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Design and assembly of the CsI(Tl) crystal module of the BESIII electro-magnetic calorimeter

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Abstract The CsI(Tl) crystal modules of the Beijing Spectrometer III (BESIII) electro-magnetic calorimeter (EMC) were designed and assembled through Monte Carlo simulation and experiments. After the assembly was finished, the performance of each crystal module was tested by cosmic rays. All crystal modules were found to work well before the installation of EMC.

Key words BESIII electro-magnetic calorimeter, CsI(Tl) crystal, crystal module

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1 Introduction

The use of CsI(T1) calorimeter has been very popular in the field of high energy physics[1—3] due to its various nice features such as large photon yield, high scintillation efficiency, small radiation length X_0 (1.86 cm), weak hygroscopicity and mechanical stability. A total of 5280 (960) CsI(T1) crystal modules for the barrel (end caps) part of the electro-magnetic calorimeter (EMC) of the Beijing Spectrometer III (BESIII), is used to measure the energies and positions of electrons and photons precisely.

The CsI(Tl) crystal modules will determine the expected performance of the calorimeters, so in the construction of the EMC, the design and the performance of the crystal module are very important. In this paper, we report the study on the design of the crystal modules of BESIII-EMC and the assembly process. Finally, some experimental tests including the cosmic-ray test of the crystal modules are introduced and the results are given.

2 Design of the crystal module

The structure of the crystal module is shown in Fig. 1. It is mainly composed of one CsI(Tl) crystal, two photodiodes (PD) and two preamplifiers.

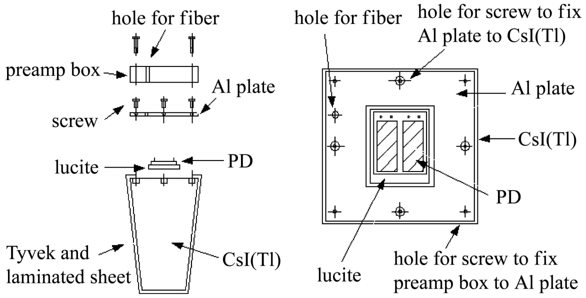

Fig. 1. The structure of the CsI(Tl) crystal module.

2.1 The dimension of CsI(Tl) crystal

In the EMC, the electrons and photons deposit their energies in the crystals by electro-magnetic showers. The energy leakage of the shower depends mostly on the length of the crystals[4, 5]. Fig. 2 shows the energy resolution as a function of the crystal length by Monte Carlo simulation. It is clear that the energy resolution improves about 0.5% for every 2 cm increase of the crystal length. To achieve the expected energy resolution of 2.5% at 1 GeV, the crystal with a length of 28 cm ($15X_0$) was chosen for the EMC.

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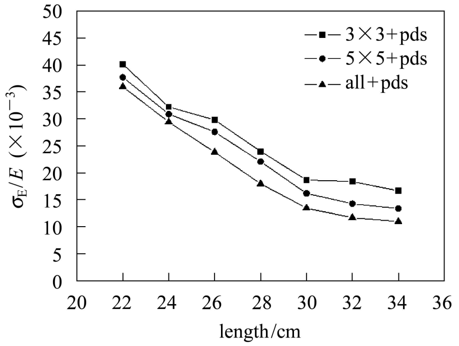

Fig. 2. Energy resolution vs. length of CsI(Tl) crystals for 3×3 crystal modules, 5×5 modules and all modules with energy deposition at 1 GeV.

The position resolution is determined by the transverse dimension of the shower and the number of the crystals with energy deposition. From the center of gravity method, smaller cross section of the crystals is advantageous for a better position resolution, but if it is much smaller than the shower dimension, the energy resolution will become worse, because the leakage of the shower through the dead materials between the crystals increases and more electronics channels lead to more noise contribution in energy measurement. Fig. 3 shows the effect of different cross section of the crystal front end on the energy and position resolutions by Monte Carlo simulation.

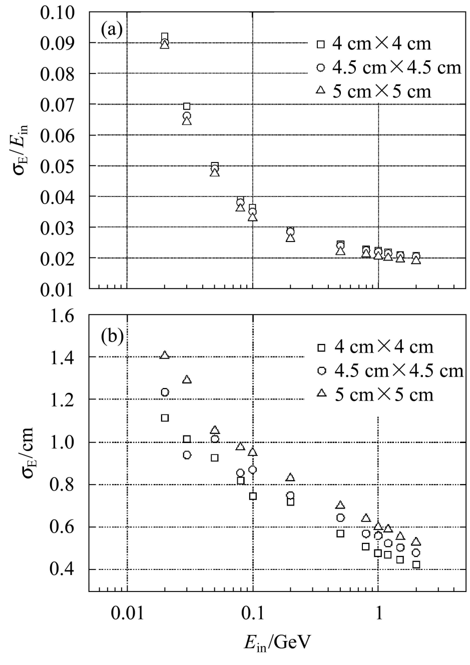

Fig. 3. Energy resolution (a) and position resolution (b) as a function of energy for the 28 cm long crystal with the cross section of 4 cm×4 cm, 4.5 cm×4.5 cm, 5 cm×5 cm at the front end respectively. Here 0.5 MeV equivalent noise is included.

In the BESIII work energy region, the minimum opening angle of the two photons from the decay of 1.5 GeV π^0 is 10°. They should spread over no less than 3.3 crystals to be separated from a single photon of the same energy.

Besides meeting the requirement of the compact mechanical structure of EMC, all crystals will be deflected 1.5° in φ direction and 1.5°—3° in Z direction to avoid the particles from the interaction point escaping from the gaps between the crystals.

From the Monte Carlo simulation and global optimization design, a typical size of CsI(Tl) crystals 5 cm×5 cm in the front end, 6.5 cm×6.5 cm in the rear end and 28 cm in length was chosen for the EMC of BESIII.

2.2 The reflection material for wrapping the crystal

CsI(Tl) crystal has a high refractive index (n=1.79). The reflection material has a remarkable effect on the collection of the crystal scintillation light[6]. Thicker reflection material results in higher light collection efficiency, but the thicker one also brings more dead materials to make the energy resolution worse, so the thin reflection films with light elements should be chosen.

Figure 4 shows the relative light output of CsI(Tl) crystal wrapped with different reflection films. Millipore and Tyvek have a high reflection efficiency (dots 10, 5, 7, and 8), while Teflon with tiny holes (used by Belle calorimeter[2]) is somewhat worse (dot 4). Furthermore, Tyvek has a reliable performance, so the double-layer Tyvek with a total thickness of 2×130 μm was chosen as the reflection material.

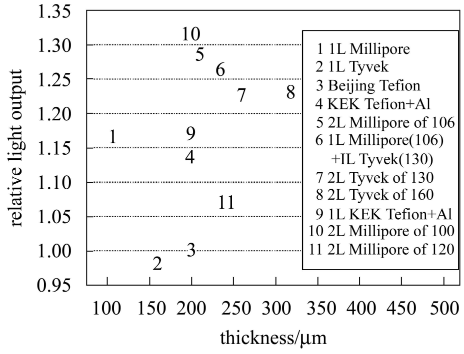

Fig. 4. Comparison of the relative light output (PD readout) of CsI(Tl) crystal wrapped with different reflection films.

Except the rear end, the other five surfaces of the crystal were wrapped with 260 μm thick Tyvek sheet first and then wrapped with a laminated sheet of 25 μm thick aluminum and 25 μm thick mylar. The aluminum layer worked as an electric shield, and the mylar was used to electrically separate each crystal from the others.

2.3 The photodiode for readout and the preamplifier

EMC will be installed in a magnetic field of 1.0 T. Silicon photodiode (PD) readout is much cheaper than that of photomultiplier tube (PMT) working in high magnetic field. In addition, the PD matches perfectly well with the emission spectrum of CsI(Tl) crystal, so we chose PD (S2744-08, the sensitive area is 1 cm×2 cm, Hamamatsu) as the readout device.

One crystal was coupled with two PDs. The electronic noise of one PD is proportional to the PD area ($S_{\rm PD}$). By using two PDs readout in one crystal module, the total noise is proportional to $\sqrt{2}S_{\rm PD}$, which can not only ensure the suitable sensitive area for scintillation light collection, but also reduce the electronic noise effectively.

The particles from the shower leakage will deposit energy in the PD directly. The reaction rate is proportional to $S_{\rm PD}$. The extra signal caused by this effect is equivalent to about 50 times of the same energy deposited in the crystal. But this effect occurs mostly for incident particles with high energy. Its probability is very small in the BESIII work energy region[7].

Low noise charge-integrated preamplifier with a gain of 1 mV/fc was designed for the EMC. Two PDs in one crystal were connected to two independent preamplifiers respectively, and their signals were summed up in a shaping amplifier with a time constant of 1 μs. The crystal module can still work even if one of the two channels is dead, so the counter module has a good safety margin against the total failure.

3 Assembly of the crystal module

In order to reduce the dead materials between the crystals and improve the energy resolution, the mechanical structure of crystal suspension was adopted in EMC. Each crystal module will be suspended on the supporting girder via an L shape aluminum plate.

In the assembly process of the crystal modules, four holes were drilled in the rear end of the crystal first and then an 8 mm thick aluminum base plate with a dimension of 50 mm×50 mm was fixed to the crystal rear end by four Φ2.8 self-tapping stainless steel screws. Two pieces of S2744-08 PDs were glued onto the center of the crystal rear end in the Al base plate coupled with a 2 mm thick Lucite as light guide. Two-component optical epoxy glue (Eccobond24 A and B, mixing mass ratio 4:1) was used for both the PDs-Lucite and the Lucite-CsI(Tl) joints. In order to improve the attachment of the coupling plate, before the gluing, the surface of the crystal was cleaned with acetone, and the surfaces of the Lucite and PDs were cleaned with alcohol. The whole gluing process was in a dry box with relative humidity smaller than 10% and a temperature of about 20 ℃.

At last, the remaining area of the light output surface including the PDs was covered with a 500 μm thick Teflon film to increase the light collection efficiency. An aluminum box housing two preamplifiers was mounted onto the aluminum base plate. All metal shields (the Al layer wrapping the crystal, the Al base plate and the Al box) were electrically connected together with the ground of the preamplifier to reduce the electronic noise.

4 Experimental test of the crystal module

4.1 Suspension test

A group of crystal modules were horizontally suspended or vertically suspended on an actual EMC supporting girder via L shape aluminum plates. After suspension for 4 days, the light outputs of the crystal modules were measured again. Fig. 5 shows the difference of relative light output between the crystal modules before and after suspension. The difference was within the measurement error. No glue joint was broken in the experiment.

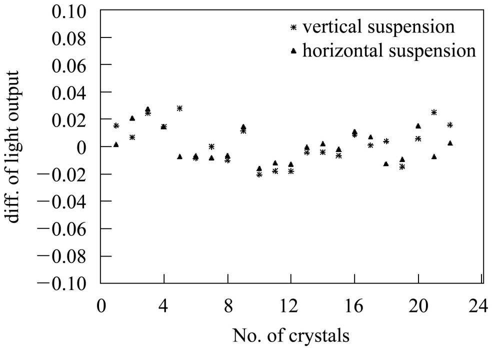

Fig. 5. Difference of light output between the crystal modules before and after suspension.

4.2 Mechanical strength

We also tested the mechanical strength of the crystal. A crystal module was horizontally suspended via an L shape aluminum plate. With a load up to 47 kg on top of the crystal, the L shape plate was deformed. Even the front end of the crystal moved down by about 80 mm, the threads in the crystal were not destroyed and the screws did not fall off from the crystal either.

These tests show that the crystals have enough mechanical strength to support all forces in the suspension installation of EMC, and the glue joint between the crystal and PDs will not be broken by the crystal suspension.

4.3 Cosmic-ray test

A cosmic-ray test system[8] was set up to test the performance of each crystal module and give its initial calibration data for EMC running. The crystal modules were put into a dark box and placed in the test system, comprising 4 layers of plastic scintillation counters and coded wavelength shifting fibers for triggering and tracking. Since the system can trace cosmic-ray tracks with a position resolution of better than 1 cm, the position and path lengths of cosmic rays in a crystal can be calculated precisely. The signals from the crystal module were summed and shaped in a post amplifier having time constant of 1 μs, and then digitized by a peak-hold ADC.

In contrast with the result measured by ^{137}Cs γ rays (PMT readout)[9], the crystal modules whose light outputs decreased more than 20% were likely to have problems, such as the breaking of the glue joint, the disconnection between the preamplifiers and PDs. Some problems of the crystal modules had been found and solved through the cosmic-ray test. Fig. 6 shows the light outputs of the barrel 5280 crystal modules measured by cosmic rays (the light output of each crystal module was normalized by the result measured by ^{137}Cs γ rays, PMT readout). All of the crystal modules work well.

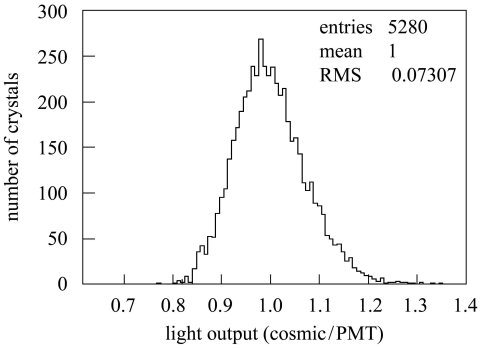

Fig. 6. The light output of barrel crystal measured by cosmic rays (normalized by the measurement result of ^{137}Cs γ ray).

5 Conclusion

The CsI(Tl) crystal modules of the BESIII-EMC were designed through Monte Carlo simulation and experimental tests. The assembly procedure of the crystal modules was set up to complete the assemblies of EMC crystal modules. Through the experimental tests, the crystal modules were confirmed to have enough mechanical strength and stability for suspension installation. The performance of each crystal module was tested by cosmic rays. All of the crystal modules worked well before the installation of EMC.

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