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MC simulation results for projective geometry version of MPD ECAL at NICA collider

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Abstract. The report describes the Monte-Carlo simulation software developed for the projective geometry version of the electromagnetic calorimeter of the MPD detector. The results of software tests and some characteristics of the calorimeter are presented.

1 Introduction

The NICA/MPD project aims at studying the nuclear matter at extreme densities [1]. Among its goals, there are searches for the critical point of the phase transition of hadronic matter into quark-gluon plasma, for restoration of chiral symmetry, for strong effects of hadron modification, etc. Direct information about the state of nuclear matter is carried out by direct photons and dileptons, since they interact only electromagnetically and are not distorted by interactions in the final state. Registration of photons and reliable identification of electron-positron pairs is impossible without an electromagnetic calorimeter. So, a construction of an electromagnetic calorimeter (ECal) was included in the first phase of multi-purpose detector MPD at the NICA collider.

2 Electromagnetic calorimeter

A view of the MPD detector is shown in Fig. 1 (left panel). In order of increasing distance from an interaction point of the NICA collider, there are main subsystems: the time projection chamber (TPC), the time-of-flight detector (TOF), the ECal and Zero Degree Calorimeter (ZDC). ECal occupies a cylindrical volume with an inner (outer) radius of 1.72 (2.15) m and a length of 6.3 m. It is assembled of 43008 shashlyk-type [2] modules of 12 radiation lengths. Each module consists of 221 alternating tiles of 1.5 mm thick plastic scintillator and 0.3 mm thick lead covered with a thin layer of reflective paint. The tiles are 4x4 cm^2. They are tightened with two metal strings using two plastic end-plates 5 and 8 mm thick. The light from the scintillators was transferred by sixteen 1 mm ∅ WLS fibers to insensitive to magnetic field Hamamatsu MAPD with a sensitive area of 6x6 mm^2. The modules are shaped into truncated pyramids by milling, so that they can fill tightly the cylindrical volume. Along the cylinder generator, the modules are arranged in rows of projective geometry [3]. The axis of each module looks at the point of interaction of the beams located on the axis of

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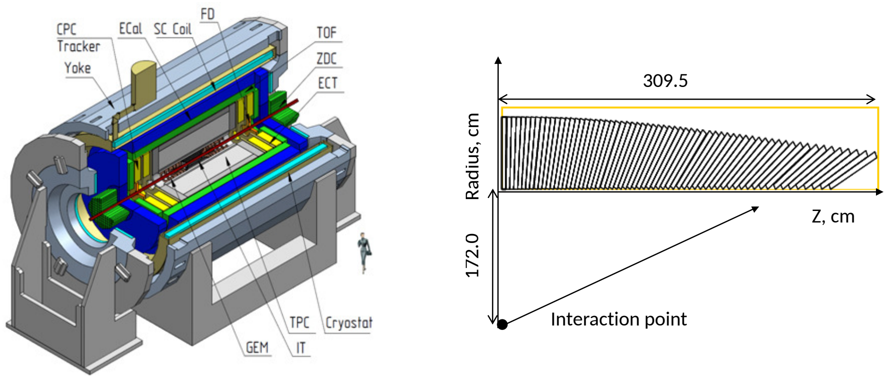

Figure 1. Overall view of the MPD detector (left panel). Projective geometry arrangement of the ECal modules (right panel)

the cylinder (Z axis) in its center. This arrangement is shown in Fig. 1 (right panel) for Z > 0. Modules of 64 types with different sizes are needed for this geometry. The rows of modules are divided into blocks and combined into 8 sectors. The gaps between the modules are 0.2 mm, between the blocks in a row – 5.2 mm, between sectors – 6.3 mm. These gaps are used for mechanical mounting of the calorimeter.

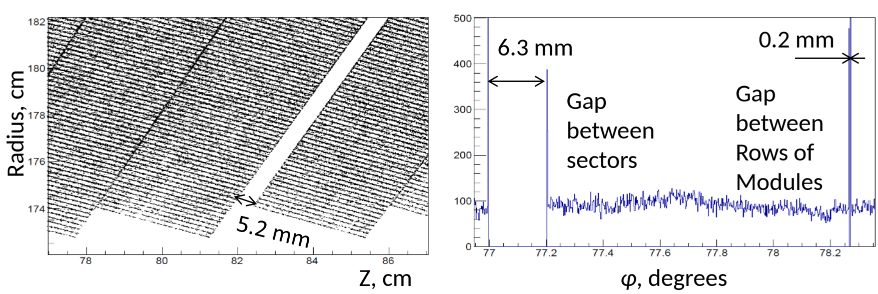

Figure 2. Distribution of GEANT4 "points" in RZ-plane (left panel) and in ϕ-angle (right panel) as a result of illumination of ECal by simulated high energy photons. The borders of active media (scintillators) are clearly seen and can be precisely checked

3 Simulation and testing ECal geometry

The macro "create_rootgeom_emc.C" was developed with the ROOT package in the FairSoft/mpdroot environment. It takes a pre-prepared MpdECALData.xml file, which contains coordinates of all vertices for all 64 types of the modules. They, as well as their tiles, are described by arbitrary "TGeoArb8" trapezoid. The modules are assembled into rows using the "AddNode" procedure, rows – into sectors. The ECal geometry description is written to the file emc_v2.root file, where v2 is the current version. It includes information on 19 millions of elementary volumes "nodes" and GEANT4 spends up to several minutes to accept these data. The correctness of the geometry representation was verified by simulating photons emitted from the interaction point. The GEANT4 output file contains the so-called "points" in the active medium (scintillator), which in turn contain information about their coordinates, energy deposition, time-of-flight,etc. Distributions of these points in the RZ plane, where R is the distance of the "point" from the Z axis, and in the plane transversal to the Z-axis in azimuth angle ϕ are shown in Fig. 2. A great convenience is that GEANT4 always puts "points" on the boundaries of the active volumes when they are crossed by electrons/positrons of an electromagnetic shower. This allows to clearly see the boundaries of the modules on the plots of Fig. 2 and confirm their compliance with the original parameters with an accuracy better than 0.1 mm.

4 Hits and clusters

To find the energy deposition in the whole module, it is necessary to sum up the energy depositions at all "points" in the module. ROOT provides a convenient FindNode function for determining the path to a module in the volume hierarchy for each "point". However, in our case, for about 1% of the "points", this function has given a wrong assignment. Possibly, this is due to the accuracy problems in GEANT4/ROOT in this rather complex geometry. So we have to use another method. The full geometric information about the modules was stored and the connection of the "point" with the module was determined by choosing the module with the nearest axis. The modules with deposited energy (hits) were renumbered in a convenient format. The full module number was determined by two numbers: the number in angle ϕ (N_ϕ) (from 0 to 335) and the number along Z-axis (N_z) (from 0 to 127). Cluster search was performed on the grid (N_ϕ x N_z). The developed procedure can use various cluster search algorithms. While the simplest algorithm was used here, that arranged the cluster from hits in the fixed area of the grid around the hit with local maximum of energy deposition. The cluster energy was determined by summing the energies of the hits, the coordinates of the cluster were determined by energy weighting the coordinates of hit centers. The same weighting was used to determine a cluster time and RMS cluster radius, which can be useful for electromagnetic showers - heavy charged particle discrimination. With this cluster algorithm the ECal performance has been studied.

5 ECal performance

The energy dependence of ECal energy resolution ($\sigma(E)$) obtained with photons is shown in Fig. 3 (left panel). It is well approximated by the formula $\sigma(E)/E = a_0/\sqrt{E} \oplus a_1$, where E is photon energy in GeV, $a_0 = 4.21 \pm 0.02\%$, $a_1 = 2.08 \pm 0.10\%$ and $\oplus$ means summation in quadratures. The obtained fitted parameters $a_{0,1}$ are in a reasonable agreement with measured on prototype at CERN [4], where $a_0 = 4.99 \pm 0.21\%$ and $a_1 = 2.14 \pm 0.29\%$. The energy resolution depends on a hit energy threshold, as it is shown in Fig. 3 (right panel) for 200 MeV photons. Measurements with the prototype have also shown that the threshold as low as 5 MeV can be used with developed electronics. The ECal coordinate resolution is demonstrated in Fig. 4 (left panel). The distribution over value $b = D_{cl} * (\theta_\gamma - \theta_{cl})$ is given for 500 MeV photons. Here, θ_γ - polar angle of the photon emission, θ_{cl} - polar angle of the cluster and D_{cl} - distance of the cluster from the interaction point. The distribution over b is independent of the position of a cluster in the ECal. It can be well fitted by a Gaussian. The Gaussian

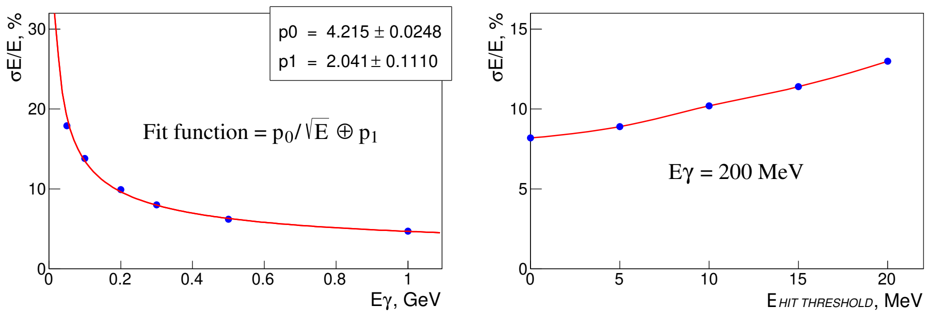

Figure 3. ECal energy resolution as a function of photon energy (left panel). Energy resolution for 200 MeV photons as a function of hit energy threshold (right panel)

parameter σ_b is a function of photon energy. For the energies larger 200 MeV this dependence can be approximated by $\sigma_b = \alpha/E_\gamma^{0.3}$, where E_γ is photon energy in GeV and free parameter $\alpha = 0.59$ cm. For high energies ECal coordinate resolution is much better than half width of the module at its center, that is about 1.75 cm. ECal angular resolution is also a function of cluster distance from the interaction point. This distance changes from 2 to 3.5 m. As a result for 1 GeV photons the angular resolution varies from 0.16 to 0.09 degree.

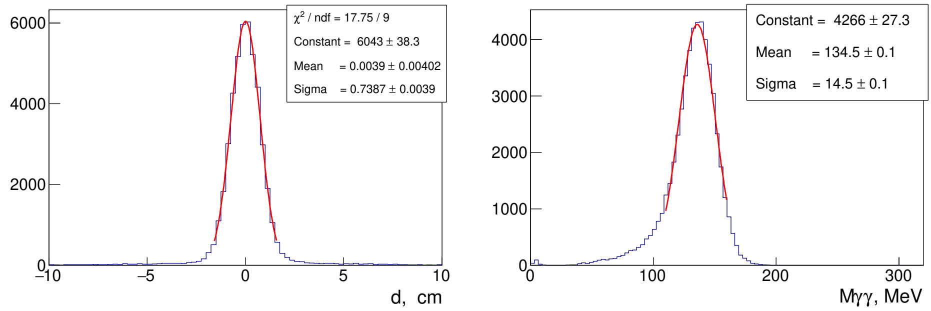

Figure 4. ECal coordinate resolution for 500 MeV photons (left panel). Resolution in π^0 mass for 200 MeV π^0 (right panel)

Appropriate energy and angle resolutions lead to a good resolution in π^0 mass, when reconstructed from its two gamma decay. It is demonstrated in Fig. 4 (right panel), where averaged over all the calorimeter an effective mass distribution of two photons, reconstructed from 200 MeV π^0 decays, is given. Resolution in π^0 mass is 14.5 MeV. If the point of pion decay is not known then smearing of the interaction point due to a finite length of the bunches in the NICA collider has to be taken into account. The expected Gaussian smearing of 24 cm results in deterioration of π^0 mass resolution by only 1 MeV.

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6 Conclusion

A geometric description of the MPD electromagnetic calorimeter has been developed, as well as software for hit and cluster finding. This software has been tested, placed in git.jinr.ru repository, and can be applied to simulate physical processes on MPD using ECal data. Appropriate energy, angular and π^0 mass resolutions of ECal have been demonstrated.

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