Calibration of MPD electromagnetic calorimeter with muons

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ABSTRACT: The shashlyk-type electromagnetic calorimeter (ECal) of the Multi-Purpose Detector at heavy-ion NICA collider is optimized to provide precise spatial and energy measurements for photons and electrons in the energy range from about 40 MeV to 2–3 GeV. To deal with high multiplicity of secondary particles from Au-Au reactions, ECal has a fine segmentation and consists of 38,400 cells (“towers”). Given the big number of “towers” and the time constraint, it is not possible to calibrate every ECal “tower” with beam. In this paper, we describe the strategy of the first-order calibration of ECal with cosmic muons.

KEYWORDS: Calorimeters; Detector alignment and calibration methods (lasers, sources, particle-beams); Heavy-ion detectors; Performance of High Energy Physics Detectors

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1 Introduction

The main goal of the Nuclotron-based Ion Collider fAcility (NICA) program at the Joint Institute for Nuclear Research (Dubna) is an experimental study of the properties of nuclear matter in the energy region of the maximum baryonic density. One of the NICA detectors, the Multi-Purpose Detector (MPD), is optimized for the study of properties of a hot and dense matter in heavy-ion collisions at $\sqrt{s_{NN}} = 4–11$ GeV [1]. Electromagnetic barrel calorimeter of MPD (ECal) is designed to provide precise energy and position measurements for photons and electrons in conditions of high multiplicity of secondary particles from the beams interactions. To meet this goal, ECal has a fine segmentation and a projective geometry where each calorimeter cell is oriented to the beams’ interaction point. In this geometry, the exact size of each cell and its position relative to neighbor cells is defined by the cell Z-position (beam direction) in the ECal barrel (see figure 1). In total, ECal consists of 38,400 cells of 64 different types that are combined into 2,400 modules of 8 different types (shown in figure 1 in different colors).

![Figure 1](image_url)  
**Figure 1.** An evolution of the ECal modules shapes as a function of Z-coordinate (beam direction) in the calorimeter barrel: from module #0 in the center of ECal (shown in pink in the left side of the figure) to the module #7 in the edge of ECal (shown in medium-blue in the right side of the figure).

2 Absolute energy calibration method

The traditional “first-level” absolute calibration of calorimeter contains usually 2 steps: 1) equalize the gain of all calorimeter cells (inter-calibration) with usage of electron beam, cosmic muons
or physics signals, and 2) find one or few absolute-energy calibration coefficients (for whole calorimeter) from electron beam tests or reconstruction of narrow invariant-mass distributions [2, 3]. The problem of this method is that it does not take into account the geometrical difference of the calorimeter cells and dependency of the calorimeter properties on the energy of the primary particle (viz., works well only in a limited energy range) and the locations of the cell and the particle hit. Attempts to correct on these effects result in additional labor-consuming measurements and “phenomenological” calibrations on impact particle energy, $p_T$, hit-position, and other non-linear dependencies [4]. Occurrence of the energy dependence is because of the composition of the electromagnetic shower changes as a function of depth, or age. In the late stages, most of the energy is deposited by soft gammas which undergo Compton scattering or photoelectric absorption, and the sampling fraction for this shower component (i.e., the fraction of the energy that contributes to the calorimeter signals) is less than that of the MIPs that dominate the early stages of the shower development [5]. MPD ECal has a limited thickness of about 11$X_0$, so increase of the primary particle energy results in the moving of the maximal-sampling-fraction region closer to the photodetector as well as moving the late-stage shower development region out of the calorimeter; that effect also minimize the absorbed-in-fibers fraction of the produced scintillation light. The reason for the dependence on the Z-position of the primary particle hit is that the calorimeter with projective geometry consists of 64 types of cells with different shapes and different surrounding of the neighbor cells, so the different fraction of the shower from different stages of development goes into neighbor cells and leaks out of the calorimeter.

Figure 2. The flow diagram of the iterative event-by-event calibration of ECal data.

Our calibration approach (see figure 2) consists of two steps also. First, we plan to establish a connection between the amplitudes of observed signals and the effective energy depositions in the active volume of the calorimeter (scintillators) for each calorimeter cell; it can be done via comparison of the calorimeter signals from cosmic muons with predictions from corresponding detailed simulation. The second step contains computer simulations to create a database (DB) of the physical properties of the calorimeter (i.e., sampling fractions, energy leaks, etc.) as functions of primary particle energy, hit position, location of the cell in the calorimeter, etc. to convert the energy deposition in the calorimeter active volume to the impact particle energy, and do it in a way
that has no dependence on phenomenology. Another big advantage of the proposed method is that no beam is needed for the absolute energy calibration of the calorimeter. With a detailed description of the ECal structure in the simulation (i.e., the exact structure of ECal towers, shapes, locations as well as measured light absorption in the WLS fibers), we hope to perform the preliminary ECal calibration with accuracy of about 3% or better.

3 Computer simulations

Both steps of the calibration require detailed computer models of the calorimeter modules. The calorimeter has the projective geometry, so the shape of each cell and it’s location relative to the neighbor cells depend on the Z-coordinate (along the beam) of the cell in the calorimeter barrel. Each module contains $2 \times 8 = 16$ calorimetric cells, and there are 8 module types of different shapes. Each calorimeter cell consists of 210 layers of 1.5-mm-thick plastic scintillator interlaid with 0.3-mm-thick lead plates. 16 WLS fibers are passed through the holes in the lead and scintillators to collect the light and transport it to the photodetector (SiPM). The far end (from the photodetector) of each fiber, as well as lead plates and the sides of the scintillators, are painted with white reflective paint to maximize the light collection. The attenuation of the light in the WLS fibers was carefully measured using the technique described in [6] (see figure 3). Taking into account the significant attenuation of the scintillation light along the WLS fibers, a convolution of the energy deposited into the scintillators with the attenuation function (viz., an effective energy deposition that is proportional to the light transported to the photodetector) represents better the calorimeter signal than just energy deposited into scintillators, so the former was used for estimation of effective sampling fractions, etc. in the simulations.

![Figure 3](image)

**Figure 3.** Left panel: attenuation of the scintillation light in the 150-cm WLS fiber with white reflective paint on the far end. Right panel: attenuation of the light in the same fiber with no reflection from the far end. The simultaneous fit of both data sets with correspondent two-attenuation-lengths functions. Details of the measurements can be found in the paper [6].

The simulation was done with FLUKA version 2011.2x.7 Monte Carlo code [7] with energy cuts and transport parameters according to one of the default FLUKA set CALORIMETRY (with minor tune).

4 Measurements with cosmic muons

For the measurements with cosmic muons, we orient the modules vertically. To select the “longitudinal” flux of muons along each cell axis (similar to that is expected during the calorimeter work on the beam), we use external scintillation trigger detectors as well as “veto” signals from neighbor
cells. Compared to usage of “transverse” muons, the dispersion of the spectrum measured with “longitudinal” orientation of the modules is insensitive to the cell’s trapezoidal shape and visible light absorption in it; that results into more compact (in comparison with other module orientations) distributions (see right panel of figure 4). The downside here is a relatively low rate of selected muons; still, the muon statistics collected in 2 weeks is expected to be enough for the measurement of ADC-to-energy coefficients with a statistical uncertainty less than 1%.

Figure 4. Left panel: the stand to test simultaneously 12 ECal modules. Right panel: the compact spectrum of signals from cosmic muons from a short (a few hours) run.

To perform the measurements with cosmic muons, the special stands were developed (left panel of figure 4). To minimize systematic uncertainties during long runs, the stands are equipped with a slow control system that controls and stabilizes the temperature inside the stands as well as compensates for a residual drift of each photodetector (SiPM) amplification by the correspondent shift of the supply voltage. Each stand allows simultaneous measurements of 12 modules; so 8 stands (for 8 different types of modules) allow the calibration of 2,400 ECal modules in one year. We plan to combine the calibration measurements with the produced modules’ quality assurance (QA). The spectra measured with cosmic rays will be compared with the simulated spectra of the energy that is deposited by muons in the scintillator plates in the modules and corrected on the attenuation of the scintillation light on its way to the photodetectors (viz., the energy that is “visible” in the calorimeter), and the ADC-to-“visible” energy coefficients will be obtained for each calorimeter cell.

5 Sampling fraction and energy leak

The preliminary computer simulations of electromagnetic showers in the ECal modules were performed. Figure 5 shows effective sampling fraction (i.e., the sampling fraction that is convoluted with light attenuation function) and energy leak from the calorimeter, and indeed these vital ECal parameters depend visibly on the impact particle energy, module/cell type, and distance from the cell of interest to the particle impact point as expected.

6 Plans and conclusions

We plan to perform the ECal calibration procedure that relies on “energy scale” measurements with MIPs (muons) and detailed simulation of the calorimeter parameters. Production of the database
calibration parameters requires massive simulations in 2020 and 2021. The simulated calibration parameters are the functions of the incident particle energy, cell location, and impact position, so no additional non-linear corrections are required. We plan to perform calibration on muons for all ECal modules during 2020 and 2021 (together with the modules QA). Preliminary test of the calibration procedure was done with a 50–500 MeV electron beam at Lebedev Physics Institute of Russian Academy of Science (Troitsk, Moscow reg., Russia); the data analysis is in progress.

It is important to mention that a correction on signal saturation because of a finite number of SiPM cells [8] should be applied on the top of this calibration.

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