Integration and Characterization of the Vertex Detector in SuperKEKB Commissioning Phase 2

H. Ye(✉)
(On behalf of the BEAST2 Collaboration)

DESY, Notkestrasse 85, 22607 Hamburg, Germany
hua.ye@desy.de

Abstract. As an upgrade of asymmetric e^+e^- collider KEKB, SuperKEKB aims to increase the peaking luminosity by a factor of 40 to $8 \times 10^{35}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$. The SuperKEKB commissioning is achieved in 3 phases. The Phase 1 was successfully finished in June 2016. Now the commissioning is working towards the Phase 2 targeting to reach the luminosity of $1 \times 10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$. In Phase 2, the beam induced background versus luminosity and beam current will be further investigated, to ensure a radiation safe operation environment for the Belle II vertex detector during the Physics data taking in Phase 3. Closed to the beam pipe, 2 pixel and 4 double-sided strip detector layers will be installed, together with the dedicated radiation monitors, FANGS, CLAWS and PLUME, which aims at investigating the backgrounds near the interacting point. The Phase 2 vertex detector integration was practiced and the combined beam tests were accomplished at DESY. In this talk, the status of the Phase 2 vertex detector and the beam tests results are presented.

1 Introduction

As an upgrade of KEKB, the SuperKEKB [1] at KEK aims at increasing the peak luminosity to $8 \times 10^{35}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$. The Belle II [2] experiment targets to explore new physics beyond the Standard Model with an extensively upgraded detector. The SuperKEKB commissioning campaign is scheduled in 3 phases. The Phase 1 was successfully finished in Jun. 2016 which achieved to circulate beams in both rings. A dedicated array of sensors was installed around the interaction point (IP) to monitor and study beam related backgrounds [3]. Now the project is tending to the Phase 2, during which the beam background will be further investigated with collisions. A dedicated vertex detector system will be used. Besides machine commissioning, the accelerator targets to achieve the peaking luminosity of $1 \times 10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$, which is actually the designed peaking luminosity of KEKB. In Apr. 2017 partial Belle II detector without the vertex detector (VXD) was rolled in. The final focusing magnets also occurred to the places. The first collision is expected in Feb. 2018. The physics run (Phase 3)

Z.-A. Liu (Ed.): TIPP 2017, SPPHY 212, pp. 77–81, 2018.
https://doi.org/10.1007/978-981-13-1313-4_16

with full Belle II detector is scheduled in late 2018. The experiment is expected to accumulate an integrated luminosity of about 50 ab^{-1} well within the next decade.

2 Vertex Detector in Phase 2

2.1 Belle II VXD

The Belle II VXD consists of 2-layer DEPFET pixels (PXD) [4] and 4-layer double-sided silicon strips [5]. The DEPFET [6] concept combines signal detection and amplification into one device. In DEPFET pixel, the electrons ionised in the depleted n-type silicon bulk accumulate at a deep internal n^+ gate, which forms a potential minimum. The drain current signal is therefore modulated proportionally to the accumulated charge. The internal gain for Belle II PXD is expected to be about 700 pA/e^-. A clear signal is required to remove the trapped charge, to reset the pixel after a reading. The DEPFET sensor is operated by 3 types of ASICs, they are Switchers which do raw control, the analog front-end named Drain Current Digitiser (DCD), and the Data Handling Processor (DHP) which does the pedestal subtraction. The DEPFET conceptual PXD of Belle II is read out continuously with a 50 kHz frame rate, together with the small pitch size ($50 \times 55 - 80\,\mu m^2$), keeps the occupancy lower than 3%. The sensor is thinned down to 75 µm to achieve a ultra-low material budget of ∼0.2% X_0 per layer. The 2-layer PXD is expected to significantly improve the resolution of the track parameter determination.

The silicon strip vertex detector (SVD) is upgraded with the channels twice as many as its predecessor. The sensor is about 300 µm thick, the p-strips run along the beam axis with pitch size of 50(75) µm and n-strips tangential to the barrel with the pitch size of 160(240) µm. Smaller pitches are used in the inner most SVD layer to improve the resolution. For the outer 3 SVD layers, trapezoidal sensors with slanted angle are adopted in the forward part, to improve the spatial precision and minimise the material budget. The fast shaping (50 ns) and radiation-hard (>1MGy) front-end (FE) APV25, which is originally developed for CMS, is adopted and thinned down to 100 µm.

2.2 Vertex Detector in Phase 2 VXD

40 times larger instantaneous luminosity is expected to induce significantly higher background level in all Belle II subdetectors. From the simulation, the QED background as well as synchrotron radiation and Touschek effect dominate in the VXD region. The dedicated vertex detector for Phase 2 (shown in Fig. 2) involves 2 PXD and 4 SVD ladders in the +x sector where the highest background level is expected. Three additional dedicated radiation monitors are arranged around the IP for further investigation of the background, they are:

FANGS (**FE-I4 ATLAS N**ear **G**amma **S**ensors): Planar pixel with Atlas IBL readout chips (FE-I4), to investigate the synchrotron radiation and the deposited energy spectrum of the background.

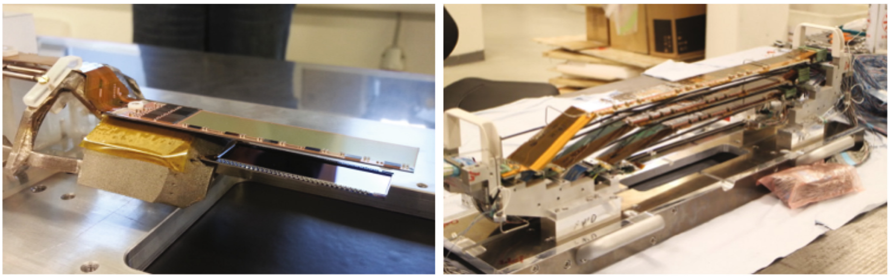

Fig. 1. The 2-layer PXD modules and 4-layer SVD modules tested in the test beam at DESY.

CLAWS (s**C**intillation **L**ight **A**nd **W**aveform **S**ensors): Plastic scintillators with SiPM readout, to study the time evolution of background and its decay constant.

PLUME (**P**ixelated **L**adder with **U**ltra-Light **M**aterial **E**mbedding): double-layer CMOS pixels, to study the spatial distribution and direction information of the background.

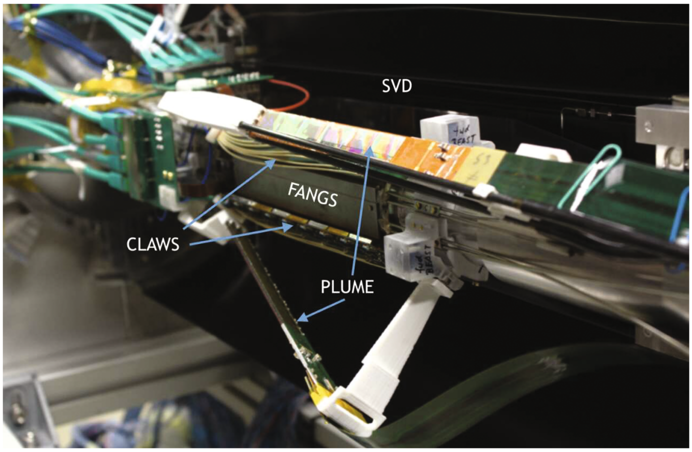

Fig. 2. The vertex detector dedicated for SuperKEKB commissioning Phase 2. The integration was tested at DESY, the thermal interference was quantified and the integration sequence was decided. During the test, SVD, FANGS, CLAWS and PLUME were involved.

The setup investigated at DESY are shown in Figs. 1 and 2. Integration of Phase 2 VXD was practised to study the thermal interference and the integration sequence. The interference between subdetectors are determined to be negligible.

3 VXD Beam Tests at DESY

The performance of the VXD system was investigated in the DESY infrastructure of test beam. Complete VXD readout chain, including high-level trigger (HLT), region of interest (ROI) determination, event building, CO_2 cooling, slow control and environmental monitoring, are involved in the tests. During the test beam in 2016 (TB16), 2 PXD modules and 4 SVD ladders were tested, then in TB17, up to 4 PXD modules, SVD, as well as FSANGS and CLAWS joined. The VXD system was illuminated with up to 6 GeV e^- beam within a solenoid magnetic field up to 1T.

The huge data rate after pedestal subtraction of PXD is impossible to be coped by the software event builder system. Most of PXD hits are contributed from background. The readout chain needs to reduce the data by a factor of 30 [7]. A distinction between background and signal becomes possible when the information of outer trackers are taken into account. The tracks from most physics relevant events have enough momentum to reach SVD. By doing online track reconstruction and tracing back to the PXD areas, the regions, referred as Regions of Interest (ROIs), with corresponding PXD hits are expected [8]. The Online Selection Nodes (ONSEN) will buffer the output data and record just the pixels inside the ROIs. The ROIs are determined from two sources: the FPGA-based SVD-only track finder Data Concentrator (DATCON) and software-based high-level trigger (HLT), which extracts ROIs using SVD and drift chamber information. Figure 3 shows an typical event in beam test.

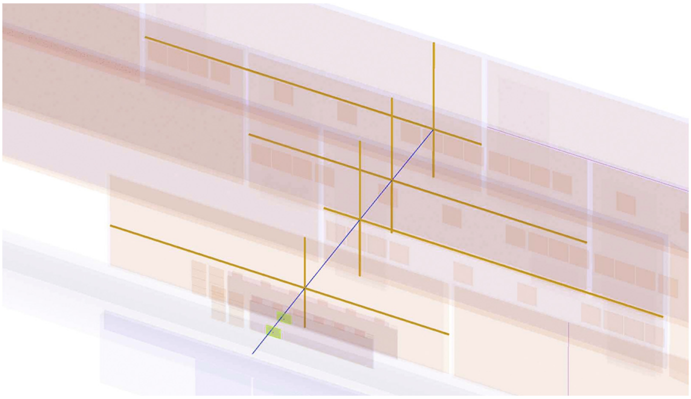

Fig. 3. An event display in the test beam at DESY. The blue curve is the reconstructed track, the yellow lines indicated the fired SVD strips, and the green regions are the determined ROI on the PXD.

In TB16, 6 layers of EUDET telescopes were placed up and downstream of the 6 VXD layers. The hit efficiency and spatial resolution of VXD sensors were determined. For PXD modules, most of matrix columns achieved an efficiency above 98%, the residual RMS for single hit clusters is determined to be 14.3 μm, which is consistent with the digital resolution of Pitch/$\sqrt{12}$ [9]. The residuals of the SVD sensors were determined as ∼11 μm in the $r - \phi$ side and ∼30 μm in z side. All SVD sensors under test achieved an averaged efficiency above 99.5% per strip in both sides [10]. The deposited charge in FANGS was quantified in TB17. One advantage of the FE-I4 chip is that the length of signal contains the deposited charge information. In FANGS, the HitOr signal in each sensor is sampled with an external FPGA 640 MHz clock, resulting in a 12-bit resolution for charge measurement. The measured mean value from Landau fit is 17.3 ke, which is comparable within a 5% error to the expected value of 18 ke for a 250 μm thick silicon sensor [11].

4 Summary and Outlook

SuperKEKB commissioning Phase 2 will start in Feb. 2018 to further investigate the beam induced background, partial Belle II detector has been rolled in and the final focusing magnets occurred in place. The dedicated vertex detector including a sector of PXD and SVD, as well as the additional radiation monitors, FANGS, CLAWS and PLUME aims to study the background near the IP and ensure a radiation safe environment for VXD operation. Integration of Phase 2 VXD was practised at DESY. The detector performance has been characterised at DESY test beam. Full VXD readout chain was integrated in the tests.

In the summer of 2017, all subdetectors studied at DESY will be shipped to KEK for Phase 2. In parallel, final PXD integration for Belle II physics run is under preparation at DESY.

References

1. Ohnisi, Y., et al.: PTEP 2013, 03A011
2. Abe, T., et al.: KEK Report 2010-1 (2010). arXiv: 1011.0352v1
3. Miroslav, G.: The Belle II / SuperKEKB Commissioning Detector - Results from the First Commissioning Phase. IPP2017 talk
4. Marinas, C.: Nucl. Instrum. Methods **731**, 31 (2013)
5. Friedl, M., et al.: Nucl. Instrum. Methods A **732**, 83 (2013)
6. Kemmer, J., Lutz, G.: Nucl. Instrum. Methods **253**, 356 (1987)
7. Geßler, T., et al.: IEEE Trans. Nucl. Sci. **62**, 1149 (2015)
8. Konno, T.: Integration of readout of the vertex detector in the Belle II DAQ system. TIPP2017 talk
9. Schwenker, B., et al.: PoS(Vertex 2016)011
10. Lück, T., et al.: PoS(Vertex 2016)057
11. Khetan, N.: Master thesis, Development and integration of the FANGS detector for the BEAST II experiment of Belle II, Rheinischen Friedrich-Wilhelms-Universität Bonn