The Level 1 Trigger System for Belle II CDC

J.-G. Shiu on behalf of the Belle II CDC trigger group

***Abstract*–The SuperKEKB collider has started its beam commissioning this year and is expected to have first collision for early physics next year. To efficiently select physics events in interest at high luminosity rate, a multifunctional trigger system is designed. In this presentation, we introduce the tracker trigger system associated with the Belle II central drift chamber (CDC) detector. This sub-trigger system is designed to perform a quick track recognition in 2-dimentional and 3-dimentional spaces. The design structure, current status, and performance studies will be discussed.**

I. Introduction

The Belle II experiment at the SuperKEKB collider at the High Energy Accelerator Research Organization in Japan (KEK) is designed for high precision measurements of rare decays of B mesons, D mesons, and tau leptons [1]. The target luminosity of the SuperKEKB is 8x10^{35} cm^{-2}s^{-1}, which is 40 times higher than its predecessor the Belle experiment at KEKB [2]. The nominal beam background rate is estimated to be at 10MHz. A real-time trigger system is designed to reject background and enhance the interested physics events in data taking with this high interaction rate [3]. In this presentation, we will focus on the track trigger part of this system associated with the Belle II CDC detector.

The SuperKEKB has successfully achieved a major milestone of its first beam circulation in February this year. This opens a new era of B factory. The CDC detector is now pursuing a standalone cosmic ray test, and will be integrated into the Belle II this summer. The CDC trigger system is scheduled to be online with full functions next year, before the first collision of Belle II experiment.

II. CDC Detector

The Belle II CDC detector is a multi-wire drift chamber composed of 14 thousand sense wires. The sense wires are configured in 9 super-layers: 5 super-layers in axial direction and the other 4 with small stereo angles (Fig. 1). The CDC detector is located in a uniform magnetic field in the axial direction. By reconstructing the curved tracks from hit information, we can measure the momentum and position of charged tracks originating near the interaction point. At the front-end readout electronics (FE), the wire hit information is discriminated to exclude random electronics noise and the signal hit timing is digitized to 1 ns precision.

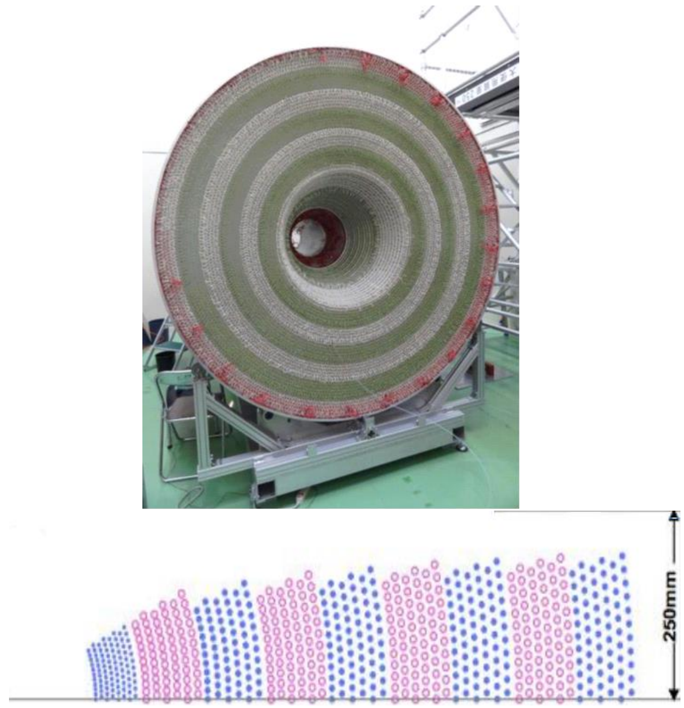

Fig. 1. The end-view of the Belle II CDC detector (top) and its wire configuration (bottom)

III. CDC Trigger

At this high luminosity, the interested physics event rate is about 20KHz. The trigger system is requested to stand at 100% efficiency at maximum 30KHz trigger rate. Considering the affordable memory buffer depth in the DAQ system, the trigger decision has to be made within 5 microsecond.

A multi-layer real-time trigger system is designed for the Belle II CDC detector to perform various tracking algorithms and to conclude a trigger decision within the latency constraint. Fig. 2 gives the schematic of the CDC trigger system. Two types of FPGA based electronics boards, merger [4] and universal trigger (UT3) board (Fig. 3), are designed for the system. One merger combines hit pattern and timing information from 4 FE boards. Total 73 merger boards are used for the system. The UT3 board plays a major role for track finding and trigger decision: track segment finder (TSF), 2D tracking, 3D tracking, and global decision logic (GDL).

IV. TSF and 2D Trigger

The TSF, one for each super-layer, collects merged hit pattern and timing information from merger boards, and

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The Belle II CDC trigger group has members from KEK (Japan), Korea University (Korea), National Taiwan University, National United University, Fu-Jen Catholic University, National Central University (Taiwan), Technical University of Munich, Ludwig-Maximilians-Universität München, and Karlsruhe Institute of Technology (Germany).

performs track segment searching (Fig. 4). The 2D tracking takes the TSF outputs for 5 axial super-layers and pursuits a track finding in the r-phi plane. The Hough transformation is adopted for track pattern recognition to reduce the processing time (Fig. 5). For track with transverse momentum (Pt) greater than 0.3 GeV, the efficiency can reach to about 100%. For track with Pt less than 0.3 GeV, only 4 or fewer axial super-layers will be hit. A special variant of the 2D tracking algorithm will be prepared to treat those low Pt tracks.

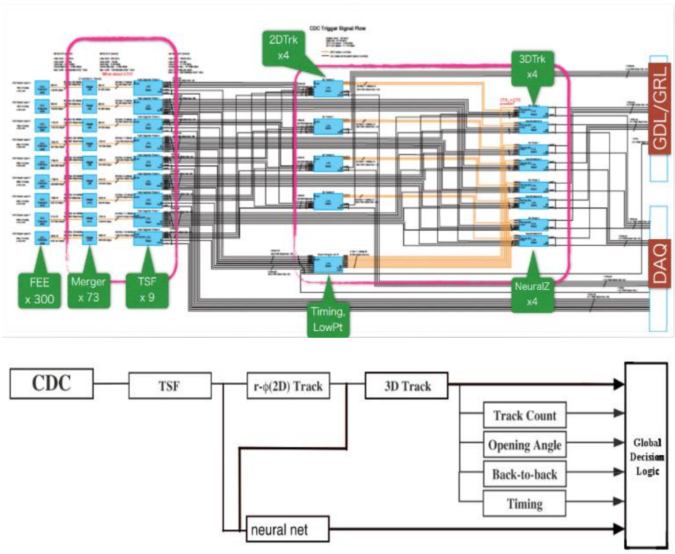

Fig. 2. The CDC trigger data flow (top) and the schematic of the trigger functions (bottom).

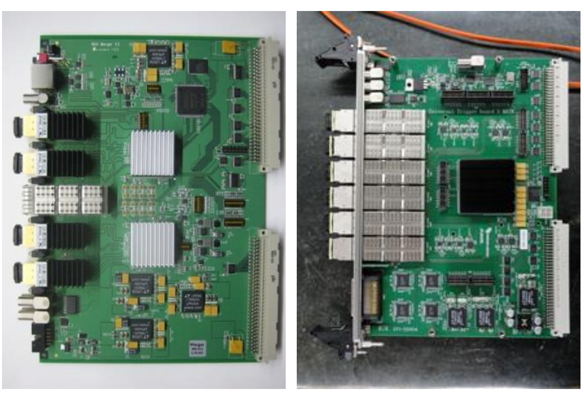

Fig 3. The merger (left) and UT3 (right) boards for the Belle II CDC trigger system.

V. 3D Trigger and Neural-Network Trigger

To improve the selection of secondary particles originating from the interaction point, a 3D tracking algorithm is implemented for the z-vertex trigger. This is new in the Belle II trigger system comparing to the Belle trigger system. The 3D tracking combines the 2D tracking results and TSF outputs for the stereo super-layers to calculate the intersection of the track and the z-axis. Taking into account the drift time to correct the hit position, we calculate the z positions of the track to fit for the helix. Using Monte-Carol simulations, we got the z-resolution less than 1 cm for tracks with Pt larger than 0.3 GeV. Besides the 2D and 3D tracking, a new study to apply neural-network technics as a complementary z-vertex tracking is ongoing. It takes the 2D tracking output and the raw drift times from all super-layers as seeds for a feed-forward network, which is trained on simulated tracks to estimate the z-vertex [5]-[6]. All the tracking outputs are sent to GDL for making various trigger logic decision.

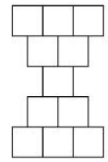

Fig 4. The geometric shape of a track segment. Each square corresponds to a sense wire cell of the CDC.

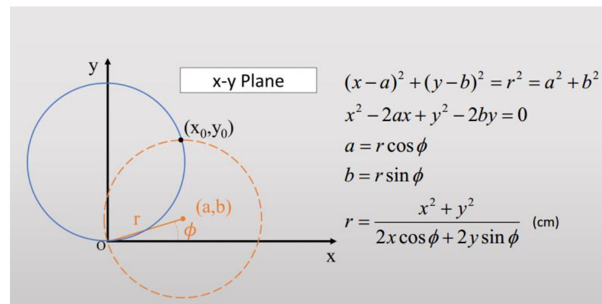

Fig. 5. The Hough transformation for CDC 2D tracking.

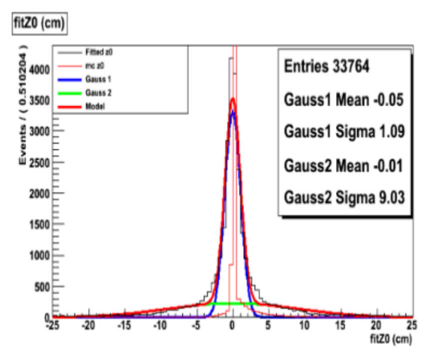

Fig. 6 The z resolution by 3D trigger (preliminary result from simulation study).

VI. Trigger Data Transmission

The trigger data flow is pipelined through gigabit optical serial links at 32MHz data rate. The transmission is constrained by the bandwidth of the serial I/O ports of the FPGA. The UT3 has one Xilinx XC6VHXT FPGA on board, which supplies up to 24 GTH and 40 GTX transceivers for high speed serial links. The bandwidth for GTX and GTH is 6.6 Gbps and 11.2 Gbps. For radiation hardness reason, the CDC FE uses Virtex 5 FPGA, which has GTP transceivers with bandwidth 3.2 Gbps. We first adopted the open source Aurora protocol for the data transmissions. However, the long transmission latency for GTX and GTH ports causes the total latency too long in this multi-layer trigger system. In order to satisfy a trigger decision within 5 micro-seconds, we developed a user-defined protocol which drastically reduced the transmission latency (Table 1). The total latency for CDC trigger system is now estimated to be less than 4 micro-second. To synchronize all the trigger electronics and to deal with any transmission error or link connection lost during the operation, we defined a set of rules for the data flow control. All the trigger electronics will be synchronized to the revolution clock of the accelerator in the beginning of a run. A clock counter as the time tag is embedded within the event data from every FE to ensure the data of same event being merged and treated together.

Table 1. The latency comparison between the Aurora and customized raw-level protocols.

Protocol	Lane rate	user_clk	Link type	Latency(ns)
Aurora 8B/10B	5.08Gbps	254MHz	GTX-GTX	185∼190
Raw-level 8B/10B	5.08Gbps	254MHz	GTX-GTX	132∼136
	5.08Gbps	254MHz	GTH-GTX	132∼136
	5.08Gbps	254MHz	GTH-GTH	91∼95
	5.08Gbps	254MHz	GTX-GTH	91∼95
Aurora 64B/66B	10.16Gbps	158.75MHz	GTH-GTH	296∼302
Raw-level 64B/66B	11.176Gbps	169.33MHz	GTH-GTH	106∼112

SUMMARY

A multi-layer multi-functional trigger system is designed for the Belle II CDC detector to perform a tracking trigger system in real time. A FPGA based universal trigger board is designed to perform different 2D and 3D track searching. A user-defined protocol is defined for high speed serial optical transmission. The total latency is estimated to be less than 4 micro-second. The full functions of this trigger system are under final development and system validation, and it will be ready for the first collision of Belle II experiment in 2017.

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