Installation of a Cosmic-Ray Trigger System to Commission the Belle II Experiment VerteX Detector with Cosmic Rays

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Abstract. In this paper, we describe the design, construction, testing, and installation of the cosmic ray trigger system used to commission the VerteX Detector (VXD) of the Belle II experiment at the High-Energy Accelerator Research Organization (KEK) in Japan. The system consists of two rows of scintillators; with six scintillators being on top of the VXD, and six at the bottom of it. The scintillators were characterized (plateaus, threshold values, coincidences rate), and when compared with the simulation values a concordant match was found for all cosmic coincidence measurements. In Phase 3 of SuperKEKB accelerator, the VXD was the last sub-detector to be integrated into the heart of Belle II detector, after it was absent from being integrated within Belle II in Phase 1 and Phase 2 of SuperKEKB machine studies. A system consisting of VXD prototype parts had been installed, into Belle II detectors, at the VXD location during Phase 2 to study background and it was found that the VXD can cope with the level of measured background: allowing the VXD to be present during Phase 3 Belle II data taking. The VXD was tested with cosmic rays outside of Belle II before it was integrated within Belle II just before Phase 3 data taking, which commenced in March 2019.

INTRODUCTION

The B-Factories accelerators PEP-II at KEKB at the KEK (Translated from Japanese to be "The High Energy Accelerator Research Organization") center, Japan, and the Stanford Linear Accelerator Center (SLAC), USA, have been extremely successful during the period 1999-2010. Belle experiment took data at KEKB and BaBar experiment took data at PEP II. Both Belle and Babar contributed to the establishment of the theory of Makoto Kobayashi and Toshihide Maskawa[1] who quantitatively explained the observed CP violation in the K-meson and B-meson systems. Both M. Kobayashi and T. Maskawa, along with Yoichiro Nambu, were awarded the 2008 Nobel Prize in Physics, where Belle and BaBar experiments were cited, in the 2008 Nobel Prize of physics press release, as main contributors to this Nobel Prize. We will discuss here the construction and installation of a cosmic ray trigger system, at KEK center in Japan, to commission the Belle II experiment VerteX Detector (VXD) with cosmic rays before it was integrated within the Belle II detector. In section 2 we will discuss the apparatus and its components; afterwards we will report in section III the results of the cosmic trigger system tests done at the bench. Then, in section 4, we will report on the assembly and studies of the system at KEK center in Japan; finally, data quality will be discussed and examined in section 5.

APPARATUS

Cosmic rays were used to commission VXD for SuperKEKB phase 3 data taking. Historically, cosmic rays had been used in the 1940s and 1950s as a source to search for new particles in fixed target experiments. Later on, in the beginning of 1960s, colliders had been built to reach higher energy collisions and cosmic rays have been used ever since to test and commission new particle trackers (detectors). Our cosmic ray trigger system is composed of four main parts; the frame, scintillators (including light-guides), photomultipliers, and a rack housing a NIM and VME crates with many data acquisition modules. We will elaborate on each of those components in this section.

The Frame

The VXD cosmic trigger system was designed to house six top scintillators and six bottom scintillators, each scintillator has dimensions of: $10cm \times 30cm \times 1cm$, as shown in Fig. 1. The cosmic trigger system had been tested at the bench during spring 2018 and results are shown in section 4. Then the cosmic trigger system was shipped to KEK to be installed in the VXD commissioning clean room near Belle II IP. The cosmic trigger system frame is designed to be fixed on the granite threaded table, where VXD sits, with scintillators surrounding VXD as shown in Fig. 2.

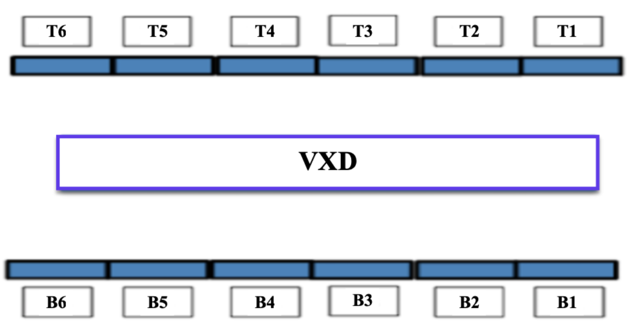

FIGURE 1. A schematic of the VXD cosmic trigger system with six top and six bottom scintillators.

Connections & Data Acquisition

We worked on making the cosmic trigger Data AcQuisition DAQ system automatic enough to control it from a host at least at the run control system. However the PMs thresholds, on the CAEN NIM discriminator modules, were the only ones not accessible from the host and were adjustable by hand. The cosmic VXD raw data are stored within the Belle II DAQ system, however we wrote a standalone DAQ in which we monitor and store cosmic scintillators coincidence rates by reading a CAEN VME V830 scaler module.

An overview of the VXD cosmic trigger system DAQ is shown in Fig. 3. The DAQ system is written in C/C++ code within a PC under a Linux/ubuntu platform. The CAEN HV SY403 module is connected to the DAQ machine, via a RS232-to-USB cable, to automatically ramp- up/ramp-down PMs HVs and monitor them together with the currents. PMs signals are first discriminated by CAEN NIM discriminator modules (N841), then the discriminated NIM signals are sent to coincidence NIM modules to generate a global trigger signal to be sent to Belle II DAQ for cosmic data taking.

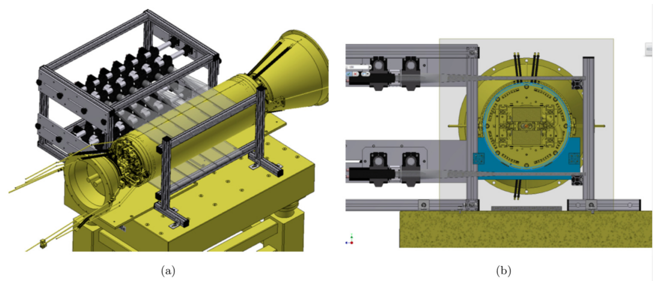

FIGURE 2. Front view (a) and a side view (b) of the cosmic trigger system frame, with its 12 scintillators. The pictures also show the way at which the VXD is fixed on the commissioning granite table at KEK.

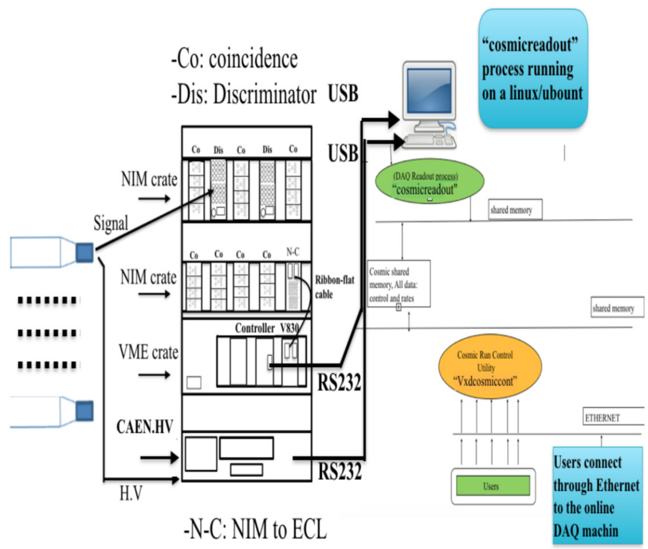

FIGURE 3. A schematic of the cosmic trigger Rack with all its NIM and VME crates with their electronic modules. At the right of the figures is the structure of the cosmic standalone DAQ.

TESTS AT THE BENCH

The cosmic trigger looks like as in Fig. 4 when the scintillators are inserted with PMs. The scintillators had been tested before being mounted in the frame two by two on top of each other. Signals were studied and plateaus measured as shown in Fig. 5. The operating HV is taken at the beginning of the plateaus to be 1250 V for the first scintillator and 1400 V for the second scintillator. Finally we measured top and bottom scintillators coincidence rates. In particular we measured coincidence rates for one top scintillator with each of the six bottom scintillators with all scintillators installed in the frame.

INSTALLATION AT KEK

Once the cosmic trigger system was tested at the bench, it was dismounted and its parts were shipped to KEK in June 2018. The scintillators were fixed on the cosmic-ray trigger frame, and then the frame was installed inside the VXD commissioning room as shown in Fig. 6. Coincidence rates versus incidence angle, of one top corner scintillator with each of the bottom scintillators are shown in Fig. 7 where the x-axis is the horizontal shift in cm of the bottom scintillators with respect to one of the top corner scintillators. We used a miss-and-hit program (written in C) to simulate cosmic rays coincidence rates between top and bottom. Fig. 7 shows that the coincidence rates, following a cosine-square behavior as known, match the simulation very well.

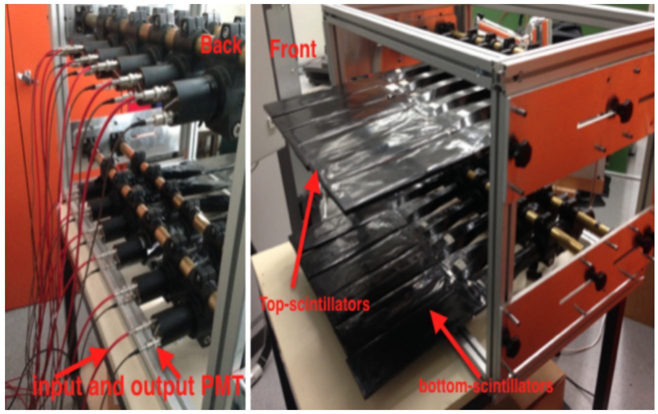

FIGURE 4. All scintillators, with PMTs, are Installed in the frame, and tested.

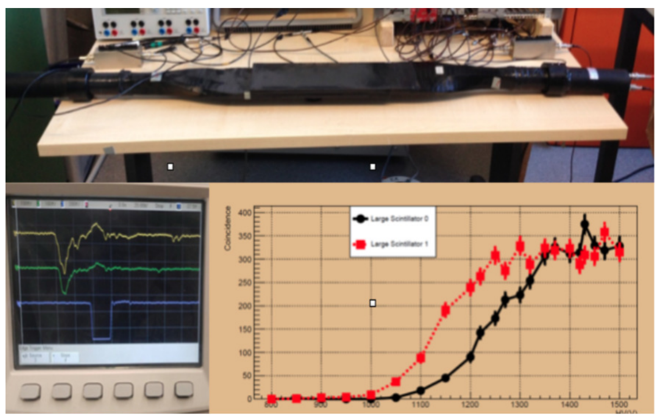

FIGURE 5. Plateaus of two scintillators tested on top of each other.

COSMIC-RAY DATA QUALITY

At the beginning of November 2018, we started taking cosmic data with the VXD in the commissioning clean room at KEK, for about 12 days. The global trigger is defined as: **OR** for all the six top scintillators, connected with **AND** of **OR** of all the six bottom scintillators. The cosmic global trigger coincidence rate had been measured during data taking using a system NIM discriminator and Coincidence CAEN modules and a CAEN VME scaler module (V830). We took several runs to measure this global coincidence rate, and all runs give stable distribution rates like in Fig. 8. The cosmic rate distribution, in Fig. 8, looks like a Poisson Distribution with a mean value of (10.05 +/- 3.12 Hz) matching the simulation result of 10.45 Hz.

We also used the Belle II Analysis Software Framework (basf2) simulation and reconstruction program to display cosmic-ray tracks in VXD. An example of such display is shown in Fig. 9 [2, 3, 4]. The cosmic-ray track is shown in r-z view (front view) and r-φ views (side view).

About 300,000 tracks were reconstructed. A full analysis of these events to align VXD will be discussed in a future paper, as this paper discusses only the construction and installation of the Belle II VXD detector cosmic-ray trigger system.

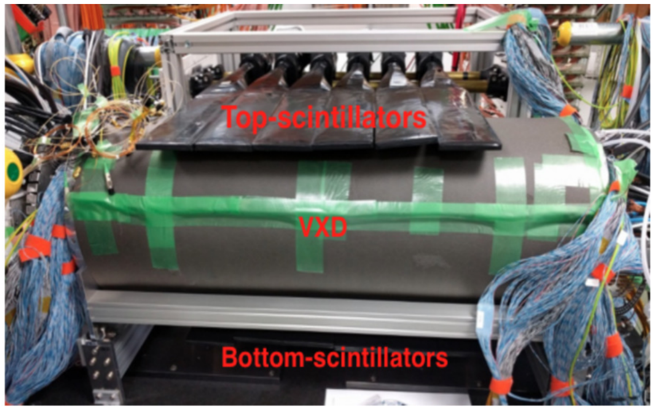

FIGURE 6. A view of the cosmic trigger system surrounding VXD, where the top scintillators are seen. The VXD is the sealed tube in the middle.

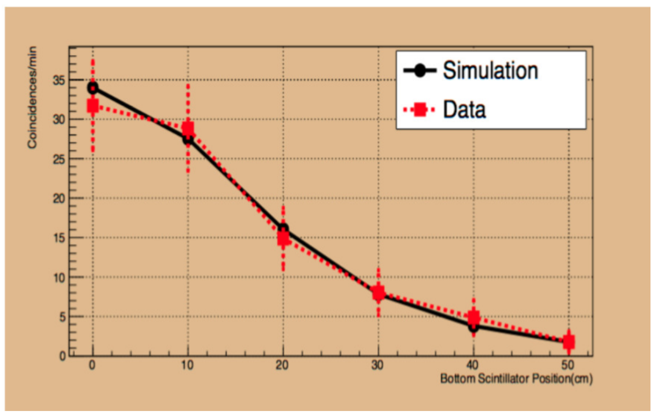

FIGURE 7. Coincidence rates of a top corner scintillator with each of the six bottom scintillators. The rates are found matching the simulation.

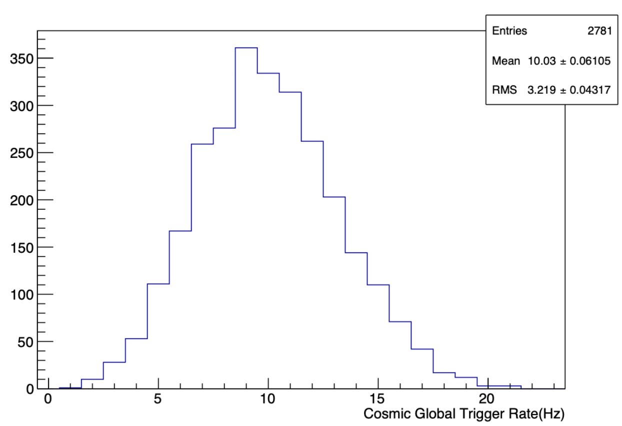

FIGURE 8. Global cosmic trigger rate had been continually measured by a VME scaler module from CAEN. The global coincidence trigger rate, of six top and six bottom scintillators, found to be (10.05 +/- 3.124) Hz matching the simulation value that is of 10.45 Hz. The distance between top and bottom scintillators is 19.2 cm.

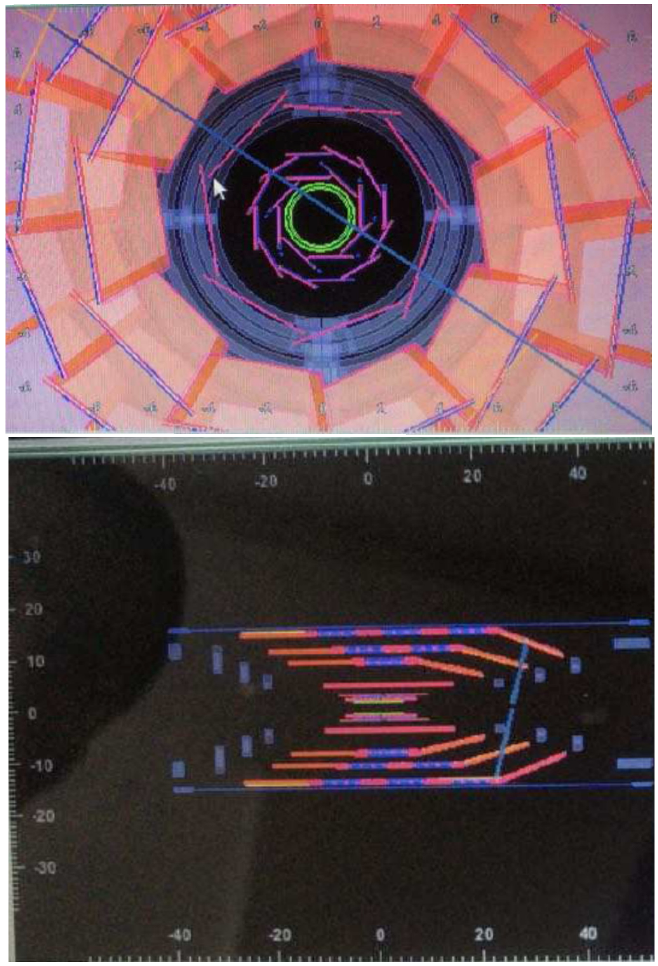

FIGURE 9. A display of a cosmic ray, triggered by our system, in r-z and r-φ views.

CONCLUSION

We designed, constructed, tested, and installed the Belle II cosmic trigger system to commission Belle II VXD detector at KEK center during fall 2018. The VXD had been assembled in a clean room at KEK before it was installed within Belle II detector at the beginning of 2019. We took cosmic-ray data on the VXD, while it was outside Belle II detector, showing events display with well reconstructed cosmic tracks which seem to match simulation results. Immense effort had been done to align Belle II VXD detector with cosmic rays so as to be commissioned before being integrated within Belle II detector. The results will be published soon, though they were already presented in conferences [5].

We are preparing ourselves to use this cosmic trigger system to commission the Belle II VXD with its full parts during 2021 SuperKEKB shutdown.

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REFERENCES

1. M. Kobayashi and T. Maskawa, Prog. Theor. Phys. **49**, 652–657 (1973).
2. T. Bilka et al, EPJ Web Conf. **245**, 02023 (2020).
3. J. Kandra et al., preprint, arXiv:1910.06289 [physics.ins-det] (2019).
4. B. Spruck et al., PoS V**ertex2019,** 015 (2020).
5. A. Halawani, R. Ayad, and M. Albalwi, "Commissioning the Belle II Vertex Detector (VXD), at KEK Center, Japan, with Comic Rays" in Bulletin of the American Physical Society, APS April Meeting (2019).