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Beam test of the BELLE extreme forward calorimeter at KEK

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Abstract

A prototype of the extreme forward calorimeter (EFC) for the BELLE detector has been tested at the KEK-PS $\pi 2$ beam line by using beams with energy from 1 to 3 GeV. Prototype EFC consists of 20 radiation hard BGO crystals in a 4×5 matrix arrangement, corresponding to $\frac{1}{8}$ of its full scale at the backward side. Due to space limitations, it has only 12 radiation lengths. The measured energy resolution is about 7–10% with linearity $\sim 1\%$. © 2000 Elsevier Science B.V. All rights reserved.

1. Introduction

Our group has been responsible for constructing the extreme forward calorimeter (EFC) [1] for the BELLE detector [2] at the KEK B-factory. The main purpose of such a device is to improve the coverage of small angles around the beam pipe. It can also be used as a luminosity monitor or a tagger for two-photon events. Due to its proximity to the accelerator beam-pipe and the high luminosity of the B-factory, we chose the radiation-hard BGO crystals [3] produced by the Institute of Inorganic Chemistry, Novosibirsk, Russia.

EFC consists of two parts, forward and backward, which surround the beam-pipe and are mounted on the front surfaces of the cryostats of the compensation solenoid magnets. In this test, we

used one sector of the backward EFC which contained 20 crystals. It corresponds to the 5 segmentations in θ and $\frac{1}{8}$ of the full ϕ region. The BGO crystals have trapezoidal shapes. The dimension of each crystal is about $2\text{ cm} \times 1.5\text{ cm} \times 12\text{ cm}$. The shower containment is somewhat poor, ~ 12 radiation lengths, because the available space at BELLE is limited.

The goal of this beam test is to check the performance of our home-made front- and rear-end electronics with the BELLE standard DAQ chain. We would determine the energy conversion factor for our detector, and set the proper gain of front-end electronics and trigger threshold. It is also a good test for our read-out software, monitoring strategy and calibration procedure. The information obtained from detector response is very important for the Monte Carlo (MC) simulation. For example, the linearity can be checked between data and MC, and MC may need some adjustment to match the measured energy resolution.

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2. Experimental setup

The schematic diagram of the setup is shown in Fig. 1. This test was taken at the $\pi 2$ beam line of KEK 12 GeV proton synchrotron area. Beam energy can be varied from 1 to 3 GeV. The beam was aimed at the center part of the prototype EFC. The beam was defined by three scintillation counters, s3–s5, and there were two Cherenkov gas chambers, c1 and c2, to select electrons. The active area of s5 was measured to be $2\text{ cm} \times 2\text{ cm}$ and the overlapped width for s4 and s3 was $< 0.5\text{ cm}$. The distance between s5 and s4/s3 was about 5 m.

Fig. 1. Schematic diagram of the beam test setup at KEK $\pi 2$ beam line.

Each BGO crystal was wrapped with $100\text{ }\mu\text{m}$ thick Teflon sheet and $25\text{ }\mu\text{m}$ thick aluminized Mylar tape. Scintillation light was collected by PIN silicon Photo-Diodes (PD), Hamamatsu s5106, and the signal was amplified by home-made preamp boards [4]. Signals from preamp boards were transmitted via 16 m long twisted pair cables to a receiver board. Signals were first fed into a gain-control operational amplifier via a transformer, and then split into two paths. One to an analog sum which will be used for trigger purpose in full EFC running. The other is connected to the charge-to-time converters, LeCroy MQT300A. After charge integration, this chip offers three dynamic ranges and encodes them into a train of ECL signals. The ratios between gains for these three ranges are about 1:8:64. Since the wide dynamic range is more than enough for our purpose, we use only the middle range.

The encoded time signal was fed into a high precision 16 bit multi-hit TDC, the LeCroy 1877S

Fig. 2. Energy spectra observed by prototype EFC for 1, 1.5, 2 and 3 GeV electrons.

FASTBUS TDC. One TDC count corresponds to ~ 0.5 ns. The gate was defined by scintillators and its width was set to $1\text{ }\mu\text{s}$. This gate signal was sent to MQT300A chip for charge integration and also to TDC1877S as the common start signal. Common start time-out (i.e. equivalent to common stop) was programmed by computer which was set to maximum, $32\text{ }\mu\text{s}$, to fully cover the MQT300A conversion time ($\sim 10\text{ }\mu\text{s}$). A front-end veto (with width $32\text{ }\mu\text{s}$) was generated while there was a gate to inhibit later hits during MQT300A digitization. The DAQ system was driven by a SPARC CPU-5 V VME board and data were logged into a local hard disk.

With a pulser, we generated empty signal triggers and accumulated pedestal events while there was no beam. We also used test pulse signals and LED signals for front-end electronics calibration and monitoring.

3. Results and discussion

The event selection was done by requiring the maximum energy to be deposited in the central crystal of the prototype EFC. Pedestals were obtained by a random (empty) trigger and subtracted. The relative gains for different crystals were obtained by minimizing the energy resolution at one fixed energy. This procedure will be the case for full EFC because the calibration will be done by using Bhabha events.

The energy spectra for electrons with 1, 1.5, 2 and 3 GeV are shown in Fig. 2. The energy resolution and linearity plots for different energies are shown in Fig. 3 and Fig. 4. It is clear that the energy resolution does not have a $1/\sqrt{E(\text{GeV})}$ pattern. This is due to the short (radiation) length ($\sim 12X_0$) of our detector. From GEANT Monte Carlo simulation, the intrinsic energy spread is about 3–5%

Fig. 3. Energy resolution vs. energy of electrons observed by prototype EFC.

Fig. 4. Linearity plot: TDC count vs. beam energy of electrons.

Fig. 5. Energy spectrum observed by the central crystal for minimum ionizing particles which are mostly pions in this case.

and the linearity is within 1% between 1 and 8 GeV.

The energy spectrum of the central crystal for events accumulated without Cherenkov signals requirement is shown in Fig. 5. It is consistent with the dE/dx of minimum ionizing particles passing through BGO which is about 8 MeV/cm. The pedestal peak is centered at zero and its width is about 30 TDC counts, i.e. ~ 15 MeV. A 50 mV preamp signal seen at the receiver for this channel causes an output of 1000 TDC counts. Also, the maximum TDC count (for middle range) after pedestal correction is around 16 000. The gain setting for our front-end electronics is appropriate.

4. Conclusion

The prototype of the extreme forward calorimeter for the BELLE detector has been tested by using beams with energy from 1 to 3 GeV at KEK $\pi 2$ beam line. The readout system consists of home-made preamps, receiver boards with charge-to-time converters, and FASTBUS TDCs. This is the final system used for EFC at BELLE. Because of the short radiation length, the energy resolution

for the prototype EFC is about 7–10% and the linearity is $\sim 1\%$. The MIPS signal observed is consistent with dE/dx of minimum ionizing particles passing through BGO. The beam test result is satisfactory, and demonstrates the success of the complete read-out chain.

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