ALIGNMENT STUDIES AT BELLE II VERTEX DETECTOR*

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The Belle II is the next generation of famous B-physics experiments and they would like to continue in success of predecessors. To provide better measurements and extend limits, the upgrades were necessary. One of the main upgrades was expanding a strip silicon detector using a pixel detector. Higher precision requires more sophisticated alignment procedure, parametrization, validation and monitoring techniques. Since the first commissioning of vertex detector, a lot of experiences have been acquired and many of features have been observed.

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1. The SuperKEKB and the Belle II detector

The Belle II detector is B factory of new generation and it is built on upgraded accelerator SuperKEKB. The main difference between SuperKEKB and its predecessor is a Nano-beam structure used for colliding e^+e^- beams. Its expected instantaneous luminosity is 8×10^{35} cm^{-2} s^{-1}, what is 50 times more than we observed during running the Belle detector. The current detector has important upgrades related to precision, efficiency and retention background [1]. Composition of detector layers is similar as in the Belle detector and cross section of detector can be found in Fig. 1.

2. The Belle II vertex detector

The Belle II vertex detector (in Fig. 2) is a composite of pixel (PXD) and strip detector (SVD). The pixel detector is organized to two-layer structure using DEPFET [2] sensors, where 16 sensors are in the first layer and

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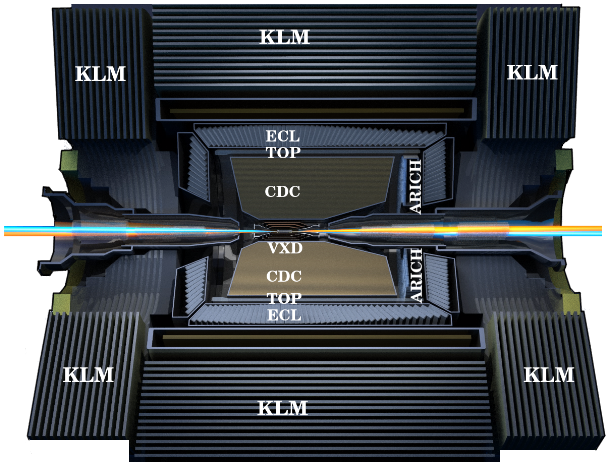

Fig. 1. Cross section of the Belle II detector: In the center of detector, the vertex detector (VXD) is situated. Main tracking detector, the central drift chamber (CDC), is around vertex. The outer layers are related to particle identification (TOP and ARICH), calorimetry (ECL), long-living kaon and muon identification (KLM).

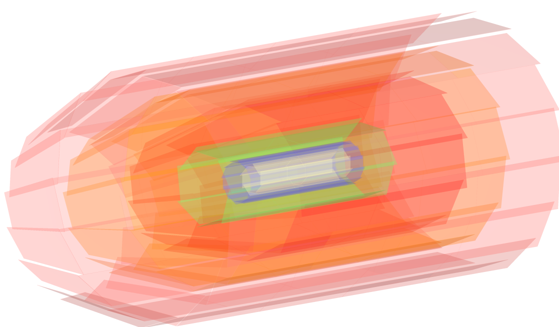

Fig. 2. The Belle vertex detector: Composition of vertex detector with different colors depend on layers. The colors are synchronized with labels in Table I. In layers higher than three, there are the trapezoidal sensors and they can be identified in forward (left) side. Other sensors are rectangular.

24 sensors are in the second layer. In each layer, a pair of sensors is mounted into ladders. The total number of sensors in pixel detector is 40. In 2017, due to unexpected troubles during mounting of pixel detector, only a partial pixel detector was installed. In the partial pixel detector, only 20 sensors are working. In 2022, the current pixel detector will be replaced by a new full pixel detector with all sensors. The strip detector is built using DSSD [3]

sensors to four layer structure. Ladders in each layer have different population of sensors: in the inner layer — two sensors, in the next layer — three sensors, in the third layer of SVD — four sensors, and in the outer layer — six sensors. The layers are composed by ladders and a different layer has different number of ladders. In the inner layer, there are seven ladders. Ten ladders are in the next layer. The third layer of SVD has twelve ladders and the last layer is built of sixteen ladders. The first sensors in the last three layers are trapezoidal and other sensors have perpendicular shape. The total number of DSSD sensors used in strip detector is 172. The technical details of vertex detector can be found in Table I.

TABLE I

Technical details for individual layers of vertex detector. The partial pixel detector (*) is installed and full detector will be installed in 2021.

	Radius [mm]	Thickness [μm]	R/ϕ pitch [μm]	Z pitch [μm]	Sensors
PXD Layer 1	14	75	50	55–60	2×8
PXD Layer 2	22	75	50	70–85	$2 \times 2^*$
SVD Layer 3	39	300	50	160	2×7
SVD Layer 4	80	300–320	75	240	3×10
SVD Layer 5	104	300–320	75	240	4×12
SVD Layer 6	135	300–320	75	240	5×16

3. Alignment of silicon detectors

The silicon sensors are used in tracking detectors, because hit positions of charged particle can be precisely measured if particles pass trough sensitive area. Hits are combine into tracks using track finding methods and during fitting procedure we are able to determine their tracking parameters. The track finding algorithms transform positions of hits from sensor local coordinates to the global detector coordinate system. In this procedure, alignment parameters are used. The alignment parameters are known very well, but sensors can be misaligned from these expected positions. Their corrections should be determined; this procedure is called the track-based alignment procedure. In the procedure, we define residual between the measured position of hit and predicted position of hit from fitted track as

$$r_{ij}(\boldsymbol{\tau}_j, \boldsymbol{a}) = u_{ij}^m - u_{ij}^p(\boldsymbol{\tau}_j, \boldsymbol{a})\,, \tag{1}$$

where $u_{ij}^{m,p}$ are measured or predicted positions of hits, $\boldsymbol{\tau}_j$ is vector of track parameters and $\boldsymbol{a}$ is vector of alignment parameters. For alignment purpose, we define

$$
\begin{aligned}
\chi^2(\boldsymbol{\tau}, \boldsymbol{a}) &= \sum_{j}^{\text{tracks}} \sum_{i}^{\text{hits}} \left(\frac{r_{ij}(\boldsymbol{\tau}_j, \boldsymbol{a})}{\sigma_{ij}} \right)^2 \\
&\approx \sum_{j}^{\text{tracks}} \sum_{i}^{\text{hits}} \frac{1}{\sigma_{ij}^2} \left(r_{ij}\left(\boldsymbol{\tau}_j^0, \boldsymbol{a}^0\right) + \frac{\partial r_{ij}}{\partial \boldsymbol{a}} \delta \boldsymbol{a} + \frac{\partial r_{ij}}{\partial \boldsymbol{\tau}_j} \delta \boldsymbol{\tau}_j \right)^2 , \qquad (2)
\end{aligned}
$$

where σ_{ij} is uncertainty of the hit position measurement. To obtain alignment correction $\delta\boldsymbol{a}$, function $\chi^2(\boldsymbol{\tau}, \boldsymbol{a})$ can be linearised and minimised. For this purpose, the Belle II detector uses the Millepede II [4] algorithm as many other high-energy detectors.

3.1. Alignment parametrization

The alignment parameters of Belle II vertex detector are organized hierarchically. It means three levels of hierarchy are used: sensor, ladder and halves (Figs. 3 and 4). Each sensor is parametrized by three shift, three rotation, three quadratic surface and four cubic surface parameters. In total, we are using 13 alignment parameters per sensor. The sensors are composed to ladders, next three shift and three rotation parameters are used for each

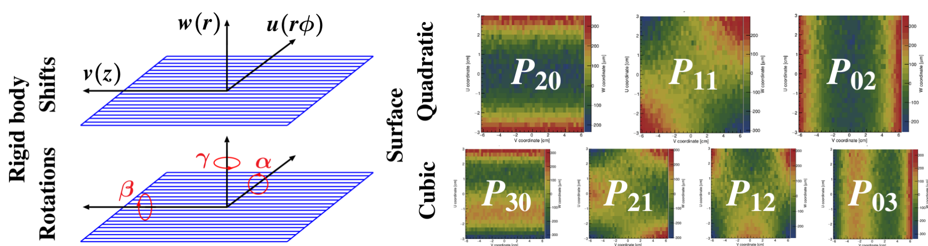

Fig. 3. Sensor alignment parameters: shift (top left) and rotation (bottom left) alignment parameters in local coordinates system and quadratic (top right) and cubic (bottom right) surface alignment parameters of sensors.

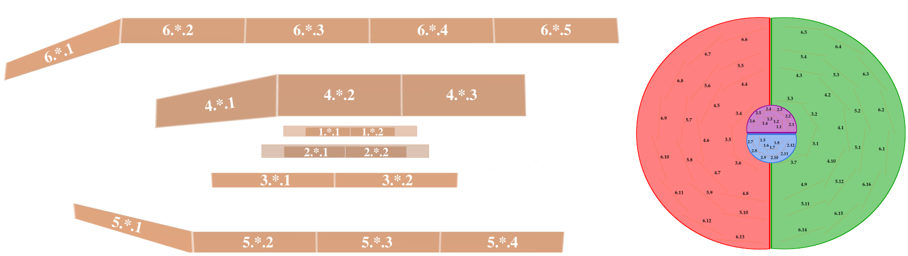

Fig. 4. Higher levels of alignment hierarchy: Sensors are organized to ladders (left) and ladders are organized to halves (right): Pat/outer right halve, Mat/outer left halve, Ying/inner top halve and Yang/inner bottom halve.

group of sensors. The ladders are organized on two different halves, which are mounted together, the next three shift and three rotation parameters per half-shell are needed. Due to different mounting procedures, independent pairs of halves for pixel (called Ying and Yang) and strip detector (called Pat and Mat) are used. In total, we are using 2496 sensor, 354 ladder and 24 half-shell parameters.

3.2. Determination alignment parameters

At the beginning of spring data taking period in 2019, vertex detector alignment parameters were determined. In alignment procedure, higher levels than sensor level were fixed and only sensor alignment parameters were determined. The resulted alignment parameters for vertex detector can be found in Figs. 5 and 6.

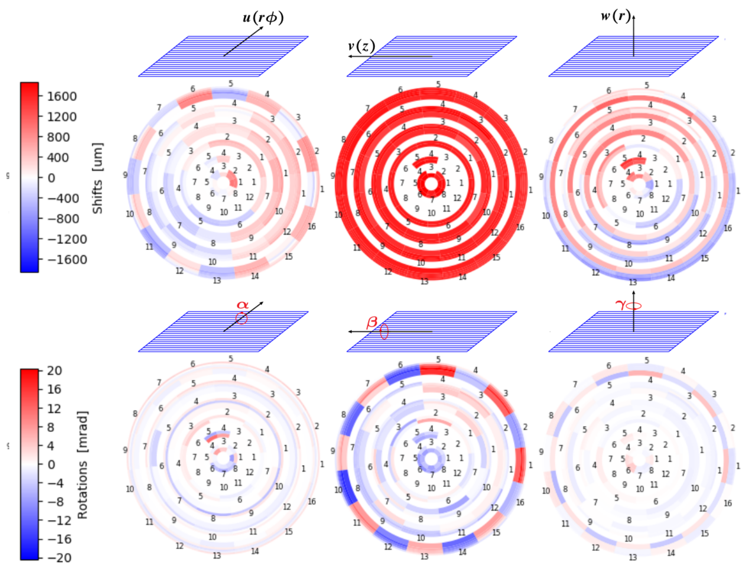

Fig. 5. Determined shift (top line) and rotation (bottom line) alignment parameters.

In alignment results, we can identify systematic features of vertex detector: systematic movement in z coordinate of vertex detector in account our reference system (CDC), a zebra effect of the last layer of SVD in u and β coordinates, non-flat shape of second-layer ladders in w, α, P_{02} and P_{03} parameters and surface deformation of middle-ladder SVD sensors in P_{20} and P_{20} parameters. All these features was known from previous experiences and they are described in Fig. 7. The systematic movement in z global coordinate and zebra effect can be covered by using higher levels of hierarchy.

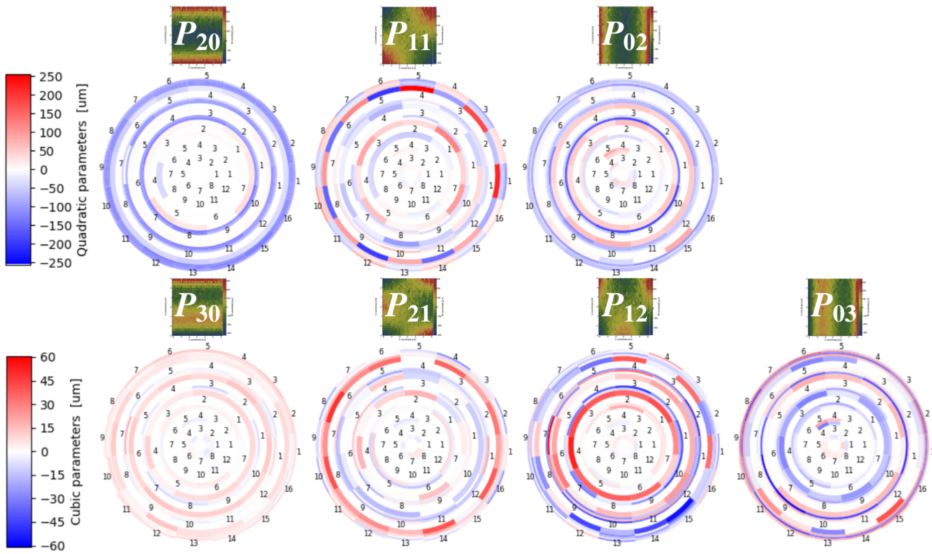

Fig. 6. Determined quadratic (top line) and cubic (bottom line) alignment parameters.

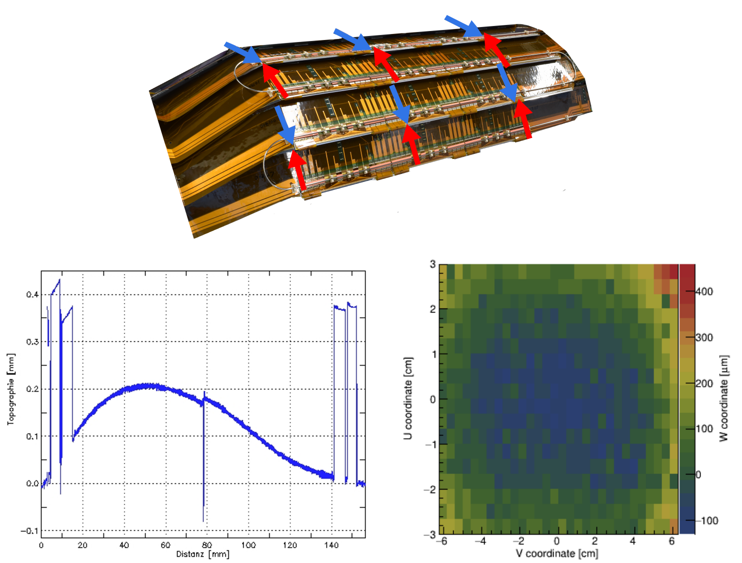

Fig. 7. Schematic picture of zebra effect (top) observed during mounting cooling pipes. Longitudinal shape of the second-layer ladder (bottom left) measured after assembly. Surface shape of middle-ladder SVD sensors (bottom right) was proved applying rigid alignment parameters only.

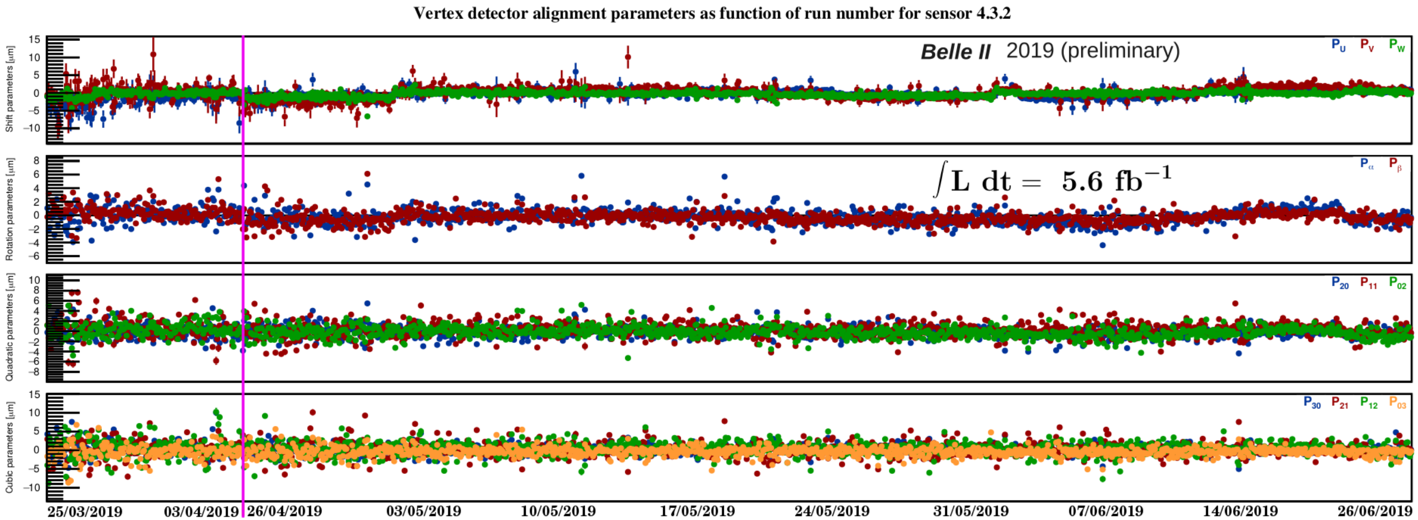

Fig. 8. Time-dependent alignment validation of sensor 4.3.2: shift (first line), rotation (second line), quadratic (third line) and cubic (fourth line) surface parameters. Due to validation procedure [5], only α and β parameters can be validated. During these data taking periods, fire accident break was happen. The units of alignment parameter axes are μm.

3.3. Time-dependent validation of alignment parameters

To confirm and control correct alignment parameters, we developed validation and monitoring alignment procedures [5, 6]. In the case of moving the sensors, ladders, layers or halves, the validation procedure should be used several times during data taking period. In the ideal case, it should run using each collection of data. In spring and summer data taking period, Belle II collect about 5.26 fb^{-1} in 1200 runs. In these periods, all alignment parameters were validated and monitored. One example of validation plot can be found in Fig. 8. Vertex alignment parameters were fluctuating in the range $\pm$ 10 μm during these data taking periods.

4. Conclusion

The Belle II vertex detector was installed in December 2018 and it has joined data taking since the beginning of 2019. To summer 2019, the Belle II detector collected about 5.26 fb^{-1} data. The data collected at the beginning of spring data taking period was used in a sophisticated alignment procedure. In alignment procedures, there are used thirteen sensor alignment parameters and six rigid body parameters for higher hierarchical levels: ladders and halves. Determined alignment parameters describe features known from previous experiences. The vertex alignment parameters were validated and monitored using developed procedures to confirm and control correct values. Alignment parameters were fluctuating in the range of $\pm$ 10 μm.

REFERENCES

[1] Z. Dolezal *et al.*, Technical Design Report, arXiv:1011.0352 [physics.ins-det].

[2] B. Paschen *et al.*, *Nucl. Instrum. Methods Phys. Res. A* **958**, 162222 (2020).

[3] Ch. Schwanda *et al.*, *PoS* **Vertex2019**, 014 (2019).

[4] V. Blobel, C. Kleinwort, arXiv:hep-ex/0208021.

[5] J. Kandra, T. Bilka, arXiv:1910.06289 [physics.ins-det].

[6] J. Kandra, T. Bilka, arXiv:1906.08940 [hep-ex].