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Calibration and Ionization Signals in the Hadronic End-Cap Calorimeter of ATLAS

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OUTLINE

- Hadronic end-cap calorimeter
- Electronics layout

- HEC electronics chain
- Chain model functions

- Calibration procedure
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- Accuracy of reconstruction

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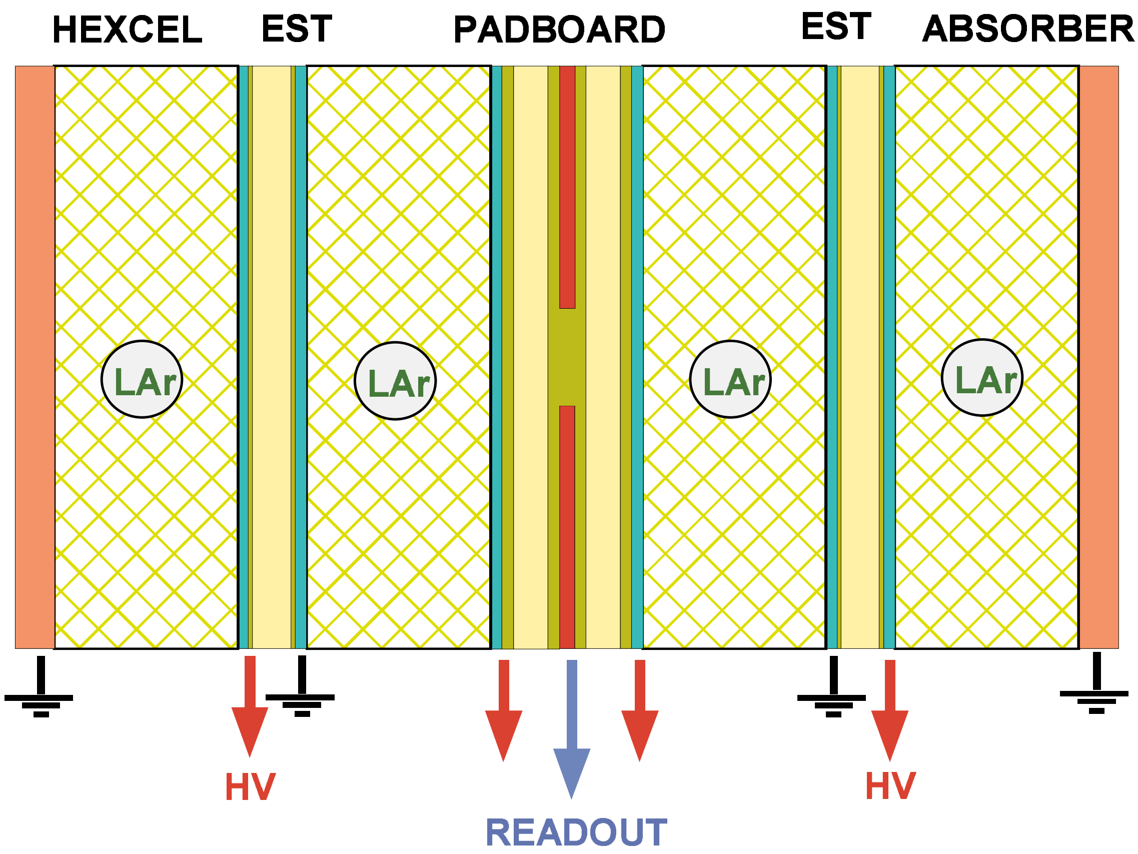
- Summary

Hadronic End-Cap Calorimeter

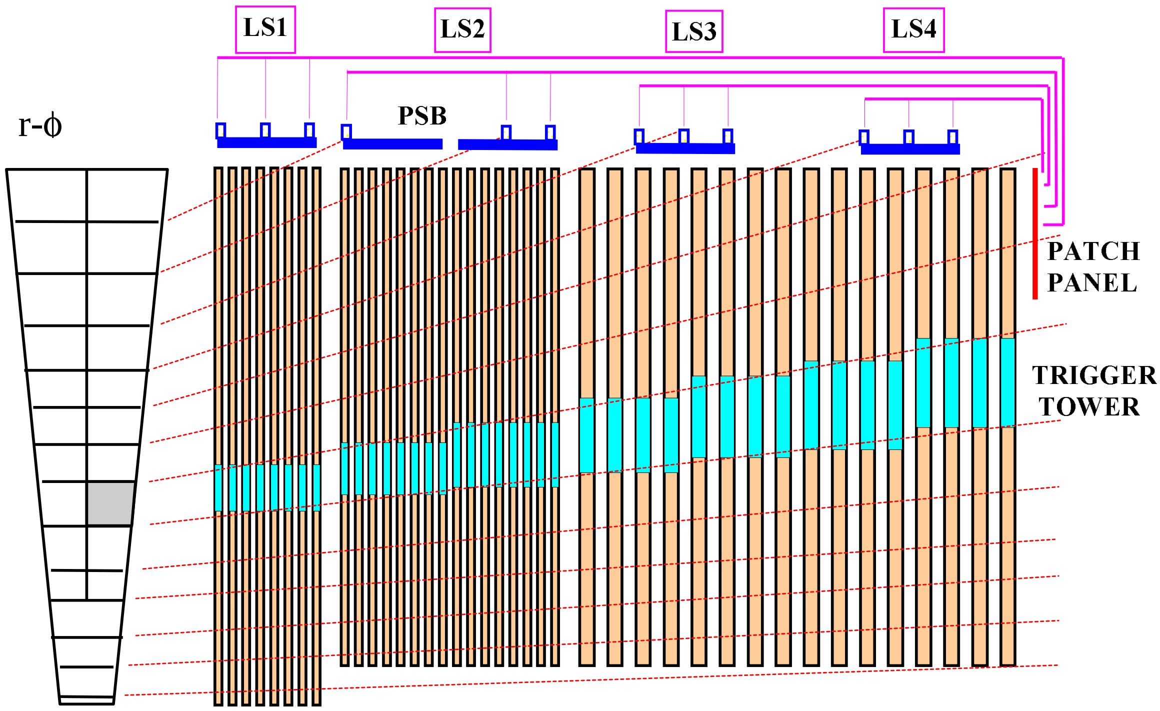
- HEC is the LAr calorimeter with copper plate absorbers and electrostatic transformer readout.



- Gap between absorber plates: 8.5 mm, LAr gap: 1.97 mm, working HV: 1800 V, electron drift time: 450 ns. Ionization current 7.7 μA/MeV
- Front module: copper 25 mm. Visible energy = 1/26, rear module: copper 50 mm. Visible energy = 1/52.
- Total 40 gaps. 4 readout longitudinal segments (8-16-8-8). Signals from 2 subsequent gaps are fed to one preamplifier.
- Pad dimensions: $\eta \times \phi = 0.1 \times 0.1$ for $\eta < 2.5$ and 0.2×0.2 for $\eta > 2.5$

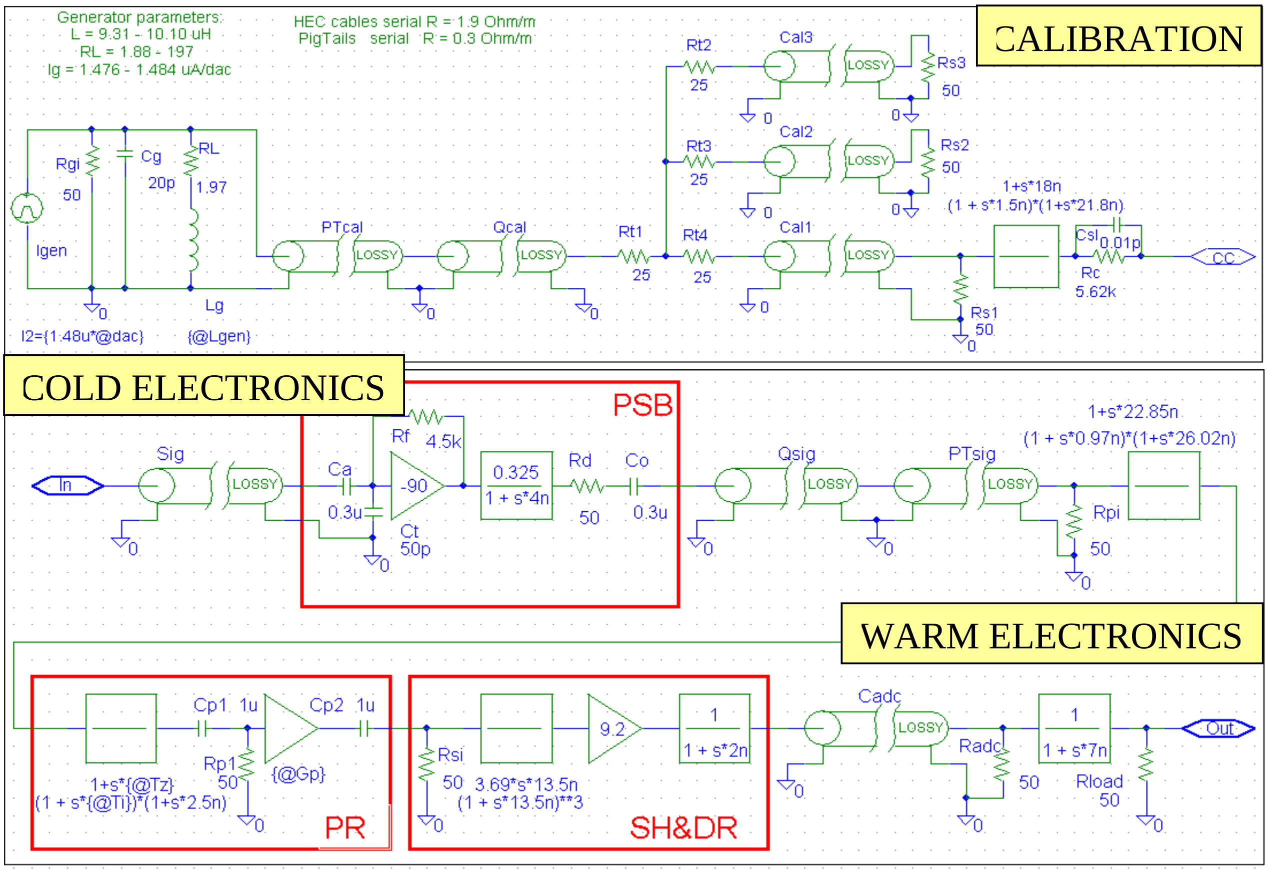
Electronics Layout

- GaAs preamplifiers are mounted on preamplifying and summing boards (PSB) placed on the outer radius of the module.



- All cables are coaxial 50Ω, from pad to PSB: 0.2–2 m, cables from PSB to patch panel: 5.6m, from patch panel to feedthrough: 2.7m. Total length: 8.5–10.3m.
- Calibration signal comes to the pad level. Calibration cables: 11.9 m.
- Warm electronics is mounted on the front-end board (FEB), placed in the crate on the feedthrough.
- Analog part of the FEB: preshaper (pole-zero compensation of rise time and additional integration) and RC^2-CR shaper.

HEC Electronics Chain



- For the calibration procedure the signals have to be described by analytical function. This function is obtained by parameterization all the chain parts (next slide).

- Rational functions (poles and zeros) in frequency domain give exponential functions in time domain.

- Parameters are obtained on the basis of a set of measurements in laboratory conditions and in the test beam setup.

- Calibration chain: 11 parameters, signal chain: 16 parameters. Two sets: at room temperature and in LAr.

HEC Chain Model Functions

Generator voltage, CDB, SL

$$Ig \cdot Rl \cdot \frac{\alpha + s \cdot \tau c}{s \cdot (1 + s \cdot \tau c)} \cdot \frac{1}{3} \cdot \frac{1}{Rc + Rin}$$

where $Rl = \frac{Rig \cdot (Rt + Rcc)}{Rig + Rt + Rcc}$, $\alpha = \frac{Rg}{Rl + Rg}$, $\tau c = \frac{Lg}{Rl + Rg}$

Calibration cable

$$\frac{ac \cdot (1 + s \cdot \tau zc)}{(1 + s \cdot \tau oc)(1 + s \cdot \tau pc)}$$

where $ac = \frac{Rt}{Rt + Rcc}$

PSB

$$\frac{Ra}{(1 + s \cdot \tau a) \cdot (1 + s \cdot \tau d)}$$

where $\tau a = Ra \cdot (Cd + Ca)$

Signal cable

$$\frac{as \cdot (1 + s \cdot \tau zs)}{(1 + s \cdot \tau os)(1 + s \cdot \tau ps)}$$

Preshaper

$$\frac{Gp \cdot (1 + s \cdot \tau pz)}{(1 + s \cdot \tau i)(1 + s \cdot \tau o)}$$

Shaper, FEB driver, ADC cable

$$\frac{Gs \cdot s \cdot \tau s}{(1 + s \cdot \tau s)^3 (1 + s \cdot \tau fd) \cdot (1 + s \cdot \tau ac)}$$

Calibration signal on pad level

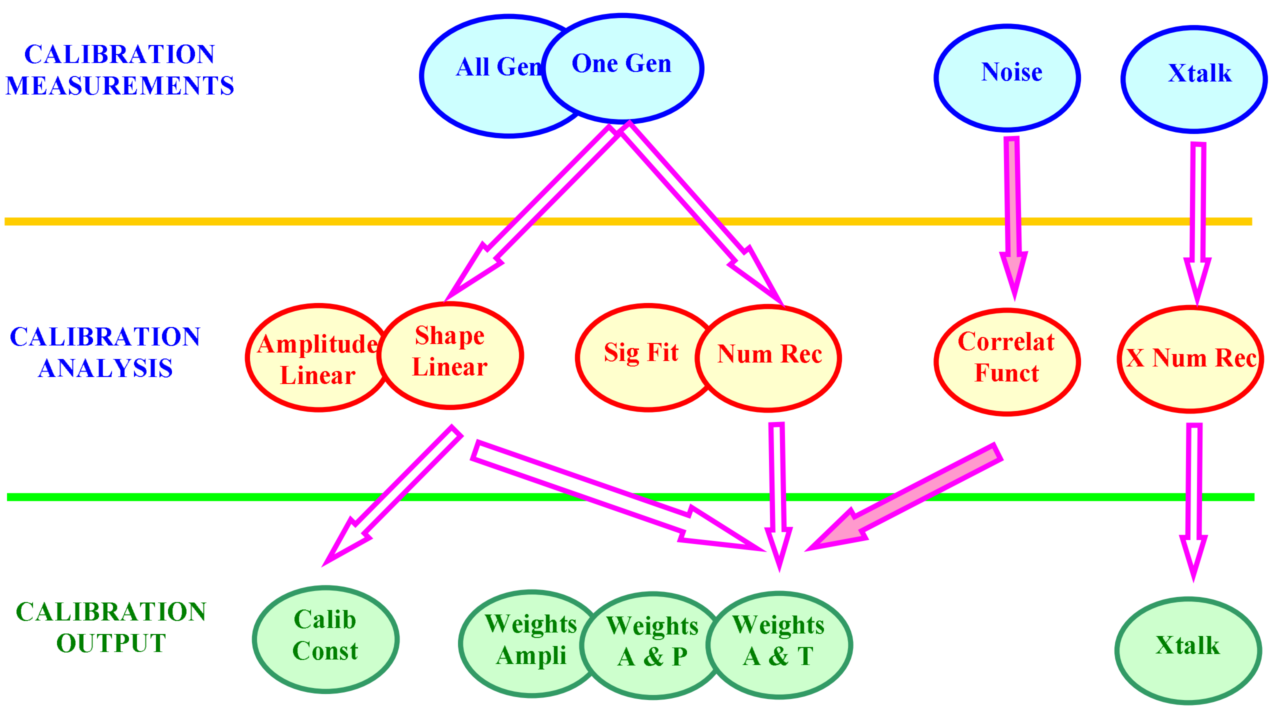
$$\frac{Ig \cdot Rl \cdot ac}{3 \cdot (Rc + Rin)} \cdot \frac{(\alpha + s \cdot \tau c)(1 + s \cdot \tau zc)}{s(1 + s \cdot \tau c)(1 + s \cdot \tau oc)(1 + s \cdot \tau pc)}$$

Signal chain transfer function

$$\frac{Ra \cdot as \cdot Gp \cdot Gs \cdot \tau s \cdot s \cdot (1 + s \cdot \tau zs)(1 + s \cdot \tau pz)}{(1 + s \cdot \tau a) \cdot (1 + s \cdot \tau d)(1 + s \cdot \tau os)(1 + s \cdot \tau ps)(1 + s \cdot \tau i)(1 + s \cdot \tau o)(1 + s \cdot \tau s)^3 (1 + s \cdot \tau fd) \cdot (1 + s \cdot \tau ac)}$$

Calibration Procedure

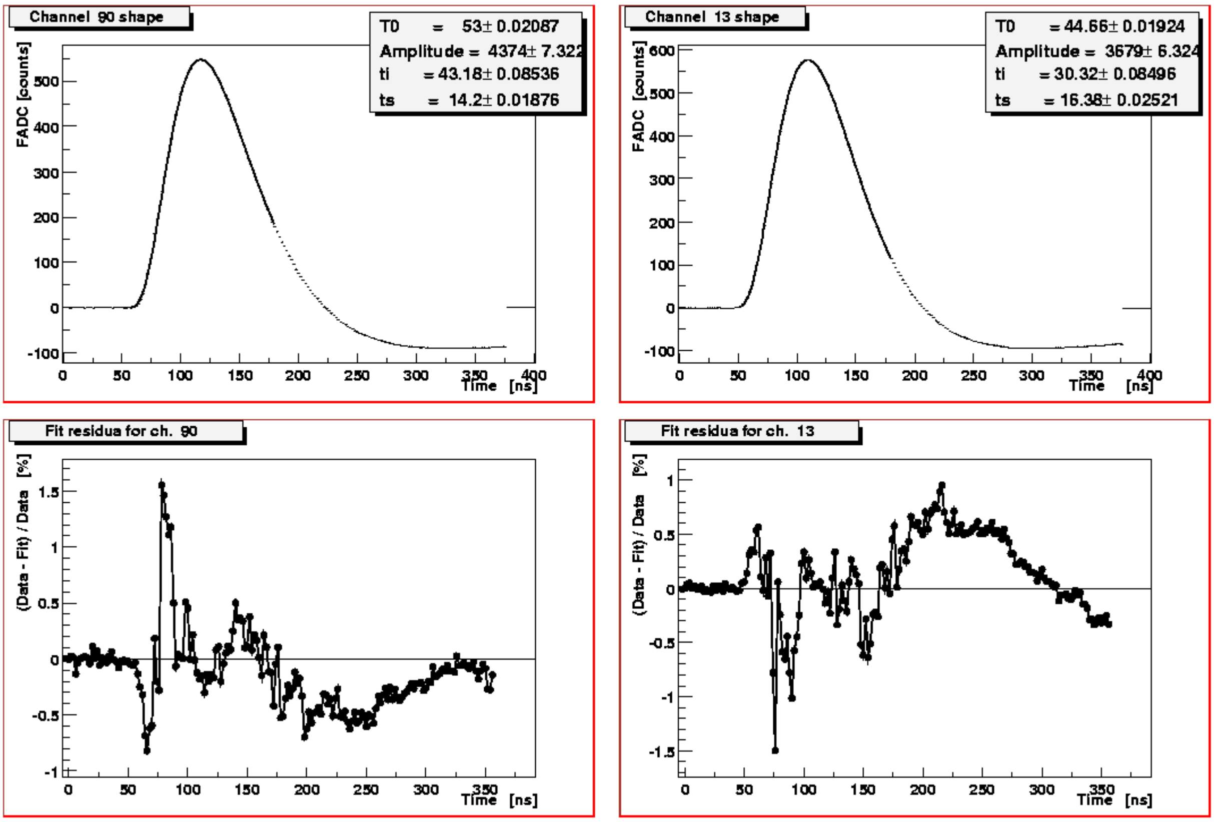
- Steps of the calibration procedure in the test beam environment:
  - Measurements (pulsing all channels, amplitude scan, delay scan);
  - Reconstruction (recalculation from calibration pulse shape to ionization signal);
  - Output (weights, nonlinearity corrections, etc.)



- Calibration board and electronics chain are very close to the final ATLAS version.
- Home made software for calibration steering and data taking.

Signal Reconstruction by Fit

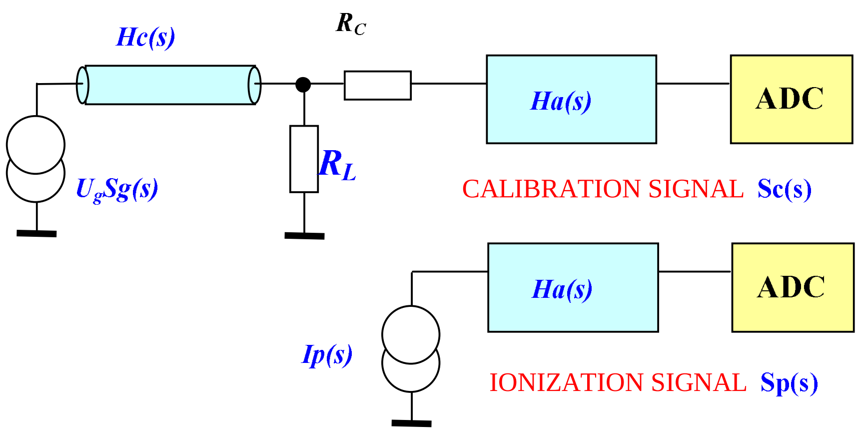
- Functions in time domain for calibration and for ionization signals are obtained analytically.
- Fit of calibration signal with 2 free parameters and then calculation of the ionization response.
- Typical fit residual in the range of signal peak is ±1%.



- Typical residual of the ionization shape prediction (checked for the restricted number of channels with electron signals) is ±2%.
- Improvement is possible by making model more complicated. Disadvantage is the CPU time needed for the analysis.

Numerical Reconstruction

- Idea is based on the fact that the ionization current is fed through the same chain as the calibration current.



- So, the prediction of particle response can be done directly from the measured calibration signal, without involving the model of the signal chain.
- Calibration and ionization signals in s-domain:

$$Sc(s) = Ig \cdot Hg(s) \cdot Hc(s) \cdot Ha(s)$$

$$Sp(s) = Ip(s) \cdot Ha(s)$$

- Signal chain response *Ha(s)* can be excluded:

$$\frac{Sp(s)}{I_P} = \left[\frac{Tr(s)}{Hg(s) \cdot Hc(s)}\right] \frac{Sc(s)}{I_C}$$

- In the time domain it gives the convolution:

$$\frac{Sp(t)}{Ip} = \int_{-\infty}^{\infty} \frac{Sc(x)}{Ic} R(t-x)dx$$

Numerical Reconstruction Algorithm

- Prediction of the ionization signal is made by calculating the convolution of the measured calibration signal with kernel function *R(t)*.
- This function is obtained from the model of the calibration chain and the triangular ionization current shape. Calculations are done analytically. The result is (*Tc(t)* is the normalized calibration shape):

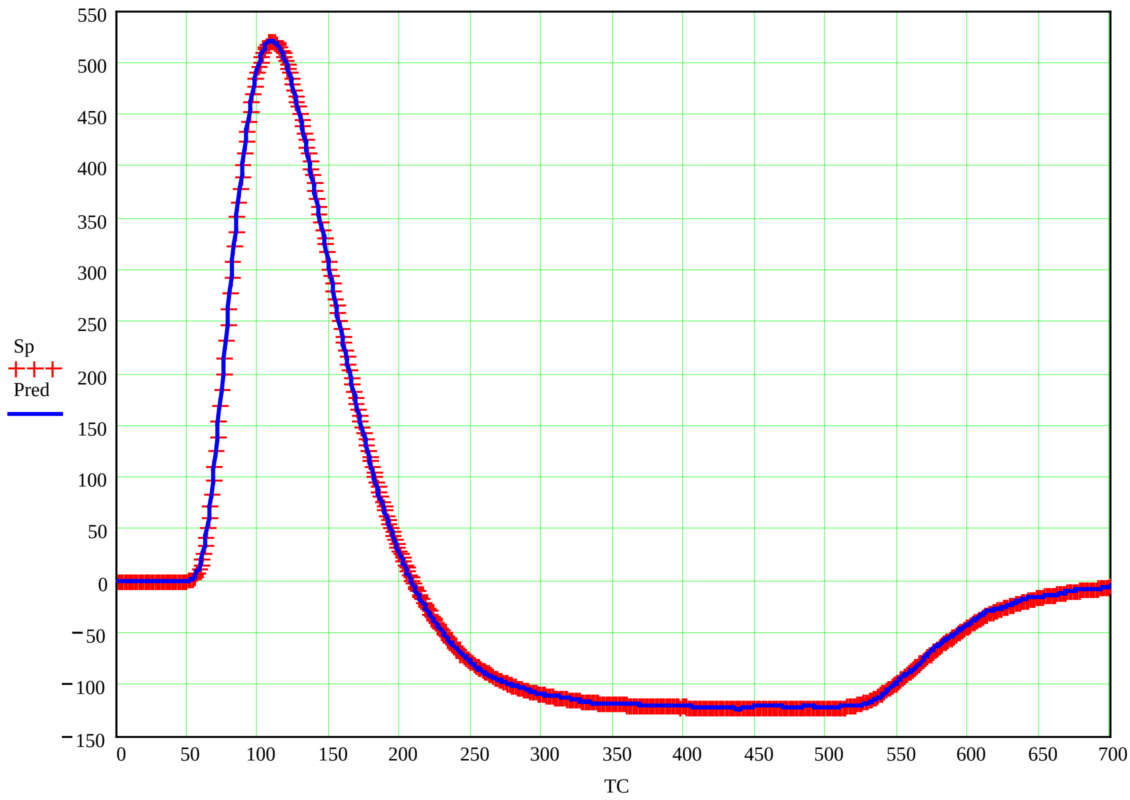
$$T_P(t) = T_C^I(t)\cdot r2 + T_C(t)\cdot\left(r1 - \frac{r2}{\tau_{DR}}\right) + T_C(t-\tau_{DR})\cdot\frac{r2}{\tau_{DR}} + \int_{t-\tau_{DR}}^{t} T_C(x)Rd(t-x)dx + \int_{-\infty}^{t-\tau_{DR}} T_C(x)Ro(t-x)dx$$

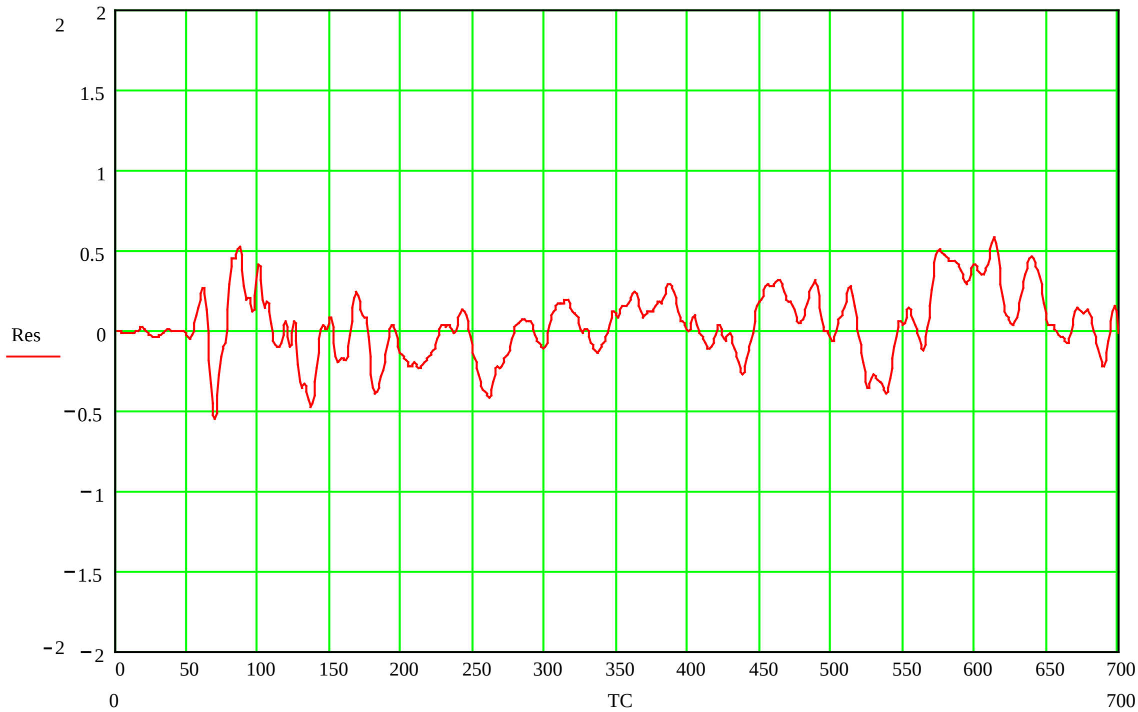
- Values of r1, r2 and other numbers are determined by the calibration chain parameters.
- Comparison shows that the NR method is much faster than the fitting procedure:

Method	Free parameters	CPU sec/ch.
NR	--	0.25
	to	6.0
	to, a	9.7
Fit	*to, a, τi*	22
	to, a, τi, τs	40

Accuracy of Reconstruction

- Checked with electron 100 GeV signals. Typical residual is ±0.5%.





Open Problems

- Calibration signal for low DAC levels is destroyed by parasitic effects like "command feedthrough". So, the precise calibration is not yet possible in the region of muon signals.
- Calibration shapes obtained in synchronous mode (delay scan) have small irregularities due to the imperfections in the delay chip. It can be avoided either by correcting delay constants or by using asynchronous mode.
- It was observed small shape variation vs. DAC level. This effect has to be studied, understood and applied in the linearization procedure (corrections for nonlinearity).
- Crosstalk between pads in the HEC can reach 2-3%. It has the shape different from the original signal shape, so the corrections are needed. Some tuning of the calibration measurements and analysis would be required.
- Accuracy of the calibration in the test beam conditions is affected by the stability of the electronics (no temperature stabilization, calibration made only once per week).

Summary

- Calibration and signal electronics of the HEC is well understood and modeled.

- The calibration procedure is established and runs in the HEC beam tests.

- Two alternative methods of the particle signal reconstruction are developed and applied for the test beam data analysis. The residuals level of $\pm 0.5\%$ is reached.

- Some minor problems still have to be solved in order to improve the quality of calibration.