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Monte Carlo study of the electromagnetic calorimeter optimization for MPD/NICA

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Different constructions of the electromagnetic calorimeter were simulated with a Monte Carlo generator. The influence of lead-scintillator sampling on the energy resolution in the conditions of fixed total length was tested. Energy resolution of the calorimeter built from rectangular modules has been compared with that of the one built from trapezoidal modules.

Key words: MC, ECAL, NICA, MPD, MpdRoot, GEANT4, energy resolution

INTRODUCTION

Electromagnetic probes, such as real and virtual photons (i.e. dileptons), provide key information on temperature, system size at the early stage of collision, and temperature evolution of the system from its formation to thermal freeze-out.

Input conditions to choose the design of electromagnetic calorimeter for MPD are the following:

- The expected high multiplicity environment implies the high segmentation of the calorimeter.
- Use of dense active medium, with a small Molière radius.
- The particle occupancy should not exceed 5% to determine the photon reconstruction efficiency with high accuracy.
- The photon detector must be able to operate in magnetic field of up to 0.5 T.
- Enough compactness to be integrated into the MPD set-up.

As a baseline option is selected heterogeneous calorimeter type "Shashlyk" which meets the above requirements. The calorimeter will consist of active medium (scintillator) and absorber (lead) and the light will be collected with the help of wavelength shifting (WLS) fibers. Such calorimeters are used in PHENIX, LHCB, KOPIO and others.

Detailed information can be found in [1].

ELECTROMAGNETIC CALORIMETER

The calorimeter will have cylindrical structure and positioned in MPD at a radius of $R = 1.78$ m. The barrel part of ECAL covers the pseudorapidity interval $-2.5 < \eta < 2.5$.

The basic building block of the calorimeter will be a module (120×120 mm^2) consisting of 9 optically isolated towers which are read out individually. Each Pb-scintillator tower consists of lead and scintillator plates. The cells of each tower are optically combined by 9 longitudinally penetrating wavelength shifting fibers.

The longitudinal dimension of the calorimeter module is limited by the design of MPD. The allocated space is 400 mm for the active media and 150 mm for the light detection module.

Table 1. Main parameters of Type 1 and Type 2

Parameters	**Type 1**	**Type 2**
Transverse size, mm^2	120×120	120×120
Number of layers	220	198
Lead absorber thickness, mm	0.3	0.5
Polystyrene scintillator thickness, mm	1.5	1.5
Molière radius, mm	26	39
Radiation length, X_0	11.8	17.7
Effective radiation length, mm	32.4	22

Different samplings were studied, but here only two of them are presented. They differ in the thickness of the absorbing plates and their parameters are given in Table 1.

Energy resolution

As shown [1] in many physical studies it is necessary to have good energy resolution of the electromagnetic calorimeter - at the level of 5-7% for electrons with energy of 1 GeV.

To obtain a permission within existing resources (the available space in the detector and and the allocated finances), all parameters of the calorimeter should be carefully optimized. Energy resolution of a Shashlyk module depends on a variety of factors [2]:

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1. Sampling, i.e. thicknesses of lead and scintillator plates.
2. Longitudinal leakage, i.e. fluctuation of energy leakage due to the finite length of module.
3. Transverse leakage, i.e. fluctuation of energy leakage due to the limited number of modules used to reconstruct an electromagnetic shower.
4. Effects of the presence of holes, fibers, and steel strips.
5. Light attenuation in the fiber.
6. Photostatistics.

In our case, the longitudinal dimension is determined by the structure of MPD. Longitudinal leakage (2) can be optimized only by varying the sampling (1), as will be shown below. The effects of factors 4-6 on the calorimeter resolution are determined by the technology. They will not be studied in this paper.

The energy resolution can be parameterized as:

$$\frac{\sigma_E}{E} = \frac{a}{\sqrt{E}} \oplus \frac{b}{E} \oplus c$$

where sign $\oplus$ denotes quadratic addition, E is a beam energy in GeV, a is the stochastic term, b is determined by the readout noise, and the constant term c is due to the detector and readout inhomogeneity and the calibration error. Since the photon detector will measure relatively low-energy photons ($E < 2$ GeV), we can ignore electronic noise [4].

Detector simulation

The main task was to find a construction of the calorimeter, which has the best energy resolution in the given conditions. The simulation environment is MpdRoot, built on FairRoot. The FairRoot framework is an object oriented simulation, reconstruction and data analysis framework based on ROOT. By using the Virtual Monte Carlo concept it is possible to perform the simulations using either Geant3 or Geant4 without changing the user code or the geometry description [3].

To investigate the characteristics of ECAL, Geant4 was used. Photons with different energies were generated by the BoxGenerator. Detector response was observed in two cases - when the particles hit the calorimeter module in the center and when they are randomly distributed over a few modules.

Geometry with rectangular modules (V1)

In this case the barrel structure of the detector is assembled from modules having rectangular shape. The construction may look as follows - three modules are grouped together in one segment ($360 \times 120 \times 400$ mm^3) and forty-nine such segments form a row. Thirty-one rows are disposed at an azimuthal angle 11.6 degrees. This geometry is shown in Fig. 1.

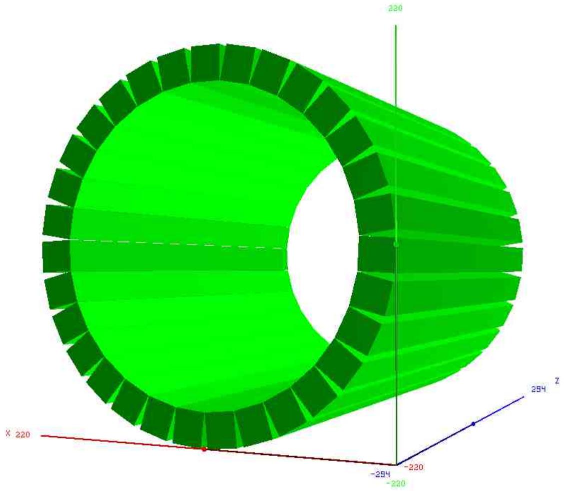

Fig. 1. Barrel part of the calorimeter in MPD built from rectangular units (Geometry V1).

The first step was to select such a thickness of the absorbing plate as to reach the best possible energy resolution. Characteristics of the two types of construction V1 were observed and the results are shown in Fig. 2. The graph shows that construction Type 1 has better resolution than Type 2 in energies less than 1 GeV, but in higher energies, electromagnetic showers begin to leak through the module. The energy interval we are interested in is less than 1 GeV, therefore it is better to use construction with 0.3-milimeter lead plates.

It is obvious that filling the cylinder with rectangular modules will leave spaces between them (Fig. 1).

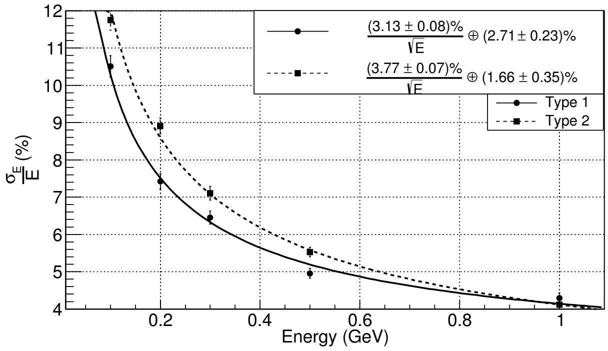

Fig. 2. Energy resolutions for both types of geometry V1 when beam photon energy hits the center of a module.

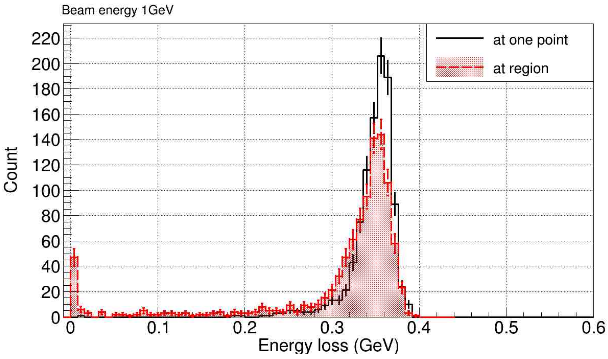

Fig. 3. Distribution of energy loss when the photon beam hits the center of a module and when it is randomly distributed in a region of few modules.

Fig. 3 shows the distribution of energy loss when the beam energy is 1 GeV and the photons hit the center of a module and when they are distributed over a region - $\phi(45^\circ, 135^\circ)$, $\theta(90^\circ, 90^\circ)$, covering few modules. The shift of energy loss to smaller values down to zero is the result of a dead zone in the calorimeter construction.

The constant term increases twice when the beam photons are generated in a region. This is shown in Fig. 4 and it is the result of the existence of empty spaces between the modules. For the improvement of the constant term and the energy resolution, a decision was taken to use a construction of trapezoidal modules.

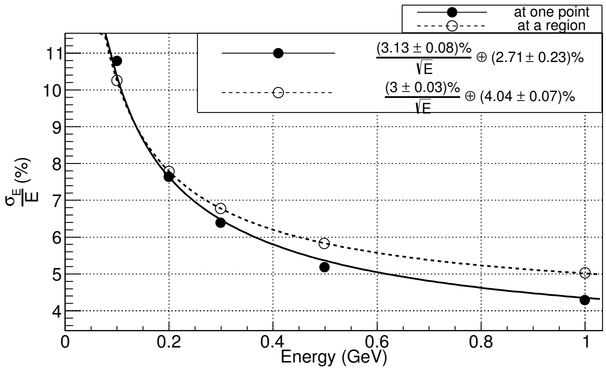

Fig. 4. Energy resolutions by type 1 when the photon beam hits the center of a module and when it is randomly distributed in a region of few modules.

Geometry with trapezoidal modules (V2)

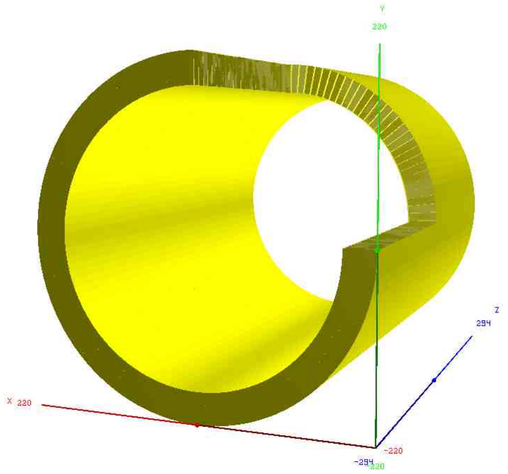

Fig. 5. Barrel part of the calorimeter in MPD built from trapezoidal units (Geometry V2).

The basic module (120×120 mm^2) is cut off on two sides at an angle 1.565 degrees in the ϕ plane. Each module is rotated by 3.13 degrees at azimuthal angle and is closely fit to the preceding one. The thickness of the lead plates is 0.3 mm. In this way a structure having no dead zones is formed (Fig. 5).

Filling the space between modules keeps the constant term stable, which can be seen in Fig. 6.

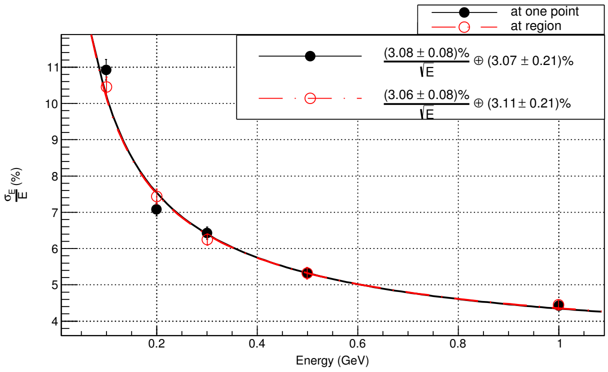

Fig. 6. Energy resolutions (Geometry V2) when the photon beam hits the center of the module and when it is randomly distributed in a region – $\phi(45^\circ, 135^\circ)$, $\theta(90^\circ, 90^\circ)$.

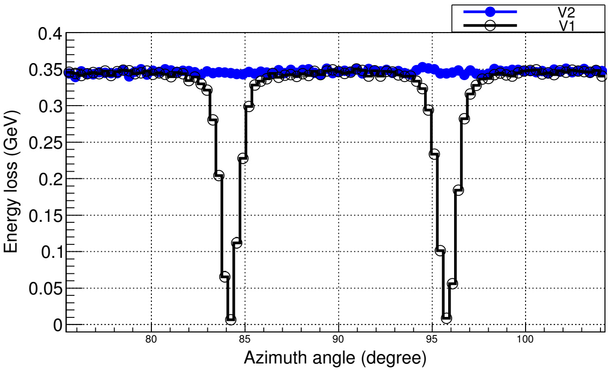

Fig. 7. Distribution of energy loss versus azimuthal angle (beam energy 1 GeV).

Figure 7 shows the distribution of energy loss versus azimuthal angle of the two constructions of ECAL with beam energy 1 GeV.

SUMMARY

It is shown a method for reducing the influence of dead zones between modules on the energy resolution of ECAL. The energy resolutions of calorimeters constructed from modules, having different cross-sections, were compared.

The test results lead to the decision to use a construction of trapezoidal modules, composed of lead plates 0.3 mm and 1.5 mm scintillator plates. In this case the detector shows the best performance, in relation to the imposed requirements.

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МОДЕЛИРАНЕ НА ЕЛЕКТРОМАГНИТНИЯ КАЛОРИМЕТЪР КЪМ NICA/MPD

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(Резюме)

Основното предназначение на електромагнитния калориметър е да измерва координатите и енергиите на електроните и фотоните, родени при сблъсъци на тежки йони. Калориметърът ще служи и за идентификация на частици. Първа стъпка в реконструкцията на събитията ще бъде търсене на π^0-мезони и изваждането на фотони, свързани с π^0-мезони, от пълния поток фотони. Останалите фотони ще се считат кандидати за директни фотони. За да се достигне необходимата чувствителност в реконструкцията на π^0 при висок шум, енергията на фотоните трябва да се измерва с висока точност. Необходимо е разрешение по енергии около 3%.

За ECAL в MPD е избран хетерогенен калориметър тип „сандвич“, изграден от пластини олово и сцинтилатор [1]. Основният модул е със страни 4 × 4 cm. Отделеното пространство в MPD за ECAL е 50 cm, което ограничава модула по дължина – не повече от 40 cm.

Главната задача бе да се моделира геометрия, която да покрива изискванията от 3% енергетично разрешение. Създадени бяха три основни модела геометрии и за всеки един от тях бяха разгледани различни вариации на запълващите сегменти (различни дебелини на оловните пластини и дължина на основния модул). Първоначално симулациите се извършваха с помощта на софтуер GEANT3, а след това с GEANT4. След проведените симулации се стигна до решение да се избере една от геометриите – с най-добро разрешение по енергии и оптимално запълване на пространството (дебелина на оловните пластини 0.3 mm и дължина на основния модул 40 cm).

Изготвени бяха два прототипа на основния модул с различни оптични влакна. Проведоха се два експеримента на електронен сноп в DESY (Германия). Извършиха се тестове на двата модула, енергийно и честотно сканиране, проверена бе електрониката, усилвателите и кабелите, изследваха се два типа фотодетектора – Zecotek и Hamamatsu. Достигна се енергетично разрешение 3.5% при 1 GeV и разрешение по време 100 ps на 1 GeV.

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