# Alignment Belle II silicon vertex detector 

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## Outline

Belle II and vertex detector

## Alignment

## Alignment results

VALIDATION VERTEX DETECTOR ALIGNMENT

MONITORING OF SYSTEMATIC DISPLACEMENT

Summary

## Belle II DETECTOR



More at Wednesday's talk about "Belle II status and Prospect" by Zdenek Dolezal

## VERTEX DETECTOR (PIXEL \& STRIP DETECTOR)

|  | Radius <br> $[\mathrm{mm}]$ | Thickness <br> $[\mu \mathrm{m}]$ | $\mathrm{R} / \phi$ pitch <br> $[\mu \mathrm{m}]$ | Z pitch <br> $[\mu \mathrm{m}]$ | Sensors |
| :--- | :---: | :---: | :---: | :---: | :---: |
| PXD Layer 1 | 14 | 75 | 50 | $55-60$ | $2 \times 8$ |
| PXD Layer 2 | 22 | 75 | 50 | $70-85$ | $2 \times 2^{*}$ |
| SVD Layer 3 | 39 | 300 | 50 | 160 | $2 \times 7$ |
| SVD Layer 4 | 80 | $300-320$ | 75 | 240 | $3 \times 10$ |
| SVD Layer 5 | 104 | $300-320$ | 75 | 240 | $4 \times 12$ |
| SVD Layer 6 | 135 | $300-320$ | 75 | 240 | $5 \times 16$ |

[^0]

Strip trapezoidal sensor


## Track based alignment procedure and Millepede II

- Sensors measure hit positions of charged particles passing their sensitive area.
- Tracking reconstruction software combine hits to a track.
- Transformations between local sensor system and global (Belle II) system are used.
- Alignment parameters are used in transformation matrices and vectors.
- Procedure, which determine alignment parameters, is called alignment procedure.
- The procedure uses residual between measured and expected positions of hits.

$$
r_{i j}\left(\boldsymbol{\tau}_{j}, \boldsymbol{a}\right)=u_{i j}^{m}-u_{i j}^{p}\left(\boldsymbol{\tau}_{j}, \boldsymbol{a}\right)
$$

$\boldsymbol{\tau}_{j}$ is vector of track parameters and $\boldsymbol{a}$ is vector of alignment parameters

- For alignment purpose $\chi^{2}$ function is defined as:

$$
\chi^{2}(\boldsymbol{\tau}, \boldsymbol{a})=\sum_{j}^{\text {tracks }} \sum_{i}^{\text {hits }}\left(\frac{r_{i j}\left(\boldsymbol{\tau}_{j}, \boldsymbol{a}\right)}{\sigma_{i j}}\right)^{2} \approx \sum_{j}^{\text {tracks }} \sum_{i}^{\text {hits }} \frac{1}{\sigma_{i j}^{2}}\left(r_{i j}\left(\boldsymbol{\tau}_{j}^{0}, \boldsymbol{a}^{0}\right)+\frac{\partial r_{i j}}{\partial \boldsymbol{a}} \delta \boldsymbol{a}+\frac{\partial r_{i j}}{\partial \boldsymbol{\tau}_{j}} \delta \boldsymbol{\tau}_{j}\right)^{2}
$$

- Millepede II is based on global linear $\chi^{2}$ minimization. [1]
- Constrains can be applied/included in the algorithm.


## VERTEX DETECTOR ALIGNMENT PARAMETERS



- It can be used per sensor:
- 6 rigid body parameters (top left)
- 7 surface parameters (top right)
$\sim 212 \cdot 13=2756$ parameters
- Per ladder (bottom left) and per halfshell (bottom right) it can be used 6 rigid parameters.
$\sim(65+4) \cdot 6=414$ parameters


## Importance of detector alignment

## - Alignment is important for time dependent CP Violation analysis

Physical distribution $\otimes$ Detector resolution $=$ Measured distribution




Sensor displacements deform detector resolution distribution.



TIME DEPENDENT ANALYSIS REQUIRES:

1) Precisely determined alignment and calibration constants.
2) Validated alignment constants and uncertainties.
3) Monitoring of systematic displacement of vertex detector

## Alignment results: Rigid body parameters



## Alignment results: Surface parameters





Sensor surface deformation in data parametrized by $\mathrm{P}_{20}$ and $\mathrm{P}_{02}$


## VALIDATION OF ALIGNMENT PARAMETERS



## TRACK-TO-HIT RESIDUALS

- Standard method for alignment validation
- Means of distributions as $u$ and $v$ parameters


## PRoJection of SEnsor SURFACE

- Dividing sensor surface to $\mathrm{n} \times \mathrm{m}$ matrix
- $W$-residual as $r_{W}=\frac{r_{U}}{\tan \alpha_{U}}=\frac{r_{V}}{\tan \alpha_{V}}$
- Weighted by $\left(\tan \alpha_{U, V}\right)^{2}$ during averaging
- Averaging all measurements in cell


## Fitting SENSOR SURFACE

- From local sensor system to Legendre
- Fitting other alignment parameters
- Parameter $\gamma$ can not be fitted


## Validation of alignment parameters: Sensor 4.3.2

- All alignment parameters (without $\gamma$ ) are validated.
- Parameters of each vertex detector sensor are studied as function of time (per run).


The validation plot presented stability of alignment parameters during data taking in spring 2019. In beginning of April fire accident break is happen. The parameters are fluctuate in range $\pm 10 \mu \mathrm{~m}$. Other sensors look very similar, otherwise alignment procedure is processed.

## Monitoring systematic displacement: Overlaps

- A track passing two neighbour ladders in one layer can be used for studying systematic displacement.

- Standard residuals in overlapping area are determined.
- Difference between them are calculated.

$$
r_{1,2}^{u, v}=\frac{m_{1,2}^{u, v}-p_{1,2}^{u, v}}{\sigma_{1,2}^{u, v}}, \quad d^{u, v}=r_{2}^{u, v}-r_{1}^{u, v}
$$


Monte Carlo results

## Monitoring systematic displacement: Cosmic data

February 2019


April 2019


First checks in February 2019 showed discrepancy between Monte Carlo and data results.

Detailed studies introduced a radial expansion of barrel strip sensors about $100 \mu \mathrm{~m}$.


The source of discrepancy was in wrongly used pitch of rectangular strip sensors. After fixing observed discrepancy data results were close to Monte Carlo. However small observed differences can be solved by improvements in reconstruction software.


Mixing of B mesons

- The studies help to understand vertex detector and check reconstruction software.
- Presented studies show our way to monitor quality of data taken by the Belle II vertex detector.
- Some experiences is published:
- Parametrization and validation in arXiv:1910.06289
- Monitoring systematics displacement in arXiv:1906.08940
- Validation of alignment parameters in APhysPolB.51.1385


Time dependent CP Violation

## talk



Legendre polynomials in one dimension Orthogonality of Legendre polynomials:


 $x \in[-1,+1]: \int_{-1}^{+1} L_{i} \cdot L_{j} \approx \delta_{i j}(=0$ for $i \neq j)$
If sensor has a uniform illumination at least along one side, the contribution from different orders are independent.

## VALIDATION OF ALIGNMENT PARAMETERS: SENSOR 4.1.2




Many of $\chi^{2}$ invariant modes are distinguishable from Nominal geometry and identified very clearly. However Telescope and $\mathbf{Z}$ expansion are very difficult recognized from Nominal geometry.


[^0]:    *PXD Layer 2 is not complete, but full pixel detector will be used after replacement in 2021.

