Commissioning and Performance of the ATLAS Calorimeter System with Proton Proton Collisions at the LHC

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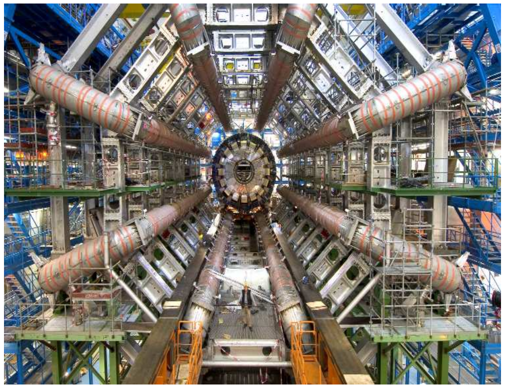
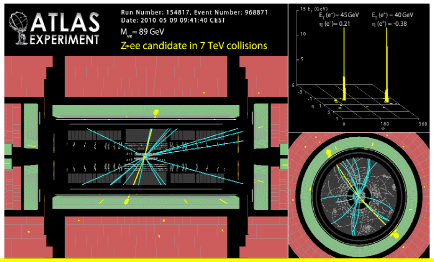
On Behalf of the ATLAS Collaboration

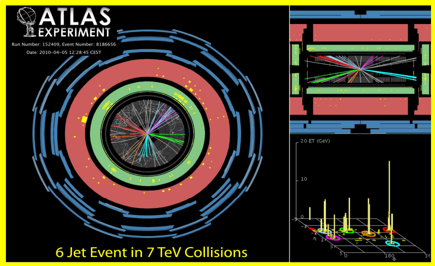
2000



2005



First Zee



First 6 jet event

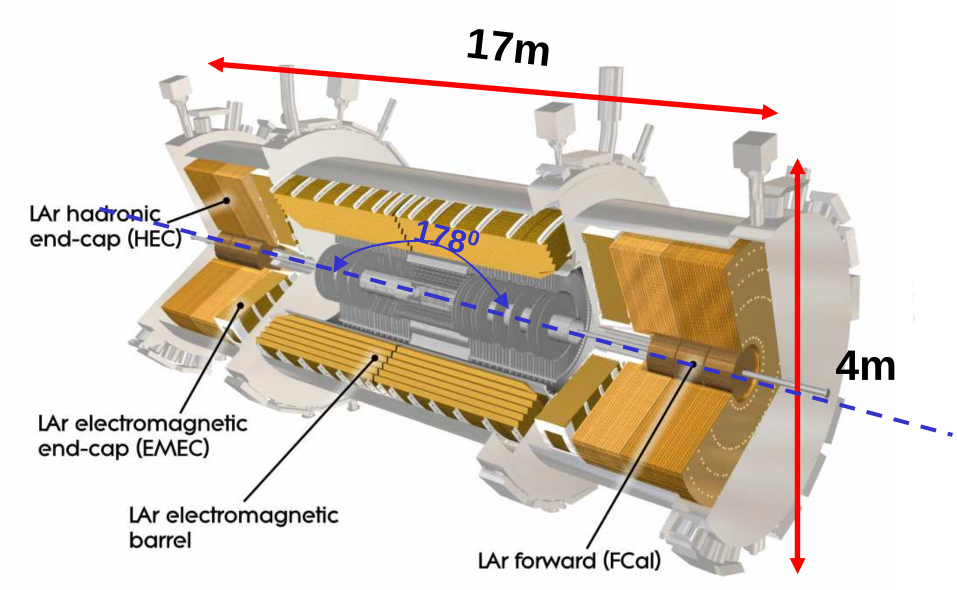
2010

ICHEP 2010, Paris, July 2010

The ATLAS calorimeter system (1)

- Composed of non compensating calorimeters

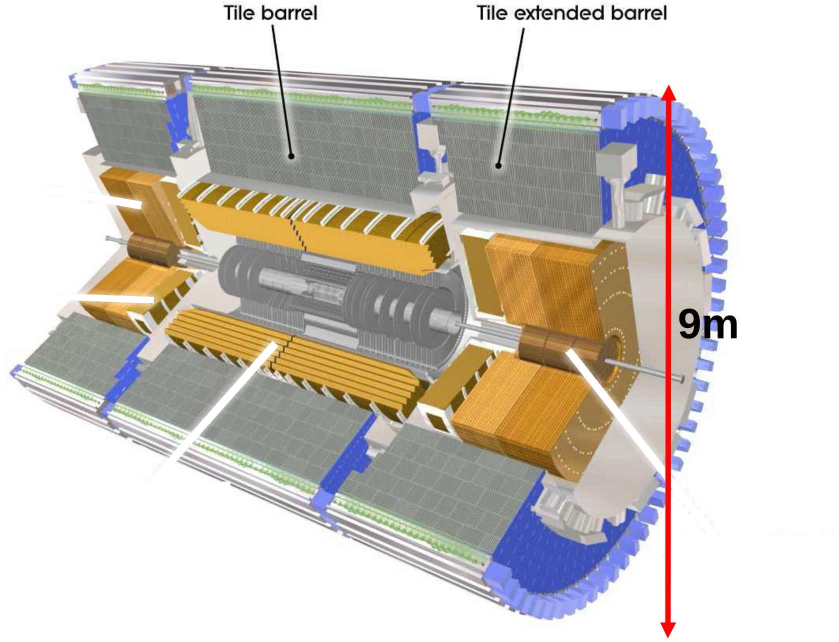
Liquid Argon (LAr) detectors in 3 cryostats → |η|<5



Intrinsically linear and stable with time

Intrinsic radiation-hard

Surrounded by Tile Calorimeter → |η|<1.7

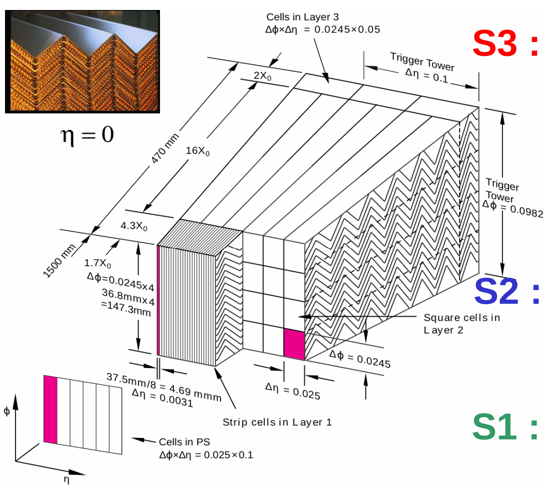


Maximum absorption depth at least cost

The ATLAS calorimeter system (2)

❑ Sampling EM calorimeter

- Absorber : lead with accordion shape
- Active material : liquid argon (90 K)
- Readout : large electrodes (2 m^2)



S3 : $\Delta\eta \times \Delta\phi$ = 0.05x0.025

Shower ends

S2 : $\Delta\eta \times \Delta\phi$ = 0.025x0.025

Shower develops

S1 : $\Delta\eta \times \Delta\phi$ ~ 0.003x0.1

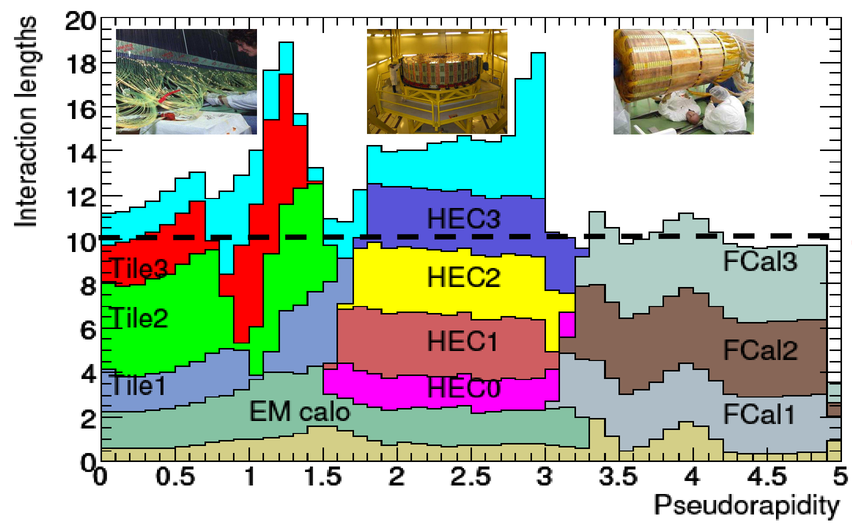
γ/π^0 separation

PS : $\Delta\eta \times \Delta\phi$ ~ 0.025x0.1

Recover energy loss

❑ Sampling hadronic calorimeters

- Mix of technologies to cover |η|<5
  - ✓ Steel + Tile scintillators ➔ Tile
  - ✓ Copper + LAr ➔ HEC
  - ✓ Copper/Tungstate + LAr ➔ FCal



Hermetic in φ, very granular (173k cells)
➔ Good e(γ) resolution, e/jet separation

Hermetic (>10 λ) up to |η|<5
➔ Good jet and Etmiss resolution

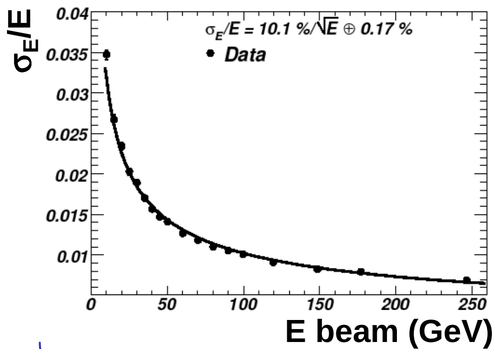
Readiness before LHC collisions

- **Commissioning started ~10 years ago on calo modules**

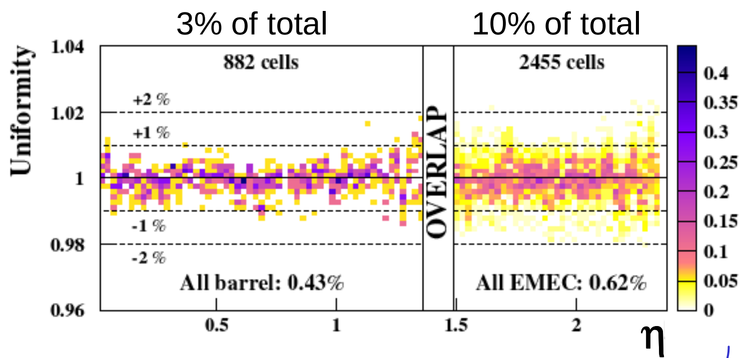
28 publications !

$\sigma_E/E = a/\sqrt{E} \oplus c$

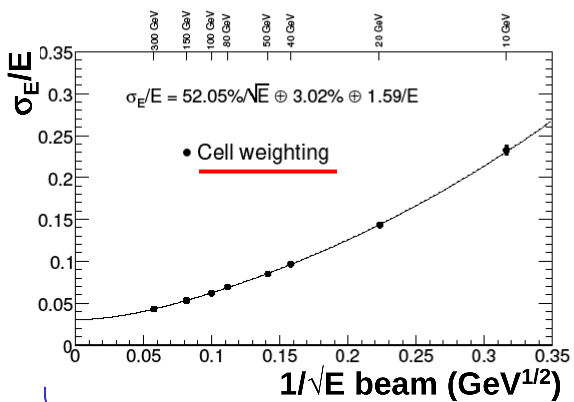
Electrons, a~10% c_{local}~0.2%



Electrons, c_{global}<0.7%



π^+, a~50%, c~3%



Individual Module (EM, HEC, FCal Tile)

ATLAS slice (EM+Tile) (with Inner Detector in front)

2000 — **2005**

- **Calorimeter system meets required specifications for physics**
- **Need to be confirmed in situ !**

Calorimeter operation (1)

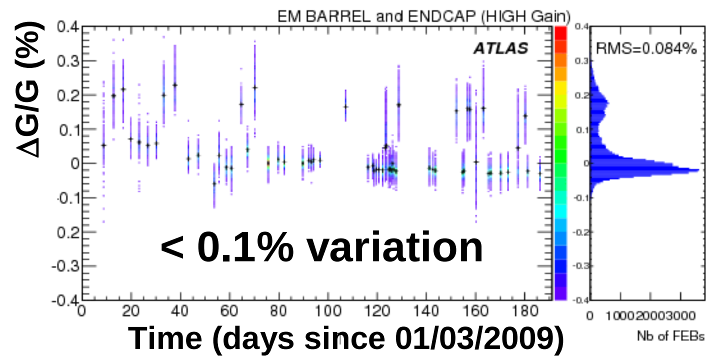
❑ System completely installed 2 years ½ ago

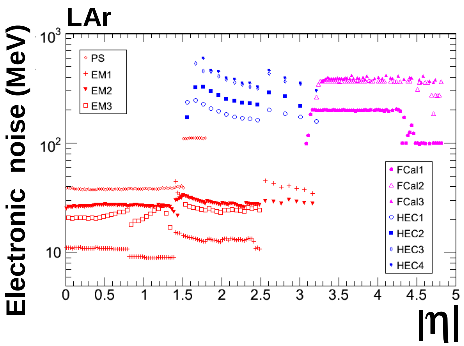
- Monitor temperature in LAr cryostats (**ΔT~60 mK**)
- Cell response check with a dedicated calibration system
  - ➔ Regular update of pedestal and gain
- Noise stable (few %) and under control

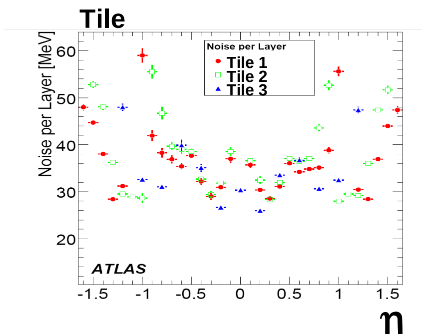
$$E^{cell} \sim F_{EM} \times G \times \sum_{i=1}^{5} a_i (s_i - p)$$

Gain — Pedestal

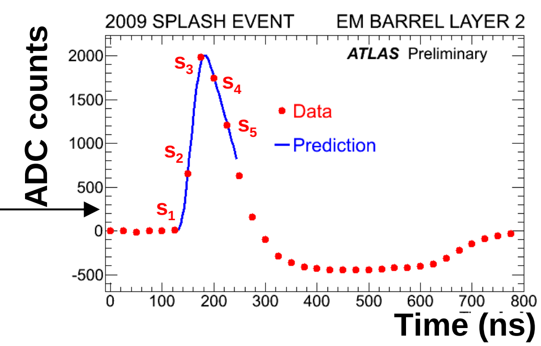
From **predicted ionization pulse + noise**







- LAr EM signal reconstruction contribution to constant term **<0.7%**
- F_{EM} mainly adjusted with electron test beam



Constantly control energy response in every 187k cells

Calorimeter operation (2)

❑ Hardware status for physics analysis

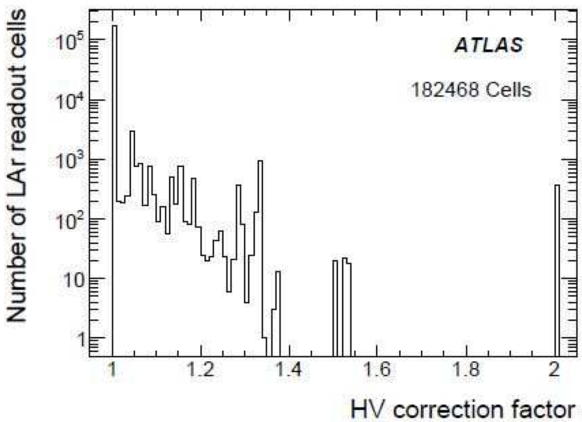
20 non functionning Optical transmitters in Front End electronics boards ➔ can be fixed during shutdown

Cells not responding to the calibration pulse, permanently or sporadically very noisy (LAr) , data corrupted (Tile)

Not nominal HV value
➔Energy corrected by a factor

	Nb cells	Working	Masked	HV Corrected
LAr EM	173 312	98.5%	0.1%	6%
LAr HEC	5632	99.9%	0.4%	19%
LAr FCal	3524	100%	0.1%	1.5%
Tile	5148	97.3%	0.2%	--

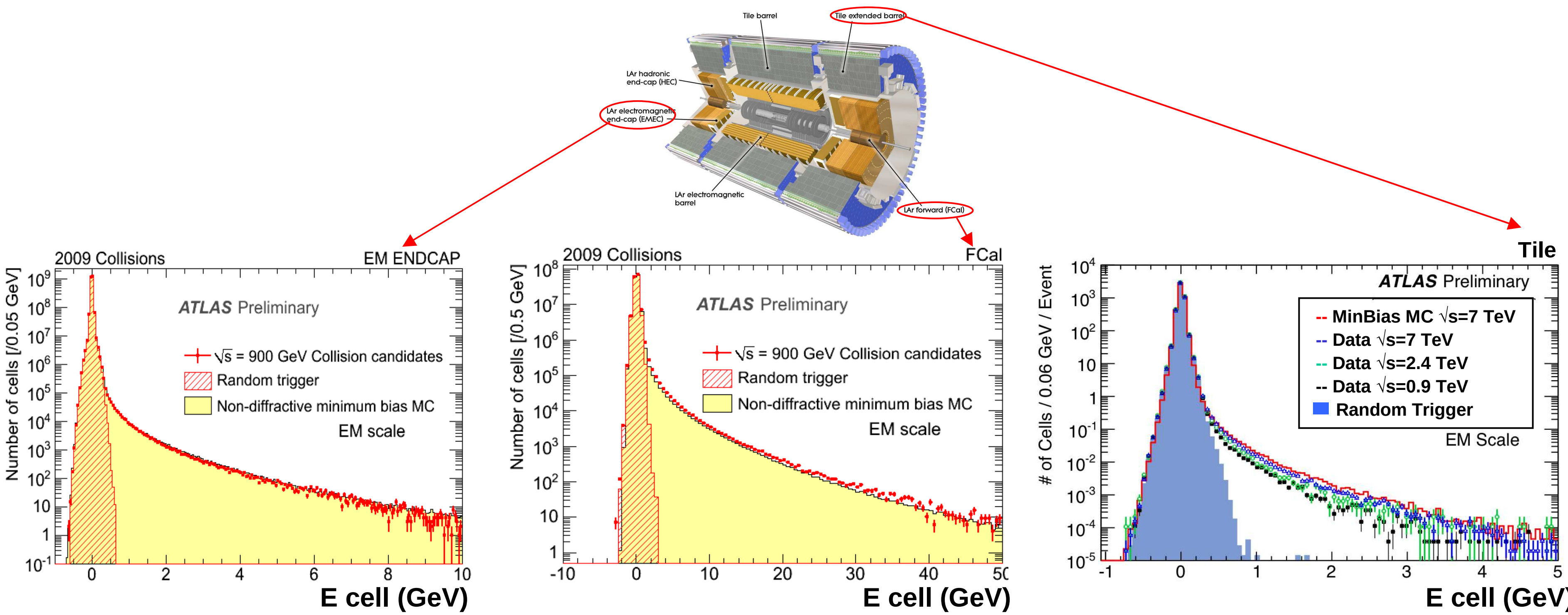
7 non functionning Front End Electronics drawers
➔can be fixed during shutdown



- Regular control of cell behaviour (online Data Quality)
- Understanding/treatment of sporadically noisy cells still to be optimised

Commissioning with LHC collisions (1)

- **Look at energy distribution in all calorimeter cells after LHC turn on !**
  - Focus on EM and first FCal module where most of the energy is deposited

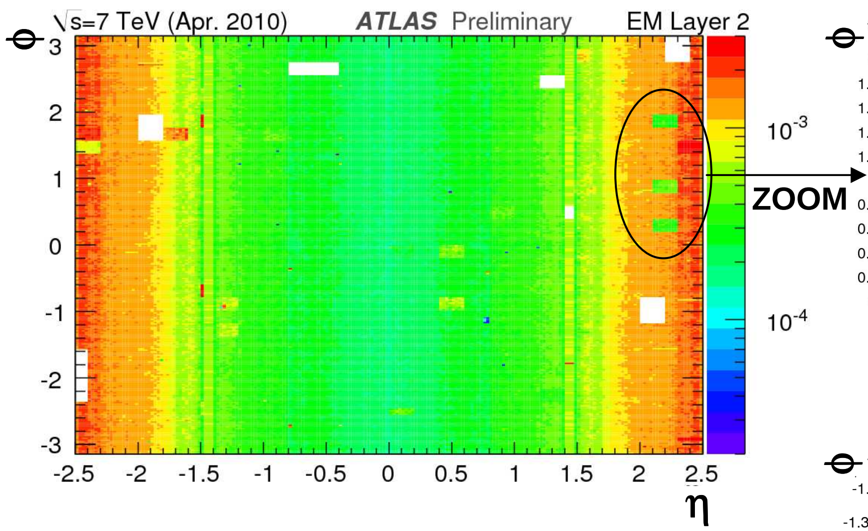


Fair agreement data Monte-Carlo in the calorimeter system

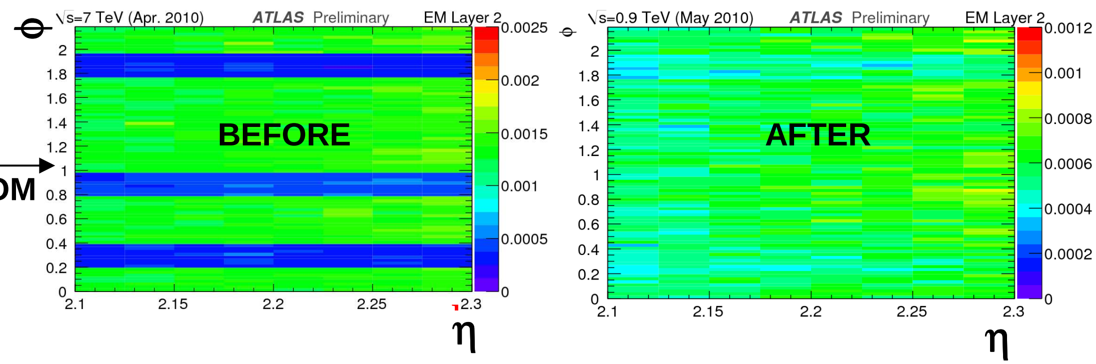
Commissioning with LHC collisions (2)

- Using first millions of minimum bias events

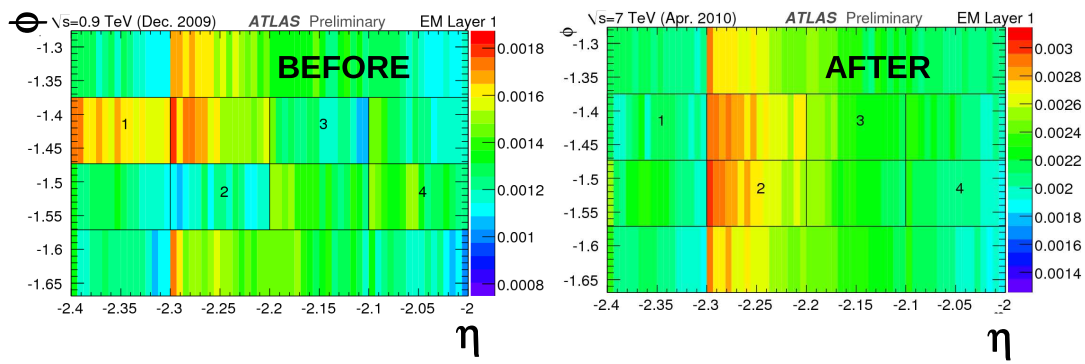
Fraction of events with E_{cell}> 5 σ_{noise}



Spot and correct for HV cable swap



Spot and correct for signal cable swap (S1)



- ➔ Non nominal (masked) cells **~0.1 %**
- ➔ HV corrected cells **~6 %**
- ➔ Can also probe material upstream
  (*see Talk by A. Morley*)

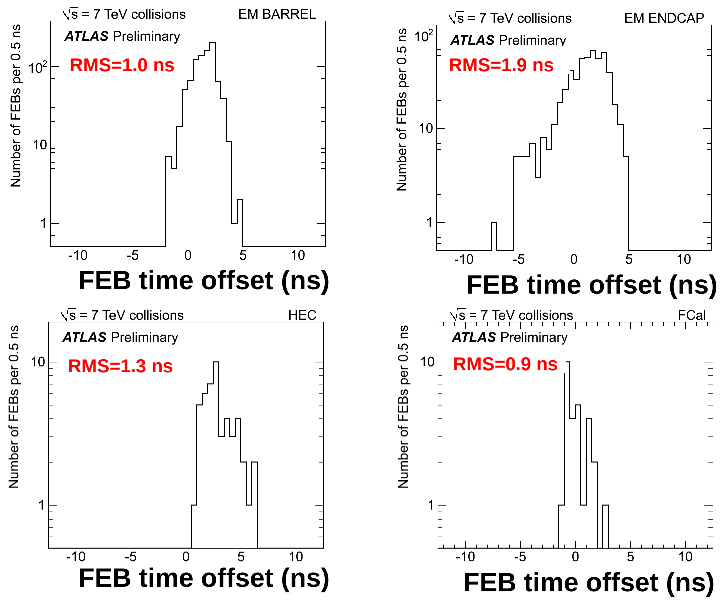
Only 0.4% of EM calo cells with unexpected behaviour (now corrected) !

Commissioning with LHC collisions (3)

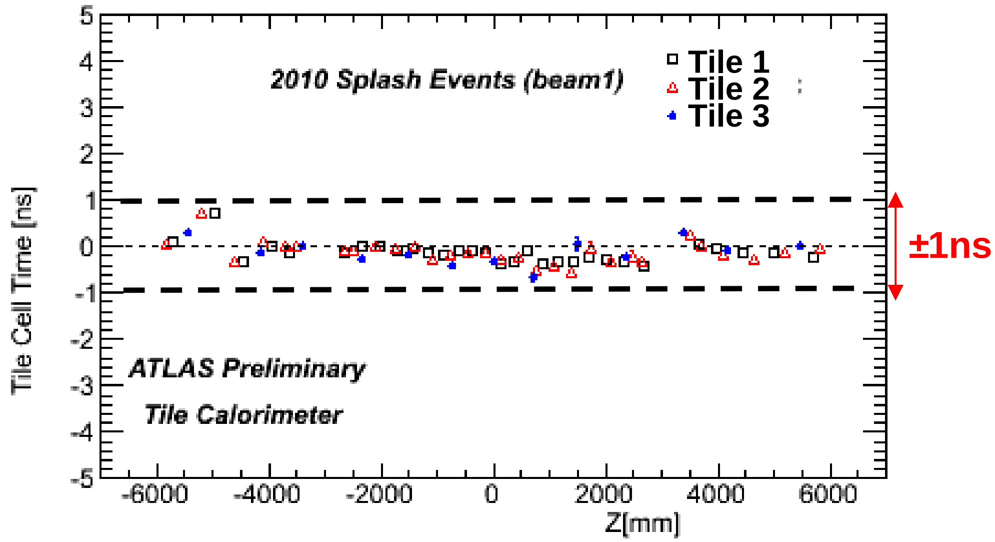
❑ Timing of calorimeter cells

- Preparation before LHC collisions using the calibration, cosmic muons
- Current status with collision data

LAr (average per electronic board [FEB])



Tile Calorimeter (average in ϕ)



➔ Ultimately in EM 100 ps/cell

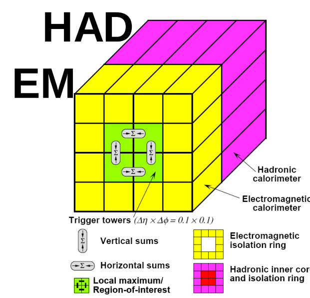
➔ Already within specifications !

Already better than 2 ns (small impact on energy reconstruction)

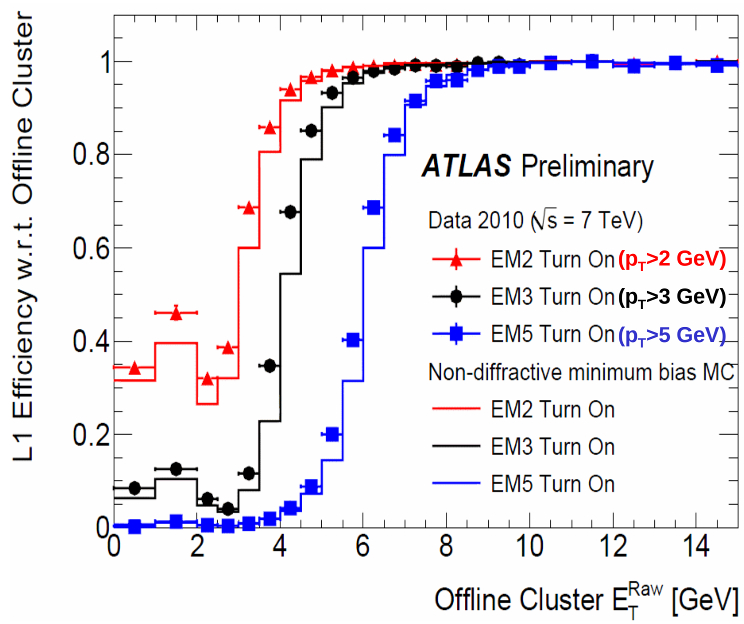
Performance with LHC collisions (1)

❑ First level Calorimeter trigger

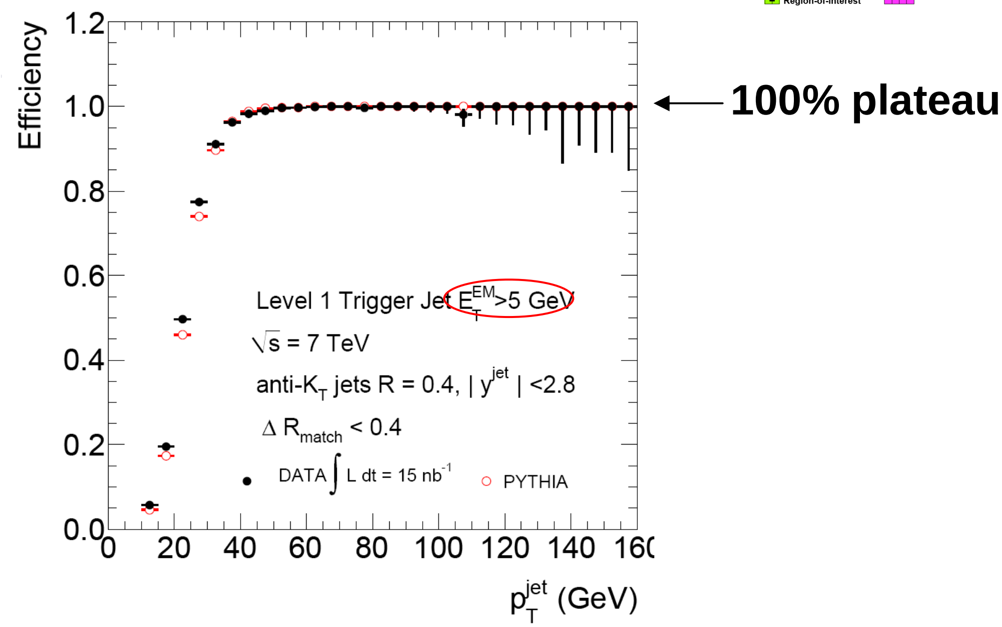
- Sum energy in predefined grid $\Delta\eta x \Delta\phi$=0.1x0.1



EM triggers



Jet Triggers



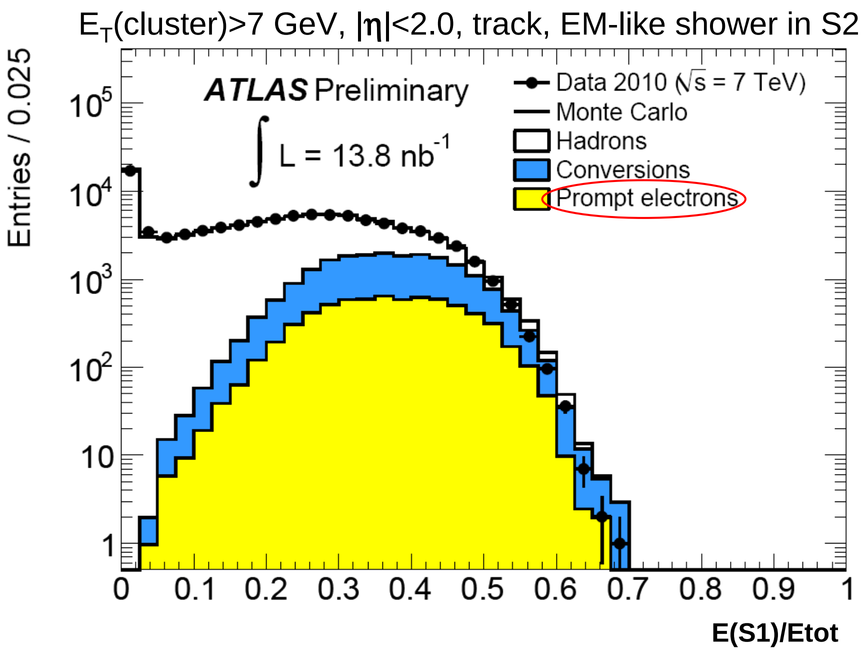
see Talk by J. Baines

Turn-on curve in fair agreement with Monte Carlo

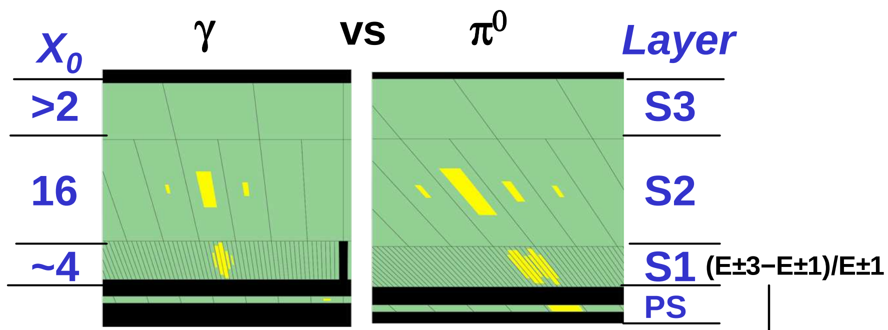
Performance with LHC collisions (2)

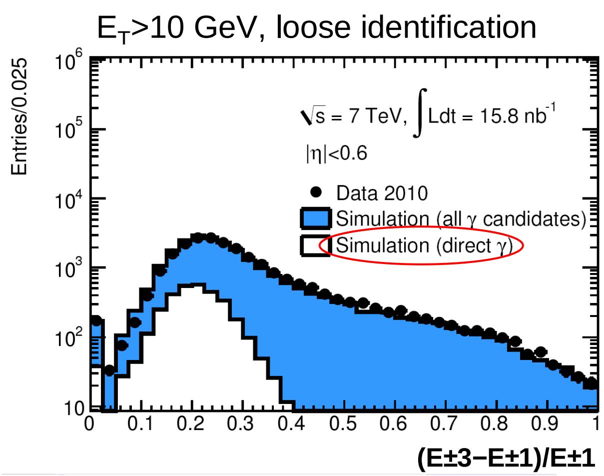
❑ Extract prompt electron/γ samples using EM calorimeter granularity

Electron vs hadrons



➔ *See Talk by S. Snyder*



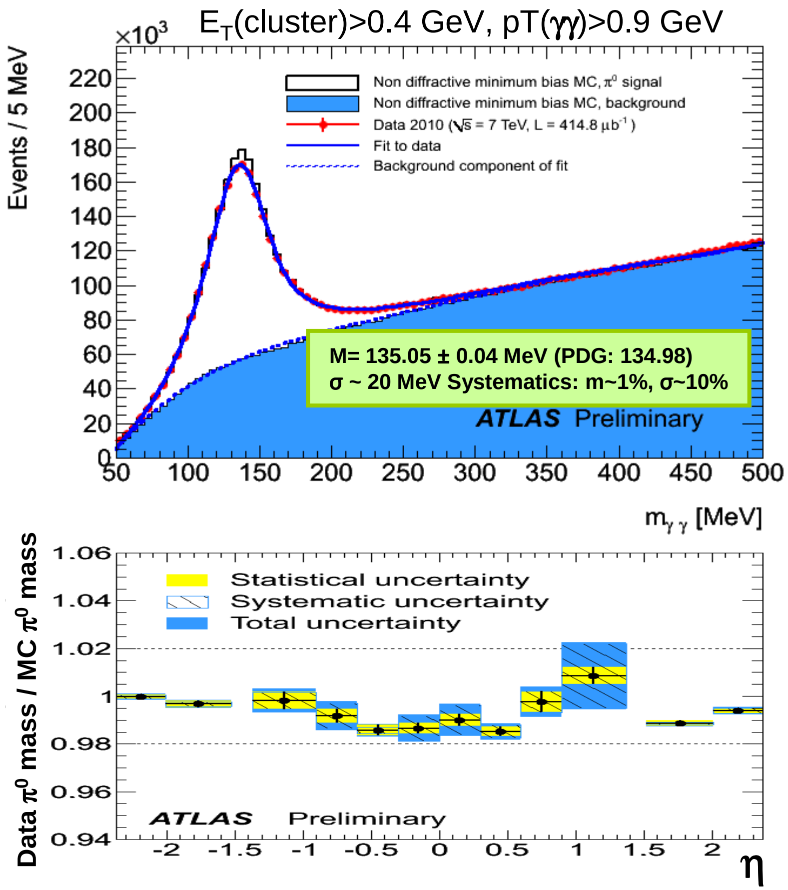


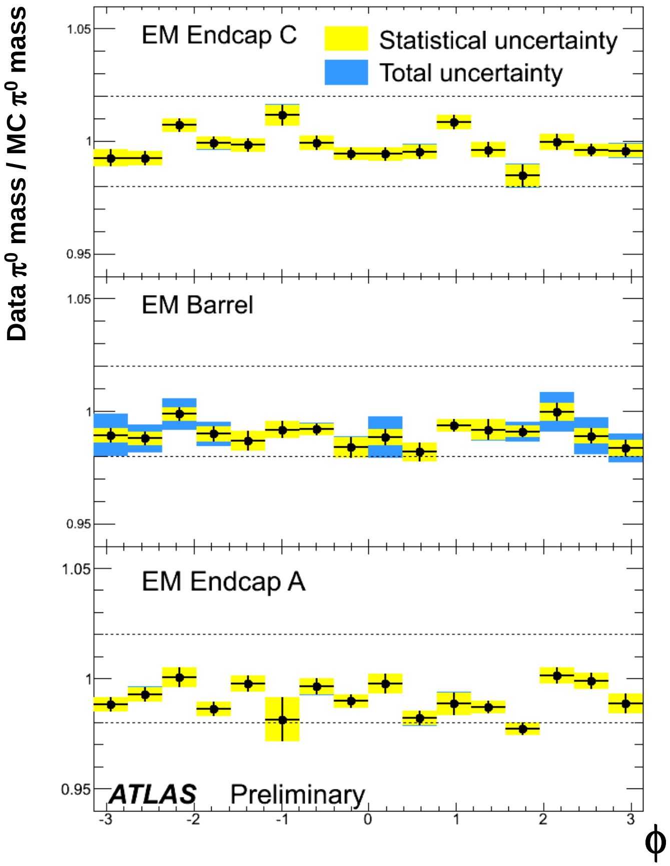
Relative energy outside S1 shower core

Good data-MC agreement for ATLAS EM calorimeter identification variables

Performance with LHC collisions (3)

- **Taste of EM calorimeter uniformity with first million of $\pi^0 \rightarrow \gamma\gamma$**



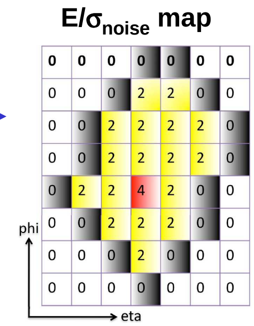


First check of energy scale over η (~ 2%) and EM calo response uniformity in φ (< 0.7%)

Performance with LHC collisions (4)

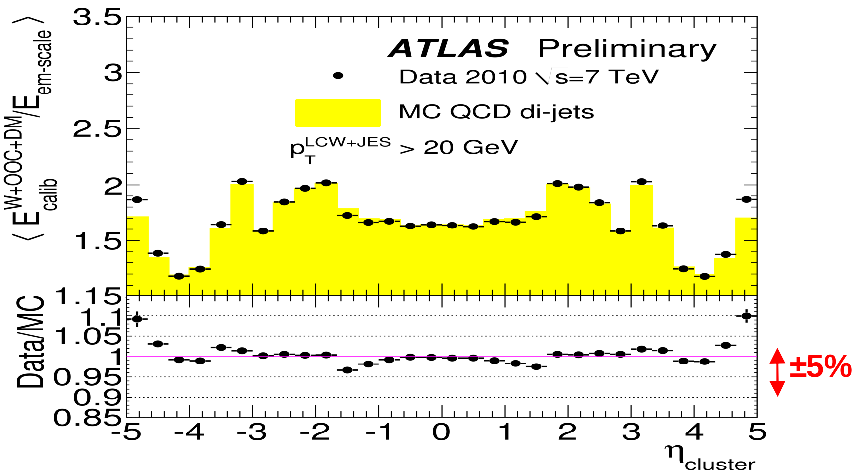
Energy calibration for jet and Etmiss

- Define **3D cluster** : ~ particle level, suppress noise

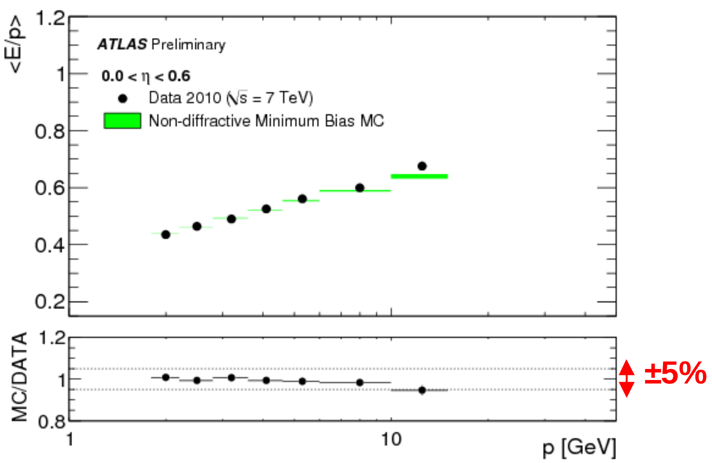


- Separate EM-like (e, γ, π^0) and HAD-like (π^+, n) with cluster moment
  - ✓ Apply weights (W) according to **cluster energy density**
- Correct for out of cone (OOC) and inner detector/cryostats material (DM)

Weight for 3D clusters entering jets (p_T>2.3)



E/p with single hadrons (|η|<2.3)



Agreement data-MC in ± 5% over the ~ full calorimeter coverage (|η|<4.5)!

Performance with LHC collisions (5)

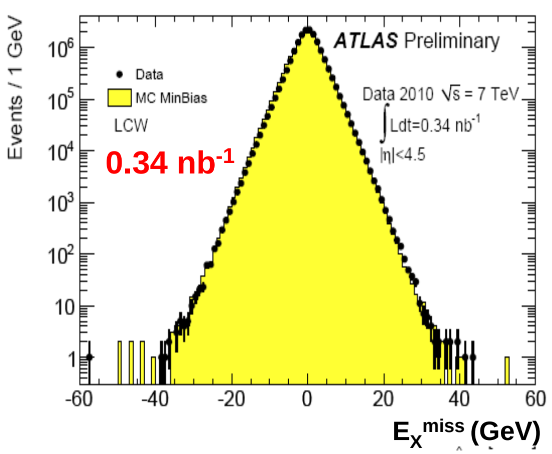
$\vec{E}_T^{miss} = -\Sigma \vec{E}_T$ (calo)

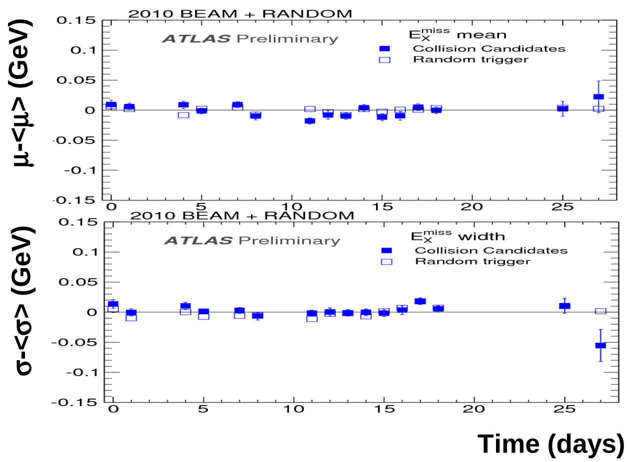
Missing transverse energy (E_T^{miss})

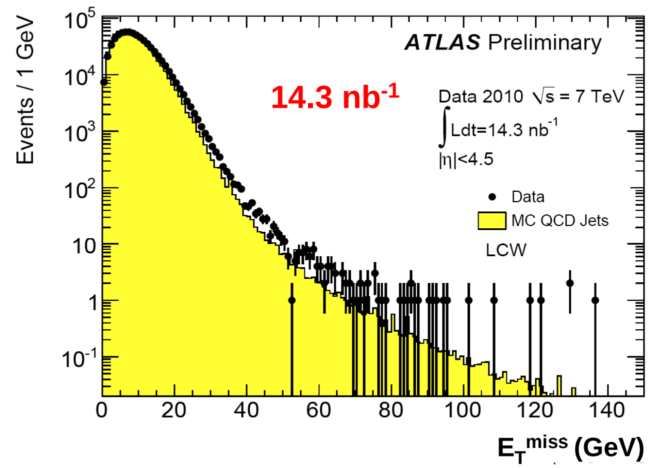
- Central for new physics search at LHC (SUSY, W', …)
- Mainly based on calorimeter (calibrated 3D cluster cell energy)

E_x^{miss} (*Minimun Bias*) ⟶ E_x^{miss} Mean (μ) and width (σ)

E_T^{miss} (*1 jet p_T>20 GeV*)







➔ Data-MC agreement: good understanding of noise, pedestal, calibration, …

➔ Very stable with time

➔ No tails above 140 GeV : understanding of calo cell behaviour

➔ *See Talk by A. Schwartzmann*

ATLAS calorimeter provides reliable and stable measurement of E_T^{miss}

Conclusions

❑ **The ATLAS calorimeter designed for optimal e, jet, E_T^{miss} measurement**

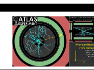
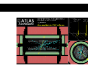
- High granularity (**~190 k cells**), depth (**>10 λ**) and coverage (**$|\eta|<5$**)
- Well prepared with test beams and continuous *in situ* training (regular calibration, cosmic, …)

➔ Currently operational at **~98.5 %** and stable with time

❑ **Commissioning and Performance with first LHC data**

- Only **0.4%** of unexpected problematic cells (corrected). Timing of front-end electronics at **2 ns**
- With 1rst million π^0 : EM calorimeter ϕ non uniformity **~0.7%**, and energy scale **~2%**
- Calibration understanding and Data-Monte Carlo agreement at **<10%** over $|\eta|<5$

❑ **Measure calorimeter linearity, uniformity, scale with pure high mass resonances**

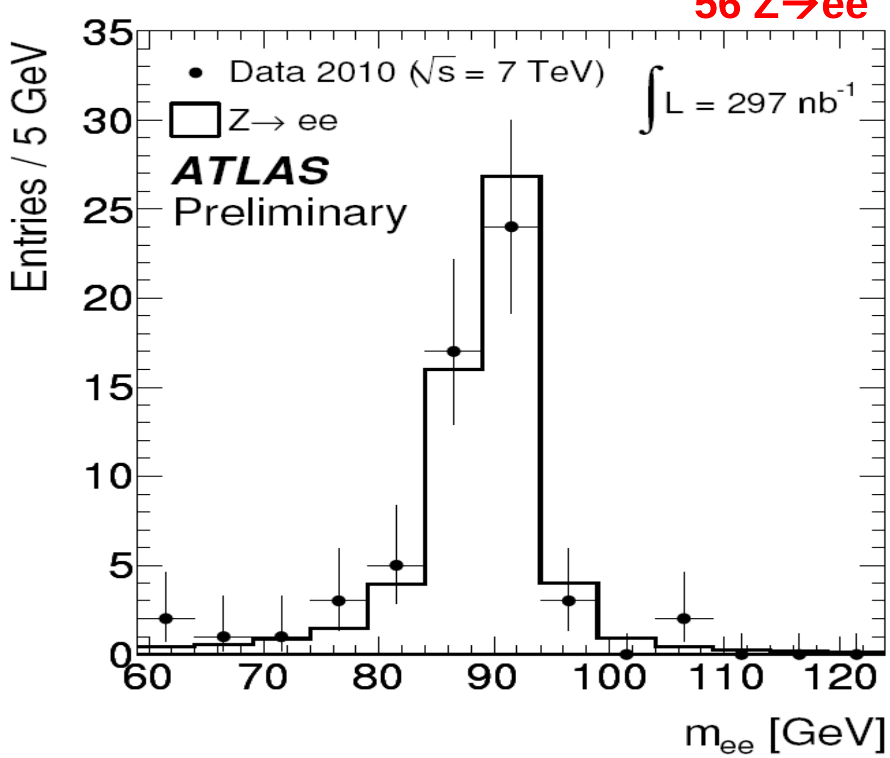
	Jpsi→ee	W→ev	Z→ee	tt→WbWb→evbjjb
If $1fb^{-1}$ end 2011 ($x10^3$)	8000	3000 	300 	10
S/B	>5	>20	>20	>10

ATLAS calorimeter system performing very well with first LHC data

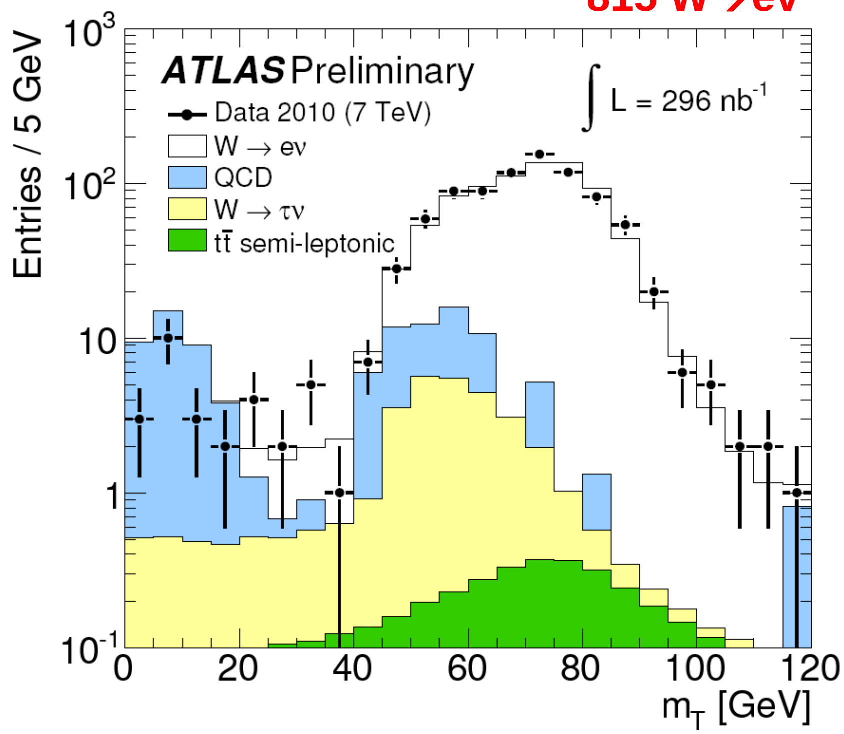
Outlooks

- **Reconstructed (transverse) mass of Z (W) with ~ all available LHC statistics**
  - Here, MC normalised to number of entries in data after electron selection

56 Z→ee



815 W→eν



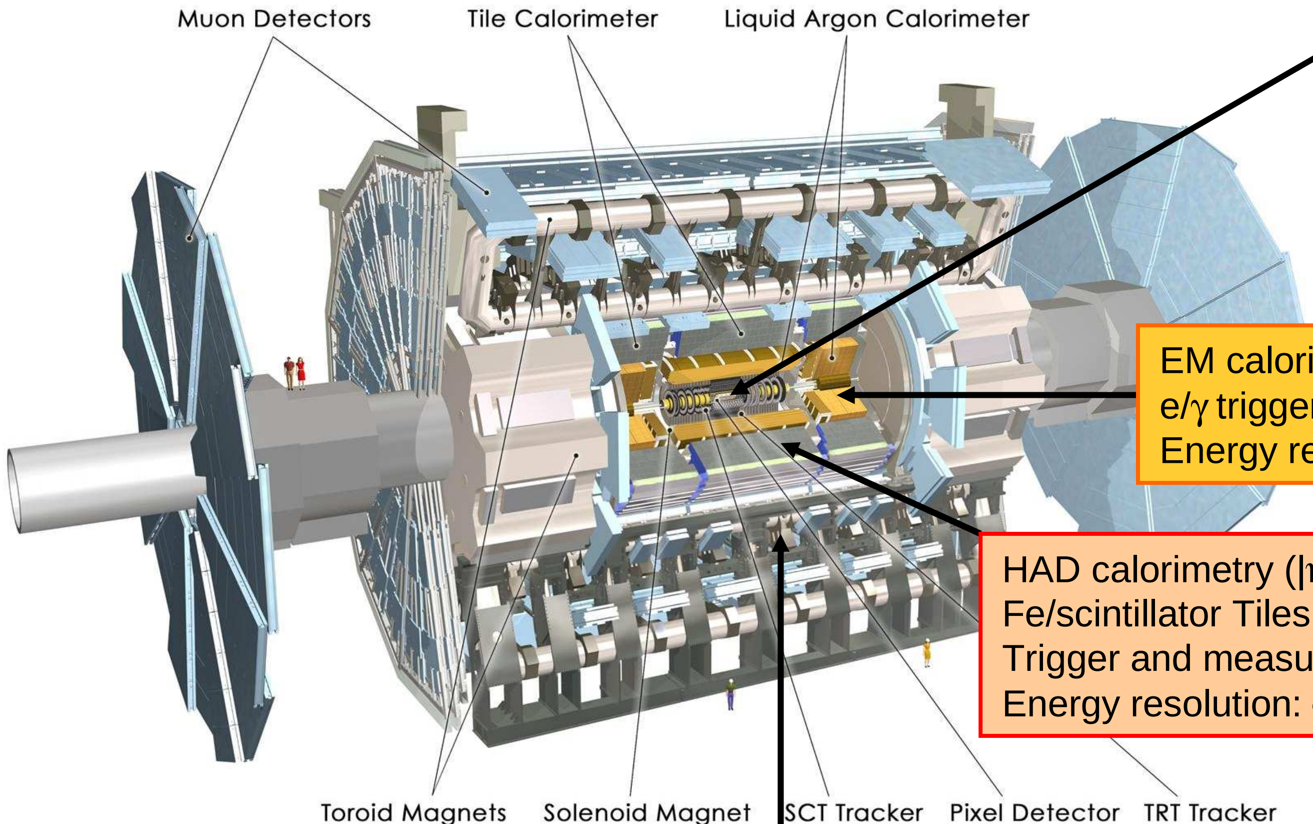
EM Energy scale indeed correct at 2% !

EM+HAD scale in agreement with MC !

SPARES

The ATLAS detector

L ~ 46 m, ∅ ~ 22 m, 7000 tons
~10^8 electronic channels



Inner Detector ($|\eta|<2.5$, B=2T): Si Pixels, Si strips, Transition Radiation detector (straws).
Precise tracking and vertexing, e/π separation.
Momentum resolution:
$\sigma/p_T \sim 0.04\%\ p_T(\mathrm{GeV}) \oplus 1.5\%$

EM calorimeter: Pb-LAr Accordion.
e/γ trigger, identification and measurement
Energy resolution: $\sigma/E \sim 10\%/\sqrt{E} \oplus 0.7\%$

HAD calorimetry ($|\eta|<5$): segmentation, hermeticity.
Fe/scintillator Tiles (central), Cu/W-LAr (forward).
Trigger and measurement of jets and missing E_T.
Energy resolution: $\sigma/E \sim 50\%/\sqrt{E} \oplus 3\%$

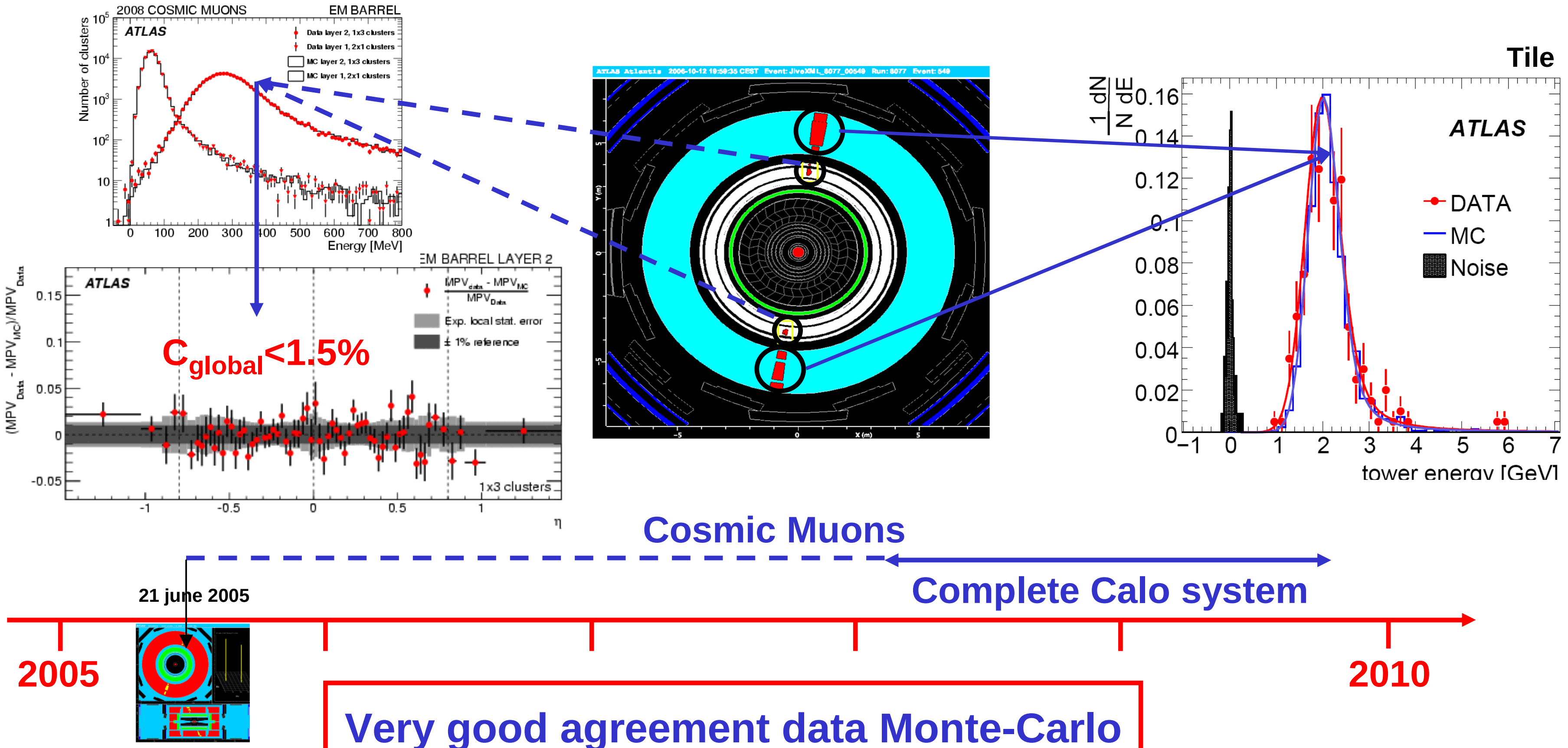
Muon Spectrometer ($|\eta|<2.7$) : air-core toroids with gas-based muon chambers.
Muon trigger and measurement with momentum resolution < 10% up to $E_\mu \sim 1$ TeV

3-level trigger reducing the rate from 40 MHz to ~200 Hz

Cosmic muon results

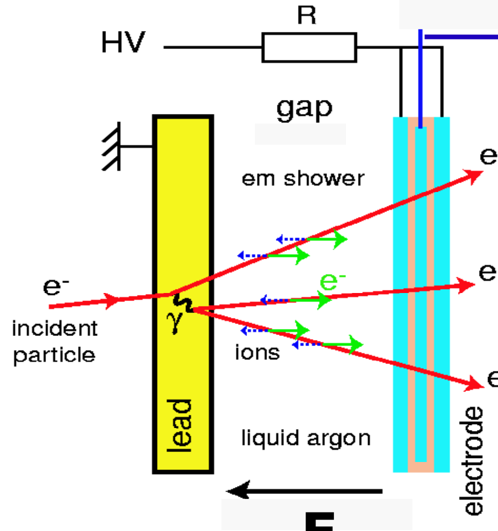
- **Commissioning continues *in situ* with cosmic muons**
  - Small deposited signal ➔ Very good check of the detector performance

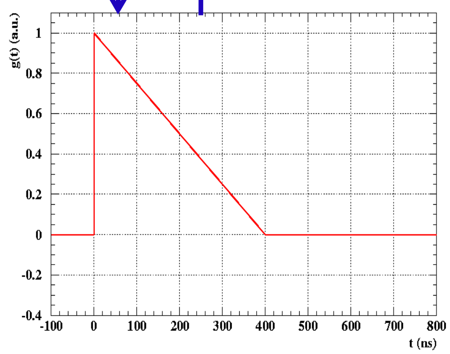
3 publications



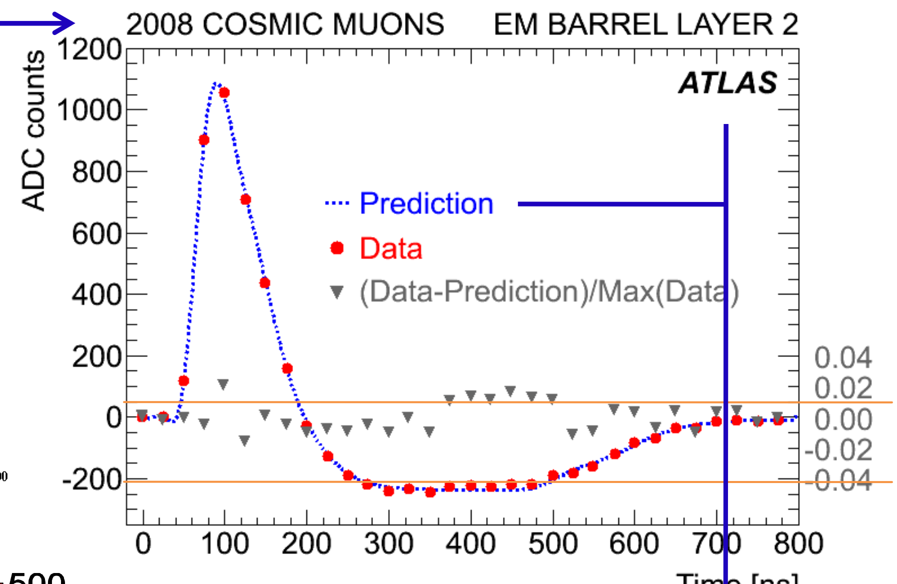
Very good agreement data Monte-Carlo

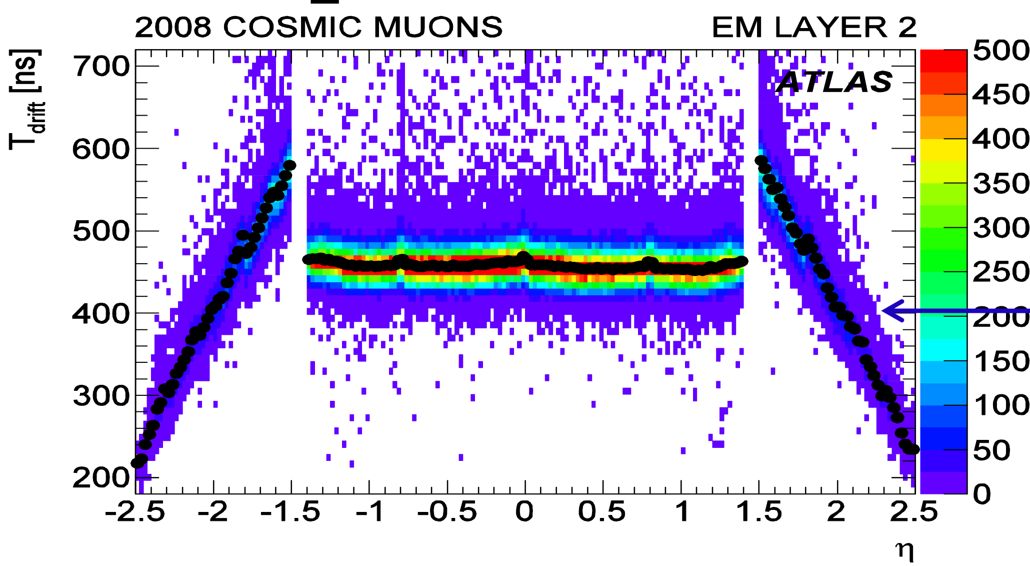
LAr Signal shape





CR-(RC)^2





The RTM(FPM diff.) method: $g_{phys}(t) = g_{cali}(t) *$

$$\mathcal{L}^{-1}\left\{\frac{(1+s\tau_{\text{cali}})(sT_{drift}-1+e^{-sT_{drift}})}{sT_{drift}(f_{\text{step}}+s\tau_{\text{cali}})}\right\} *$$

$$\mathcal{L}^{-1}\left\{\frac{1}{1+s^2LC+sRC}\right\}$$

Prediction depend on the knowledge of drift time measurement

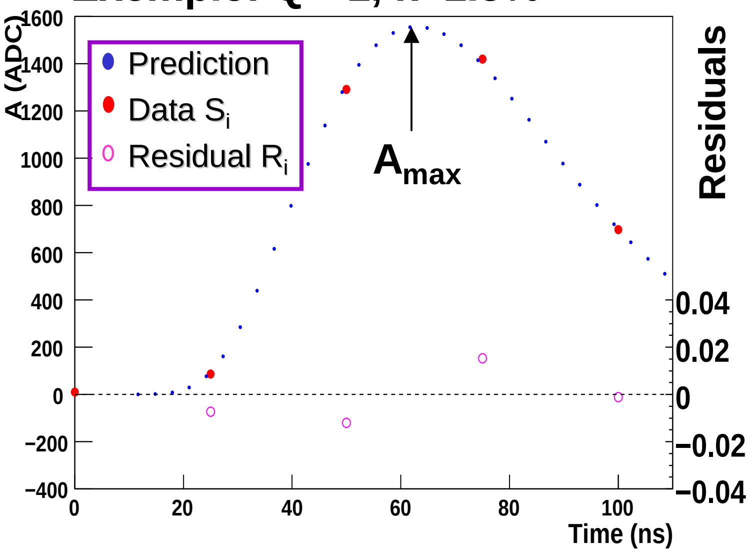
EM Calorimeter : signal reconstruction

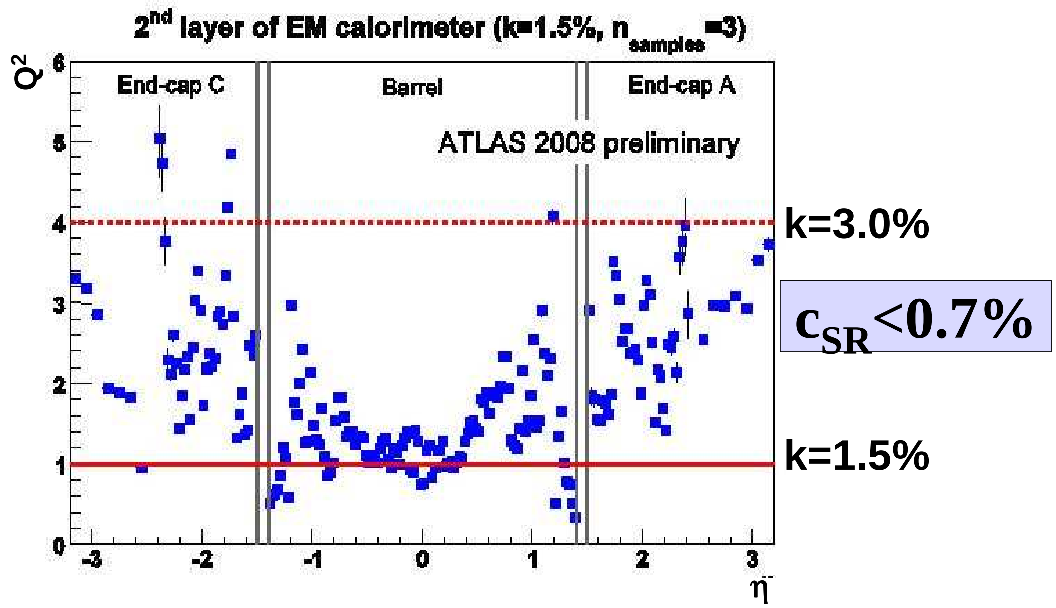
❑ Quality of signal reconstruction (SR)

- A_{max} accuracy (**k**) depends on the precision of electrical cell modelling
- Check quality on high energetic cells (E>5 GeV) : σ_{noise} negligible

$$Q^2 = \frac{1}{NDoF} \sum_{i=1}^{n_{samples}} \frac{(S_i - \mathrm{A}_{\max} \times \mathrm{Pred.})^2}{(\mathrm{kA}_{\max})^2} = \frac{1}{NDoF} \sum_{i=1}^{n_{samples}} \left(\frac{\mathrm{R}_i}{\mathrm{k}} \right)^2$$

Exemple: Q^2=1, k=1.5%

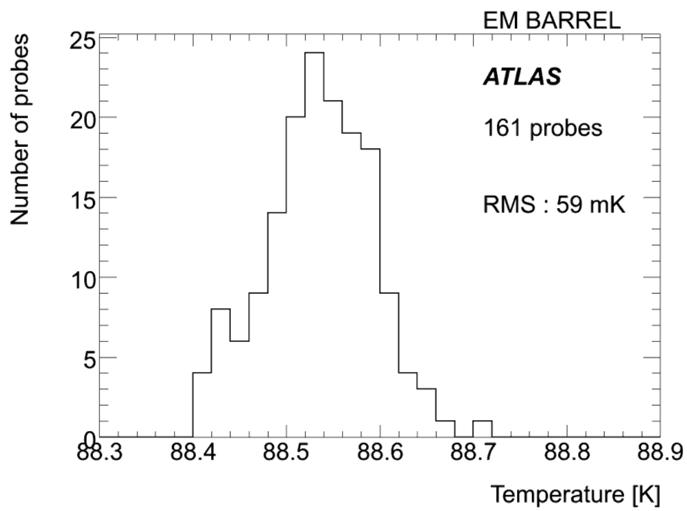




➔ **Signal reconstruction under control on the whole calorimeter coverage**

LAr Temperature and purity

❑ LAr Temperature



- LAr signal sensitivity 2%/K (density: -0.45%/K , Velocity: -1.55%/K) ➔ Require 100mK stability and homogeneity
- Using 150-200 PT100 probes in each cryostats immersed in liquid argon
- Homogeneity **59mK**, with **1.5mK** RMS for each probe over 10 days

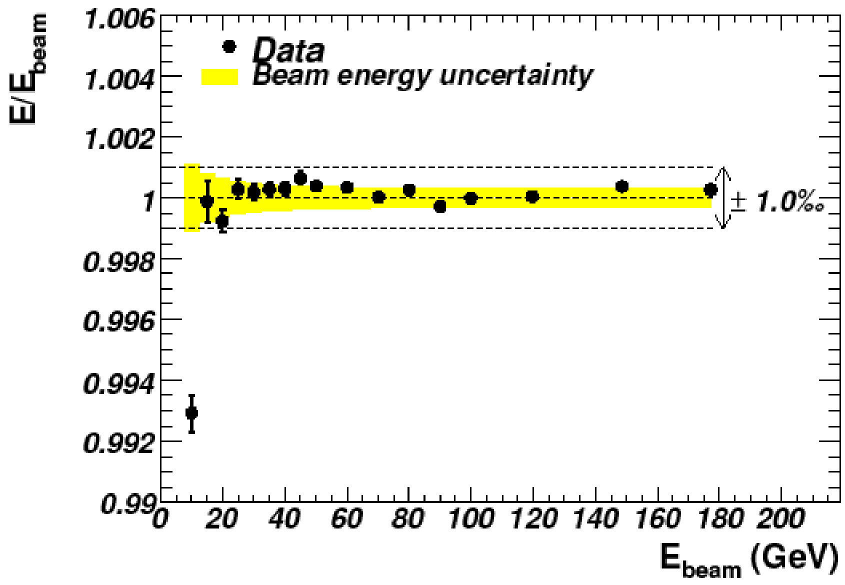
❑ LAr Purity

- Electronegative impurities would reduce the measured signal ➔ Require purity <1000ppb
- 30 purity monitors in the three cryostats
- Measured impurity: **Barrel ~ 200ppb, EndCap ~ 140ppb**

Well within required 0.2% uncertainties of signal

EM Calorimeter linearrity

- From test beam results



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