The ATLAS Liquid Argon electromagnetic calorimeter

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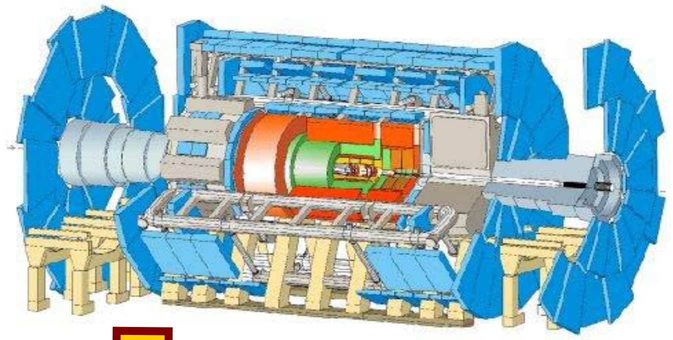
- The ATLAS electromagnetic calorimeter design
- Calorimeter performance: selected testbeams results
- Status of the detector construction and commissioning

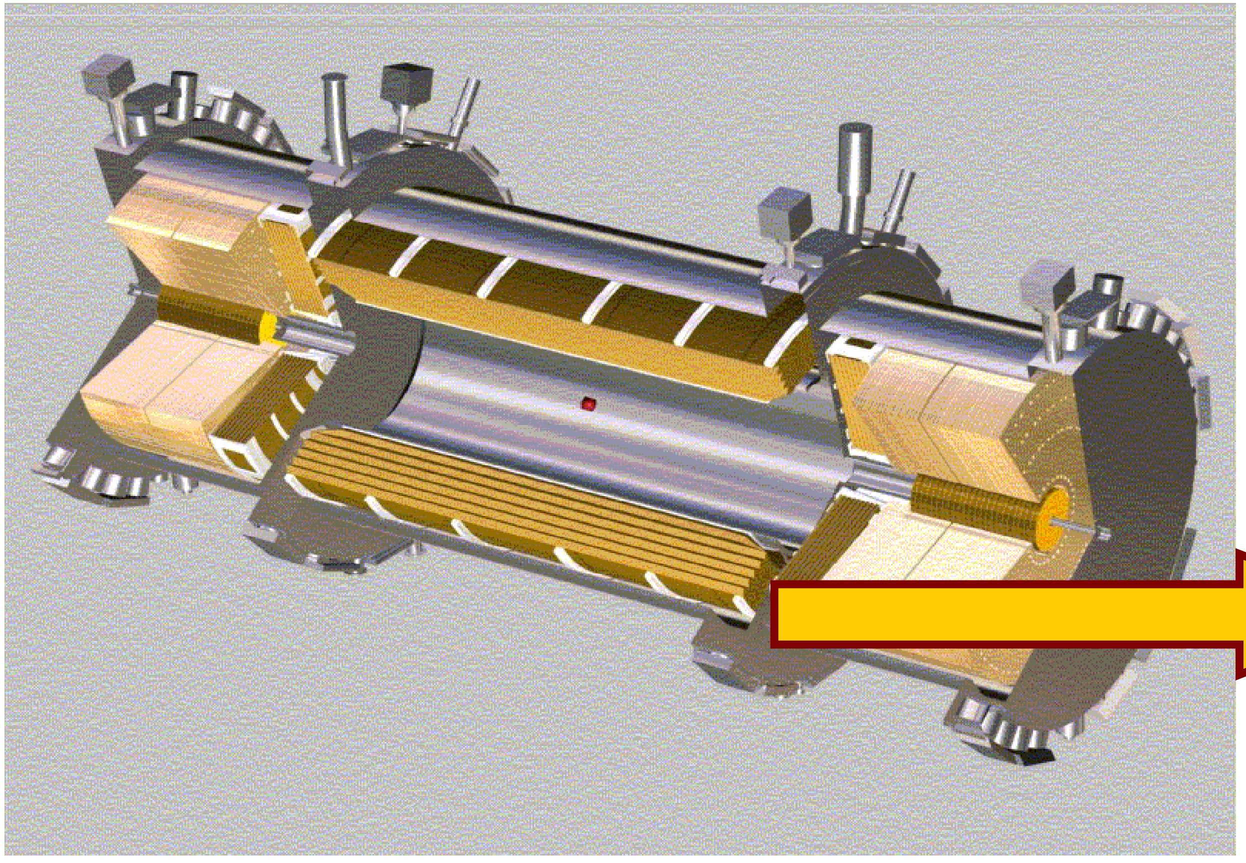
The ATLAS em calorimeter design

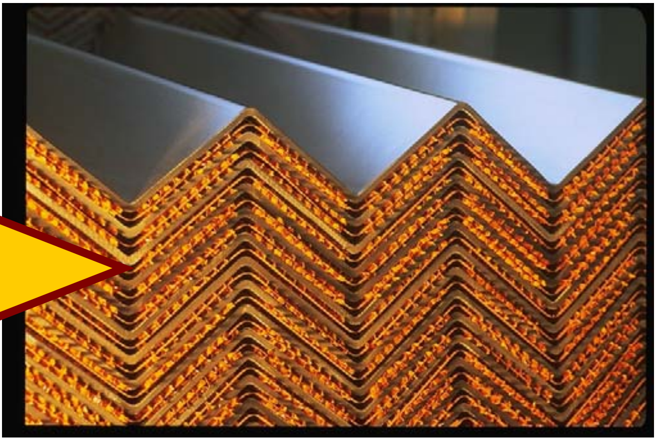
- **Rapidity coverage:**
  - largest possible acceptance to observe `rare' physics processes: best possible granularity up to $\eta=2.5$
- **Radiation hardness**
- **Response uniformity and linearity:**
  - A 0.7 % energy resolution constant term is required over $0<|\eta|<2.5$ (Higgs physics): local constant term $\sim$0.5%+ on-site physics-based calibration *($Z \to e^+e^-$)*.
  - of the order of few ‰ from the GeV to TeV range:
- **Position measurement resolution:**
  - Angular resolution should scale as 50 mrad/$\sqrt{E}$ to ensure the $\gamma\gamma$ invariant mass reconstruction inside the SM low-mass Higgs boson discovery limits.
- **Particle identification/rejection**
  - γ/Jet separation $\sim 10^3$ and further γ/π^0 rejection = 3 for e_γ = 90%

The ATLAS em calorimeter design

The ATLAS electromagnetic calorimeter is a lead–liquid Argon sampling calorimeter with an accordion geometry

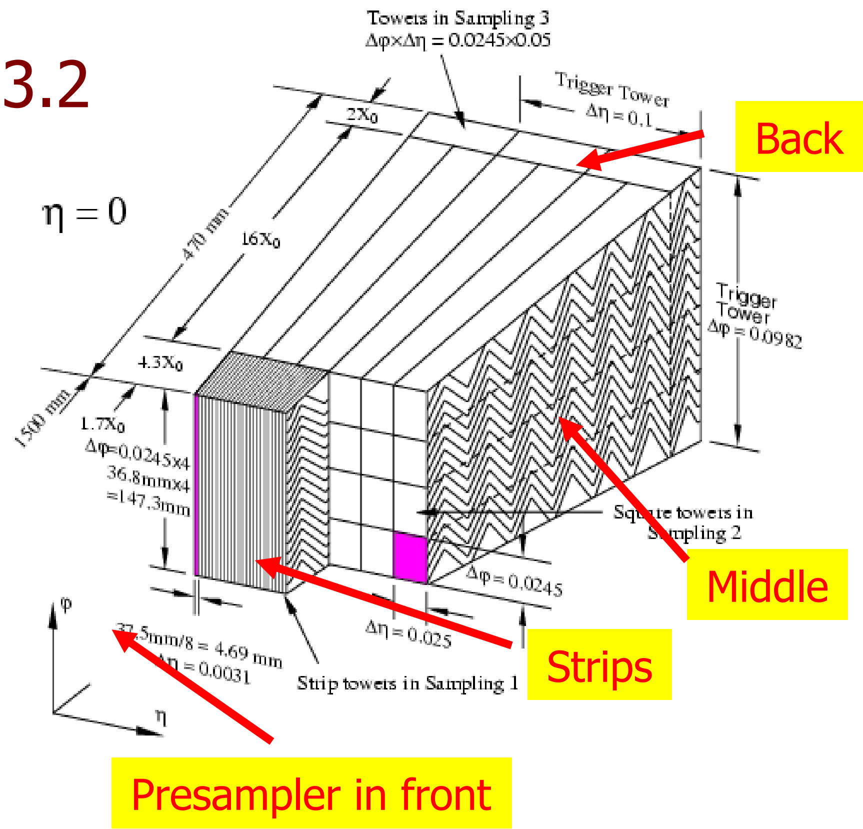




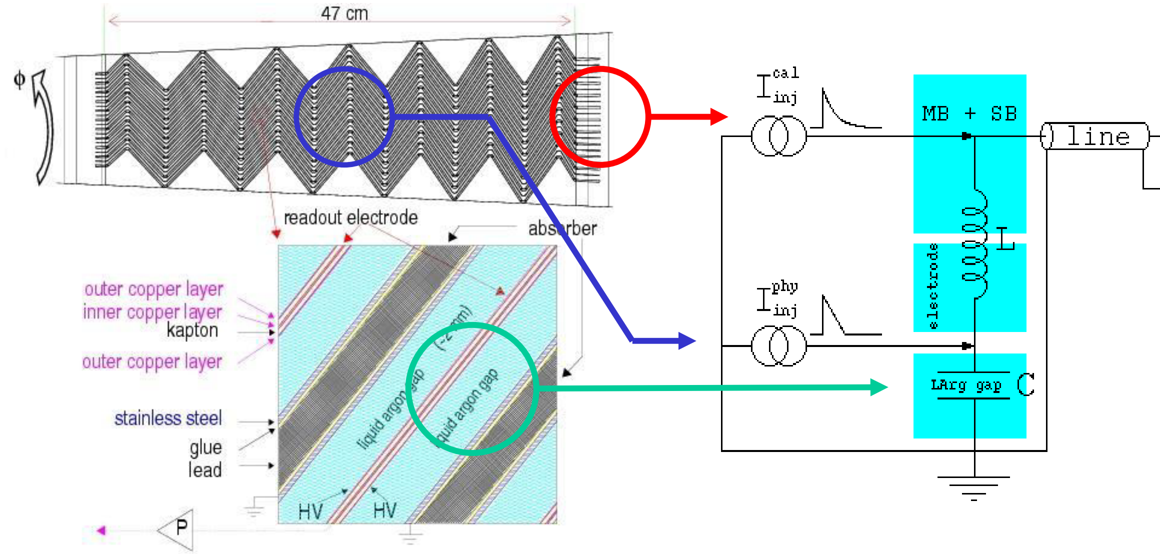


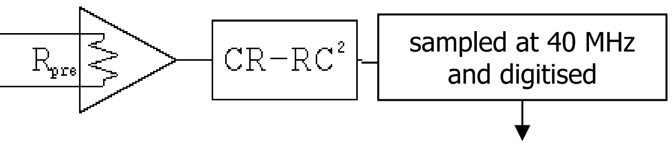
The ATLAS em calorimeter design

- Full azimuthal coverage
- Pseudorapidity coverage $0 < |\eta| < 3.2$
- Longitudinal segmentation
- Presampler to recover energy lost in the upstream material $\approx 2X_0$
- High granularity: 200000 read out channels
- Electronic calibration



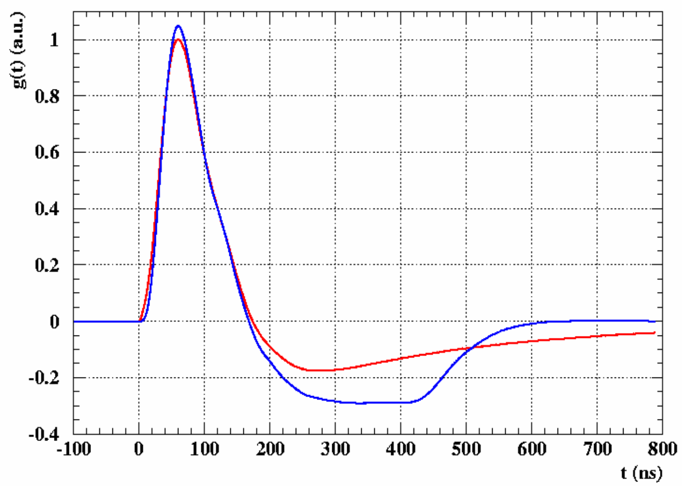
The ATLAS em calorimeter design: electronic calibration





$$\begin{cases} A = \sum_{i=1}^{5} a_i s_i \\ A\tau = \sum_{i=1}^{5} b_i s_i \end{cases}$$

- The physics signal is triangular ~ 400 ns : signal peak is reconstructed using *multiple sampling* (5 samples every 25 ns) and *Optimal filtering* tecniques which minimize electronic noise and pileup
- A calibration signal that mimics the physics one is used to calibrate the readout gain (~0.2% accuracy)
- physics and calibration signals differ in shape and amplitude (different injected waveform and injection point) : the physics waveform is predicted from the calibration and the prediction is used to compute OFC.

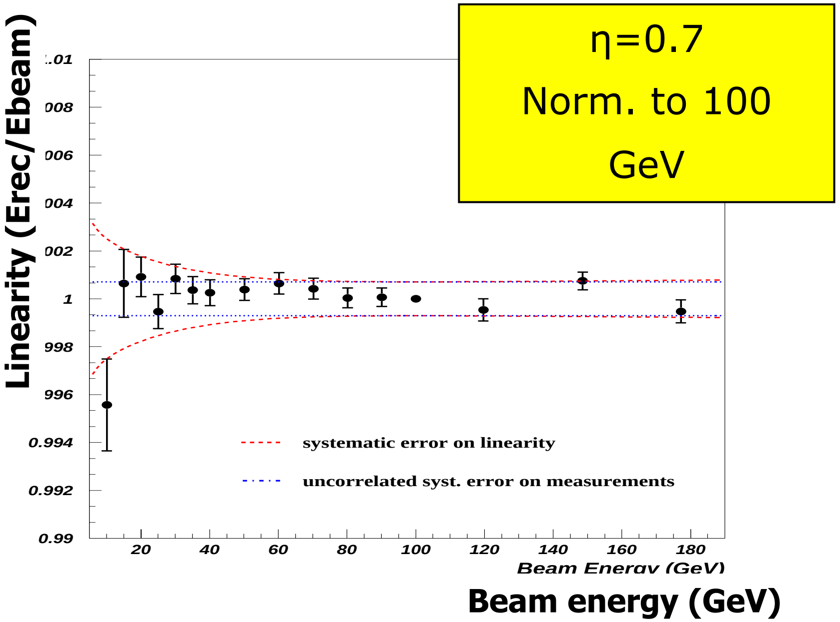


The ATLAS em calorimeter design : calibration

Complex reconstruction and calibration procedure:

- **Energy reconstruction : fixed cone or `topological clustering'**
  - Corrections for energy lost in upstream material (~2 X_0) and longitudinal leakage. A weigh for the presampler and an event based leakage correction obtained from a detailed G4 based MC. Both weights and leakage correction are independent on particle energy if parameterised as a function of the shower depth (residual η dependence)
  - Corrections for energy outside the cluster
- **Corrections for direction reconstruction**
- **In situ calibration with $Z \rightarrow ee$ events:**
  - In each $\Delta\eta x \Delta\varphi$=0.2x0.4 region (440) the local constant term is expected <0.5% (electronic calibration). Global constant term ~0.7% in a few days at 10^{33} $cm^{-2}s^{-1}$ (10^5 events required)

Calorimeter performance: linearity and energy resolution



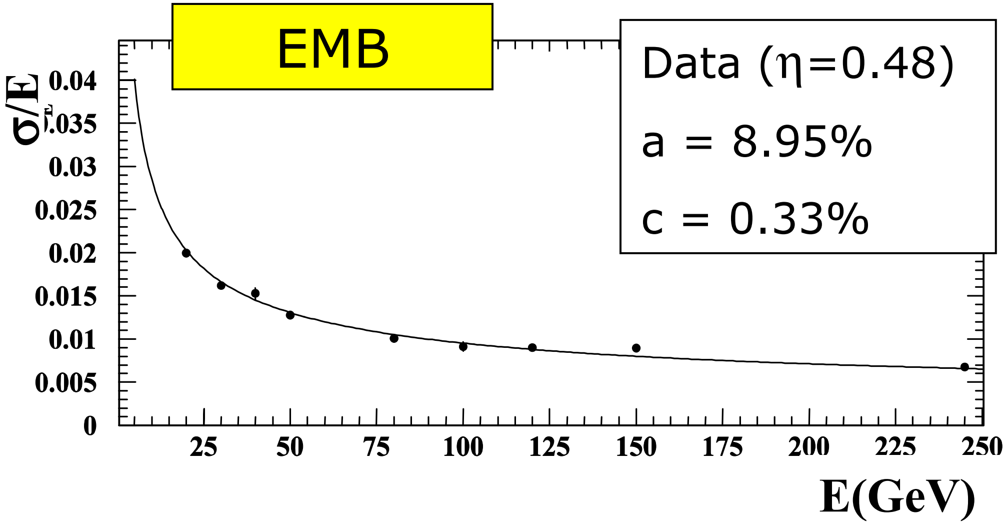
Detector linear is within:

- ✓ **±0.25% E>10 GeV**
- ✓ **± 0.1% E > 40 GeV**
- Within specification
- This calibration approach provide good linearity, while preserving energy resolution…

$$\frac{\sigma_E}{E} = \frac{a}{\sqrt{E}} \oplus \frac{b}{E} \oplus c$$

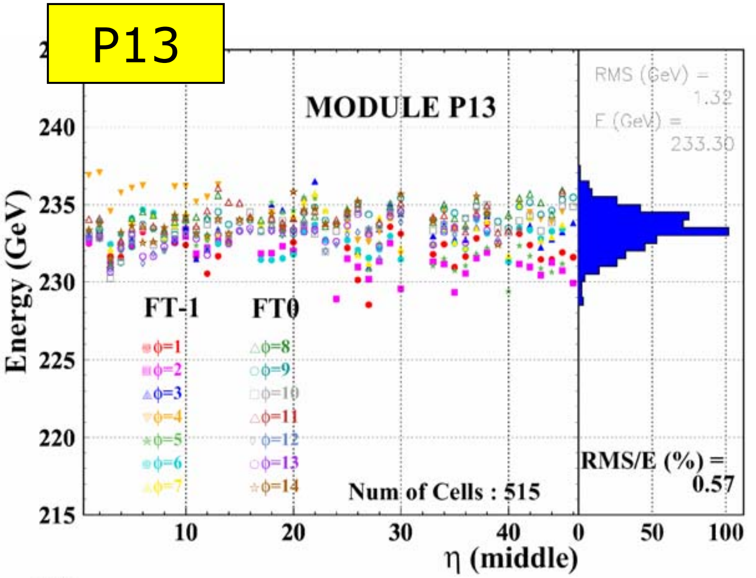
Detector resolution:

- EM Barrel : **a<10%**
- EM Endcap: **a<12.5%**
- Within specification

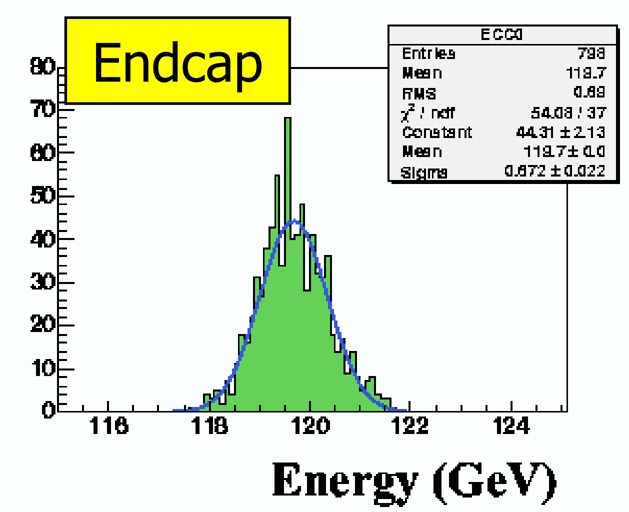


This calibration approach provide good linearity, while preserving energy resolution…

Calorimeter performance: uniformity



- ❑ Easy to reach ~1% (online raw reconstruction)
- ❑ More a long work to reach TDR advertised performance…
  - OFC including LC correction…
  - Longitudinal weights (cfr. Linearity…)
- ❑ Global constant term is within specification (**~0.7%**)



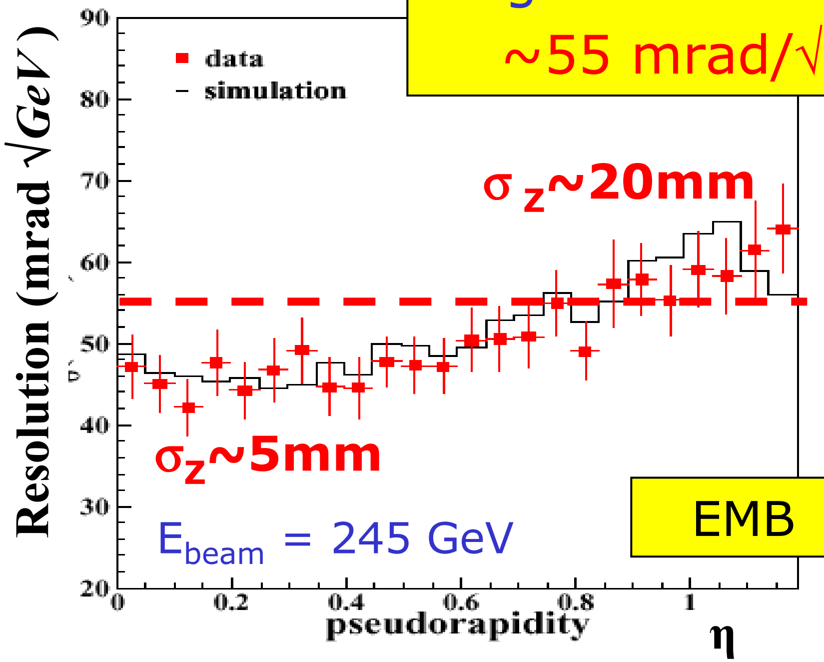
	P13	P15
RMS	**0.57%**	**0.64%**

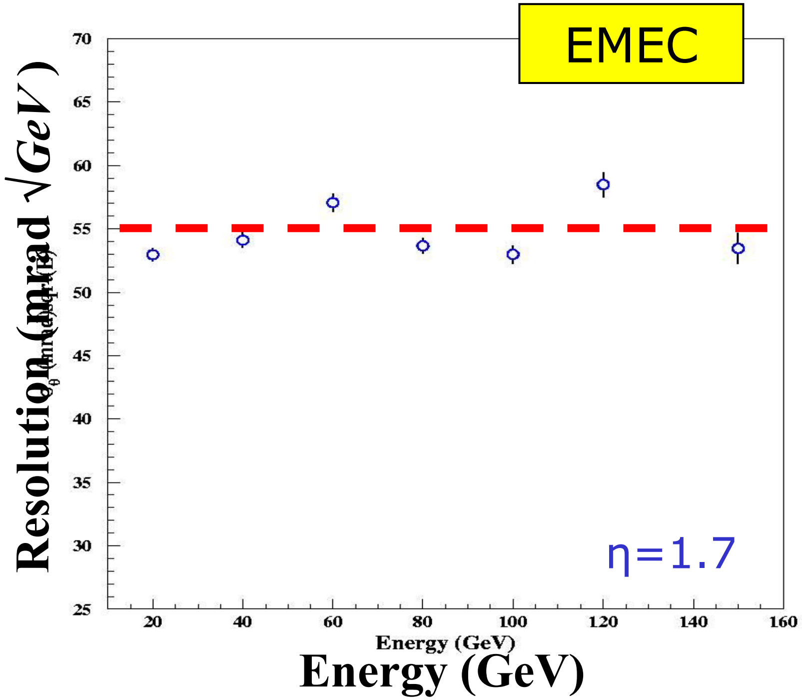
	ECC0	ECC1	ECC5
RMS	**0.58%**	**0.53%**	**0.55%**

Calorimeter performance: position resolution

- The combination of S1 and S2 η position measurements with longitudinal shower barycentres gives an independent angular information…

Angular resolution
~55 mrad/√E

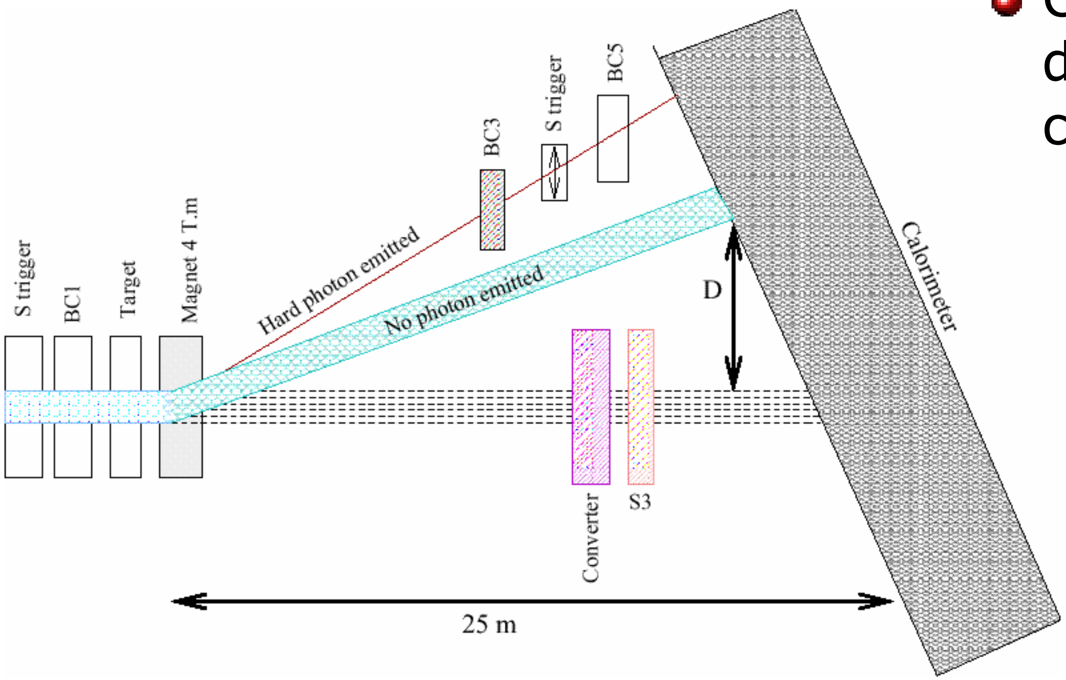




- $H \rightarrow \gamma\gamma$ vertex reconstructed with < 20 mm accuracy
- LHC interaction point : σ_Z~56mm

Calorimeter performance: γ/π^0 separation

- Reducible background to $H \rightarrow \gamma\gamma$ is faked photon from jet-jet (γ-jet) events with a typical rate larger by 10^6 (10^3)
- S1 (strips) section depth has been designed to reject jets with leading π_0 (strips fine segmentation: $\Delta\eta = 0.025/8 \cong 5$ mm)
- A dedicated setup has been used to produce γ in H8 beam line



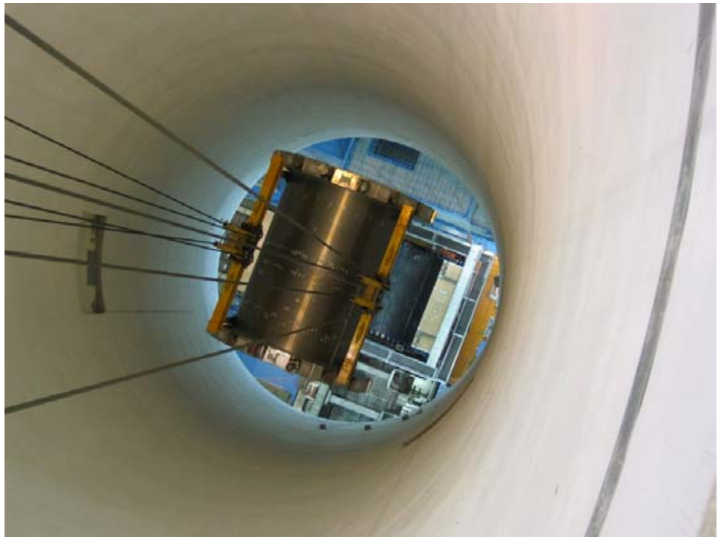
- Cover 5-70 GeV spectrum with different beam energy and magnet current
  - Superimpose 2 γ events to simulate π_0 with 50 GeV P_T

Data:	$\langle R \rangle = 3.54 \pm 0.12$
MC:	$\langle R \rangle = 3.66 \pm 0.10$

~84% single photon

Barrel calorimeter status

- 32 modules produced and tested at cold between 2001-2003. Assembly and insertion in cryostat end 2003
- Cool down and quality test in 2004
- Down in the Pit (october 2004)



Barrel calorimeter status: electrical quality control

- HV system test: some sectors at reduced voltage or with shorts on one side but no acceptance loss.

- All channels have been pulsed via calibration line and checked

Out of 110 000 channels : 15 open channels, 8 ground short circuits and 1 open calibration line

31 output channels (0.028 %) with problems.

- Calibration injection resistors measured with ‰ accuracy

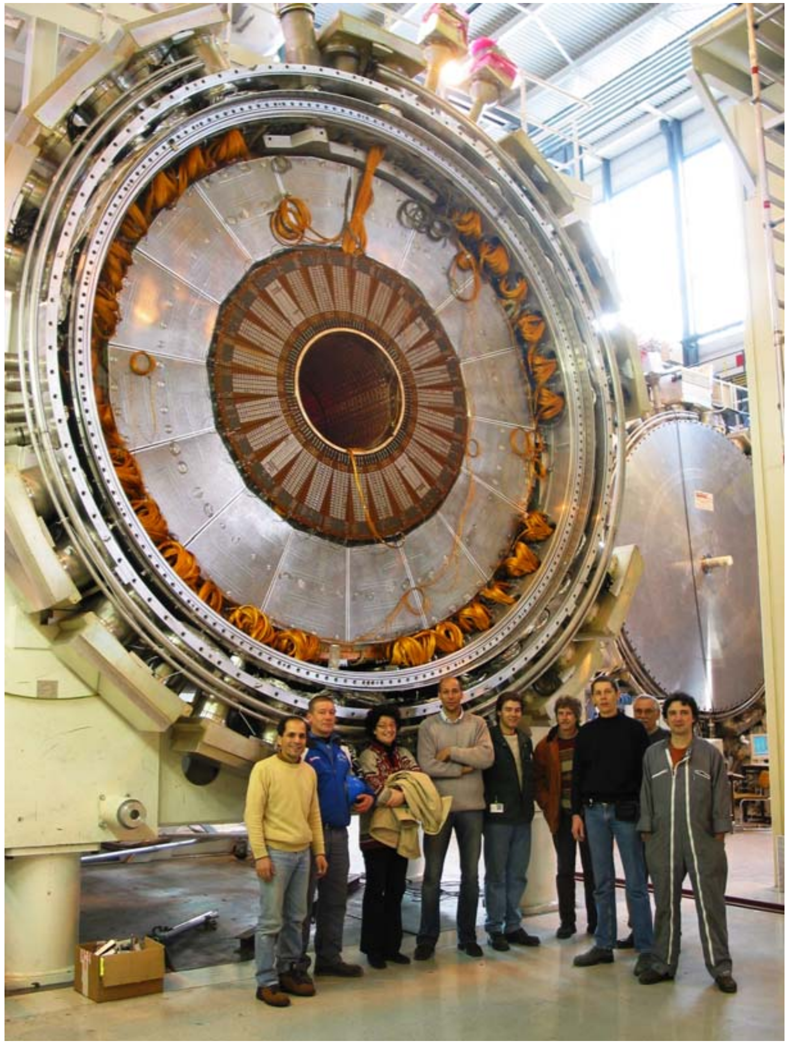
- Network analyzer measurements to extract LC per cell

- Time Domain Reflectometry (TDR)

Endcaps status:

ENDCAP C

- Assembly and integration finished. Cool down OK (now warming up)
- Quality tests finished. Analysis of the data ongoing, preliminary results:
  - Few problems in HV as in the barrel
  - 6 dead channels (out of 31872) from TPA tests
- Down in the pit end of september 2005



ENDCAP A

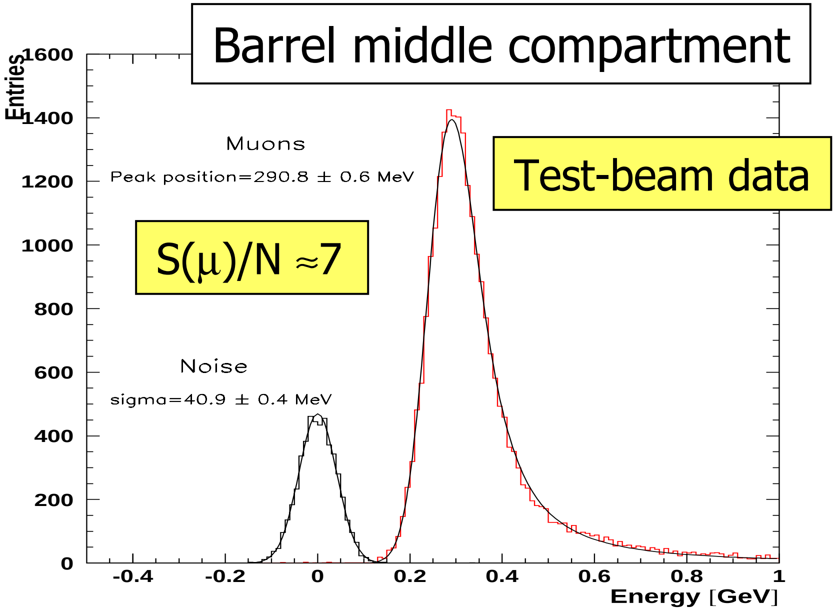
- Assembly and integration finished
- Cool down scheduled for may 2005
- Lowering in the pit by the end of this year

Commissioning with cosmics (barrel)

Cosmic muons can be used to detect problems and to check calibration:

- Enough for initial detector shake-down (catalog problems, gain operation experience, some alignment/calibration, detector synchronization, …)

- Over 3 months assuming 50% data taking efficiency ~ 100 μ/cell (with |z|<30 cm and Ecell>100 MeV) can be collected over |η| <=1 and 70 % of φ coverage



From studies with test-beam muons:
can check (and correct) calorimeter response variation vs η to 0.5% in < 3 months of cosmics runs

Note : not at level of ultimate calibration uniformity (~ 0.25%) but already a good starting point

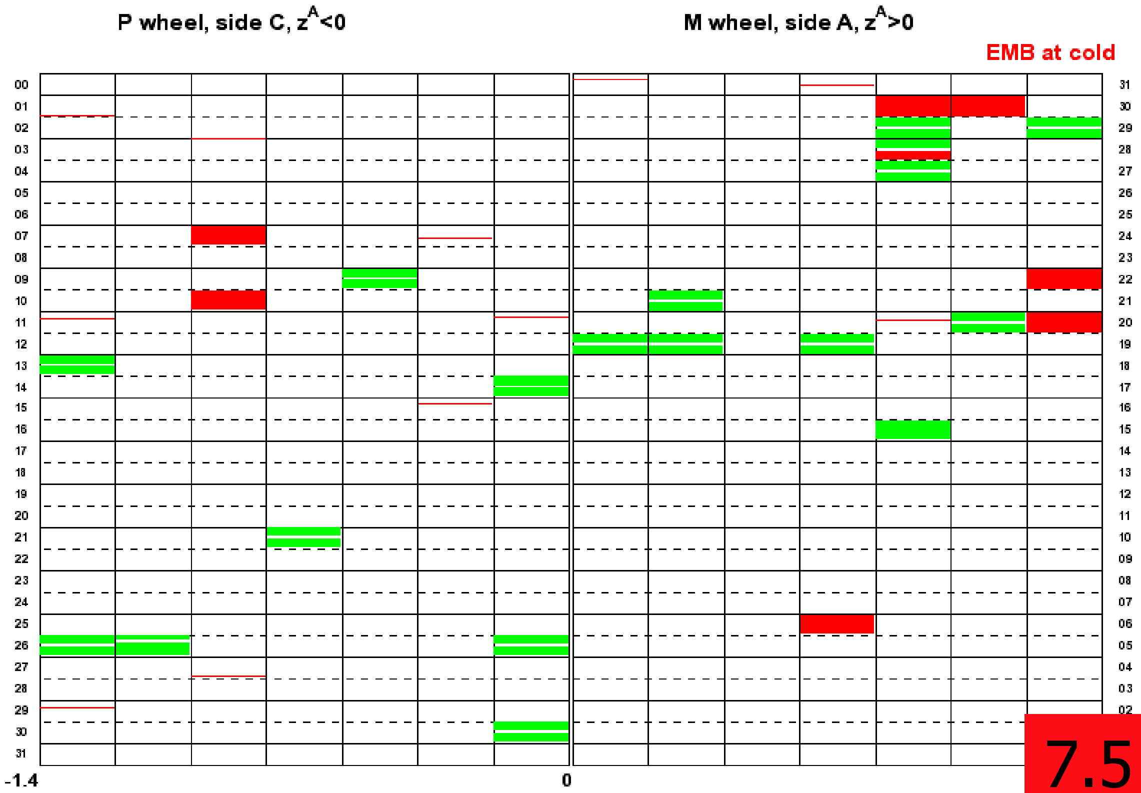
Conclusion

- Barrel calorimeter construction is finished.
  - Cool down and quality tests (HV +electrical tests) succesfully performed
  - Moved in the pit
- First endcap finished and tested at cold
  - Analysis of the data still ongoing: preliminary results as expected
- Second endcap ready by the end of this year
- Commissioning with μ(beginning 2006)
  - Very good exercise to understand the detector (especially read-out!)
- Extensive testbeam activities demonstrated that the design requirements are fulfilled
- Still a lot to learn/do to go from testbeam to full ATLAS setup calorimeter (calibration/reconstruction) to be ready for D-day…

BACKUP SLIDES

Barrel calorimeter status: HV quality control

High voltage is supplied on each side by different lines in a sector of
$\Delta\eta \times \Delta\varphi = 0.2 \times 0.2$ (32 electrodes)



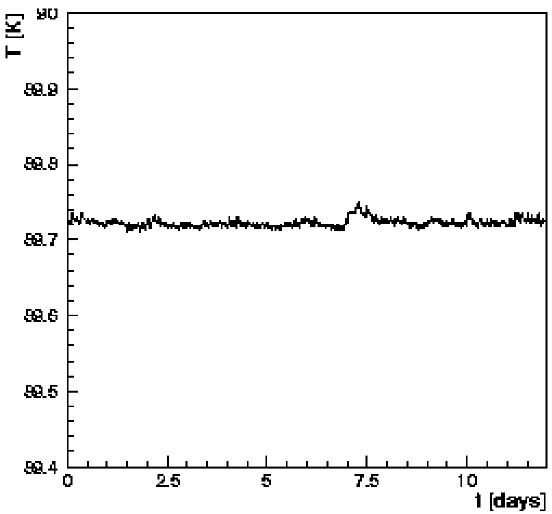
Calorimeter in LAr, 2kV, 10days

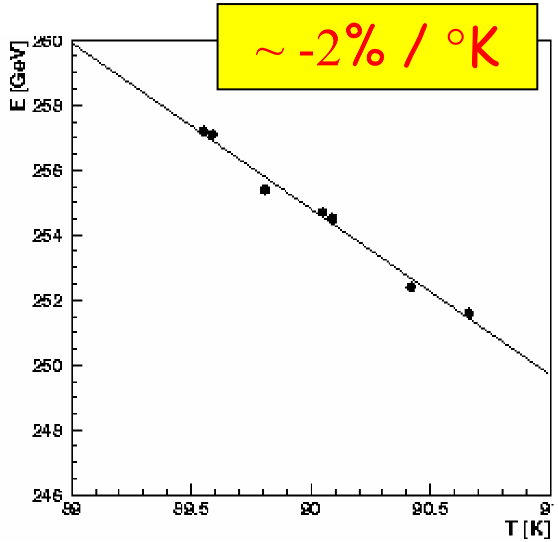
Sector in short (one side)

Half-sector tested at 1.2kV

7.5 sectors/448,1side in short
No acceptance loss

Testbeam results: stability:



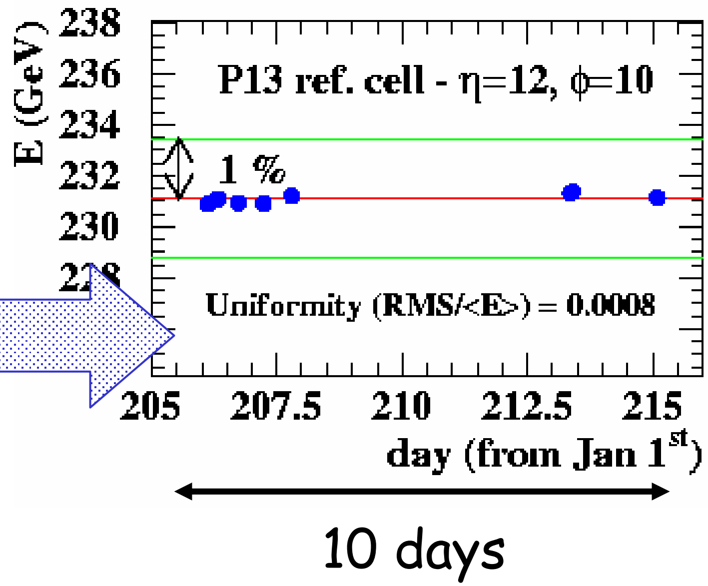


The temperature dependence of the physics signal is due to:

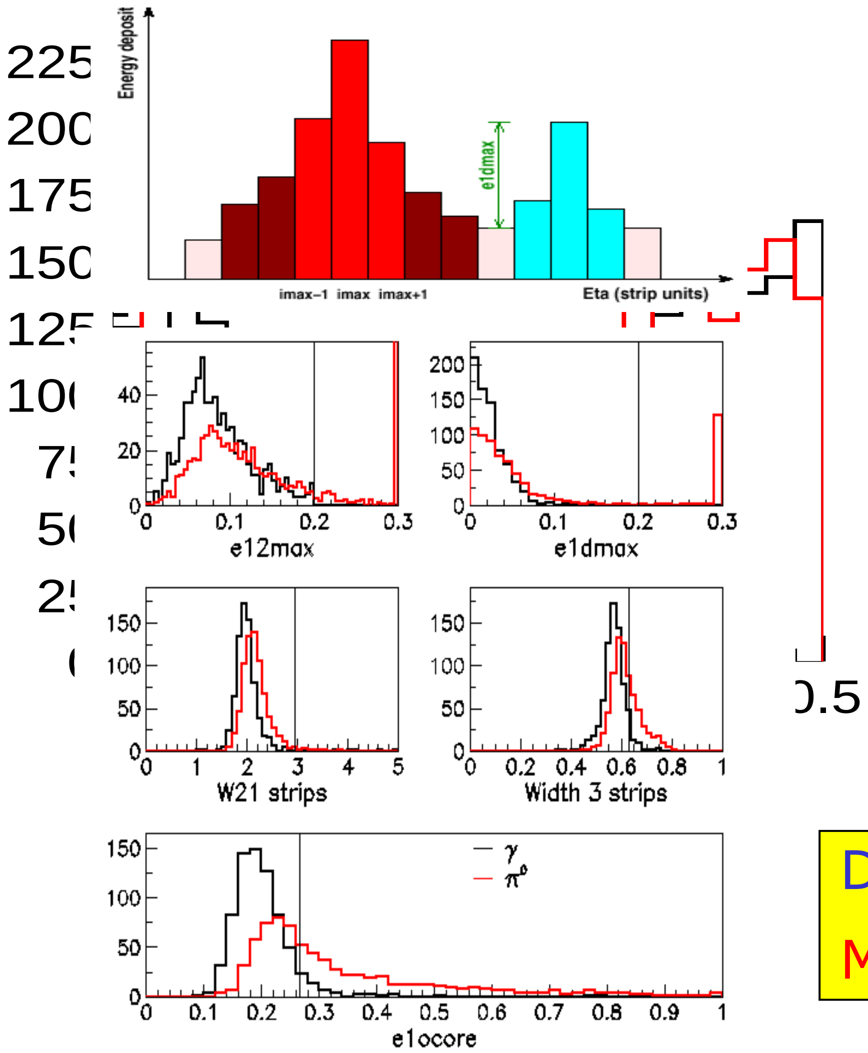
- Argon density vs T : -0.45 %/°K
- Drift velocity vs T : -1.55 %/°K

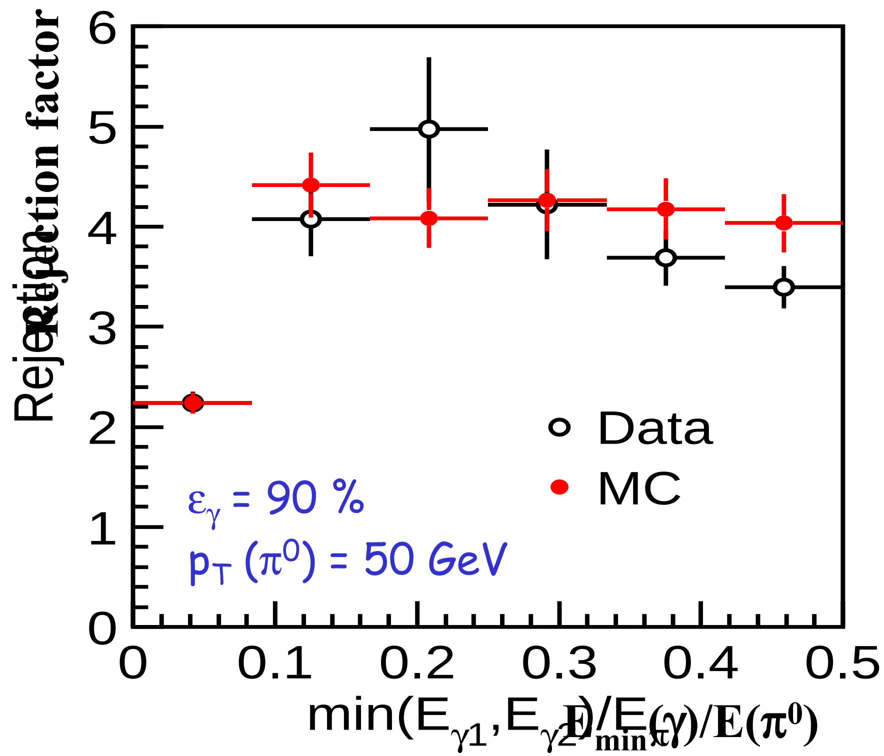
A reference cell has been shot during all testbeam period

Stability over 10 days ~ 0.08 %



Calorimeter performance: γ/π^0 separation





Data: <R> = 3.54 ± 0.12

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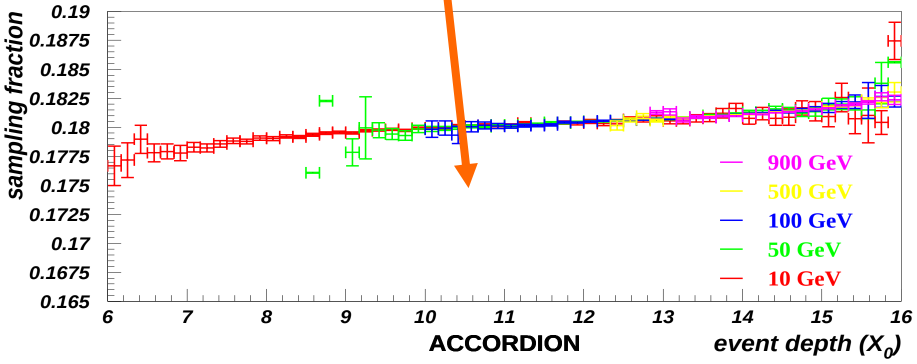
~84% single photon

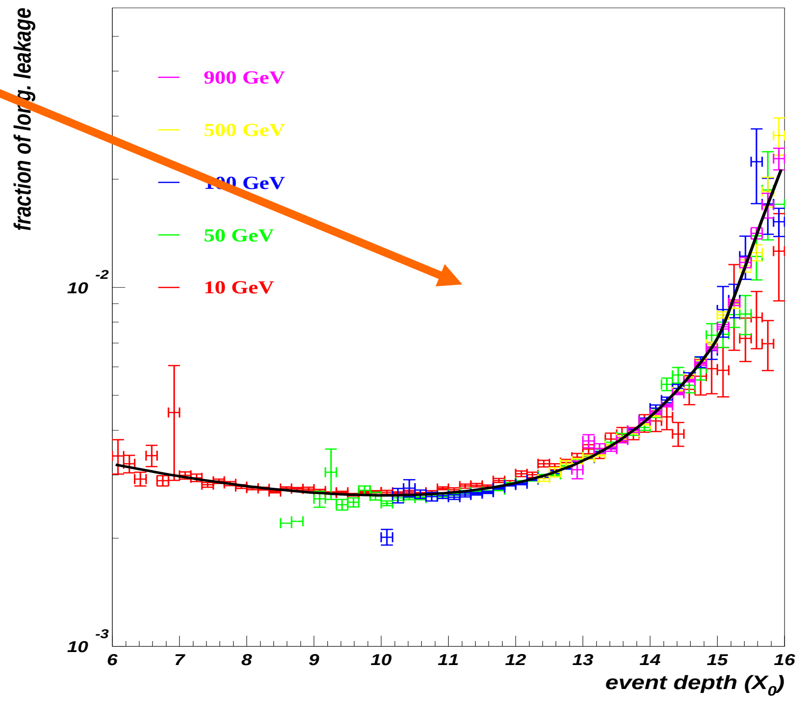
The ATLAS em calorimeter design : calibration

Calibration coefficients can be parametrized as a function of the shower depth so that they become energy independent!

❑Longitudinal leakage % as a functionof the shower depth

❑Intrinsic response of the calorimeter (*sampling fraction*) as a function of the shower depth





Intercalibration using Z$\rightarrow$ee events:

- The local constant term should be of the order of $\approx$ 0.5% (mechanics, electronics…) in each $\Delta\eta$ x $\Delta\varphi$ = 0.2 x 0.4 region (tot 440 regions)

- Expected rms miscalibration between different regions $\leq$ 1.5 %

- Long range non-uniformity correction: intercalibration of different calorimeter regions using $Z\rightarrow e^+e^-$

- Calibration using Z reduces the global constant term to $\approx$ 0.7 % in a few days of nominal conditions data taking

Intercalibration using Z→ee events:

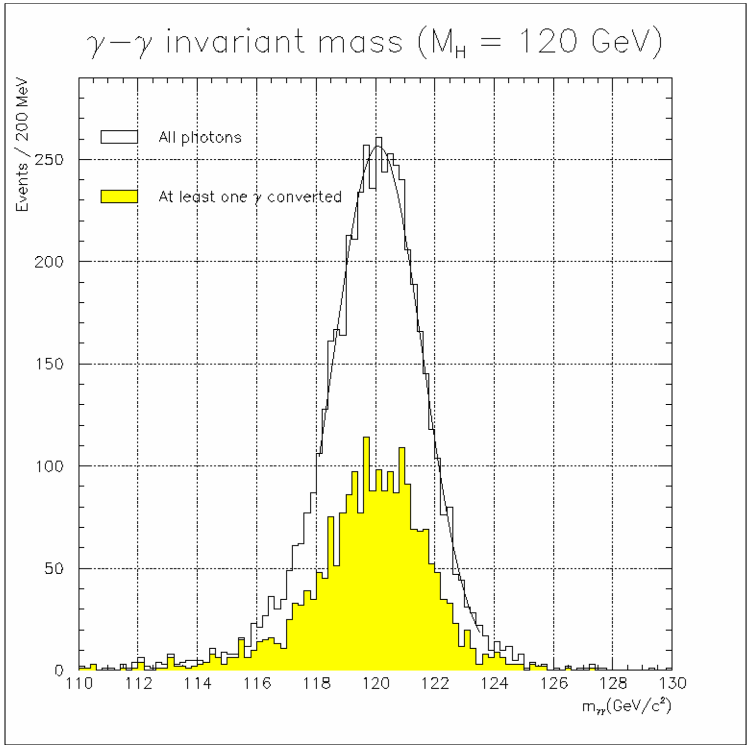
- Build a reference M_{e+e-} distribution from $Z \rightarrow e^+e^-$
- Divide the EM acceptance into regions and generate a 'decalibration' factor α_i for each region *i* with 1.5% rms.
- Smear the e^+ e^- energies : $E_i^{new} = E_i^{true} * (1+ \alpha_i)$
- Build the smeared M_{e+e}
- Neglecting second order terms

$$M^{new} = M^{true} * \left(1 - \frac{\alpha_i + \alpha_j}{2}\right) = M^{true} * \left(1 - \frac{\beta_{ij}}{2}\right)$$

- Fit M^{new} with the reference M_{e+e-} for each couple (i,j) and extract β_{ij}
- Extract α_i by a least square method (β_{ij} are not correlated)

H→γγ reconstruction:

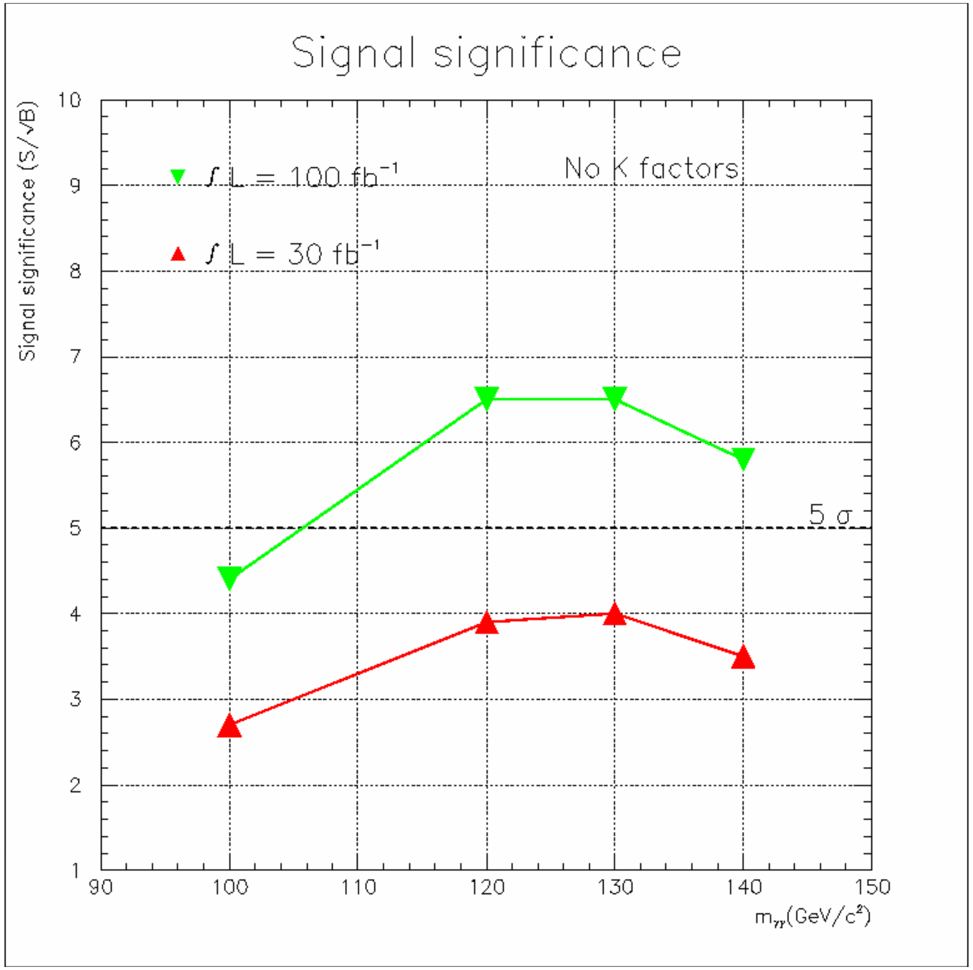
- γγ invariant mass has been reconstructed for each M_H
  - Invariant mass resolutions have been evaluated
  - The acceptances have been computed taking into account geometrical acceptance, photon identification efficiency (80%), mass bin (±1.4 sigma)



	Mass resolution	Acceptance * efficiency	Nr. of events
100 GeV	1.31	0.23	1045
120 GeV	1.43	0.26	1283
130 GeV	1.55	0.28	1186
140 GeV	1.66	0.28	950

(All numbers in the table refer to 100 fb^{-1} of integrated luminosity collected at 10^{34} cm^{-2} s^{-1})

$H \to \gamma\gamma$ channel discovery potential:



- 100 fb^{-1} collected in high luminosity conditions (10^{34} cm^{-2} s^{-1})
- 30 fb^{-1} collected in low luminosity conditions ((2)*10^{33} $cm^{-2}s^{-1}$)
- Last official results reported in physics TDR (PYTHIA 5.7 with CTEQ2L)
- Latest simulations (PYTHIA 6.2 and CTEQ5L) and analysis confirm the published results with a slight degradation (< 10%)