Nuclear Inst. and Methods in Physics Research, A 958 (2020) 162833

Contents lists available at ScienceDirect

Nuclear Inst. and Methods in Physics Research, A

journal homepage: www.elsevier.com/locate/nima

Beam test results of two shashlyk ECal modules for NICA-MPD

Yulei Li [a], Dong Han [a], Yi Wang [a,*], Chendi Shen [a], Viacheslav Golovatyuk [b], Igor Tyapkin [b], Boyana Dabrowska [b,c], Yury Krechetov [b], Zhicheng Zhou [a], Yuanjing Li [a]

[a] Key Laboratory of Particle and Radiation Imaging, Department of Engineering Physics, Tsinghua University, Beijing 100084, China
[b] Joint Institute for Nuclear Research, JINR, Joint-Curie 6, 141980 Dubna, Moscow region, Russia
[c] Plovdiv University "Paisii Hilendarski", 24 Tsar Assen Str.Plovdiv, 4000 Plovdiv, Bulgaria

ARTICLE INFO

Keywords:
Shashlyk electromagnetic calorimeter
Beam test
Energy resolution
Time resolution

ABSTRACT

Electromagnetic calorimeter (ECal) is an important detector of the Multi Purpose Detector (MPD) at the NICA collider. A shashlyk-type ECal will be constructed for MPD. The particular goals of the MPD ECal are to measure of spatial positions and energy of photons and electrons. The whole ECal consists of 43008 shashlyk tower and each tower consists of 220 layers of 1.5mm scintillator +0.3mm lead plates. 16 Wave Length Shifted fibers are used to collect light signals. The SiPM detector is used to read out the signals. After being amplified, the signal was sent to a waveform sampling circuit to obtain the waveform of each incident particle. Two ECal prototype modules were developed in Tsinghua University and the beam test were carried out at DESY on August of 2018. MPD ROOT is used to analysis the test data.The results show that number of photoelectron (Npe) changes linearly with the electron energy. 4.5% energy resolution, 212.4ps time resolution and 4.7mm spatial resolution are also achieved. All these results show that the prototype of ECal is fully capable of the requirement of the MPD. In this article, the structure of the shashlyk module and its performance in beam test are described.

1. Introduction

The physics program of the MPD project (Fig. 1) at the NICA heavy-ion program at JINR (Dubna) is optimized for the study of properties of hot and dense matter in heavy-ion collisions within the energy range from 4 to 11 GeV [1–3]. The main goal of electromagnetic calorimeter in MPD is to identify electrons, photons and measure their energy with high precision [4]. High granularity of the ECal together with excellent energy resolution and good timing performances will enhance the overall efficiency and particle identification capabilities of the MPD detector.

Considering the price, the time resolution and the possibility of realization. The target spectrometer ECal is going to be built from the shashlyk-type [4]. Shashlyk ECal has been already realized in the COMPASS-II [5,6], PHENIX [7], LHCb [8] and ALICE [9]. A wedge shaped ECal were be designed since the MPD project requires much higher energy resolution. Beam test of two shashlyk calorimeter prototype developed by Tsinghua University were carried out at DESY (Germany) with the use of electron beam in the energy region from 1 to 5 GeV. The results of energy linearity, energy resolution, time resolution and spatial resolution are presented.

2. Shashlyk ECal tower

The "shashlyk" tower is a lead-scintillator sandwich which read out by means 16 of Wave Length Shifting (WLS) fibers passing through the holes in scintillator and lead. An example of the "shashlyk" calorimeter tower is shown in Fig. 2.

The whole ECal in MPD consists of 43008 shashlyk towers, and a single shashlyk ECal is defined as a tower. Each tower consisting of 220 layers of 0.3 mm lead plates with painting and 1.5 mm thick scintillator sheets. The cross section of the tower is a square with a side length of 4 cm. As shown in Fig. 3(a) 3(b) 3(c), each scintillator plate has 16 wedge-shaped holes equidistantly arranged in the square, inserted by 16 WLS fibers with a diameter of 1.0 mm. One end of each fiber was polished and painted with mirror painting for light reflection. The other end was collected in one bunch, squeezed, polished, and connected to a silicon photomultiplier (SiPM Hamamatsu S13360-6025PE). The profiles of module were painted with TiO_2 based reflective painting to improved light reflection efficiency [10]. A splicing design similar to Lego bricks was used for those scintillator plates to simplify the splicing process and enhance its stability (Fig. 3(d)). The electronics of the readout system is self-made by JINA.

Tsinghua University is a member of MPD collaboration and is in charge of design and production of ECal modules. Besides strict R&D,

* Corresponding author.
E-mail address: yiwang@mail.tsinghua.edu.cn (Y. Wang).

https://doi.org/10.1016/j.nima.2019.162833
Received 31 March 2019; Received in revised form 19 September 2019; Accepted 21 September 2019
Available online 27 September 2019

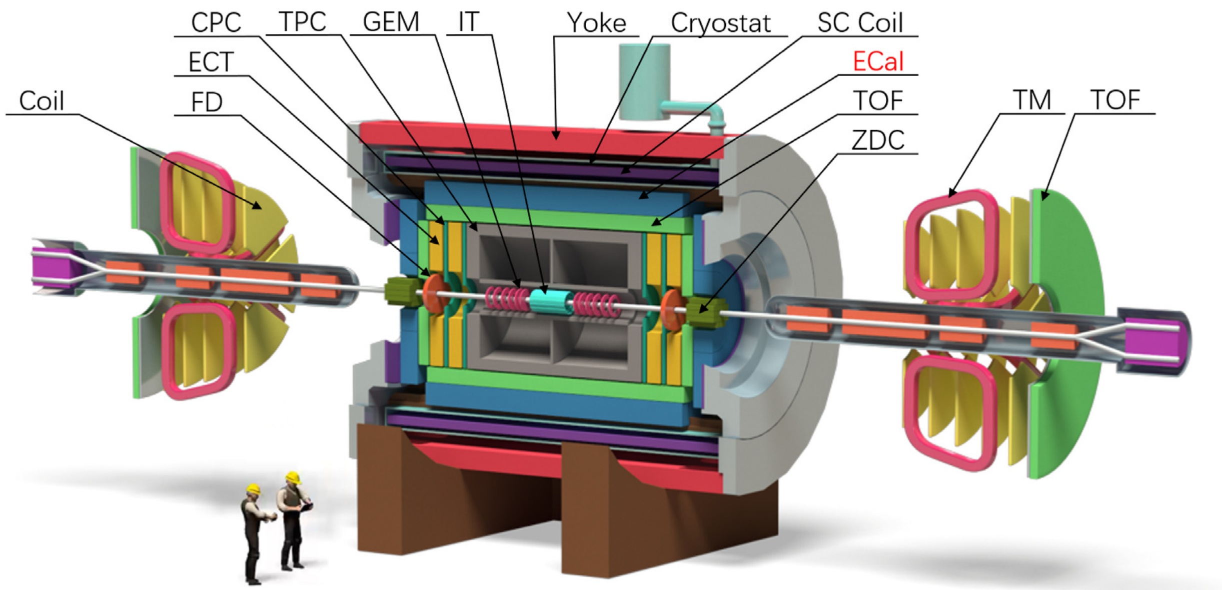


Fig. 1. The structure of Multi-Purpose Detector (MPD).

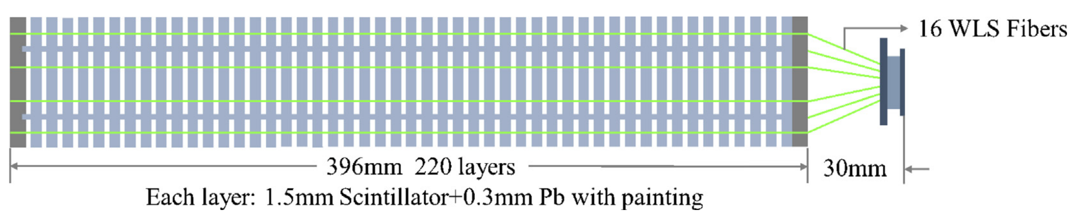


Fig. 2. The structure of the Shashlyk ECal.

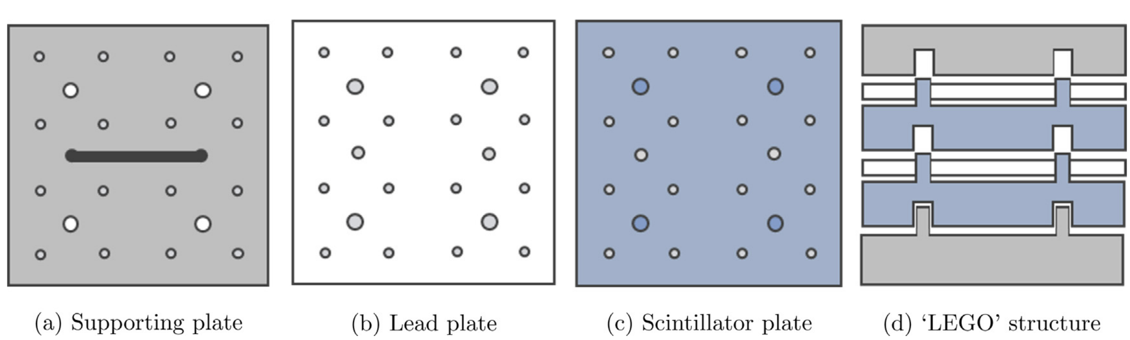


Fig. 3. The structure of various plates in ECal.

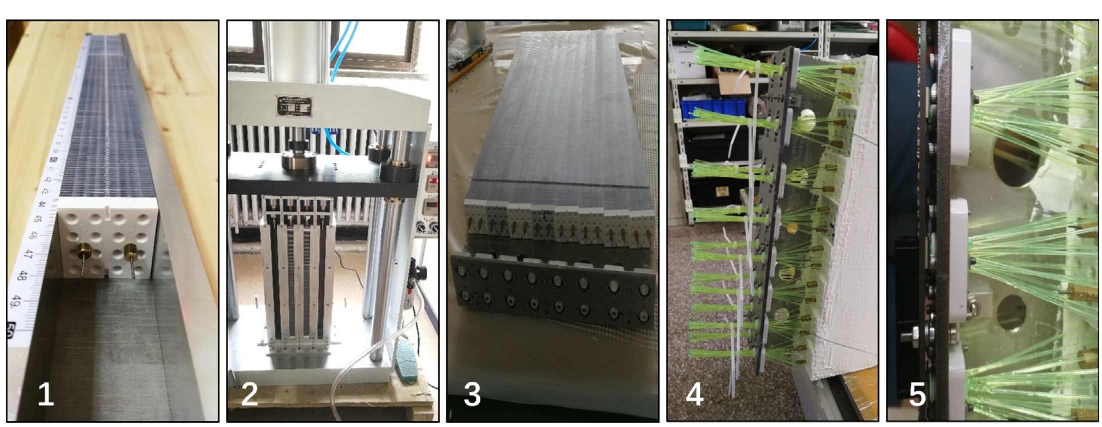
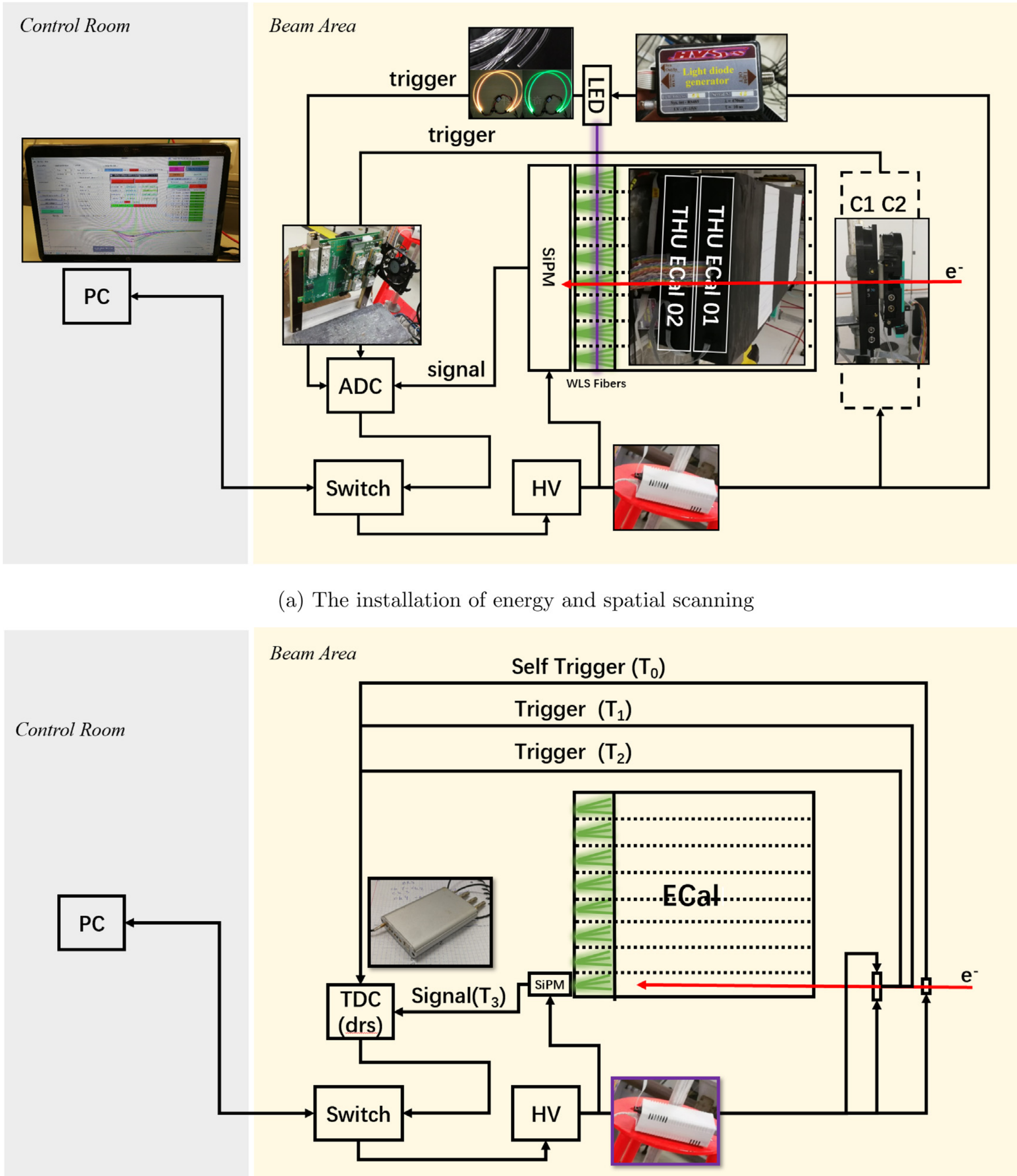


Fig. 4. The procedure of tower & module assembling.



(a) The installation of energy and spatial scanning

(b) The installation of time information scanning

Fig. 5. Beam test system for the shashlyk prototype studies.

the art and craft for production is also important. Assembling procedure in brief can be described as a following (Fig. 4):

1. Assembling a tower by using 220 alternating layers of lead and scintillator plates in the mold, pulled together with one loops of a steel string. Strings are fixed by the two tension screws.

2. Sixteen towers are pressed with a special machine.

3. 2 times 8 towers are cut at a small angle and bonded into one module.

4. The end of fibers are glued in bunches and connected with SiPM separately.

5. Cut and polished the fibers, connecting the PCB plate with SiPM detector and wrapped with shading paper.

The main parameters of shashlyk tower are listed below in Table 1.

Table 1
Main parameters of ECal.

Parameters of main tower	
Transverse size, mm^2	40 × 40
Number of WLS fibers	16
Number of layers	220
Lead absorber thickness, mm	0.35
Scintillator thickness, mm	1.5
Moliere radius, mm	62
Number of radiation length, X_0	11.8
Effective radiation length, mm	32.4

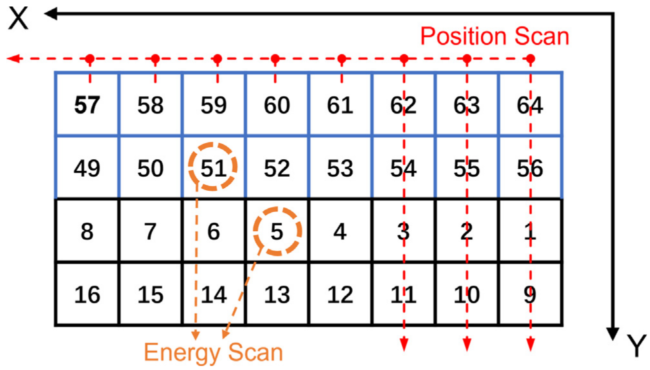


Fig. 6. The process of beam test.

3. Beam test at DESY

3.1. Experimental set up

On August 2018, two prototype modules of the ECal, each consisting of 16 towers, were subjected to a beam test in Hamburg, Germany. The two prototypes modules named THU ECal 01 and 02 were installed on the x, y-moving table.

In the beam test, the energies of electron beams was between 1 to 6 GeV, an energy spread of 5% and a divergence of 1mrad.

The experimental set up of this beam time is illustrated in Fig. 5(a). The two ECal prototype positioned in the x, y-moving table which can be remotely controlled in control room with a precision of 0.4 mm. One of a trigger of the experimental setup used the coincidence of 2 scintillator counters — C1, C2. The other used the LED and illuminating fiber as a monitoring system to monitor the stability of the entire test. Amplitude information obtained by SiPM conversion of light was measured by 32-bit charge sensitive ADC modules 076D-3170 over 16 ns gate. The high voltage system was controlled by the ethernet switch provided high voltage for the different plug-ins of the entire experiment. The final data is collected on the computer through the switch.

When the time information is collected (in Fig. 5(b)), the original ADC (sampling rate 62.5 MHz) is replaced by 4-bit DRS4 (sampling rate 5 GHz) for higher time resolution, three of which are triggers, so the performance of time resolution of one module is studied.

Each tower of the prototype was defined with a number (1–16, 49–64). Lateral energy scanning, longitudinal energy scanning of energy from 1.0 GeV to 5.0 GeV for tower 51 and tower 05 and time information scanning were performed. Eight columns were scanned along the x-axis direction, and each position was scanned every 5 mm for a total of 264 position points (in Fig. 6).

3.2. Calibration

A LED with short blue light is used for the calibration of ECal channels and also for the performance monitoring. Fig. 7(a) shows the signal of the Integral ADC of the four towers in the y direction under the same light intensity. It can be seen the signal amplitude of each tower is different. After correction by multiplied different coefficients which we set, the amplitude is very uniform (Fig. 7(b)).

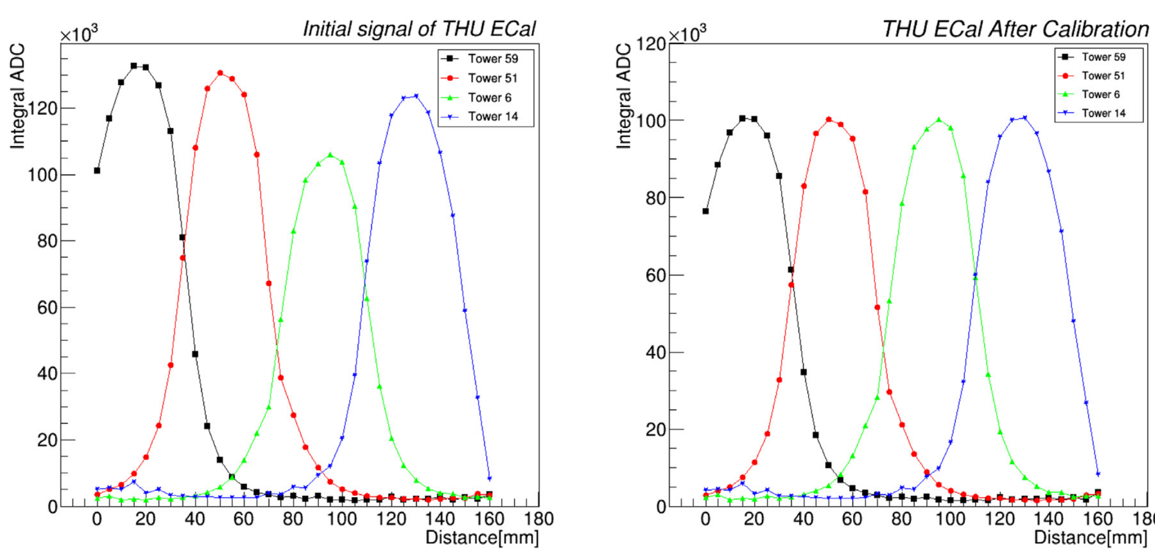
3.3. Energy linearity and energy resolution

After dedicated calibration runs, The number of photoelectrons generated by THU ECal 01 were integrated at different beam energies. The energy E of the beam particle measured in the calorimeter prototype is linearly correlated with the number of photoelectron (Npe), as illustrated by Fig. 8(a). Energy resolution can be obtained from the peak through Gaussian fit of the sampled waveform. The energy resolution σ/E at the energies from 1 to 5 GeV are shown in Fig. 8(b). For THU ECal 02, there is a very good consistency with THU ECal 01 in energy linearity and energy resolution. A quadratic fit to these experimental data gives $\sigma/E = (0.044 \pm 0.002)/\sqrt{(E)} + (0.017 \pm 0.001)$ (GeV) and $\sigma/E = (0.045 \pm 0.0003)/\sqrt{(E)} + (0.017 \pm 0.0002)$ (GeV).

3.4. Time resolution

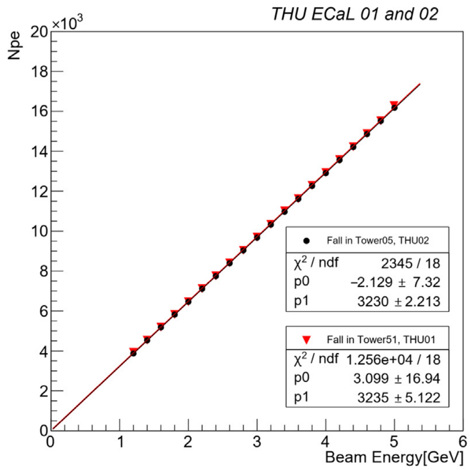
The time resolution is usually defined as a fixed threshold and the standard deviation of the threshold crossing time t. Due to the fixed threshold, signals with larger pulse height have earlier t. This time walk is only related with the signal amplitude and therefore should be corrected with amplitude a [11], the relationship of t and a is fit and corrected with the function:

$$t = p_0 + \frac{p_1}{\sqrt{a}} + \frac{p_2}{a} + p_3 a \tag{1}$$

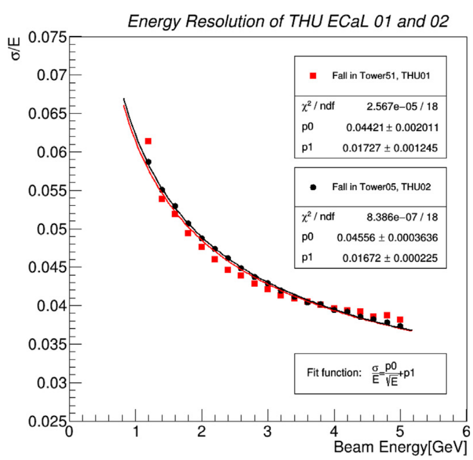


(a) Before calibration (b) After calibration

Fig. 7. The Integral ADC of different distance about calibration.



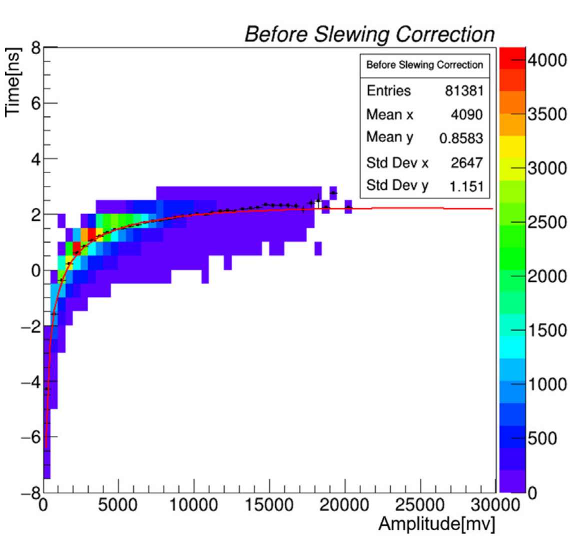
(a) Linear Fit of Beam Energy and Npe



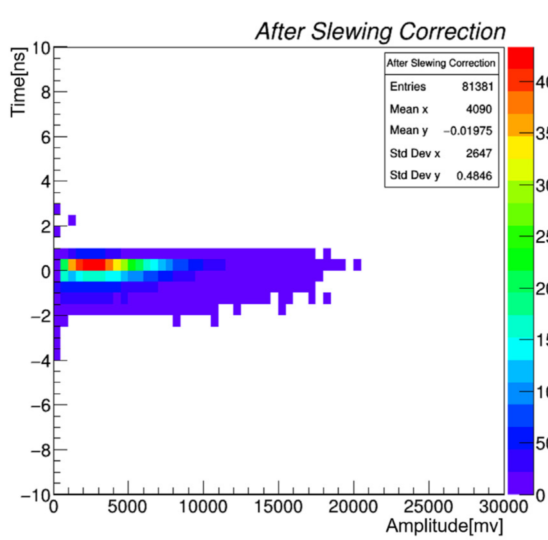
(b) Energy8Resolution

Fig. 8. Energy performance of ECal prototype.

Fig. 9(a) is the 2D distribution of a versus t before the slewing correction, while Fig. 9(b) is the distributions after the correction.



(a) Before slewing correction



(b) After slewing correction

Fig. 9. Time performance of ECal prototype.

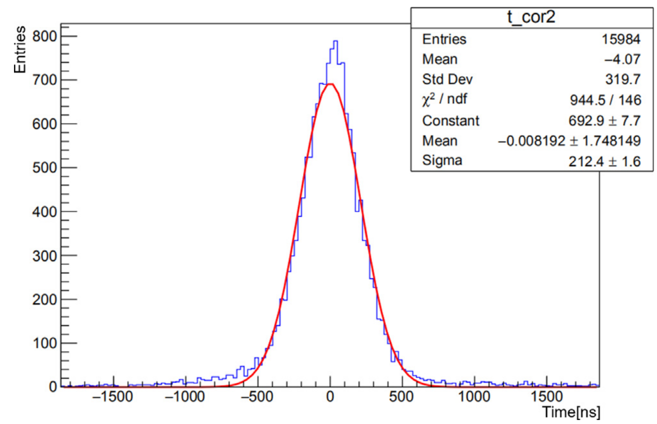


Fig. 10. Time resolution.

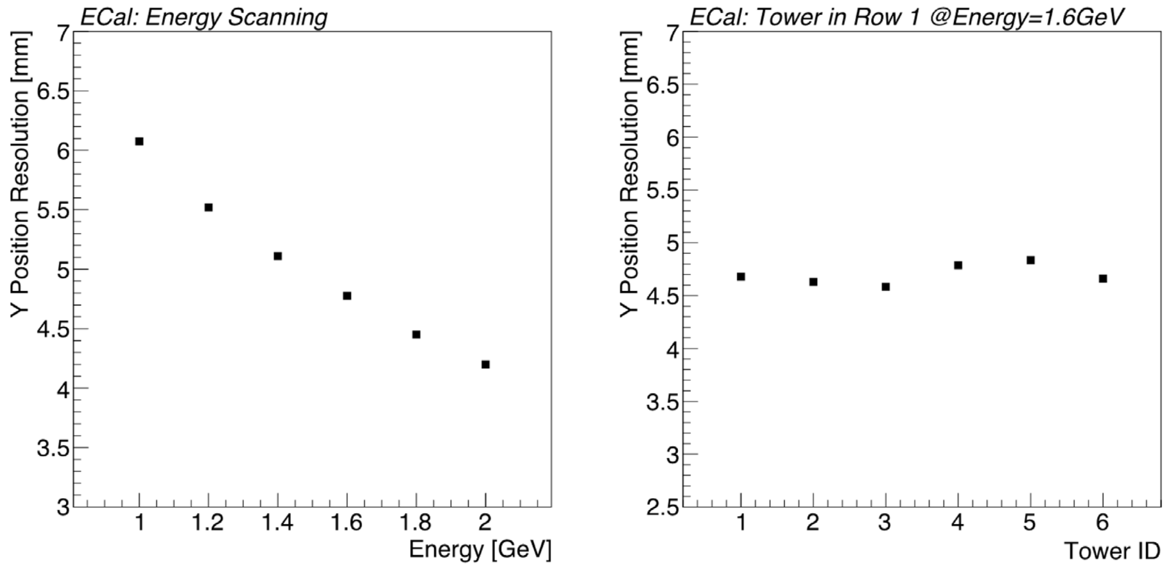
These plots prove that the dependence of a and t is largely eliminated by the correction, and the final time resolution for this Shashlyk ECal is 212.4 ps (Fig. 10).

3.5. Spatial resolution

From the data of the position scan, the Center of Gravity technique was used to study spatial resolution. Fig. 11(a) shows the spatial resolution is around 4.7 mm at 1.6 GeV after corrected. Fig. 11(b) shows that the different towers have good uniformity. Neural network methods will be used in the study of spatial resolution for better spatial resolution in the future [12].

4. Conclusion

Two shashlyk ECal prototypes were designed and assembled at Tsinghua University. The measurements of energy, time and spatial resolutions of the two modules have been carried out at the DESY test beam facility. The results for 40 × 40 mm^2 cell size are the following. The Npe(@1 GeV) is 3500 and the good linearity was obtained. The other main performance are: energy resolution is around 4.4%, time resolution 212.4ps and spatial resolution around 4.7 mm. All of the performance meet the MPD requirement.



(a) Spatial resolution (b) Spatial resolution

Fig. 11. Spatial resolution.

Acknowledgments

The work is supported by National Natural Science Foundation of China under Grant No. 11420101004, 11461141011, 11275108, 11735009. This work is also supported by the Ministry of Science and Technology, China under Grant No. 2015CB856905, 2016 YFA0400100.

References

[1] G. Trubnikov, A. Kovalenko, V. Kekelidze, I. Meshkov, R. Lednicky, A. Sissakian, A. Sorin, Heavy Ion Collider Project NICA/MPD at JINR (Dubna), 2011.

[2] V. Kekelidze, A.D. Kovalenko, V. Matveev, G. Trubnikov, R. Lednicky, A. Sorin, I. Meshkov, Scientific program of NICA at JINR, PoS (2013) 411.

[3] V. Kekelidze, A. Kovalenko, R. Lednicky, V. Matveev, I. Meshkov, A. Sorin, G. Trubnikov, Status of the NICA Project at JINR, Citeseer, 2014.

[4] MPD NICA technical design report of the electromagnetic calorimeter (ECal), http://mpd.jinr.ru/wp-content/uploads/2017/09/TDR_ECAL_v1.3.pdf.

[5] N. Anfimov, V. Anosov, I. Chirikov-Zorin, D. Fedoseev, O. Gavrishchuk, N. Khovanskiy, Z. Krumshtein, R. Leitner, G. Meshcheryakov, A. Nagaytsev, et al., Shashlyk EM calorimeter prototype readout by MAPD with superhigh pixel density for COMPASS II, Nucl. Instrum. Methods Phys. Res. A 718 (2013) 75–77.

[6] I. Chirikov-Zorin, Z. Krumshtein, A. Olchevski, The design of a photodetector unit of a new Shashlyk EM calorimeter for COMPASS II, Nucl. Instrum. Methods Phys. Res. A 824 (2016) 674–677.

[7] L. Aphecetche, T. Awes, J. Banning, S. Bathe, A. Bazilevsky, S. Belikov, S. Belyaev, C. Blume, M. Bobrek, D. Bucher, et al., PHENIX Calorimeter, Nucl. Instrum. Methods Phys. Res. A 499 (2–3) (2003) 521–536.

[8] R. Dzhelyadin, L. Collaboration, et al., The LHCb calorimeter detectors, Nucl. Instrum. Methods Phys. Res. A 581 (1–2) (2007) 384–388.

[9] A. Fantoni, A. collaboration, et al., The ALICE electromagnetic calorimeter: EMCAL, J. Phys. 293 (1) (2011) 012043.

[10] G. Atoian, G. Britvich, S. Chernichenko, S. Dhawan, V. Issakov, O. Karavichev, T. Karavicheva, V. Marin, A. Poblaguev, I. Shein, et al., An improved Shashlyk calorimeter, Nucl. Instrum. Methods Phys. Res. A 584 (2–3) (2008) 291–303.

[11] F. Wang, D. Han, Y. Wang, Y. Yu, Q. Zhang, B. Guo, Y. Li, A standalone simulation framework of the MRPC detector read out in waveforms, J. Instrum. 13 (09) (2018) P09007.

[12] F. Wang, Improving the spatial resolution of NICA ECAL through new reconstruction method, 2019, ArXiv preprint arXiv:1902.03629.