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The Event Timing Finder for the Central Drift Chamber Level-1 Trigger at the Belle II experiment

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Abstract. The level-1 trigger system of the Belle II experiment is designed to select physics events of interest with almost 100% efficiency for hadronic events. In terms of event timing decision, the level-1 trigger is required to have an accuracy of less than 10 ns. The Central Drift Chamber (CDC) level-1 trigger provides the event timing information as one of the level-1 timing sources. We developed the new algorithm to measure the event timing with an accuracy of about 10 ns based on the CDC hit timing. Two-dimensional charged track reconstruction by Hough transformation was utilized to reduce high background hits. We used a new-developed general-purpose FPGA board (Universal Trigger board 4) for this module for the first time. We report the performance of the new algorithm using e^+e^- collision data collected in 2020.

1. Introduction

The Belle II experiment at SuperKEKB electron-positron collider aims to explore flavor phyisics with high statistics data of B meson and τ lepton processes. The Belle II detector [1], a general-purpose spectrometer installed at an interaction point, consists of six sub-detectors.

Belle II Level-1 trigger system [2] (TRG) is a hardware trigger for selecting physics events of interest while reducing background events. Four sub-triggers using four sub-detectors detect the characteristics of the event, and the global decision logic module makes a final trigger decision based on the sub-triggers information. TRG adopts field-programmable gate array (FPGA) based circuits and has been continuously upgraded.

The TRG is required to determine an event timing with an accuracy of 10 ns or less. This requirement is from the timing decision precision of data sampling for the vertex detector. For high efficiency and redundancy, the event timing is determined based on the information of three sub-triggers: barrel PID detector, electromagnetic calorimeter, and Central Drift Chamber

(CDC). The CDC [3] is a gas drift chamber and has a sensitivity to charged track events. In timing detection in CDCTRG, the event timing can be estimated by selecting an early hit, a hit with a short drift time, among hits having a maximum drift time of 600 ns. A conventilnal timing decision method on CDCTRG determined the event timing by selecting the earliest hit among hits associated with two-dimensional reconstructed tracks. The event timing accuracy was about 20 ns. We have developed a new event timing finder module (ETF) for CDCTRG to improve the accuracy and detection efficiency.

2. CDC Event Timing Finder Algorithm

The new algorithm aimed to improve the accuracy and efficiency by taking into account more hits and reducing background hits not derived from event.

2.1. Central Drift Chamber

The CDC consists of 14,000 sense wires arranged concentrically in 56 layers. The wires with the same angle for every 6 layers (8 layers only for the most interior) make up a super layer (SL). SL is arranged like AUAVAUAVA from the inner side, where A indicates an axial SL in which a wire is parallel to a magnetic field, U and V indicate a stereo SL, which is slightly angled with respect to the axial SL.

2.2. Track Segment

CDCTRG [4] consists of the track segment finder, 2D track finder, 3D track finder, and ETF. The track segment finder [5] detects track segments to reduce data size for online track reconstruction and provides the information to the track finder modules and ETF. The track segemnt is detected in each Super Layer based on hit pattern. The shape of track segment is shown in Fig. 1. Its position and a hit timing information digitized to a least significant bit of 2 ns are transmitted to the latter module. The track segment information only of axial SL is transmitted to the ETF.

The ETF receives a different hit timing information from that used for the track finder module. The track finder modules receive the hit timing of a specific layer in a track segment called 'priority timing', which is used for the conventional method. On the other hand, the ETF uses the earliest hit timing among hits in a track segment called 'fastest timing'. The comparison of timing distribution is shown in Fig. 2. Since the fastest timing is the shortest drift timing in the track segment, it becomes likely to have information closer to the event timing.

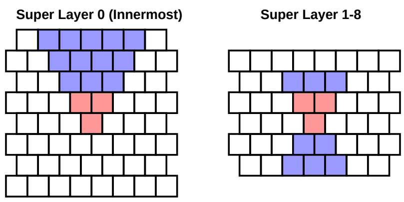

Figure 1. Wire geometry of track segemnts. The shaded cells indicate the shape of track segemnt. The hit timing in the red cell is used for priority timing. The left one is the shape for the innermost super layer, SL0. The right one is the outer super layers, SL1-8.

2.3. Event Timing Finder

ETF algorithm is composed of two-dimensional track reconstruction and timing estimation from multiple hits.

Track segment hits include many background hits that are not derived from events such as beam background and crosstalk, whose hit timing is independent of event timing. In order to reduce these background hits, the track is reconstructed by a two-dimensional Hough transform inside the ETF module, and only the hits associated with the reconstructed track are used for timing calculation.

The configuration of the Hough transform is the same as used in the 2D finder module and requires a coincidence of four out of five axial SL. In addition, another Hough transform logic requiring a coincidence of inner three axial SL is implemented. This makes it possible to detect the event timing even for short tracks that have low transverse momentum or pass forward and backward end-cap.

To determine the event timing, the ETF calculates a median value among up to 64 the fastest timings. As shown in Fig. 3, compared with the case of selecting the earliest timing used in the conventional method, the influence of the residual background hits can be suppressed and the efficiency is improved. The detected event timing is transmitted to the global decision logic to determine the global event timing, and to the 3D track finder module to use the time origin information.

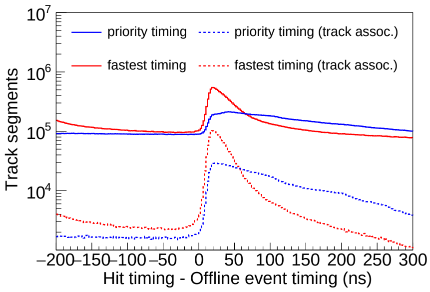

Figure 2. The hit timing distribution relative to offline reconstructed event timing. The red lines are priority timing and the blue lines are fastest timing. The solid and dashed lines show before and after background reduction by association with 2D track.

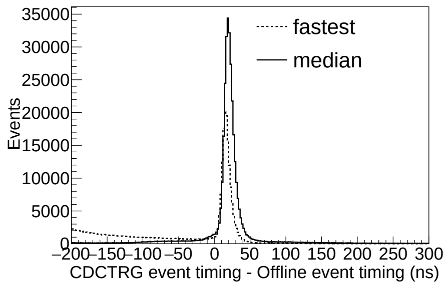

Figure 3. The estimated event timing relative to offline reconstructed event timing. The solid line shows a median among fastest timings and the dashed line shows the earliest timing among fastest timings. The estimated event timing is calculated by algorithm simulation.

3. Universal Trigger Board 4

The ETF logic was implemented on a new-developed general-purpose FPGA board, Universal Trigger board (UT) 4. The specifications of UT3, which are mainly used at present, and UT4 are summarized in Table 1. The performance of the main FPGA has been greatly improved in UT4 in order to realize a larger scale and complicated logic. High speed optical serial link is utilized for transmission between UT modules. A sub FPGA is implemented on UT4, which improves the convenience of UT4 board operation via VME.

4. Performance

The performance of ETF was evaluated using electron-positron collision data acquired in October–December 2020. The accuracy of the event time is measured by comparing the timing detected by the ETF with the high-precision event timing obtained by offline event reconstruction. The difference distribution is shown in Fig. 4. The standard deviation of the event timing resolution is around 10 ns, which is twice the accuracy improvement of the

Table 1. Specification for Universal Trigger board 3 and 4

	UT3	UT4
Main FPGA	Virtex-6 VC6VH380/565T	Virtex-7 UltraScale XCVU080/160
Sub FPGA	–	Artix-7 XC7A15T
Logic gates	382k / 580k	975k / 2027k
Total bandwidth of optical links	530 Gpbs	1300 Gbps

conventional CDCTRG event timing detection algorithm. In this method, the number of hits increases as the number of tracks, and the event timing resolution improves. A time resolution of 5.3 ns was achieved in hadron events, most of which have four or more tracks.

The efficiency to detect the event timing by ETF relative to the events for which TRG signal was fired was evaluated. By improving the time accuracy and dealing with short tracks, the efficiency was improved. The efficiency for hadron events is improved from $87.2 \pm 0.2\%$ to $94.2 \pm 0.3\%$, which includes 3% point improvement due to the short tracks.

This accurate event timing improved the vertex resolution on the 3D track finder module using a neural network. This is expected to reduce a TRG rate that is triggered by beam background tracks emitted out of the interaction point.

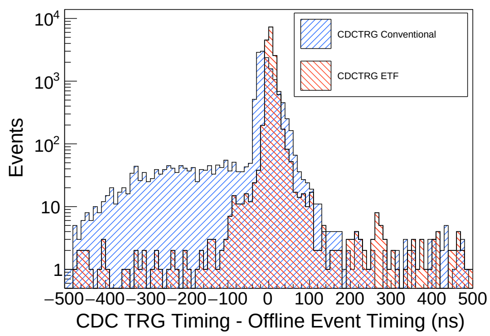

Figure 4. CDCTRG event timing distribution relative to offline reconstructed event timing. The blue histogram shows the timing provided by the conventional method, and the red one shows the timing provided by the ETF.

5. Conclusion

We developed a CDC ETF module to improve the accuracy and efficiency of event timing detection in the Belle II experimental level-1 trigger. The new method adopts the fastest timing, reduction of background hits through two-dimensional track reconstruction and median selection. These features were implemented on a new-developed FPGA board. In the performance evaluation in e^+e^- collision, an event timing resolution of about 10 ns was achieved and the efficiency to detect the event timing was improved.

References

[1] T. Abe *et al.* [Belle-II], [arXiv:1011.0352 [physics.ins-det]].
[2] Y. Iwasaki, B. Cheon and E. Won *et al.*, IEEE Trans. Nucl. Sci. **58**, 1807-1815 (2011)
[3] N. Taniguchi [Belle-II], JINST **12**, no.06, C06014 (2017)
[4] Y. T. Lai, M. Aoyama and H. Bae *et al.*, JINST **15**, no.06, C06063 (2020)
[5] K. L. Unger, S. Bähr and J. Beckerand *et al.*, PoS **TWEPP2019**, 145 (2020)