Calibration of the LHCb calorimetric system

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27 February – 3 March 2017, Novosibirsk, Russia

LHCb calorimeter system

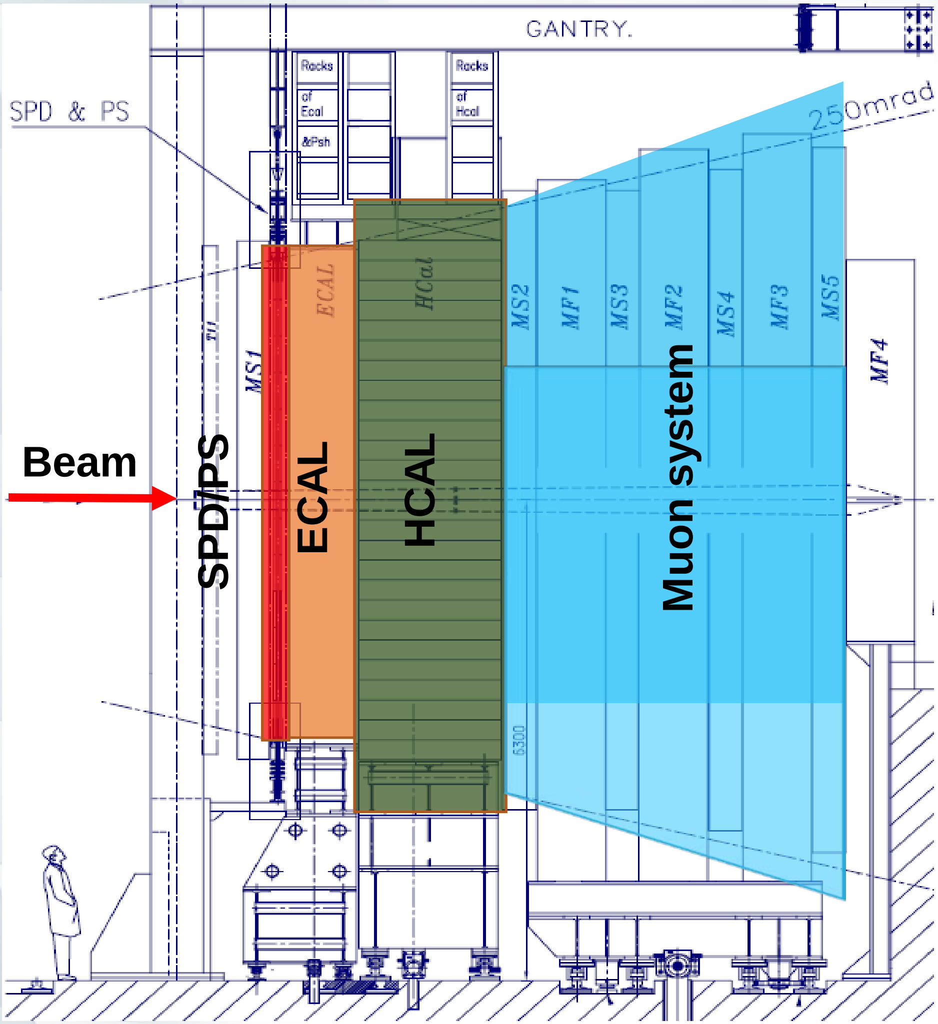


Fig. 1: General view of the LHCb calorimeter and muon system

Calorimeter system consists of:

- **scintillator-pad detector (SPD);**
- **preshower detector (PS);**
- **electromagnetic calorimeter (ECAL);**
- **hadronic calorimeter (HCAL)**

Main goals:

- **to provide Level-0 (L0) trigger;**
- **particle identification and energy reconstruction**

- **More details on design of the LHCb calorimeter system: talk of Yuri Guz**

SPD and PS

SPD/PS description:

- **Structure:**
  - **Scintillator Pad – lead plane – Scintillator Pad;**
- **Light collection and readout:**
  - **WLS – fibers**
  - **64-channel multi - anode PMT HAMAMATSU R7600**

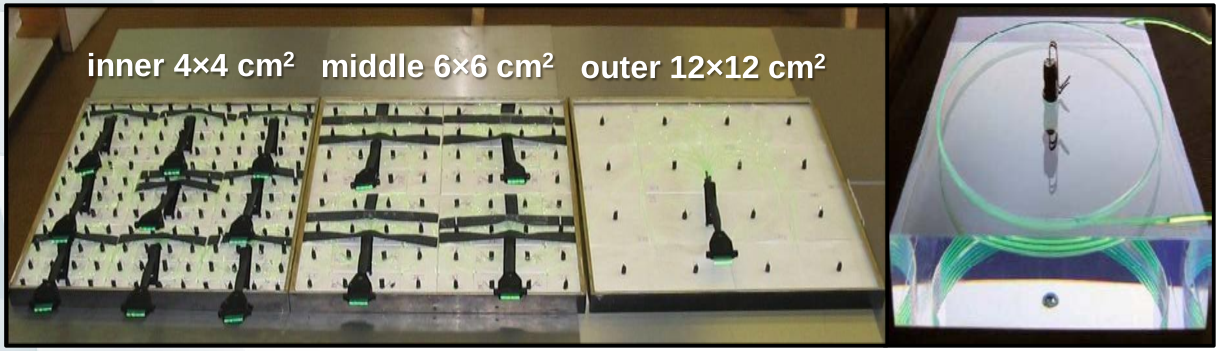


Fig. 2: Photo of the SPD/PS modules

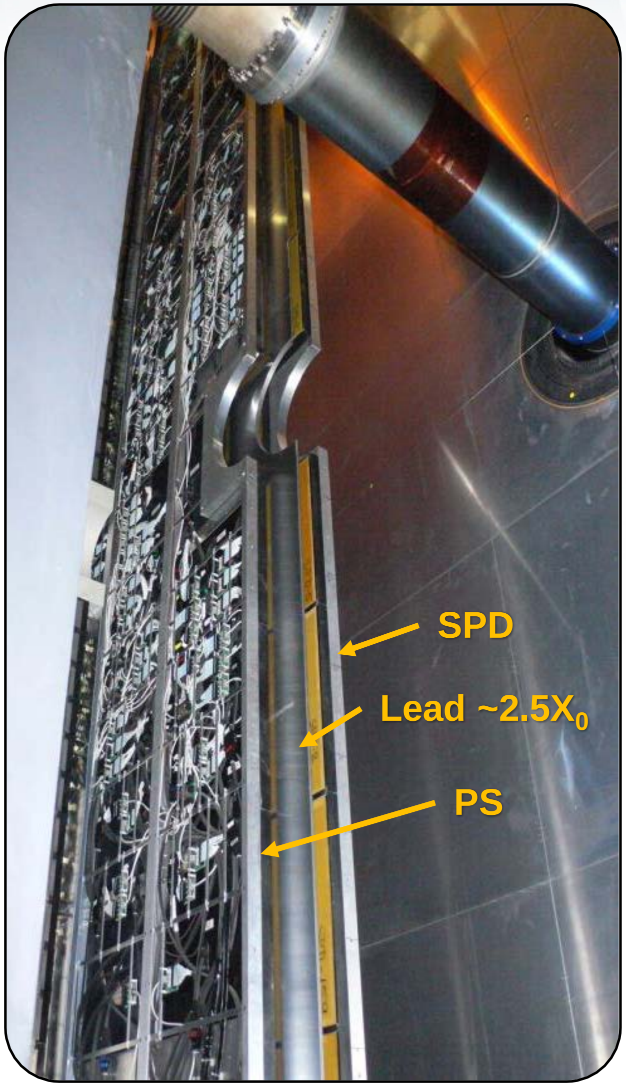


Fig. 3: Photo of the SPD and PS

ECAL

ECAL description:

- **performed in «shashlik» technology;**
- **subdivided into three zones: outer (1), middle (2) and inner (3);**
- **number of detection cells depending on zone**

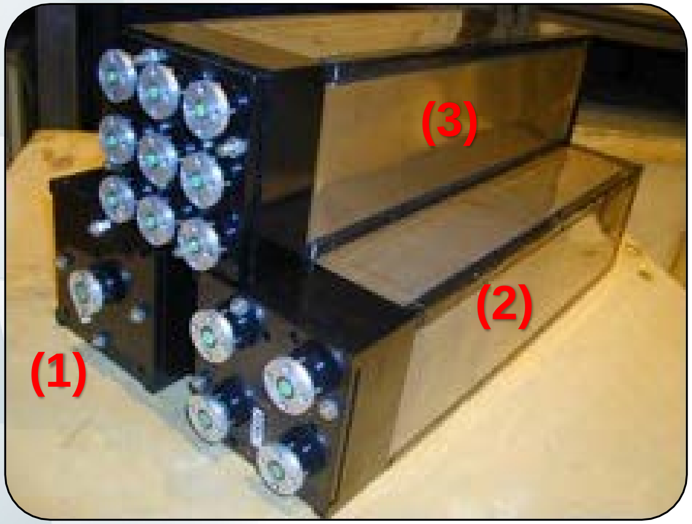


Fig. 4: Photo of the ECAL modules for three sections

Energy resolution:

$$\frac{\sigma_E}{E} = \frac{(8.5 \div 9.5)\%}{\sqrt{E}} \oplus 0.8\%,$$

where *E* – energy in GeV

[2008 JINST 3 S08005]

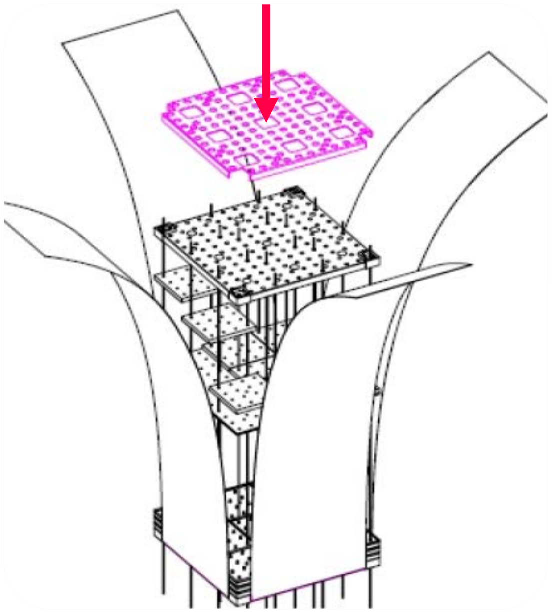


Fig. 5: Inner structure of the ECAL module

HCAL

HCAL description:

- **performed in the ATLAS TileCal technology;**
- **two symmetrical halves, system is subdivided into inner and outer zones;**
- **detection cells are subdivided into six sections in longitudinal direction**

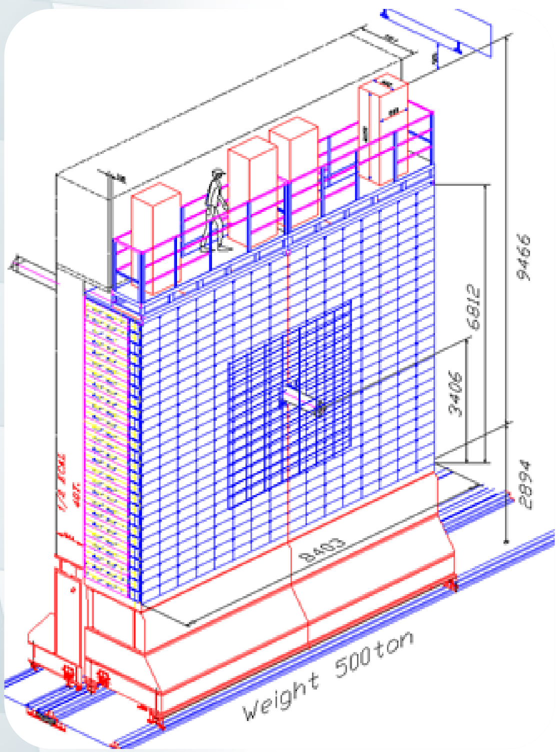


Fig. 6: Schematic view of the HCAL

Energy resolution:

$$\frac{\sigma_E}{E} = \frac{(69 \pm 5)\%}{\sqrt{E}} \oplus (9 \pm 2)\%,$$

where *E* – energy in GeV

[2008 JINST 3 S08005]

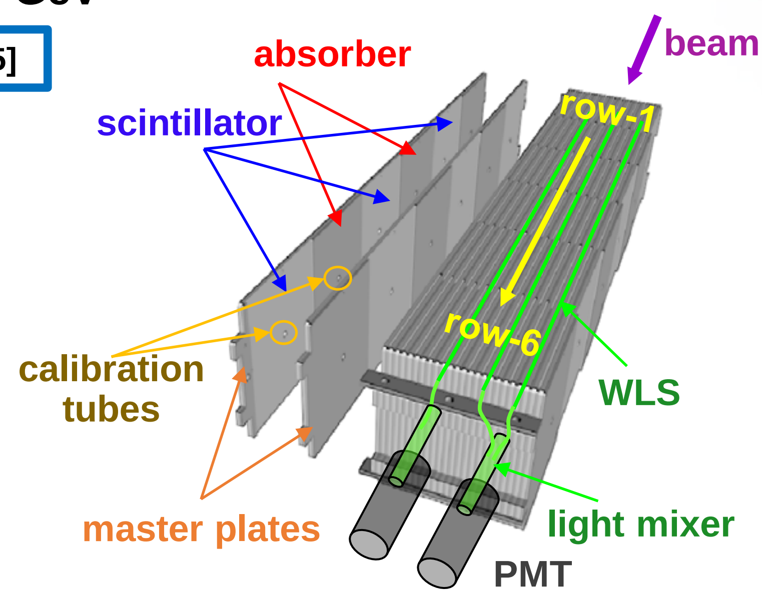


Fig. 7: Inner structure of the HCAL cell

Calorimeter system functionalities

PS/SPD particle identification for L0 photon and electron trigger:

- e^-, π^0, γ separation by PS;
- γ/MIP separation by SPD;
- charged multiplicity by SPD

ECAL:

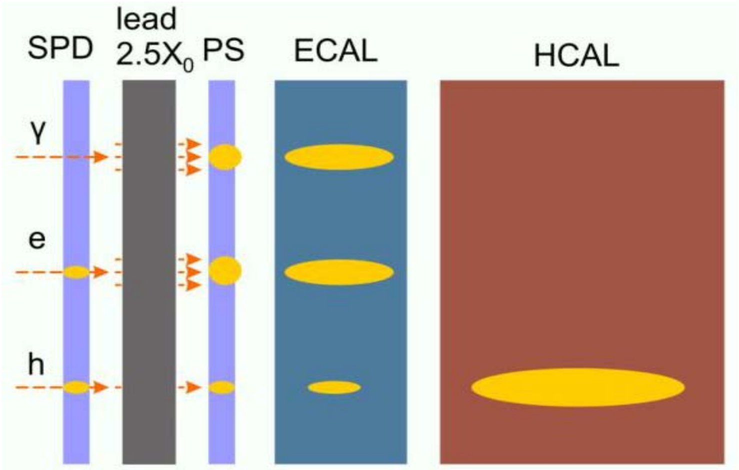
- high E_T electrons, photons and π^0 for L0 trigger;
- reconstruction of π^0 and photons (+ PS);
- particle ID (+ PS)

HCAL:

- high E_T hadrons;
- contributes to Muon ID;
- provides ~ 70% of L0 trigger output (500 kHz out of ~1 MHz)

Table 1: Coincidence of the calorimeter system

SPD	PS	ECAL	HCAL	
1	1	1	0	e
0	1	1	0	γ
1	0	0	1	h



Calorimeter system parameter summary

Table 2: Selected parameters of calorimeter system

Sub-detector	SPD/PS	ECAL	HCAL
Number of channels	2×6016	6016	1488
Lateral size	6.2×7.6 m^2	6.3×7.8 m^2	6.8×8.4 m^2
cell size in mm: • **inner** • **middle** • **outer**	SPD(PS): 39.66(39.84); 59.5(59.76); 119(119.5)	40.4; 60.6; 121.2	131.3; (no middle section);262.6
Longitudinal depth	180 mm – 2.5X_0 – 0.1 λ_I	835 mm - 25X_0 – 1.1 λ_I	1655 mm - 5.6 λ_I
Light yield	~ 20 ph.el./MIP	~ 3000 ph.el./GeV	~ 105 ph.el./GeV
Basic requirement	Average light yield ~ 20 ph.el./MIP	$\frac{(8.5 \div 9.5)\%}{\sqrt{E}} \oplus 0.8\%$	$\frac{\sigma_E}{E} = \frac{(69 \pm 5)\%}{\sqrt{E}} \oplus (9 \pm 2)\%$
Dynamic range	0-100 MIPs – 1 bit (SPD) 10 bits (PS)	$E^{max} = 10 + 7 \cdot \sin\Theta$	$E^{max} = 30 / \sin\Theta$

ECAL and HCAL dynamic range adjusted in each cell according to cells: $\sin\Theta = \sqrt{x^2 + y^2} / \sqrt{x^2 + y^2 + z^2}$

ECAL calibration strategy

Method:	Accuracy:	Periodicity:
• Initial calibration	• ~ 10%	• before LHC startup
• energy flow method	• ~ 5%	• with the first data in 2010
• π^0 meson reconstruction	• ~ 2 – 2.5%	• every month

[Int. J. Mod. Phys. A 30 (2015) 1530022]

Stability of PMT gains is monitored each 15 minutes by an LED system. Corrections are applied automatically.

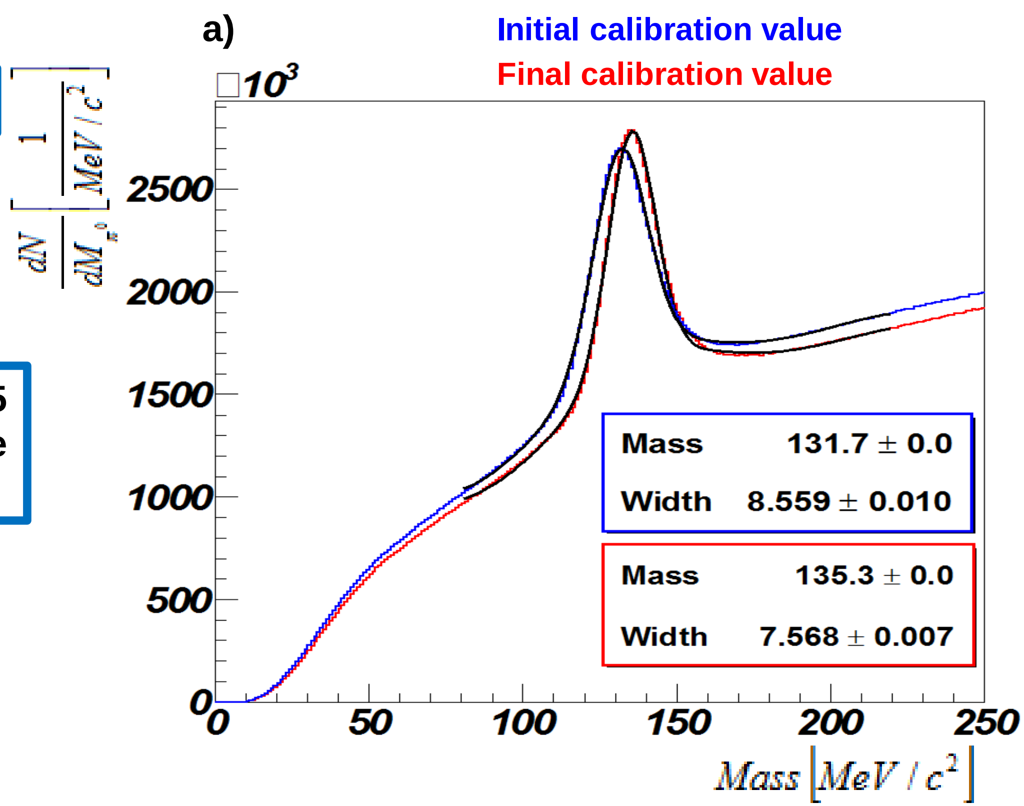


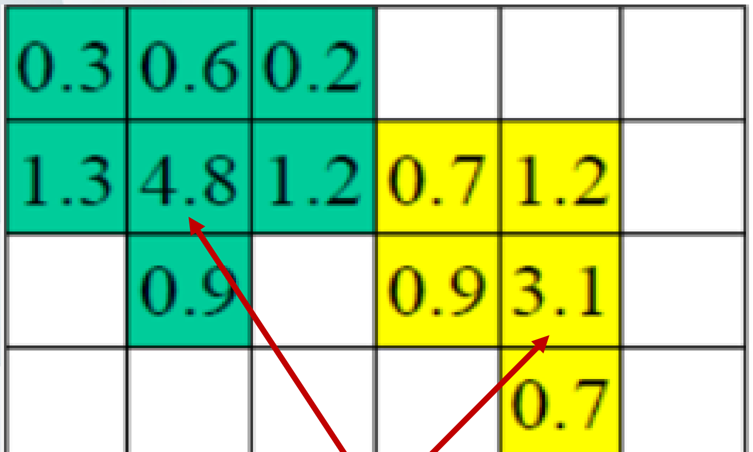
Fig. 8: Distribution of π^0-meson invariant mass

ECAL π^0 invariant mass calibration

The fine absolute calibration method uses reconstructed π^0 meson invariant mass:

- **allows to achieve the accuracy of calibration of 2%**

Step 1: photon reconstruction by the standard experiment algorithms



Central (seed) cells of the cluster

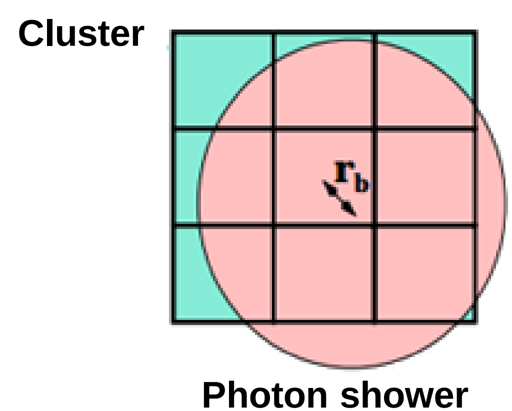
Fig. 9: Energy deposition in the cluster cells

Reconstructed photon energy:

$$E_\gamma^{rec} = E_{prs} \times \beta + (E_{seed} + \sum_{i \neq seed} E_i') \times \alpha$$

Energy deposition in preshower detector

Out of the shower outside the cluster
Moliere radius 3.5 cm



- **seed cell is defined as maximum energy cell in the cluster;**
- **at low energy deposition in the preshower detector the reconstructed photon energy is substantially defined by the energy of the seed cell**

ECAL π^0 invariant mass calibration

Step 2: selection of photon pairs, which form π^0-candidate

Algorithm in C++ language

$$M_{\pi^0}^2 = 2E_1^\gamma E_2^\gamma (1 - \cos\theta_{\gamma\gamma})$$

Photons energies ($E_1^\gamma E_2^\gamma$)

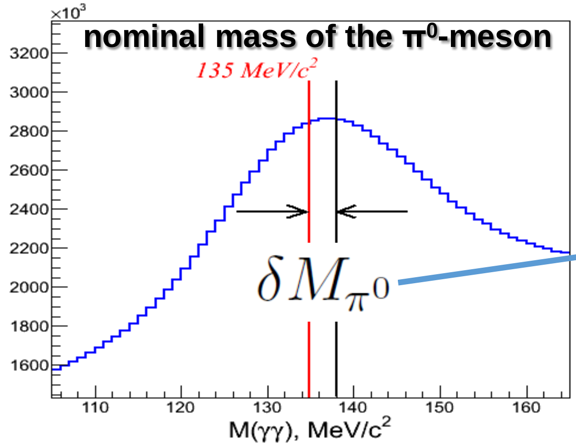
Opening angle between photons ($\cos\theta_{\gamma\gamma}$)

For all ECAL cells

Step 3: select photon pairs, for which the cell is the central cell of the cluster

Step 4: determination of the shift of π^0-meson mass from the nominal value in the given cell

Program modules in Python language



$$\frac{\delta M_{\pi^0}}{M_{\pi^0}} = \frac{1}{2}\frac{\delta E_1^\gamma}{E_1}$$

Fig. 10: Distribution of π^0-meson invariant mass

ECAL π^0 invariant mass calibration

Step 5: estimation of the calibration coefficient:

Program modules in Python language

$$\lambda = 1.0 - \frac{\delta M_{\pi^0}}{M_{\pi^0}}$$

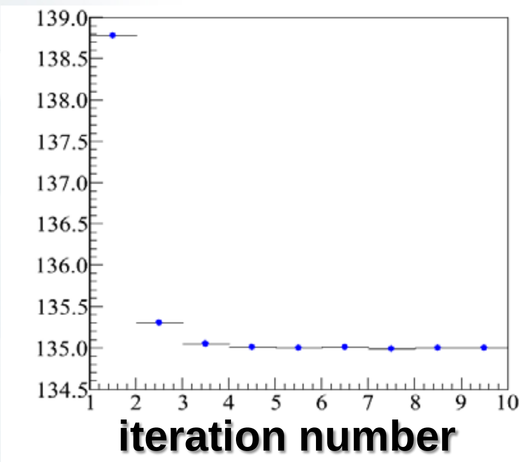
Step 6: «primary» iterations

Program modules in Python language

To correct for the fact that not all photon energy is deposited in the central cell of the cluster

π^0-meson invariant mass

a)



$$\lambda = \lambda_1 \times \lambda_2 \times \ldots \times \lambda_N$$

N – number of iterations, required to achieve convergence

mass resolution of π^0-meson

b)

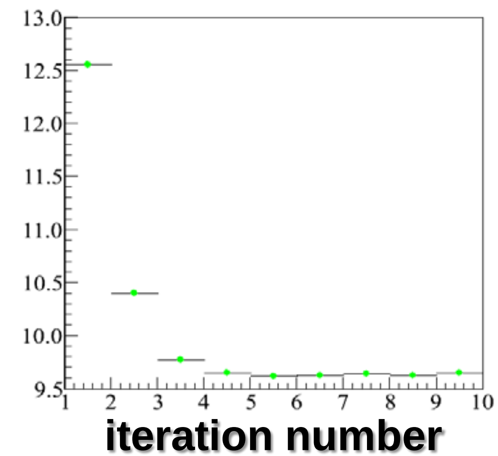


Fig. 11: Dependences of π^0 invariant mass (a) and mass resolution (b) on the number of iterations

Step 7: «secondary» iterations

Algorithm in C++ language

To account for the fact, that after applying calibration coefficients the cluster positions may change. After the third "secondary" iteration the values of majority of the coefficients vary by no more than 1%

HCAL cesium calibration system

HCAL calibration is performed with ^{137}Cs source:

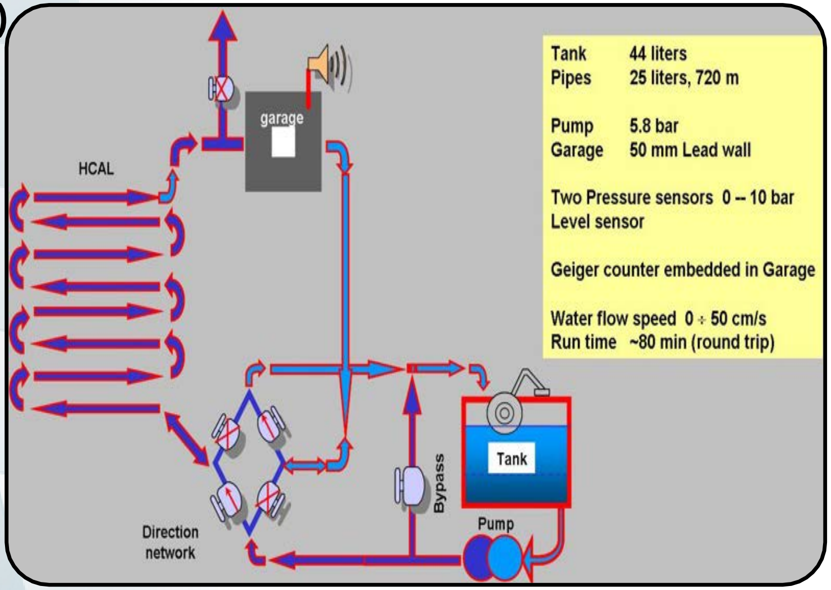
- **similar to the ATLAS TileCal system**
- **two ~ 10 mCi ^{137}Cs sources used (1 per each detector half);**

Features:

- **allows to measure the response of every scintillating tile;**
- **absolute normalization ~10% (the accuracy of the source activity measurements)**

During data taking LED monitoring system is used to control HCAL response

a)



b)

Each peak corresponds to response of one scintillator tile

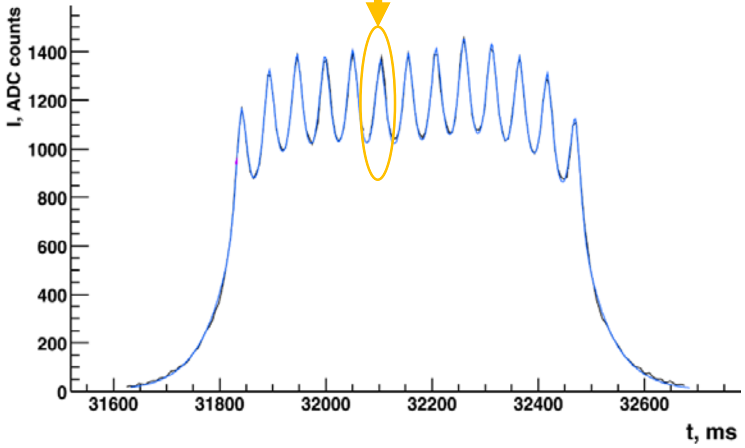


Fig. 12: Sketch of hydraulic system (a), PMT anode current as a function of run time (b)

^{137}Cs source movement system

Each module has a ~ 27 m embedded six-fold pipe. The pipe passes through the centers of each tile row. All modules are connected together.

- **between calibrations the source is housed inside lead container (so-called garage), the hydraulic pipe system is integrated into it;**
- **the source is driven by a pump, a system of valves determines the direction of water flow;**
- **average source speed ~ 30 cm/sec;**
- **calibration data taking is performed for both capsule movement directions**

Fig. 13: Photo of the garage

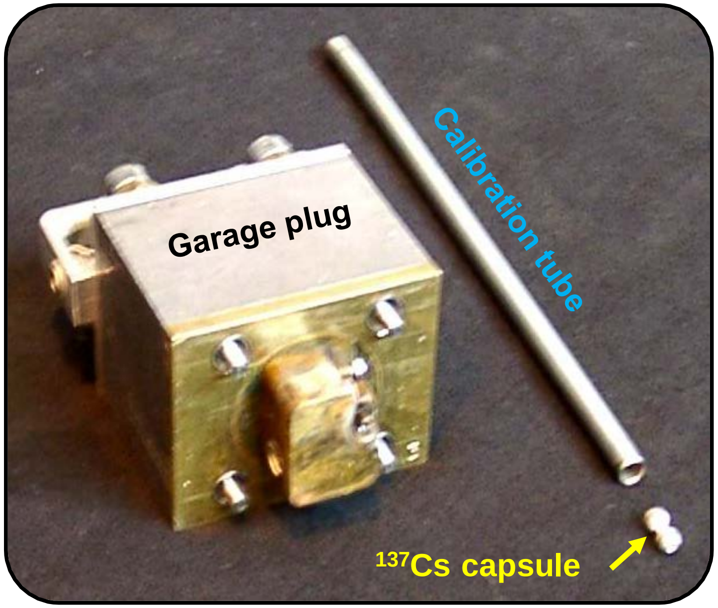


Fig. 14: Hydraulic system elements

HCAL ^{137}Cs calibration beam test results

The precision of the ^{137}Cs calibration was studied at the 50 GeV π^- beam in 2003 at SPS X7. Independent calibrations coincide within 2-3%. The ratio of sensitivities to ^{137}Cs γ - radiation to hadrons and scintillator light yield was measured:

$$\kappa_{Cs} = 41.07(20.88)\left[\frac{\text{nA/mCi}}{pC/GeV}\right]$$

- ratio of the sensitivities to ^{137}Cs and hadronic shower for outer (inner) cells

$$P_h = 105 \pm 5\left[\frac{\text{ph. el.}}{\text{GeV}}\right]$$

- scintillator light yield

[LHCb note 2003-143]

a) b)

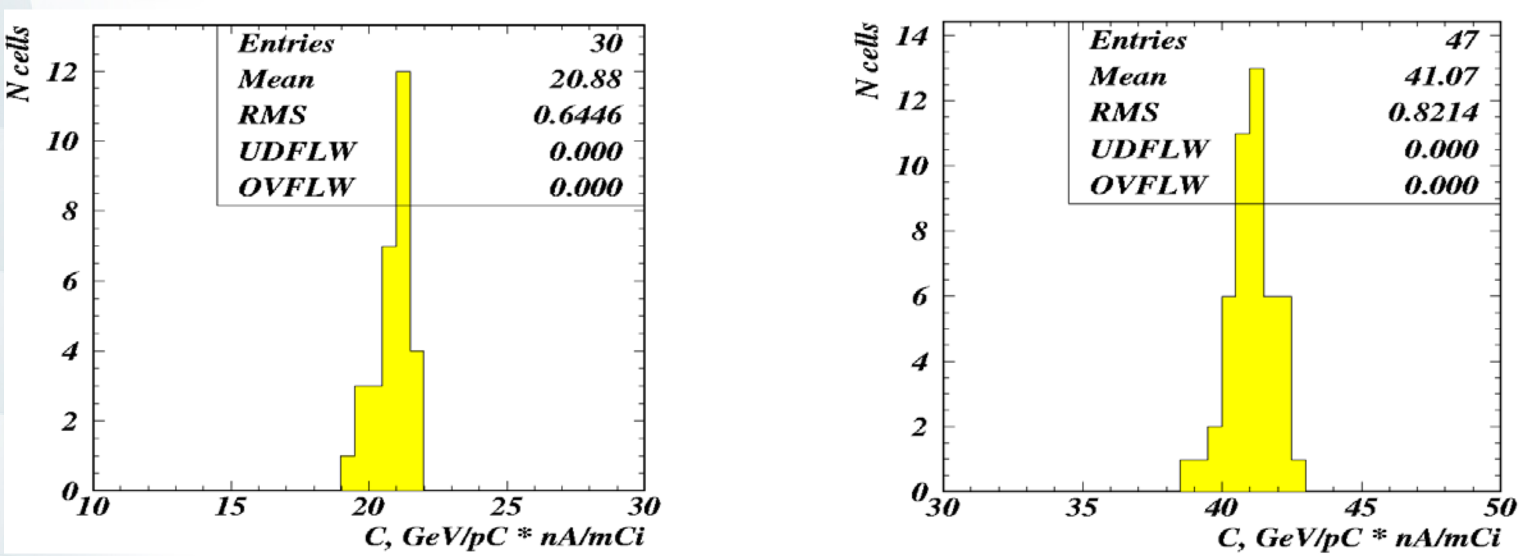


Fig. 15: The distribution of the ratio S_{Cs}/S_{π} for inner (a) and outer (b) cells

HCAL ^{137}Cs calibration data

Calibration data from 14.09.2016: measured PMT anode currents, illustrates the nominal calibration

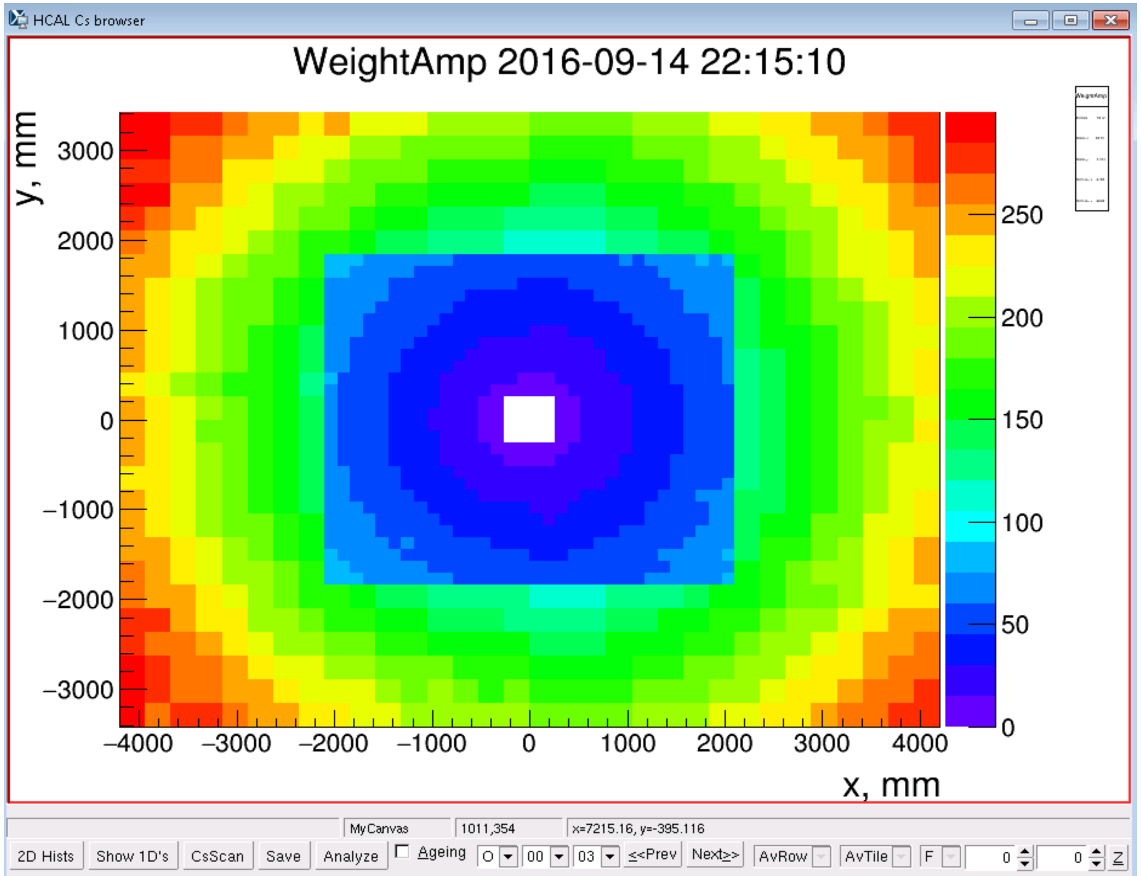


Fig. 16: Calibration results (map of average PMT anode currents)

HCAL ^{137}Cs calibration multipass runs

The effective regulation curves can be obtained from several sequential ^{137}Cs runs at different PMT HV settings. Multipass calibration is carried out once a year.

A PMT regulation curve could be parameterized in the form:

$$G^{eff} = G_0^{eff} \cdot HV^{\alpha}$$

G^{eff} **- determined under assumption that the light yield of the cell is ~100 ph.el/GeV**

The main goal is to obtain PMT regulation curve parameters, G_0 and α, at the HV range around the expected working point (±20%).

The α parameter is then used to calculate HV corrections

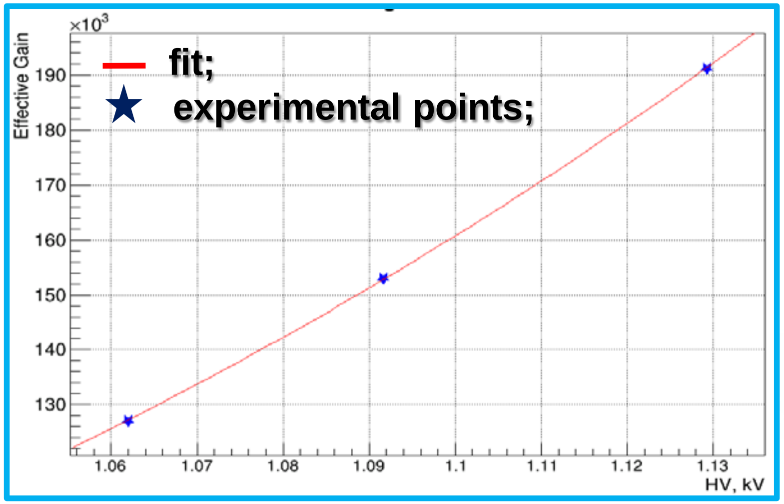


Fig. 17: Typical view of the PMT regulation curve

a) **b)**

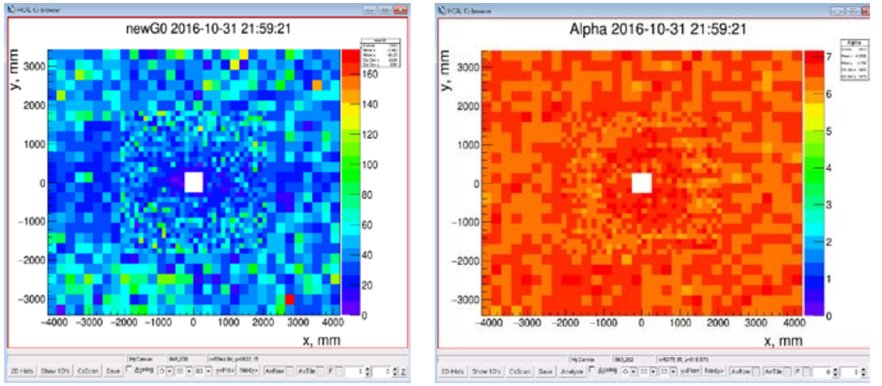
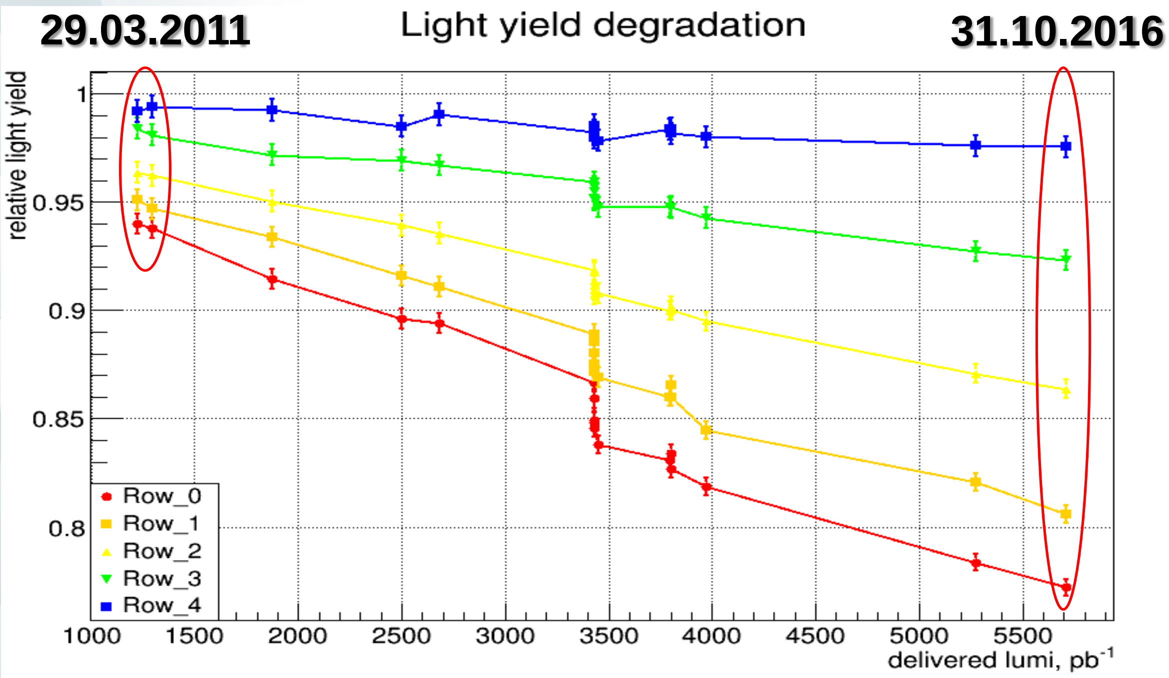


Fig. 18: Multipass calibration results: distributions of G_0 (a) and α (b) parameters of regulation curve

HCAL ageing monitoring

^{137}Cs calibration system allows to measure the response A_i of every individual scintillating tile row i. Therefore degradation of relative light yield A_i/A_5 is measured with respect to a reference ^{137}Cs run at zero luminosity:

$$R_i = \left(\frac{A_i}{A_5}\right) \Big/ \left(\frac{A_i^{ref}}{A_5^{ref}}\right),$$ A_i^{ref} and A_5^{ref} – reference amplitudes, from the ^{137}Cs scan of 29.03.2011



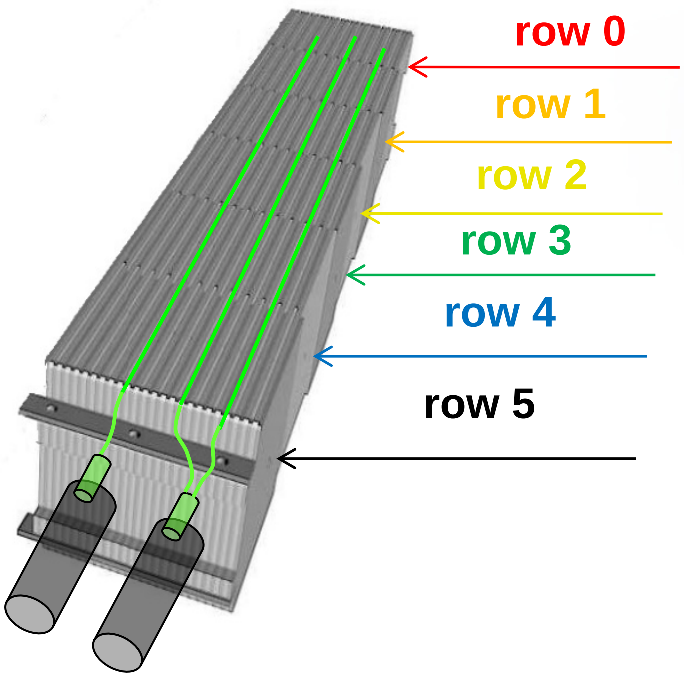


Fig. 19: Light yield degradation; average over 44 central cells

Conclusion

ECAL:

- **calibration based on reconstruction of the π^0 meson invariant mass is carried out on a monthly basis;**
- **allowed to achieve a calibration accuracy of 2 - 2.5%**

HCAL:

- **the cesium calibration system is regularly used for the HCAL calibration starting from the beginning of the LHCb operation in 2008;**
- **this method provides very detailed information about the calorimeter and allows to measure the response of every individual scintillating tile and the average characteristics of entire cell**

The presented methods allow to achieve fast and accurate calibration of ECAL and HCAL. Calorimeter system is in excellent condition and always ready for work

Thank you for attention!