PROCEEDINGS OF SCIENCE

NICA/MPD Electromagnetic Calorimeter based on Multipixel Avalanche Photodetector

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A Multi Purpose Detector (MPD) is being constructed for the Heavy-Ion Collider at Dubna (NICA). One of the important components of MPD setup is an Electromagnetic Calorimeter, which will operate in the magnetic field of MPD solenoid and provide good energy and space resolution to detect particles in the energy range from ~100 MeV to few GeV. For this purpose the, so-called, "shashlyk" sampling structure with the fiber readout to the silicon Multi Pixel Avalanche Photodetector is used. The genuine design is similar to the one developed by us for COMPASS experiment but a number of important modifications have been introduced to better meet MPD resolution, large volume thermo-stabilization and other requirements. These details are presented in the report along with the beam test results obtained with the MPD/NICA module prototypes.

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1.Introduction

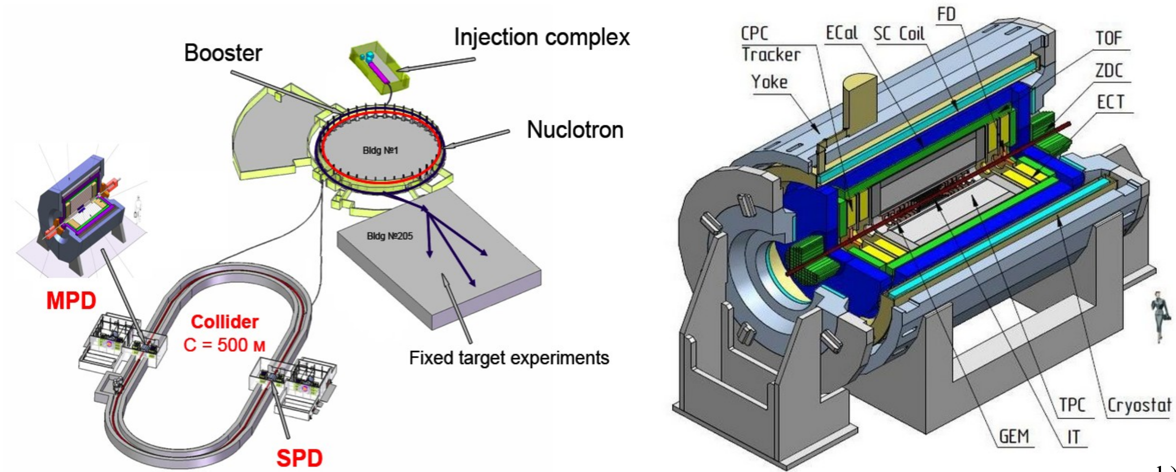
The main goal of the NICA/MPD project is to start in the coming years experimental study of hot and dense strongly interacting QCD matter and search for a possible manifestation of the mixed phase formation and critical endpoint in heavy ion collisions.

Tasks:

- Deconfinement;
- Symmetry braking;
- Antimatter;

Parameters:

- $\sqrt{S_{NN}}$ = 4-11 GeV;
- Beams from *p* to *Au*;
- L ~ 10^{27} (Au), 10^{32} (p)[$cm^{-2}c^{-1}$];



a) b)

Figure 1: *NICA(a) and MPD(b).*

Electromagnetic probes, such as real and virtual photons (i.e. dileptons), provide key measurements to answer the questions concerning the temperatures, the corresponding system sizes of the matter at the early stages, and the temperature evolution of the system from the formation time to thermal freeze-out. The primary role of the electromagnetic calorimeter is to measure the spatial position and energy of electrons and photons produced in heavy ion collisions. It will also play a major role in the particle identification due to the high time resolution for the detected particles. The first step in the event reconstruction will be a search for the π^o and subtraction of photons associated with π^o from the full photon flux. Remaining photons labeled as a candidates to the prompt photons. The expected high multiplicity environment implies a high segmentation of the calorimeter [1].

2.Electromagnetic calorimeter type "Shashlyk"

As a baseline option is selected heterogeneous calorimeter type "Shashlyk"(Fig.2) which meets the MPD requirements:

- high segmentation;
- low Moli'ere radius;
- occupancy below 5%;
- energy resolution (3 ÷ 5)%;
- time resolution ~ 100 psec is desirable;
- must be able to operate in magnetic field;

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 [4], LHCB, KOPIO [5] and others. The genuine design is similar to the one developed by us for COMPASS experiment [7] but a number of important modifications have been introduced to better meet MPD resolution, large volume thermo-stabilization and other requirements.

2.1ECal geometry

The MPD 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 (120x120 mm^2) consisting of 9 optically isolated towers which are read out individually. The light from each tower is read-out by 16 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.

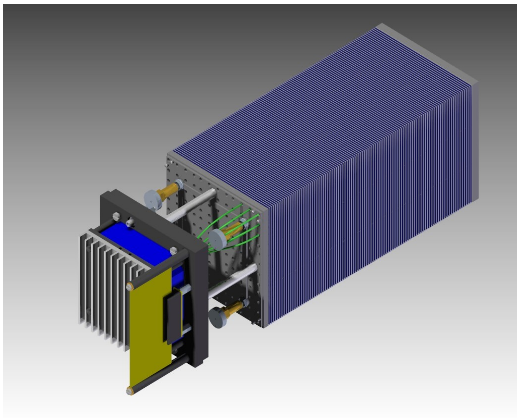


Figure 2: *Shashlyk modul.*

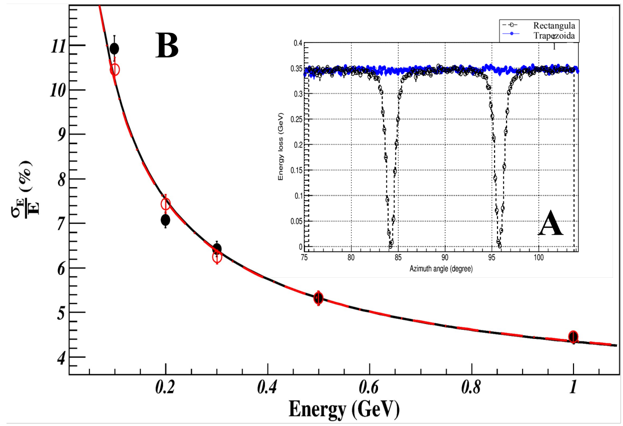


Figure 3: *Distribution of calorimeter response versus azimuthal angle of hitting photons in two cases - when the module is rectangular (●) and it is trapezoidal (●)(A). Energy resolutions (trapezoidal modul) when the photon beam hits the center (○) of the module and when it is randomly distributed in a region of few modules (○)(B).*

The MC test results (Fig.3) lead to the decision to use trapezoidal modules in state of conventional rectangular one. Calorimeter constructed from the trapezoidal modules will have significantly less dead space. Modul optimized to the MPD conditions will have following sampling – 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.

2.2Electronics

Few types of Micro-Pixel Avalanche Diodes (MAPD) have been tested when they appeared in the market. The most acceptable for our purposes are:

– ZECOTEC which has an extermely high pixel density (up to 40000), but due to the long dead time has a limited counting rate.

– HAMAMATSU (S12572-015P) is very compact SMD device with higher gain, low dead time and lower temperature dependency of amplification.

All electronic devices necessary for the calorimeter operation are specially developed in our institute:

ADC - ADC64s2 is a 64-channel 12-bit 62.5 MS/s ADC device with signal processing core and Ethernet interface. It is capable of precise time synchronization by White Rabbit network (up to 10 ps). Data readout, trigger and timing function is performed by single fiber-optical link. Optional QSFP connector may be used to provide external clock for very high precision measurements as well as trigger and readout links [6]. Power consumption is about 50 mW/ch and proper cooling required. The size of the board is 130x128x40 mm^3.

LED generator – To make a precise calibration of each ECal registration channel and also for the continuous monitoring of channel amplification LED generator of short bright blue light signals has been designed and built. Main requirement to this device is its stability. Light intensity variation should be less 1%. To reach such stability the digital feedback loop has been implemented to the device - the pin-diode has been located on the LED backside and the information from this diode is used for the automatic correction of LED intensity.

High voltage systems – High voltage system have been created by the HVSys company and consist of up to 127 nine channel boards, one system unit and one system bus. Through the flat cable each board is connected to the ECal module. One line of this cable is dedicated to the temperature measurements used to perform voltage correction to compensate temperature dependency of the MAPD amplification.

3.Experimental results

Many tests of the ECal prototypes were carried out DESY (Hamburg, Germany) and at CERN, SPS (Geneve, Swiss). Test results have been used to improve module design and electronics property. Here same latest results are presented.

3.1Energy measurements

Possibility to make correct energy reconstruction from the ECal measurements strongly depends on the ECal resolution and capability of precise calibration of all calorimeter channels. Photodetector MAPD is a priori non linear device, taking into account that it is a digital device with limited number of pixels. As a result, expected nonlinearity is observed in the ECal response to the energy of penetrating electrons (Fig.4).

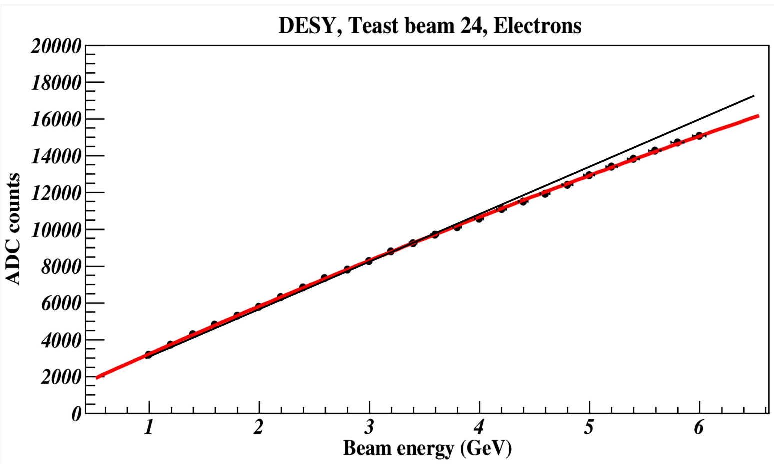


Figure 4: *Detector response to the hitting electrons of different energies.*

The curves on the Fig.4 are very smooth and carefully measured what leaves a good chance to make a precise ECal calibration.

Test beam of CERN SPS has been used to study ECal energy resolution (due to very small energy spread in this beam). Experimentally measured energy resolution is little worse in the low energy region, than it was expected from the MC (Fig.5).

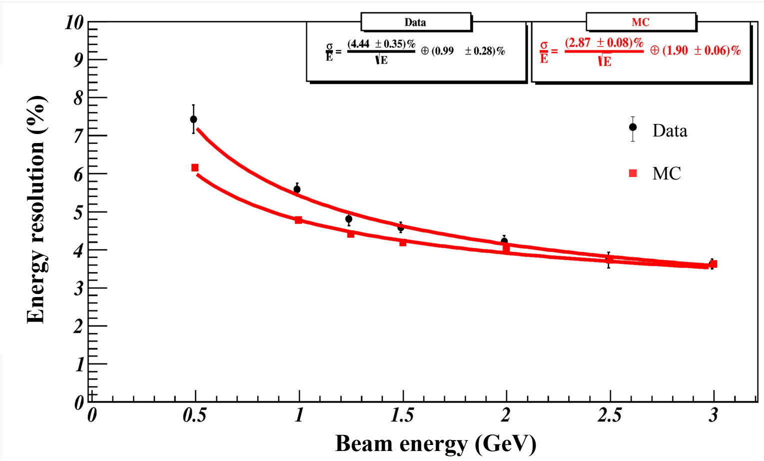


Figure 5: *Energy resolution vs electron energy for data and MC.*

On the Fig.6a spectra of the ECal response to the electrons and muons are illustrating rather good agreement with MC predictions. Pedestal width is very small that allows to set registration threshold at the level of 20-30 MeV. Slight mismatch between data and MC in the energy region less 1 GeV (Fig.6a) disappeared at higher energies (Fig.6b).

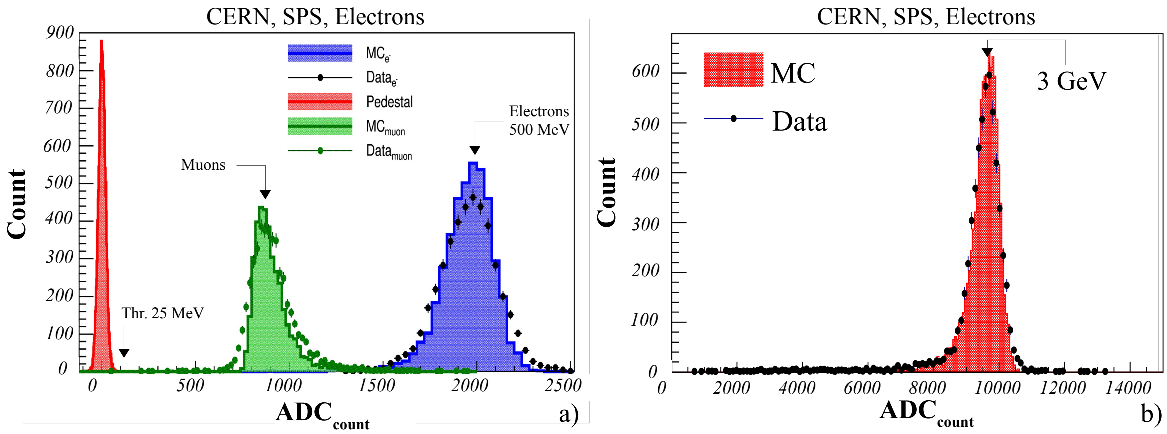


Figure 6: *Signal spectrum for the pedestal, muons, electrons (0.5(a) and 3 GeV(b)).*

3.2Time measurements

The time resolution is highly desirable for the ECal to participate in the time-of-flight measurements and reduce a pile-up noise. Measurements of time resolution done by the different methods with completely different electronics shows perfect agreement (Fig.7).

The time resolution in our case is a strong function of number of detected photoelectrons. Arrows on the Fig.7 just indicating place of MIP particles and 1 GeV electrons for the one of ECal prototypes. Improving the light collection we can improve time resolution.

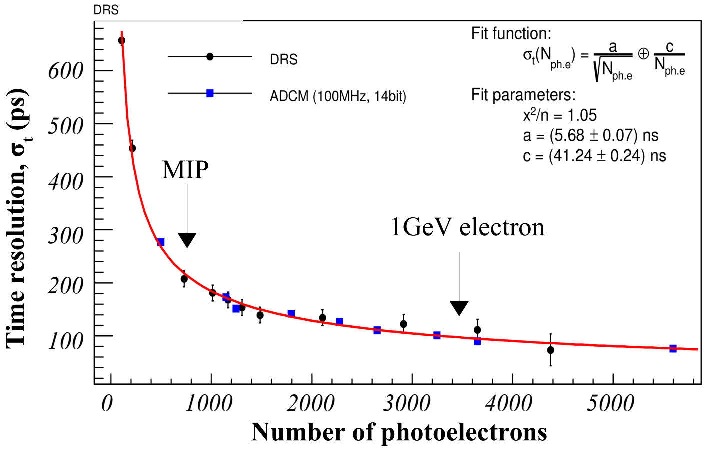


Figure 7: *Time resolution vs number of detected photoelectrons measured with different methods and different electronics. Time bin: DRS -200 ps [8] and ADCM – 10 ns [6].*

3.3Coordinate measurements

A possibility to perform a coordinate measurements from the ECal was tested during 2015 test beam run at DESY. Set up from two modules was used. The coordinate in this case is determined as a weighted average of all active towers. The beam position measurements are not in good agreement with the real place of the beam. Systematic deviations are observed from the expected linear dependency (Fig.8). This deviations are very close to sinusoidal with "0" in the center and on the edges of each module.

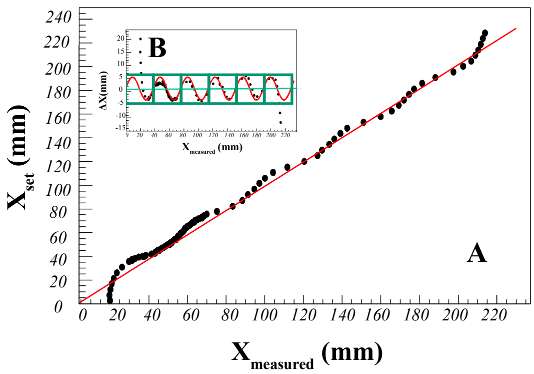


Figure 8: *Correlation between set and measured coordinates (A). Deviation of the measured coordinates from the linear dependence (B).*

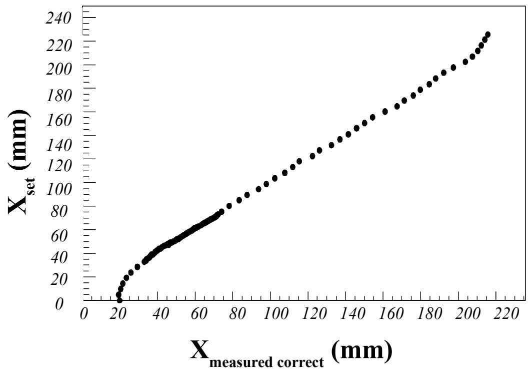


Figure 9: *Correlation between set and measured coordinates after correction.*

The fitting of this sinusoidal dependency have been used to correct reconstructed *x* position value and corrected result is shown in Fig.9. Accuracy of the coordinate measurements obviously depends from the number of active towers and the accuracy of each of them, therefore from the energy deposited in the electromagnetic shower. This dependence was measured at DESY test beam (Fig.10). In the NICA energy region ECal can measure electromagnetic shower position with precision of a few millimeters. Evidently the nature of the observed nonlinearity in the coordinate measurements is the dependency of the calorimeter response from the beam position. This feature is clearly seen in the measurements presented on the Fig.11. To make a precise measurments, energy should be corrected by the coordinate dependent function.

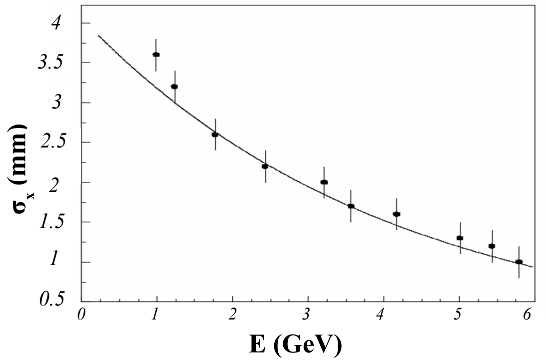


Figure 10: *Space resolution versus energy of hitting electron.*

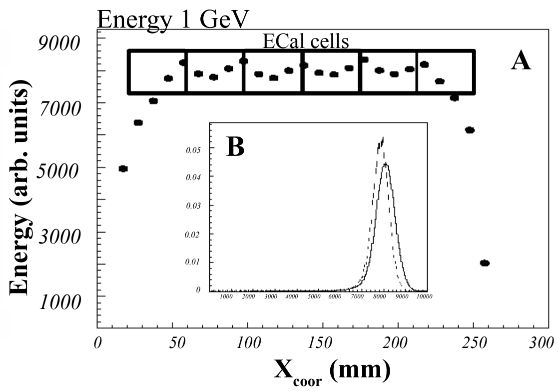


Figure 11: *Dependence of the measured energy from the beam position (A). Distribution of measured energy hitting center (dotted line) and edge of module (solid line)(B).*

4.Summary

Requirements from the physics tasks to the ECal of MPD detector were studied and MC study was done to choose a proper design of the calorimeter.

By the common effort of ISMA factory (Kharkov, Ukraine) and JINR(DLNP, LHEP) "Shashlyk" type calorimeter have been designed and test production is started.

The set of devices to operate the calorimeter with light registration by MAPD detectors was constructed:

- ADC64s2 is a 64-channel 12-bit 62.5 MS/s ADC device;
- HV module with automatic temperature compensation;
- LED sources of light flashes with internal stabilization;

Many beam tests which have been performed at CERN and at DESY are shown reasonable agreement with MC predictions. Time resolution up to 100 psec has been reached. Position resolution depends from the energy of electromagnetic particles and varies from 5 to 2 mm for the NICA energies. The necessity of the calorimeter response correction versus beam position is shown.

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