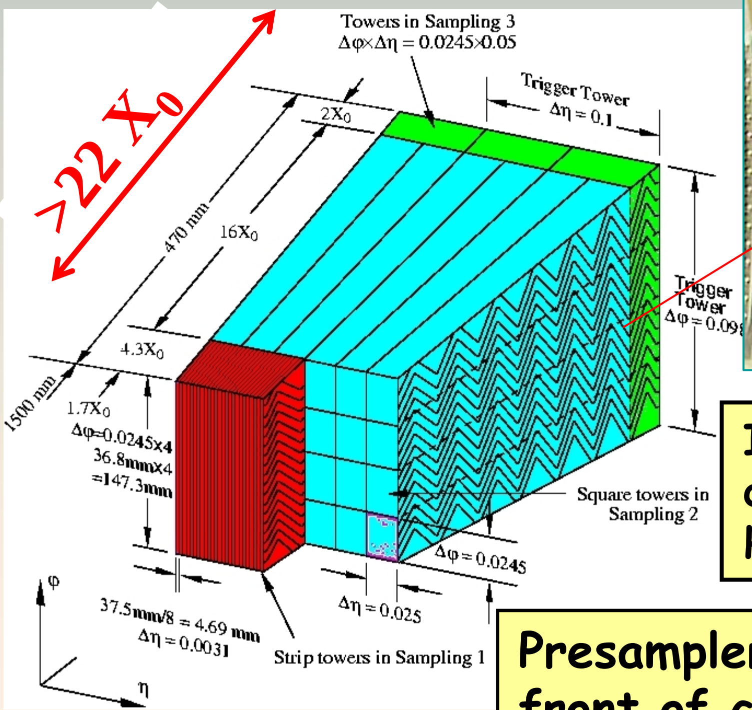
Uniformity in ATLAS EM Calo measured in test beams

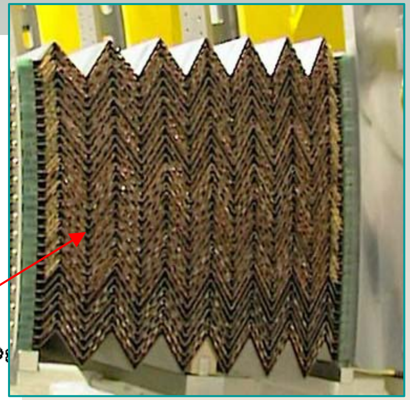
- Constraints on the EM calorimeter constant term
- Energy reconstruction
- Uniformity results with test beams 2000-2002
  - 3 endcap cap modules
  - 3 barrel modules

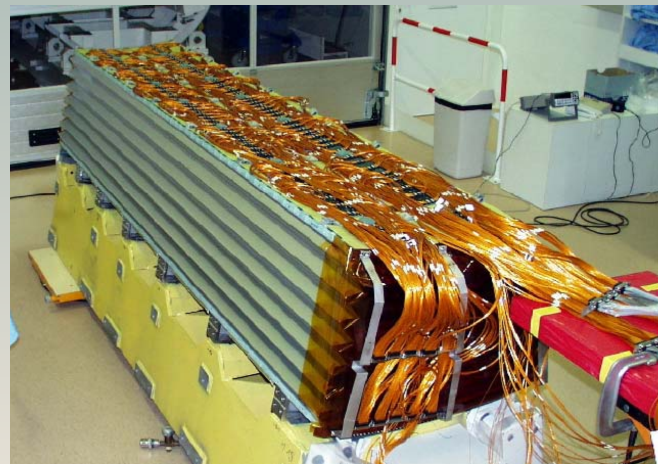
dedicated to deep understanding of the EM calorimeter

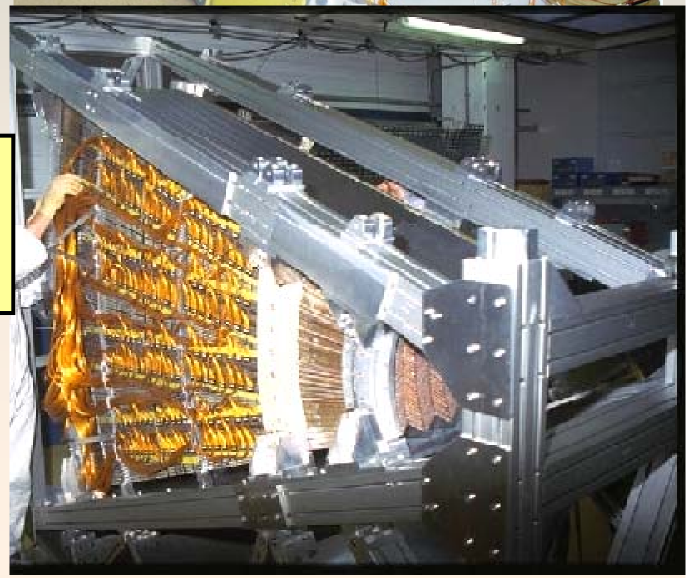
Accordion Liquid Argon calorimeter

Lead/Liquid Argon sampling calorimeter with accordion shape :







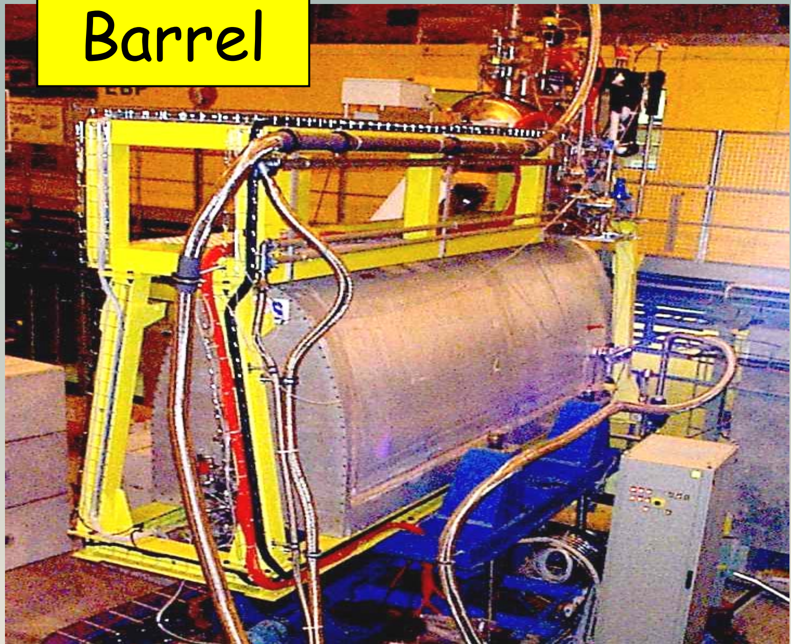


In End Cap, gap depends on radius: HV effects

Presampler in front of calo up to η = 1.8

Test beam Setups

Barrel

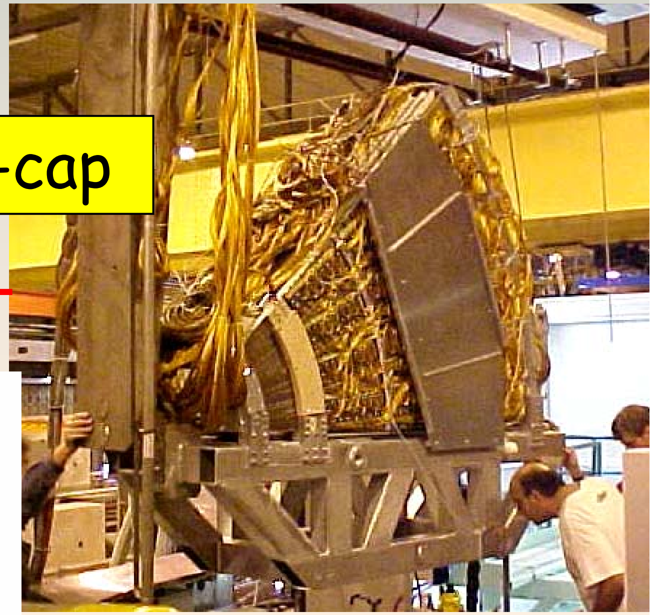


2000-2002: 6 (3 barrel and 3 end-cap) production modules

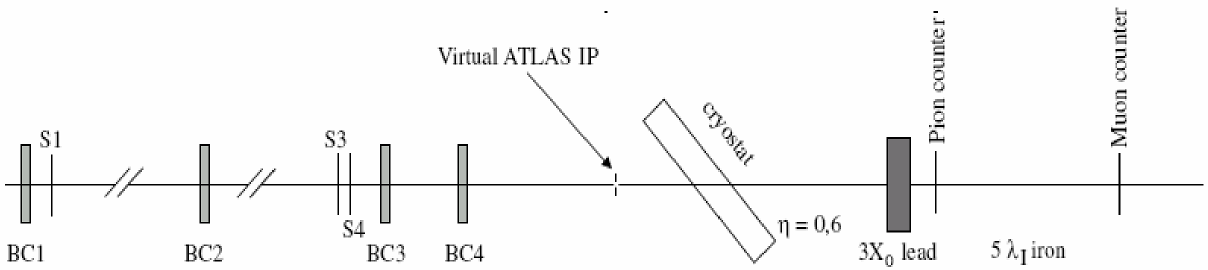
scan in E and η over whole modules

2004 : Combined test beam (see Walter's talk),final electronics+ DAQ

End-cap



ATLAS-like electronics



Constant Term in ATLAS EM calo

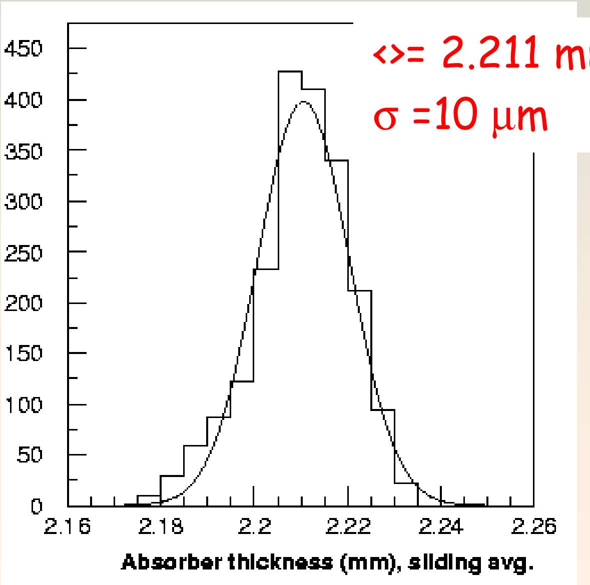
- with a constant term ~ 0.7%, effect on H → $\gamma\gamma$ resolution small: keep constant term as low as possible
- Total Constant term $c = c_{Loc} \oplus c_{LR} < 0.7\%$ for high energy measurement
- c_{Loc} "Local contribution" to constant term < 0.5%
  - variation in $\Delta\eta \times \Delta\phi = 0.2 \times 0.4$ (16 x 8= 128 Middle cells), measured in Test Beam
- c_{LR} Long range variations: corrected with Z → ee events
  - 250 electrons in each unit of $\Delta\eta \times \Delta\phi = 0.2 \times 0.4$, 440 such regions in ATLAS

  10^5 Z → ee events (few days @ 1Hz) to achieve $c_{LR} < 0.4\%$

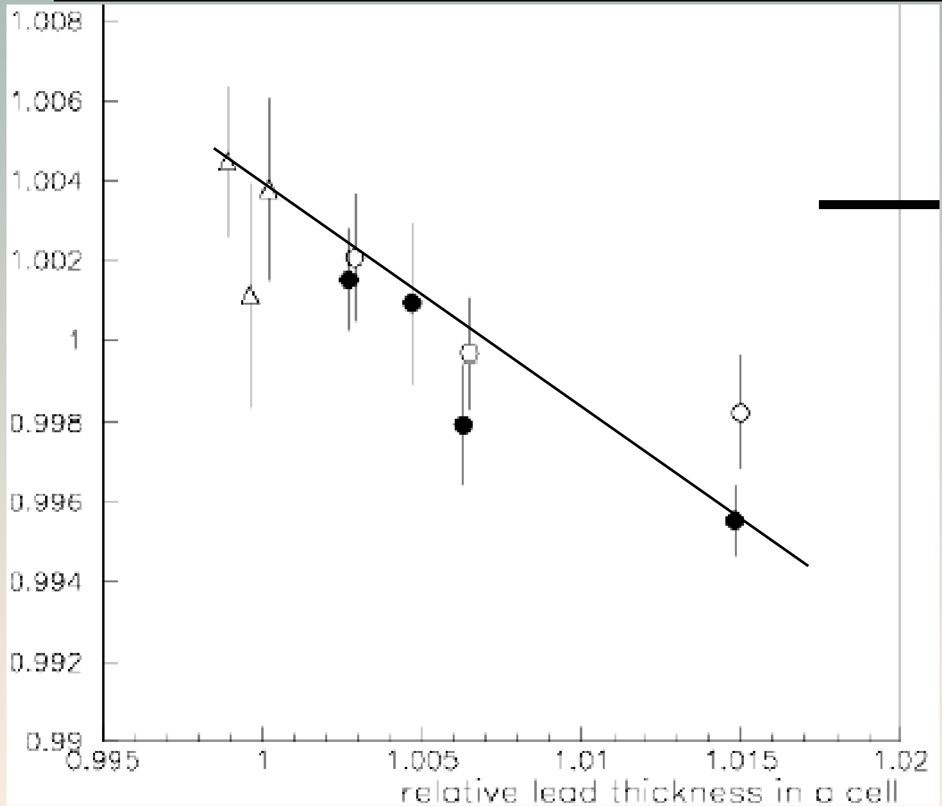
Example of contribution to constant term

Efforts during construction, calorimeter modules as reproducible as possible : few corrections, as small as possible

Absorber thickness



Effect of variation in lead thickness



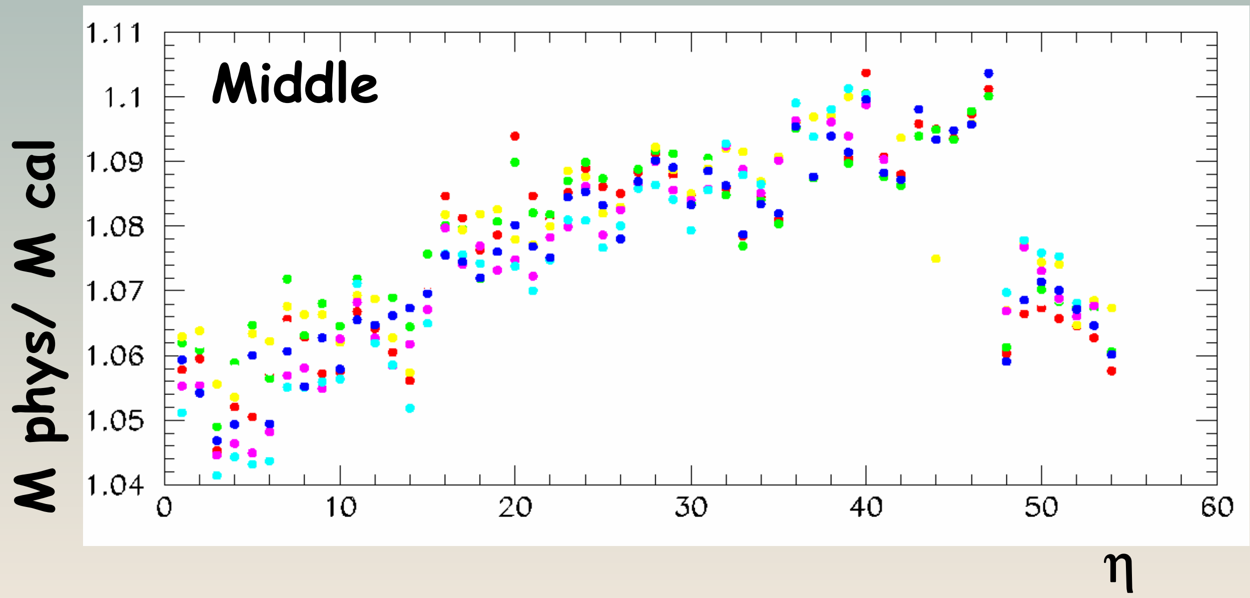
Relative lead thickness

1% Pb variation → 0.6% drop in response

Measured dispersion σ = 9 μm (calo)

Translates to < 2 ‰ effect on constant term

Calibration – physics signal difference



η from 0 to 56 in middle cell numbers

η= [0, 1.4]

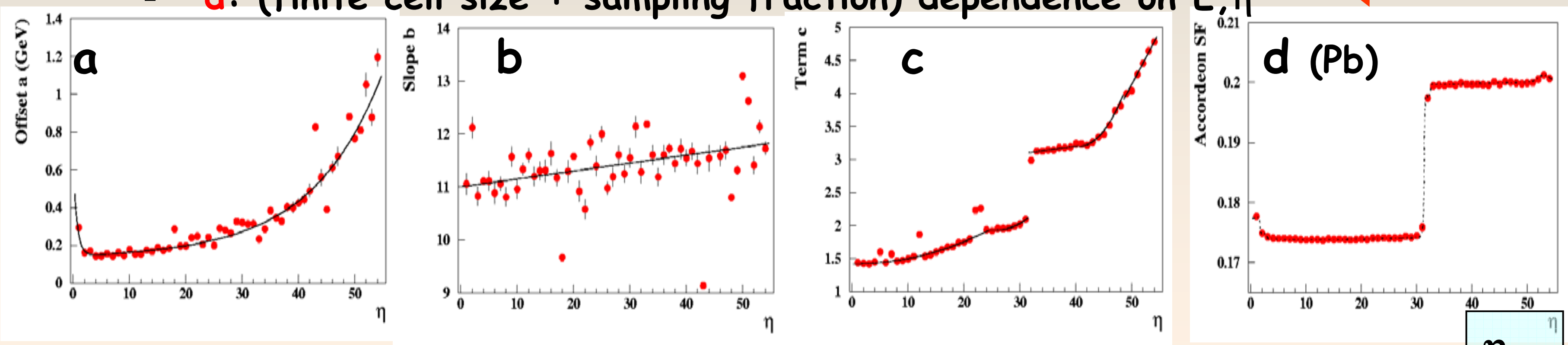
Φ = 9,..14

- Different injection points for signal and calibration
- Marco's talk: signal reconstruction has to be well controlled, if the constant term is to be kept below 0.7%
- Important effect on the final uniformity (~1% effect if not corrected)

Energy reconstruction: EM cluster (I)

$$E_{rec} = a_{E,\eta} + b_{E,\eta} E_{PS}^{Clus} + c_{E,\eta}\sqrt{E_{PS}^{Clus} . E_{1}^{Clus}} + d_{E,\eta} \sum_{i=1,3} E_{i}^{Clus}$$

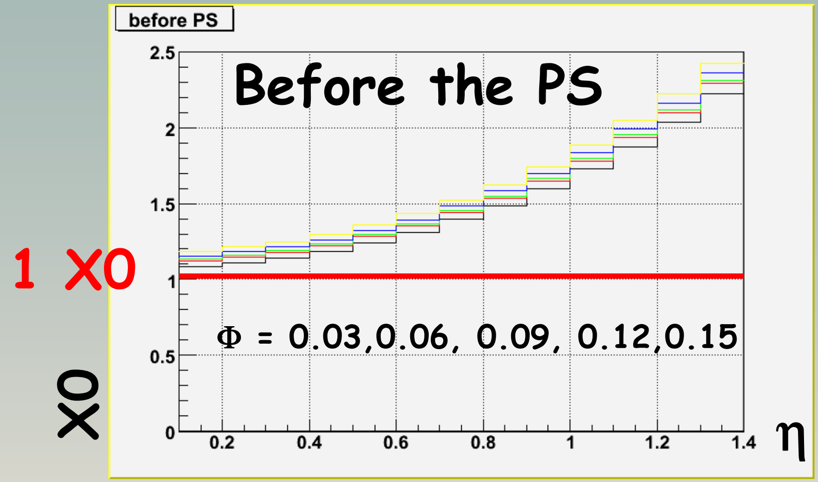
- Determined on MC, depend on η and on E (see W.Lamp's talk for linearity) . Determined at one ϕ only, applies to all ϕ
- a : Primary electron energy lost (offset)
- b: material in front of the calorimeter (~1.5 X0)
- c: 0.9 X0 of cables, electronics and support structure
- d: (finite cell size + sampling fraction) dependence on E,η

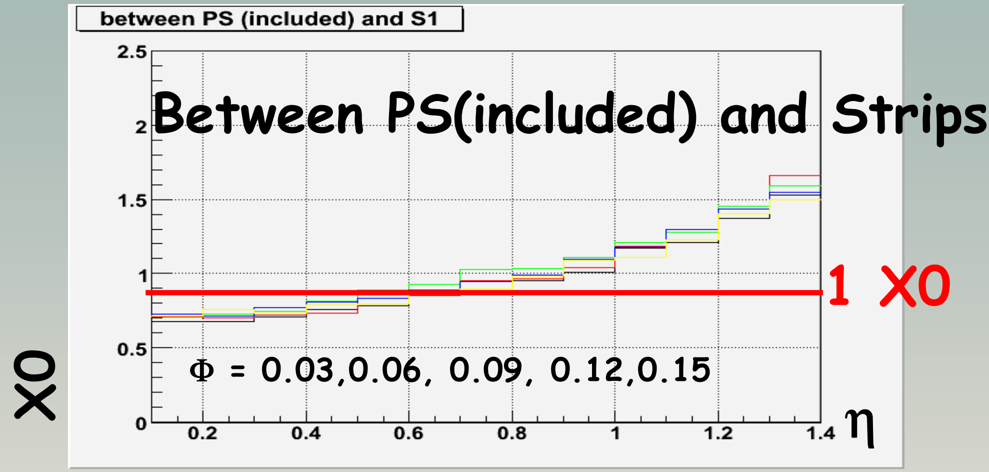


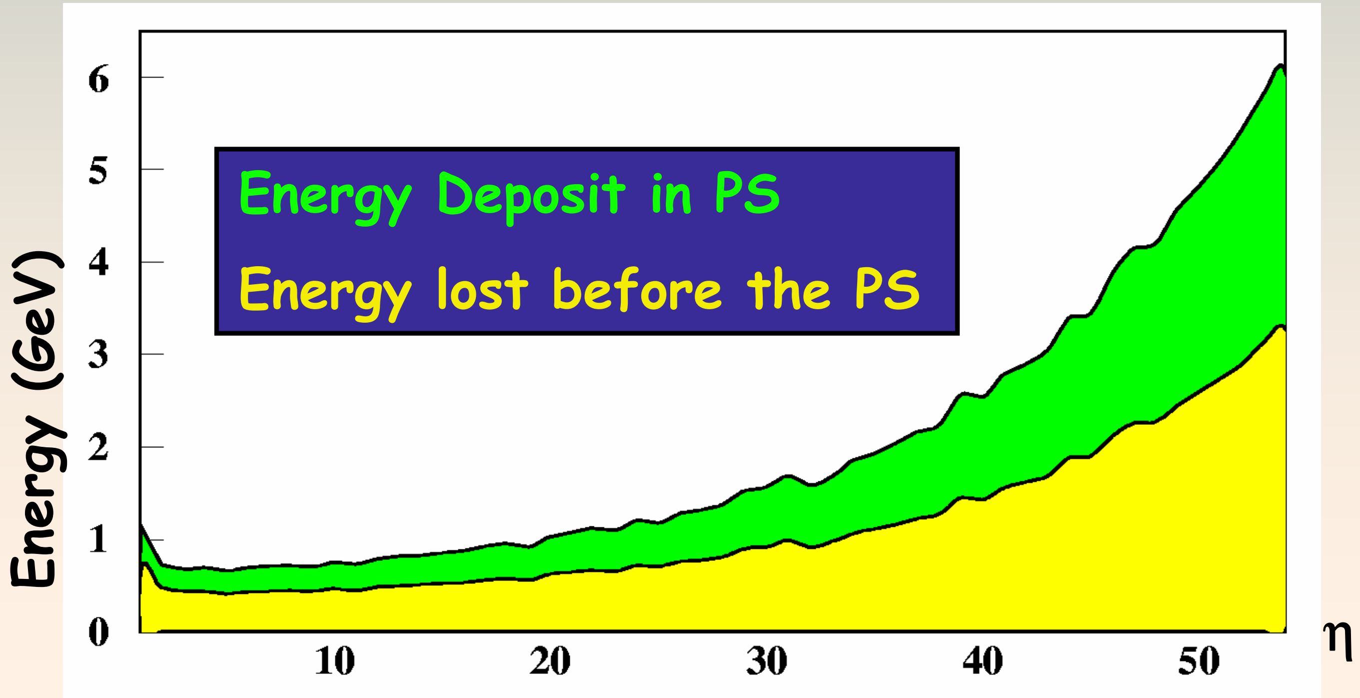
η

245 GeV e-, scan in η

Matter distribution in test beam MC







Energy reconstruction II

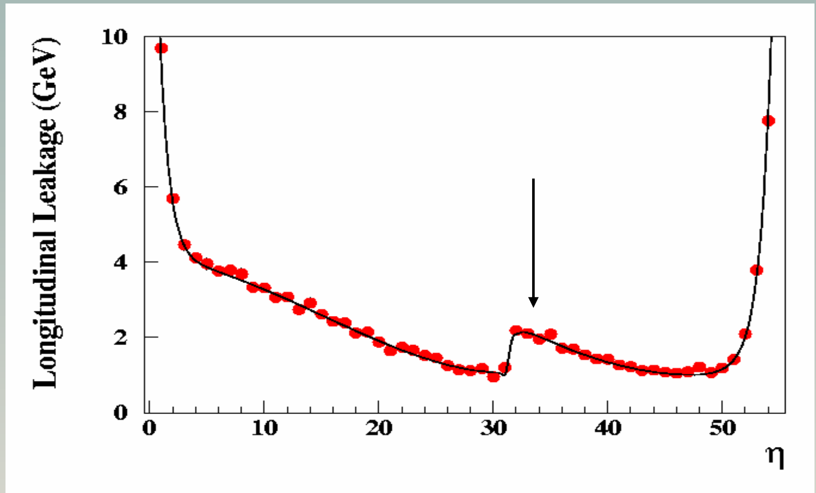
$$E_{final} = (E_{rec} + E^{Leakage}) \times f_{\text{Cell Impact}} \times f_{\text{Nuclear Binding}} \times f_{\text{Tr}}$$

- Leakage (next slide)
- Transverse leakage, accordion effects in ϕ correction for a 3x3 cluster
- Nuclear-Binding: nuclear binding energy compensation,

  0.2% effect @ 245 GeV between electrode A and B
- Tr: Correction for electrode in transition region (see later)

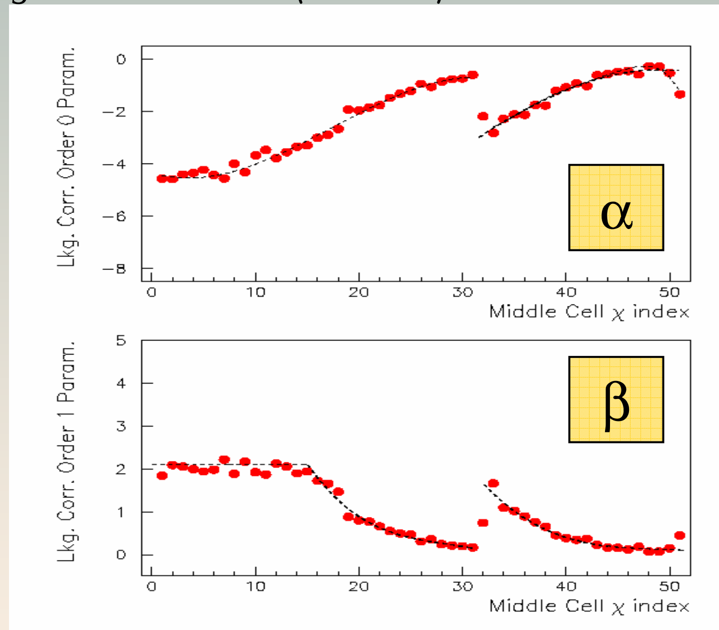
  (no E field)

Longitudinal leakage



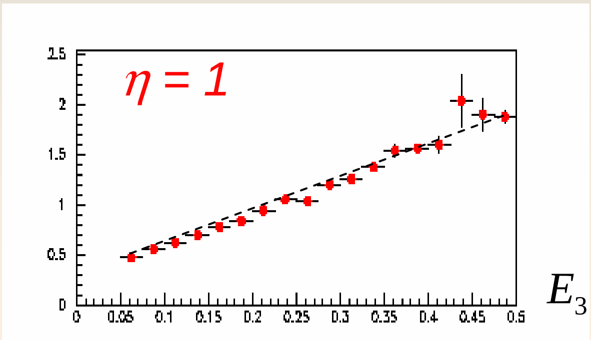
Linearity: small leakage contribution, use of the average value only.

$$E_{Leakage}(E_{Calo}) = \langle E_{Leak} \rangle$$



Uniformity: correlation of leakage/energy in the back E3

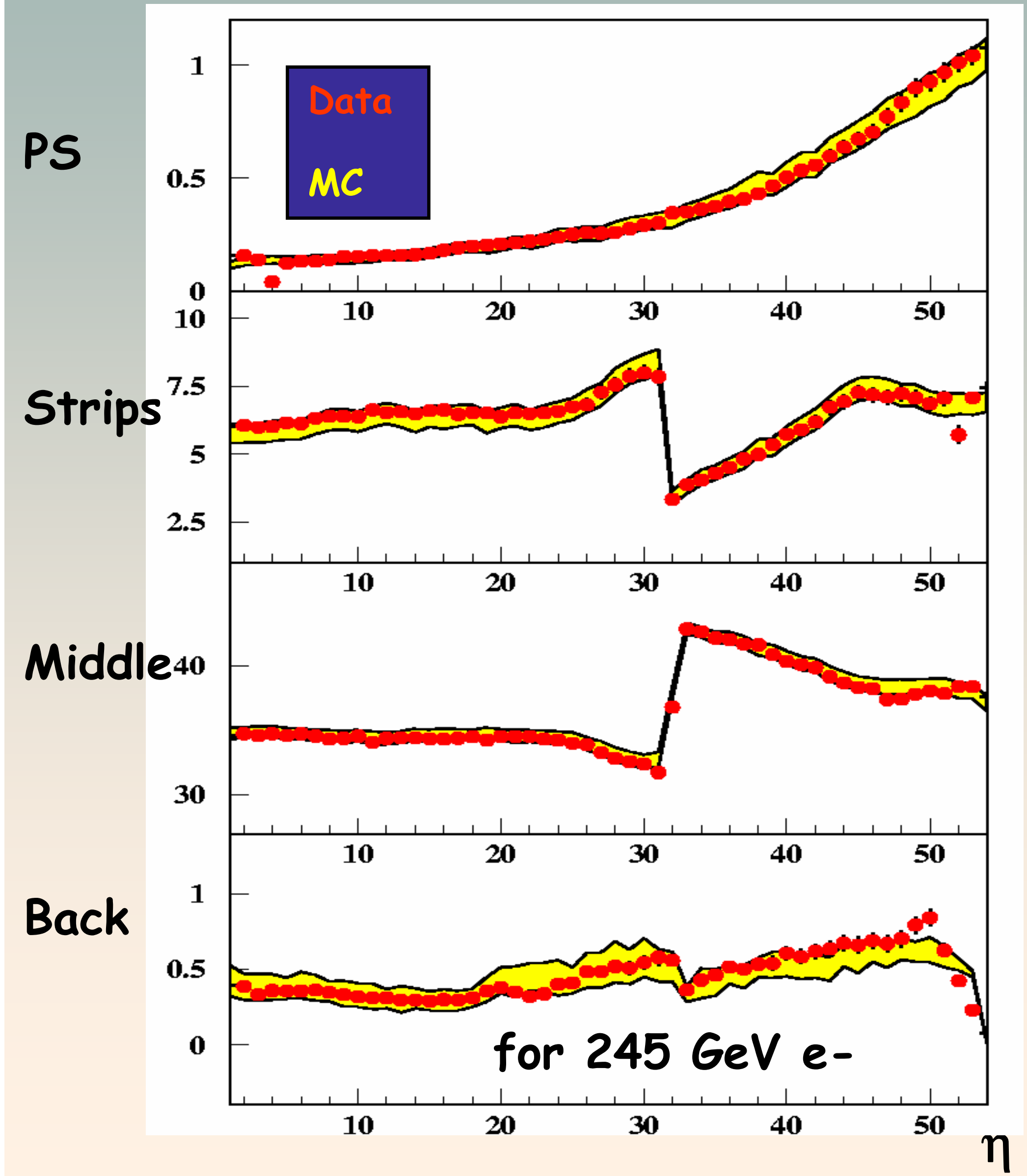
$$\frac{E_{Leak}}{\langle E_{Leak} \rangle}$$



$$\frac{E_{Leak}}{\langle E_{Leak} \rangle}(\eta, E_3) = \alpha + \beta \times E_3$$

If no leakage parameterization, becomes a dominant effect for uniformity (0.6% contribution)

Deposited energy in Data and MC



Deposited energies = f(η) in the PS and in the 3 calorimeter compartments before applying the correction factors a,d,c,d

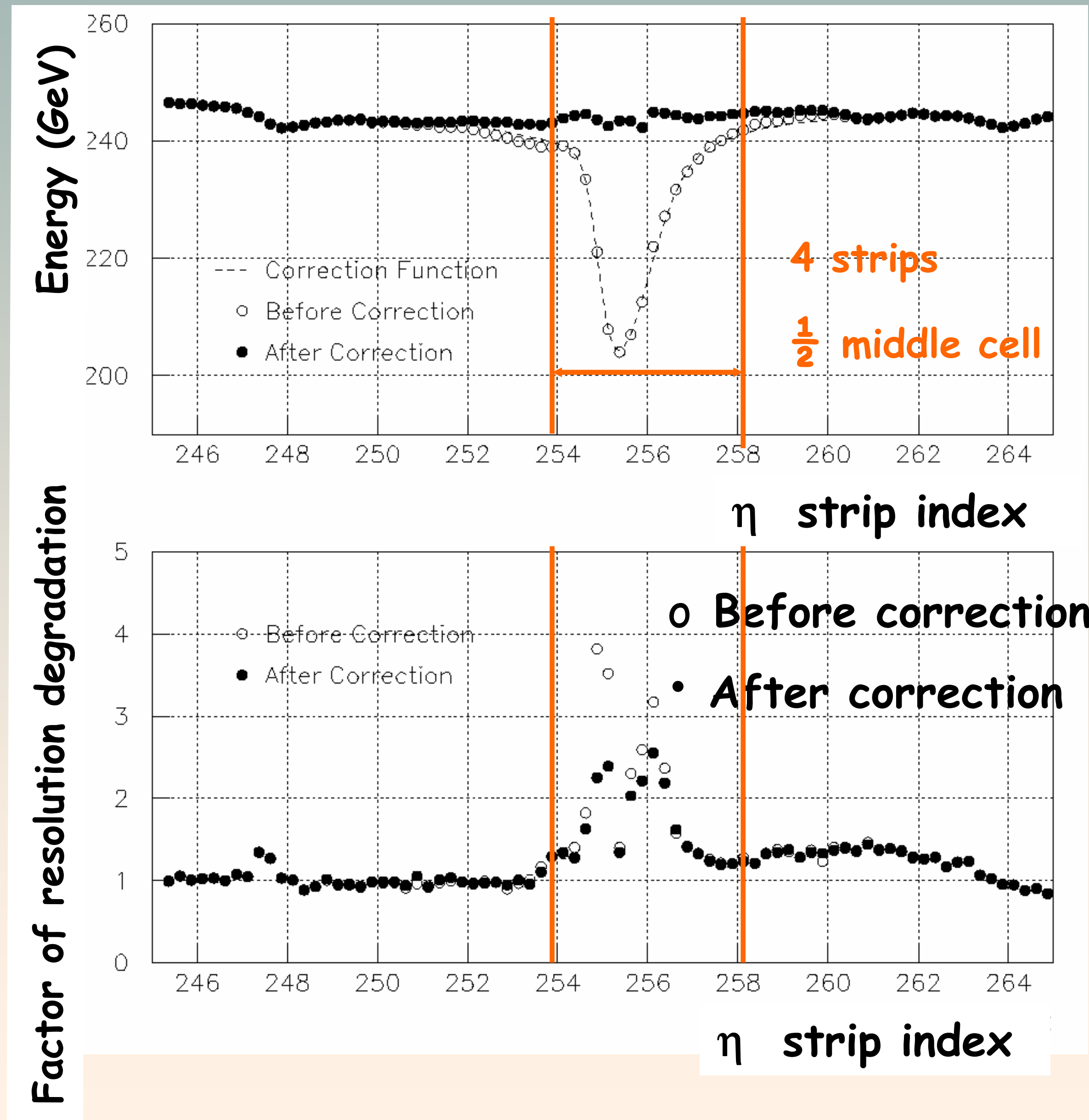
Excellent Data / Mc agreement in all samplings and in PS

Result in detailed studies of many fine effects in data (Xtalk,M_{phys}/ M_{cal}…)

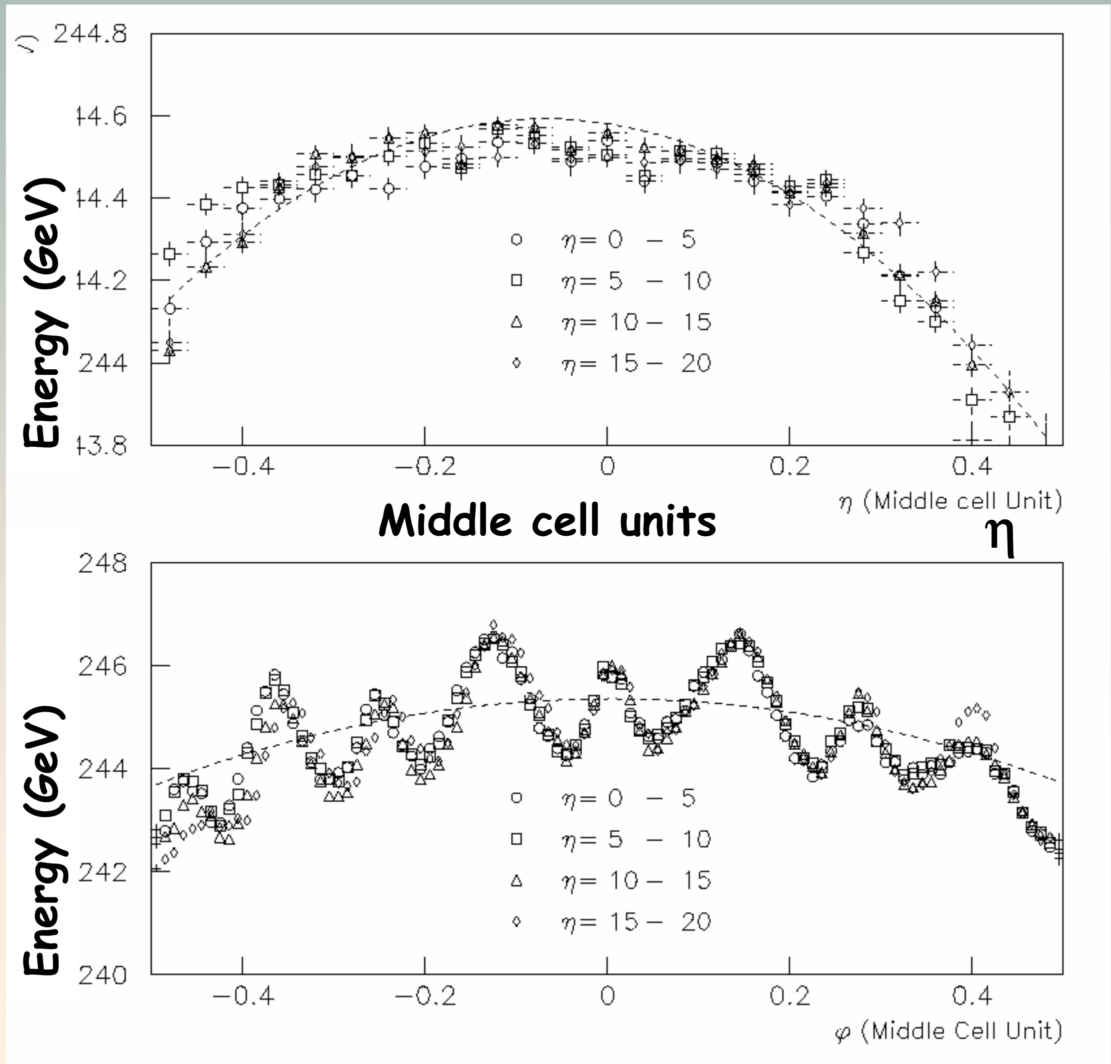
Transition correction

Problem in E field in transition region between electrodes A and B

In 4 strips, degradation of E resolution by a factor 2



Final energy corrections (barrel)



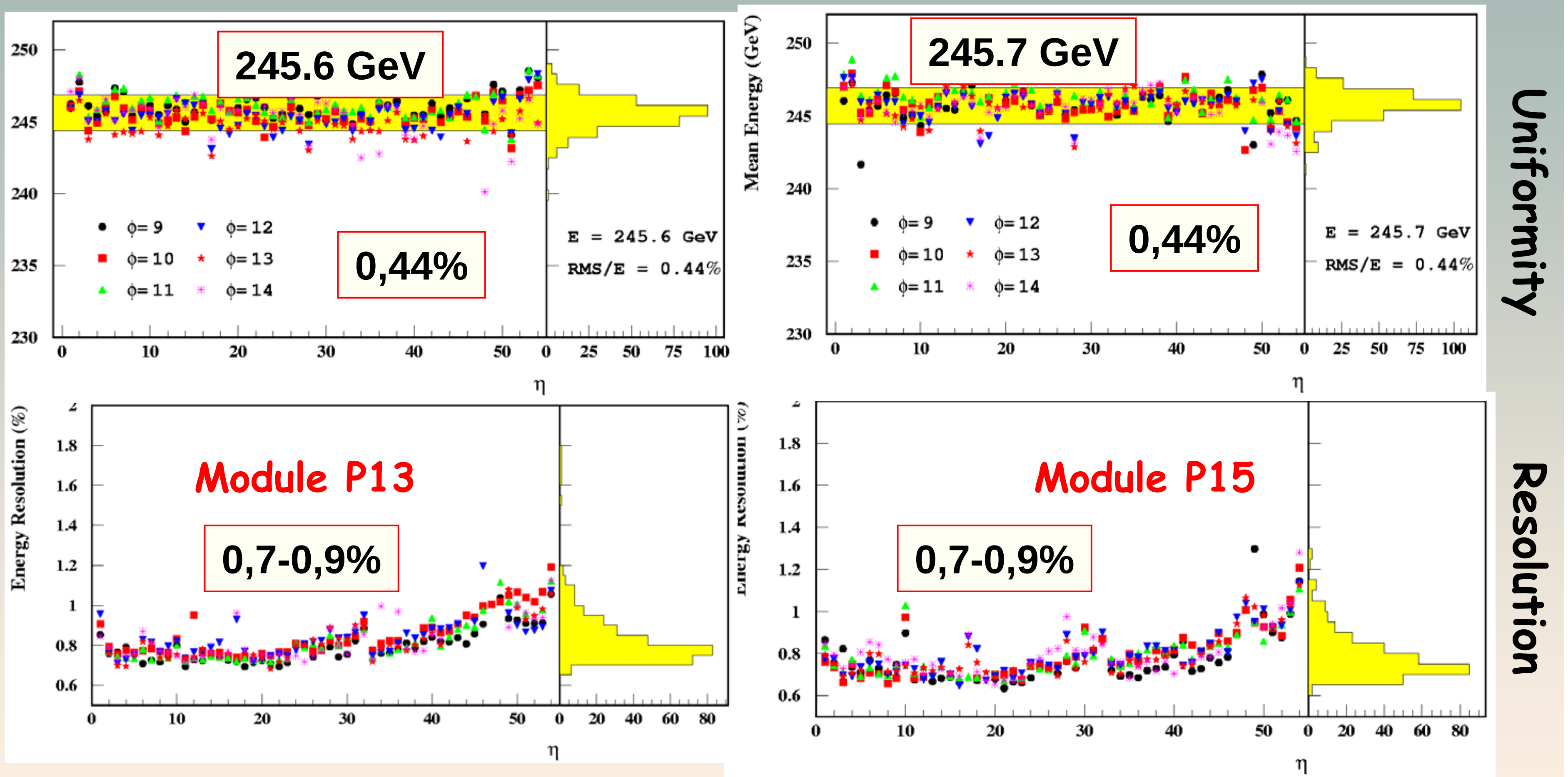
φ

Universality of corrections which are determined on Data in the barrel, the same for all modules.

Different corrections only between A and B electrodes.

In η very small mechanical deformation of accordion not observable

Uniformity barrel results



Module	P13	P15	M10
Global constant term	0.62%	0.56%	0.65%

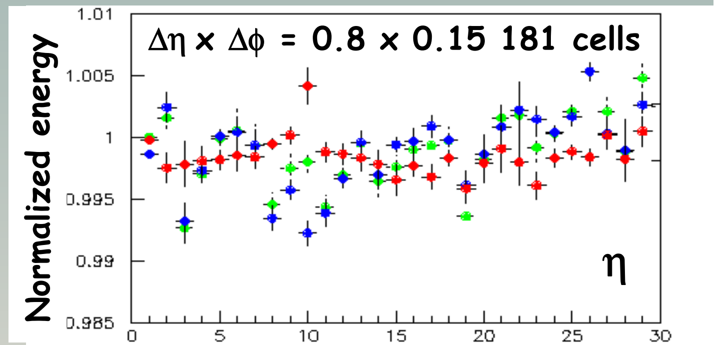
Comb TB 2004:

0.55 % over ~30 cells

Understanding of the uniformity

Energy scale
P13/P15 ~ 5 10^{-4} !

P13 0.34% rms
P15 0.34 %
P13/P15 0.24%



Uniformity over 300 cells < 0.5 %

From ATLAS physics TDR

Source	Contribution to uniformity
Mechanics: Pb + Ar gap	< 0.25 %
Calibration: amplitude + stability	< 0.25 %
Signal Reconstruction + inductance	< 0.3 %
Φ modulation + longitudinal leakage	< 0.25 %

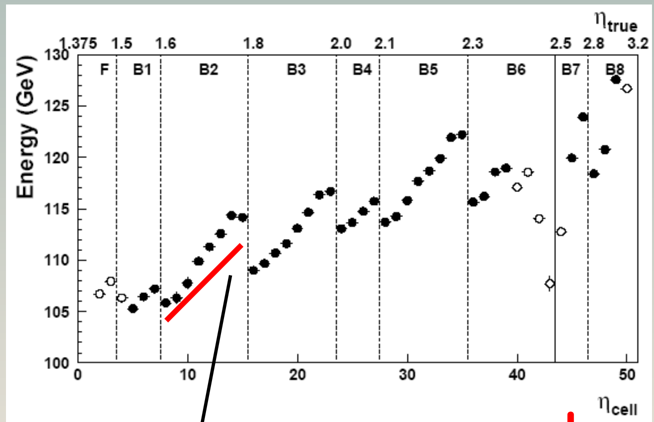
0.5 %

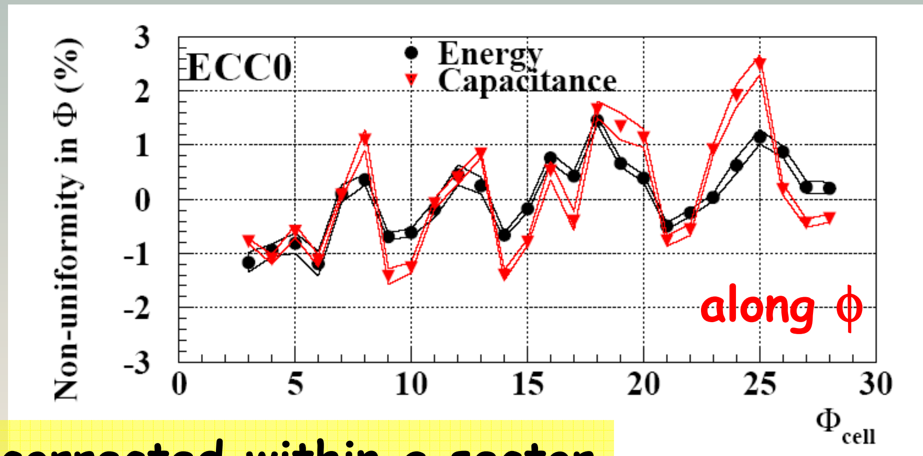
Over η < 0.8 region (181 cells)

- Correlated non-uniformity P13/P15: 0.29 %
- Uncorrelated non-uniformity : 0.17 % (P15) and 0.17 % (P13)

Endcap uniformity

Scan @ 120 GeV on 3 out of 16 modules, in H6 beam line

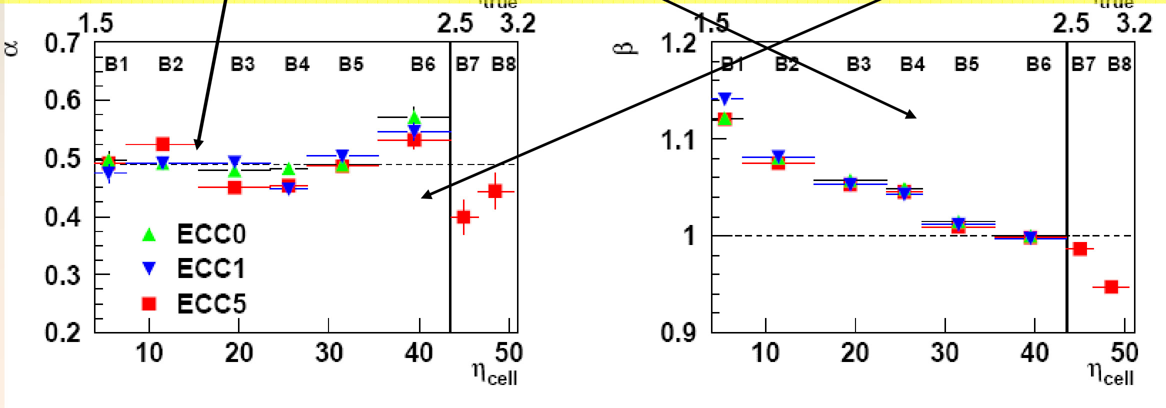




along φ

along η

HV to be adjusted per sector and corrected within a sector



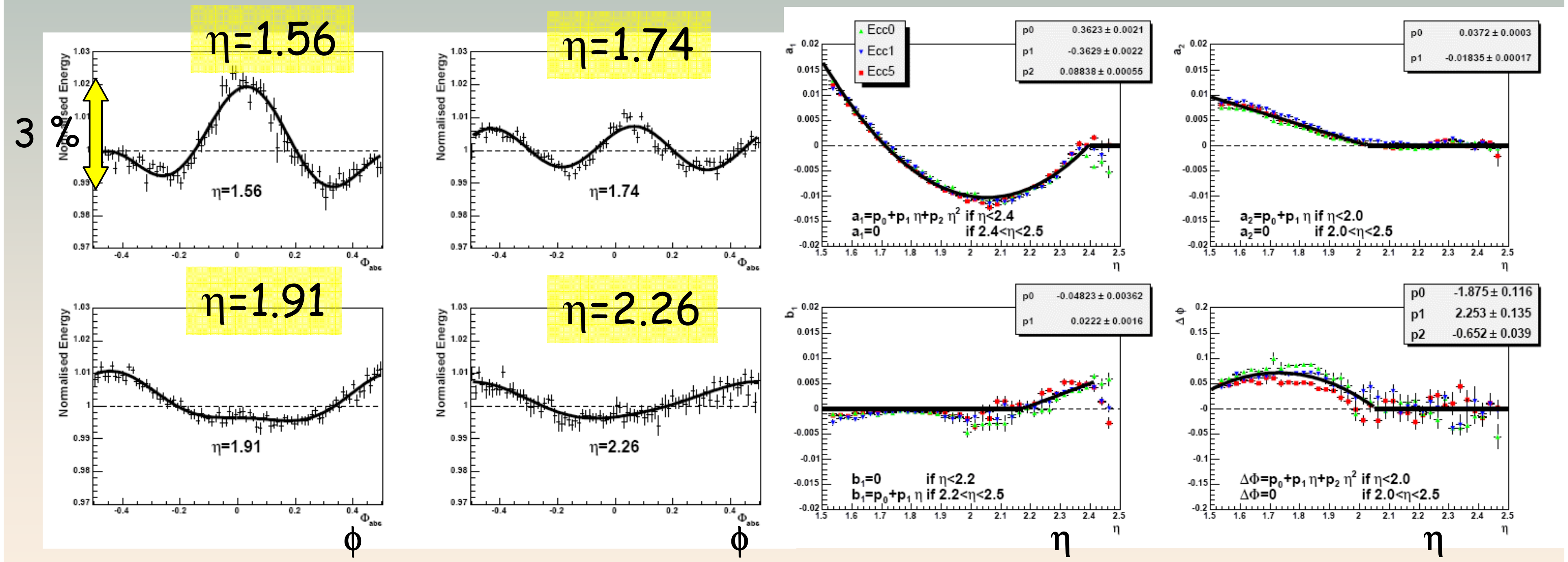
slope normalization

Mechanical deformation in φ: effect seen on C, corrected in TB

Expected to be smaller when whole wheel in ATLAS

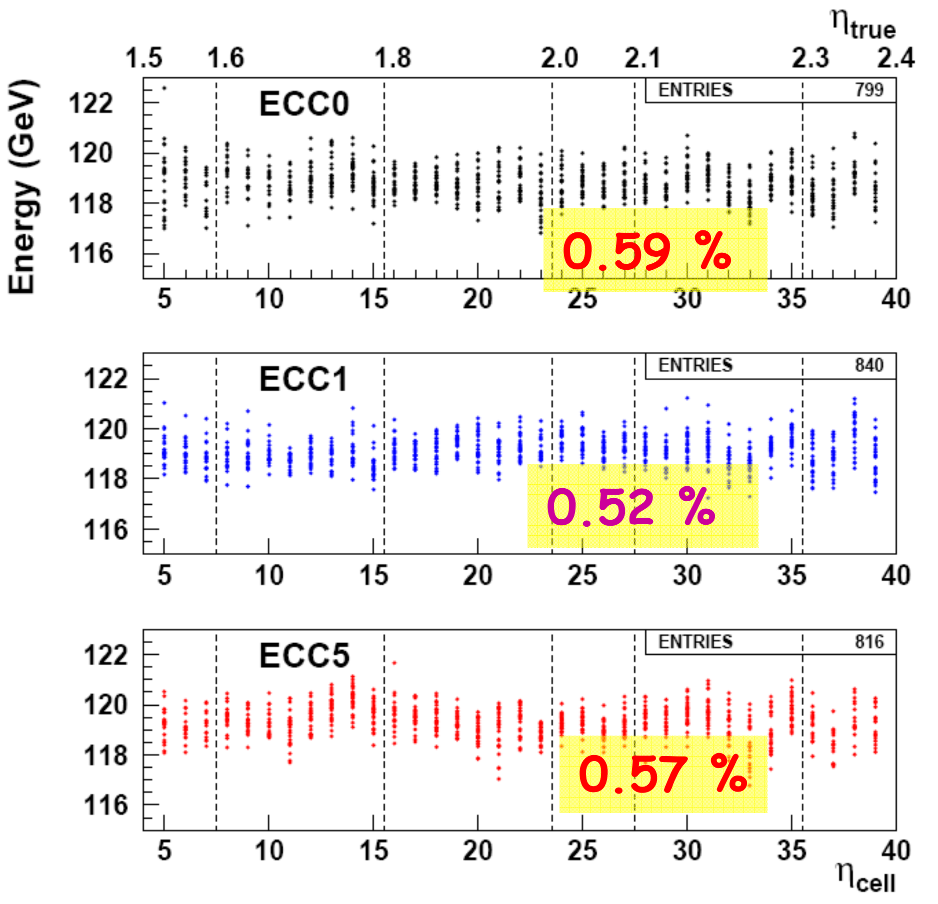
Endcap modulation corrections

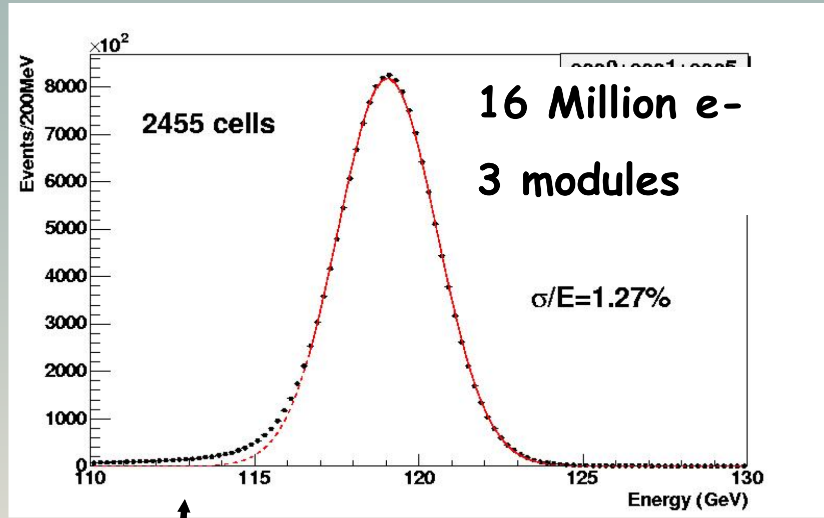
Impact point correction within the cell to be parameterized versus ϕ and η. Modulation in ϕ depend on η, well reproduced.

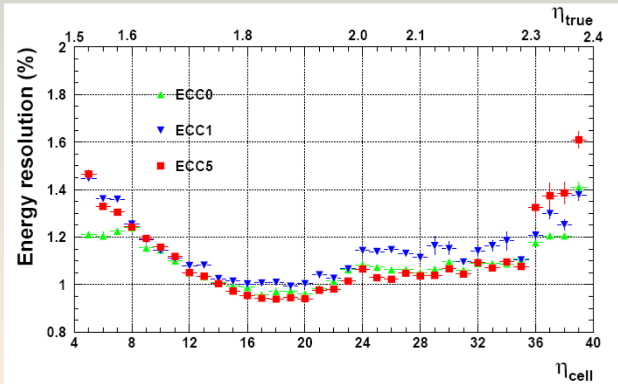


No need to parameterize corrections versus in η in the barrel, only for η< and > 0.8

Endcap uniformity results







Outer wheel

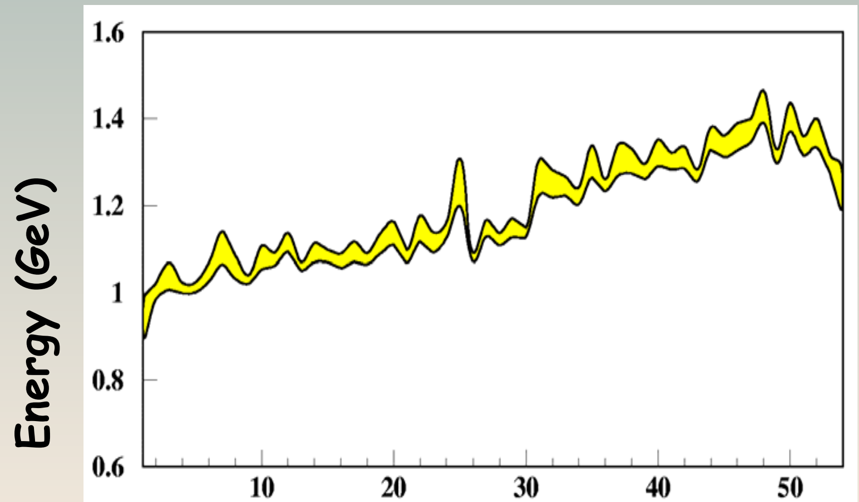
η=1.5 to 2.4

	Outer wheel			Inner wheel
Module	ECC0	ECC1	ECC5	ECC5
σ/E	1.27%	1.28%	1.22%	1.26%
Constant term	**0.70%**	**0.72%**	**0.61%**	**0.78%**

Conclusion

- Uniformity tested in 6 production modules of the ATLAS EM calorimeter in dedicated and combined test beams
- Unique occasion to study the calorimeter in great detail and to precisely tune the MC
- Performances well within expectations :
  - 0.44 % global uniformity over one module
  - Energy scale between modules known at 10^{-3} level

Nuclear-Binding: nuclear binding energy compensation, 0.2% variation between electrode A and B, due to λ0/X0 difference



Nuclear binding energy in calorimeter

η index