Relative pre-calibration of the ALICE electromagnetic calorimeter EMCAL

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Abstract. Several experiments showed that calorimetry is an essential tool for the Quark-Gluon Plasma study. ALICE, on the LHC collider, therefore integrated two electromagnetic calorimeters in its design. We will explain how the relative pre-calibration of one of them, the EMCAL, is performed thanks to cosmic muons, through an iterative procedure which consists in varying the high-voltage associated to each channel to adjust its gain. After 3 iterations of high-voltage tuning, of which each requires a day of data-taking, the dispersion (rms over mean) of the channel amplitude of the response to a muon at minimum ionisation is found to be less than 2%. We also show that more iterations allow to lower this value down to 1%.

The results obtained at the RHIC ultra-relativistic heavy-ion collider in the domain of the Quark-Gluon Plasma study showed the importance of jets, photons and heavy flavor (charm and beauty) particles to probe the partonic medium created in such collisions. ALICE is the experiment dedicated to the study of the Quark-Gluon Plasma at the CERN LHC collider. Since jets, photons and heavy flavor particles are very well studied using an electromagnetic calorimeter in conjunction with a TPC, the ALICE experiment integrated two electromagnetic calorimeters in its design: PHOS and EMCAL. After an introduction to the physics motivations and a brief presentation of the EMCAL, the method and results of the relative pre-calibration of the channels before insertion of the detector in ALICE will be detailed.

1. Physics motivations
The strong interaction, one of the four known fundamental forces, can be studied by measuring the properties of the analog of the electromagnetic plasma for the strong force. In the past years, much progress has been done both on the experimental and theoretical sides. For example, new experimental results have constantly been validating or constraining calculations carried out with the theory of the strong interaction, Quantum Chromodynamics (QCD). The particles which are sensitive to the strong interaction, quarks and gluons (partons), carry a strong force charge, or color charge. As for the electromagnetic interaction, increasing the color charge density screens the strong force potential down to a value for which color deconfinement is reached. Such a medium is called a Quark-Gluon Plasma (QGP).

To achieve this large color charge density, ultrarelativistic heavy ion collisions are done. The studies ultimately performed with the RHIC collider have shown that a QGP is undoubtedly produced and has interesting properties [1]. The next large experiment dedicated to the QGP
study is ALICE, at the CERN LHC collider. p-p, p-Pb and Pb-Pb collisions will be looked at, and their unprecedented energy will allow for the first time for a quantitative study of the QGP.

Many probes carry information about the QGP phase of the collision, but results obtained at the RHIC collider have pointed to the importance of calorimetry. Photons (unaffected by the strong interaction), jets and azimuthal correlations between jets and hadrons or photons, and heavy flavor decaying leptonically, will allow to probe the temperature, density, equation of state of the medium, as well as to test various QCD predictions. They will furthermore provide data to constrain the nucleon and nuclei parton content, and can also be triggered for selecting particularly interesting collisions. For these reasons, two of the ALICE subdetectors are electromagnetic calorimeters. The expected ALICE Physics performance can be found in [2; 3].

2. The ALICE electromagnetic calorimeter EMCAL

The EMCal electromagnetic calorimeter is the ALICE calorimeter which has the largest acceptance; it spans 1.4 units of pseudo-rapidity \( \eta \) and 100 degrees in azimuth \( \varphi \). It divides into 10 supermodules and 11 520 towers of size \( \Delta \varphi \times \Delta \eta = 0.0143 \times 0.0143 \). Each supermodule in turn divides into 24 stripmodules along the beam direction, of \( 2 \times 24 \) towers each. For the towers to be close to a projective geometry, a given stripmodule is tilted by 1.5° with respect to the neighboring stripmodule in the direction of the experiment center (cf. figure 1).

The chosen calorimeter technology is Shashlik, for which the towers consist of a 20.1 radiation lengths lead-scintillator sandwich crossed by wavelength shifting fibers, which guide the emitted photons towards an Avalanche PhotoDiode (APD). The APD are operated at room temperature, with electron multiplication factors around 30. Beam tests performed with an \( 8 \times 8 \) tower prototype with electron beams from 0.5 to 100 GeV allowed to measure an EMCal energy resolution of 
\[
\frac{\sigma_E}{E} (%) = 1.7 + \frac{11.1}{\sqrt{E \text{(GeV)}}} + \frac{5.1}{E \text{(GeV)}}
\]
[4]. More details on the detector design and properties can be found in [5; 6].

Because various towers don’t have strictly identical properties (scintillator or lead thickness, light attenuation, etc...), a given energy deposit does not lead to an identical response from two different towers. A relative calibration must therefore be done, and consists in changing, tower per tower, the APD gains in a way that they compensate for the tower-to-tower variations of the response, and eventually achieve a uniformity in the response of the supermodule.

A pre-calibration with cosmic muons, before insertion of the supermodules in the ALICE experiment, was expected to provide a dispersion (RMS divided by the mean) of the average amplitude of the towers’ response better than 10 %. The next section will present the procedure and results of this calibration. Since the postponement of the LHC startup allowed to have 40 % of the EMCal installed for the first Physics runs, i.e. 4 out of the 10 supermodules, this will soon be improved by an on-site relative and absolute calibration thanks to e.g. \( \pi^0 \) decays to photons (which can be associated with photon electroconversion), minimum ionizing particles coming from the proton-proton collisions, or electrons identified in the tracking detectors.

3. Relative pre-calibration

3.1. Relative pre-calibration procedure

Cosmic muons were chosen as a permanent and free source of minimum ionizing particles (MIP). Simulations of their energy distribution have shown that roughly two thirds of them cross the whole calorimeter thickness and behave as MIP, with a mean deposited energy in the active part (scintillator) of about 28 MeV, which corresponds to a \( \sim 300 \) MeV incoming electron.

Since the vast majority of the APD have undergone test bench measurements [7], the value of their gain \( G \) as a function of the high voltage \( V \) applied to the APD is known, and the relative calibration is therefore performed through individual APD high-voltage tuning. The parametrization used is 
\[
G = A_i + B_i e^{k_i V},
\]
where \( A_i, B_i \) and \( k_i \) are the parameters of a fit.
performed over the data taken with APD $i$ on the test bench. For the few APD of which the gain dependence as a function of the high voltage is not known, average parameters $A_i = \alpha(V_{30}^{i})$, $B_i = \beta(V_{30}^{i})$, $k_i = \kappa(V_{30}^{i})$ are calculated, where $V_{30}^{i}$ stands for the voltage defined as $G(V_{30}^{i}) = A + B e^{k V_{30}^{i}} = 30 A$, and $\alpha$, $\beta$, $\kappa$ are fits over a significant part of the APD database. These average parameters showed to be good enough to tune the APD gains when no measurement of these parameters was available.

The relative calibration procedure therefore consists in calculating a new high voltage for each APD by measuring the average amplitude from cosmic muons data taking and choosing a reference value to be achieved. The procedure is repeated, and results in a lowering of the towers’ response dispersion after each iteration.

3.2. Experimental bench

The measurements were carried out on an experimental bench schematized on figure 1. A supermodule is calibrated by thirds, of 8 stripmodules each. The experimental bench consists in 16 scintillator paddles placed by pairs above and under the stripmodules. The size, position and orientation of the paddles are such that a particle which crosses both paddles of a pair necessarily crosses the associated stripmodule, and only that one.

On both ends of a paddle, the photons created in the scintillating medium are guided to a photomultiplier tube. When all four photomultipliers of a pair of top and bottom scintillator paddles see a signal, a trigger is issued and the whole 1/3 supermodule data is read. The paddle pair which triggered is identified, and the times at which the signal has been seen by each of the four photomultipliers are also registered.

![Figure 1. Schematic view of the experimental bench along the beam direction $z$: sketched are the stripmodules, a third of which being placed between scintillator paddles. A pair of paddles is fired by a cosmic muon.](image)

3.3. Cosmics signal selection

Because of the simple configuration of the scintillator paddles, the cosmic muons which issue a trigger don’t necessarily cross a single tower. The distribution of the length of the muons’ paths through a tower is therefore broad, and that of the energy deposit is consequently wide as well. Since a reasonable precision on the average $\text{MIP}$ signal amplitude requires a narrower deposited energy distribution, the muons which cross more than one tower must be discarded. This is achieved by the means of two cuts described below. Figure 2 shows the distribution of the signal amplitudes for a given tower without cuts and with all cuts applied.

The isolation cut consists in discarding a cosmic muon when a tower neighboring the tower of interest also has some signal. Because of the noise, the isolation cut level has been set to the minimal value of 3 ADC, which corresponds to a 5-6 $MeV$ energy deposit.

The second cut uses the time information of the signal arrival to the photomultipliers. For a given paddle, the time difference between the “left” and “right” arrival times gives the position along the paddle of the muon trajectory with an accuracy of 2 to 3 centimeters. Figure 3 shows the distribution, for 12 out of 24 towers, of this time difference for the muons which gave a signal.
in a selected tower. Figure 4 shows the linear behavior of the means of these distributions as a function of the tower number, which is bijectively related to the distance along the strip.

![Figure 2. Distribution of the signal amplitude for the collected muons without cuts (line), and with all selection cuts applied (filled histogram).](image)

![Figure 3. Time difference for muons which gave a signal in a given tower, every two tower.](image)

Studies showed that both cuts applied together strongly reduce the contribution of oblique muons. The shift of the average mip signal amplitude to lower values induced by a loosening of the isolation cut from 3 to 5 ADC is negligible. This shift is of a fraction of ADC when the time difference cut is not applied.

3.4. Tower mip signal amplitude

The distribution of the signal amplitude for the collected muons after the two selection cuts is fitted with a gaussian shape for every tower \(i\), with a resulting \(\chi^2/ndf\) between 0.5 and 3.0. The mean \(\mu_i\) of the gaussian fit is then taken as the average mip signal amplitude for the considered tower. The desired average signal amplitude chosen as a target for the convergence process is around 16 ADC (the chosen value depended on the test hall temperature).

The \(\text{rms} \, \sigma_i\) of the gaussian fit was such that the relative width \(\sigma_i/\mu_i\) approximatively ranged from 14 to 17 % for the 1/3 supermodule looked at in this study. We estimated the magnitude of various contributions:

- A simulation showed that the fluctuations in the energy deposited in the scintillators range from 12 to 16 %;
- The calorimeter intrinsic resolution due to the statistics of photoelectrons is about 4 %;
- The digitization leads to a 1.8 % uncertainty;
- The smearing due to temperature fluctuations during data taking for the results presented here was estimated to be between 1.5 and 3 %. This result includes the APD-to-APD variation of the gain dependence on the temperature \((\frac{\partial G}{\partial T} = -1.5 \text{ to } -4 \%/K)\), and the uncertainty on the measurement of the temperature variations \((\approx 0.2 ^\circ)\).
- Other contributions like the electronic noise, the signal fit or the residual oblique muons still have to be estimated, but only the electronic noise is expected to be somewhat significant. The present status of the study does not allow to draw strict conclusions, but the data shows that the deposited energy fluctuations are the main contribution to the variance of the signal amplitude distributions, and does not leave much space to significant unknown contributions.

The statistical uncertainty on the measured average mip signal amplitude for each tower is then calculated as \(\sigma_{\mu,i} = \sigma_i/\sqrt{N_i}\), with \(N_i\) the number of signal entries for tower \(i\). 24 hours of data taking showed to be sufficient to reach a statistical relative uncertainty on the average mip signal amplitude below the 1 % level for almost all the towers; this sets the limit on
the reachable level of relative calibration with cosmic muons over these timescales. Figure 5 shows the distribution of this relative uncertainty for a supermodule. The statistics has been accumulated for 1354 minutes for one third. The results for the two other thirds, with data taking times of 975 and 910 minutes, were scaled to 1354 minutes of data taking. The asymmetric queue to larger relative uncertainties results from two contributions. The first one is shown as the grey histogram, and comes from the towers located on both ends of the stripmodules along the scintillator paddles’ direction: as the paddles have the same length as the stripmodules, not all the cosmic muons which cross these towers will issue a trigger. The second contribution is due to the towers which belong to the most tilted stripmodules and originates from the cosine squared dependence of the cosmic muons rate on the azimuthal angle.

![Figure 4](image1.png)

**Figure 4.** Mean time difference as a function of the tower number.

![Figure 5](image2.png)

**Figure 5.** Typical distribution of the relative uncertainty on the average MIP signal amplitudes for a supermodule for a ≃ 24-hour data taking period. The grey histogram shows the contribution of the towers located on both ends of the stripmodules only.

### 3.5. Relative calibration results

As explained earlier, the average MIP signal amplitude is adjusted by tuning the APD high voltages. As shown in figure 6, the 16 × 24 measured average MIP signal amplitudes of the 1/3 supermodule used for these tests progressively converge towards the desired value, with a steadily decreasing dispersion even up to the 5th iteration, down to the 1% level. The data taking time was chosen to be sufficient to have statistical errors significantly lower than the dispersion value. We simultaneously controlled the RMS of the distribution of the APD high voltages difference between two consecutive iterations \(HV_n - HV_{n-1}\): as expected, this RMS decreases, except for the 4th iteration because of a significant change of the temperature in the experimental hall. We stopped at the 5th iteration, as this RMS was getting close to the high voltage digitization value of 0.2 V/bit, which corresponds to about 0.5% on the relative gain.

Figure 7 shows the initial and final average MIP signal amplitude distributions for the 1/3 supermodule on which these studies have been performed. Most third supermodules have been observed to behave similarly, with initial dispersions worse than 10% and a value better than 2% reached after 2 or 3 iterations, i.e. a number well below the requirements. The steadily dropping dispersion of the average MIP signal amplitudes up to the 5th iteration indicates that the relative calibration, usually provided with 3 iterations, is reliable.

### 4. Conclusions

As the various towers of a calorimeter don’t have strictly identical geometrical, physical, chemical or electronical properties, they generate different signals as a response to the same deposited energy, unless a relative calibration is performed. The EMCAL, one of the two electromagnetic...
calorimeters of the ALICE experiment, undergoes a relative pre-calibration before insertion in the experiment, by measuring the response to minimum ionizing cosmic muons and adjusting the channel gains so that the calorimeter’s response is uniform over all the channels.

While ongoing simulation studies aim at better quantifying the systematic uncertainties and the bias (towers on the edges, most tilted stripmodules), we already showed that three one-day periods of cosmic muons data taking were sufficient to perform the relative calibration of a 1/3 supermodule down to a dispersion of 2%, well below the 10% requirement. This pre-calibration will be used as a starting point for refined relative and absolute calibration thanks to e.g. particle decays into photons or electrons. The target relative calibration value is 1% and will essentially be limited by the statistics collected.

These very procedure and experimental bench will also be used for the relative pre-calibration of the third ALICE electromagnetic calorimeter, DCal, which has identical technology and properties to the EMCal and a slightly smaller acceptance.

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