Calibration of NICA-MPD electromagnetic calorimeter modules with cosmic muons

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Abstract. The large barrel-shaped, shashlyk-type electromagnetic calorimeter (ECal) is an important part of the Multi-Purpose Detector (MPD) of the heavy-ion NICA experiment, and is designed to provide spatial and energy measurements for photons and electrons in the energy range from 40 MeV to 2–3 GeV. To deal with the high multiplicity, the ECal is finely segmented and made up of 38,400 cells (‘towers’) which are grouped into modules of 16 ’towers’ each. ECal projective geometry of the ‘towers’ oriented towards the beam interaction zone results in 8 different types of modules depending on their position in the ECal. As beam calibration of each individual ‘tower’ is time and resource expensive, we discuss our strategy of calibration for the ECal modules with cosmic muons and present some preliminary results.

1. Introduction

The Nuclotron-based Ion Collider fAcility (NICA) is an under construction experiment at the Joint Institute for Nuclear Research, Dubna, Russia. It is aimed at mixed phase investigations and searching for critical endpoint in heavy ion collisions. To study the hot and dense baryonic matter from such heavy ion collisions, the NICA experiment has a Multi-Purpose Detector (NICA-MPD). Inside this NICA-MPD an Electromagnetic Calorimeter (ECal) is present along with other detectors and trackers. The MPD-ECal is designed to precisely measure the position and energy of electrons and photons emerging from beam interaction zone under conditions of high multiplicity of particles [1].

1.1. Electromagnetic Calorimeter in NICA-MPD

Particle ($e^-$) identification in decay processes within the MPD is one of the main objectives of ECal. The reconstruction of decays having photon participation is another of its objectives along with measurements of photon flux.

In order to handle a high multiplicity of secondary particles and to fulfill objectives defined by the experiment the ECal is highly segmented. A dense active medium with small Molière radius, good spatial resolution with particle occupancy below 5% and minimal shower overlap are some of the requirements for this ECal. A time resolution below 1 ns is also desired and the ECal must be operable in magnetic field up to 0.5 T. These specific set of requirements determined the unique design parameters for each cell and the entire ECal by extension [2].
1.2. Projective geometry of the ECal
The ECal has a projective geometry with its cells or 'towers' oriented towards the beam interaction zone [2]. The heterogeneous calorimeter’s each tower is made up of 210 alternating layers of plastic scintillator (width=1.5 mm) and lead (width=0.3 mm) plates with crosssection of \(40 \times 40 \text{ mm}^2\) at the top. The tower is trapezoidal in shape and tapers towards the bottom where the size reduces to \(\sim 33 \text{ mm}\). The milling angles of the towers in \(Z\)-axis direction is \(0.9^\circ\) and \(1.2^\circ\) along the \(XY\) plane. Collection of light is done by wavelength shifting (WLS) fiber that passes through each tower like a ‘shashlyk’. In every ECal module there are 16 such towers grouped together into 2 rows of 8 cells (figure 1). There are a total of 38,400 towers arranged in to 2400 modules. The modules are distinguishable by the tower’s angle along \(Z\)-axis with 8 types of modules (figure 2) [3, 4]. The modules are also grouped into sectors in the \(XY\)-plane giving the ECal a cylindrical shape. The readout electronics board for each module would be attached at the top.

![Figure 1. 2×8 towers in a module.](image1)

![Figure 2. 64 different towers into 8 types of modules](image2)

2. Calibration of ECal modules using cosmic muons
The ECal modules have to be calibrated before assembly inside the MPD. This is to ascertain the variation in performance of individual towers. As there are 2400 ECal modules to calibrate, using cosmic muons can be a faster and efficient approach, as multiple modules can be calibrated in parallel. Two different methods were proposed for calibration: first is direct but less efficient (longitudinal cosmic muons), second is faster but requires some correction (transverse cosmic muons).

2.1. Longitudinal cosmic muons
The ECal module, when kept in an upright position with readout electronics at top, can be used to collect the cosmic muons that pass through individual towers (figure 3). Selection of events can be done by placing triggers both above and below the towers with an AND-operation logic mode to isolate cosmic muons. Another selection process is to consider muons that only pass straight through without tagging nearby towers. The recorded event responses by towers will have a waveform that contains both the signal and pedestal (figure 4). The signal region is integrated and the average pedestal value (first few samples of the waveform) is subtracted. Such integral values for a large number of events will give us distributions for individual towers of a module. Comparing extracted peak values from those distributions indicate performance variation between towers in a module.

2.2. Transverse cosmic muons
The transverse method of collecting cosmic events is done by selecting those events that pass through towers of a row in the module (figure 5). This method is faster in comparison to the longitudinal cosmic muons. Top and bottom towers act as triggers for calibrating the towers.
in between. And second towers from top and bottom become the triggers for calibrating the edge towers. Trigger towers having waveform signals (figure 6) greater than a minimum value (usually set \( \sim 600 \) ADC values in analysis), those cosmic events are selected. Pedestal corrected integrated signal is taken from waveform of towers and aggregated by events. Extracted peaks from the distributions are compared with different types of modules (figure 7).

2.3. Different orientations of module
The modules assembled in to sectors have different angles of orientation. In order to investigate the possibility of calibrating those modules by cosmic muons, different orientations along horizontal and vertical planes were tested. Apart from extreme angles of orientation, the signals are similar (figure 8) for different angles (\(-90^\circ, 15^\circ, 30^\circ, 56^\circ, 90^\circ\)). The angle would be \(0^\circ\) only if the vertical axis and a centroid line running through the module are parallel. \(90^\circ\) orientation signify the module is perpendicular to vertical plane whereas at \(-90^\circ\) module is flipped horizontally and vertically. The cosmic muon flux will deteriorate if the module is parallel to the horizontal plane (side of module is parallel) or very close to being parallel.

2.4. Separation between module and readout electronics
The readout electronics board mounted on each module will be cooled and needs to be easily serviceable. The mounted separation gap will play a role in amount of photons captured by the Multi-pixelated Avalanche Photodiodes (MAPD). The gap \(d = c - (a + b)\) between the fiber-end and MAPD (figure 9) was tested for different values of \(d = [0.0, 0.8, 1.0, 4.2]\) mm for module type 1. Pixel correction can be applied to the average ADC values using,

\[
N_{\text{pix}} = -N_{\text{tot}} \cdot \ln(1 - \frac{N_{\text{exp}}}{N_{\text{tot}}}),
\]

where \(N_{\text{exp}}\) is the extracted peak value from distribution of integrated

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**Figure 3.** Side View of longitudinal orientation.

**Figure 4.** Waveform for longitudinal cosmic muon event.

**Figure 5.** Side view with orientation of module at \(90^\circ\).

**Figure 6.** Waveform for transverse cosmic muon event.
Figure 7. Comparison by transverse cosmic muons.

signals and $N_{\text{tot}}$ is the total number of pixels in the MAPD.

For optimum signal, during assembly of each tower the fiber-ends should be parallel to MAPD else signal loss will be significant (figure 9) even at smaller gaps ($d < 0.8 \text{ mm}$). A previous problem with the fiber-ends in this tested older module has been fixed. In newer modules the variation of signal has been minimum at few hundred microns gap after preliminary tests.

Figure 9. Different gap between MAPD and fiber-end

3. Stability of calibration using cosmic muons

3.1. Test of stability over long duration

The modules were tested for a long duration of 100 hours (figure 11) using longitudinal cosmic muons. The external room temperature around the module electronics were varied. The corrected board voltage (figure 11) due to this change in temperature maintained the overall stability (figure 12).

3.2. Time resolution studies

Cosmic muon events crossing through all 8 towers of a row in a module were selected. For such events the individual waveforms of signal were fitted and time value obtained from the fit function at 30% of the peak were considered. Difference in time, $\Delta t = t_i - t_j$ for $i^{th}$ and $j^{th}$ towers in that row for multiple events were put in a distribution (figure 13 (a)). The extracted $\sigma t$ for various $i^{th}$ and $j^{th}$ towers show a variation within channels (towers) of the same board (figure 13 (b)). The variations arise due to noise in electronics.
Figure 11. Voltage correction in electronics.

Figure 12. Stability is maintained.

Figure 13. (a) Distribution of $\Delta t$ for two towers, (b) $\sigma t$ distributions with different towers of board C12 (solid) and board C10 (dotted).

Figure 14. Artificial cut of the signal.

Figure 15. Reconstruction from fraction of signal,
3.3. Truncated waveform studies
The waveform of the signal of a tower can get truncated from reaching maximum level of electronics (ADC 14 bits). From DESY-2018 data of 1.6 GeV electron, a waveform is shown artificially cutted (figure 14) and reconstructed. Average values and resolution as a function of available fraction of the signal is compared (figure 15). At 50% or more availability of signal, complete reconstruction is possible as resolution is constant.

4. Conclusions
Multiple MPD-ECal modules were tested, and calibration using transverse cosmic muons is faster than longitudinal cosmic muons. Tower responses are similar and steady for different types of modules and transverse cosmic muons at various orientation of modules give similar results. A gap within few hundred microns (<0.8 mm) between readout board and fiber-end had the optimum signal. Even with temperature correction in board, the module response for longitudinal cosmic muons was stable for a duration of 100 hours. A time resolution of < 1 ns can be achieved for very low energy particles.

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