

Electromagnetic Calorimeter Upgrade for Belle2

Isamu Nakamura (中村 勇)

KEK, 1-1 Oho, Tsukuba, Ibaraki 305-0801, Japan

E-mail: isamu.nakamura@kek.jp

Abstract. Upgrade of the Belle electromagnetic calorimeter is summarized. The Belle experiment will be upgraded to cope with higher luminosity accelerator SuperKEKB. For the electromagnetic calorimeter, readout electronics will be replaced to introduce waveform analysis. This is to reduce effect from gamma rays produced in accelerator, that will be much higher than that observed in current Belle experiment.

1. SuperKEKB and Belle2

After successful operation, the KEKB asymmetric e^+e^- collider and the Belle Detector [1] accumulated data corresponding to an integrated luminosity of 1 ab^{-1} . The experiment stopped data taking by the end of June 2010 and started to improve its performance. The SuperKEKB, successor of KEKB accelerator aims for 50 times more luminosity by squeezing the beam to about 1/20 of current KEKB and by putting twice more current. With SuperKEKB accelerator, trigger rate of Belle experiment is expected to reach as high as 20–30 kHz. Beam related background is also expected to increase. Requirement for the Belle2 detector is to have same or better performance compared to the Belle detector under 10–20 times more background, though it is very difficult to make an accurate estimation of beam background without actual accelerator operation. In the Belle2 detector upgrade, completely new tracking detector consists of two layers of DEPFET Pixel detector, four layers of Double-sided Silicon Strip detector and small cell drift chamber will be installed. Particle ID devices will also be completely new. For barrel region, Time-Of-Propagation Čerenkov detector replaces current TOF and Aerogel Čerenkov detector while proximity focusing Aerogel-RICH detector will be installed in the forward endcap. For calorimeter crystals and preamplifiers are kept but all readout electronics will be replaced. The solenoid magnet as well as the barrel muon and K_L^0 detector (KLM) will be kept. The RPC of the endcap KLM will be replaced with Scintillator strip detector. All DAQ electronics and trigger system will also be renewed. The detail of SuperKEKB/Belle2 upgrade can be found in elsewhere [2, 3].

2. The Belle Calorimeter

The main purpose of the electromagnetic calorimeter is to detect γ and π^0 from B meson decay. Energy of such γ ranges from MeV to GeV. Energy resolution is very important because for some analyses one has to separate signal and background events only with mass distribution. To separate two photons from high momentum π^0 , fine granularity is required. Hermeticity is also very important to study final states with neutrino. The Belle electromagnetic calorimeter consists of 8736 CsI(Tl) crystals with typical dimension of $6 \times 6 \times 30 \text{ cm}^3$. The length corresponds

to about $16 X_0$. Figure 1 shows the schematic view of the calorimeter. The calorimeter has pointing geometry and covers polar angle from 12° to 155° . The scintillation light of the CsI(Tl) crystal has $\lambda = 560$ nm with rather slow decay constant of $1.3 \mu\text{sec}$ but abundant light output of about 50000 p.e./MeV. The light is read out by two independent sets of silicon PIN photodiodes (Hamamatsu S2744-08) with sensitive area of $10 \times 20 \text{ mm}^2$ connected to charge sensitive preamplifier. The signals are sent to the front-end electronics with cable of typically 10 m long. Two signals from preamplifiers are first added and then processed with two shaper with $0.2(\text{fast})$ and $1\mu\text{sec}(\text{slow})$ shaping time. The fast signal are used to generate trigger signal while the slow signal is then sent to LeCroy MQT300A charge-to-time converter. The MQT converts 3 range/12 bit charge information into 15 bit timing information which corresponds to 18 bit dynamic range. The time encoded energy information is then recorded with LeCroy 1877S Fastbus TDC. The readout system consists of about 100 TDC boards in five crates read out by three VME systems. It takes about $30 \mu\text{sec}$ to read out one physics event. The trigger rate is about 300 Hz with instantaneous luminosity of $10^{34} \text{ cm}^{-2}\text{sec}^{-1}$, which corresponds to about 1% readout deadtime. With 10 kHz trigger rate deadtime is 30% that is not acceptable. Although the signal is recorded with TDC, only energy is recorded. No event timing information is available.

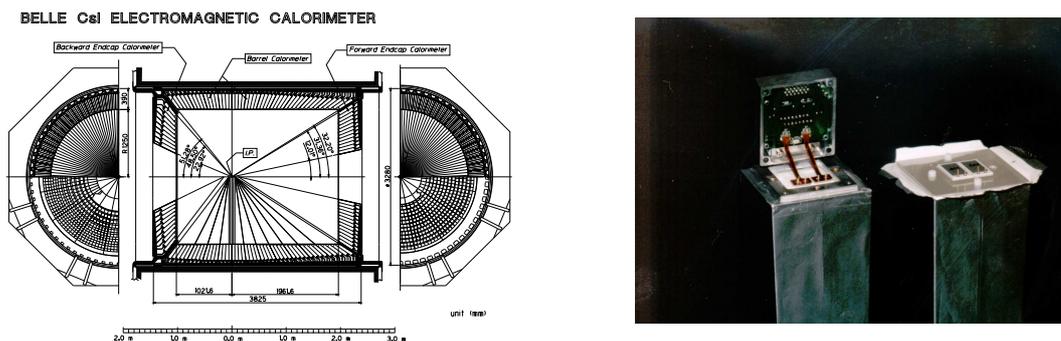


Figure 1. (Left) The Belle Electromagnetic Calorimeter. (Right) A counter.

The effect of accelerator background is estimated in the current Belle experiment using randomly triggered event. At current Belle calorimeter, each crystal receive $0.5\text{--}1$ MeV energy from accelerator background as shown in Figure 2(left), where average energy deposition in one crystal is plotted as a function of polar angle. Figure 2(right) shows the energy sum in the calorimeter as functions of total beam current and average instantaneous luminosity. From the figure it seems background is linearly behaved to the beam current rather than luminosity. Therefore a factor 3–10 higher background is rough estimation for the Belle2, as beam current increase is only a factor of 2.

Radiation damage is an issue for high luminosity collider experiment and the calorimeter is no exception. Figure 3(left) shows dark current of photodiode in inner forward region as a function of time in days since the start of the calorimeter operation. Dark current increase is about 10 nA in barrel and increase toward the beam pipe upto 200 nA . The highest is inner part of forward endcap. The dark current increase is mostly due to neutron radiation. Figure 3(right) is dark current increase as a function of neutron fluence obtained by the study performed in a reactor. The 200 nA dark current corresponds to about 10^{11} neutrons/cm². Hence 10^{12} neutrons/cm² is expected in Belle2.

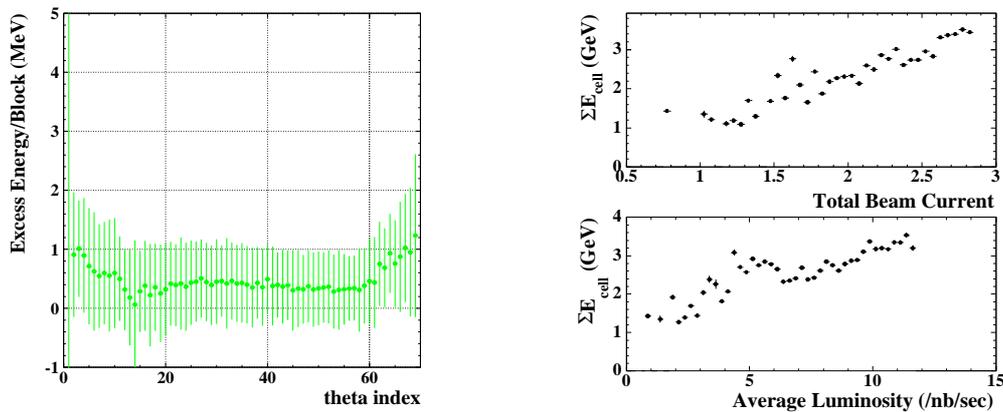


Figure 2. (Left) Energy deposit from beam background as a function of polar angle. (Right) Energy deposit as functions of total beam current(top) and instantaneous luminosity(bottom).

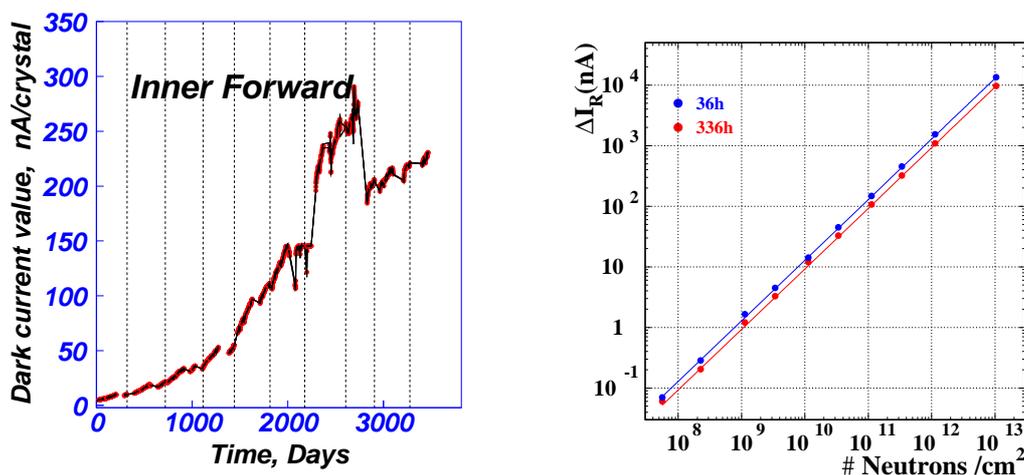


Figure 3. (Left) Dark current of Photodiode as a function of time. Large increase around 2500 is due to temperature increase. (Right) Dark current increase as a function of neutron fluence.

3. Belle2 Calorimeter Upgrade

In the Belle2 experiment trigger rate will be as high as 30 kHz and background will be 10 times as high as Belle. To cope with such situation waveform sampling together with pipelined readout will be introduced. The former enables us to use timing information to discriminate off-timing hits while the latter can eliminate effectively readout deadtime. Figure 4 shows simulated timing distribution.

To realise above readout electronics are replaced to new one. Figure 5 shows the schematic diagram of new readout system. Part of the system is Shaper Digitizer board which receives preamplified signals from 16 crystals. Two preamplifier signals from one crystal are summed and processed with shaper with time constant of $0.5\mu\text{s}$ which is shortened from $1.0\mu\text{s}$. Reducing shaping time further is not efficient as the time constant of scintillation is $1.3\mu\text{s}$. Signal after shaping is digitized by 18 bit ADC with 1.8 MHz sampling rate and sent to pipeline buffer in FPGA which is $512(290\mu\text{s})$ deep. Once trigger is issued, waveform fitting is performed in FPGA using 16 samples to extract timing and amplitude. According to simulation study a factor of

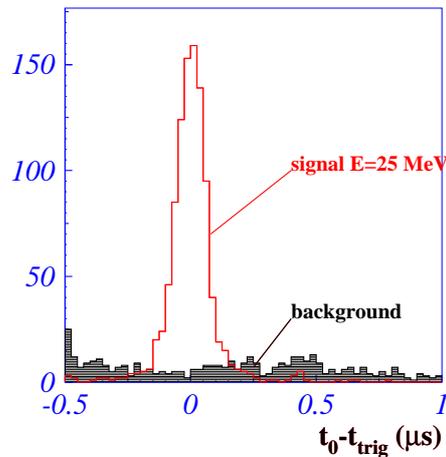


Figure 4. Expected timing distribution with new electronics.

seven reduction of fake cluster is expected with upgraded readout system.

To readout all 8736 crystals, total of 576 Shaper Digitizer boards are placed in 52 VME crates. In each VME crate a Collector board will be installed. The Collector board receives trigger signal, distribute it to Shaper Digitizer boards in the crate, receives fitted timing and amplitude and sends them to backend DAQ system via optical link. Introducing Collector board greatly reduce the number of cables from detector to electronics hut. The Collector board can also supply calibration signal.

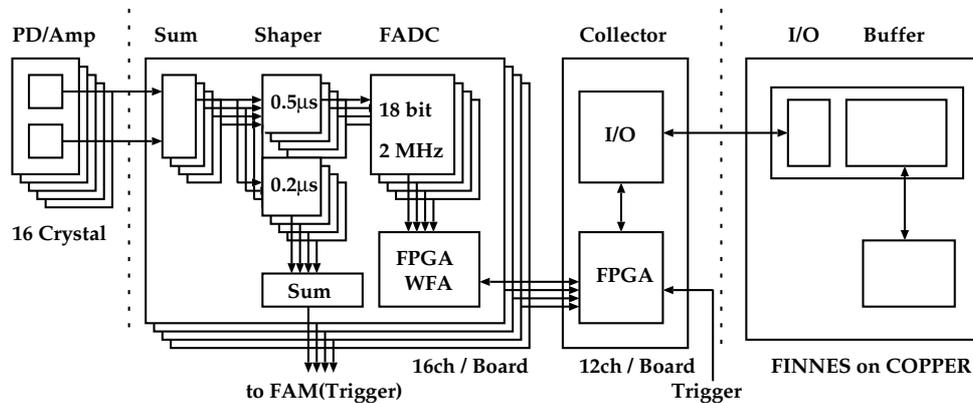


Figure 5. Schematic Diagram of new DAQ system.

4. Preparation Status

To test the scheme of waveform fitting, prototype with TKO formfactor, which is used in the Belle Calorimeter, is produced. This TKO prototype has same analog part and ADC as new Shaper Digitizer board and is compatible with current Belle DAQ system. Eight boards, corresponding to 1/8 (120 channels) of backward endcap, are installed to the Belle and the data had been taken since summer of 2009 to the end of experiment. Figure 6(left) shows energy distribution of bhabha events collected with prototype board compared with current board.

One can find that the prototype boards are working as good as current board. Figure 6(right) is difference of timing obtained from waveform fitting to the event timing reconstructed offline by other sub detectors. Timing resolution is better than 10 ns for 100 MeV gamma.

Currently R&D study with prototype VME shaper digitizer and collector boards, produced recently, are ongoing. Figure 7 shows prototype Shaper Digitizer(left) and Collector(right) boards. The plan is to finalise the board design by the end of 2010.

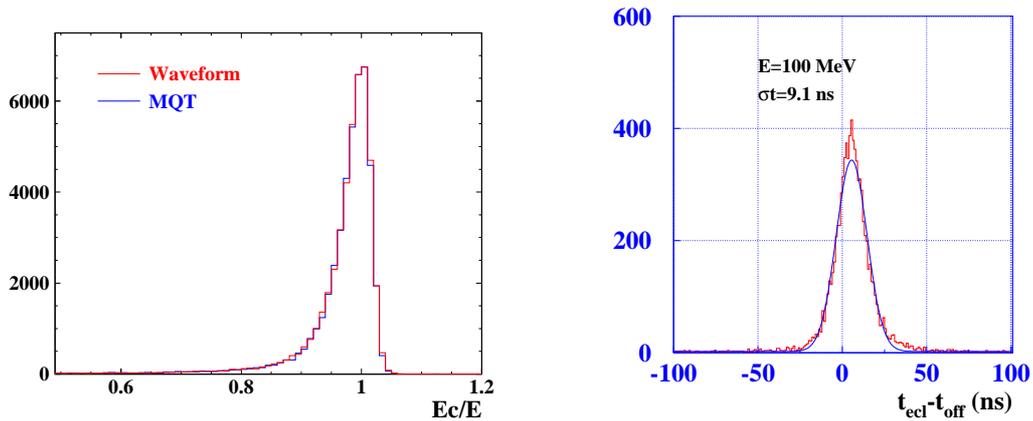


Figure 6. (left) Energy distribution for bhabha events. (right) timing resolution.



Figure 7. (Left) Shaper Digitizer prototype. (Right) Collector prototype.

References

- [1] A. Abashian *et al.*, Nuclear Instruments and Methods A479 117(2002)
- [2] SuperKEKB Letter of Intent, KEK Report 04-4
- [3] Belle II Technical Design Report in preparation.