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Performance of the Belle II Silicon Vertex Detector

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The Belle II experiment at the SuperKEKB collider of KEK (Japan) will accumulate 50 ab^{-1} of e$^+$e$^-$ collision data at an unprecedented instantaneous luminosity of $8 \times 10^{35} cm^{-2} s^{-1}$, about 40 times larger than its predecessor. The Belle II VerteX Detector plays a crucial role in the rich Belle II physics program, especially for time-dependent measurements. It consists of two layers of DEPFET-based pixels (PXD) and four layers of double sided silicon strip detectors (SVD). The VerteX Detector has been recently completed and installed in Belle II for the physics run started in spring 2019. We report here results on the commissioning of the SVD and its performance measured with the first collision data set.

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1. Introduction

The Belle II experiment [1] is held at the SuperKEKB asymmetric e^+e^- collider [2], located in the KEK laboratory (Tsukuba, Ibaraki Prefecture, Japan). SuperKEKB is a major upgrade of the KEKB collider, aiming to reach an unprecedented instantaneous luminosity of 8×10^{35} cm^{-2}s^{-1}, that will be reached reducing the vertical beta function at the interaction point (IP) by a factor 20 and increasing beam currents to twice those of KEKB. Such instantaneous luminosity will allow Belle II to collect up to 50 ab^{-1} of data in ten years of operation. The SuperKEKB accelerator consists of two rings, one for an electron beam of 7 GeV energy and one for a positron beam of 4 GeV, corresponding to a center of mass energy of $\sim$ 10.58 GeV, around the $\Upsilon(4S)$ resonance. The $\Upsilon(4S)$ will thus be produced with a sizeable relativistic boost in the laboratory frame ($\beta\gamma = 0.28$), although significantly reduced with respect to KEKB ($\beta\gamma = 0.425$). The Belle II sub-detector nearest to the IP is the VerteX Detector (VXD), which is fundamental for the measurement of the impact parameters of charged tracks and for the reconstruction of primary and secondary *B* and *D* mesons decay vertexes. It consists of two inner layers (1 and 2) of a silicon PiXel Detector (PXD) followed by four layers of a Silicon Vertex Detector (SVD), which is composed by double sided silicon strip sensors. The whole VXD is immersed in a 1.5 T solenoidal magnetic field. A picture of one half of the VXD is shown in fig. 1. SVD sensors are organised in a barrel geometry with a polar

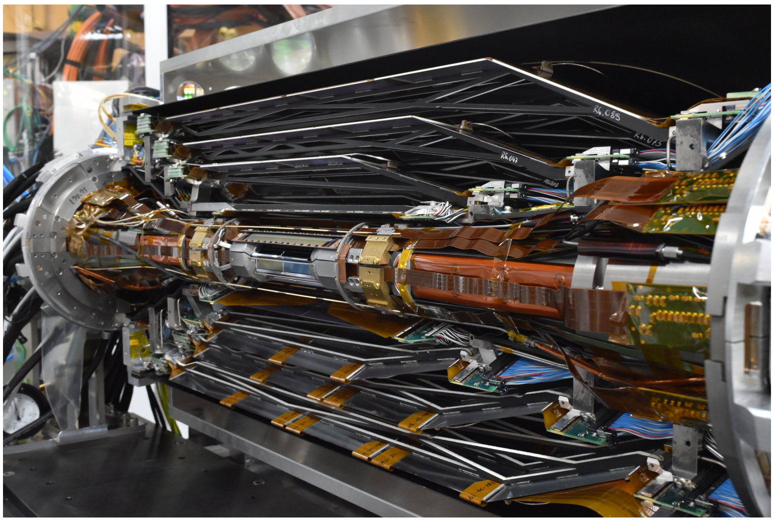

Figure 1: The Belle II VerteX Detector (VXD).

angle coverage from 17° in the forward region to 150° in the backward region and with a radius going from 39 mm for the inner layer to 135 mm for the outer layer. In the forward region slanted trapezoidal sensors are used to optimise the angular coverage and the particle incidence angle. Only three different kind of sensors, fabricated on 172 silicon wafers and with n-type substrate of 320 μm thickness, are used, two rectangular and one trapezoidal. Readout pitches are 50-75 μm in r-ϕ direction and 160-240 in z direction, which is parallel to the electron beam direction of motion. The readout chip is the APV25 [3], which is tolerant to high radiation doses (more than 100 Mrad) and the combination of short shaping time (50 ns) and online pulse shape processing will keep the occupancies to an acceptable level for the performance even under the severe background conditions at the SuperKEKB design luminosity. APV25 chips to be used for the inner sensors have been thinned from the original 300 μm thickness down to 100 μm and placed on top of the sensors using the so called "*Origami*" chip-on-sensor concept [4] [5]. To protect the detector and assure its performance, a full monitoring system [6] is used to check humidity inside the VXD volume, temperatures of the cooling system and of silicon sensors, radiation dose deposited on the detector.

The full VerteX Detector assembly has been completed and installed in the Belle II detector in November 2018, the data taking started in March 2019 and first months have been used to evaluate SVD performance.

2. Cluster energy and SNR vs track angle

Cluster energy depends on the incident angle of the particle on the sensor. Considering the IP position with respect to the SVD, a higher cluster energy is expected in the backward and forward sensors because of the higher incident angle of tracks. These expectations were confirmed by the cluster energy distribution for sensors at different positions in the z direction, as shown in fig. 2, where the cluster energy is higher for layer 3 forward sensors with respect to the backward ones.

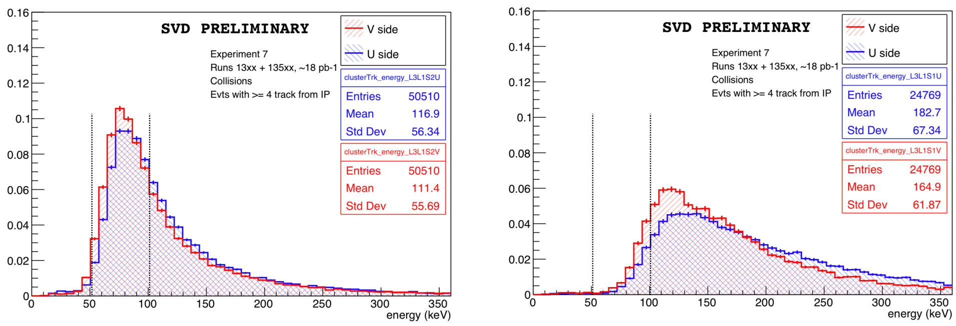

Figure 2: Cluster energy for Layer 3 backward (left) and forward (right) sensors.

The cluster signal-to-noise ratio, defined as

$$SNR_{cls} = \frac{\sum_{strips} S_i}{\sqrt{\sum_{strips} N_i^2}} \tag{2.1}$$

depends on strip noise and on collected charge: noise is higher in r-ϕ side, that has longer strips, but signal depends also on sensor position due to the track incident angle and it is in general slightly lower on the z side, because of the charge loss due to the floating strips and the large pitch. In the end the noise difference is the dominant effect and SNR results higher on the z side. The measured SNR most probable value (MPV) in all sensors is between 15 and 25 for the r-ϕ side, and 18 to 30 for the z side.

3. Sensors efficiency

The efficiency of a sensor is calculated as the fraction of times a cluster is found within $\pm$0.5 mm from the extrapolated position of tracks on the sensor. Forward and backward sensors have

Efficiency	r-ϕ	z
Layer 3	(99.75±0.02)%	(98.46±0.05)%
Layer 4	(99.66±0.04)%	(99.37±0.06)%
Layer 5	(99.62±0.06)%	(99.43±0.08)%
Layer 6	(99.30±0.10)%	(99.30±0.10)%

Table 1: Average efficiencies for SVD sensors divided by layer and by side.

efficiencies slightly higher than barrel sensors. On average, the efficiency is above 99% for most of the sensors, with the exception of a L3 sensor that had a read-out chip masked due to a bad cable connection that was recovered at the end of the first run. The average efficiencies for all SVD sensors are listed in table 1.

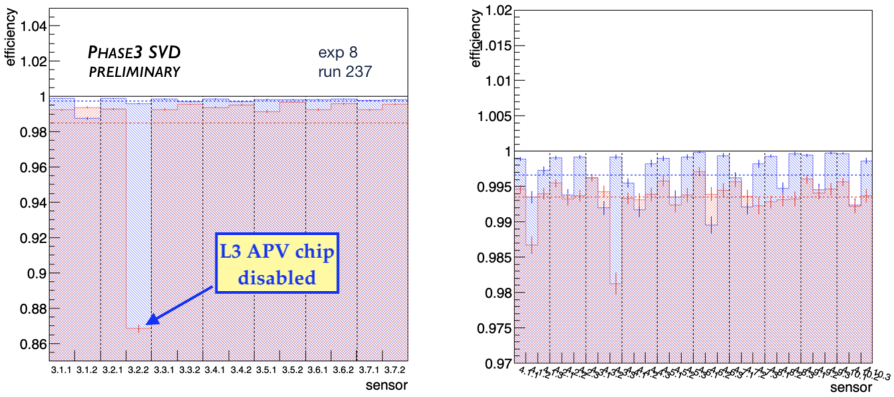

Figure 3: SVD sensors efficiencies for Layer 3 (left) and Layer 4 (right).

4. Hit time resolution

A precise determination of the SVD hit time is crucial to significantly reduce the occupancy by rejecting off-time particles due to background events. In addition, the pattern recognition performance will be enhanced by a precise hit time evaluation reducing the number of space points: for each sensor side, a rejection of 30% clusters is expected, which will result in a reduction of 50% space points (3D hits) per sensor.

The SVD hit time has been evaluated using the information on the trigger time, the sampling of the signal response and information obtained from calibrations. The SVD hit time resolution, obtained with the timing of the Central Drift Chamber (CDC) as a reference, is 1.8 ns as shown in fig. 4. It has been produced with data taken during the commissioning run of 2018, when only a slice of the full VerteX Detector was installed.

5. Conclusions

The Silicon Vertex Detector, installed in the Belle II experiment together with the PiXel De-

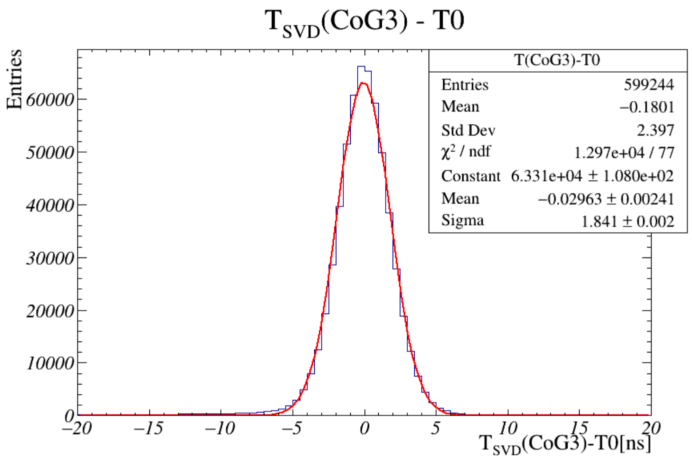

Figure 4: SVD hit time resolution obtained with CDC as a reference.

tector in November 2018, started physics data taking in March 2019. All sensors are working as expected, with efficiencies above 99% and Signal-to-Noise Ratios between 15 and 30. The hit time resolution shows very promising results for background rejection and tracking performance improvement, that will become crucial approaching design luminosity. No major issues were observed in the SVD during the first period of data taking.

6. Acknowledgements

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