Current Status and Performance of the BESIII Electromagnetic Calorimeter

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Abstract. The BESIII experiment is located at the Beijing Electron Positron Collider (BEPCII) in China. Its electromagnetic calorimeter (EMC) consists of 6240 CsI(Tl) crystals, each read out by two Photodiodes (PD) at the end of the crystal. Changes in the response of the calorimeter due to radiation damage in the crystals or changes in the photo detector output are monitored with a light pulser system.

1. Introduction
The Beijing Electron Positron Collider II (BEPCII) is a symmetric collider with a double storage ring. The center of mass energy of the $e^+e^-$ system can be varied from 2.0 to 4.6 GeV with an energy spread of 1.1 MeV at 3.686 GeV. Inside the Beijing Spectroscopy III (BESIII) experiment [1] the electrons and positrons collide under a crossing angle of 11 mrad.

The detector is composed of several subsystems. The Multilayer Drift Chamber (MDC) is the inner most detector. It provides excellent tracking with momentum resolution of $\sigma_p/p = 0.5\%$@1 GeV and a spatial resolution of $\sigma_{xy} = 130 \mu$m. The next detector is the Time of Flight (TOF) system used for particle identification. The TOF is composed of two plastic scintillator bars providing a time resolution of $\sigma_T = 100$ ps. Behind the TOF the Electromagnetic Calorimeter (EMC) is located followed by the 1 T magnet and the muon system. The muon system uses 9 layers of resistive plate chambers for the detection of the muon tracks.

Overall BESIII has about 40000 read out channels with a data rate of 5 kHz and 50 MB/s, respectively.

2. BESIII Electromagnetic Calorimeter
The BESIII EMC is based on CsI(Tl) crystals [2] with a designed energy resolution of 2.5% and a position resolution of 6 mm for 1 GeV showers. The EMC consists of a barrel and two endcaps as shown in figure 1. The barrel is segmented in 44 rings in theta each consisting of 120 crystals. The two endcaps are arranged in 6 rings in radial direction. A total of 6240 crystals are used. The crystals are 28 cm (15.1$X_0$) long with an average front size of 5.2 by 5.2 cm$^2$ and an average rear size of 6.4 by 6.4 cm$^2$. In order to minimize the dead material and gaps between neighboring crystals, they are suspended from a support girder, i.e. there is no supporting walls between the crystals. There is however a 5 cm gap between the last rings of the barrel and the endcaps of the EMC.

Two Hamamatsu S2744-08 photodiodes are glued to the back face of every crystal. The
photodiodes have a size of 1 cm $\times$ 2 cm and are readout by a preamplifier [3]. The signals from the preamplifier are send to the main amplifier with 1 $\mu$s shaping time and then digitized by a Q module. The noise of the read out chain is required to be less than 1100 electrons which corresponds to the signal of a 220 keV shower. For RF shielding the read out units are housed in an aluminium box. This read out box is attached to the crystal by four screws drilled into the crystal and then mounted to the support structure. In order to prevent the CsI(Tl) crystals from deliquescence and to maintain the humidity inside the calorimeter in a suitable range, the EMC is flushed with freeze-dried compressed air.

3. Operation Experience

According to the design, the allowed radiation dose per year should be less than 200 rad at the crystals. In order to monitor the applied radiation dose, Radiation-sensing Field-Effect Transistors (RadFET) based on a metal-oxide-silicon p-channel structure are used. RadFETs are integrated dosimeters which measure the dose by the virtue of the field effect caused by space charge trapped in an inorganic insulator. The RadFETs are distributed at a radius close to the crystal position. Inside the barrel four rows with 12 probes along the $z$ direction at $\varphi = 0^\circ, 90^\circ, 180^\circ$, and $270^\circ$ are placed. Inside both endcaps 12 additional probes are placed. The integrated dose accumulated from the beginning of operation in 2009 to December 2013 is shown in figure 2. In six years of operation the maximum integral dose is about 1754 rad. It is striking to note that the integral dose at the west endcap is much larger than at the east endcap. This is due to the fact, that BEPCII is also used for synchrotron radiation experiments. In this operation mode only electrons are used, accelerated from east to west. Thus the west endcap is exposed to high synchrotron radiation while the east endcap is not.

To check the quality of a module and monitor radiation damages LED-fiber units consisting of a LED, light mixer and fiber bundle are used. In order to monitor the crystal’s light output and response of the photodiodes each crystal is connected to one fiber. The light intensity of the LED-fiber system can be adjusted to simulate the energy deposite in a crystal from 10 MeV to 1.5 GeV. Two independent references using an Am$^{241}$ source are used to monitor the variances of each LED. The stability of the LED-fiber system is less than 1% in a run.

Overall 76 units are used in the EMC, 60 units in the barrel each serving 88 crystals and 16 units
in the endcaps each serving 60 crystals. During data taking the system is used to determine bad channels and monitoring of the performance of the EMC, including the gain reduction due to radiation damages. Figure 3 shows the relative decrease of the light output measured by the LED-fiber system. In most cases the decrease is less than 10%. Only 30 crystals show a decrease larger than 10% and among them only 10 crystals exceed 20%. The results are in agreement with the offline calibration using Bhabha scattering events. Also these numbers have not been increased in the last two run periods.

In the time from April 2009 to September 2010 17 crystals showed a sudden decrease of the light output by about 15%. This was caused by an ungluing of the photodiodes from the crystal. There is one crystal with a relative light output of less than 20%. This may be caused by a total drop of the photodiodes from this crystal. These losses in light output can be recovered through offline calibration.

Each crystal is read out by two PDs and two preamplifiers. The signals from the preamplifiers are fed to differential amplifiers and then go through a switching stage. By default the selection
“$A + B$” is used, which builds the sum of both signals. After 2011 however nine crystals were only read out by one PD. For those channels the selection “$2A \lor 2B$” is used to boost the signal of the remaining PD by a factor of two.

4. Performance of the EMC

For calibration of the gain of each crystal BESIII uses Bhabha events. From this data the energy peak and resolution of each channel can be determined at 1.5 GeV. Figure 4 shows the measured energy resolution. It can be seen that the results from data taking in 2009 and 2012 are in very good agreement with each other and with the results from Monte Carlo simulations at a center of mass energy of 3.097 GeV. After six years of operation no distinctly decrease of the crystals light output can be observed. The energy resolution in the barrel part of the EMC is about 2.3% and 4.1% in the endcaps. In this plot also the gap between barrel and endcaps is clearly visible.

![Figure 4. Energy resolution of crystals for Bhabha at 1.5 GeV, $E_{CMS} = m(J/\psi)$.](image)

5. Conclusion

The status and performance of the BESIII calorimeter is very good. All 6240 channels are working well, the total integral radiation dose is still in an acceptable region. The decrease of the light output monitored with a LED-fiber system is for most of the crystals below 10% and the losses due to ungluing of the photodiodes and failures of the electronics could be compensated. The BESIII EMC is taking data smoothly and there is no degradation of the performance after six years of operation.

References

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