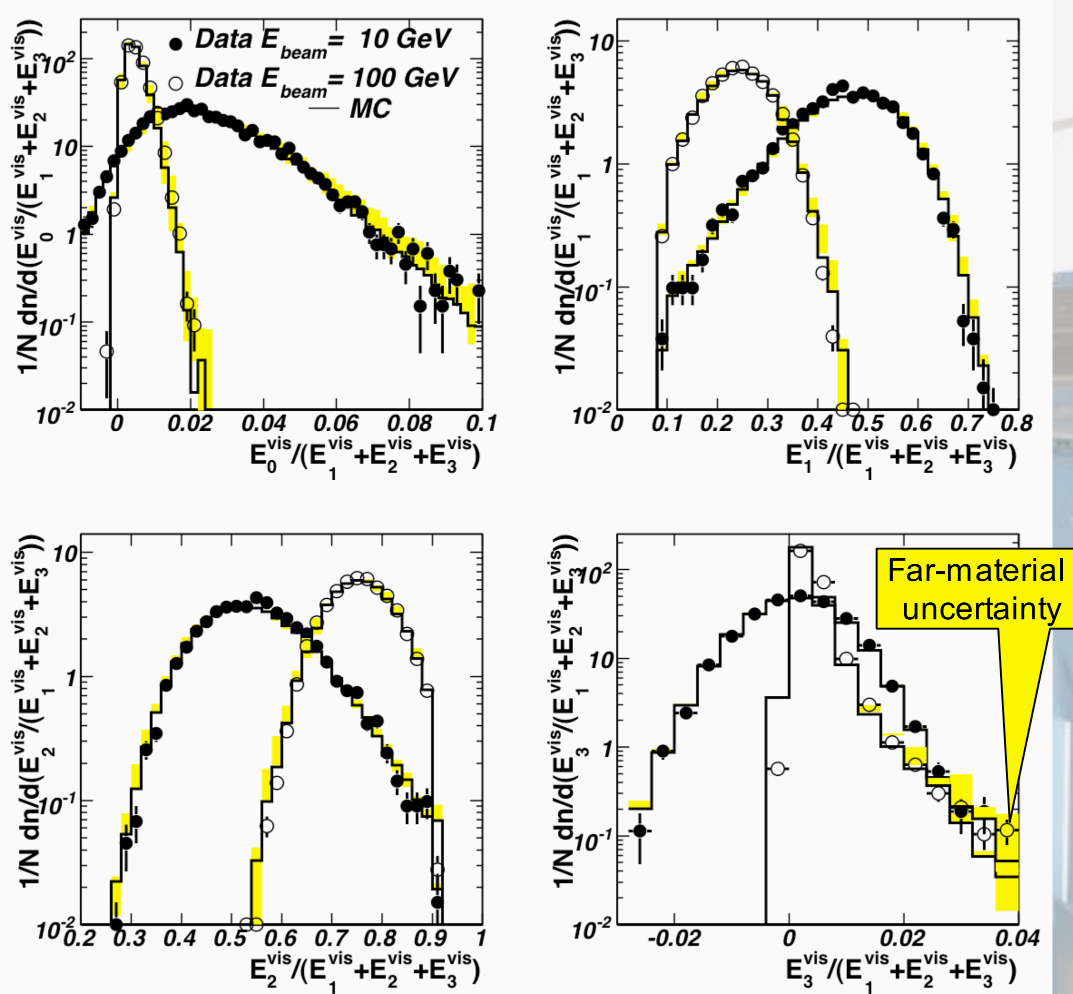


- Good linearity and resolution achieved
- Constants depend on impact point (upstream material) and on the energy.
  - Can be parameterized.
- Constants are derived from a MC simulation of the detector setup.

MC Data Comparison (1)

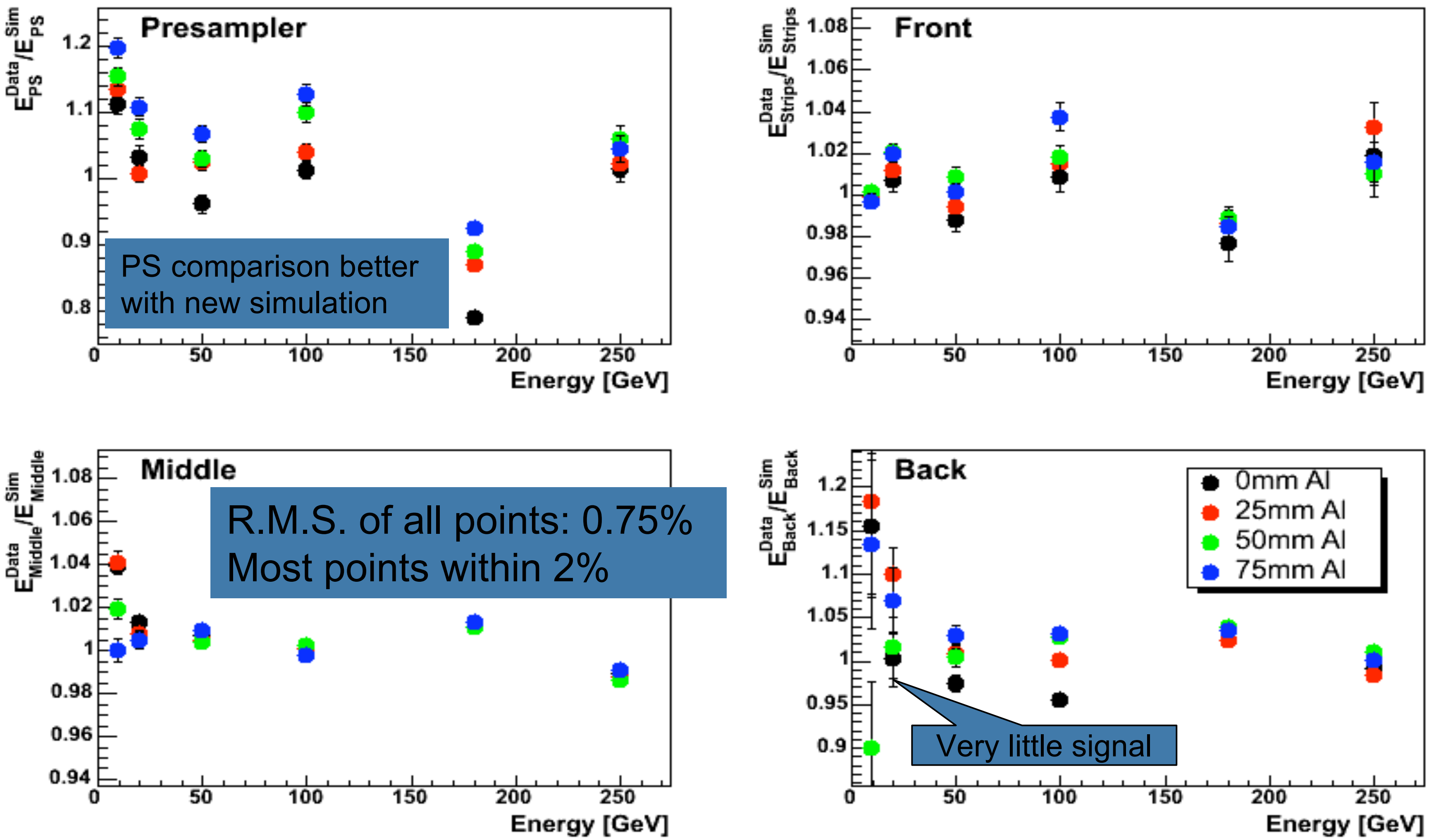
- Most difficult issue:
  - Accurate description of upstream material
    - Air and beam-pipe windows between energy-defining spectrometer and calorimeter (~0.15 X_0)
    - Cables and electronics in the gap between Presampler and Accordion
  - Plots shown use "equivalent material" in the geometry.
    - Meanwhile better understood, new simulation of 2004 run being produced.
- More plots in M. Delmastro's talk

Comparison of energy fraction in each layer for 10 GeV and 100 GeV (2002-run)

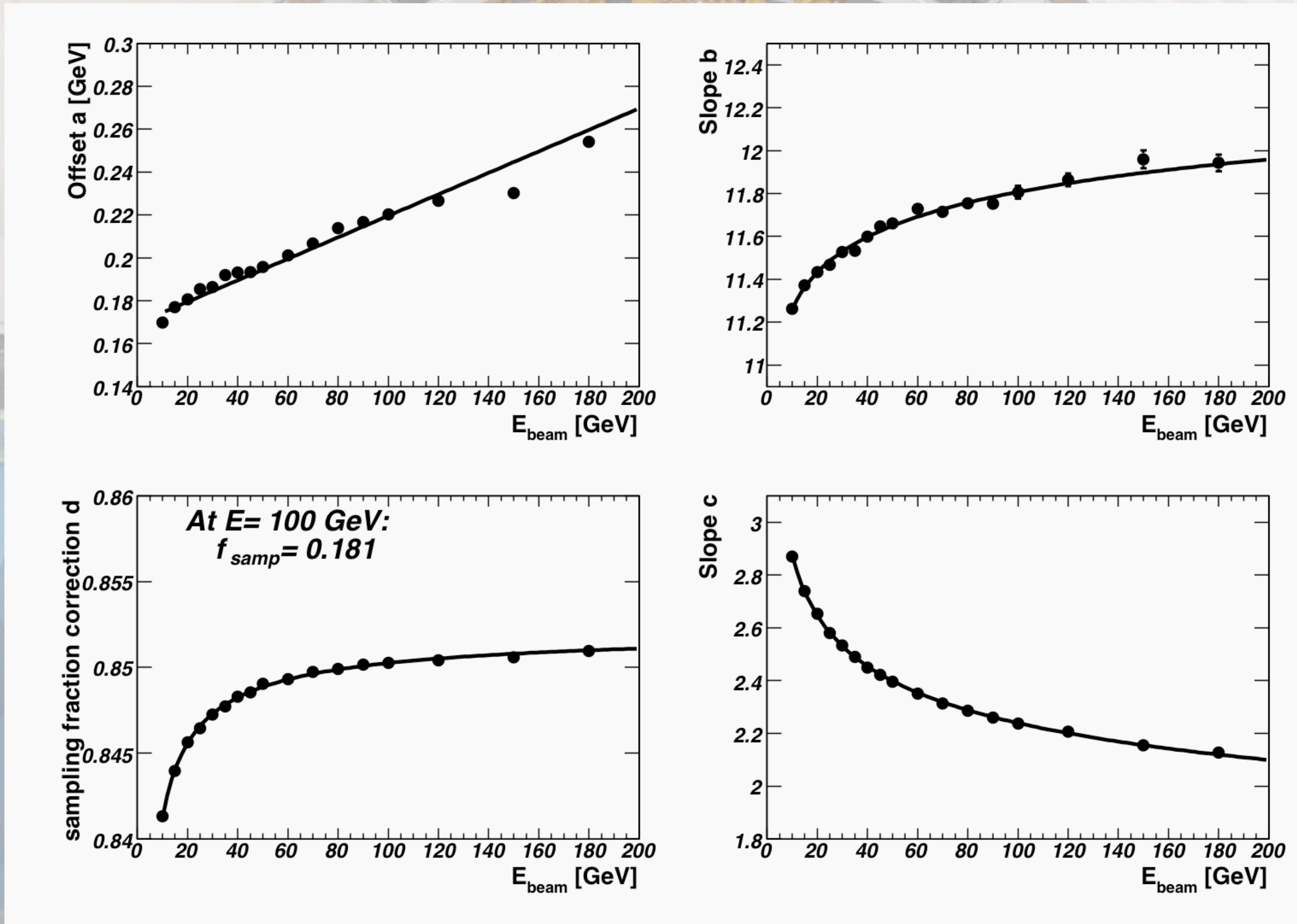


MC-Data Comparison (2)

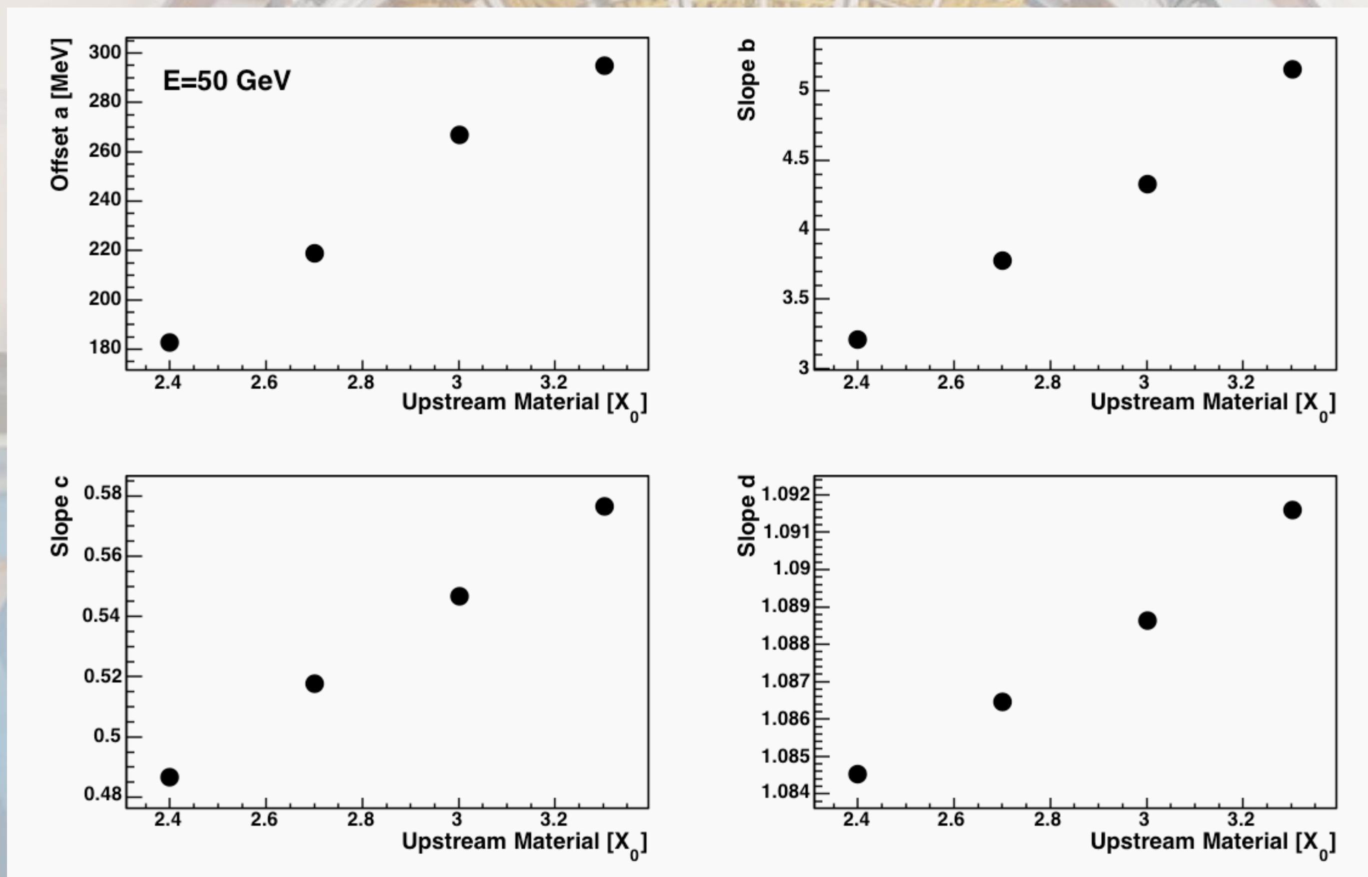
Ratio of mean energy in each compartment for all energies and all material configuration (2004-run)



Calibration Constants - 2002 Run

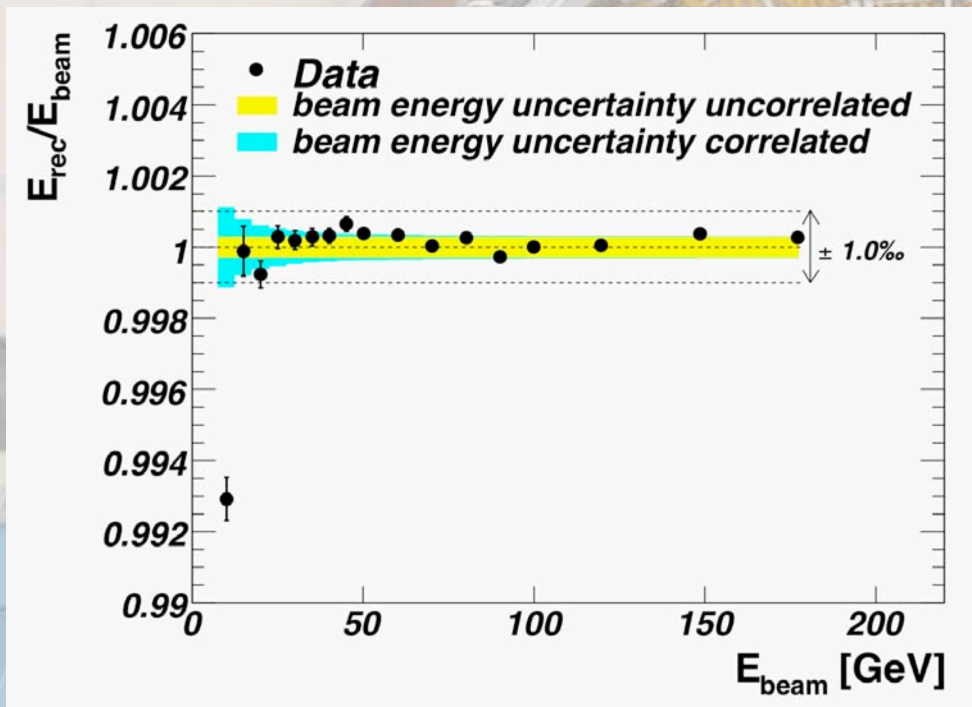


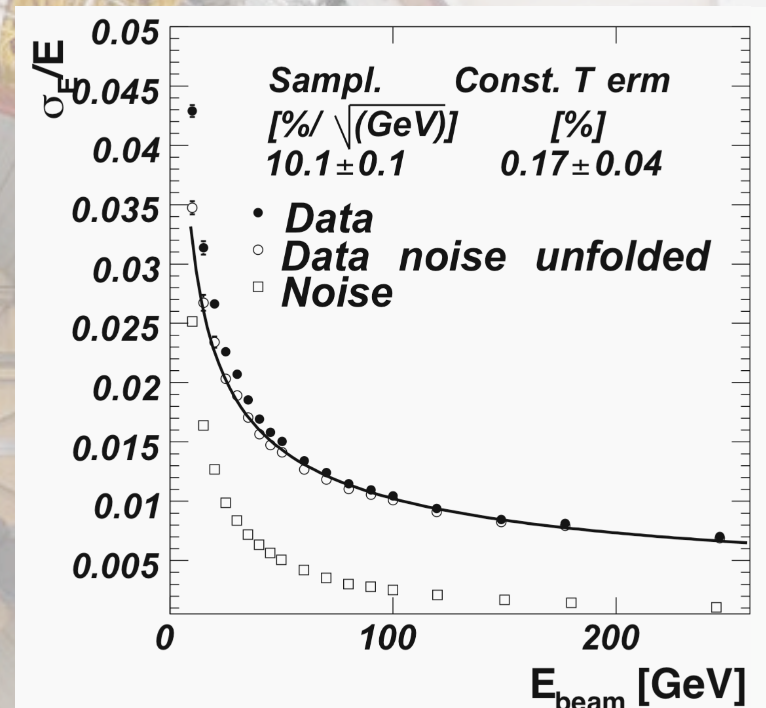
Calibration Constants - 2004 Run
Dependence on upstream material



- All parameters rise when material is added
  - More energy lost upstream, later part of the shower is measured.

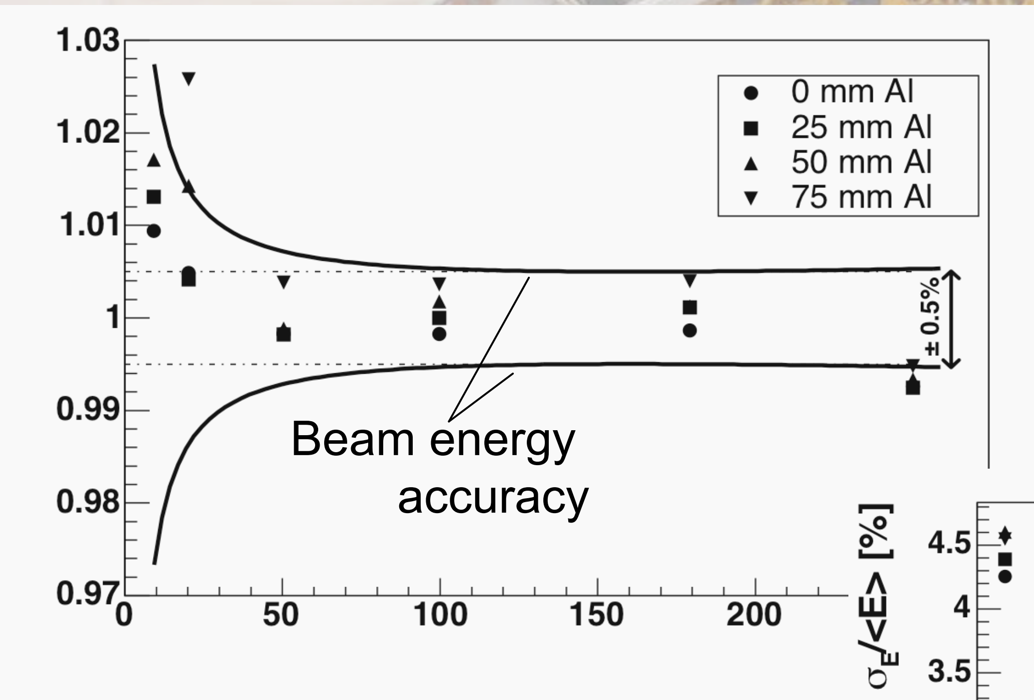
Linearity and Resolution - 2002 Run



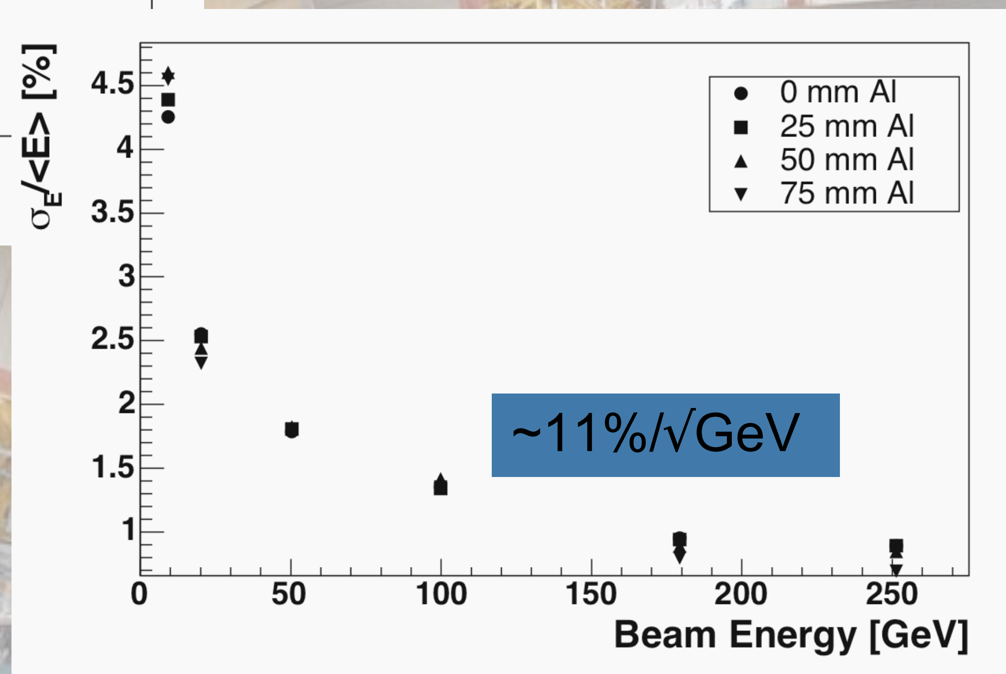


- Procedure yields an excellent linearity (better than ±0.1% for E>10 GeV) while preserving the resolution.

Linearity and Resolution - 2004 Run

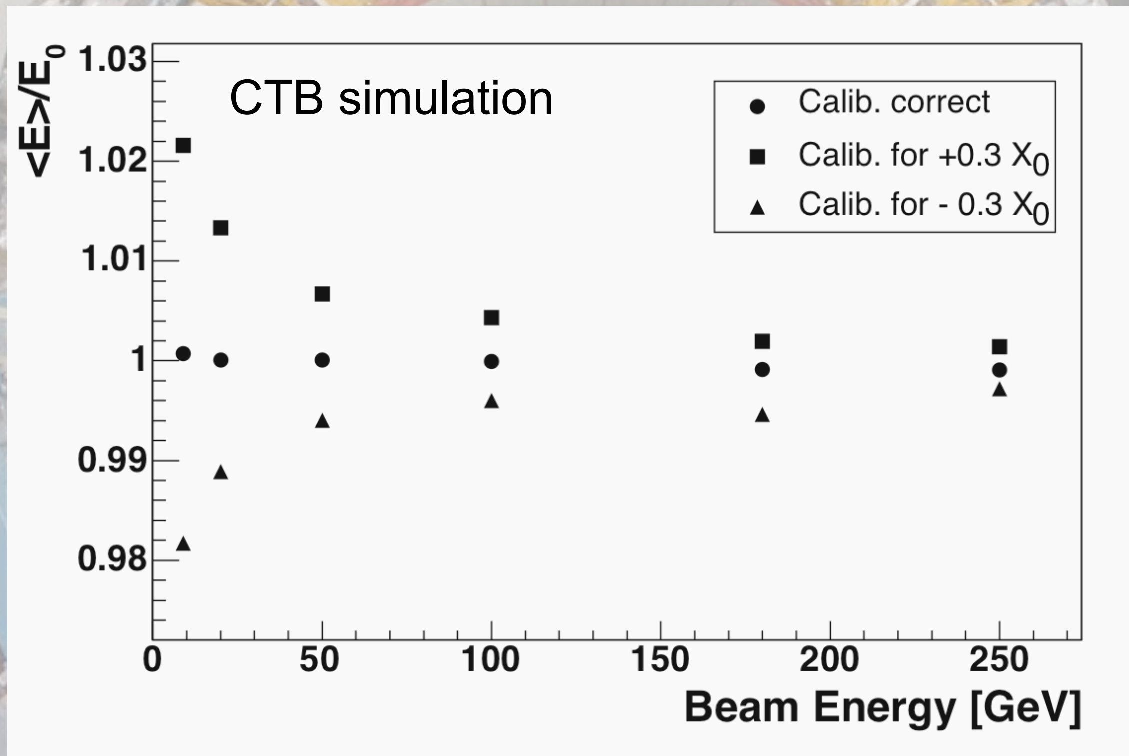


- Procedure works also for larger amounts of upstream matter
  - Linear within the beam energy accuracy
  - Work in progess…



Effect of wrongly estimated upstream material

- Apply calibration constants derived for slightly different setup
  - ■ Upstream material **over**estimated by 0.3 X_0
  - ▲ Upstream material **under**estimated by 0.3 X_0



- Resulting error within 1% for energies at 50 GeV
  - Initial material estimation in ATLAS won't be perfect ……

Conclusions

- Analysis of 2002 Linearity Scan almost finished.
  - Linearity of 0.1% achieved
  - Submitted to NIM for publication
- Analysis of 2004 Linearity/Material Scan well advanced.
  - To be included in the analysis:
    - More detailed simulation of upstream material distribution
    - Better understanding of the beam energy accuracy
- Knowledge obtained from Testbeam analysis is incorporated in ATLAS software and will be important for proper energy reconstruction once data is coming.