Recent results of the ATLAS Barrel Combined Test-beam

Marco Delmastro

(on behalf of the ATLAS liquid Argon group)

Università degli Studi di Milano and INFN (Milano, Italy)

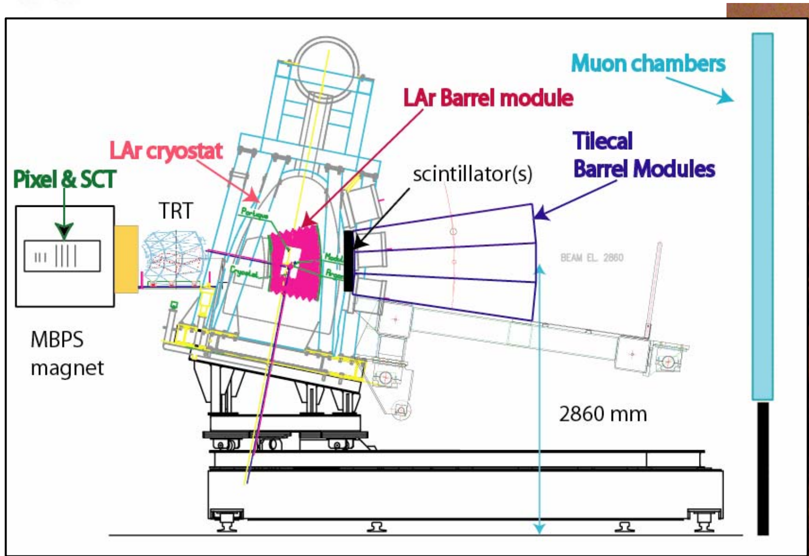
CERN (Geneva, Switzerland)

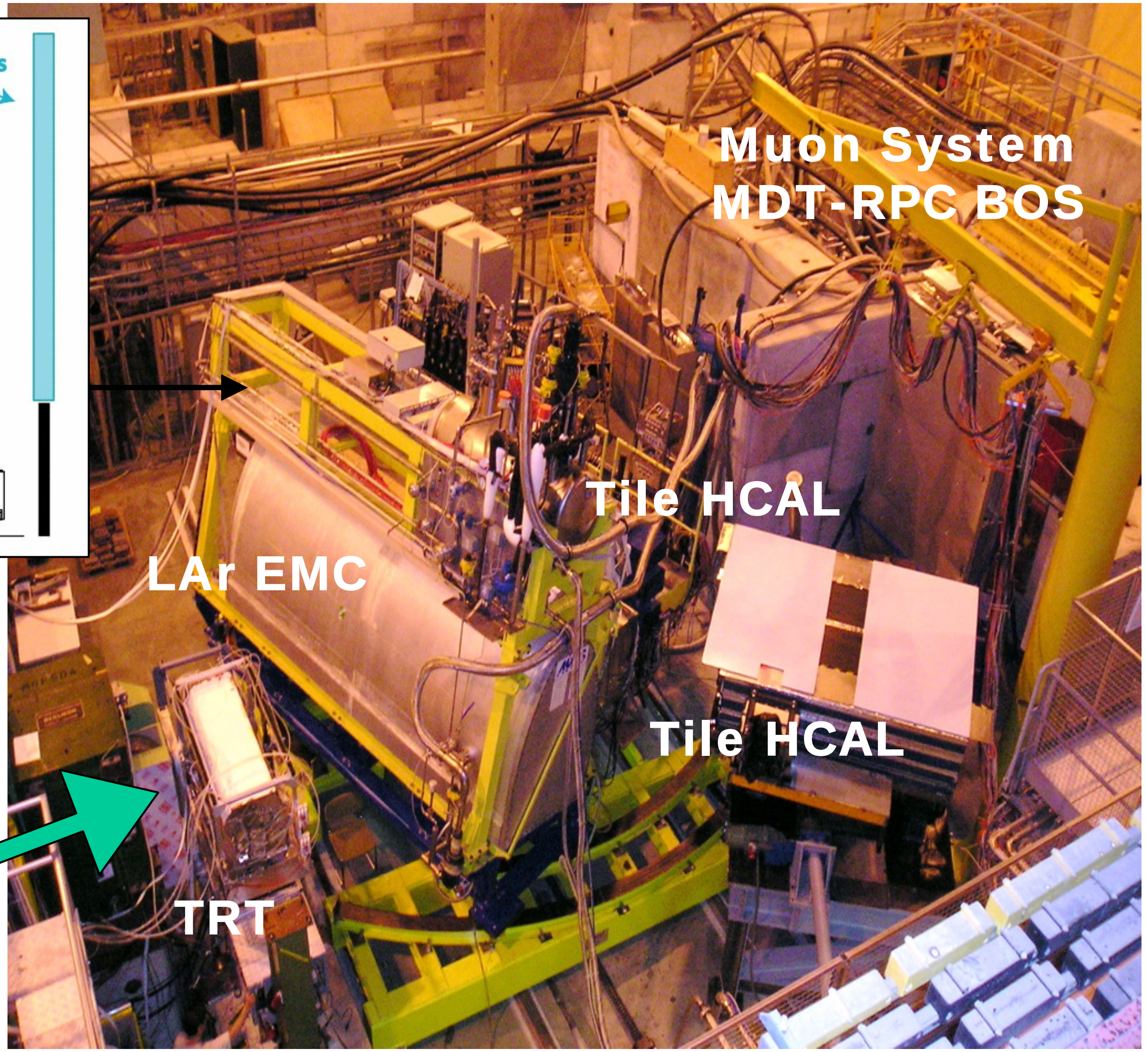
- From "digits" to "raw" energy: the electronics calibration of the LAr electromagnetic calorimeter
- Description of electrons in the detector: data vs. Monte-Carlo comparison
- Combined studies with the electromagnetic calorimetry
  - ✓ Converted photon reconstruction (tracker+EMC)

Other related presentations at CALOR 2006

- General description of the ATLAS LAr electromagnetic calorimeter:
  - ✓ Martin Aleksa: *"The ATLAS Liquid Argon Calorimeter: Construction, Integration, Commissioning"*
- Uniformity of the response to electrons:
  - ✓ Irena Nikolic: *"Recent Results on the Uniformity of the Liquid Argon Calorimeter Measured in Test Beams"*
- Linearity of the response to electrons:
  - ✓ Walter Lampl: *"Studies of the Linearity of the ATLAS Electromagnetic Calorimeter Response"*
- Response to pions:
  - ✓ Vincent Giangiobbe: *"Studies of the response of the ATLAS barrel calorimeters to pions using 2004 combined test beam data"*

ATLAS Barrel Combined Test-beam 2004

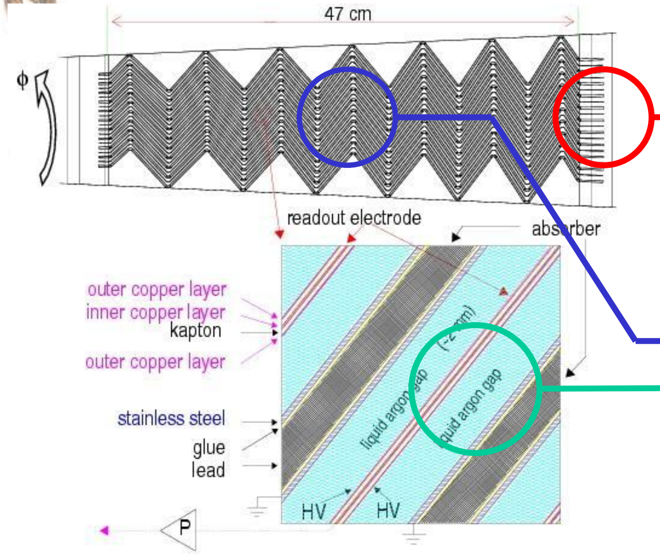


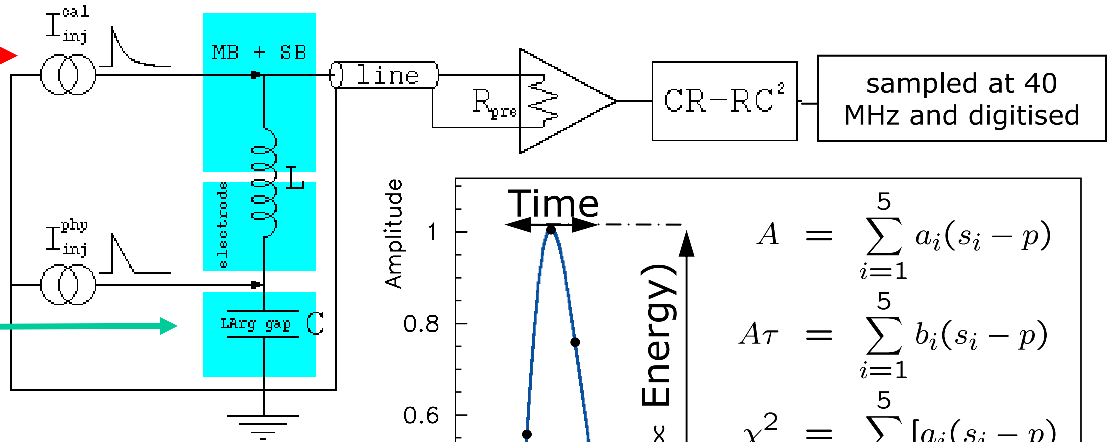


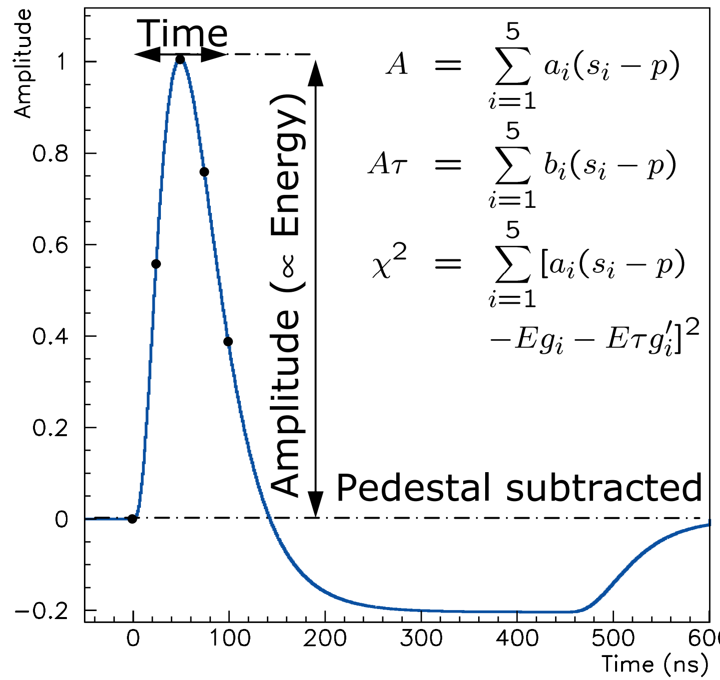
- Drift chambers: beam position
- Scintillators: trigger
- Calorimeters on η moving table
- H8 beam: e, γ, μ, π and p
- Energy: 1 to 350 GeV

LAr electronics calibration:

From digits to “raw” energy







Optimal Filtering Coefficients

ADC to GeV (Ramps)

Pedestals

$$E = \sum_{j=1}^{2} F_j \left(\sum_{i=1}^{5} a_i (ADC_i - P) \right)^j$$

Energy

Raw Samples

The ionization signal is sampled every 25 ns by a 12 bits ADC in 3 gains. 6 samples are recorded at the CTB for redundancy (5 at ATLAS). Energy is reconstructed offline (online in ROD at ATLAS).

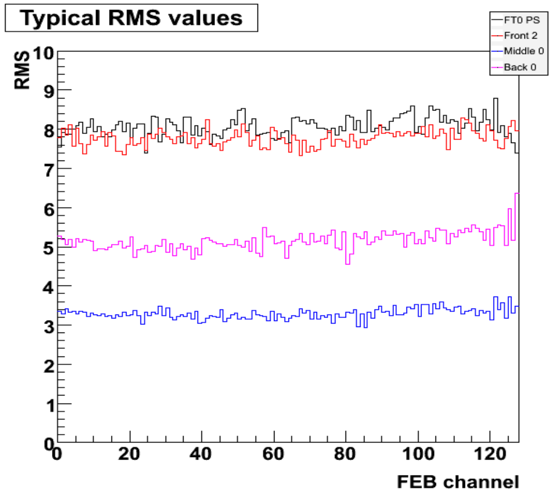
LAr electronics calibration:

LAr electronic calibration runs

pedestals and noise

FEB are read with no input signal to obtain:

- Pedestal
- Noise
- Noise autocorrelation (OFC computation)

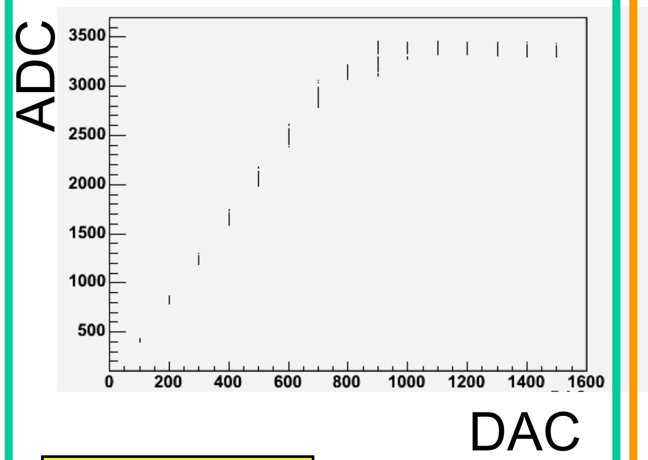


Every 8 hours

ADC $\rightarrow$ MeV conversion

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

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

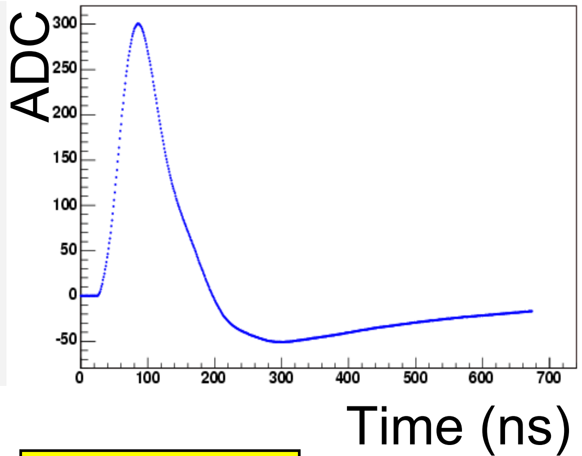


Every 8 hours

response to current pulse

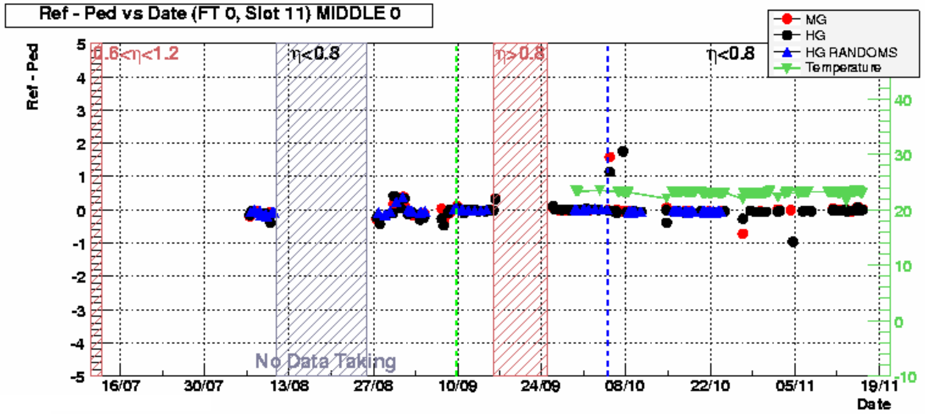
All cells are pulsed with a known current signal:

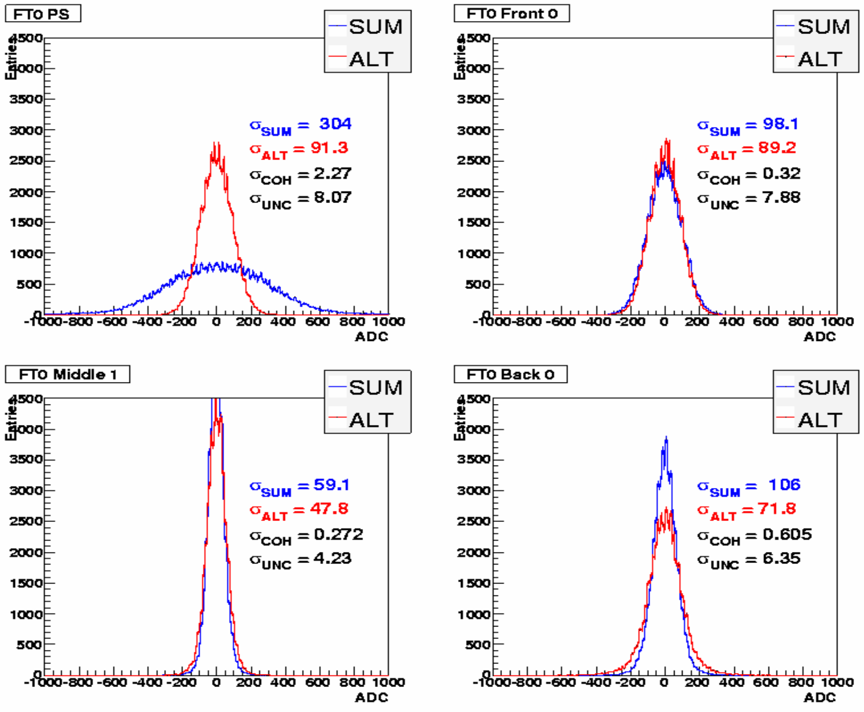
- A delay between calibration pulses and DAQ is introduced
- The full calibration curve is reconstructed (Δt=1ns)



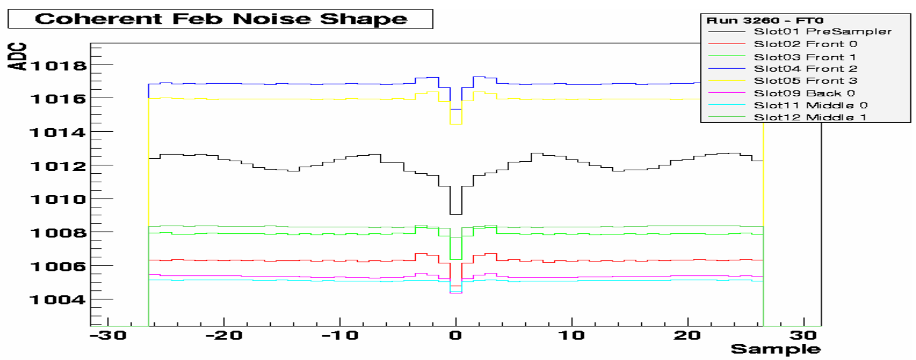
Every change of cabling

LAr electronics calibration: Pedestals and noise





- Pedestal and noise levels are measured regularly (every 8 hours)
- Measured with two approaches:
  - ✓ Dedicated "pedestal" runs (the FEBs are read without calibration signal or beam)
  - ✓ Random triggers during standard physics runs
- Stability is very good (<1ADC), small temperature variations are easily corrected for
- Noise and coherent noise are as expected
  - ✓ Coherent noise was particularly high in the pre-sampler FEB, related to a unidentified 2.5 MHz noise source

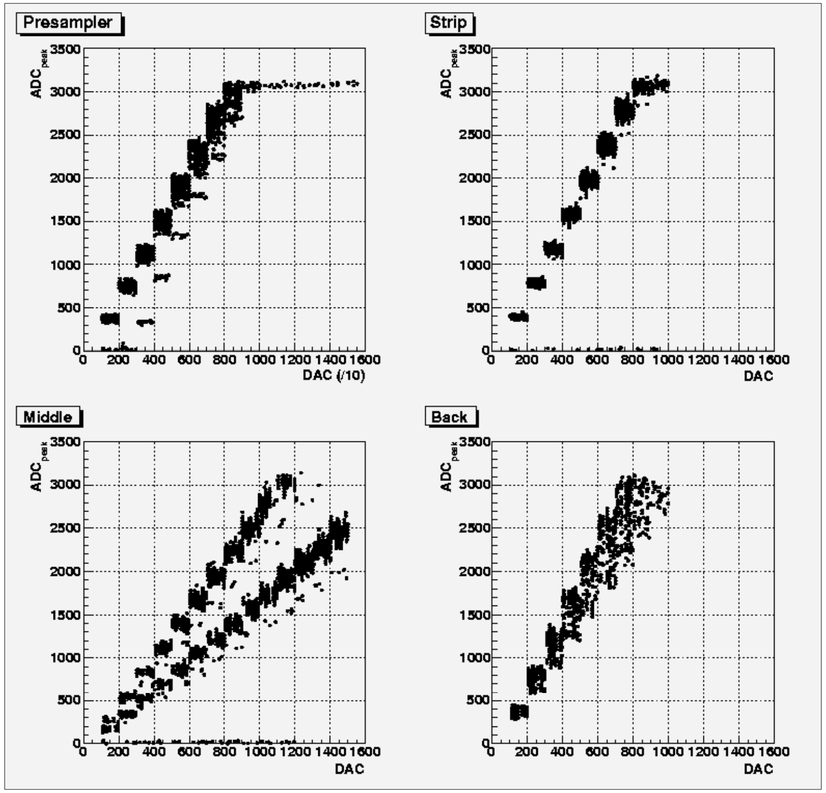


LAr electronics calibration:

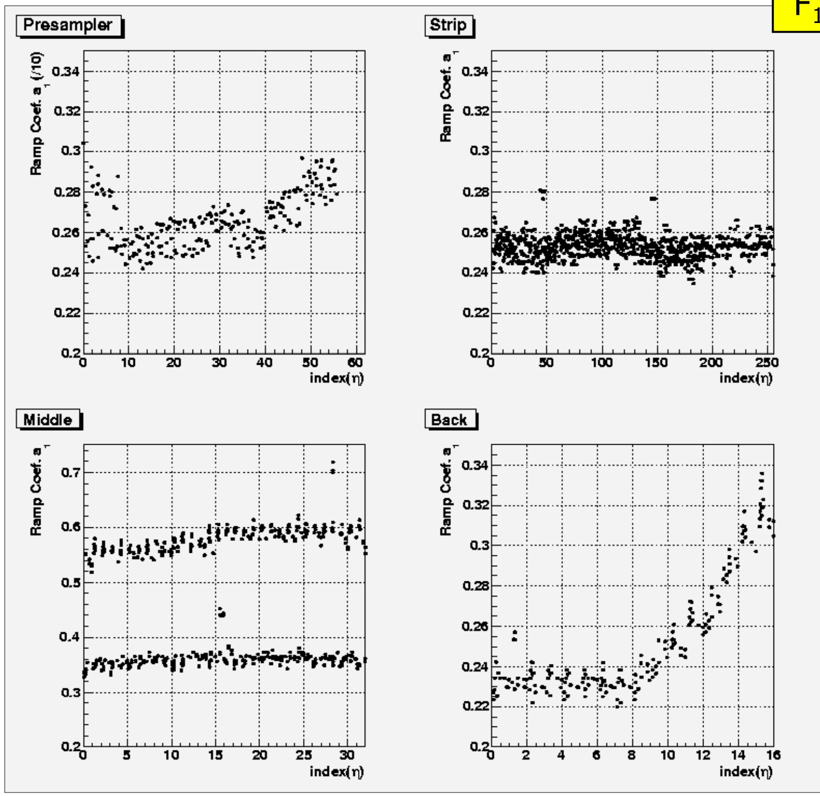
ADC → MeV conversion (1)

- Electronic gain of each channel is measured regularly (every 8 hours)
- The DAC versus ADC curve is fitted with a second order polynomial
  - ✓ $\mathbf{DAC = F_0 + F_1 \cdot ADC + F_2 \cdot ADC^2}$

- Other (global) conversion factors:
  - ✓ **DAC2μA**: from calibration boards and injection resistance data
  - ✓ **μA2MeV**: computed from detailed simulation of charge collection in accordion gaps
  - ✓ $\mathbf{f_{samp}}$: computed from simulation

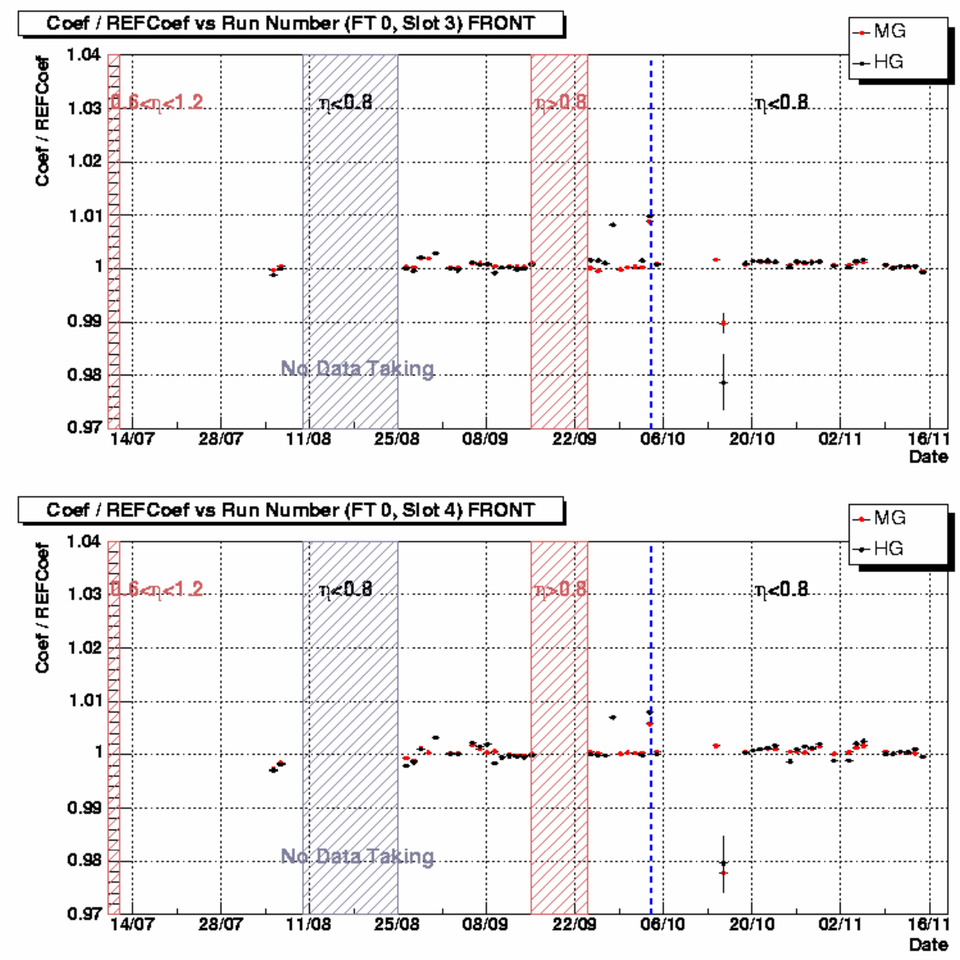


F1

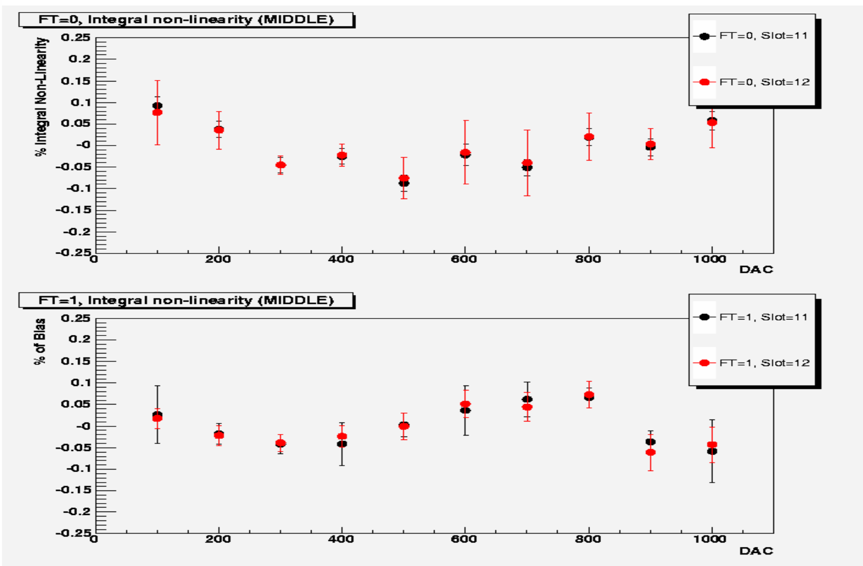


LAr electronics calibration:

ADC → MeV conversion (2)



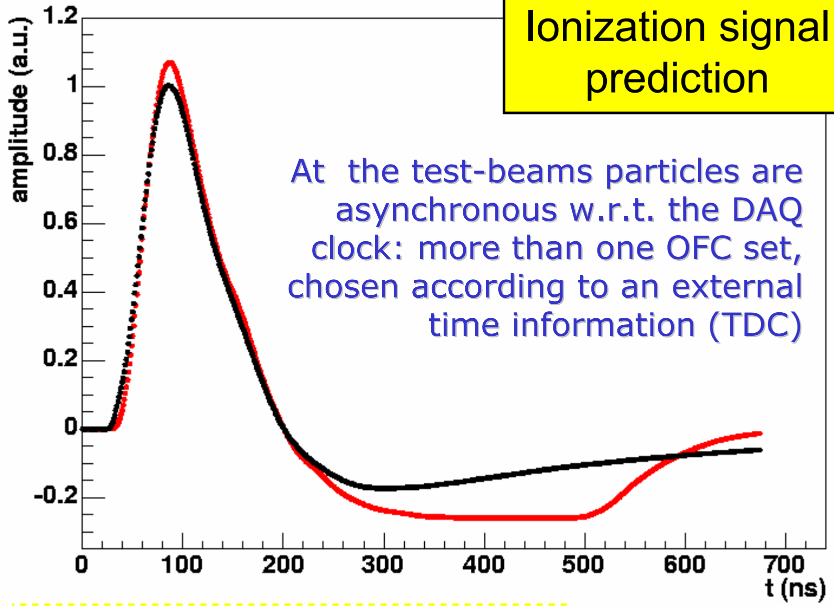
- The electronic gains is very stable: we observed variations up to a few permil
  - ✓ A clear temperature dependence was observed…
  - ✓ … and is corrected for in offline reconstruction thanks the excellent time granularity of the conditions database
- Integral non-linearity of the readout remains below 0.1% as required and measured on test bench



LAr electronics calibration:

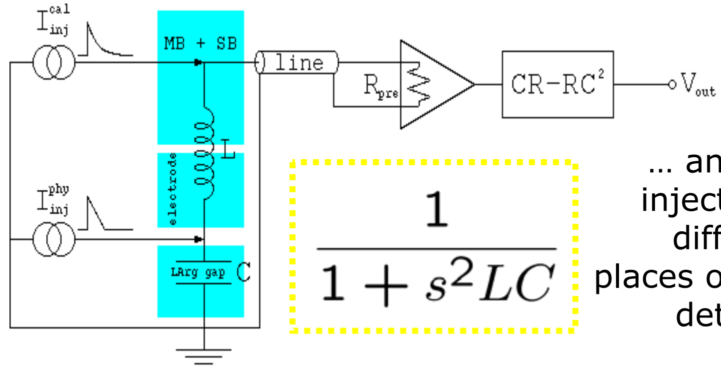
Optimal Filtering Coefficients

- The use of OF reconstruction allows to
  - ✓ Minimize noise contributions (at CTB only electronic noise, at ATLAS would include pile-up)
  - ✓ Minimize jitter-related effects
- OFC computation implies the knowledge of:
  - ✓ **noise autocorrelation:**
    - computed from pedestal data
  - ✓ **normalized ionization pulse:**
    - predicted from the corresponding calibration profiles according to the electrical model of the readout cell
    - Predicted pulses includes the correction for the distortion introduced by the electrical properties of the cells



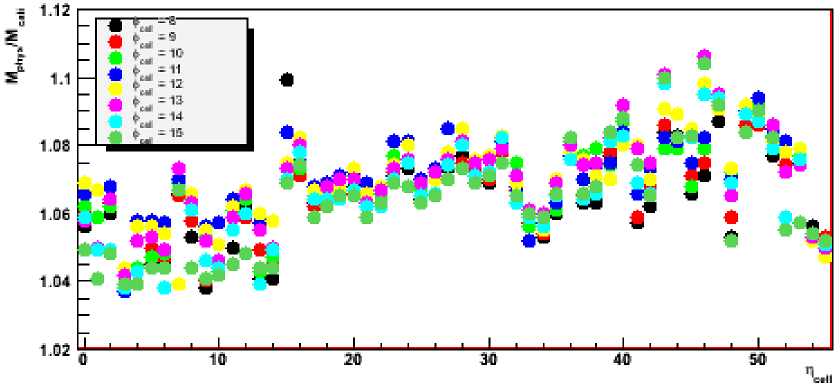
$$\frac{(1+s\tau_{\text{cali}})(sT_d - 1 + e^{-sT_d})}{sT_d(f_{\text{step}} + s\tau_{\text{cali}})}$$

calibration and ionization pulses are different…

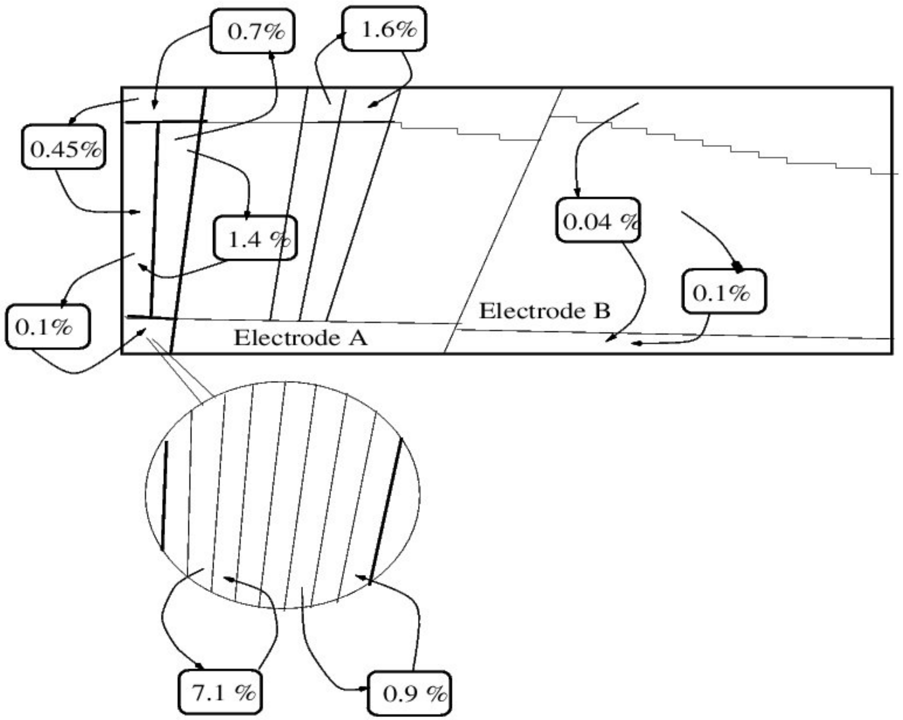


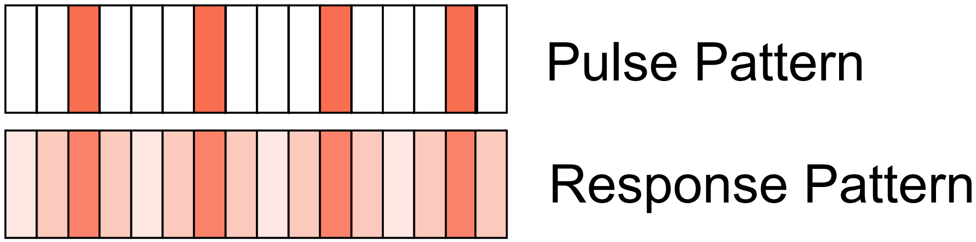
$$\frac{1}{1+s^2LC}$$

… and are injected in different places on the detector



LAr electronics calibration:
Cross-talk effects





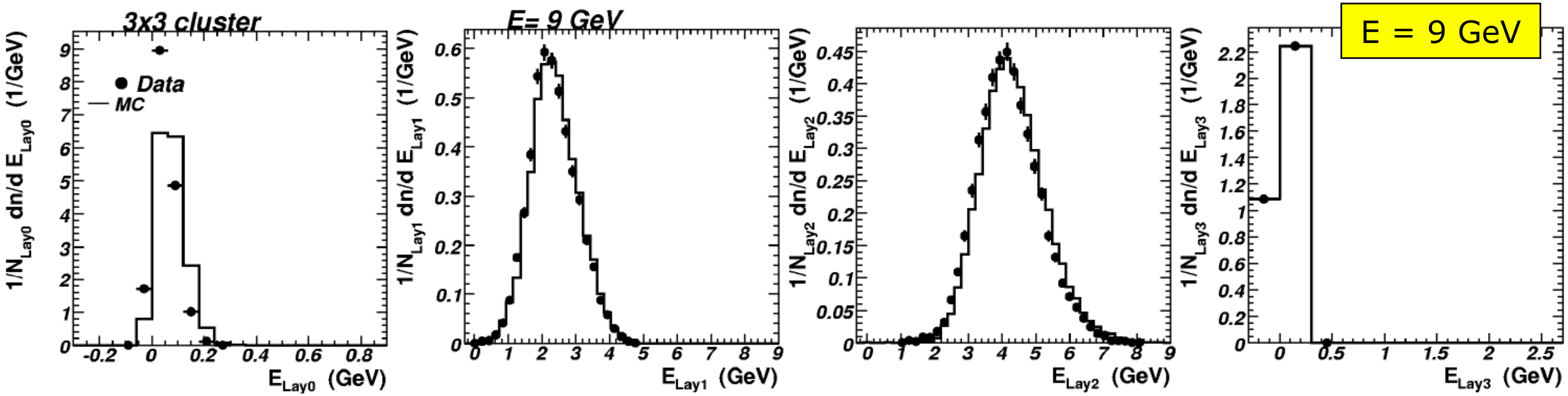
- The EMC cells share part of their collected current because of cross-talk
  - ✓ In general the effect is negligible, and compensated by the clustering algorithm
- The effect is non negligible for the first sampling
  - ✓ The actual electronic gain is overestimated (~9%)
  - ✓ The pulse shapes obtained injecting the calibration current are "wrong" w.r.t. the one generated by a particle shower (cluster)
    - If these shapes are directly used to compute OFC, the use of these "wrong" OFC lead to a underestimation of the ADC peak (~1-3%)
  - ✓ The combined effects lead to a global overestimation of the first sampling cluster energy of ~7%
  - ✓ We have an effective recipe to treat the effect (gain correction + proper OFC)

Description of electrons in the detector:

Data vs. Monte-Carlo (E < 9 GeV)

- A good description of the energy deposits in the EMC is crucial to obtain the proper energy scale calibration
  - ✓ see W. Lampl talk in this session for details…
- Two simulation for two different beam-line setups
  - ✓ "Very Low Energy" (1-9 GeV)
    - momentum selection is done very close to the CTB trigger
  - ✓ E > 9GeV (9 GeV –180 GeV)

VLE: very good description of energy deposits in each EMC layers

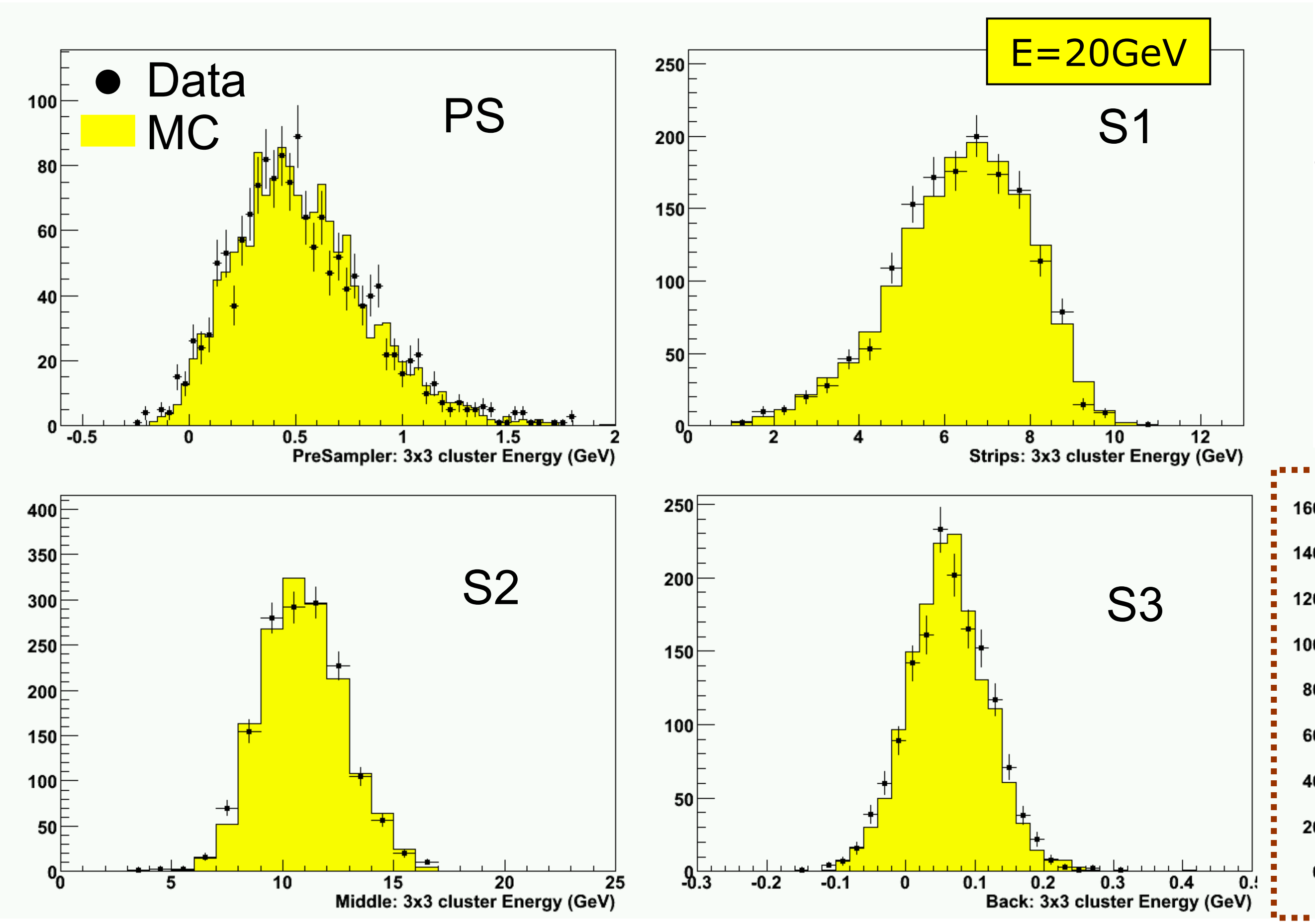


Similar good agreement results down to E = 2 GeV

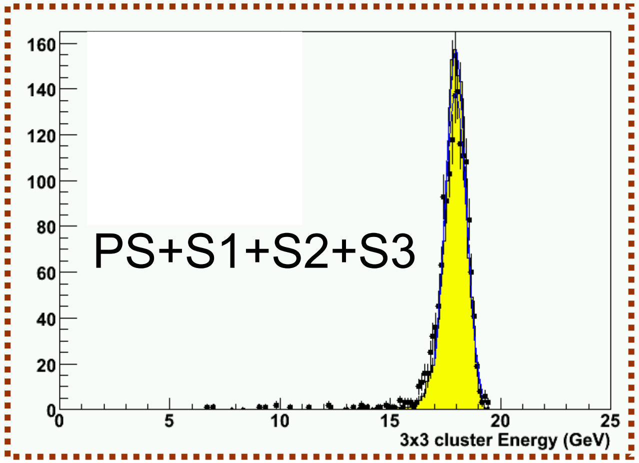
Description of electrons in the detector:

data vs. Monte-Carlo (E > 9 GeV)

E > 9 GeV: very good description of energy deposits in each EMC layers

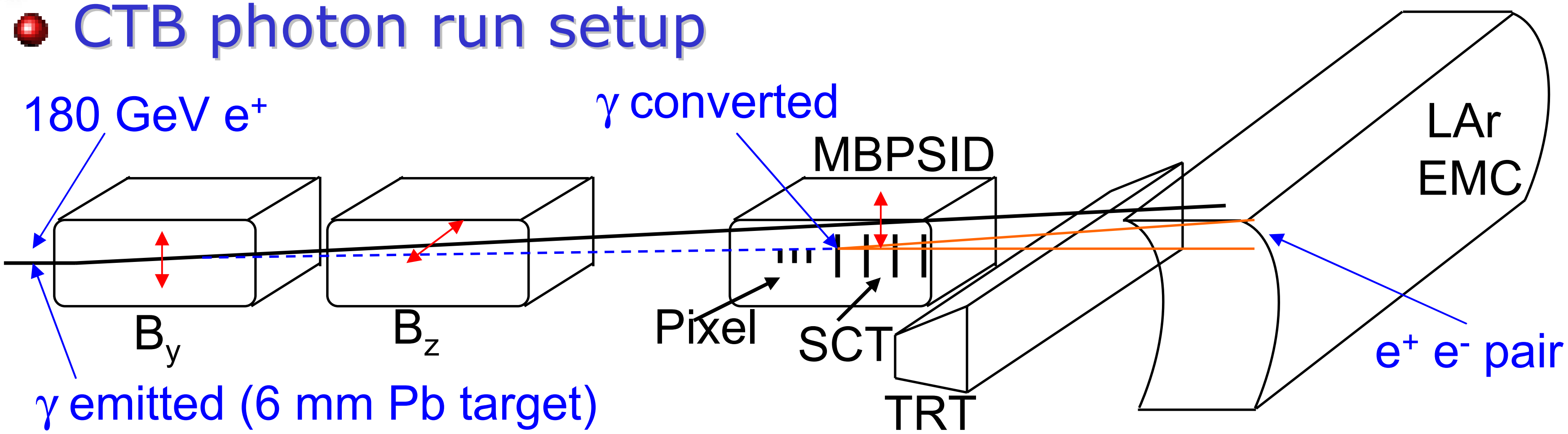


Similar good agreement results up to E = 180 GeV

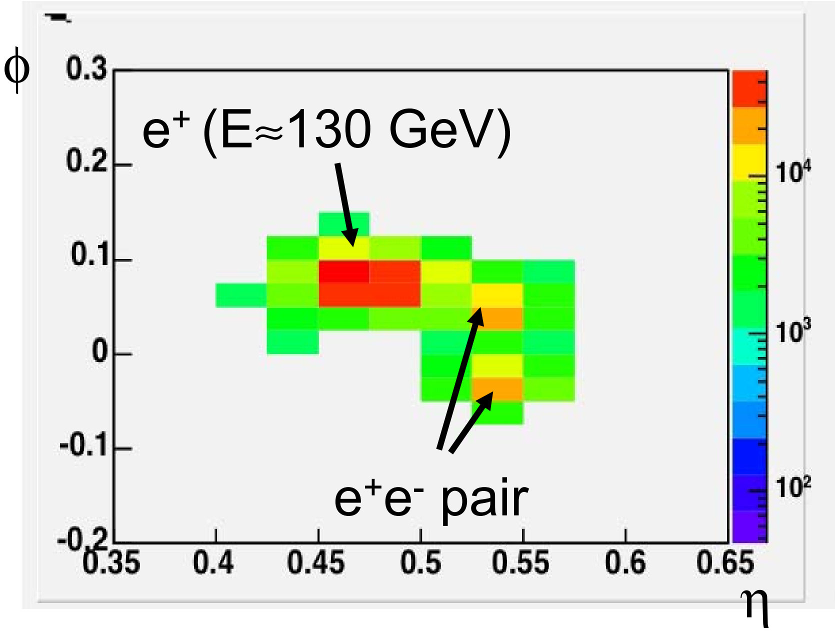


Converted photon reconstruction

- CTB photon run setup



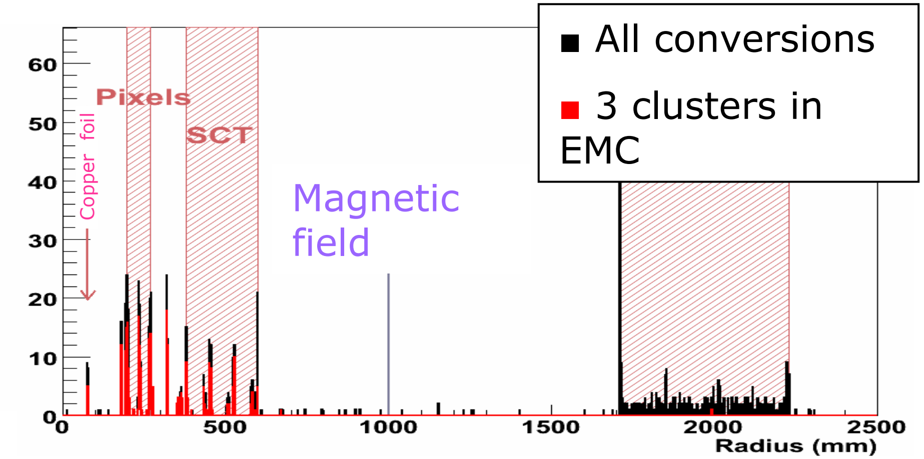
- Topological clustering is used to reconstruct 3 objects in EMC:
  - ✓ main e^+
  - ✓ e^+e^- pair from converted γ
- Next step: combine with tracker, compute E/p

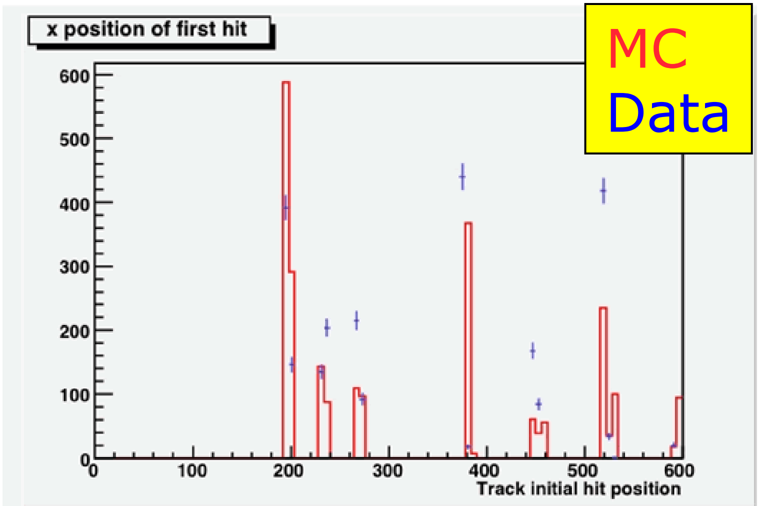


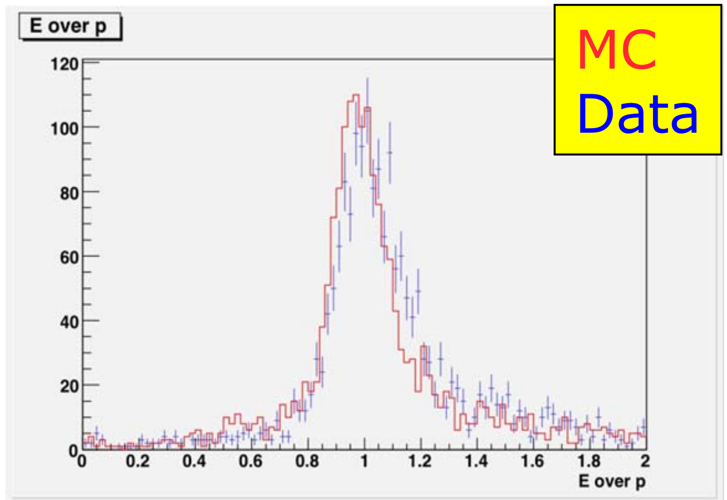
Performances of the electromagnetic calorimetry at the CTB:

Converted photon reconstruction

- Backtracking of e^+e^- pair nicely indicates the pixels and SCT layers as conversion points
- A good association between clusters in EMC and conversion positions is found
- First measurement of E/p is obtained, agreement between data and MC is good!



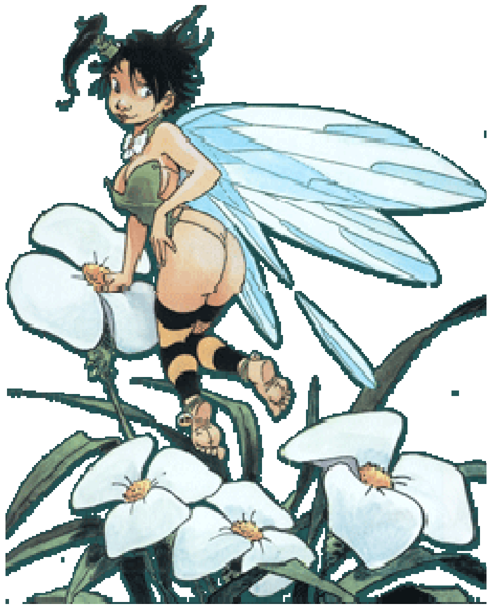




Conclusions

- The 2004 ATLAS CTB was an unprecedented occasion to exercise the electronics calibration of the LAr electromagnetic calorimeter
  - ✓ The full electronic calibration chain was implemented
  - ✓ Performances of the ATLAS LAr final electronics were studied, requirements
  - ✓ All the EMC electronics calibration procedures have been implemented in the ATLAS reconstruction software, system is ready for full EMC commissioning (summer 2006) and ATLAS data taking
- The response of the detector to electrons is very well understood
  - ✓ Very good agreement between data and Monte-Carlo in the different beam-line setups
  - ✓ Simulation can be used to compute calibration weights (see other talks in this session)
- Combined studies are ongoing, first results are very encouraging

Additional slides for curious kids



Optimal filtering coefficients (1)

$$f(t) = Ag(t-\tau) + n(t) \cong A\{g(t) - \tau g'(t)\} + n(t)$$

$$S_k = A(g_k - \tau g'_k) + n_k$$

$$\langle n_k \rangle = 0$$

$$\langle n_i n_j \rangle = R_{ij}$$

noise autocorrelation function

Choose coefficients for the expressions:

$$U = \sum_{k=1}^{N} a_k S_k \qquad V = \sum_{k=1}^{N} b_k S_k$$

such to minimize σ_U and σ_V with the constraints:

$$\langle U \rangle = A \Rightarrow \sum_{k=1}^{N} a_k g_k = 1 \quad , \quad \sum_{k=1}^{N} a_k g'_k = 0$$

$$\langle V \rangle = A\tau \Rightarrow \sum_{k=1}^{N} b_k g_k = 0 \quad , \quad \sum_{k=1}^{N} b_k g'_k = -1$$

$$\sigma_U^2 = \mathrm{Var}[U] = \sum_{ij} a_i a_j R_{ij}$$

$$\sigma_V^2 = \mathrm{Var}[V] = \sum_{ij} b_i b_j R_{ij}$$

Optimal filtering coefficients (2)

Solve with Lagrange multipliers:

Peak equations:

$$0 = \frac{\partial}{\partial a_k}\left\{\frac{1}{2}\sum_{ij} a_i a_j R_{ij} - \lambda \sum_i a_i g_i - \mu \sum_i a_i g'_i\right\}$$
$$= \sum_i a_i R_{ik} - (\lambda g_k + \mu g'_k)$$

$$\Rightarrow a_i = \lambda \sum_k R^{-1}_{ik} g_k + \mu \sum_k R^{-1}_{ik} g'_k$$

$$\lambda = \frac{Q_2}{\Delta}$$
$$\mu = -\frac{Q_3}{\Delta}$$

Time equations:

$$0 = \frac{\partial}{\partial b_k}\left\{\frac{1}{2}\sum_{ij} b_i b_j R_{ij} - \rho \sum_i b_i g_i - \sigma \sum_i b_i g'_i\right\}$$
$$= \sum_i b_i R_{ik} - (\rho g_k + \sigma g'_k)$$

$$\Rightarrow b_i = \rho \sum_k R^{-1}_{ik} g_k + \sigma \sum_k R^{-1}_{ik} g'_k$$

$$\rho = \frac{Q_3}{\Delta}$$
$$\sigma = -\frac{Q_1}{\Delta}$$

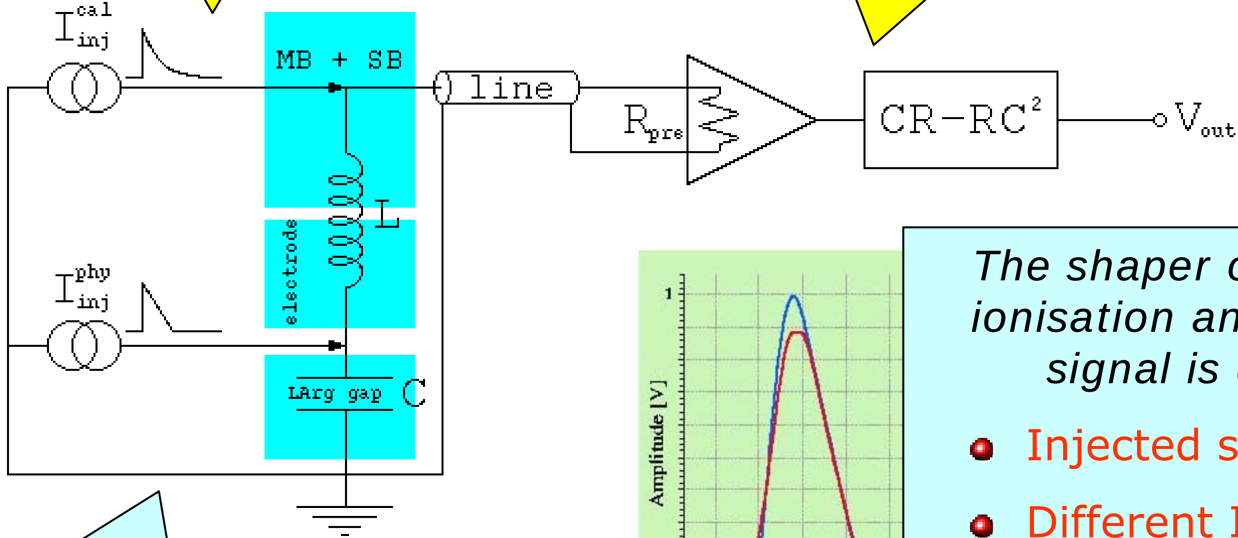
$$Q_1 = \sum_{ij} g_i g_j R^{-1}_{ij} \qquad Q_3 = \sum_{ij} g_i g'_j R^{-1}_{ij}$$
$$Q_2 = \sum_{ij} g'_i g'_j R^{-1}_{ij} \qquad \Delta = Q_1 Q_2 - Q_3^2$$

LAr electronic calibration strategy (1)

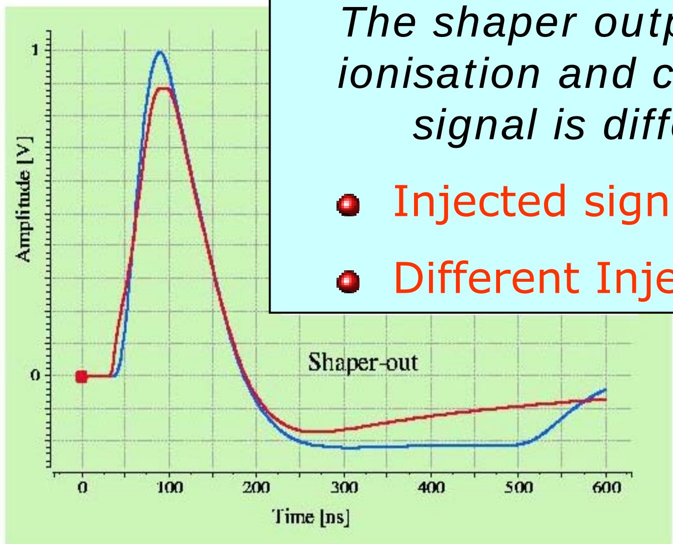
A known exponential current pulse is injected at the MB level…

… and reconstructed through the full readout chain. The actual gain of each readout channel is computed.

local constant term < 0.5 %
$(\Delta\eta \times \Delta\phi = 0.2 \times 0.4)$



The triangular ionisation signal is generated at the LAr gap level.



The shaper output of the ionisation and calibration signal is different!

- Injected signal shape
- Different Injection point

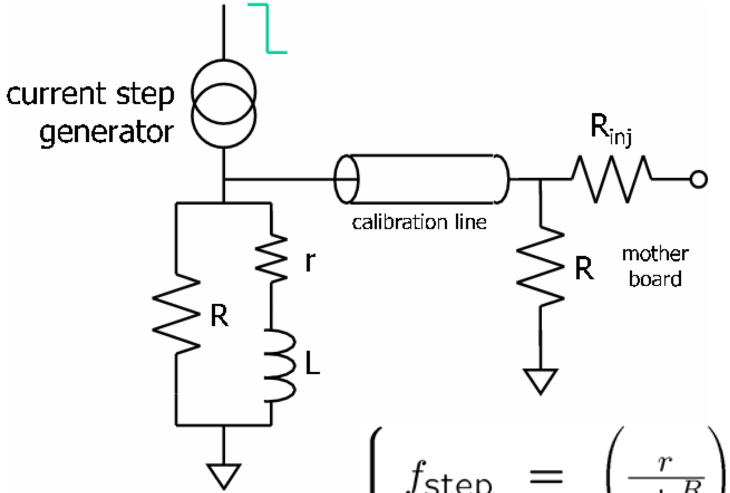
LAr electronic calibration strategy (2)

triangular ionization signal:

$$I^{\text{phys}}(s) = I_0^{\text{phys}} \left[\frac{1}{s} - \frac{1 - e^{-sT_d}}{s^2 T_d} \right]$$

"exponential" calibration signal :

$$\begin{cases} I^{\text{cali}}(t) & = & I_0^{\text{cali}} \left[\left(1 - f_{\text{step}}\right) e^{-\frac{t}{\tau_{\text{cali}}}} + f_{\text{step}} \right] \\ I^{\text{cali}}(s) & = & I_0^{\text{cali}} \left[\frac{(1 - f\,step)\tau_{\text{cali}}}{1 + s\tau_{\text{cali}}} + \frac{f_{\text{step}}}{s} \right] \end{cases}$$



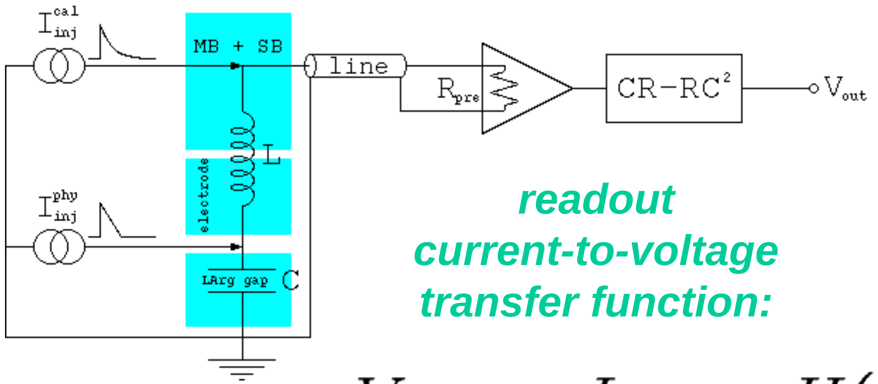
$$\begin{cases} f_{\text{step}} & = & \left(\frac{r}{r + \frac{R}{2}} \right) \\ \tau_{\text{cali}} & = & \left(\frac{L}{r + \frac{R}{2}} \right) \end{cases}$$

calibration signal:

$$I_{\text{line}}^{\text{cali}}(s) = I_{\text{inj}}^{\text{cali}}(s) \frac{\frac{1}{sC} + sL}{\frac{1}{sC} + sL + Z_{\text{line}}}$$

ionization signal:

$$I_{\text{line}}^{\text{phys}}(s) = I_{\text{inj}}^{\text{phys}}(s) \frac{\frac{1}{sC}}{\frac{1}{sC} + sL + Z_{\text{line}}}$$



readout current-to-voltage transfer function:

$$V_{\text{out}} = I_{\text{line}} \times H(s)$$

LAr electronic calibration strategy (3)

In order to complete the cell equalization, the readout gain computed with the calibration signal…

… is to applied to an ionisation signal that has been corrected!

Injection point correction: ***LC***

$$\begin{cases} g^{\text{phys}}(s) = g^{\text{cali}}(s) \times \left(\frac{(1+s\tau_{\text{cali}})(sT_d - 1 + e^{-sT_d})}{sT_d(f_{\text{step}} + s\tau_{\text{cali}})} \right) \times \left(\frac{1}{1+s^2 LC} \right) \\ \max\left\{ g^{\text{cali}}(t) \right\} = 1 \end{cases}$$

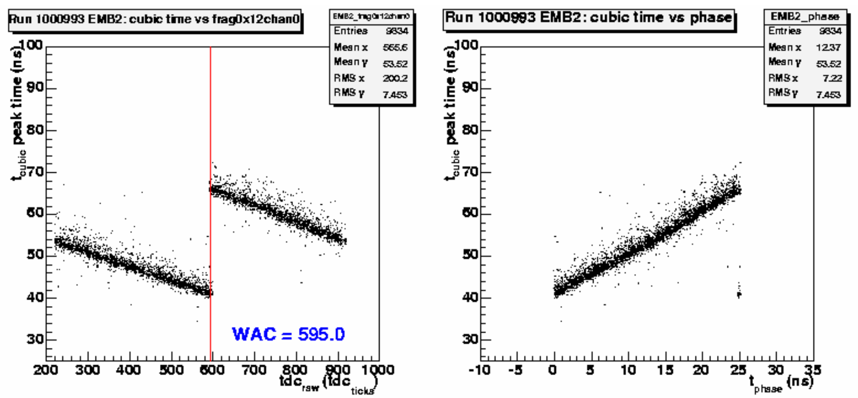
The triangular ionisation pulse generated at the LAr gap level is "normalized" when it corresponds to a unitary calibration pulse injected at the MB level…

Injected signal shape difference correction: T_d, f_{step}, τ_{cali}

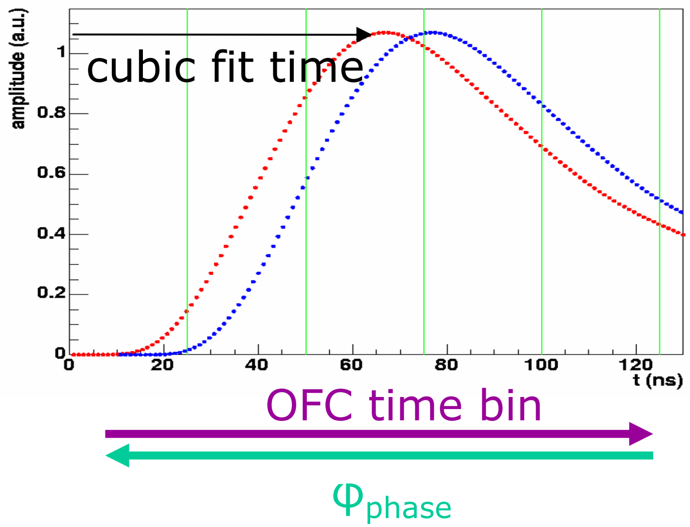
LAr electronics calibration:

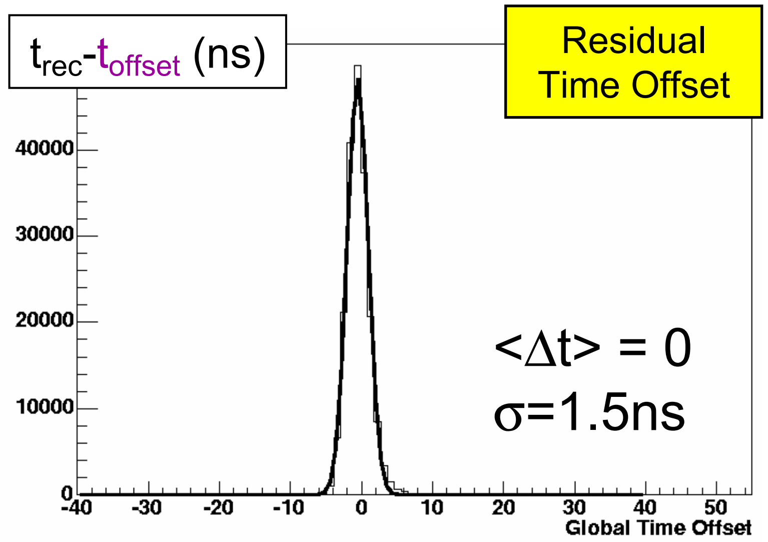
OFC Time Tuning at CTB

- At 2004 CTB particles are asynchronous w.r.t. the DAQ clock…
  - ✓ More than one OFC set is needed!
    - corresponding to different portions of the pulse
  - ✓ The good OFC set is chosen according to an external time information (TDC) providing φ_{phase}



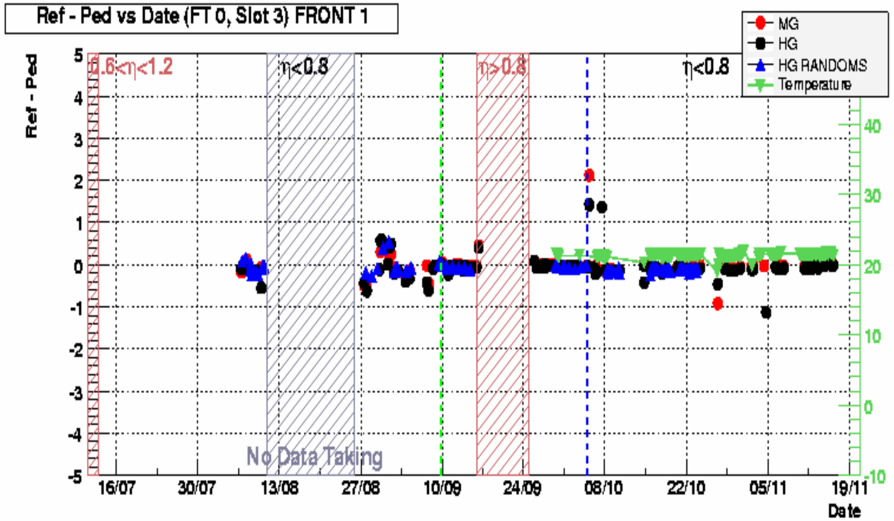
- The global trigger setup changed frequently (~10 times!)
  - ✓ it is has been necessary to implement a "timing offsets" mechanism to choose the proper OFC set in each period…
  - ✓ $t_{offset} = \varphi_{phase} + t_{FEB} + t_{global}$
  - ✓ Offsets (t_{FEB}, t_{global}) have been computed using an iterative procedure exploiting the timing information provided by the OFC reconstruction
    - t_{FEB}: FEB timing (when the signal is sampled)
    - t_{global}: Global trigger timing changes

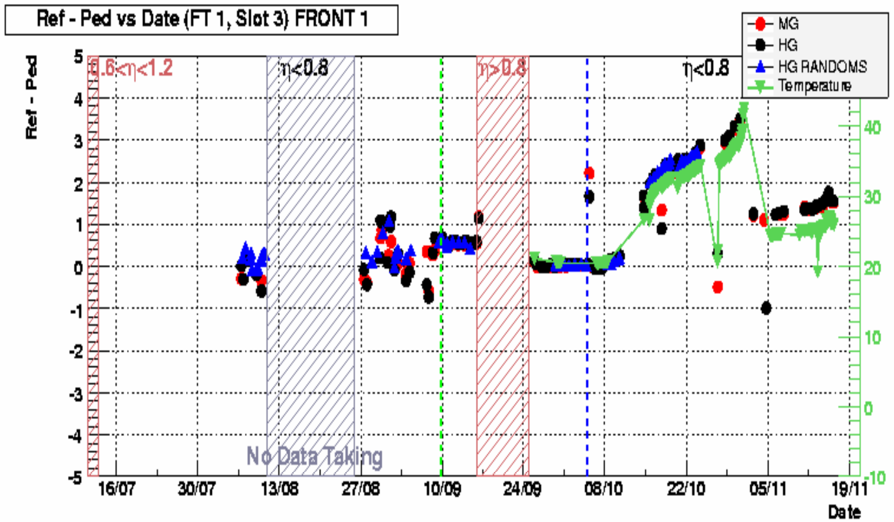




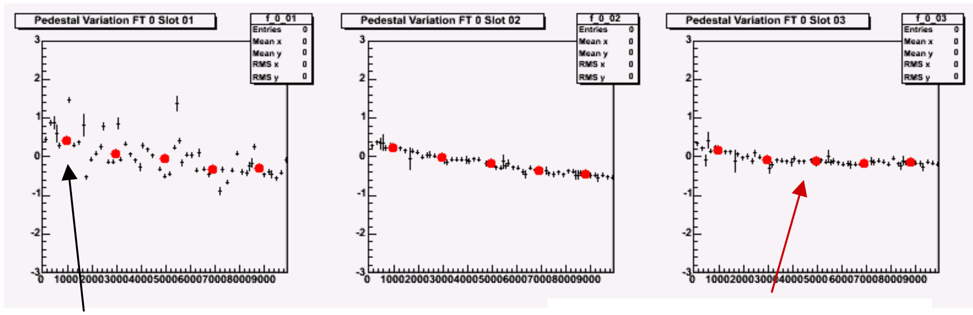
LAr electronics calibration:

Pedestals temperature variation





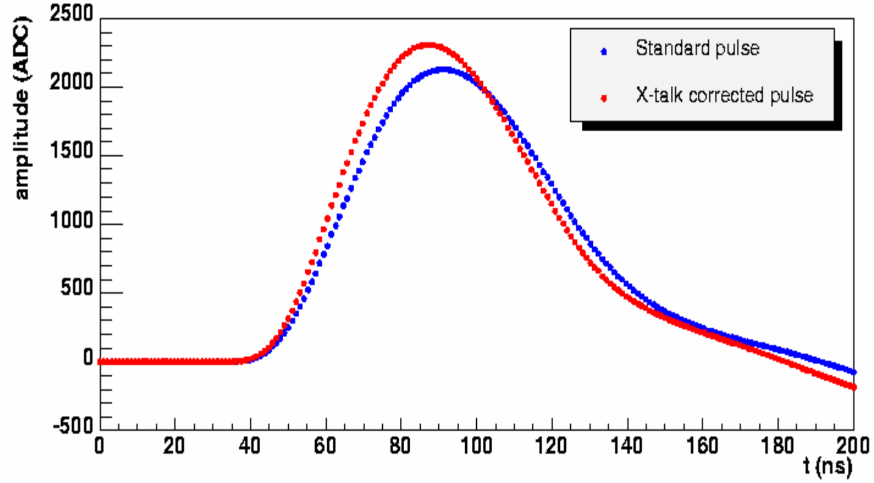
- In general a very good stability of pedestals was observed…
- … but the temperature dependence may become important in case of cooling problems
  - ✓ FEC cooling was not the ATLAS final system, such an important correction is not expected at ATLAS
- The effect is small, but since we are looking for precision, we uses pedestals from random trigger varying during a run

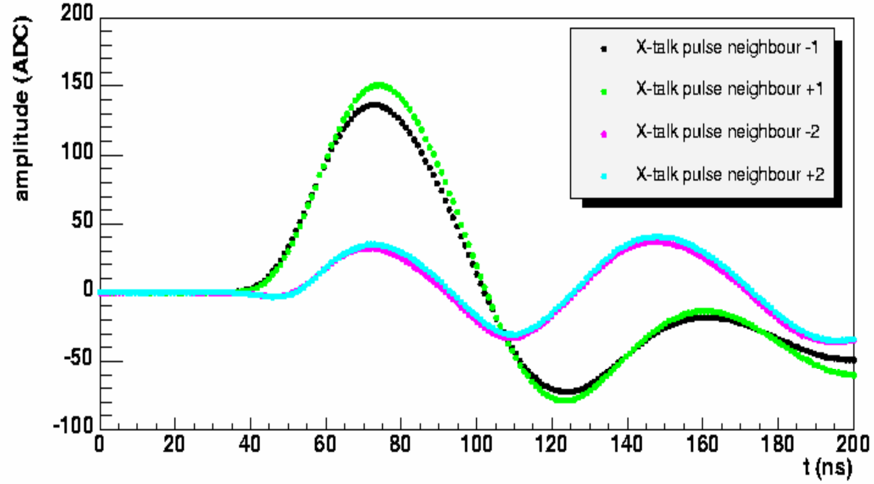


Difference w.r.t. reference pedestal run as a function of the event (< 3 ADC)

Average value as saved in conditions database

Cross talk correction in the EMC first sampling

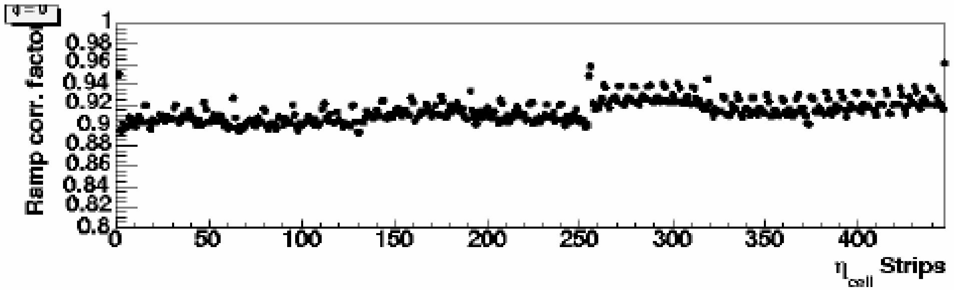




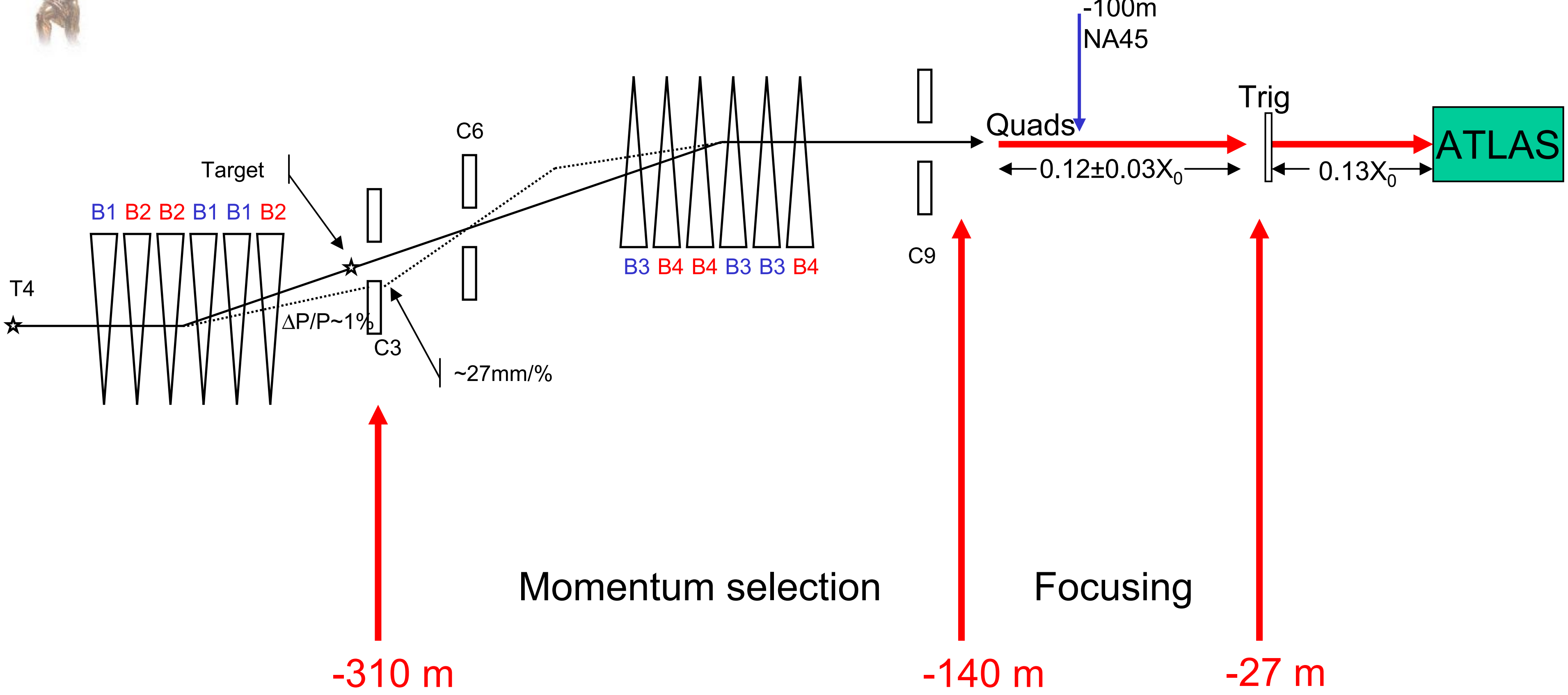
- Prescription

$$\widetilde{E}_{w/o\ X-Talk} = E_{pulsed} + E^1_{1st\ Nghb.} + E^2_{1st\ Nghb.} + \frac{E^1_{2nd\ Nghb.} + E^2_{2nd\ Nghb.}}{2}$$

- Electronic gain correction
  - ✓ Ration between delay pulse peaks without an with X-talk prescription
- OFC correction
  - ✓ Use cross-talk corrected calibration pulses to predict physics pulses, from which compute OFC

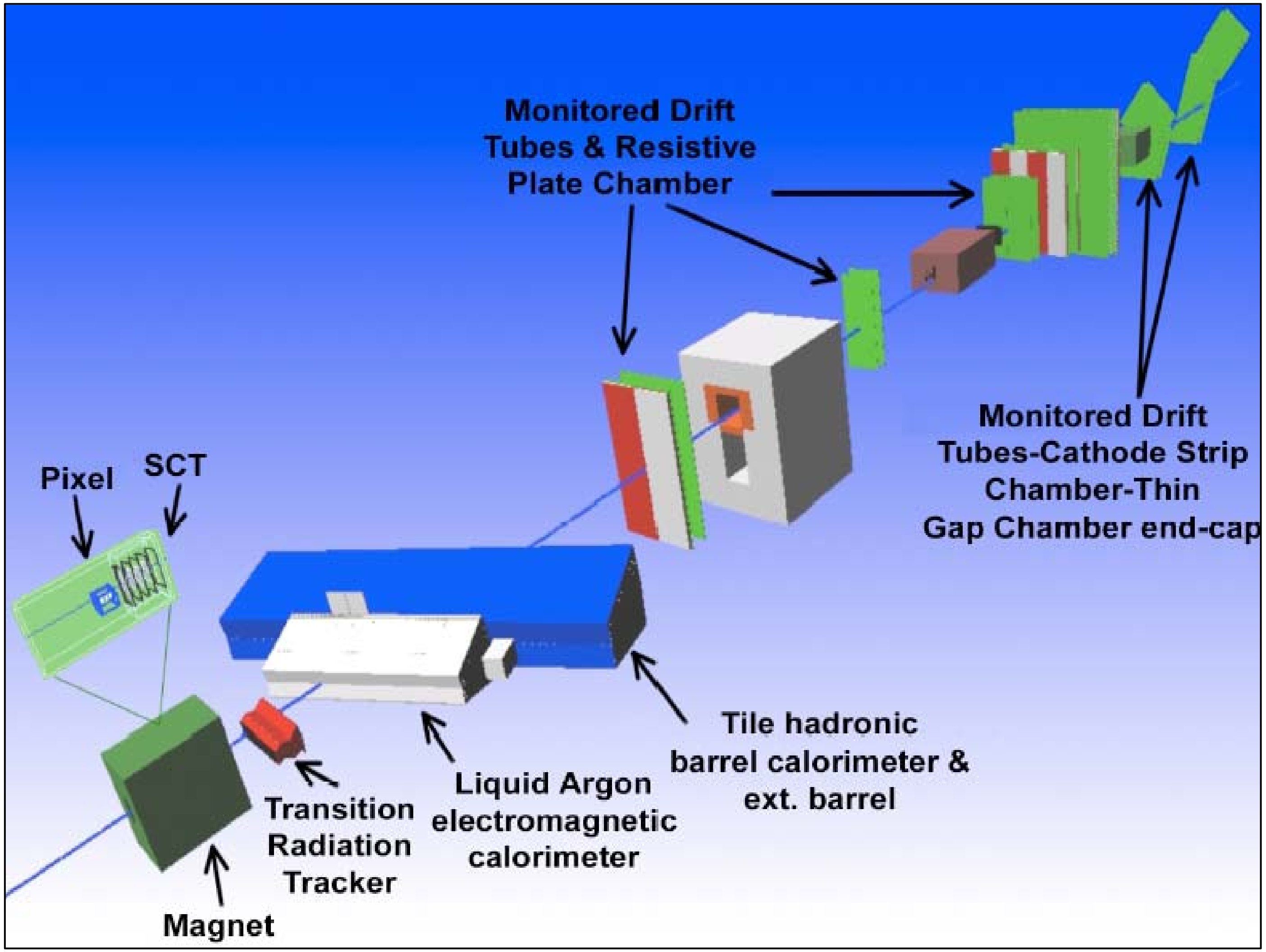


H8 beam line



Trigger acceptance depends on energy loss and angular distribution of electrons. Acceptance functions have been produced and will be tested with data in combined runs. Inner Detector an important player here.

H8 G4 simulation setup

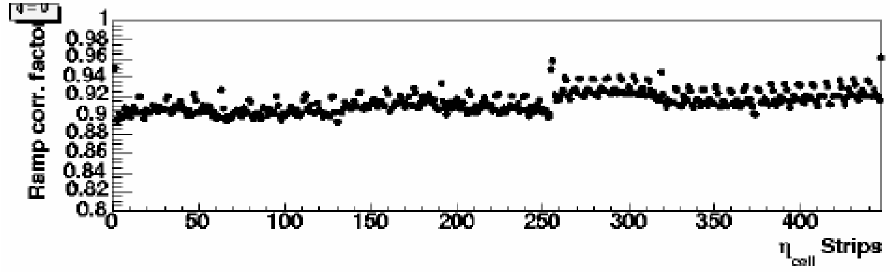


EMC G4 simulation details

Data factors:

PS Correction = **1235/1149** → G4 → (ADC2MeV G4v4.8) / (ADC2MeV G4v4.7)

Strip X-talk Correction = **0.91** → Measured →



MC factors:

EM global scale = **0.975** → Matched → Tuned on high energy run

PS scale = **0.946** → Losses at φ=0 due to non-modelling of the PS module crack.

Back-tracking data quality

- Initial track parameters are obtained from the input TRT track
- Field integral information is used to make a momentum estimate
- Actual tracking is obtained using the xKalman technique