Electromagnetic calorimeter for MPD spectrometer at NICA collider

A.Yu. Semenov, S. Bazylev, E. Belyaeva, M. Bhattacharjee, B. Dabrowska, D. Egorov, V. Golovatyuk, Yu. Krechetov, A. Shutov, V. Shutov, S. Sukhovarov, A. Terletskiy and I. Tyapkin on behalf of MPD collaboration

Abstract: The Multi-Purpose Detector (MPD) is designed to study a hot and dense baryonic matter formed in heavy-ion collisions at $\sqrt{s_{NN}} = 4$–11 GeV at the NICA accelerator complex (Dubna, Russia). A large-sized electromagnetic calorimeter (ECal) of the MPD spectrometer will provide precise spatial and energy measurements for photons and electrons in the central pseudorapidity region of $|\eta| < 1.2$. The Shashlyk-type sampling structure of the ECal is optimized for the photons energy range from about 40 MeV to 2–3 GeV. Fine segmentation and projective geometry of the calorimeter allow dealing with a high multiplicity of secondary particles from Au-Au reactions. In this paper, we report on a design, a construction status and expected parameters of the ECal.

Keywords: Calorimeters; Heavy-ion detectors; Instrumentation and methods for heavy-ion reactions and fission studies

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1 Introduction

The main goal of the Multi-Purpose Detector (MPD) at Nuclotron-based Ion Collider fAcility (NICA) is a study of signals from hot baryonic matter with maximal density that might be produced in collisions of heavy ions at $\sqrt{s_{NN}} = 4–11$ GeV [1, 2]. The experimental program with heavy ions at NICA includes event-by-event measurements of observables that are expected to be sensitive to high-density effects and phase transitions: particle yields, particle yields ratios, fluctuations, and correlations. The MPD spectrometer (figure 1) has a 2-$\pi$ azimuthal acceptance, low material budget, and can handle event rate up to 6 kHz. Solenoid magnet with 0.5 T magnetic field and the barrel Time-Projection-Chamber (TPC) tracking system provide the measurements of momenta of charged particles with sufficient accuracy (about 2% at $p_t = 300$ MeV/c) and vertex finding. The measurements of $dE/dx$ with TPC together with Time-of-Flight measurements allow $\pi/K$ separation up to 1.5 GeV/c, and $K/p$ separation up to 3 GeV/c. The electromagnetic barrel calorimeter (ECal) as an important part of MPD provides an access to the electromagnetic probes such as direct photons and lepton pairs, decays of neutral mesons, and significantly improves electron/hadron separation.

2 Electromagnetic calorimeter modules

Large-sized (about 6-meters-long and 4.5-meters in diameter) ECal covers the central pseudorapidity region of $|\eta| < 1.2$ (figure 1), and is optimized for precise spatial and energy measurements for photons and electrons in the energy range from about 40 MeV to 2–3 GeV [3]. To deal with a high multiplicity of secondary particles from central heavy-ion collisions, ECal has a fine segmentation and consists of 38,400 cells (towers); each tower covers azimuthal angle $\Delta\phi \approx 1.2^0$ and $\Delta\eta \approx 0.0187$. Taking all requirements (high energy resolution, large enough distance to the vertex, small Moliere radius, ability to work in the high magnetic field, high time resolution, and a reasonable price) into consideration, a “shashlyk”-type electromagnetic calorimeter was selected [4]. Each tower has a sandwich structure of 210 polystyrene scintillator [5, 6] and 210 lead plates with 16 Wave Length Shifting (WLS) fibers Kuraray Y-11 (200) [7] that penetrate the plates to collect the scintillation...
light and transport it to the photodetector; the far (from the photodetector) end of the fiber is painted
with white light-reflecting paint to increase an amount of the collected light. The thickness of each
scintillator plate is 1.5 mm, and the thickness of the lead plate is 0.3 mm. Monte-Carlo simulations
suggest that such a proportion of scintillators and lead converters provides the sampling fraction of
about 34–39% (depending on energy), and results into relatively small stochastic term and a good
energy resolution in the energy range below 1 GeV. A dark side of this calorimeter design is that
the limited space inside the MPD magnet leads to the limited ECal thickness just above 11 X₀ and
the correspondent energy leak from the backend of the calorimeter; though the leak does not exceed
10–12% in the ECal energy range.

Each ECal module consists of 16 towers that are glued together. The geometry of each
module depends on the module Z-coordinate (beam direction) location with respect to the beams
interception point (figure 2). The advantage of the calorimeter with the projective geometry (where
the towers are inclined along the beam axis to keep the tower axis to be consistent with the direct
view to the beams intersection region) is a reduction of dead zones, increase of detector efficiency,
improvement of a linearity and an energy resolution of the calorimeter measurements in conditions
of high multiplicity of secondary particles from the collisions of heavy ions.

In total, the ECal will contain 2,400 modules of 8 different types. The production of the ECal
modules is divided between Russian (25%) and Chinese (75%) facilities. The production of the
modules in Russia is started in 2019, and the production in China is expected to be started in 2020.

3 ECal mechanical structure

From a geometrical point of view, the ECal is divided into 25 sectors or 50 half-sectors (see right
panel in figure 3); each half-sector contains 6×8 = 48 modules of 8 different types. These modules
are located in the half-sector container (basket) made of fiberglass material. The rigidity of the
container is enough to provide deformation less than 0.5 mm under a full half-sector load of about
1.5 tons.
Figure 2. Top: evolution of ECal modules shape along the beam direction from the center to the edge of MPD. Bottom left: photo of the module from the MPD center (type 0, the leftmost section in the top panel). Bottom right: photo of the module from the edge of MPD (type 7, the rightmost section in the top panel).

Figure 3. Left panel: the power frame of ECal. Right panel: the half-sector container (basket) is shown with installed electronics.

Original MPD construction plan was to build ECal as a self-supporting structure. After sharing the modules production between Russian and Chinese institutions and corresponding differences in the modules delivery schedule, the decision was made to locate the calorimeter half-sectors into carbon-composite power MPD frame (shown in left panel in figure 3) which is strong enough to hold the total weight of the ECal and other MPD detectors (about 100 tons) with a maximal deformation of 2–3 mm, that makes possible to install and extract any ECal half-sector without dismounting the whole MPD spectrometer.

In addition to the modules, half-sector includes ECal readout electronics. To keep the ability to extract and reinstall calorimeter electronics (for service and repair), special electronics installation system was developed. Electronics support is provided by 3-m-long boxes; each box serves 2×8 = 16 modules. Outside each box, 16 front-end boards with 16 photodetectors (6×6 mm$^2$ Hamamatsu S13360-6025PE MPPC [8, 9]), preamplifiers and slow-control electronics (that controls the temperature and makes the corresponding correction of about 45 mV/deg. on photodetectors supply
voltage) are located, while the JINR-designed 64-channel 14-bit 62.5 MS/s Pipelined ADC64ECAL boards [10] are housed inside the heat-isolated box to minimize influence on photodetectors. The heat production is estimated as about 150 W per half-sector (or about 7.5 kW for whole ECal), and the water-cooling system is used to evacuate the heat from the boxes.

4 ECal module tests

Tests of the single prototype modules were performed with electron beams at DESY (Hamburg, Germany) and Lebedev Physics Institute of Russian Academy of Science (Troitsk, Russia). For the measurements with electron beam energies above 1 GeV at DESY, a visible deviation from linearity for the ECal response was observed (see left panel in figure 4). It was found that this deviation is connected mostly with the signal saturation because of the limited number of pixels in the MPPC; the correction on this effect restores the linearity. The signal time was produced from an analysis of the ADC waveform front, and the time resolution for one tower is presented in figure 4 (right panel). The blue star in this plot corresponds to the time measurement with cosmic muons that travels through ECal modules in a transverse direction, and this result is consistent with measurements on the electron beam. The green line on the plot presents results of a special time measurement with high-precision and high-frequency ADCs and allows estimation of the contribution of “standard” ECal electronics to the measured time resolution.

![Figure 4. Results of the linearity (left panel) and the time resolution (right panel) measurements of prototype ECal modules with the electron beam at DESY.](image)

An energy resolution of the single ECal module was measured recently with relatively-low-energy electron beam in Troitsk. The obtained data (shown in blue in figure 5) are in a good agreement with results of Monte-Carlo simulations for a single module (shown in red in figure 5). The same Monte-Carlo simulation made with whole calorimeter (dash-dotted black line in figure 5) allows to make a preliminary estimation of the expected energy resolution of the ECal:

$$\frac{\Delta E}{E} \approx \frac{3.0\%}{\sqrt{E(\text{GeV})}} \oplus 2.4\%$$ (4.1)

5 Conclusions

A large-sized barrel electromagnetic calorimeter for the MPD spectrometer is under construction in Joint Institute for Nuclear Research (Dubna, Russia). The “shashlyk”-type calorimeter is optimized
to deal with high multiplicity of secondary particles from heavy-ion collisions at the NICA accelerator complex. The production of the calorimeter modules is shared between Russian and Chinese institutions. The prototype modules tests with electron beams in DESY and Troitsk demonstrate that the measured calorimeter parameters are in a good agreement with expectations.

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