CALOR2000

Operating a Small Angle Calorimeter at BELLE

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Abstract

A small angle calorimeter called EFC has been installed at BELLE, KEK. It consists of 320 radiation hard BGO crystals. The data acquisition, trigger and monitoring systems of EFC are reported. The important emphasis is on the stability of EFC related to radiation recovery. This has been tested before and confirmed by a careful calibration method with Bhabha events. EFC has been running smoothly and offer the online luminosity information reliably since its installation.

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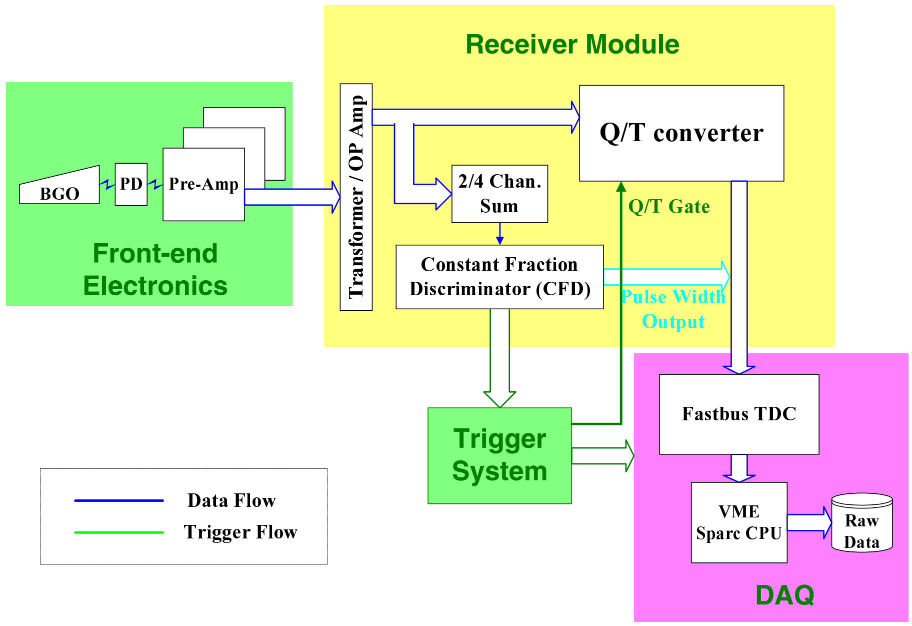

Figure 1: Schematic diagram of the EFC readout electronics and DAQ system

1 Introduction

A small angle calorimeter called Extreme Forward Calorimeter (EFC) [1] has been installed last April in the BELLE detector [2] at the KEK B-factory. The main functions of EFC are providing the online luminosity information to the detector and accelerator, and acting as a tagger for two-photon events. The electromagnetic shower medium is Bismuth Germanate ($Bi_4Ge_3O_{12}$), commonly known as BGO. Since the radiation hardness is an important issue for this device, we choose the radiation-hard BGO crystals [3] produced by the Institute of Inorganic Chemistry, Novosibirsk, Russia. Its radiation hardness has been checked to be good after receiving 100Mrad dose[4].

EFC consists of two parts, forward and backward, which are mounted on the front surfaces of the cryostats of the compensating solenoids of KEKB.The angular coverage is from 6.4^0 to 11.5^0 and from 163.3^0 to 171.2^0 for forward and backward respectively. Each part consists of 160 BGO crystals with 5 segments in θ and 32 segments in ϕ.Due to space limitation, the lengths are only 12 and 11 radiation lengths for the forward and the backward BGOs.

2 Readout Electronics and DAQ

Figure 1 is the schematic diagram of the EFC readout electronics and Data AcQuisition (DAQ) system. Each BGO crystal is wrapped with 100μm thick

Teflon and 25μm thick aluminum tape. Scintillation light is converted by pin silicon Photo-Diodes (PD), HPK s5106, into charge signal and is amplified by home made preamp boards[5]. The interface between BGO crystal and photodiode is glued with RTV KE45T, which is radiation-hard and stable after temperature cycling.

Differential signals from preamp boards are transmitted via 16 meter long twisted pair cables to the receiver boards. Transformers and gain control operational amplifiers are used for common mode noise rejection and gain adjusting. Then the signal is split into two paths: one to a charge-to-time conversion (LeCroy MQT300A) unit and the other to a constant fraction discriminator unit for trigger purpose. The MQT300A chip can integrate the input charge with three different dynamic ranges and encode them into a single time ECL signal. The ratios between gains for these three ranges are 1:8:64. The gate width used for charge integration is about 330ns.

The encoded time signals are then fed into ECL fan-out modules via 60m long twisted pair cables and split into a dual DAQ system, which consists of two almost identical sets of Fastbus and VME crates, called global and local DAQ, separately. The local DAQ is specifically for taking data in parallel with BELLE global DAQ without any interference. This is important for monitoring and calibration purpose. The digitization is done with 16-bit multi-hit Fastbus TDCs (LRS 1887S) [6] operated in common-stop mode. The maximum data taking rate for the local DAQ is about 500Hz.

3 Trigger System

The basic EFC trigger unit is a *trigger cell*. Two neighboring ϕ segments (each segment consists of 5 crystals) of the detector have three trigger cells according to different θ angles. In the innermost ring, a trigger cell consists of two crystals and its signal is formed by the analog sum of these two channels. The other two trigger cells consist of four crystals. The trigger output of each cell is generated by the CFD circuit in the receiver module. Currently the trigger thresholds are set to 150 mV ($\sim$ 2 GeV) for the forward and 75 mV ($\sim$ 1 GeV) for the backward.

These trigger output are then grouped into four sectors in ϕ with a logical OR in the forward and the backward, respectively, as shown in Fig. 2. A typical trigger rate of one sector is around 50 Hz at instantaneous luminosity of $10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$.

The Bhabha trigger is defined by a back-to-back coincidence of energetic electromagnetic showers and the logic is

$$(\mathsf{F1} \cap \mathsf{B3}) \cup (\mathsf{F2} \cap \mathsf{B2}) \cup (\mathsf{F3} \cap \mathsf{B1}) \cup (\mathsf{F4} \cap \mathsf{B4}).$$

Besides being used for the global DAQ and local DAQ, the Bhabha trigger signal is also sent to a CAMAC scalar for on-line luminosity measurement.

To make a reliable measurement of luminosity, one has to subtract the accidental rate of the Bhabha trigger. A logic is made by geometrically wrong

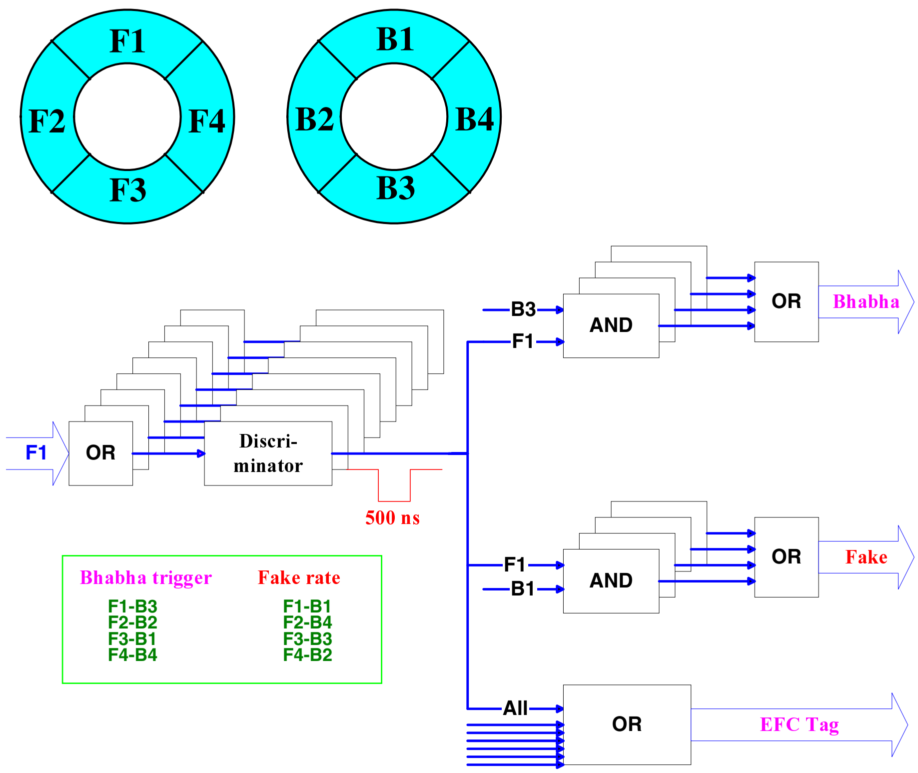

Figure 2: A schematic diagram of EFC trigger sectors and trigger logic for Bhabha, Fake Bhabha, and EFC-tag triggers.

combinations (not back-to-back) of trigger sectors to estimate such fake rate. The EFC Bhabha trigger rate at instantaneous luminosity of $10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ is 64Hz and the fake rate is less than 0.1Hz under normal beam condition. Fig. 3 shows an operational history of a typical beam fill at KEKB. EFC forward-backward coincidence rate and its fake rate are shown as a function of time in second together with e^+ and e^- beam currents of KEKB. A net EFC rate is zero during injection period of KEKB where no luminosity is expected.

The EFC-Tag trigger is defined as a logical OR of all the forward trigger sectors. Currently, two kinds of "*tagged two-photon*" triggers are implemented in Belle data taking. One is defined as EFC-Tag AND *at least one full CDC track*; the other is EFC-Tag AND *at least one ECL cluster*. Each one gives a trigger rate of around 2 Hz at instantaneous luminosity of $10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$.

A schematic diagram of both Bhabha and EFC-Tag trigger is shown in Fig. 2.

4 Monitoring System

For monitoring the detector response and calibrating front-end electronics, we have set-up for charge-injection at preamps, pulsing light directly from LEDs or via optical fibers onto BGO crystals. A pulsing system, called Smart Pulsing Generator (SPG), was developed to supply these needs. With SPG, a computer-controllable pulsing pattern can be set and the pulses are sent to one or more channels at a time, instead of a usual all-on/all-off method. This feature can make the calibration work much easier and isolate cross-talk effects.

There is a concern about the radiation damage of PD because that the PD being used can only work properly within receiving 100Krad dose [7], one need to monitor the radiation damage by measuring the dark current of the PD. A dark current readout system is implemented to accomplish this. For the first year running, there is no significant change of PD dark current. This is because the received dose by PD is much smaller then the dose received at the BGO front surface[8].

Since the BGO scintillation light output has a temperature dependence of $\sim 1\%$ per degree Celsius [10], temperature of the EFC detector has to be kept constant and monitored. A water cooling pipe is built inside the inner cylinder of EFC container to maintain the detector temperature. Also an air cooling system is installed to prevent the front-end electronics from overheat. To monitor the detector temperature, NS LM35D temperature sensors are used and distributed around the inner cylinder and preamp boards. The temperature sensor signals are passed through the preamp circuits and are read out together with crystal signals. The temperature of EFC reaches a stable value around 30 minutes later after power-on.

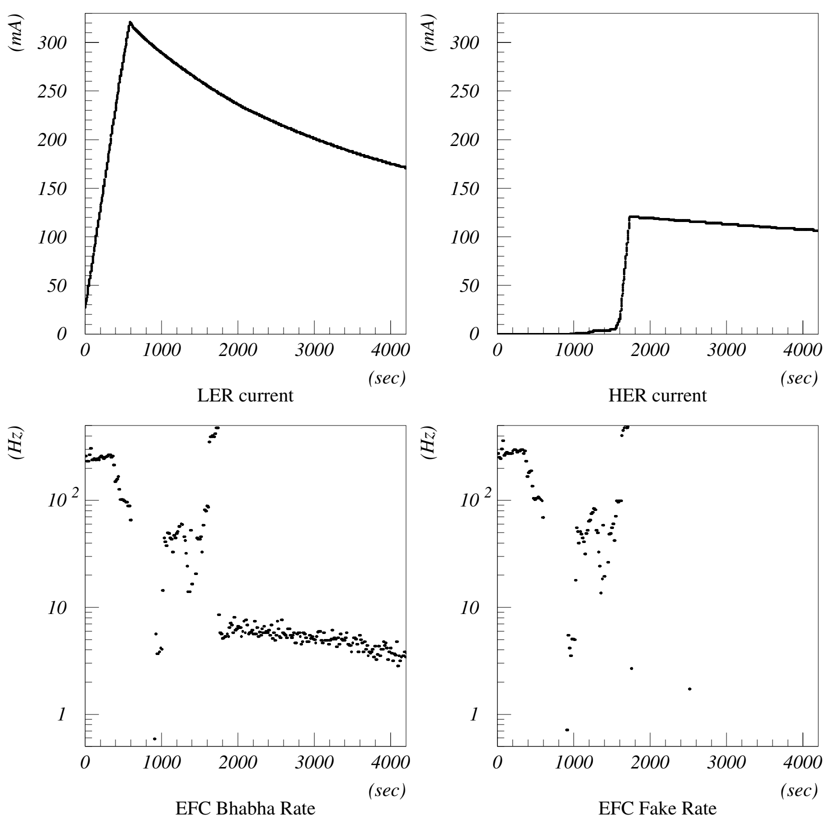

Figure 3: An operational history of a typical beam fill of KEKB. The two top figures show e^+ and e^- beam currents of KEKB. The two bottom figures show EFC forward-backward coincidence rate and its accidental rate.

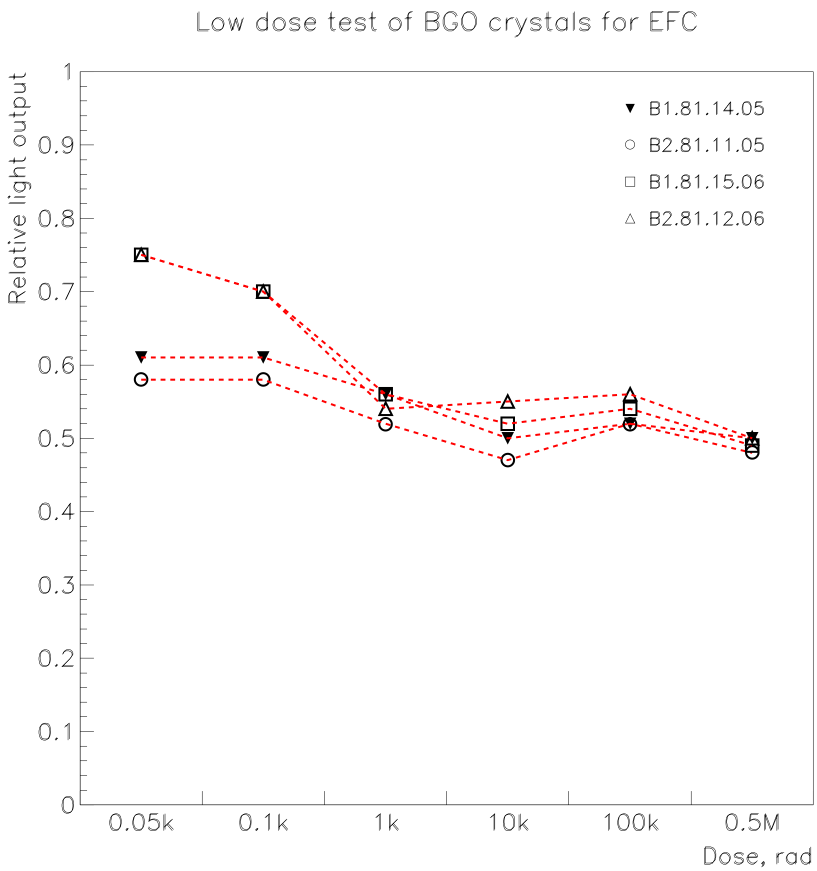

Figure 4: Light output vs. dosage. Crystals B1.81.14.05 and B2.81.11.05 have been pre-radiated with 10Mrad dose. The relative light output shown here are all normalized to the values before any radiation. Note these four crystals are from the same ingot with ingot number 81.

5 Recovery from Radiation Damage

Before the installation of EFC, the recovery behavior of BGO from radiation damage was carefully studied. We used a ^{60}Co with radioactivity of 1000 Curie to mimic the BELLE running environment. The results for crystals from a typical ingot are shown in Fig. 4. Note two of the crystals have already been pre-radiated with 10 Mrad dose. They recovered very slowly after days to a bit higher value (from 50% to 60%). It is clear that all crystals from the same ingot reach a somewhat stable state after receiving 1 Krad dose. The drop is close to 50% which is about the same value obtained in 10 Mrad test.

We randomly selected more crystals from different ingots to study the dose rate issue. These crystals were separated into groups to obtain 1 Krad dose. The exposure time is between one hour and twenty hours. The results are summarized in the following table.

Time of measurements	Dose rate									
	1.0Krad/h			0.2Krad/h		0.125Krad/h		0.05Krad/h		
	B1.A	B1.B	B1.C	B1.D	B1.E	B1.F	B1.G	B2.H	B2.I	B2.J
Just after irradiation	0.60	0.59	0.62	0.62	0.69	0.68	0.74	0.48	0.52	0.52
5 days	0.56	0.56	0.58	0.69	0.67	0.67	0.75	0.53	0.56	0.53
13 days	0.52	0.55	0.57	0.64	0.63	0.62	0.70	0.68	0.77	0.74
14 days	0.57	0.60	0.62	0.70	0.68	0.69	0.76	0.63	0.72	0.68

Table 1: Monitoring the light output of BGO crystals after accumulating 1 Krad dose at different rates.

The light yields seem to drop significantly just after accumulating 1 Krad dose in all cases. The drop is between 25% and 50% depending on different ingots. It is clear that the recovery is not fast. This feature is different from the crystals produced in small quantity [4][9] which show fast recovery between 1 hour to 10 hour after receiving Mrad dose. We think that, owing to this, the dose rate will not make much difference for BELLE operation conditions and most of the crystals will reach stable state after receiving 1 Krad dose or around Krad scale.

6 Calibration

Due to the space limitation, the forward and backward EFC do not form a perfect match for Bhabha events. Only the inner 2 layers of forward EFC and the outer 3 layers of backward EFC can trigger back-to-back Bhabha events. However, based on Monte Carlo (MC) study, and the rates from Bhabha trigger and ALL-OR trigger, the Bhabha scattering contribute 73% (83%) of the forward (backward) ALL-OR trigger rate. Other processes like Coulomb scattering, bremstrahlung,two photon and beam gas interaction are less important. Fig. 5 shows the single crystal energy spectra of MC Bhabha events for some

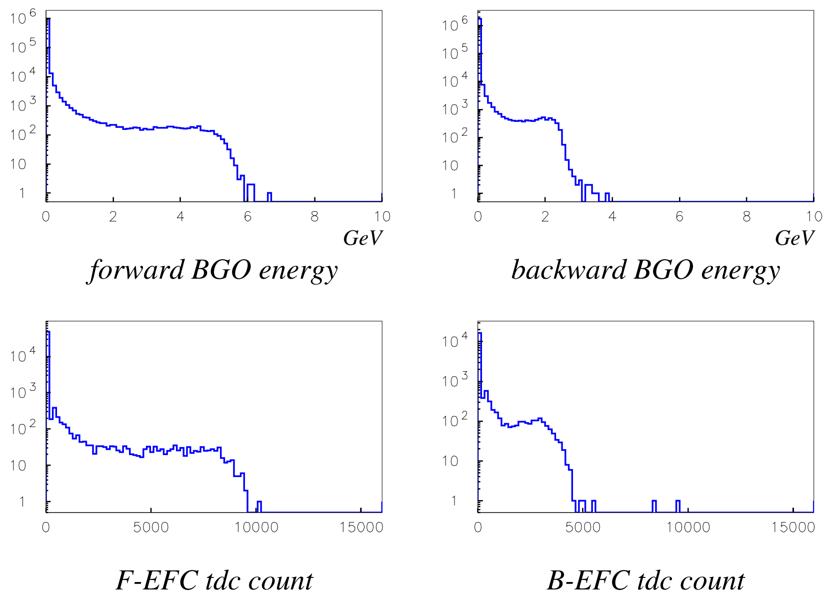

Figure 5: The Monte-Carlo energy spectra of a forward and a backward EFC BGO crystals for Bhabha events and the observed TDC counts from the experimental data taken with ALL-OR trigger.

typical channels and the experimental data of those channels taken by ALL-OR trigger. They agree very well. Therefore, we took EFC 'forward All-OR' and 'backward ALL-OR' two different data sets by local DAQ to calibrate EFC.

The gain of each channel is first determined by the end point of the corresponding single crystal energy spectrum. However, this is only a rough estimation. The fine tuning is achieved by the following procedure. First one can choose a target crystal which has the maximum energy deposit and make an energy sum with its neighboring crystals. The energy sum is made with 9 crystals if the target crystal is not an edge crystal, and is made with 6 if it is an edge crystal. The gain of this target crystal is then determined by matching the data peak position with the MC peak position. Fig. 6 demonstrates how this works.

After the gain calibration, the observed energy spectra look the same for data and MC. However, the MC has a narrower width. This is due to the light propagation/collection is not simulated with our GEANT program. A stand-alone MC code confirmed this smearing effect. We put a 10% and 14% smearing factors for forward and backward respectively. The energy spectra of edge and non-edge clusters are shown in Fig. 7 for both data and MC. They agree with

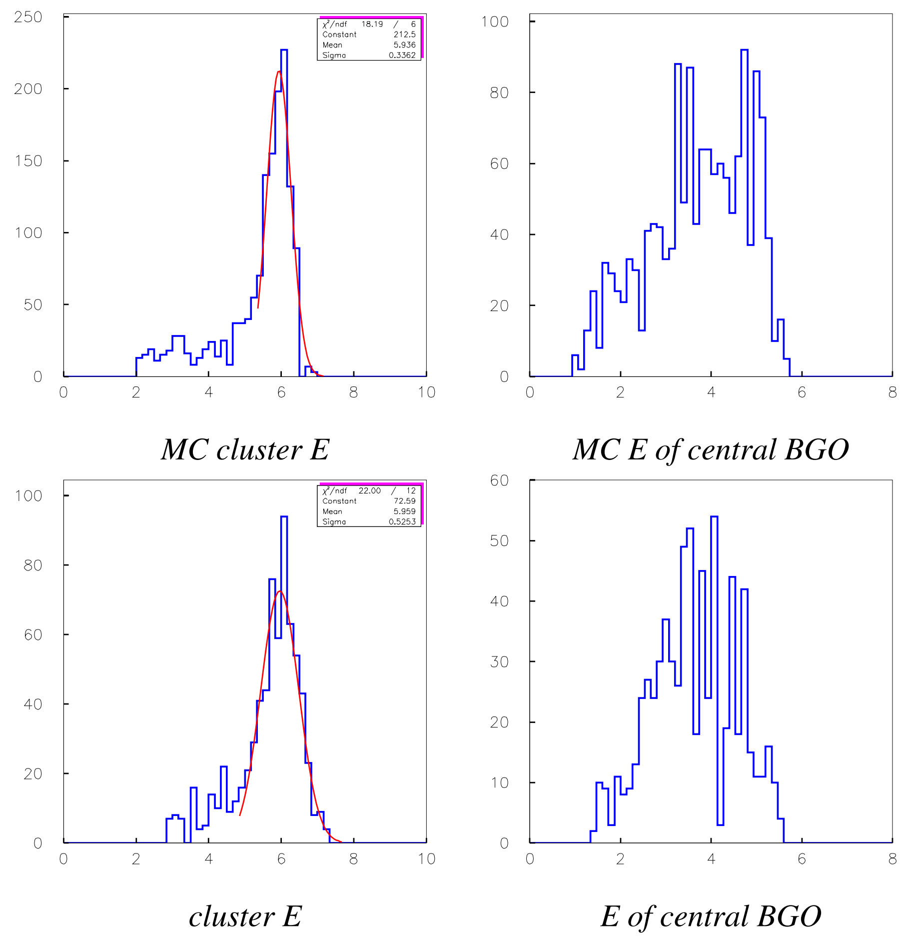

Figure 6: The cluster energy spectra and the central crystal energy spectra observed by EFC for both Monte-Carlo and experiment data. The measured energy of experiment data is adjusted to match Monte-Carlo by changing the calibration constant of the central crystal.

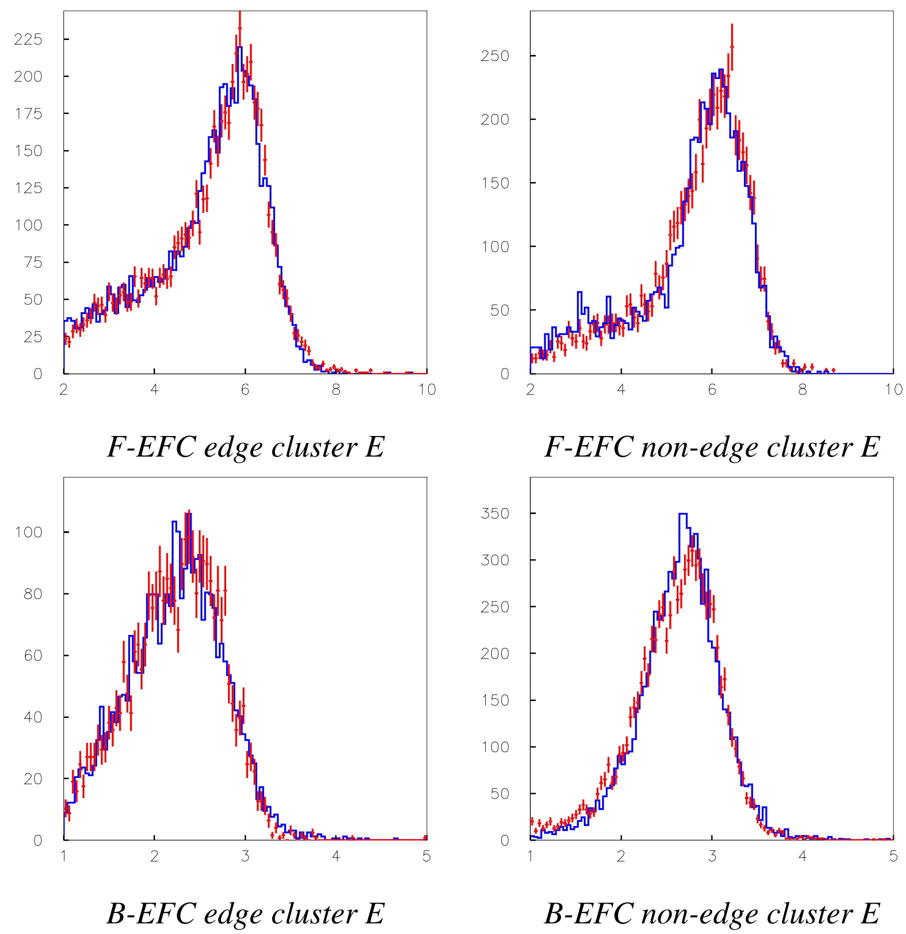

Figure 7: The energy spectra of Bhabha detected by EFC in edge and non-edge clusters. The blue histograms are the smeared Monte-Carlo and red dots are Data.

each other very well.

One interesting thing is to check the BGO recovery effect. The calibrated gains are held fixed and applied to different runs for a month data taking period. The peak positions of Bhabha clusters only changed within the fluctuations of electronics variations. Thus the recovery effect is confirmed to be small.

7 Summary

EFC has been installed at BELLE, KEK. The DAQ, trigger and monitoring systems have been reported. The calibration procedure is unbiased and robust. Observed energy spectra of Bhabha events show nice agreement between data and MC. This proves that EFC can give correct Q^2 estimation for triggered two photon events. The system is very stable and the BGO recovery effect is checked to be small. EFC has been running smoothly and offered the online luminosity information reliably since its installation.

8 Acknowledgements

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