Belle2c Calorimeter Upgrade (Status and Plan)

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Abstract. Upgrade of KEKB Accelerator and Belle2 Detector are on going, aiming for starting physics data taking with 50 times higher instantaneous luminosity in FY2015. The belle electromagnetic calorimeter consists of CsI(Tl) crystals read out by two photodiodes, covering polar angle of 12-155 degrees. A total of 8736 counters are installed in a barrel and two endcap modules. The Belle2 upgrade of electromagnetic calorimeter is in two steps. For the beginning of Belle2, all readout electronics will be replaced to cope with higher event rate. A waveform sampling will be introduced to reduce an effect from severe accelerator background. Replacement of CsI(Tl) crystals to faster undoped CsI crystals are also planned. In the talk, detail of Belle2 upgrade will be presented as well as status of preparation and plans for crystal replacement.

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 K0L 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 π0 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 $\pi^0$, 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 $6 \times 6 \times 30$ 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 $\mu$s 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 $10 \times 20$ 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(fast) and 1$\mu$s(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 $\mu$s to read out one physics event. The trigger rate is about 300 Hz with instantaneous luminosity of $10^{34}$ cm$^{-2}$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.

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 to use timing information to discriminate off-timing hits while the latter can eliminate effectively readout deadtime. Figure 2 shows simulated timing distribution.

To realise above readout electronics are replaced to new one. Figure 3 shows the schematic diagram of new readout system. Hart 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$\mu$s which is shortened from 1.0$\mu$s. Reducing shaping time further is not efficient as the time constant of scintillation is 1.3 $\mu$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$\mu$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 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 Belle2 standard optical link. Introducing Collector board greatly reduce the number of cables from detector to electronics hut. The Collector board can also supply calibration signal.

4. Status
4.1. Detector
After the run end, Belle detector was rolled out from the accelerator and was dismantled for the preparation of upgrade. All barrel sub-detectors inside barrel calorimeter as well as the endcap calorimeters (Figure 4) were taken out. After dismantling, the big earthquake happened on Mar.11. Since the detectors were already taken apart, there’s no major damages visible from...
outside. Since the crystals, photodiodes and preamplifier circuit will be used in Belle2, test was performed to make sure the counters are functional. Since the old readout system were already removed from the detector, an older prototype shaper amplifier module(Figure 4) was used. The module has the same shapers and preamplifiers as the belle readout system, can send calibration signals to the preamplifiers as well as driving pulse to LED flasher installed in the counter. Using the module about 900 counters corresponding to one eighth of all barrel channels were tested and found to be all functional. The test of all barrel channels and endcap channels will be performed after a part of new readout system become ready.

![Figure 4](image-url) (Left) Backward endcap calorimeter taken out from the Belle. (Right) The old prototype readout module.

4.2. Readout System

![Figure 5](image-url) (Left) Shaper Digitizer prototype. (Right) Collector prototype.

Recently 12 “final” prototype shaper digitizer boards(Figure 5 Left) and a second prototype collector module(Figure 5 Right) were delivered. It enable us to perform “one crate test” with configuration similar to the actual experiment. These prototype shaper digitizer boards are tested using either calibration pulse distributed from the prototype collector module or cosmic ray signals from the counters. Figure 6(Left) shows the distribution of amplitude from pedestals. Noise of the read out were measured to be ~300 keV and ~20 keV for incoherent and coherent noise, respectively. Figure 6(Center) shows the correlation of input charge and
measured amplitude and Figure 6 (Right) shows non-linearity. The non-linearity of \( \sim 0.3\% \) was obtained. Both noise and non-linearity measured in the prototype modules fulfill our requirement.

![Graphs showing pedestal distribution, measured amplitude, and non-linearity.](image)

**Figure 6.** (Left) Pedestal distribution. (Center) Measured amplitude as a function of input charge. (Right) Non-linearity of the board.

Currently 100 barrel shaper digitizer boards are being produced and will be delivered on March 2013. Our plan is to produce all 432 barrel boards and all 52 collector boards by the end of March 2014, and to start installation in 2014. The endcap part will be ready by early 2015.

**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.