NRC “Kurchatov Institute”

Calibration of the photon spectrometer PHOS of the ALICE experiment

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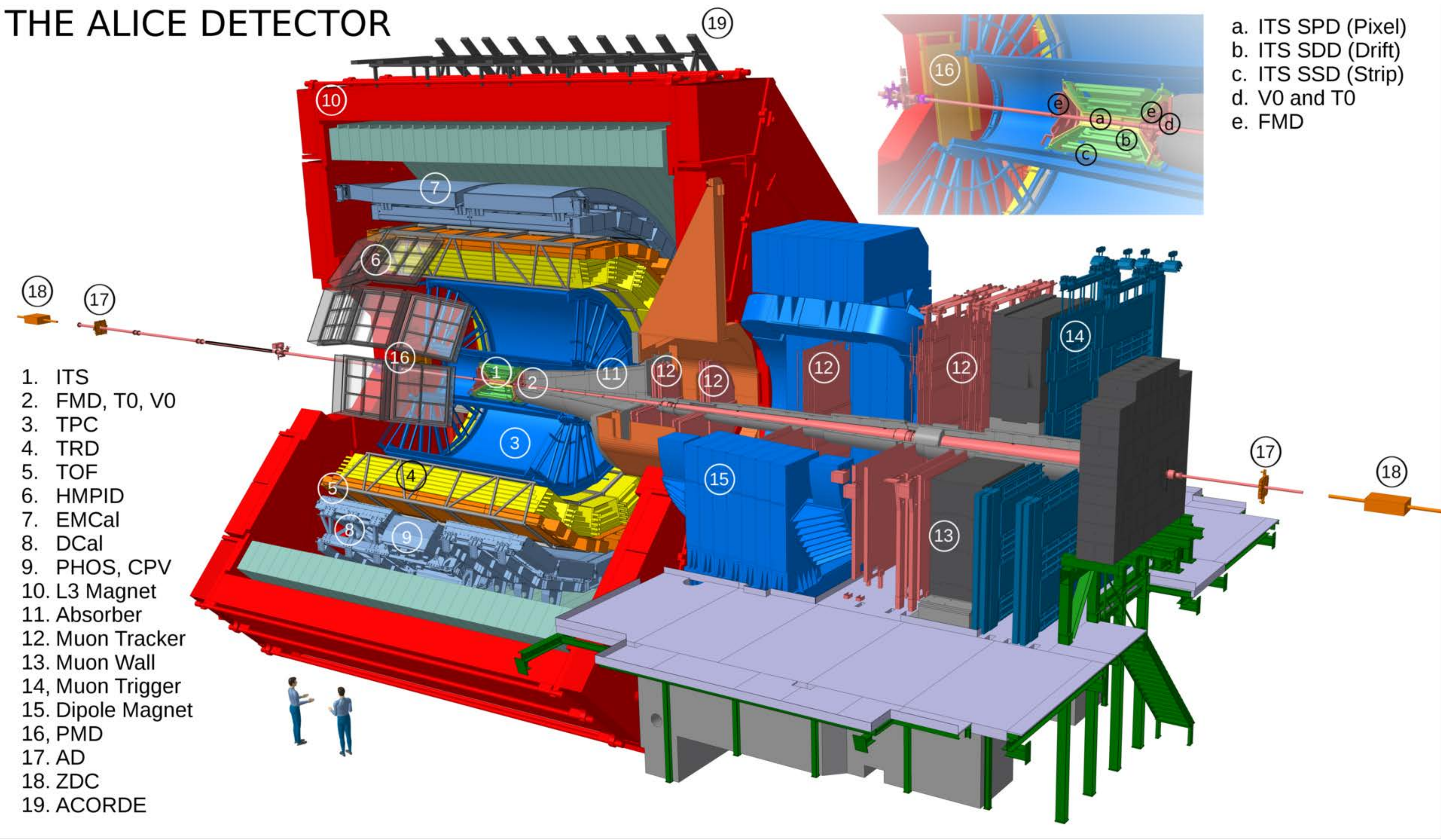
for the ALICE collaboration

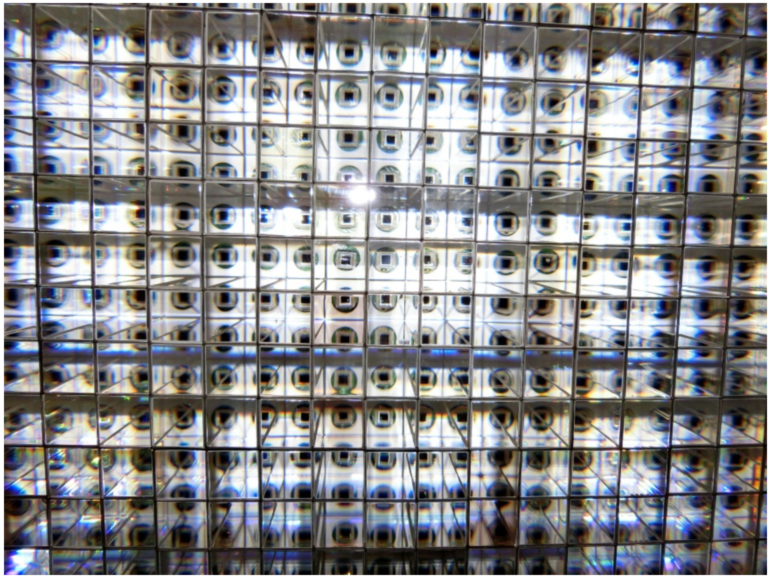
The ALICE experiment at the LHC

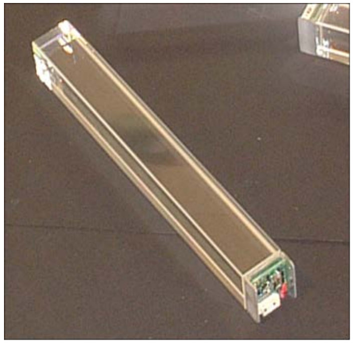


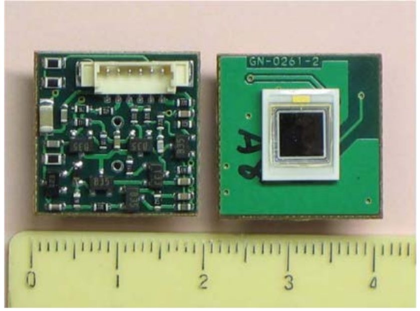
- ALICE is dedicated to studies of the Quark-gluon plasma (QGP)
- Good tracking and PID capabilities are coupled with electromagnetic-probe measurements with the help of EMCal and PHOS
- Two large data taking periods: 2010-2013 and 2015-2018. Not only A-A collisions, also pp collisions at energies up to 13 TeV.

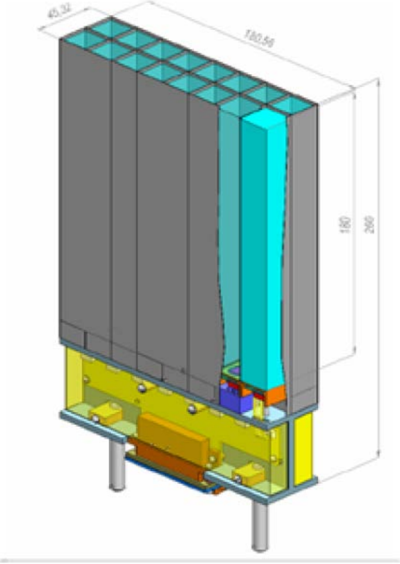
The PHOton Spectrometer of ALICE

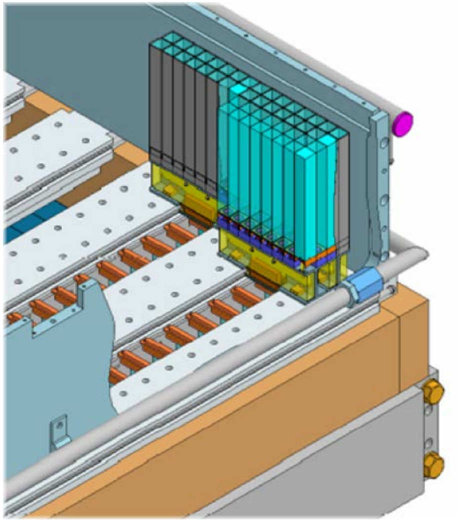
- PHoton Spectrometer of ALICE (PHOS) is a high granularity electromagnetic calorimeter based on PbWO4 crystals made for precision measurements of photons and neutral mesons in a wide p_T range
- Energy dynamical range of PHOS: 10 MeV – 100 GeV
- Avalanche PhotoDiode (APD) is chosen as a photodetector.
- Crystals are assembled into strip-units and then into modules. 3 modules consist of 56x64 elements, 4th is 56x32.
- Excellent energy resolution of PHOS makes the realization of physics tasks possible. But it also requires **best possible energy calibration** of the detector!











Energy calibration procedure steps

Several aspects of energy calibration should be considered:

0) Gain ratio calibration: low gain (E > ~ 5 GeV) requires separate calibration
1) Relative gain calibration: equalization of the response of all channels to the same energy deposition.

- Pre-calibration: adjusting the amplification of the APD
- Fine calibration: π^0 peak adjustment (offline)
  - Toy Monte-Carlo optimization

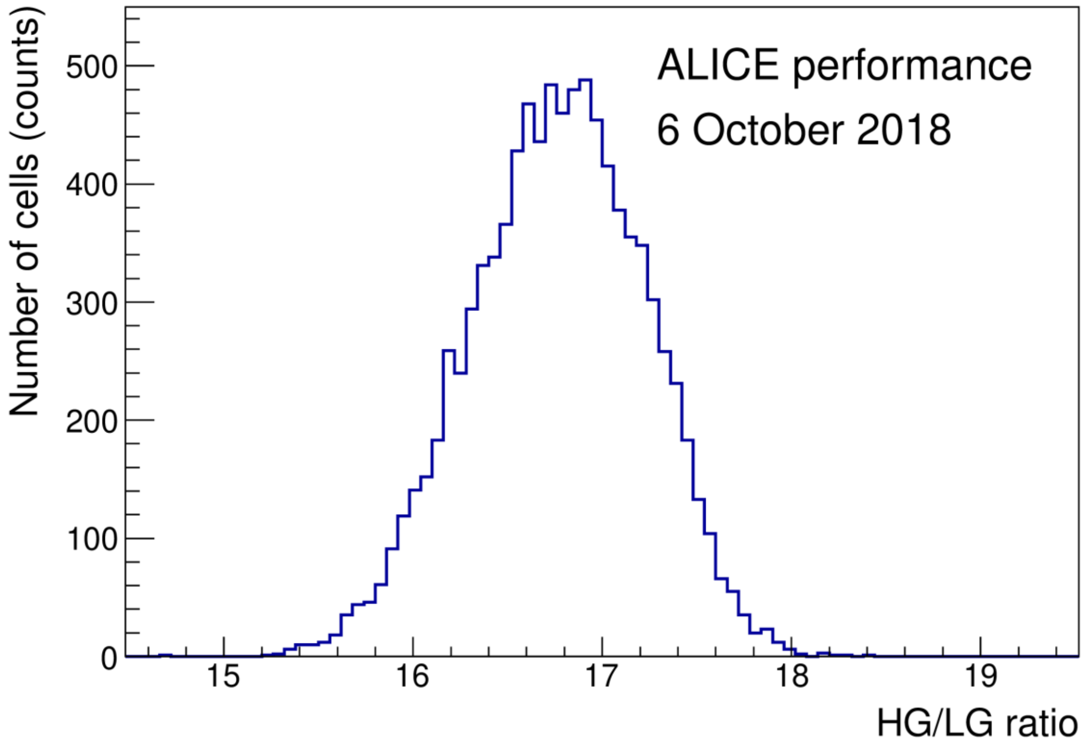
2) Absolute energy calibration: If the description of the detector geometry in the reconstruction software differs from reality, some bias is introduced into the absolute energy scale.

- Check the energy scale: electrons E/p ratio
- Geometrical alignment verification using electrons

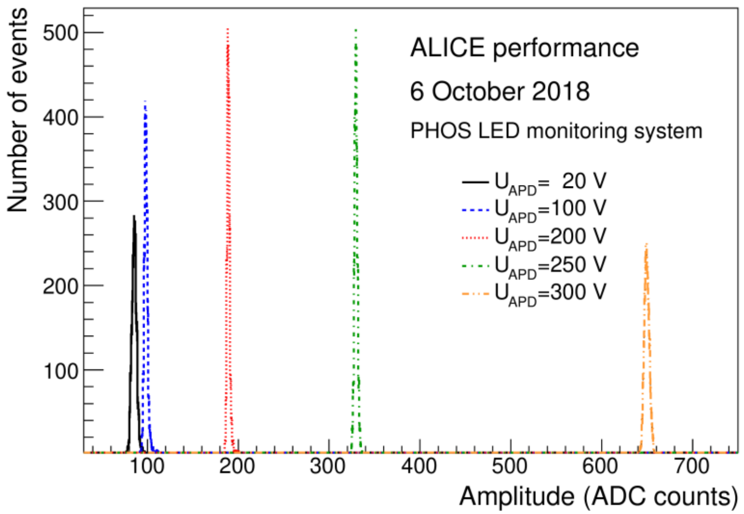
3) Non-linearity correction
4) Time-dependent energy calibration correction

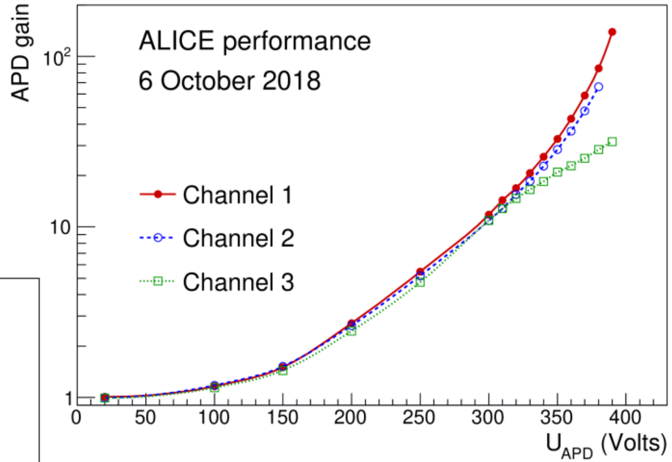
Gain ratio calibration

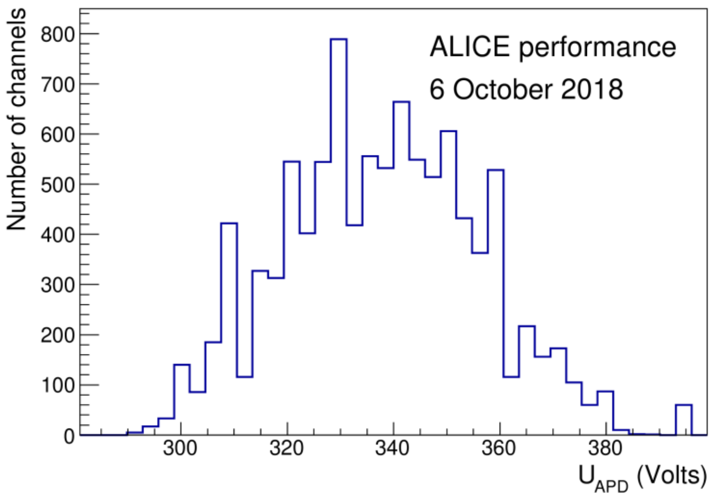
- Low gain calibration is performed using LED monitoring system of PHOS
- Signal from LED is measured simultaneously in high- and low-gain. The ratio is calculated
- The high-to-low gain ratio is stable and thus does not need to be frequently measured and updated.

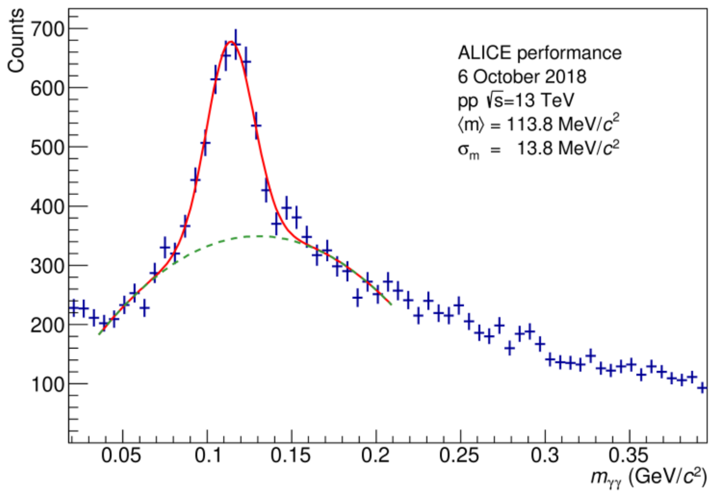


- The APD gain depends on voltage applied to it
- This dependence was measured using LED monitoring system of PHOS
- The APD gain was calculated as the ratio of the measured amplitude at a given voltage to the amplitude at 20V (dark current is negligible)
- APD gain was set to 29 for all channels.
- Bias voltage varies from 290 to 395 V with a mean value of 330 V
- π^0 peak with pre-calibration is in wrong position and the width is large → fine calibration is required





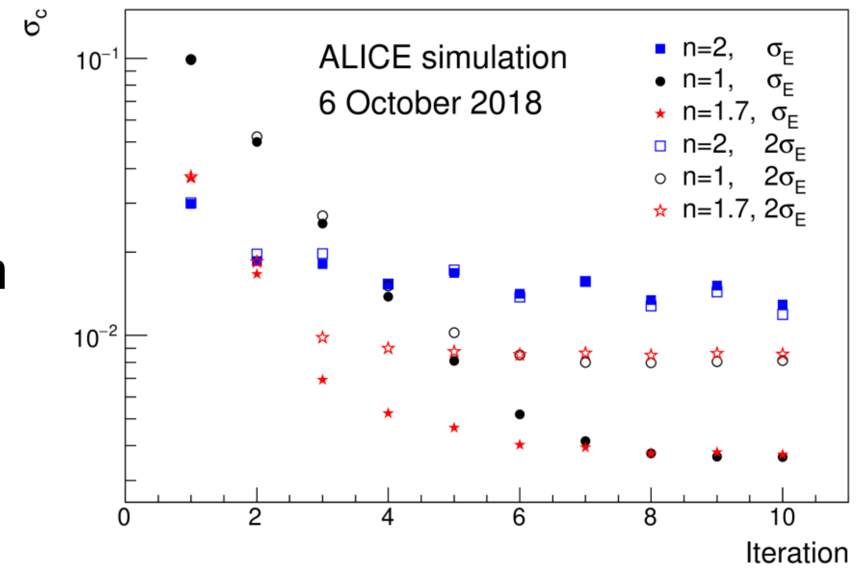


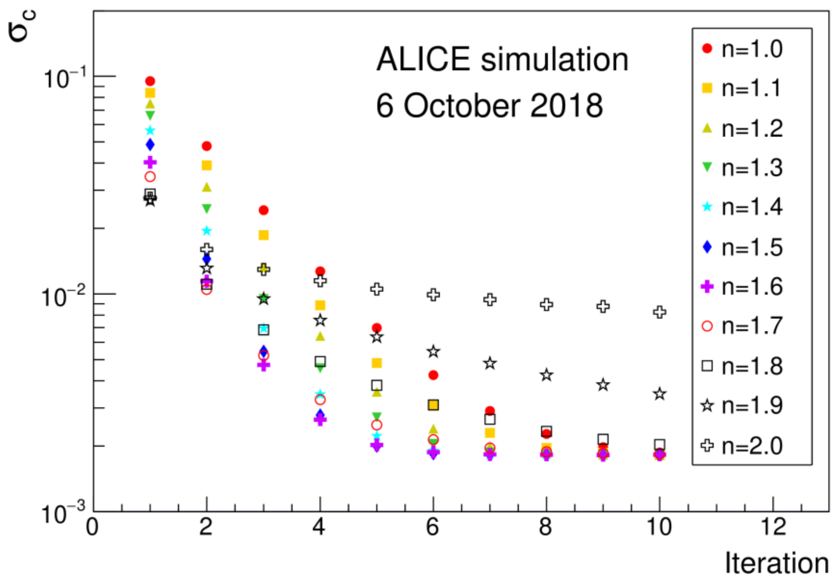


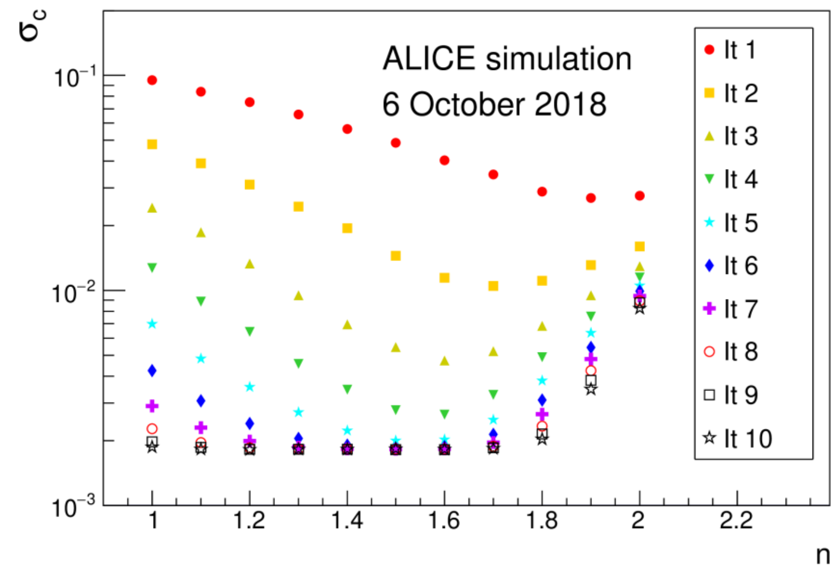
Calibration using π^0 peak: Toy Monte-Carlo

$$E_{\mathrm{corr}} = \alpha_i \cdot c_i \cdot E_{\mathrm{meas}} \qquad c_i = \left(\frac{m_\pi}{m_i}\right)^n$$

- Iterative calibration procedure is performed using π^0 mass position for the given cell.
- Toy Monte-Carlo simulation is performed for optimization of *n*: 100x100 cells calorimeter with random gaussian distribution of calibration coefficient α_i with width 20%.
- *n*=2 – oscillations
- *n*=1.7 – best accuracy after 2-3 iterations

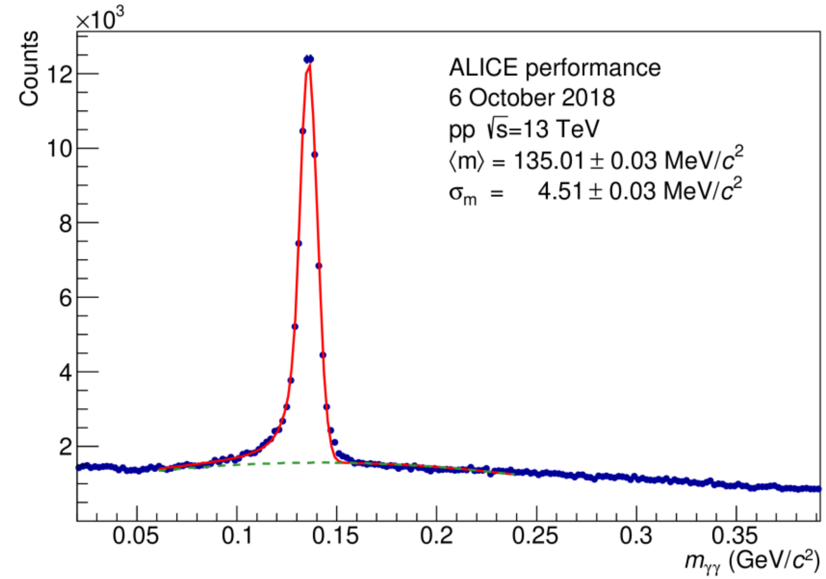


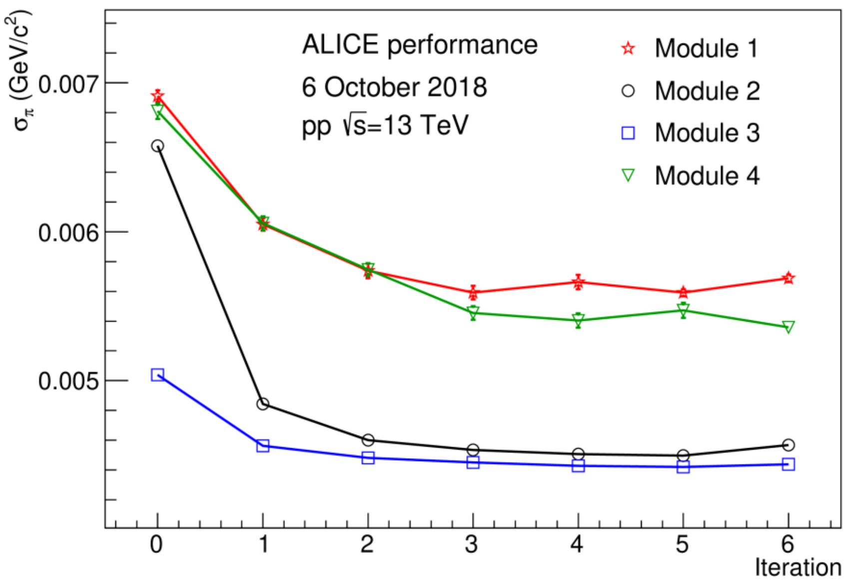


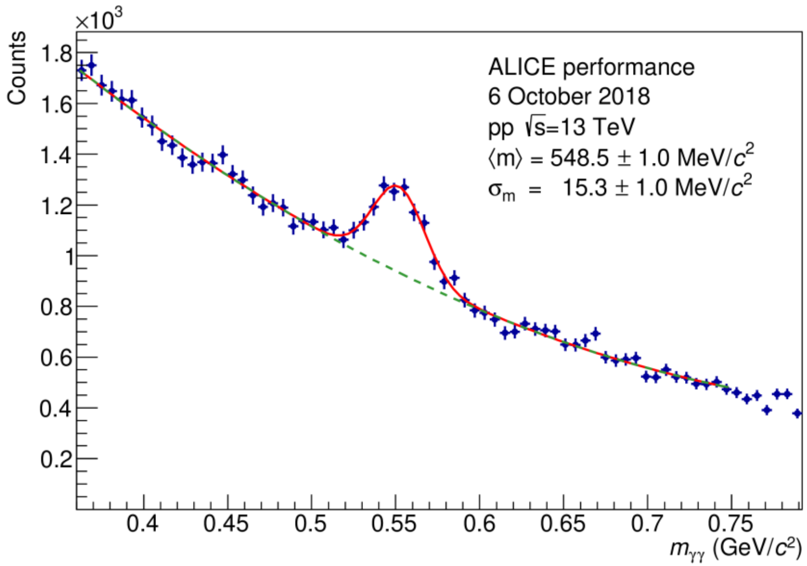


Calibration using π^0 peak: pp data

- Method was used for calibration of pp data at $\sqrt{s}$=13 TeV collected in 2017.
- 3 iterations are enough for almost final result
- p_T cut: p_T > 1.7 GeV/c (reduce combinatorial background)
- η-meson peak is also at its PDG position
- Width of π^0: $\sigma \approx 4$ MeV/c^2 which is close to the ideal resolution.

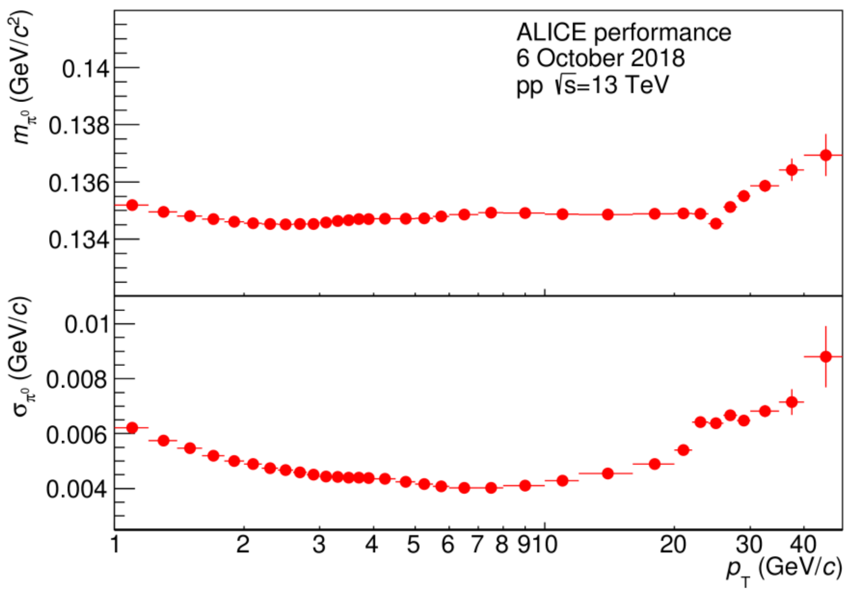


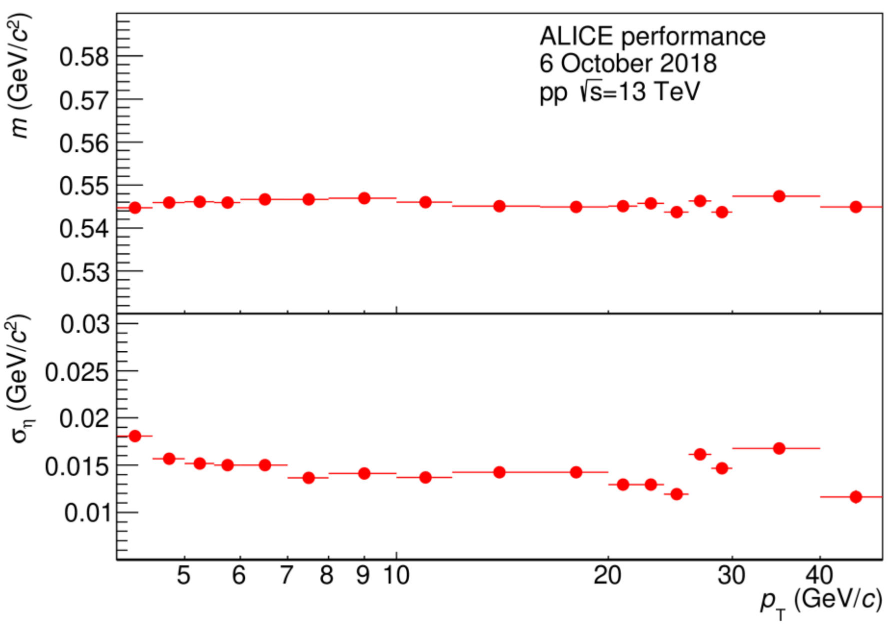




Calibration using π^0 peak: pp data

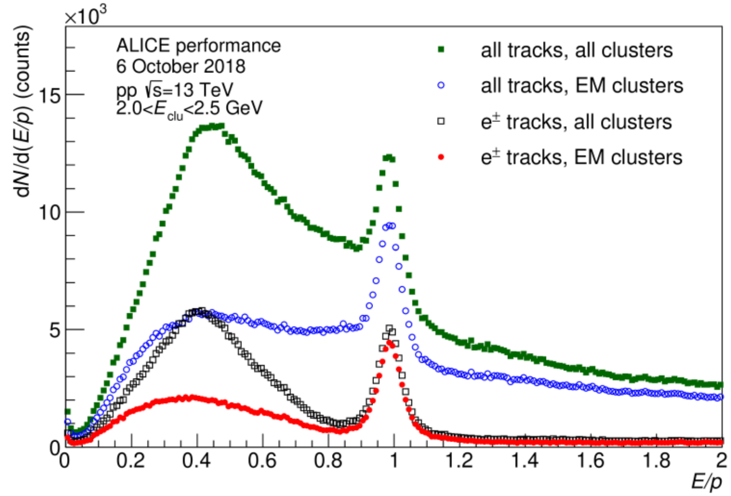
- Mass of π^0 starts to rise at $p_T \approx 25$ GeV/*c* due to overlapping of decay photon clusters
- For η meson this effect begins only at ≈ 80 GeV/*c*.

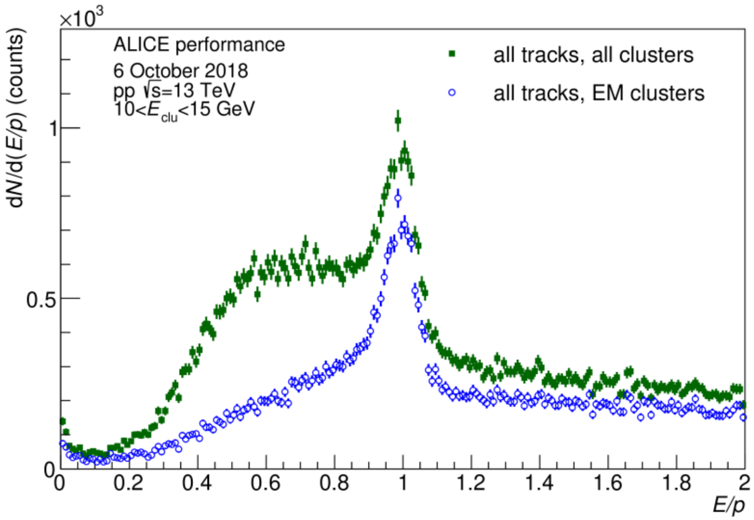




Calibration using identified electrons

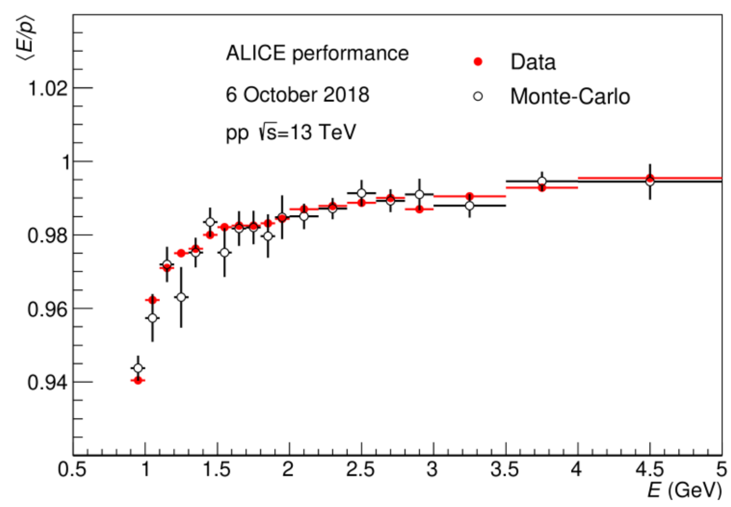
- Electrons (identified with d*E*/d*x*) in ALICE Central Tracking System are matched with clusters in PHOS, and *E*/*p* ratio is constructed.
- Independent method for calibration.
- Calorimeter geometry mis-alignment is checked
- Channel-by-channel calibration is not possible due to low statistics
- ‘EM clusters’ - photon PID based on shower shape is used

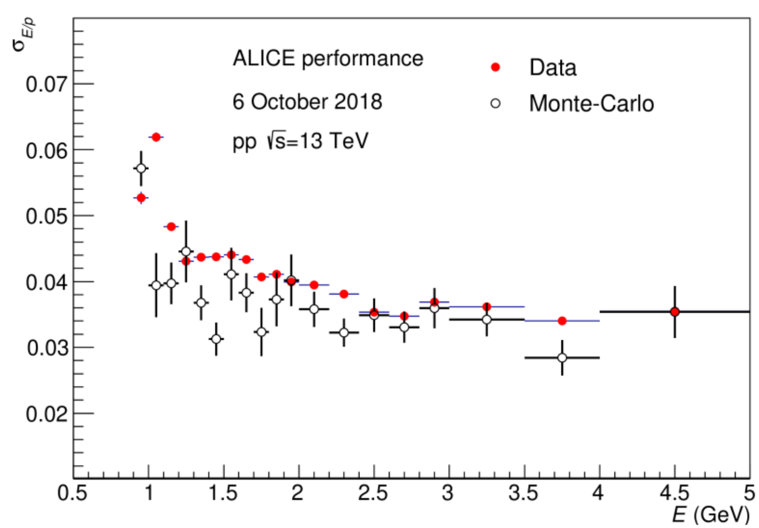




Calibration using identified electrons

- Comparison of <*E*/*p*> and *σ* with Monte-Carlo simulation using PYTHIA shows good agreement
- Absolute energy-scale uncertainty is obtained



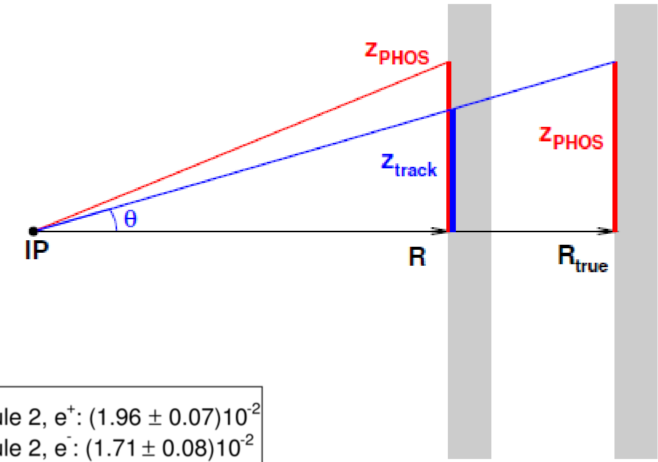


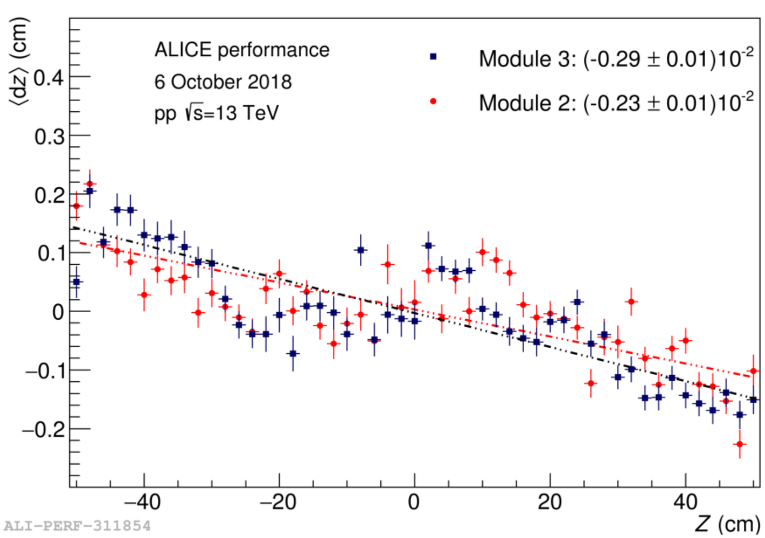
Geometrical alignment study

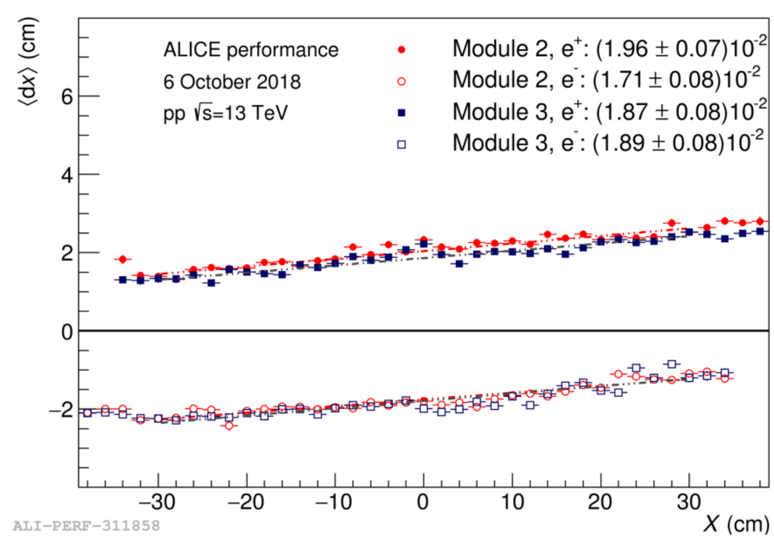
- Matching of identified electrons with clusters in the calorimeter can be used to estimate mis-alignment in *z* and *x* directions
- Correction factor of electrons is used due to the fact that electron showers are created one X_0 (0.9 cm for PHOS) earlier than the photon ones. This effect corresponds to the slope B_e=-0.19 10^{-2} in <d*Z*>(*z*) dependence. Actual value is slightly larger which corresponds to 4 mm shift in *R*.
- For <d*X*>(*x*) positrons and electrons show similar slope but different offset due to magnetic field.
- Two modules are in agreement

$$dZ = z_{\mathrm{PHOS}} - z_{\mathrm{track}} = z_{\mathrm{PHOS}} - R\tan\theta = z_{\mathrm{PHOS}}\left(1 - \frac{R}{R_{\mathrm{true}}}\right)$$

$$\delta Z_e = -X_0 \sin\left(\arctan\frac{z_{\mathrm{PHOS}}}{R_{\mathrm{true}}}\right)$$





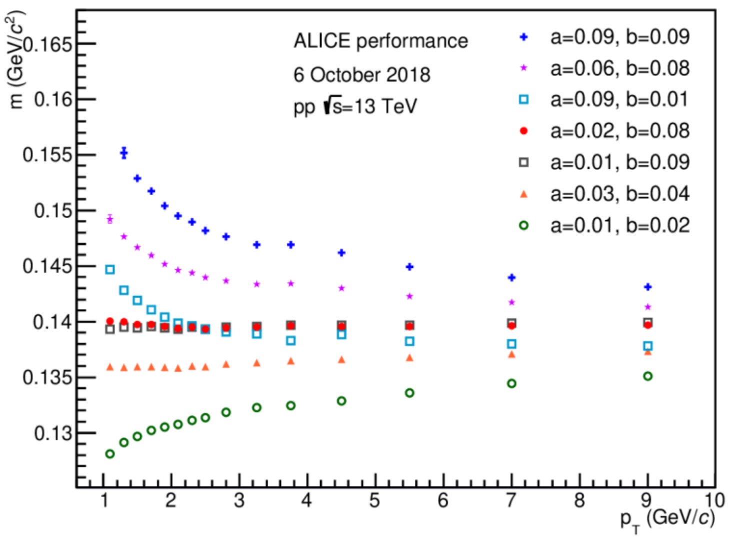


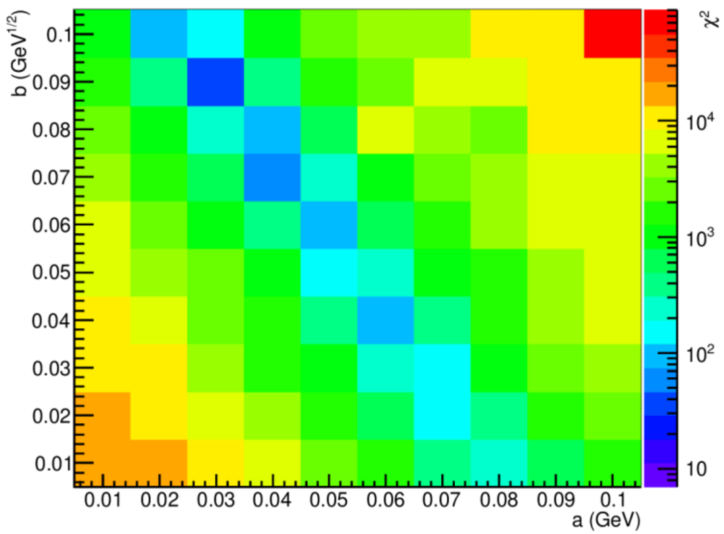
Non-linearity correction

- Non-linearity correction was obtained for π^0 mass dependence on p_T of π^0
- Non-linearity corrected cluster energy is calculated:

$$E_{\rm corr} = a + b\sqrt{E} + cE + dE^2$$

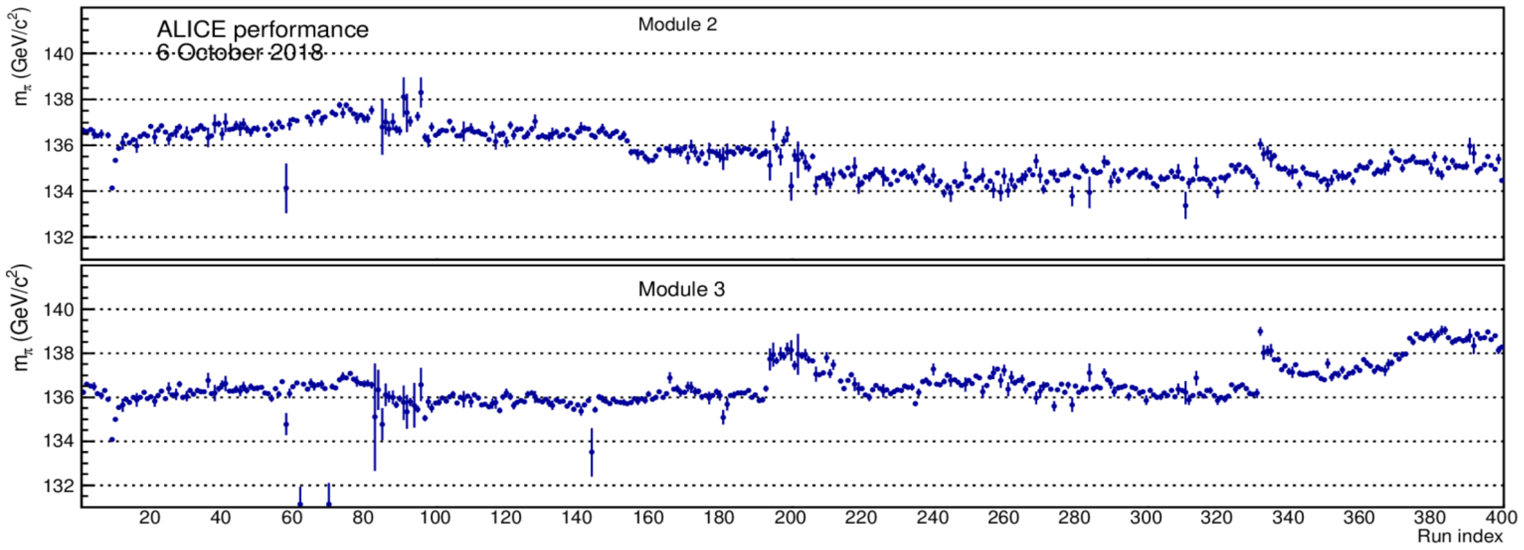
- c=1.050 and d=2.49 10^{-4} are constants related to shower leakage and threshold effects, which were calculated with Monte-Carlo simulations
- a and b were found with minimization of χ^2 of $m(p_T)$ dependence fit with constant function.
- Best values were obtained: (a=0.03±0.01 GeV, b = 0.090±0.005 GeV$^{1/2}$)





Run-by-run calibration

- Calibration coefficient could change with time (for long data taking periods)
- In each run π^0 mass was calculated and calibration coefficients were corrected by m_{mean}/m_{run} factor for each module.
- Correlated trends are related to the powering of the PHOS front-end electronics and therefore temperature of the crystal matrix.
- Uncorrelated trends may have different reasons: switching on or off front-end cards, formation of ice blocks the pipes of the cooling system etc.
- No visible global correlated trend of a decrease of the peak position in all modules due to radiation



Conclusions

- Calibration procedure for ALICE PHOS detector was established: pre-calibration using APD gain adjustment and final calibration using π^0 mass
- Optimization of calibration using π^0 mass was performed with Toy Monte-Carlo model
- Energy scale and mis-alignment of PHOS were checked with matching of clusters in calorimeter with identified electrons in ALICE tracking system
- Non-linearity correction for PHOS was estimated
- Run-by-run correction of calibration coefficients was implemented
- Final calibration of pp data at $\sqrt{s}$=13 TeV collected in 2017 was performed using all described techniques and we obtained π^0 and η peak positions close to their PDG mass values over wide p_T ranges with widths close to the ideal calorimeter:

$$\sigma^{\pi 0} = 4.51 \pm 0.03 \text{ MeV}/c^2$$

$$\sigma^{\eta} = 15.3 \pm 1.0 \text{ MeV}/c^2$$

Backup

Comparison in pp and Pb-Pb at 5.02 TeV