Commissioning of the ATLAS LAr Calorimeter

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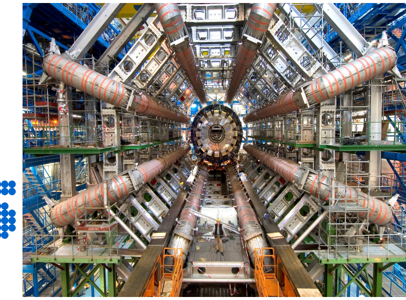
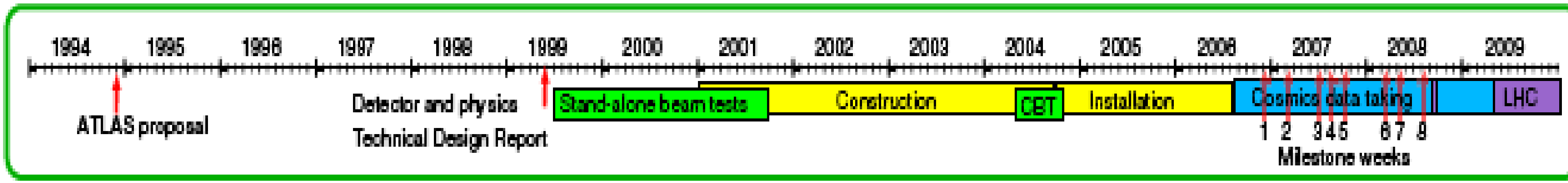
Outline:

- ATLAS in-situ commissioning steps
- Introduction to the ATLAS LAr Calorimeter
- Detector calibration
- Calorimeter performances with cosmic muons and first LHC beams

ATLAS In-Situ Commissioning Steps

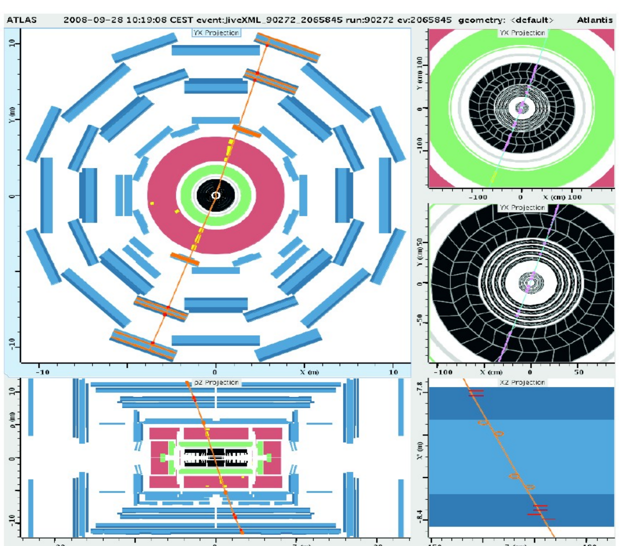


- In situ commissioning of ATLAS detectors ongoing since 4 years:



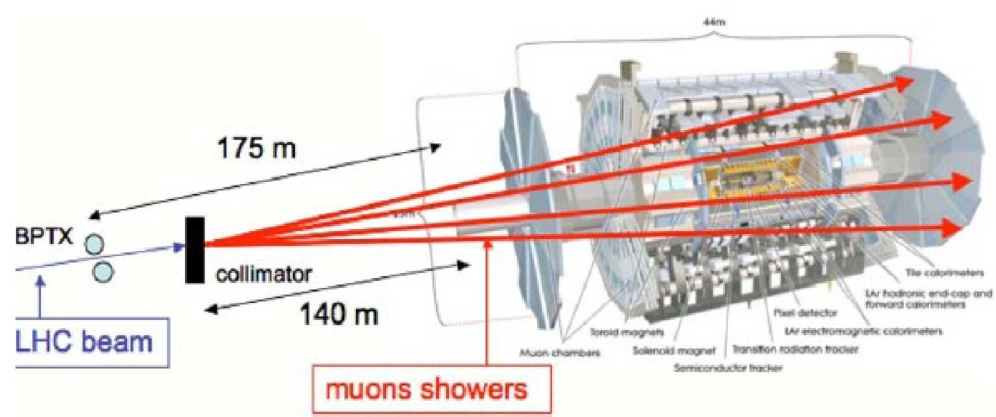
Cosmic muons (since 2005)

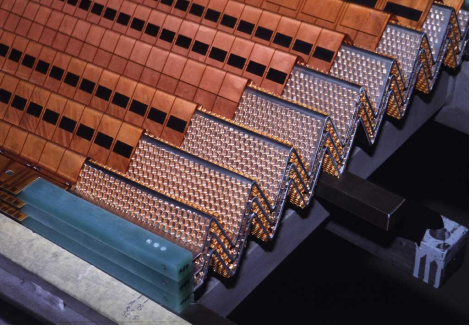
Muon: Minimum Ionizing Particle (MIP) in LAr calorimeter



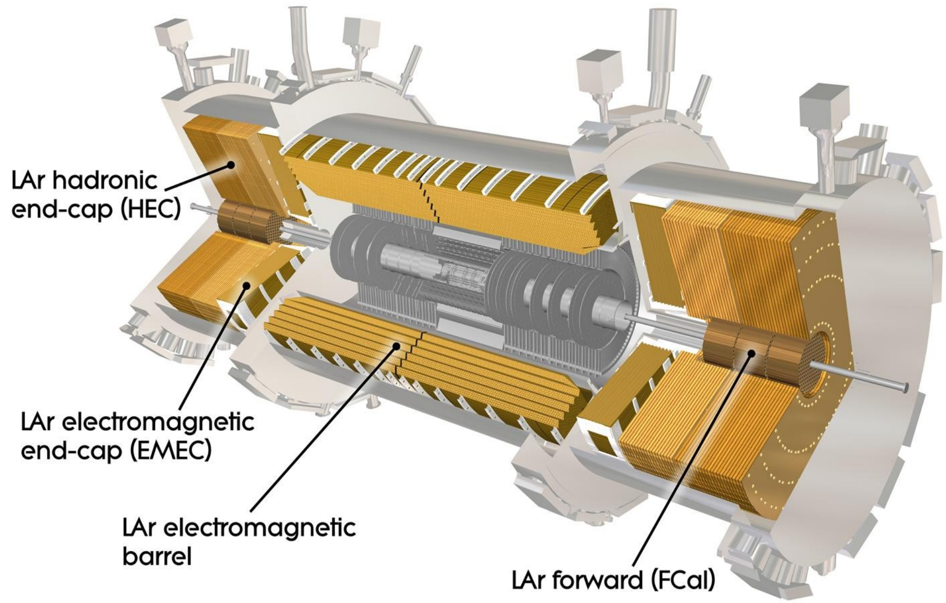
First LHC Beams (Sept. 10-12, 2008)

Very large energy deposited in most of LAr cells !





Introduction to the ATLAS LAr Calorimeter [1/3]



- Sampling calorimeters: Lar+Pb/Cu/W
- Standard barrel/endcap structure:

- barrel: electromagnetic (EM)
  (presampler up to |η|=1.8)

- endcap: EM + hadronic (HAD)
+ forward (FCAL)

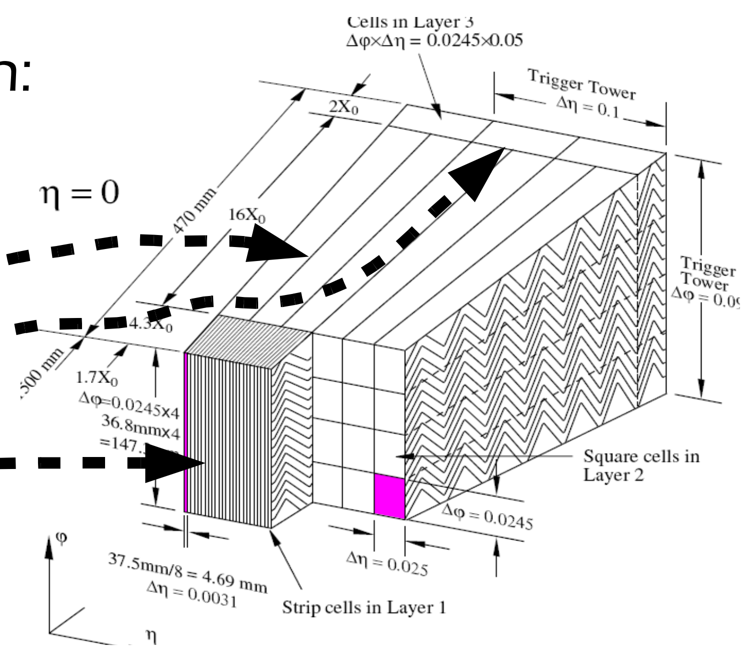
- Segmentation: lateral (eta,phi) but also in depth:
- Energy resolution:

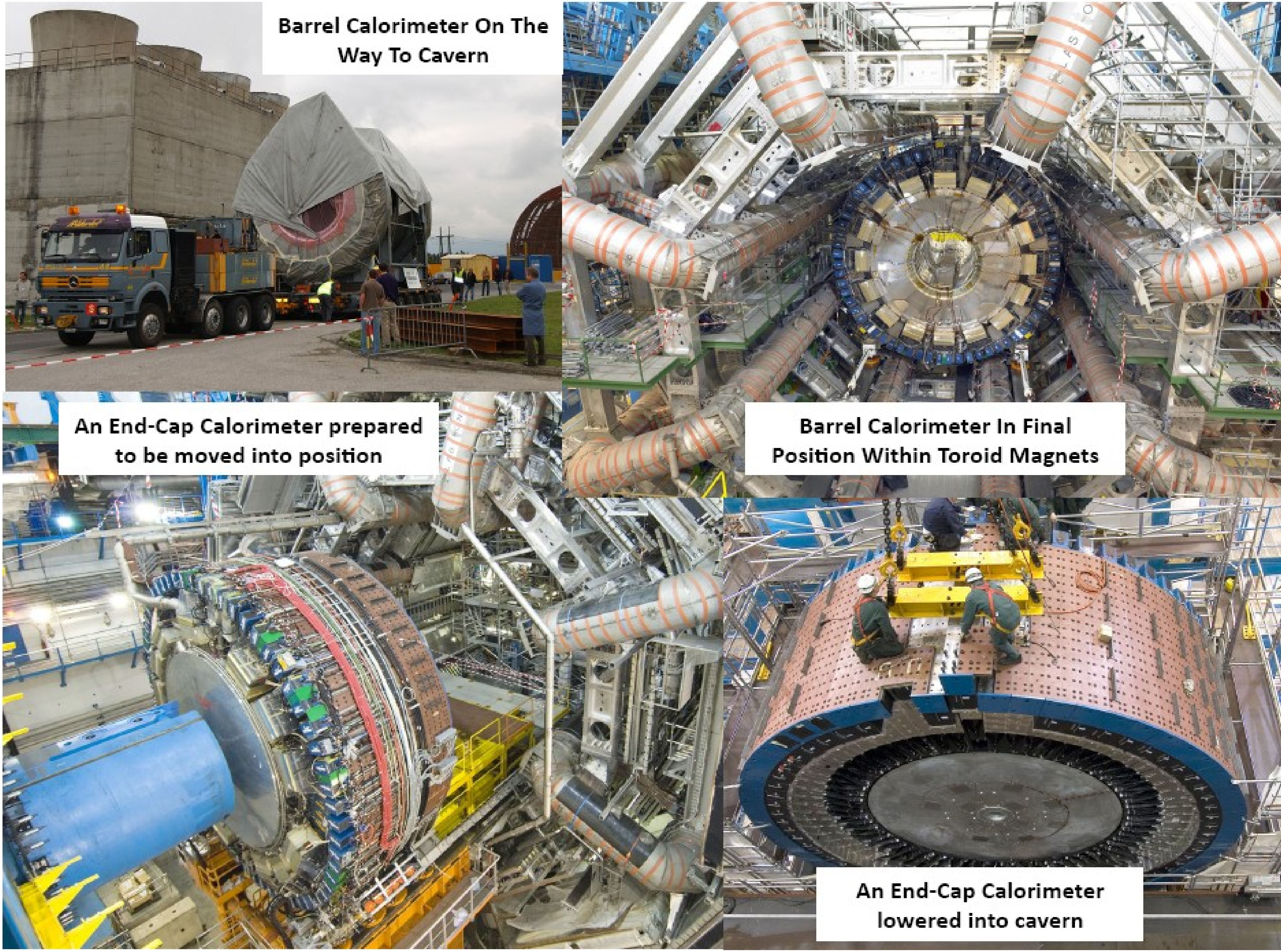
σ /E ~ 10%/√E ⊕ 0.7% (EM)

σ /E ~ 50%/√E ⊕ 3% (HAD)

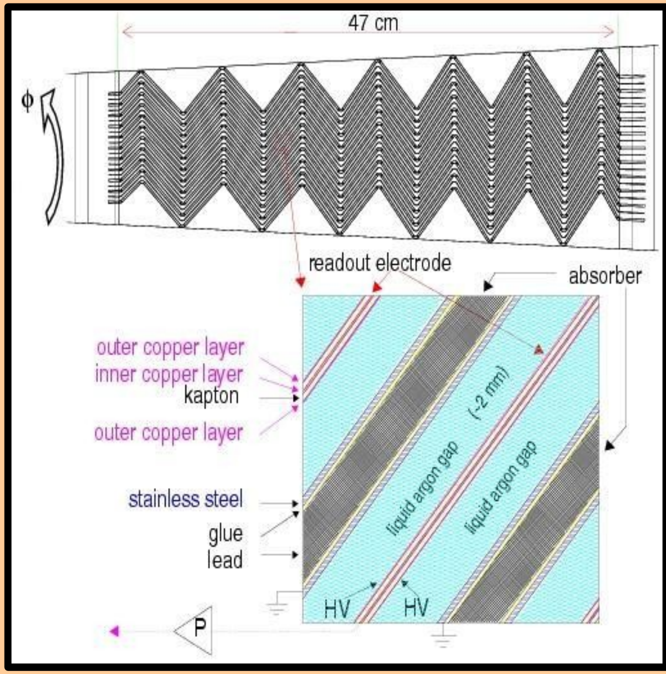
σ /E ~ 100%/√E ⊕ 10% (FCAL)

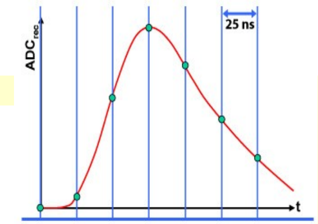
- (Pre-Sampler)
- Strips
- Middle
- Back

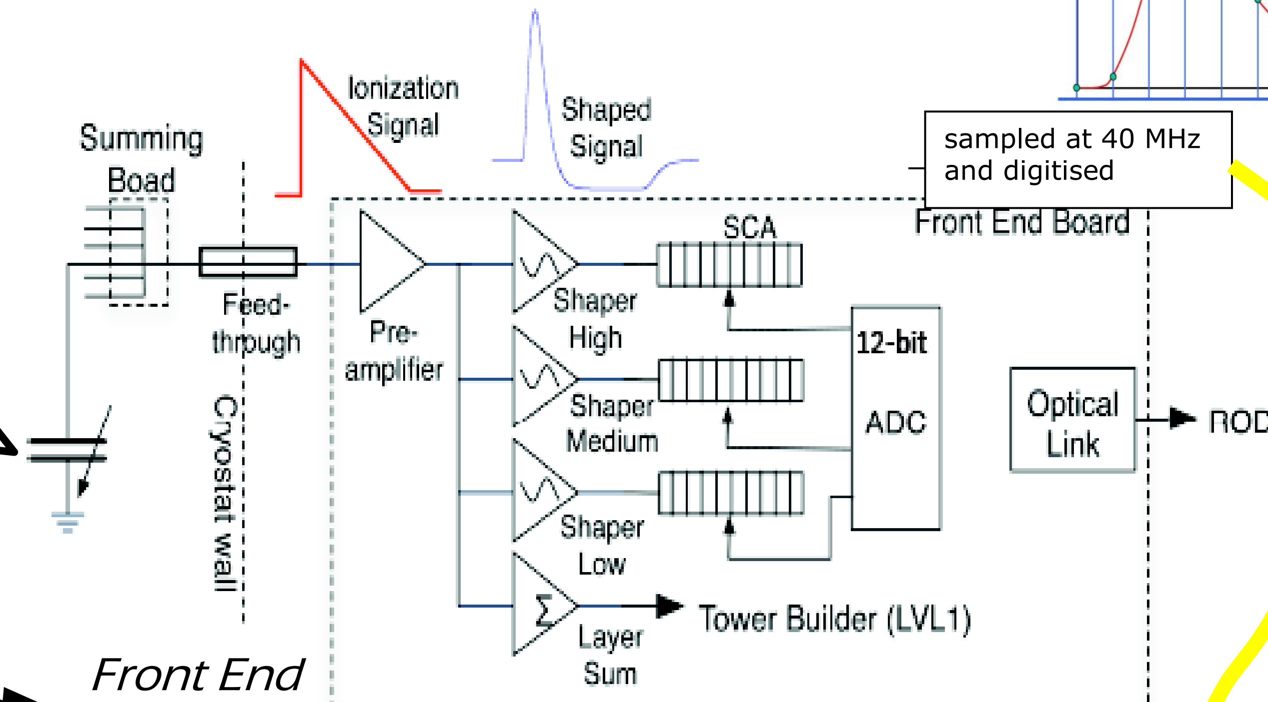



Barrel Calorimeter On The Way To Cavern
Barrel Calorimeter In Final Position Within Toroid Magnets
An End-Cap Calorimeter prepared to be moved into position
An End-Cap Calorimeter lowered into cavern

Introduction to the ATLAS LAr Calorimeter [2/3]







Calorimeter → *Front End Electronics* → *Back End Electronics*

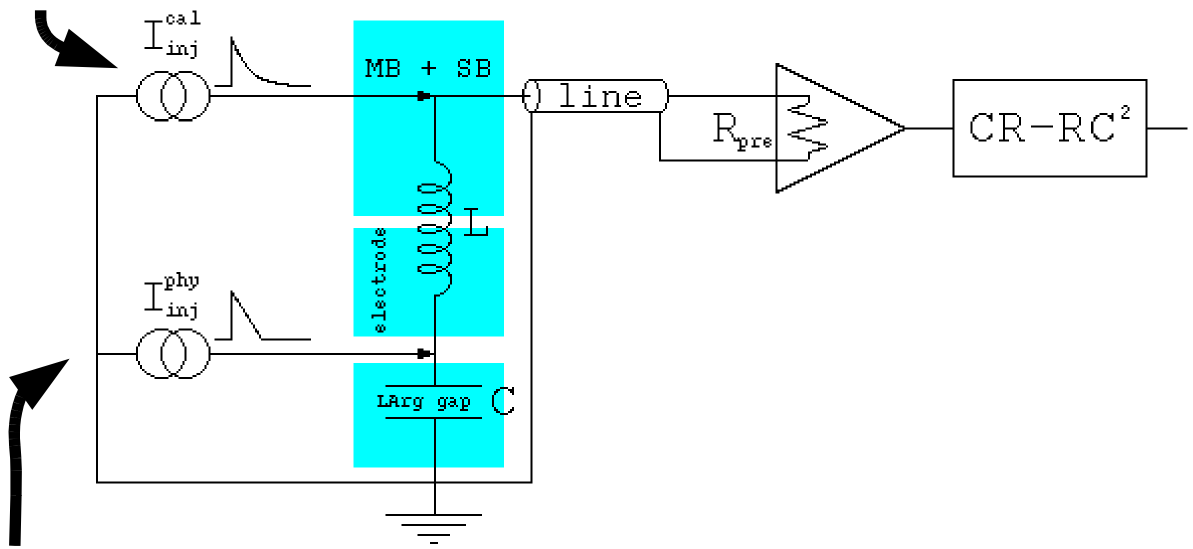
$$E_{\text{cell}} = F_{\mu\text{A}\rightarrow\text{MeV}} \cdot F_{DAC\rightarrow\mu\text{A}} \cdot \frac{1}{\frac{\text{M}_{\text{phys}}}{\text{M}_{\text{cali}}}} \cdot R \left[\sum_{j=1}^{N_{\text{samples}}} a_j \left(s_j - p \right) \right]$$

- Energy: E_{cell}
- Energy Conversion: $F_{\mu\text{A}\rightarrow\text{MeV}}$
- Calibration board: $F_{DAC\rightarrow\mu\text{A}}$
- Phys/Cal Difference: $\frac{\text{M}_{\text{phys}}}{\text{M}_{\text{cali}}}$
- ADC to DAC (Ramps): R
- Optimal Filtering Coefficients: a_j
- Pulse Samples: s_j
- Pedestals: p

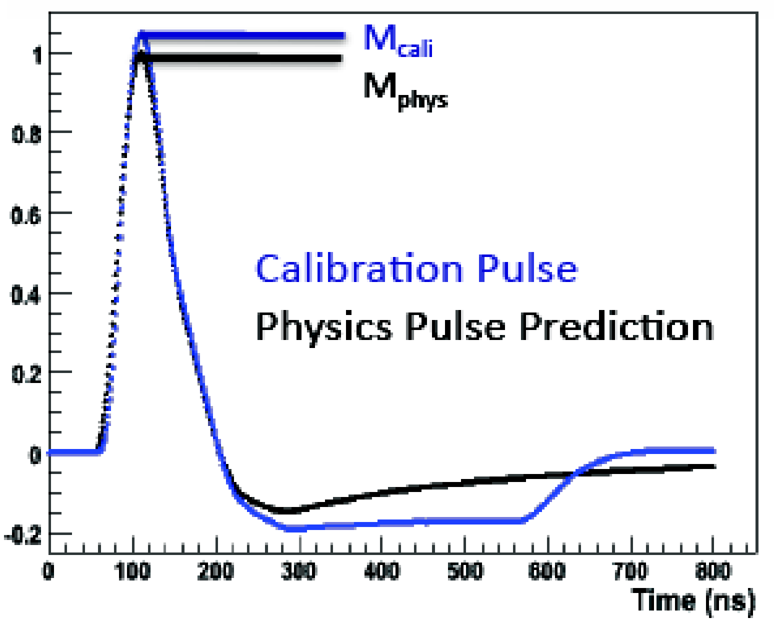
Introduction to the ATLAS LAr Calorimeter (3/3): The Calibration System

- Used to compute several electronics-related constants, including optimal filtering coefficients
- Calibration and physics pulse are different due to different injected signal and injection points: methods exist to predict physics pulses from calibration pulse

Calibration signal: exponential



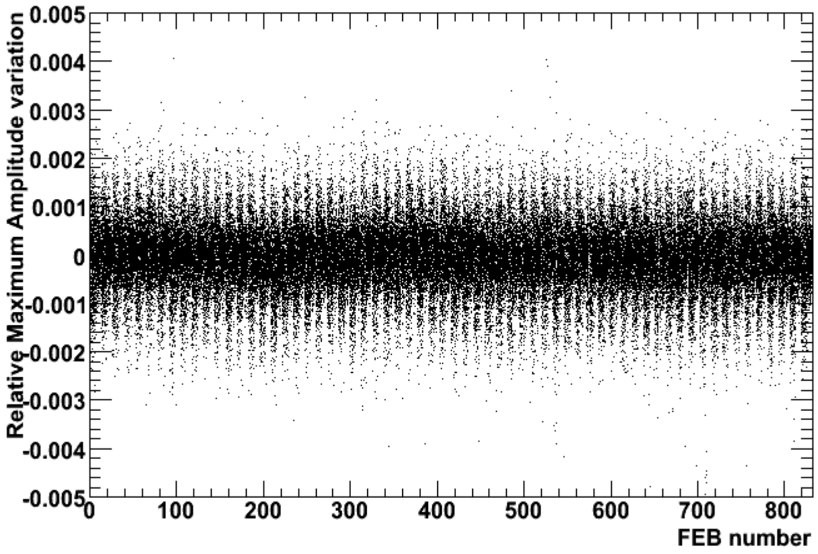
Physics signal: triangular



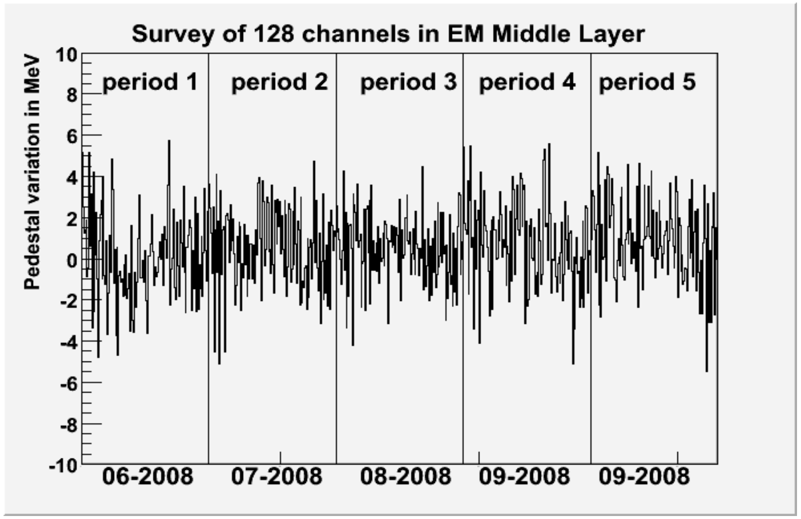
Calibration Constants Stability

- Calibration runs taken frequently: check stability of constants

Shape Maximum Variations:



Pedestal Variations:



- sensitive to many factors (calibration pulse, shapers, pedestal, ...)
- if shaper properties drift, OFCs must be recomputed
- variations < 0.1%

- sensitive to FEB temperature
- variations < 1 to 3 MeV (<< 1 ADC) depending on sampling

→ quite stable over several monthes !

Calorimeter Performances

Results from random triggers, cosmics muons and first beams:

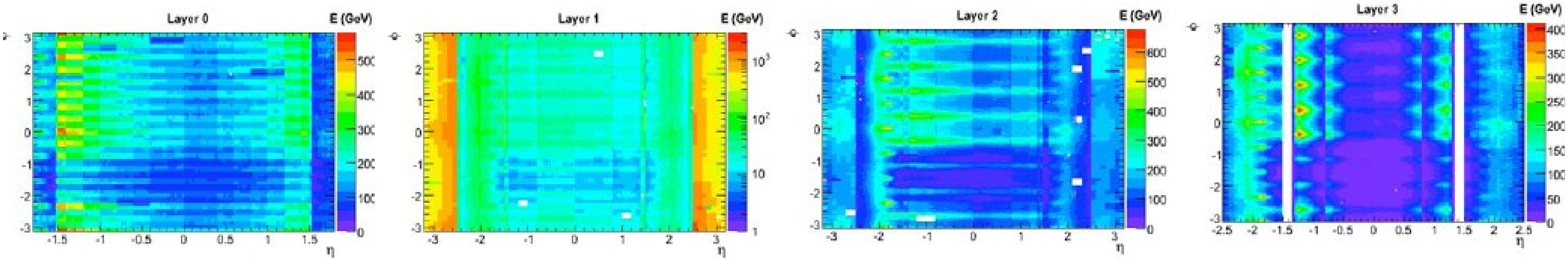
- High energy deposit (from beam splashes)
- Timing Alignment
- Ionization pulse shapes
- Calorimeter Uniformity
- Missing Transverse Energy
- Electrons from Ionisation in Cosmic Muons

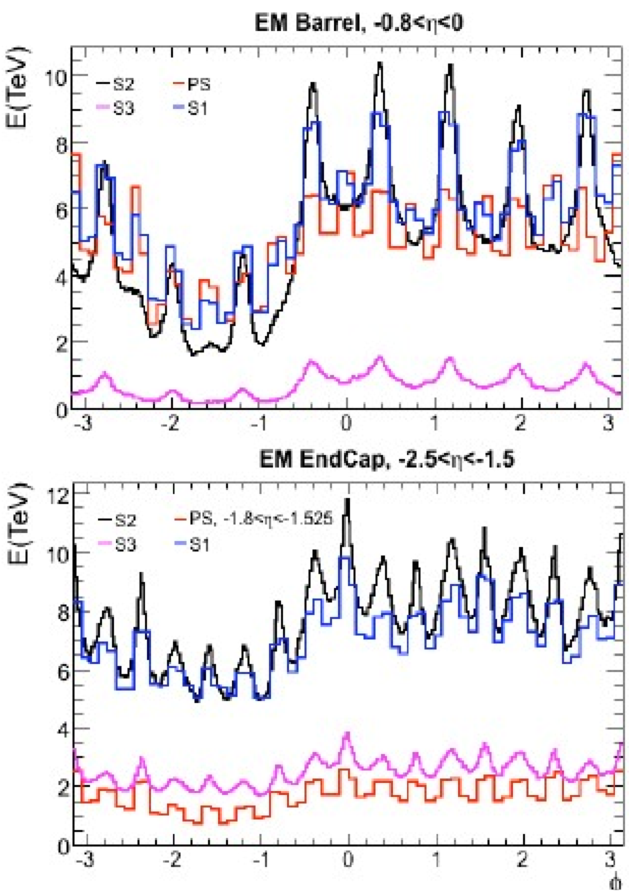
Current detector status:

- Dead channels: 0.017%
- Dead readout: 0.9% (0.7% of which recovered during shutdown)

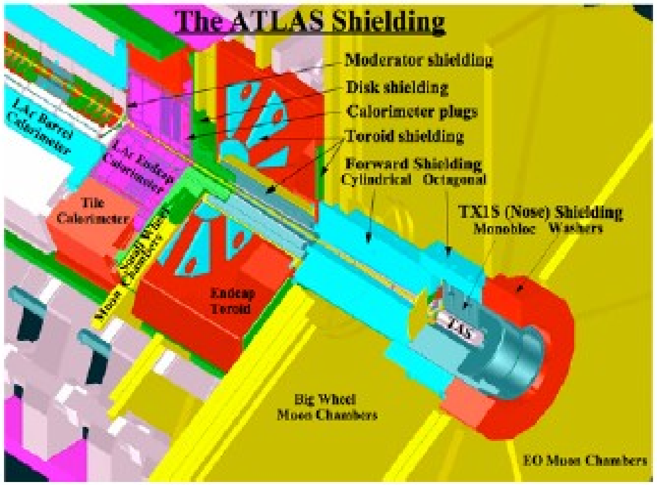
High Energy Deposits

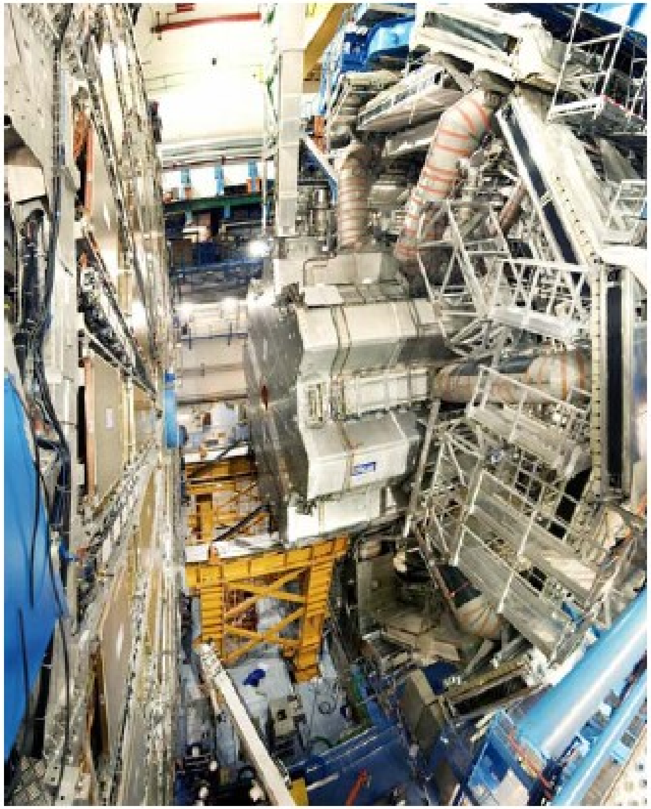
Eta-phi coverage per layer: exhibit 8-fold structures from endcap toroid:





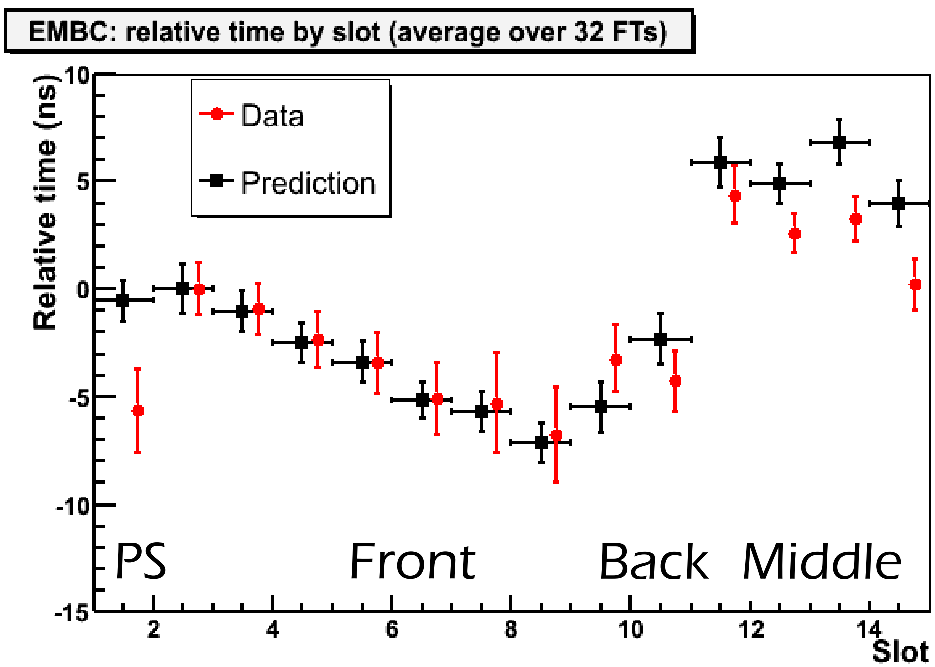
Energy vs ϕ plots display this more clearly. 16-fold structure also visible due to additional material.

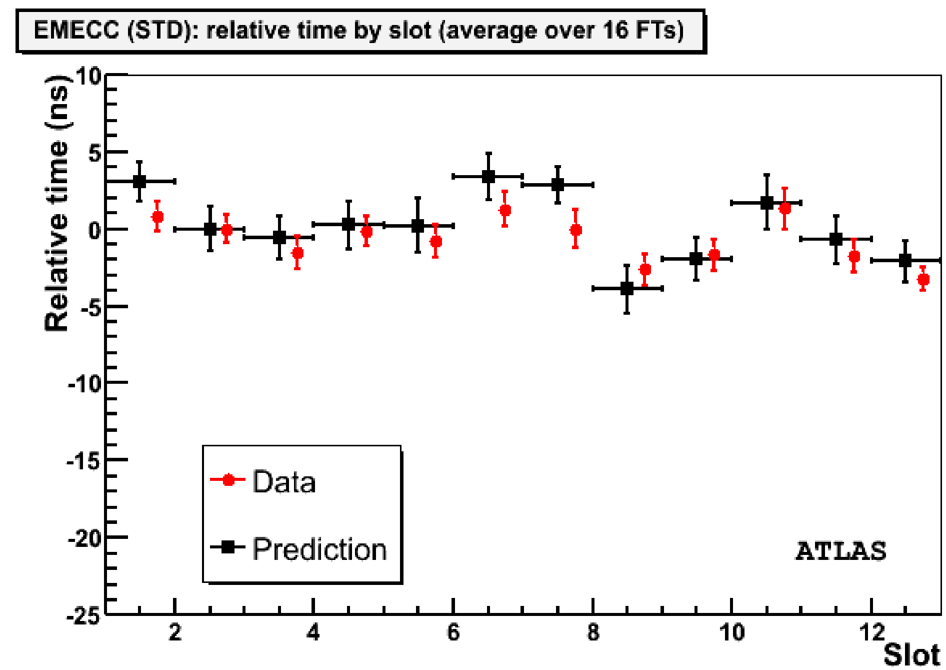




Timing Alignment

- Predicted (=calibration) versus measured (=physics) timing:
  - Measurement: time obtained from Optimal Filtering algorithm + time of flight correction
  - Prediction: calibration pulse + readout path
- Adjustable delay per Front End Board (FEB): obtain values for first collisions !

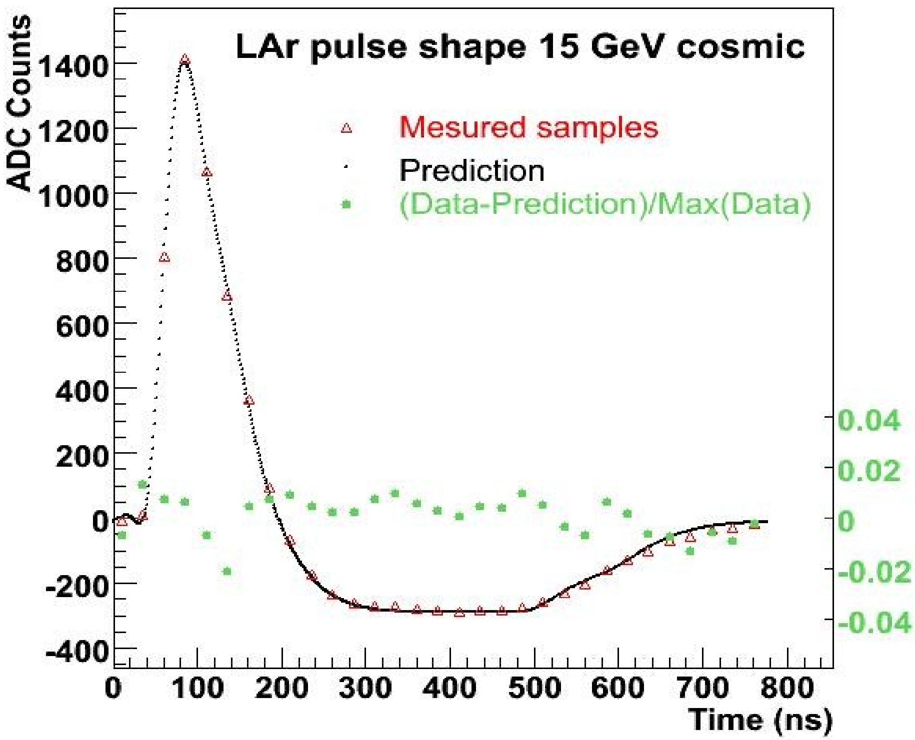




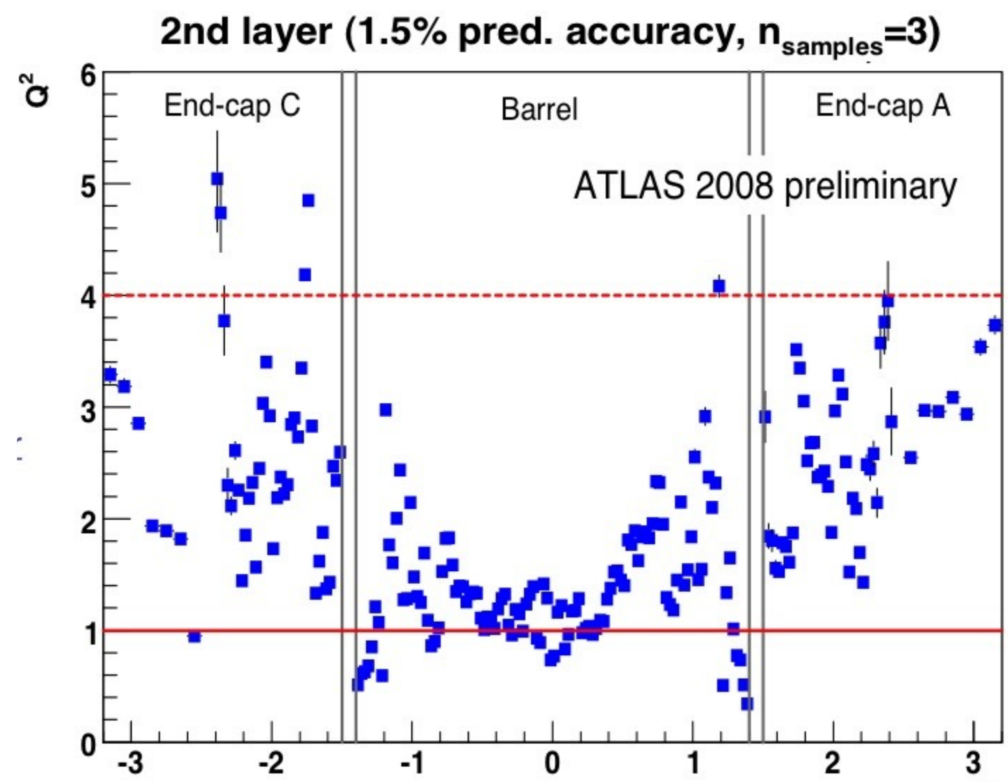
Agreement better than ± 2ns

Ionization Pulse Shape

Cosmic Muons



First Beams



- Recorded 32 samples from cosmics muons, to be compared with prediction:

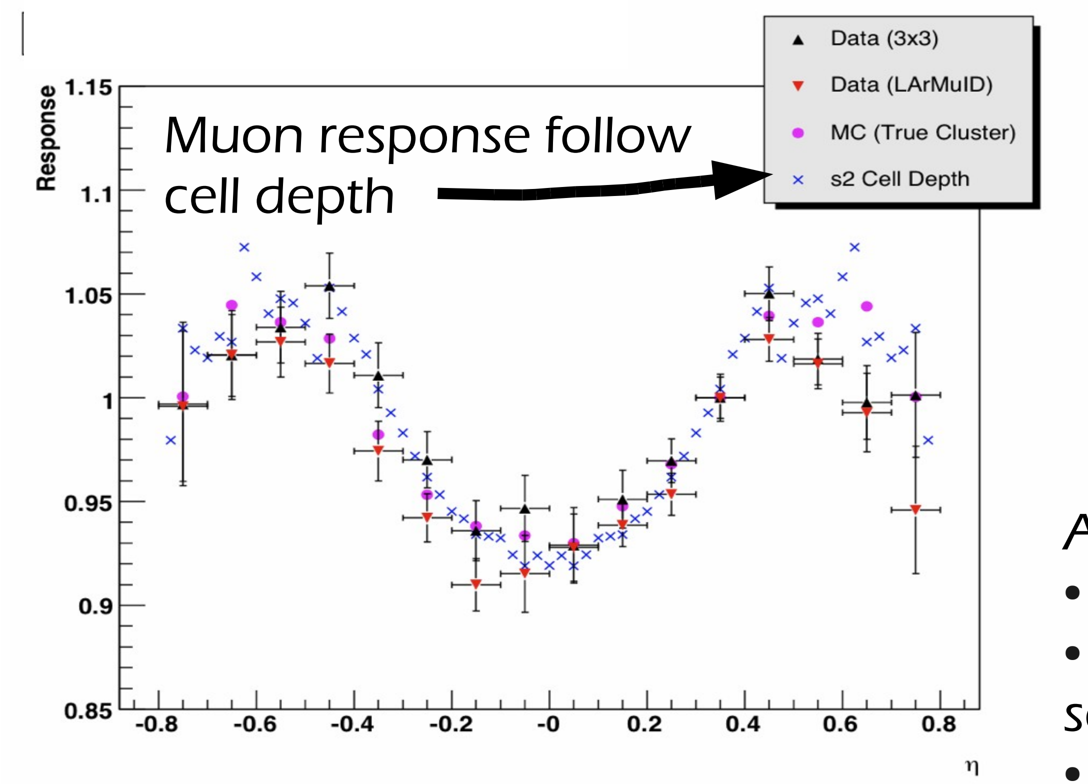
Good agreement (< 2%) is observed !

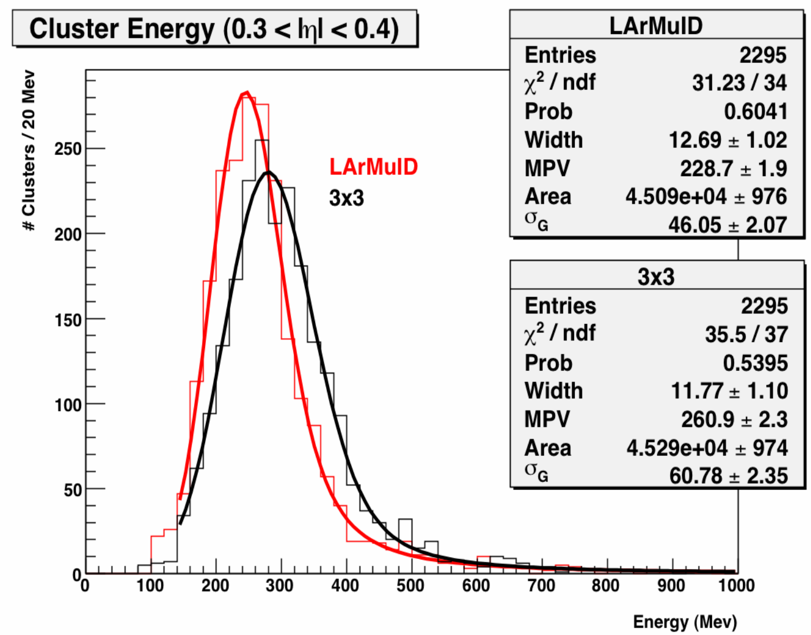
- Quality estimator $Q^2 = \frac{1}{nDoF} \sum_{i=1}^{n_{samples}} \frac{(A_i^{data} - A_i^{pred})^2}{\sigma_{noise}^2 + \sigma_{pred}^2}$
- Q^2=1, prediction accuracy = 1.5% (barrel)
  Q^2=4, prediction degraded by 2 (endcap)
- Contrib. to constant term: 0.2 – 0.5% in EMB

Cosmic Muons

Calorimeter Uniformity

- In-situ calorimeter uniformity was measured with cosmics in 2006/2007 for 9 modules (Inner Detector not available then)
- Systematic uncertainty on energy scale: 5%
- Agreement between MC and better than 2%:



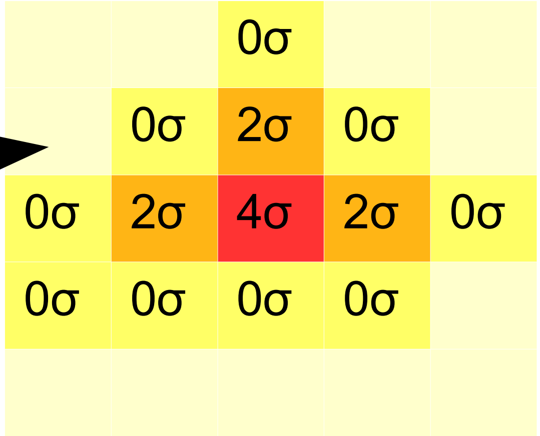


Analysis currently re-done with 2008 data:

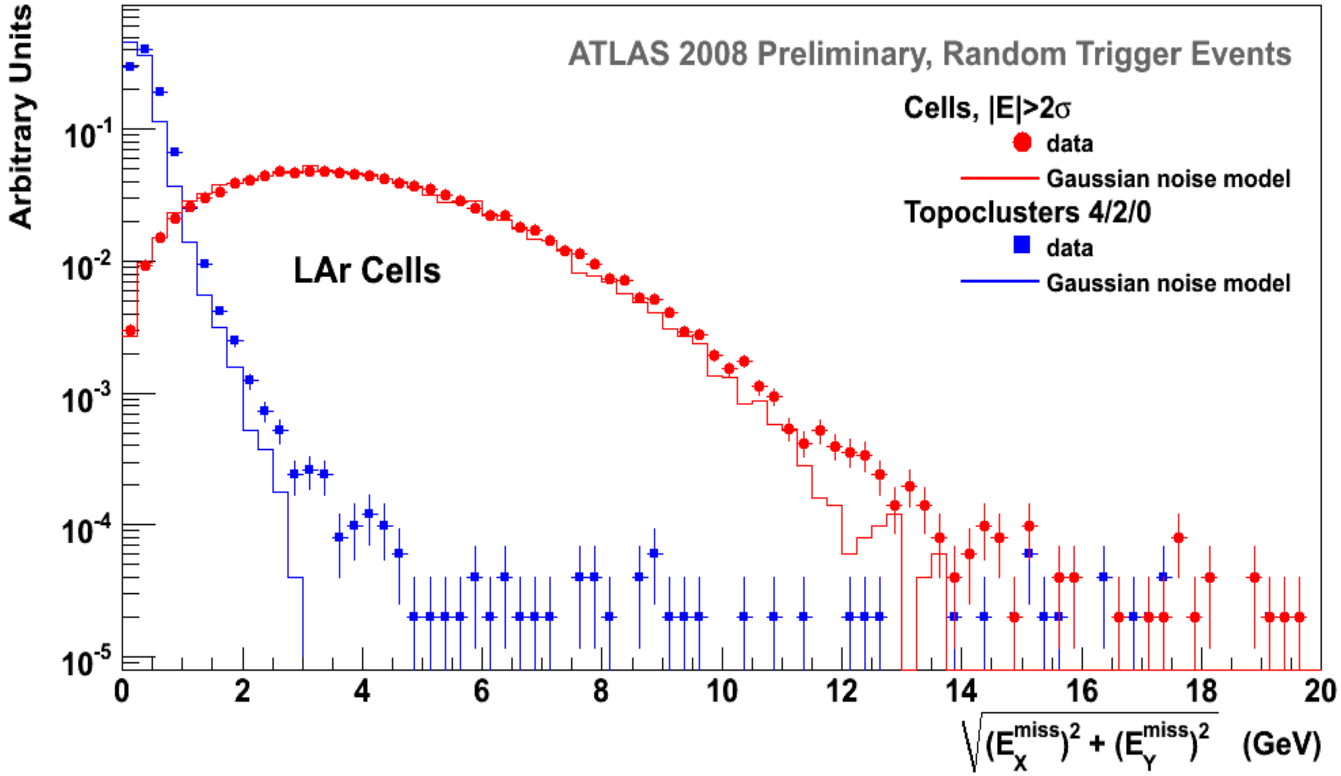
- All modules are readout
- Inner Detector included: better event selection using tracks
- Much more statistics

Missing Transverse Energy

- Two noise-suppression methods to compute Etmiss:
  - All cells with |E|>2 sigmas_noise
  - Topological clusters "4-2-0"



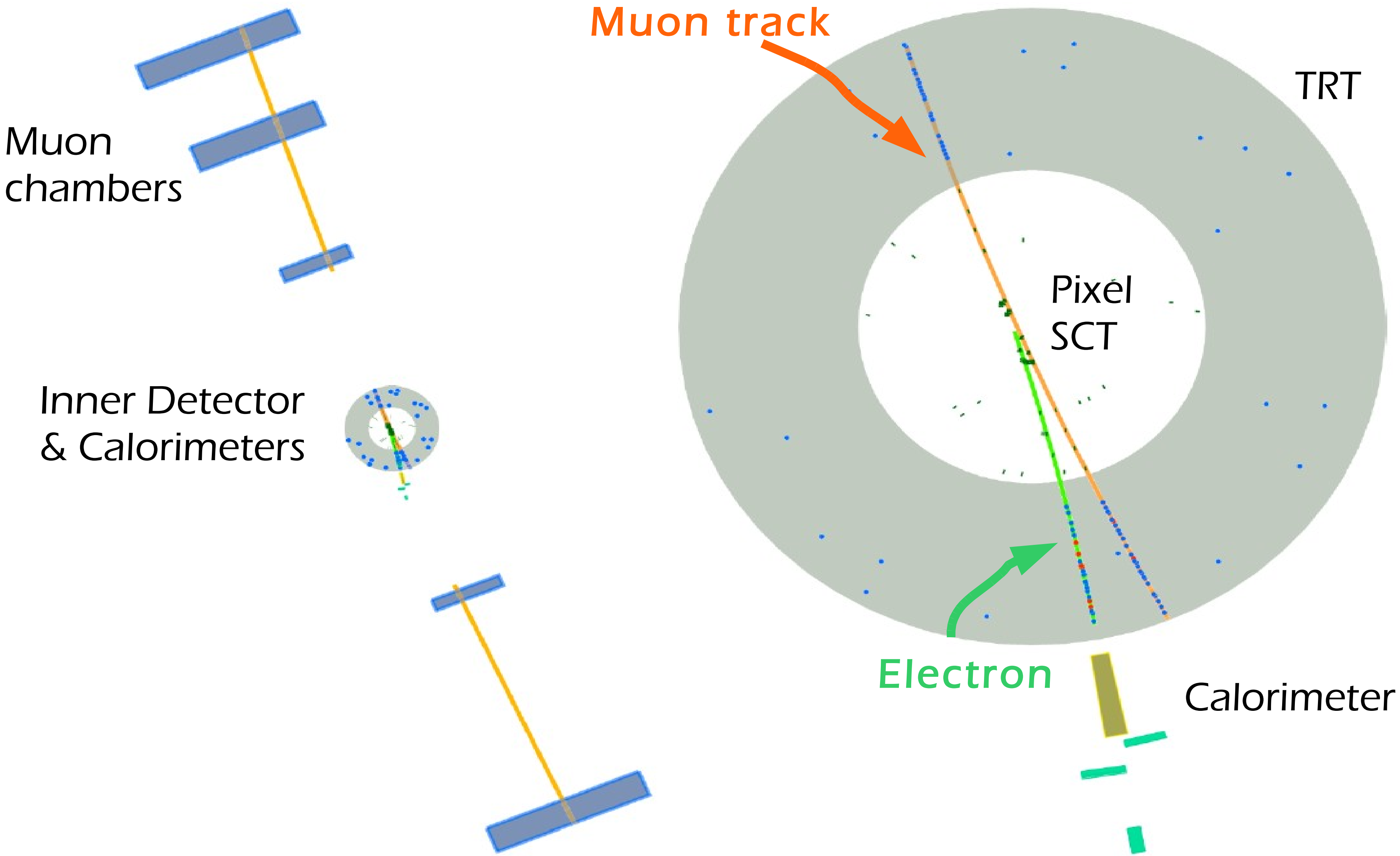
- Noisy cells are masked, noise is measured in random events:



Compared to toy model:

- good agreement except tails coming from coherent PS noise [understood and fixed]
- Good understanding of calorimeter noise !

Electrons from Ionisation in Cosmic Muons (1/3)

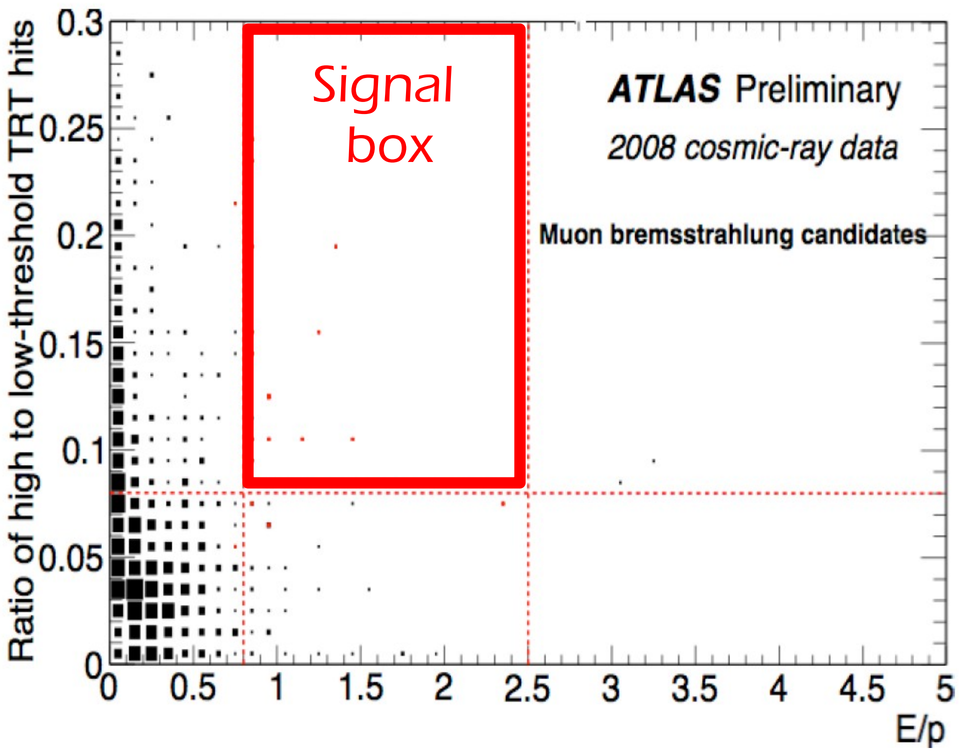


Cosmic Muons

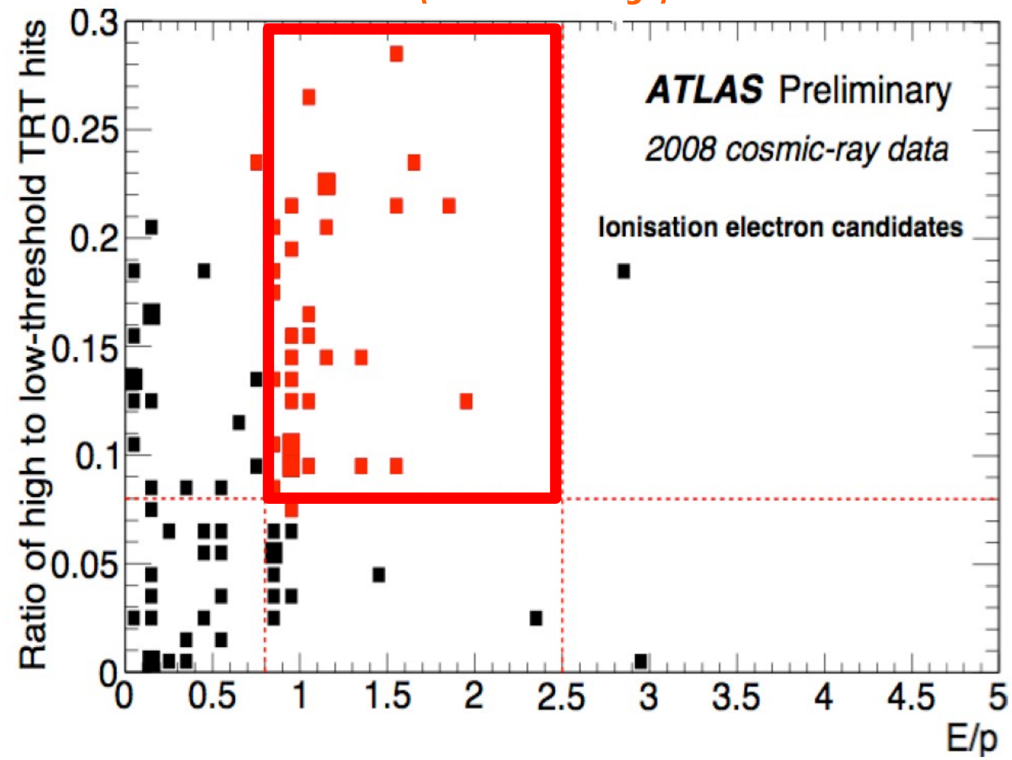
Electrons from Ionisation in Cosmic Muons [2/3]

- EM clusters (ET>3 GeV) + loose (downward) track match + electron-like shower shapes [note: track-based L2 trigger]
- Look at high-threshold TRT hits (large value = electron) vs E/p (=1 for electrons) for the two following populations:

1229 events with 1 track: Bremsstrahlung candidates



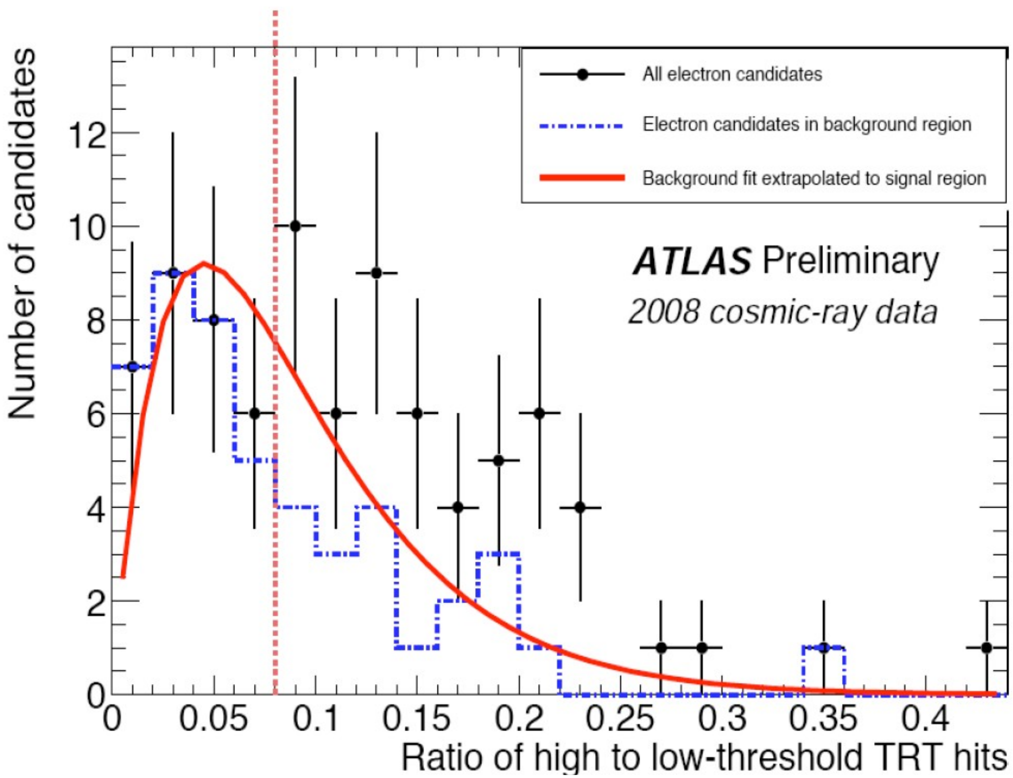
85 events with 2 tracks: Ionization (delta-ray) candidates

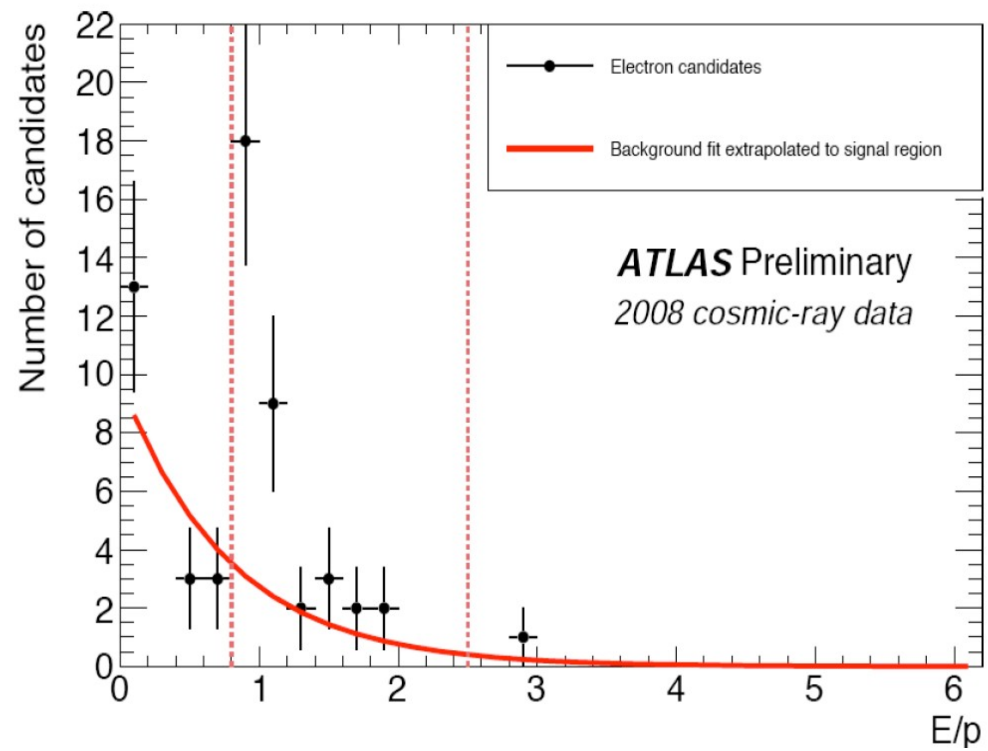


Cosmic Muons

Electrons from Ionisation in Cosmic Muons (3/3)

- 2D (Binned) Maximum Likelihood fit to extract electron signal in the ionization sample
- Background shape taken from the bremsstrahlung sample



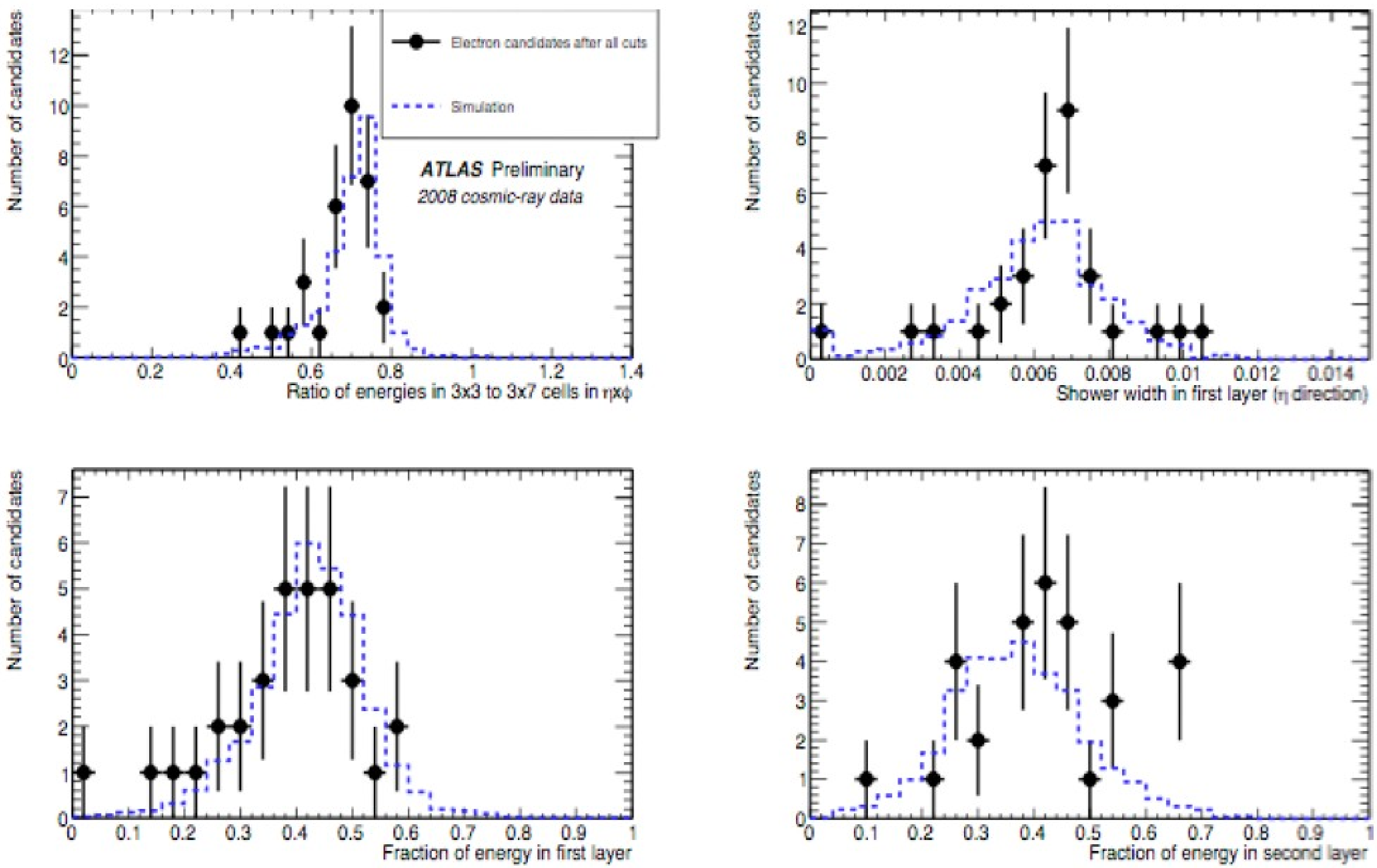


32 [negatively charged] electron candidates are found

Cosmic Muons

Electrons from Cosmics Delta-Rays (2/3)

Comparison of shower shapes between candidates and Monte Carlo simulation of 5 GeV projective electrons

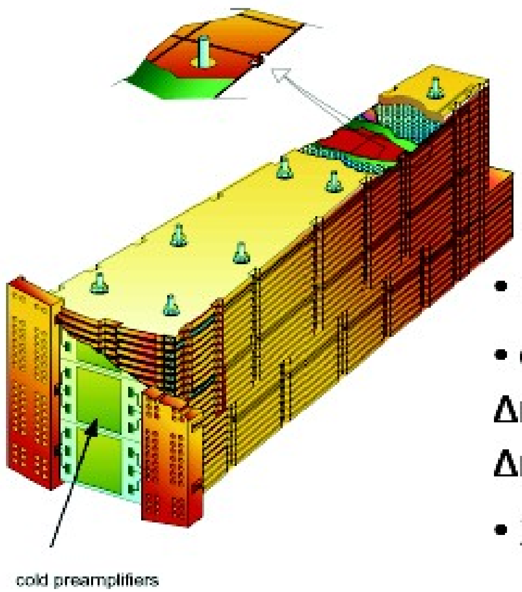


Conclusion

- In situ commissioning of LAr calorimeter ongoing since 4 years !
  - Initial set of calibration constants (incl. timing) is available for first collisions
  - Performances measured with cosmics and first beams, and are at the expected level
  - Even saw our first electrons and could study shower shapes
- Current shutdown allowed to fix residual problems (Low Voltage Power Supplies LVPS, FEB refurbishment, …)
- **Eagerly waiting for the "second beams" !**

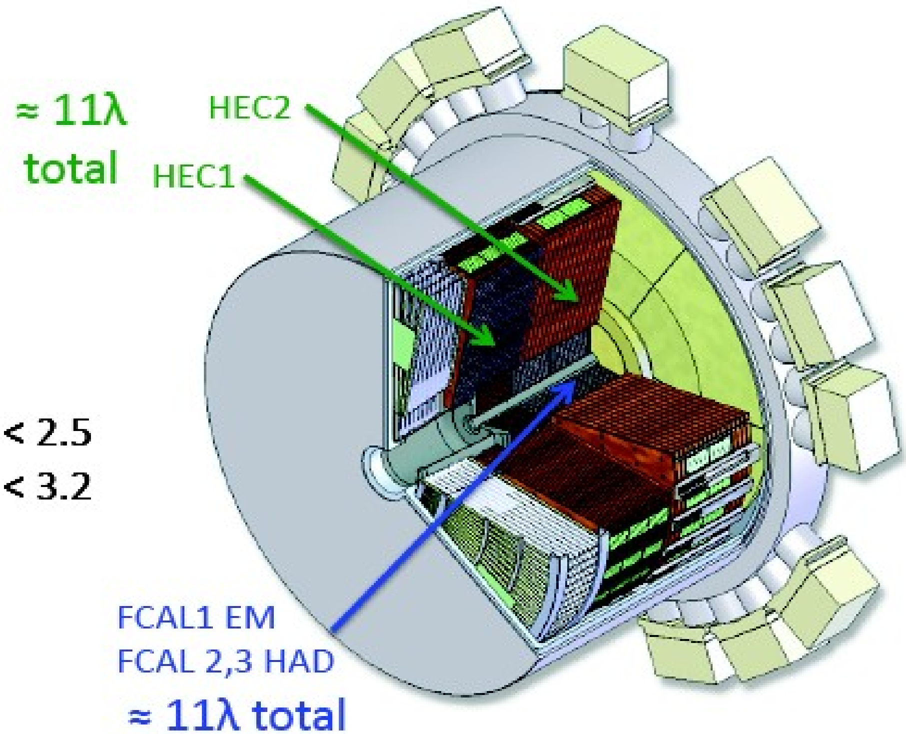
Backup Slides

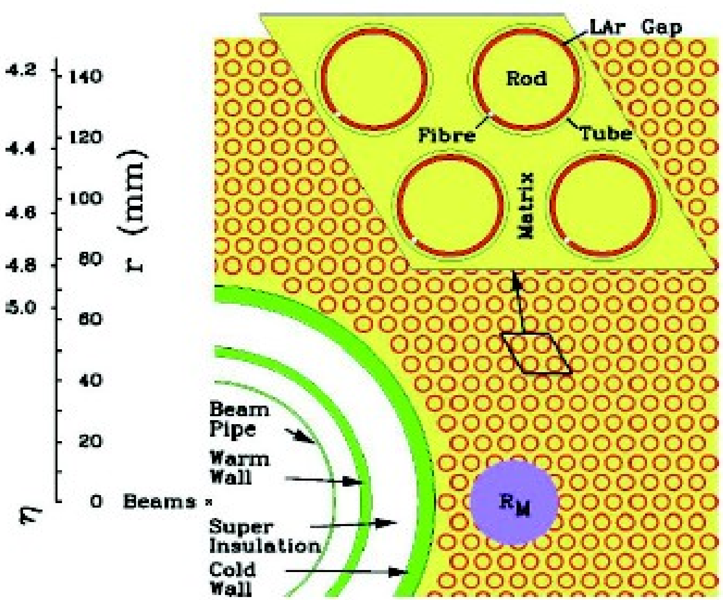
Properties of the Hadronic End-Cap (HEC) and Forward Calorimeters



HEC

- Flat copper plate design
- Granularity:
$\Delta\eta\times\Delta\phi = 0.1 \times 0.1$ for $1.5 < |\eta| < 2.5$
$\Delta\eta\times\Delta\phi = 0.2 \times 0.2$ for $2.5 < |\eta| < 3.2$
- 2816 channels per end-cap





FCAL

- Plates (copper EM, tungsten HAD) have holes drilled longitudinally into which electrode is placed.
- Electrode consists of copper or tungsten rod and tube, separated by radiation hard plastic fiber to produce gap.
- Granularity: $\Delta\eta\times\Delta\phi \cong 0.2 \times 0.2$
- 1762 channels per end-cap

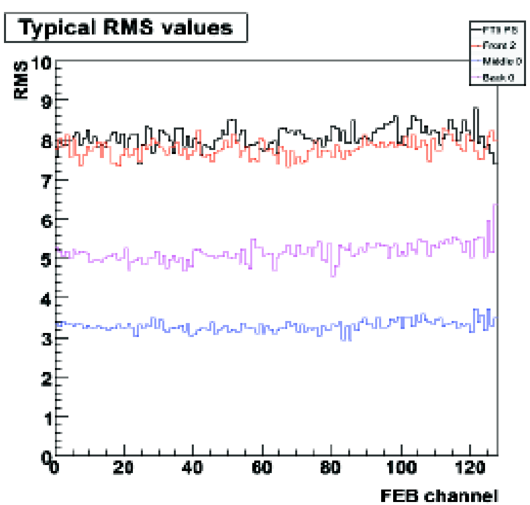
6

Calibration Constants

pedestals and noise

FEB are read with no input signal to obtain:

- Pedestal
- Noise
- Noise autocorrelation (OFC computation)

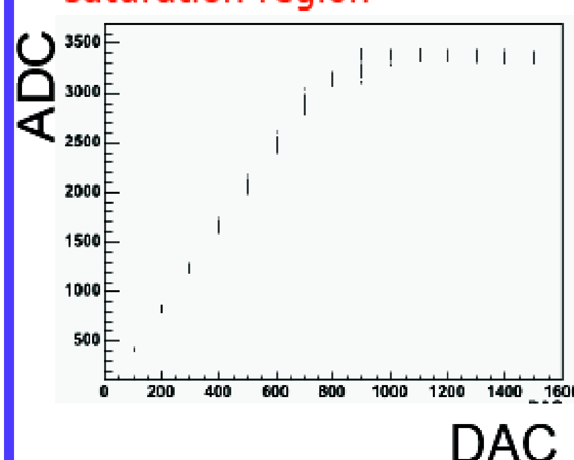


PEDESTAL

ADC → MeV conversion

$$F = \text{ADC2DAC} \times \text{DAC2}\mu\text{A} \times \mu\text{A2MeV}$$

- Scan input current (DAC)
- Fit DAC vs ADC curve with a first (second) order polynomial, outside of saturation region

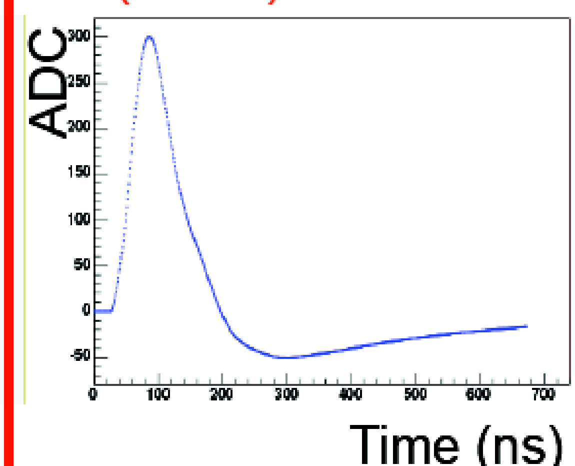


RAMP

response to current pulse

All cells are pulsed with a known current signal:

- A delay between calibration pulses and DAQ is introduced
- The full calibration curve is reconstructed (Δt=1ns)



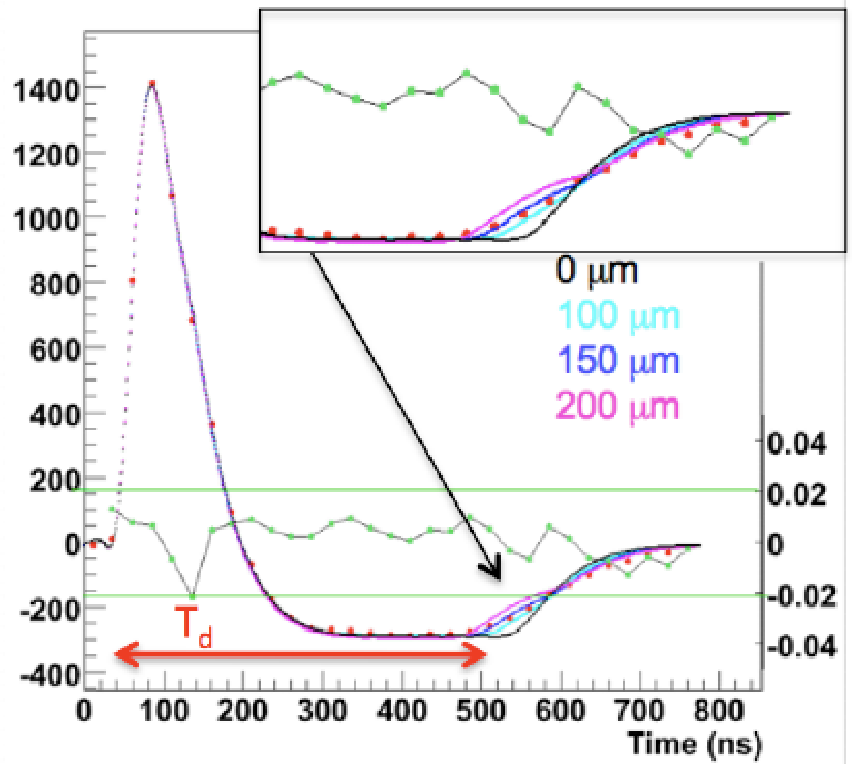
DELAY

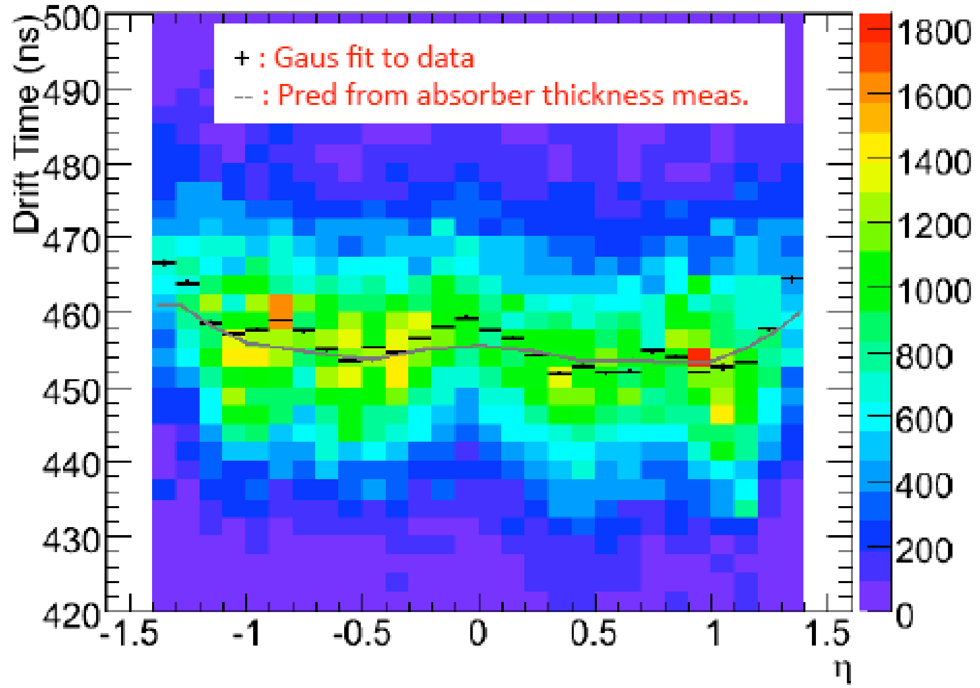
Quality of Physics Pulse Shape Determination (2)

• The drift time is an important parameter in the physics pulse shape prediction.

• Also sensitive to the purity of the LAr.

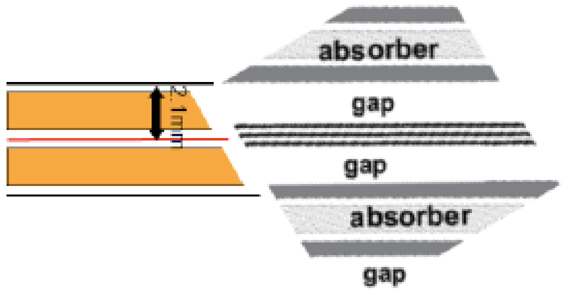
• Detailed drift time measurements have been made with ~350k EM barrel cosmic pulses with E > 1 GeV taken in 32 sample read out mode.





• Drift time varies with η as a result of observed ~100 µm shifts of electrode within LAr gap.

• Study has concluded the contribution of the gap variation to the response non–uniformity is not larger than 0.3%.



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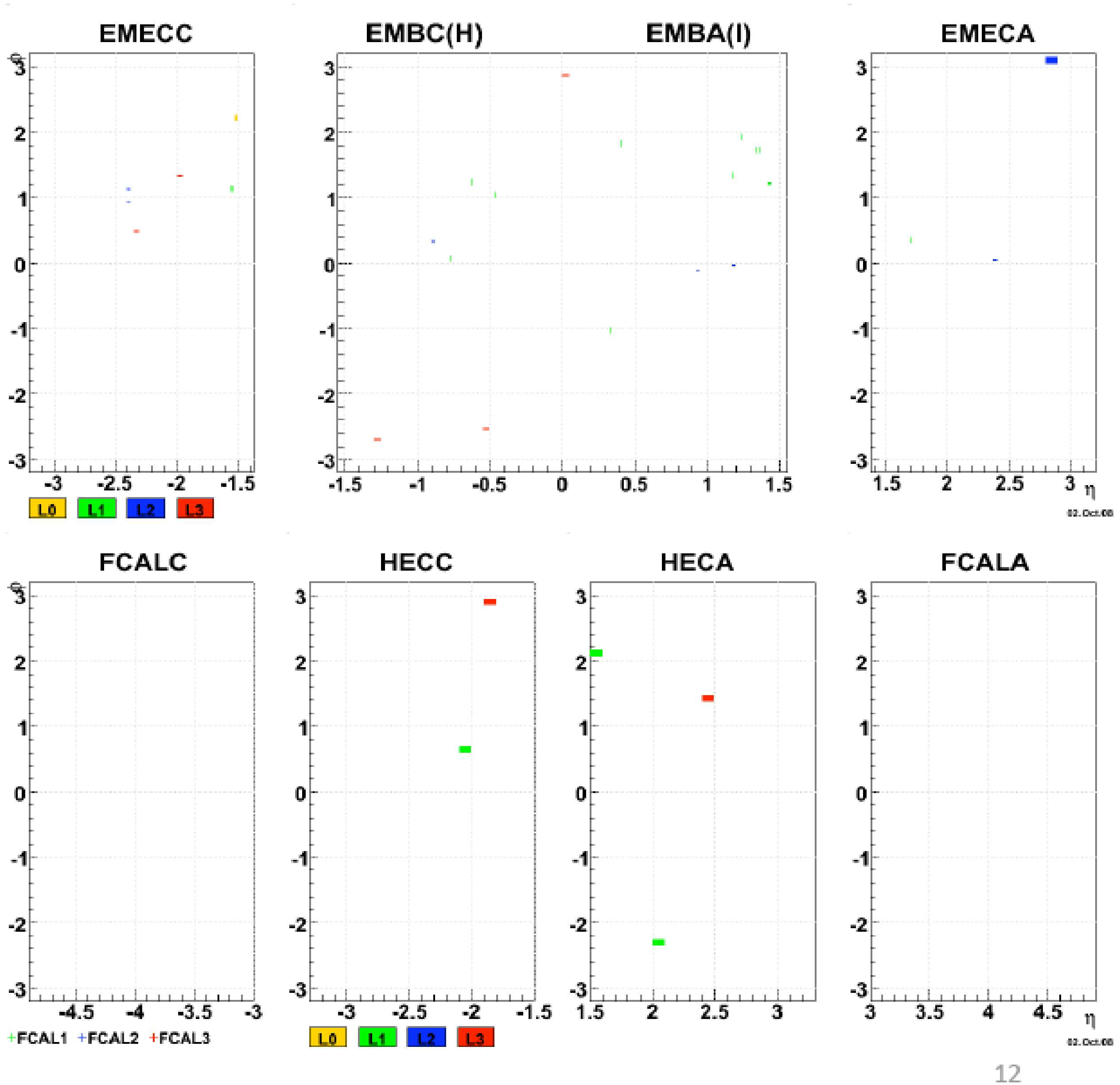
Survey of Dead / Problematic Channels (1)

Dead Channels For Physics

- Status in autumn 2008
- η-ϕ map of dead channels within detector for which a signal can not be extracted or is not reliable for physics use.
- No repair foreseen for this class of dead channels
- Amount to < 0.02% of total



Survey of Dead / Problematic Channels (2)

Dead Channels In Readout

• Channels that were not being read out in autumn 2008.

• One class are channels are from FEBs for which the optical connection has failed.

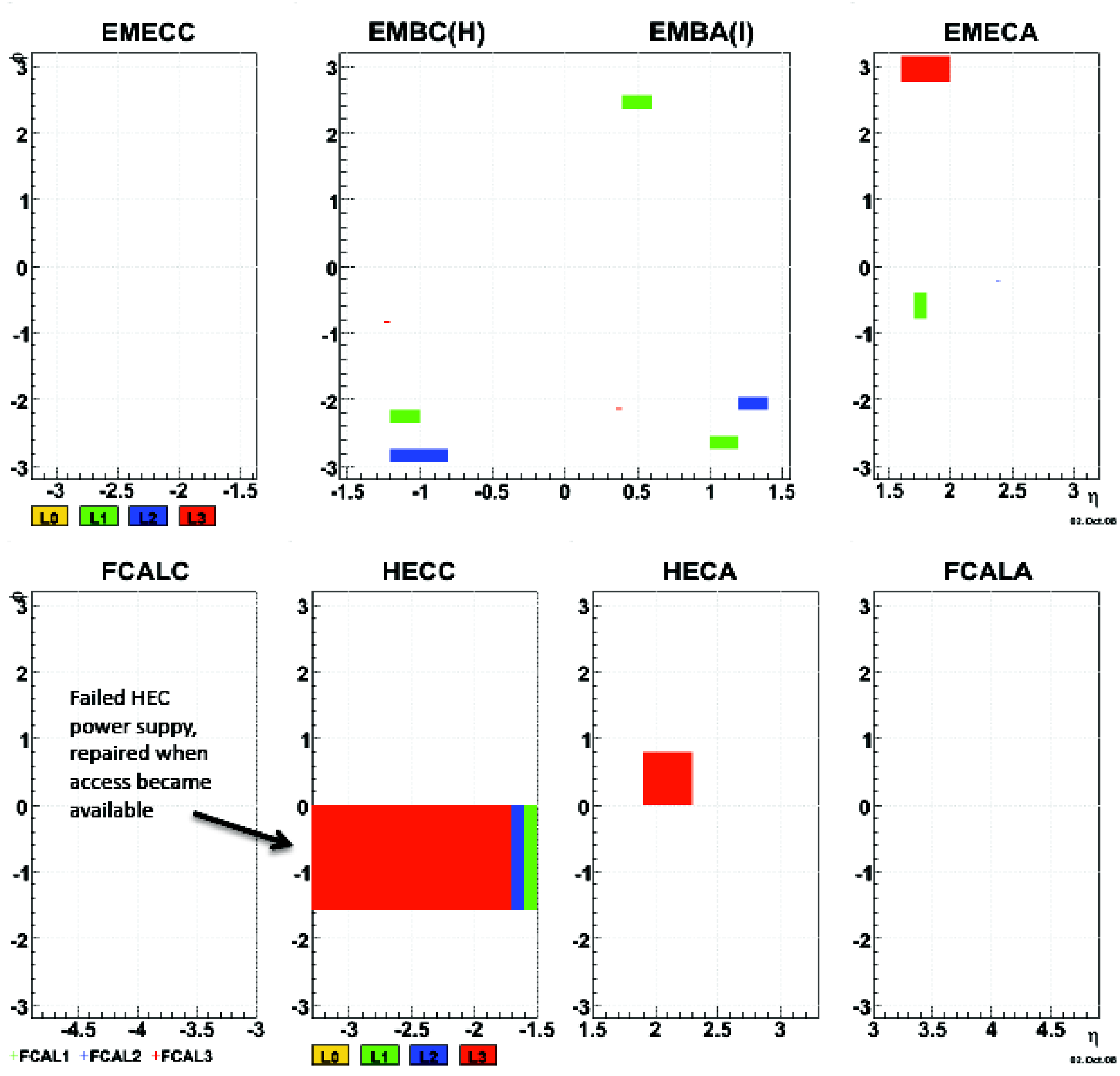
• A second class are channels from FEBs which can not be supplied low voltage as a result of a failed power supply.

• All of these problematic FEBs and power supplies have since been replaced.

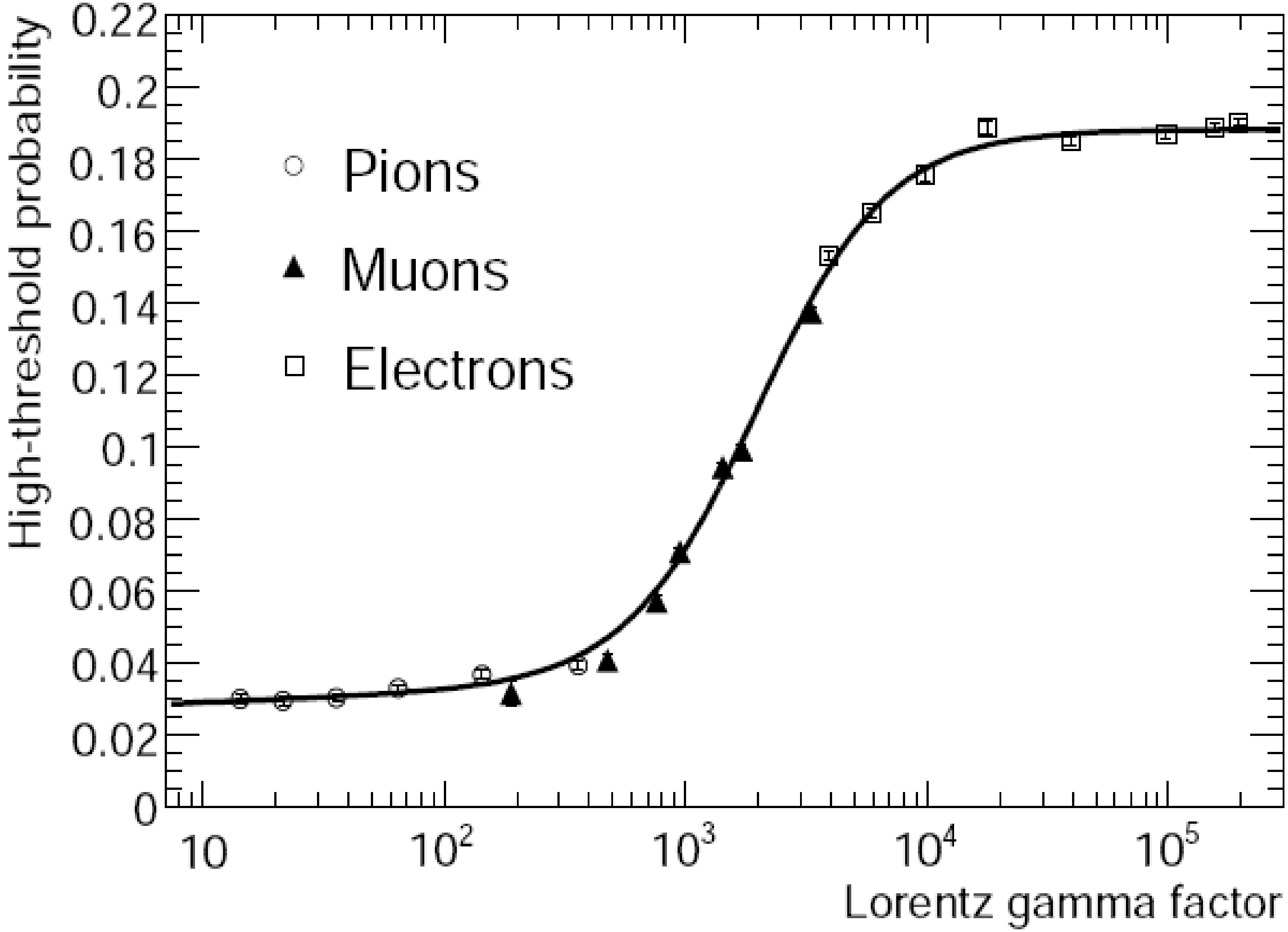
Reduced HV Channels

• 6% channels operating at below nominal HV (see back-up for map).

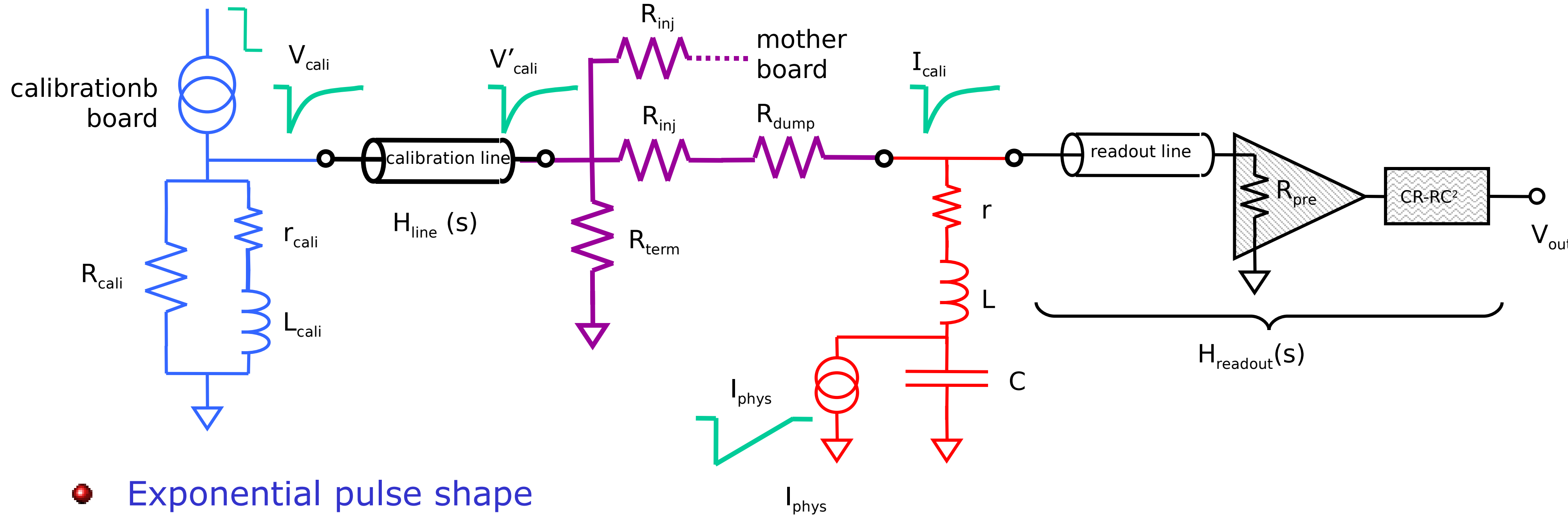
• Channels are good for physics. Correction factor applied, slight degradation of signal to noise.



Transition Radiation Tracker
High Threshold Probability



Pulse Shape Prediction



- Exponential pulse shape depends on CB elements

$$\begin{cases} f_{\text{step}} = \left(\dfrac{r_{\text{cali}}}{r_{\text{cali}}+\frac{R_{\text{cali}}}{2}}\right) \\ \tau_{\text{cali}} = \left(\dfrac{L_{\text{cali}}}{r_{\text{cali}}+\frac{R_{\text{cali}}}{2}}\right) \end{cases}$$

- R_{term} is such that $1/R_{term} + n/(R_{inj}+R_{dump}) = 1/R_{cali}$
- The injected calibration current is $I_{cali} = V'_{cali}/(R_{inj}+R_{dump})$

- The ionization pulse is (currently) predicted as:

$$I_{\text{phys}}(s) = I_{\text{cali}}(s) \times \left(\frac{(1+s\tau_{\text{cali}})(sT_d - 1 + e^{-sT_d})}{sT_d(f_{\text{step}} + s\tau_{\text{cali}})}\right) \times \left(\frac{1}{1+srC+s^2LC}\right)$$