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Status of the electromagnetic calorimeter trigger system at Belle II.

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Status of the electromagnetic calorimeter trigger system at Belle II.

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Abstract. The Belle II experiment at SuperKEKB collider in Japan has been under the construction toward physics run in 2017 with 40 times higher instantaneous luminosity than the KEKB collider. The main physics goal of the Belle II is to search for the New Physics in rare B decays and τ lepton decays. We have developed an Electromagnetic Calorimeter hardware trigger system that generates a trigger signal by two main triggers, total energy and cluster counting. Analog signals from 16 CsI(Tl) crystals are merged at ShaperDSP, and which are sent to FAM consisting of Flash-ADC and FPGA. ETM receives 52 FAM data from TMM and makes a ECL trigger signal which is sent to GRL and GDL, then the final Belle II trigger signal is generated by GDL which analyzes all trigger signals from each Belle II detector. In this article, the overall design scheme and current status of the ECL trigger system is reported.

1. Introduction

The Belle experiment [1] at KEK in Japan took 772 million pairs of B- and $\overline{B}$-mesons produced by the KEKB accelerator [2] to study CP violations in the neutral B-meson system. Most of the results are in good agreement with the Standard Model (SM) predictions of the Cabibbo-Kobayashi-Maskawa (CKM) structure of quark flavor mixing and CP violation in B decay [3], D-$\overline{D}$ mixing [4] and so on. The SuperKEKB accelerator [5] and the Belle II experiment are expected to find new physics beyond SM in flavor physics. Figure 1 shows the schematic of the Belle II detector.

The total cross sections and trigger rate of physical processes at the target luminosity of $8 \times 10^{35} cm^{-2}s^{-1}$, which is 40 times higher than the peak value of the KEKB collider (Table 1), are listed in Table 2. Since the high trigger rate for Bhabha and $\gamma\gamma$ at this luminosity, a 1/100 pre-scale factor is applied to these triggers. The level 1 trigger requirements of the Belle II experiment are shown in Table 3.

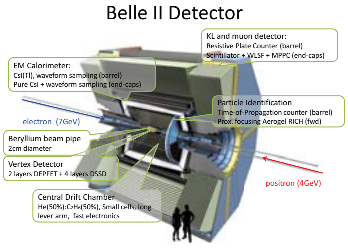

Figure 1: The Belle II detector

Parameters (e^+ / e^-)	KEKB (Achieved)	SuperKEKB (Expected)
Energy (GeV)	3.5 / 8.0	4.0 / 7.0
β_y^*	5.5 / 5.9	0.27 / 0.30
β_x^*	120 / 120	3.2 / 2.5
I(A)	1.64 / 1.19	3.60 / 2.62
Luminosity ($10^{34} cm^{-2}s^{-1}$)	2.11	80

Table 1: Fundamental parameters of the KEKB and SuperKEKB accelerators.

Physics process	Cross section (nb)	Rate (Hz)
$e^+e^- \to \Upsilon(4S) \to B\overline{B}$	1.1	880
$e^+e^- \to$ continuum	3.4	2700
$e^+e^- \to \mu^+\mu^-$	1.1	880
$e^+e^- \to \tau^+\tau^-$	0.9	720
$e^+e^- \to$ Bhabha [a]	44	350 [c]
$e^+e^- \to \gamma\gamma$ [a]	2.4	19 [c]
$e^+e^- \to e^+e^- + 2\gamma$ [b]	13	10000 [d]
Total	66	~15000

[a] $\theta_{lab} \geq 17°$
[b] $\theta_{lab} \geq 17°$, $p_t \geq 0.1\mathrm{GeV}/c$
[c] The rate is pre-scaled by a factor of 1/100
[d] The rate is estimated by the luminosity component in Belle L1 trigger rate

Table 2: Total cross section and trigger rates for $L = 8 \times 10^{35}$ cm^{-2}s^{-1} from possible physics processes at the $\Upsilon(4S)$ energy region.

Trigger efficiency ($\Upsilon(4S)$)	100%
Max. Trigger Rate	30kHz
Trigger Latency	< 5 μs
Timing precision	< 10 ns
Min. event separation	200 ns

Table 3: Level 1 trigger requirements of Belle II.

2. Belle II Trigger System

The schematic overview of the Belle II trigger system is shown in Figure 2. It consists of four sub-trigger systems : (1) Charged track information such as momentum, position, and charge from CDC trigger. (2) Energy deposit information, energy cluster information, and Bhabha identification from ECL trigger. (3) Precise timing and hit topology information from Barrel PID (BPID) trigger. (4) μ track information from KLM trigger. The global decision logic (GDL) receives all sub-trigger information and makes the final trigger.

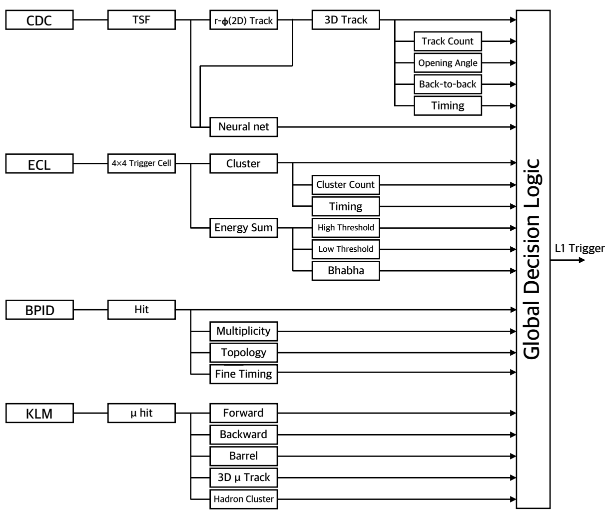

Figure 2: The Belle II trigger system schematic. GDL, where the final online trigger decision is performed, receives information from four sub-trigger.

3. ECL Trigger System

Since π^0 or other particles produce photons in a wide energy range, a high resolution electromagnetic calorimeter (ECL) is a very important part of the Belle II detector for a precise energy measurement of photon and trigger signal generation. ECL, which contains 8763 CsI(Tl) crystals in total, consists of barrel, forward and backward endcap sections.

The basic framework and idea are same as Belle trigger system [1][6]. The different point between Belle and Belle II is that Belle II must deal with a much higher trigger rate due to high luminosity and beam background. To make the ECL trigger performance more robust and flexible, we adopted a new trigger scheme that utilizes a readout electronics architecture with Flash-ADC (FADC) and FPGA components and serial data transmission.

The block diagram of ECL trigger readout electronics system is shown in Figure 3. We develop four components of the trigger electronics : a fast shaper circuit built in the digital signal processing shaper module (ShaperDSP), a FADC analysis module (FAM), a trigger merger module (TMM), and an ECL trigger master (ETM).

The data of electromagnetic energy deposition in CsI(Tl) crystals counter is sent to ShaperDSP through photo-diodes (PD) attached to one CsI(Tl) crystal and pre-amplifier. 16 fast-shaping signals from neighboring 4×4 crystals are merged in the fast shaper circuit. This is implemented on the main shaper board to form an analog trigger sum called the trigger cell (TC). TC is a basic unit in ECL trigger system and 576 TCs used in total. The analog TC informations are transmitted to FAM.

On FAM, as shown in Figure 4, the analog TC data is digitized by FADC and the digitized data are passed to FPGA(XC7K160T). In order to measure energy and decide timing, Belle experiment used the *simple method*. While for Belle II, we prepare a wave form analysis in FPGA, so called *fit method*. The *simple method* also used for debugging. The *fit method* is applied to 12 data points at every 8 MHz clock and performs the following chi-square fit :

$$\chi^2 = \sum_{i,j} \{y_i - Af(t_i - \delta t - t_0) - P\} S_{ij}^{-1} \{y_j - Af(t_j - \delta t - t_0) - P\}$$

where $y_{i(j)}$ is data point and S_{ij} is noise covariance matrix for $i(j)$th sampled data. f denote fit function which consists of pedestal with first 4 points and signal with last 8 points, and P is pedestal. By performing chi-square fit, we measure A and t_0 which represent reconstructed signal amplitude and signal start timing on minimum δt, respectively. In the firmware logic, A, t_0 and P are computed on FPGA.

Table 4 shows TC energy and timing resolutions for two methods estimated by a ECL trigger simulator (TSim-ECL) which include the expected beam background in Belle II. According to this result, timing resolution improvement is performed by *fit method*.

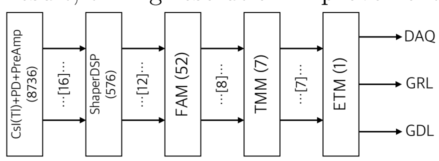

Figure 3: Hardware configuration of the ECL trigger system. The number in a parentheses(bracket) shows the number of set of "CsI(Tl) + PD + PreAmp" and ECL trigger electronics boards (the number of inputs to the one board).

Method	Input E (MeV)	Resolution (RMS)	
		E (MeV)	T (ns)
simple	100 - 200	2.7	35.52
	1000 - 1100	2.8	10.15
	8000 - 8100	2.8	4.83
fit	100 - 200	2.2	5.52
	1000 - 1100	2.2	0.61
	8000 - 8100	3.7	0.25

Table 4: TC energy and timing resolution comparison between *simple* and *fit method* for different input energies.

All FAM send the hitted TC energy and timing informations to TMM by GTX serial link. TMM, as shown in Figure 5, merge all TC informations by FPGA(XC7K325T) and send it to ETM which is shown in Figure 6. All FAM and TMM board mass production were done.

By receiving all TC energy and timing information from TMM, ETM generate two trigger signals on FPGA (XC6VHX380T) : physics trigger and Bhabha trigger. Basic strategy for physics trigger is same as Belle. Physics trigger condition is as following : (1) total energy trigger (E_{tot}), which is a total energy sum in barrel and forward-endcap excluding most inner layer, greater than 1 GeV. (2) the number of isolated clusters (ICN), which is to count the number of tracks that deposit the energy in ECL, is bigger than 3. If one event satisfies the condition (1) or (2) without Bhabha trigger condition, ETM generate physics trigger signal. In order to suppress Bhabha process in Belle, 2-Dim(r-θ) back-to-back topology is required for the two clusters together with an energy threshold for the sum of the two clusters. However, Belle II trigger system require an improved Bhabha veto logic because of 40 times higher luminosity, so 3-Dim(r-θ-ϕ) back-to-back topology will be used for Bhabha veto trigger. And we can separate charged and neutral tracks by performing ECL and CDC trigger matching at GDL state.

Figure 4: Photograph of the FAM board.

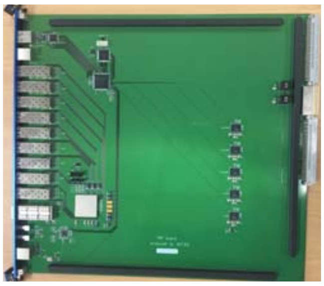

Figure 5: Photograph of the TMM board.

Figure 6: Photograph of the ETM board.

4. Conclusion

The SuperKEKB collider and the Belle II detector will probe for new physics phenomena in rare B meson, D meson and τ lepton decays. The online trigger system is required for reducing high trigger rates from beam backgrounds during data taking from the super KEKB collider to the Belle II detector. The ECL trigger should be robust and flexible to satisfy all trigger system requirements in high trigger rate environment. All ECL trigger electronics, FAM, TMM, and ETM, mass production and test were done. In this article, we have described the status of ECL trigger system.

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