Electronic Calibration of the ATLAS LAr Calorimeter and commissioning with Cosmic Muon Signals

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CALOR'08, LHC session

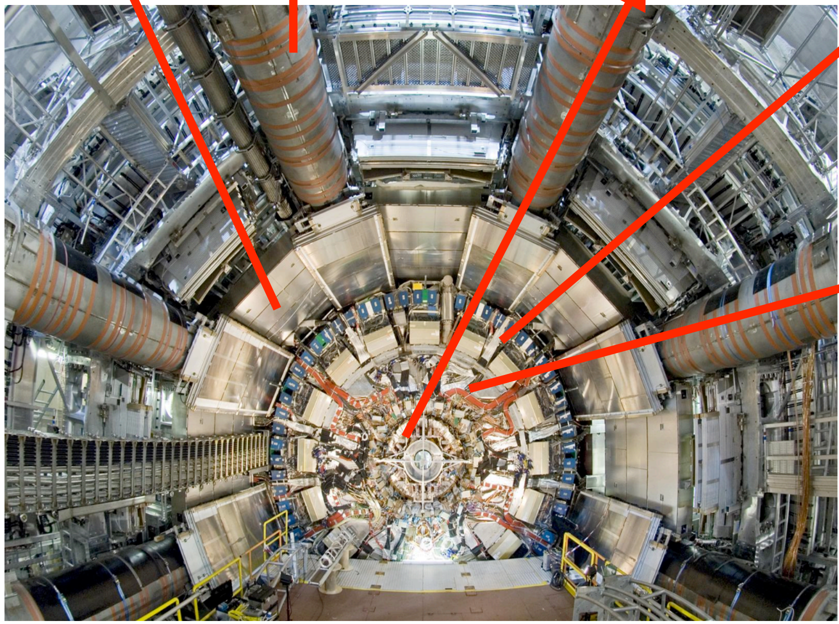
ATLAS Status in the cavern

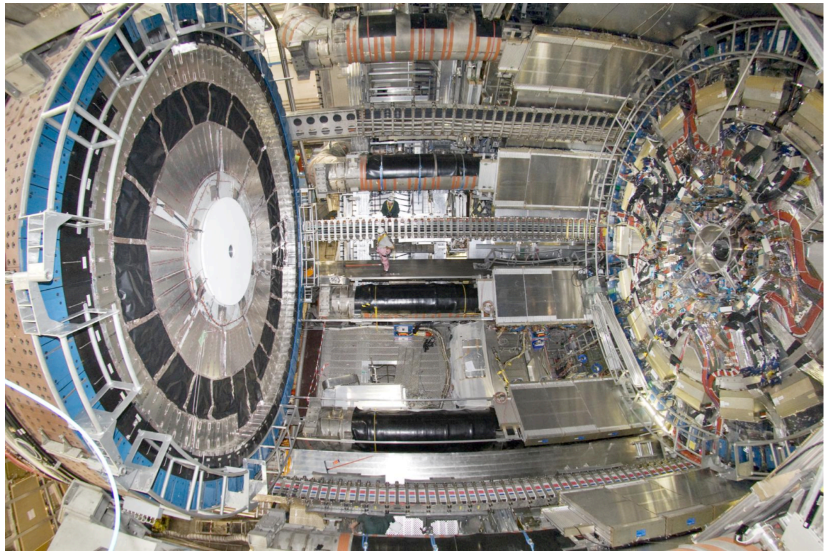
Muon spectrometer (2006-2008)

Toroid magnets (2004-2005)

Inner detector (2007-2008)

Tile Calorimeter (2005-2006)





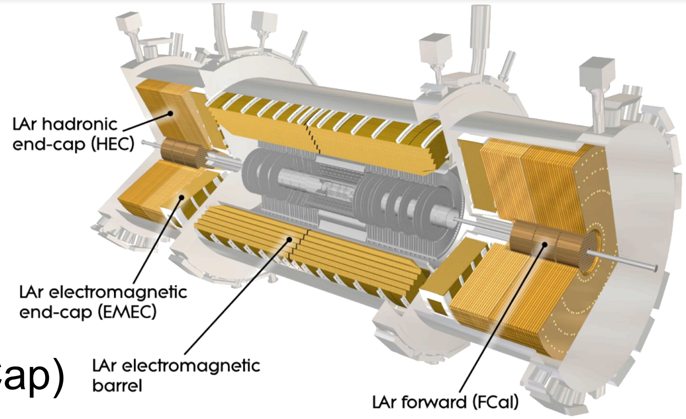
Full LAr Calorimeter one of the first in the ATLAS cavern (2005-2006)

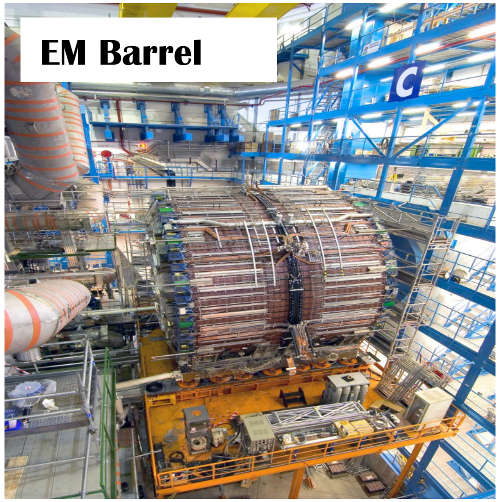
⇨ ATLAS is closed in the final position and ready to take data

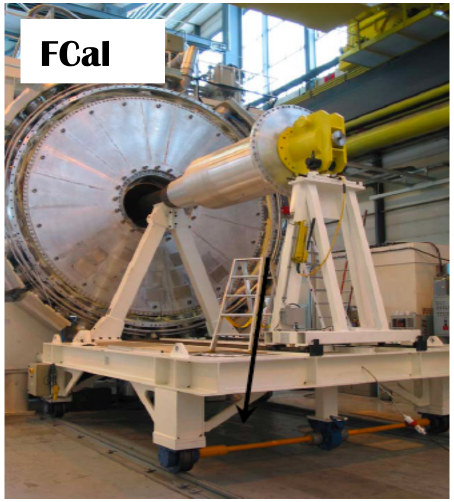
⇨ LAr Calorimeter was ready in situ for commissioning in summer 2006

Liquid Argon Calorimeter

- See Henric Wilkens' presentation
- ATLAS LAr Calorimeter is a sampling calorimeter:
  - ✓ Good pseudorapidity coverage ($|\eta| < 4.9$)
    - → LAr Electromagnetic Calorimeter (EMC), $|\eta|<3.2$
    - → Hadronic End-Caps (HEC), $1.5 <|\eta|<3.2$ (2 wheels per End-Cap)
    - → Forward Calorimeter (FCal), $3.2< |\eta| < 4.9$ (3 wheels per End-Cap)



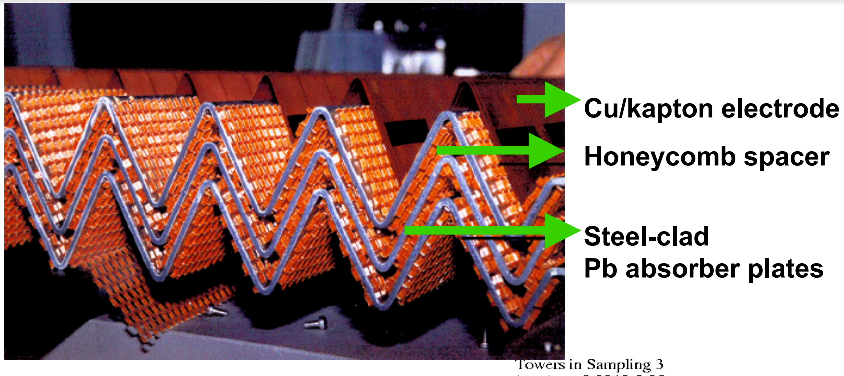




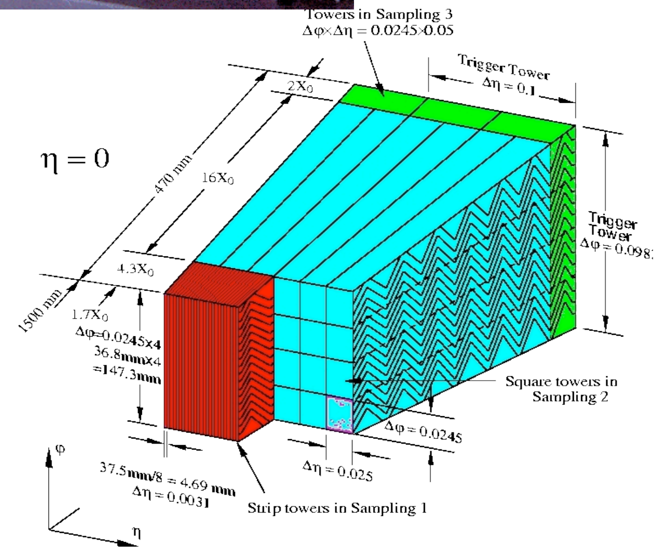
⇨ **High granularity ~190k readout channels in total (90 % is EM calorimeter)**

Liquid Argon electromagnetic Calorimeter

- **Full azimuthal coverage due to accordion geometry**
- **Longitudinal segmentation: three compartments**
  - presampler (S0)
  - front (S1) (~ 4 X_0)
  - middle (S2) (~ 16 X_0)
  - back (S3) (2-12 X_0)



- **Transversal segmentation:**
  - **η direction,** S1 (0.025/8-0.025), S2 (0.025), S3 (0.05)
    - → One Barrel ($|\eta|$ < 1.475), Two End-Caps (1.375 < $|\eta|$ < 3.2)
  - **ϕ direction,** S1 (0.1), S2 (0.025), S3 (0.025)

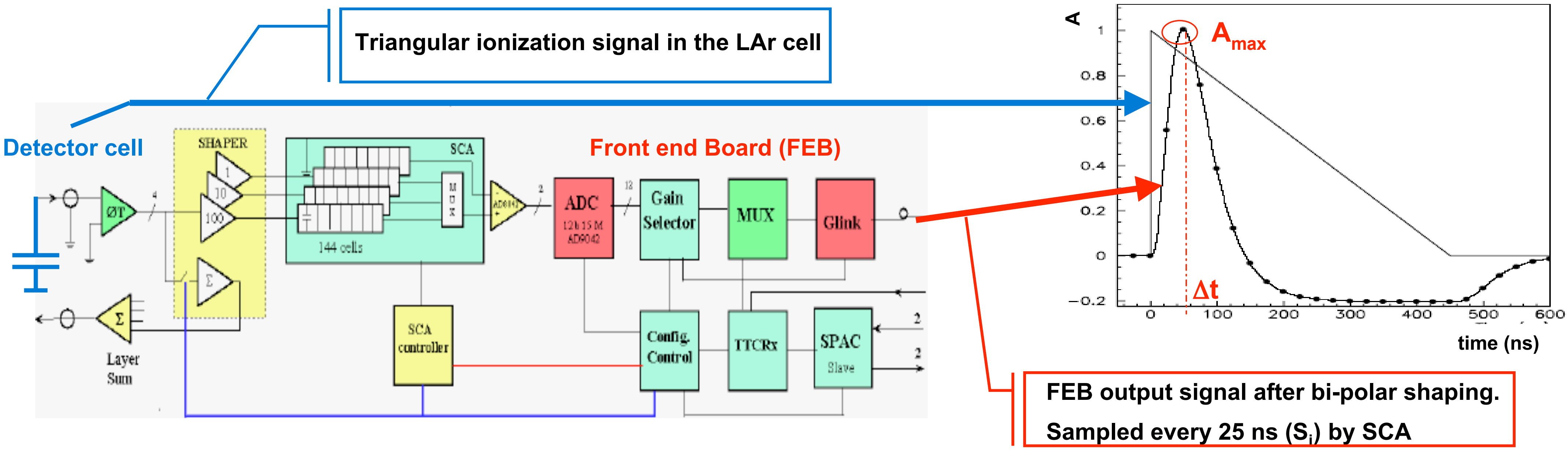


⇨ **~170k channels in EM calorimeter with very demanding requirements**

⇨ **Test beam check EM performance (on few % of EM coverage)**

⇨ **Commissioning needed for good performance at LHC start**

Physics signal for the EM Calorimeter



- The Optimal Filtering (OF): signal maximum amplitude (A_{max}), temporal position (Δt)

$$A_{max} = \sum_{i=1}^{n} a_i S_i$$

$$\Delta t = \frac{\sum_{i=1}^{n} b_i S_i}{A_{max}}$$

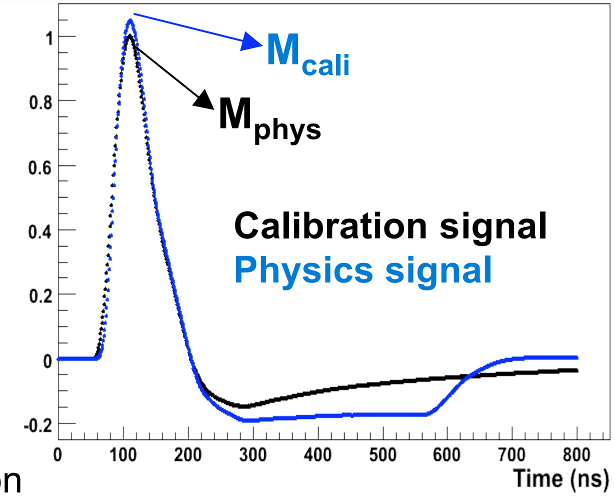
OF coefficients (OFC), $\mathbf{a_i}$ and $\mathbf{b_i}$, are calculated from the signal shape with the condition to minimize the noise (including pile-up)

Default value for n in physics mode is 5 samples

⇨ **Need to know signal shape and the autocorrelation matrix for every cell**

Calibration chain

- **Monitoring ~170k cells requires:**
  - ✓ **A dedicated calibration system**
    - → Send "physics like" signal and use the physics read out
  - ✓ **Regular calibration runs like in LHC running period:**
    - → **"Pedestal" (P):** noise and autocorrelation matrix for OFC computation
    - → **"Ramp" (g):** compute electronic gain/cell
    - → **"Delay"**, cell response to a **calibration signal shape ➡ physics signal shape ➡ OFC**
      - → A calibration board injects a signal similar to the ionization signal in steps of ns for each cell



- **Energy per cell is calculated as:**

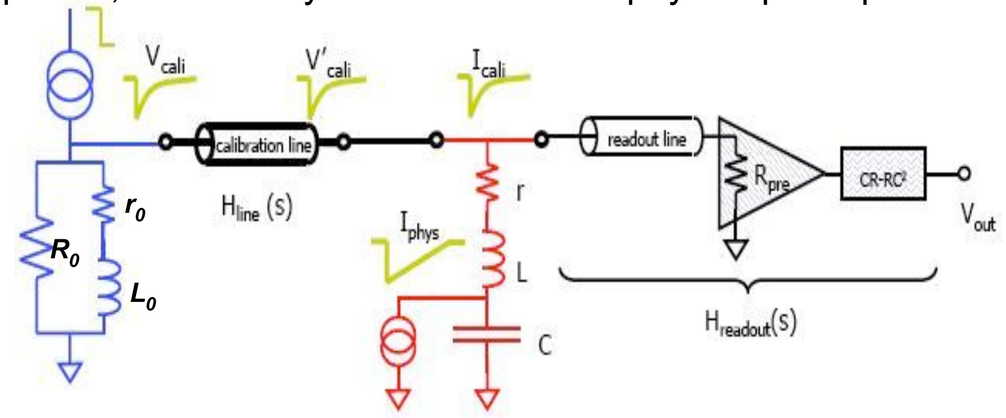
$$E(GeV) = f_{DAC\to\mu A} \times f_{\mu A\to GeV} \times \frac{M_{cali}}{M_{phys}} \times g_{ADC\to DAC} \sum_{i=1}^{n} a_i (S_i - P)$$

Reconstruction in EM Calorimeter

RTM Method

"Factorization of the readout response"

The readout response of each cell is probed by the calibration pulses, and directly transferred to the physics pulse prediction



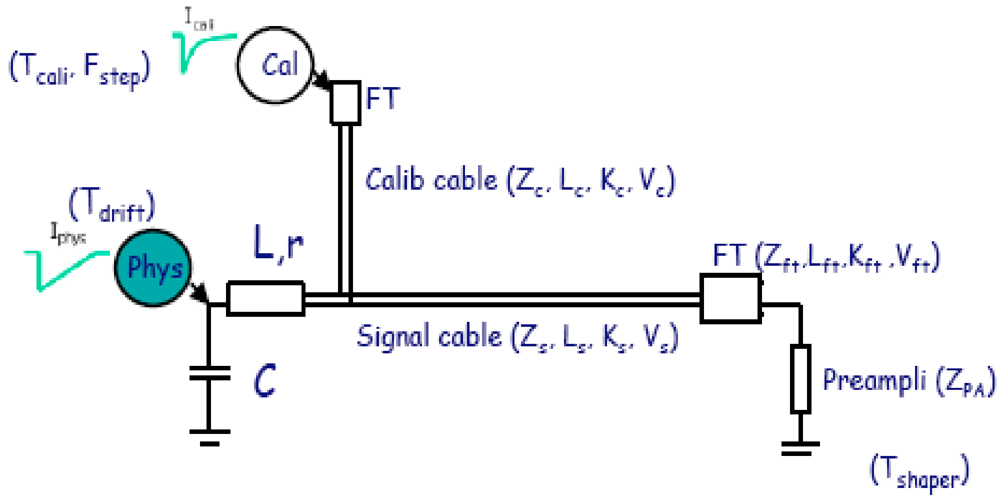
✓ The cell and pulse parameters (f_{step},T_{cali}, rC, LC) are completely obtained from the calibration pulses

✓ The only additional parameter required it T_{drift} (now from calculation, can be refined when enough data is collected)

→ This method was successfully used in 2004 Test beam and is the default in the commissioning

FPP Method

"Analytical model of the readout response"



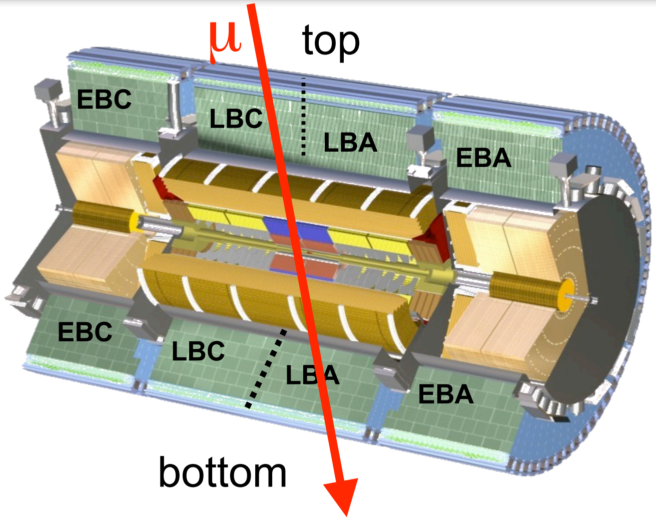
✓ Uses measured parameters where possible

✓ A few parameters (T_{shaper}, Z_s) are left free to vary in order to match the measured calibration pulse response thus absorbing residual effects absent in the model

→ Currently, available only in the barrel

Commissioning with cosmic muon signals

- Cosmics are the first physics data before LHC start



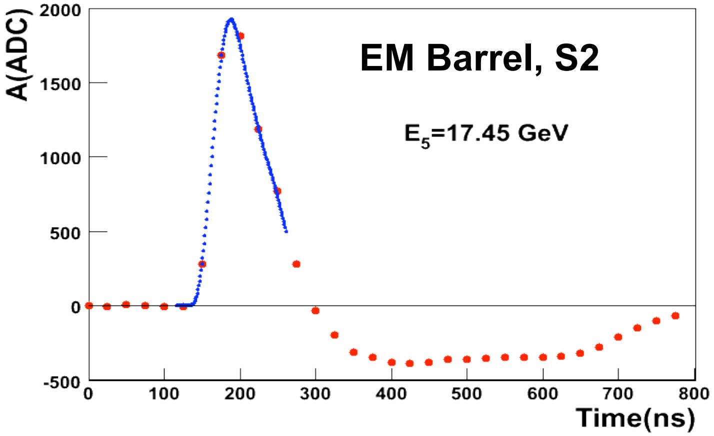
- Trigger configuration for cosmic muons:
  - ✓ Dedicated trigger with Tile towers, $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$
  - ✓ Recently, other triggers (e.g. LVL1 Calo)
- ★ Special data taking weeks since 2006, ~ few 10^6 events

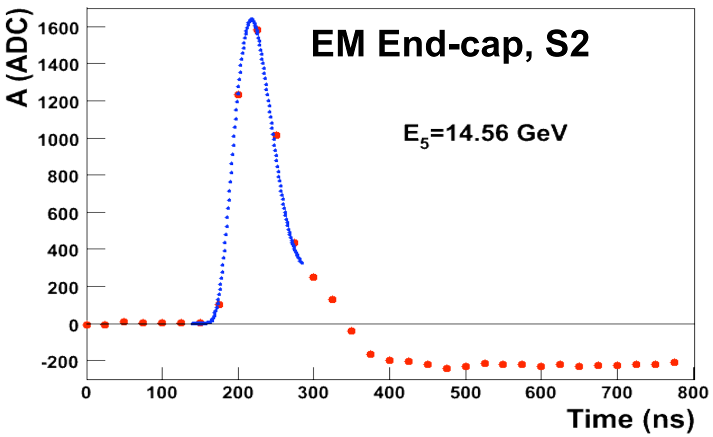
  (results presented with Tile Trigger)

- What can we do with cosmic muons?
  1. Cosmic muons ➡ bremsstrahlung photons ➡ EM shower
     - ✓ Select only high energy deposit, E>500 MeV (1% of the statistic)
       - ✓ Check the quality of the predicted signal reconstruction
  2. Cosmic muons as Minimum Ionizing Particles (MIP)
     - ✓ Small and non projective signal requires special attention
       - ✓ Check the EM performance (uniformity and timing)

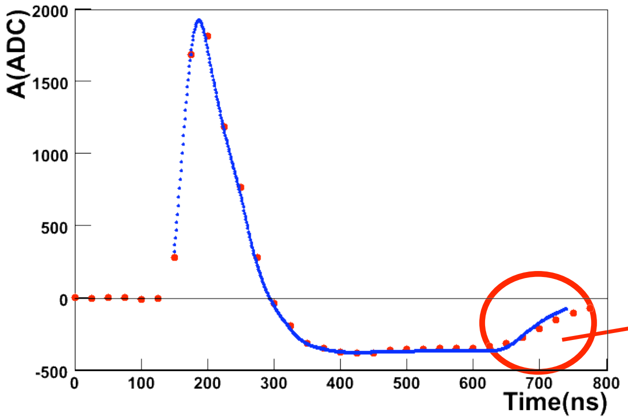
Studies with high energy muons (1)

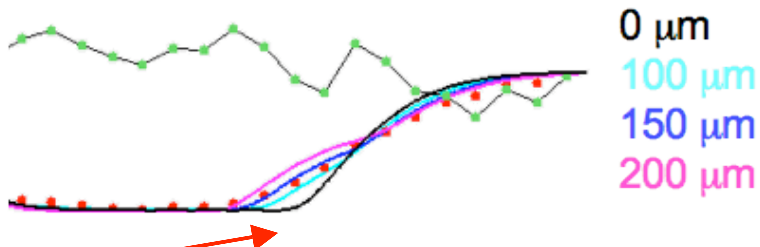
- Prediction of physics pulses using RTM method (default for commissioning)
  - ✓ Good agreement for first samples for $|\eta|<3.2$





  - ✓ Good description of the undershoot but its end (negligible effect on the peak energy ➡ in LHC 5 samples will be used)





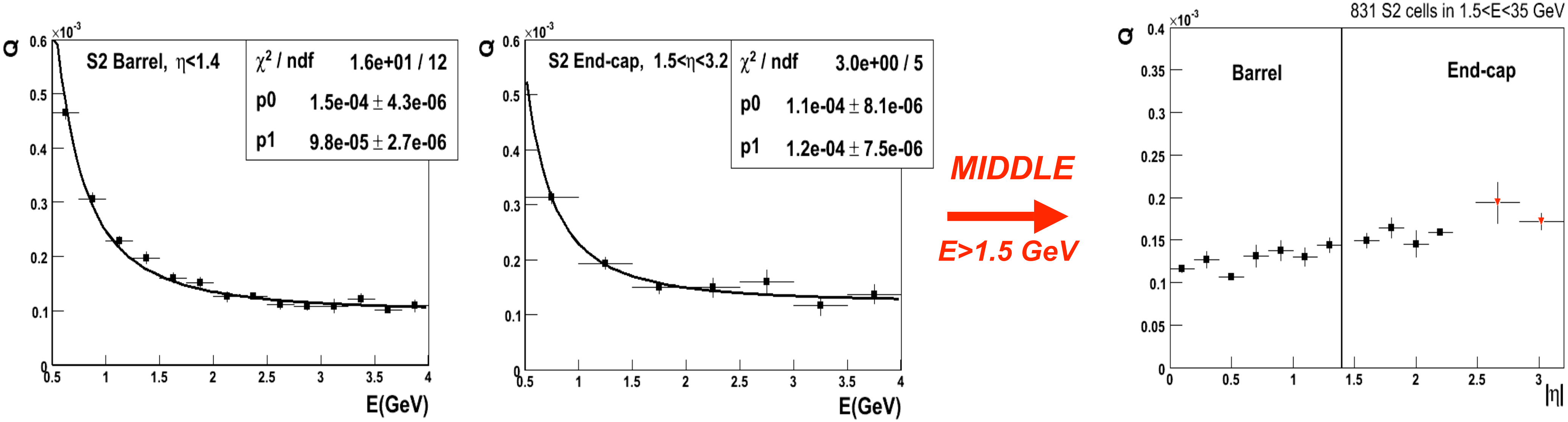
Displacement of the readout electrode in between the absorbers

⇨ **Very good understanding of the pulse (low systematic from the signal reconstruction)**

Studies with high energy muons (2)

- **First in situ study over the complete EM calorimeter coverage**
  - ✓ Only solution for EMEC: select high energetic cells (non projective muons)
  - ✓ Quantitative comparison of data and predicted pulse

$$Q = \frac{\chi^2}{n_{samples} \times A^2_{max}} = \frac{p_0}{E^2} + p_1 \begin{cases} \frac{p_0}{E^2} & \text{due to the gaussian noise fluctuation} \\ p_1 & \text{reflect the quality of the prediction} \end{cases}$$

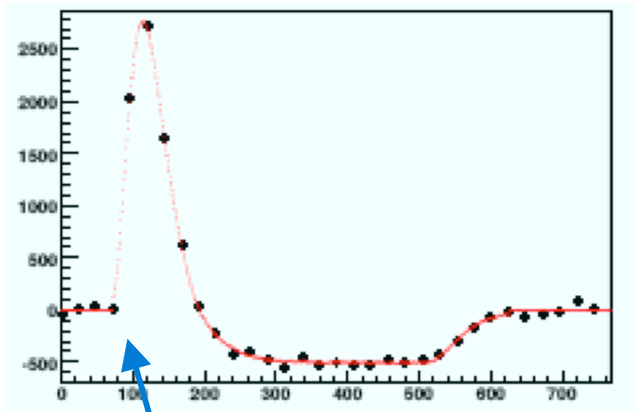


⇨ **Coherence of the signal reconstruction quality in complete EM calorimeter coverage**

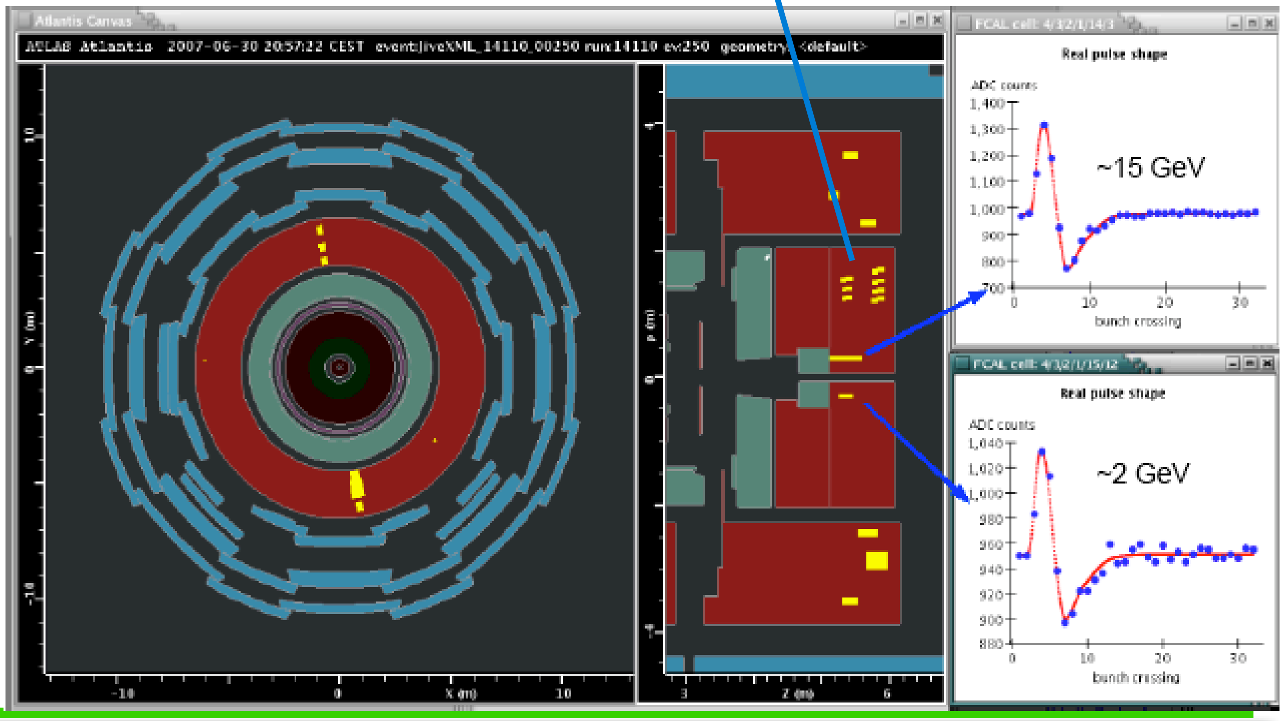
High energy pulses in FCal and HEC

- **Signal reconstruction less crucial than for EM**

- **Cosmic signal in the HEC**
  - ✓ One example of the prediction quality for the pulse shape

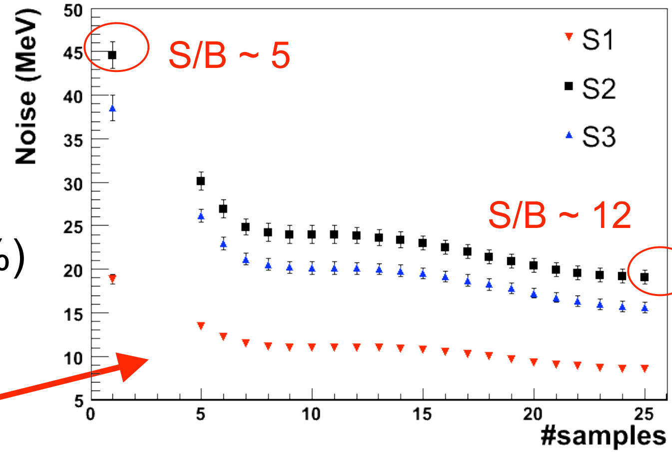


- **Cosmic signal in the FCal**
  - ✓ Good agreement between the cosmic shape and the predicted physic shape extracted from the Test Beam results



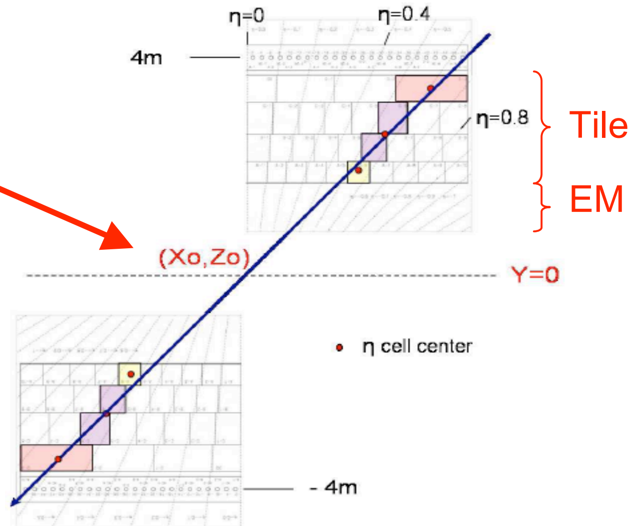
Studies with MIP cosmic muons (1)

- **Need to consider all cells**
  - ✓ Problematic channels (calibration system and cosmic analysis):
    - → Dead channels for physics (0.013 %)
    - → Channels without calibration signal, good for physics (0.05%)



  - ✓ Mandatory for "small" muon signal
    - → Reduce noise by increasing the number of samples uses for the signal reconstruction

  - ✓ Projectivity: muon goes through nominal Interaction Point (IP)
    - → Trajectory is extracted by fitting with a straight line the position of Tile cells
    - → Cut on the y=0 plane muon crossing point $(\Delta X_0, \Delta Z_0) < (30\text{ cm}, 30\text{ cm})$

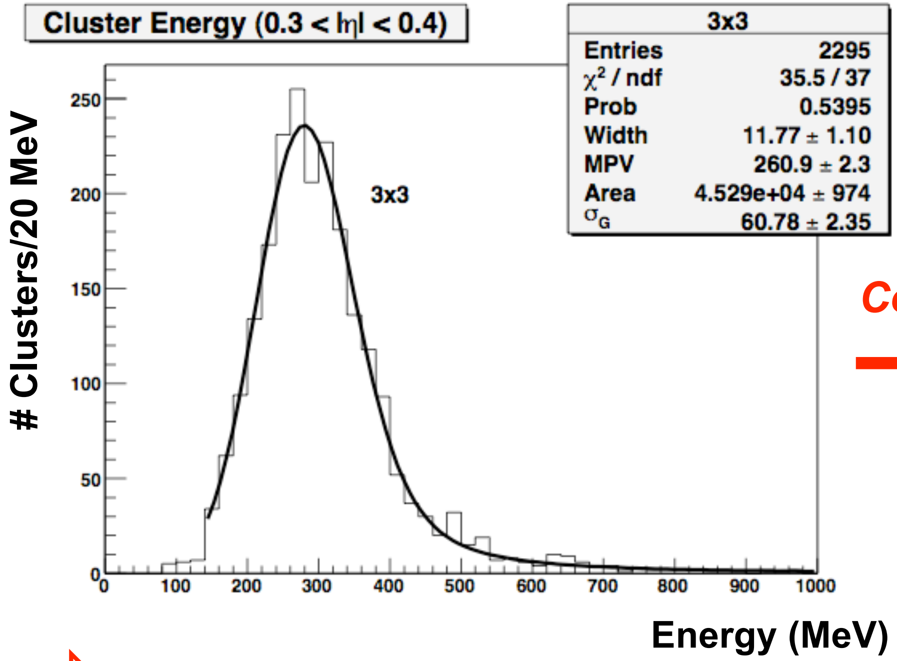


⇨ **Allow to extract pure "projective" muon sample**

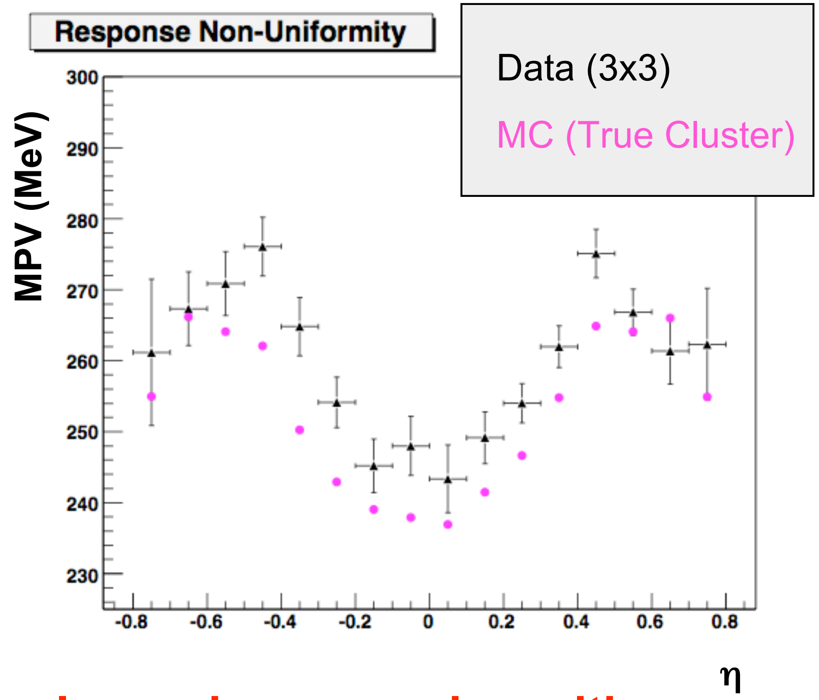
Studies with MIP cosmic muons (2)

- **Cosmic muons are minimum ionizing particles (MIPs) …**
  - ✓ Weakly depend on input muon energy
  - ✓ Path length variation is “small” with projectivity cut

- **… that should follow a Landau Distribution**



Cover all η≤0.8

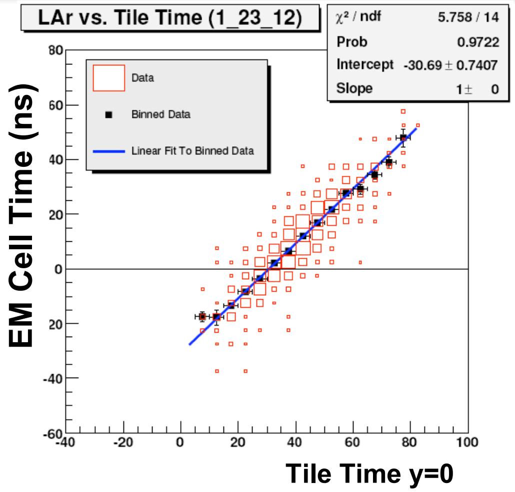


⇨ Agrees with the simulation to within 3% for typical cosmic energy depositions

Studies with MIP cosmic muons (3)

Linear correlation between EM and Tile Time

- ✓ Tile time is measured in each cell, and extrapolated to Y=0 plane (considering time of flight)
- ✓ It is used to correct the timing of each readout FEB

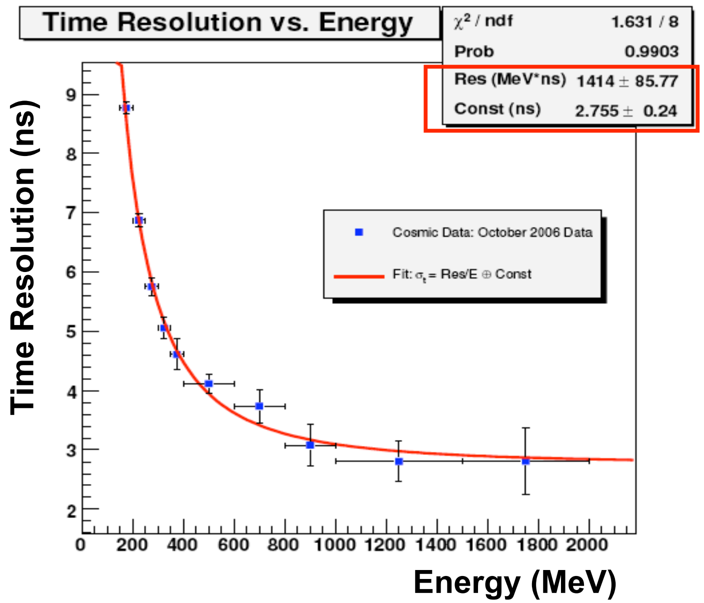


The dependence of the timing (T_{EM}-T_{Tile}) resolution with energy

- ✓ Data points fitted using

$$\sigma_t = \sqrt{\left(\frac{Res}{E}\right)^2 + (const)^2}$$

- ✓ Agreement with the EM TB results for the "Res" term (TB 1420 MeV. ns)
- ✓ Not possible extract information about "const" term for EM (TB 0.65 ns)
  - ➡ due to the larger Tile timing resolution and bad timing between tile towers



⇨ **Encouraging results for the LHC start**

Conclusions

- **ATLAS is now complete and commissioning all detectors**
  - ✓ LAr detectors were one of the first to start (2006)

- **Despite the small and mostly non-projective signals,**
  cosmic muons provide a first in situ test of LAr detectors :
  - ✓ Electronic chain is well understood
  - ✓ Coherent results in $|\eta|<3.2$
  - ✓ MIP muons extracted and successfully compared with simulation

- **Gives confidence that LAr detectors will be fully operational when LHC data will come**

SPARES

Physics requirements for the EM Calorimeter

Requirements for the EM Calorimeter

- Energy resolution:

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

  - **"sampling term"**: $a<10\%\sqrt{\text{GeV}}$;
  - **"constant term" :** **$c<0.7\%$**
  - **"noise term" : n<50 MeV /cell)**

- Angular resolution: **50 mrad/√E**
- Temporal resolution: **0.1 ns**

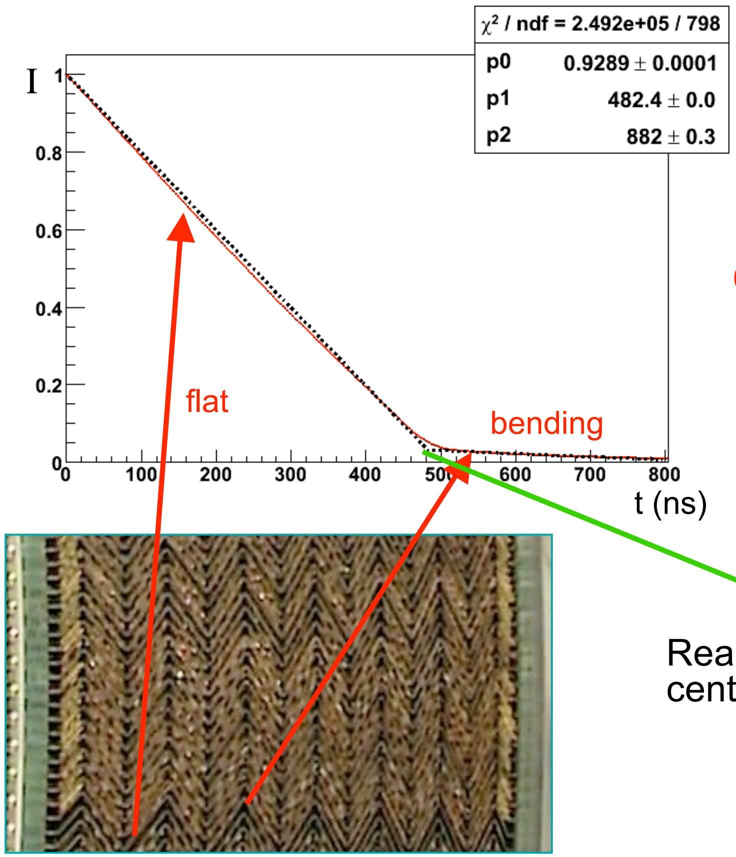
Properties of the EM Calorimeter

- Different between EM Barrel and End-cap calorimeter

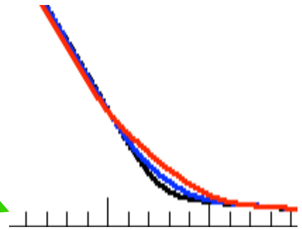
	Barrel	End-caps (outer wheel)
Gap (absorbent - electrode) (mm)	2.1	3.1 to 0.9
Folding angle (º)	70 to 90	60 to 120
Drift time t_{drift}(ns)	470	600 to 200
Sampling fraction (%)	25 to 28	30 to 14
High Voltage (V)	2000	2500 to 1000
L: S2 cell inductance (nH)	25 to 35	50 to 20
C: S2 cell capacitance (pF)	1400 to 1900	1200 to 600

Studies with high energy muons

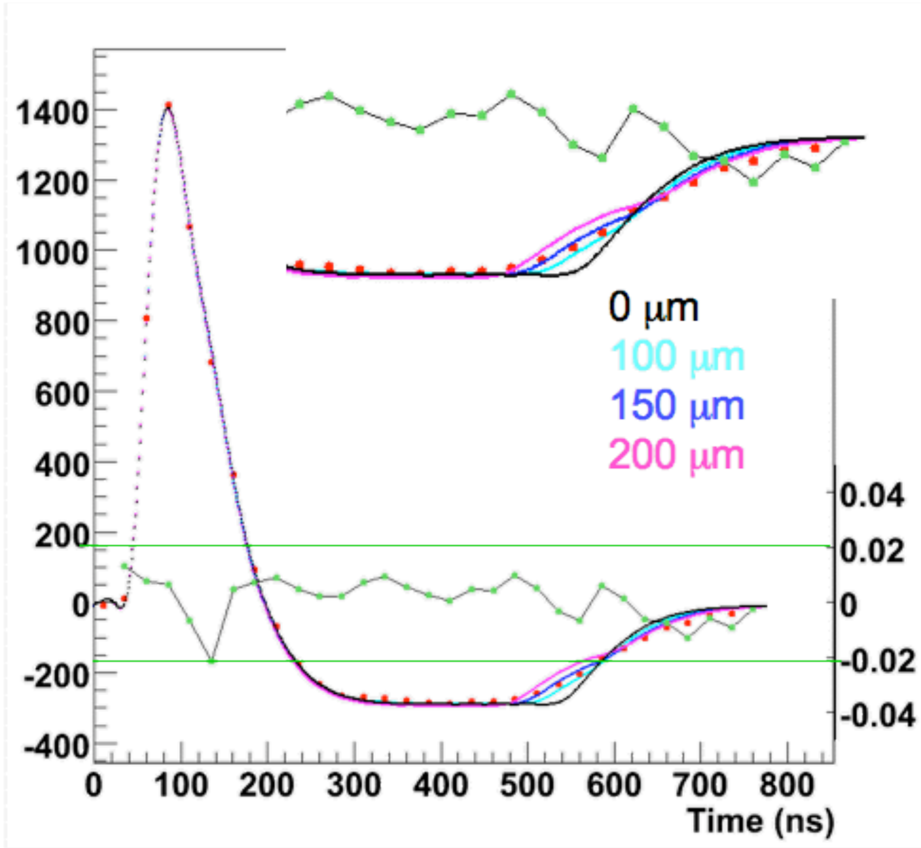
- Can be used to tune the T_{drift} values when enough 32-samples data will be available



Check with data



Readout electrode is off-centred by a fraction x



⇨ **Negligible impact on energy measurement**