Calibration and alignment of the Belle II tracker

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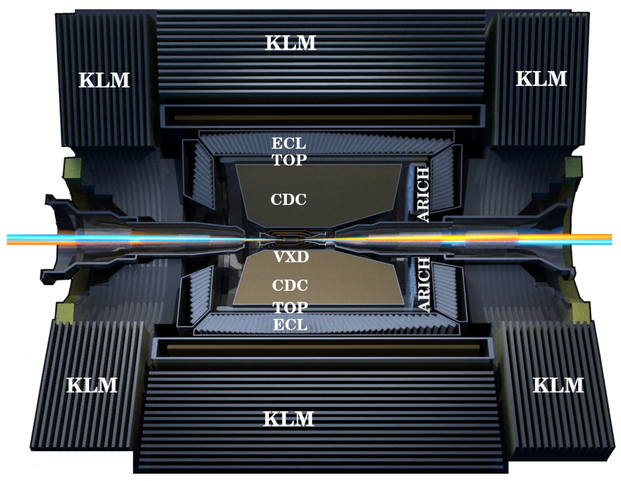
more information in presentations "Performance of Belle II tracking in central drift chamber", "Performance of the Belle II Silicon vertex Detector stand alone track finder" and "The Phase 2 run of the Belle II experiment"

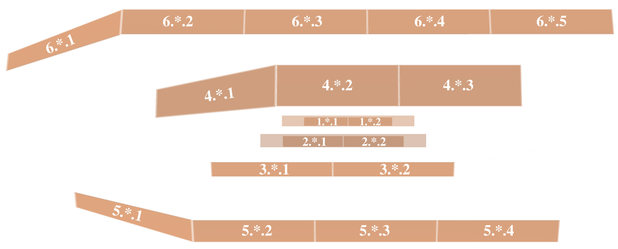
Belle II & Vertex detector

Belle II:
- KEK, Tsukuba, Japan
- e^-e^+ asymmetric collider (SuperKEKB)
- Study of CP violation in B-meson decay
- Next generation B-factory

Vertex detector (VXD):
- DEPFET pixel (PXD) sensors
- Double-sided strip (SVD) sensors
- Thickness of pixel sensors is 75 μm.
- Thickness of strip sensors is 300 - 320 μm.



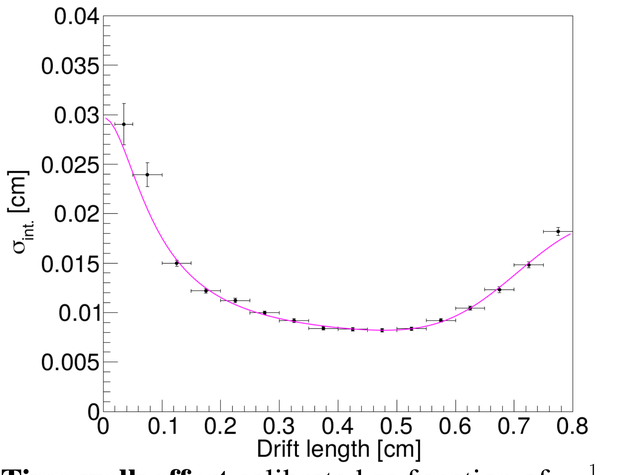
Cross-section of Belle II detector



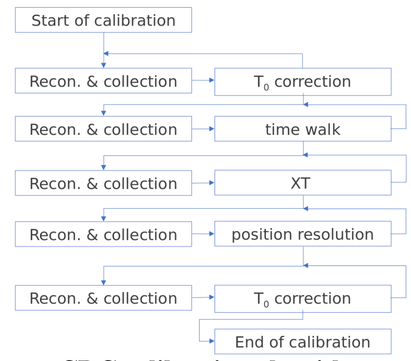
Arrangement of pixel and strip sensors in ladders
Pixel sensors are in two inner layers (center).
Strip sensors are four outer layers (top and bottom).
The first sensors (left) in three outer layers are slanted and trapezoidal.

Calibration and alignment of Central Drift Chamber

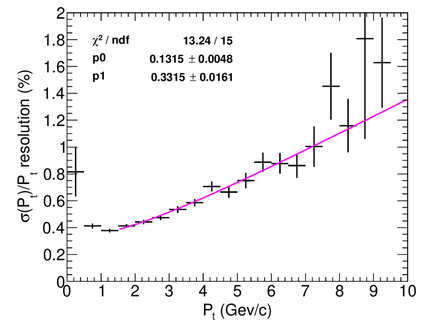
- Calibration is based on 4 stages:
1. **T_0 correction**: Minimization of drift time residual
2. **XT relation**: $XT = XT(layer, L/R, \alpha, \theta)$
3. **Position resolution**: $\sigma = \sigma(x, layer, L/R, \alpha, \theta)$
   where α, θ mean incidence and polar angle.



4. **Time walk effect** calibrated as function of $\frac{1}{\sqrt{ADC}}$
5. **Wire by wire alignment** using cosmic muons

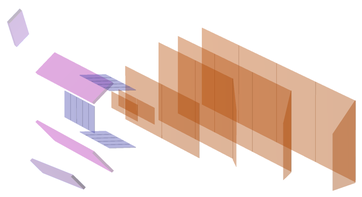
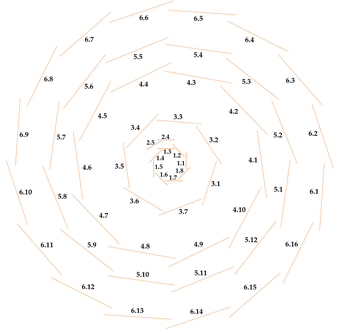
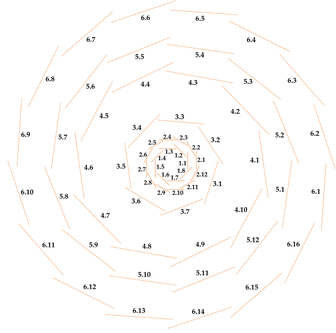
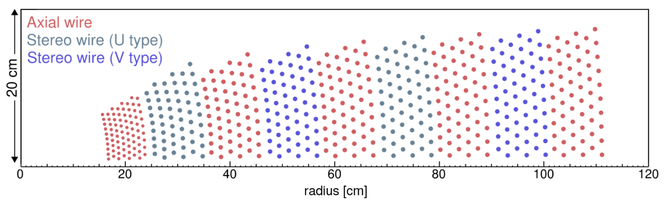


CDC calibration algorithm



P_t resolution: $p_0 \cdot P_t \oplus p_1$

Phases of the Belle II tracker

	Commissioning run	Early physics run	Later physics run
Period	March 2018 - July 2018	Spring 2019 - Summer 2020	Autumn 2020 - ∞
Layout of vertex detector			
PXD	4 sensors	20 sensors	Full: 40 sensors in 2 layers
SVD	14 sensors	Full: 172 sensors in 4 layers	
Central Drift Chamber	- Gold plated tungsten wires - Radius of wires is 15 μm - 14 336 wires in 56 layers - $He(50\%) + C_2H_6(50\%)$ - Polar angle $\in (17°, 150°)$		

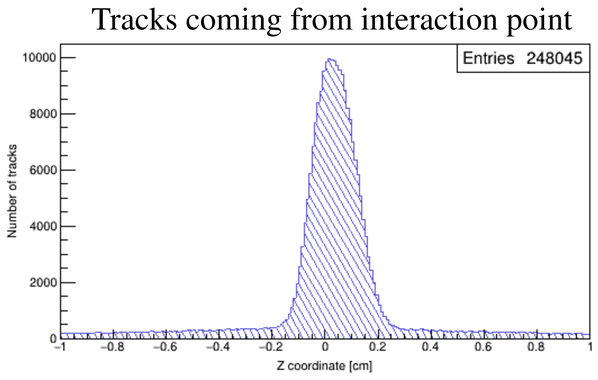
Type of collected data during Commissioning run

- Data was collected in two different data taking periods:

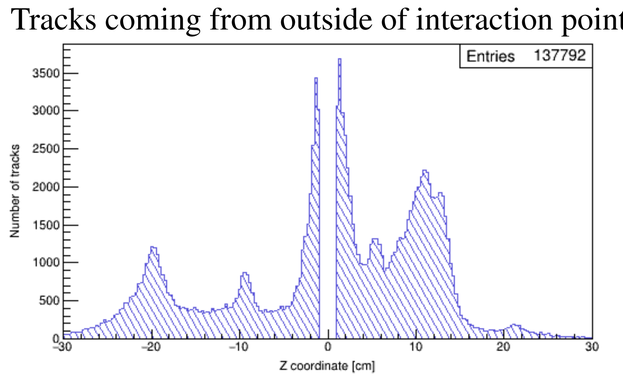
I) Cosmic ray in magnetic field: Event: 166932, Run: 1615 (16/05/2018), Experiment: 3
- Cosmic muon passed through full CDC volume and hit one VXD sensor

II) Tracks coming from collisions

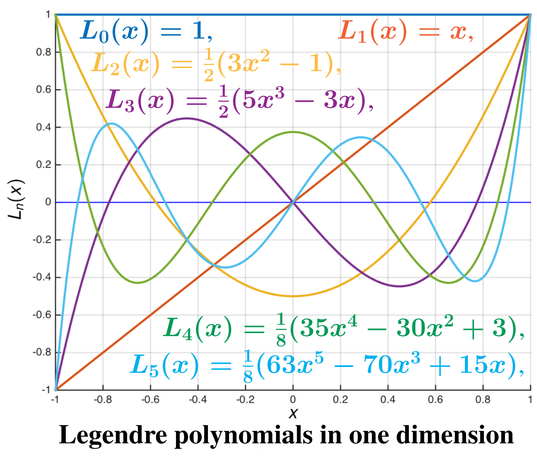
Tracks coming from interaction point



Tracks coming from outside of interaction point



Legendre polynomials & VXD alignment parametrization

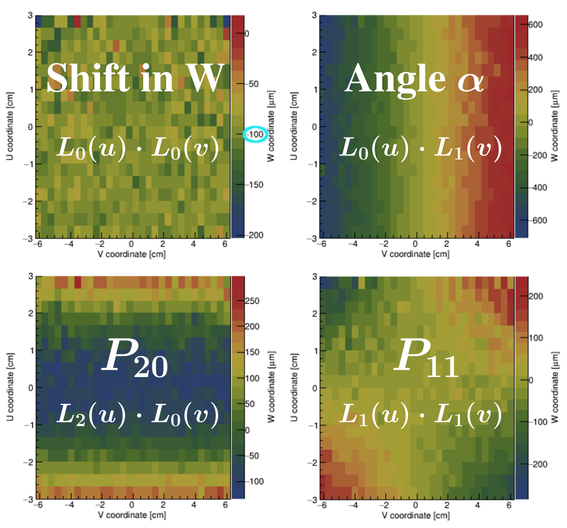


Legendre polynomials in one dimension

Orthogonality of Legendre polynomials:

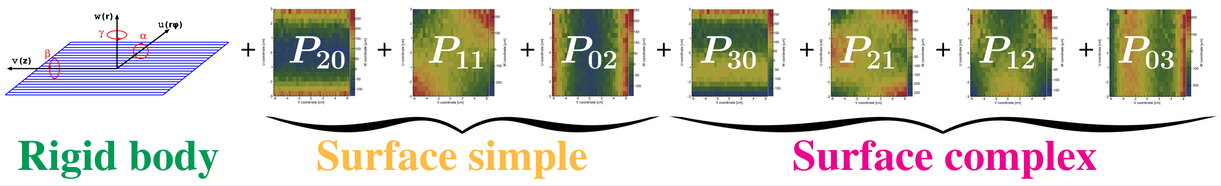
$$x \in [-1, +1] : \int_{-1}^{+1} L_i \cdot L_j \approx \delta_{ij} (= 0 \text{ for } i \neq j)$$

If sensor has a uniform illumination at least along one side, the contribution from different orders are independent.



Legendre polynomials in VXD alignment. Surface orders can be used depending on necessity.

VXD Alignment strategy

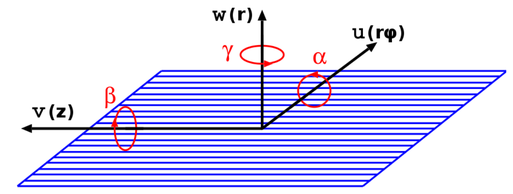


Alignment of vertex detector powered by MP II & GBL

- We are using track based alignment and parameters are estimated using Millepede II
- MP II is based on global linear χ^2 minimization and constraints can be applied/included.
- Tracks are refitted by General Broken Lines to provide Millepede II input.
- The CDC is used as reference for VXD geometry.
- VXD alignment procedure is able to determine 6 rigid body parameters:
  3 shifts (u, v and w) and 3 rotations (α, β and γ) per each VXD sensor
- If necessary, VXD alignment can be extended to more parameters for elimination of surface deformation, Lorentz angle estimation, ...

VXD Alignment strategy	Number per sensor	Total number
Rigid body	6	$6 \times 18 = 108$
Surface simple	$6 + 3$	$9 \times 18 = 162$
Surface complex	$6 + 3 + 4$	$13 \times 18 = 234$

VXD alignment parameters as function of strategy



Description of rigid body alignment parameters

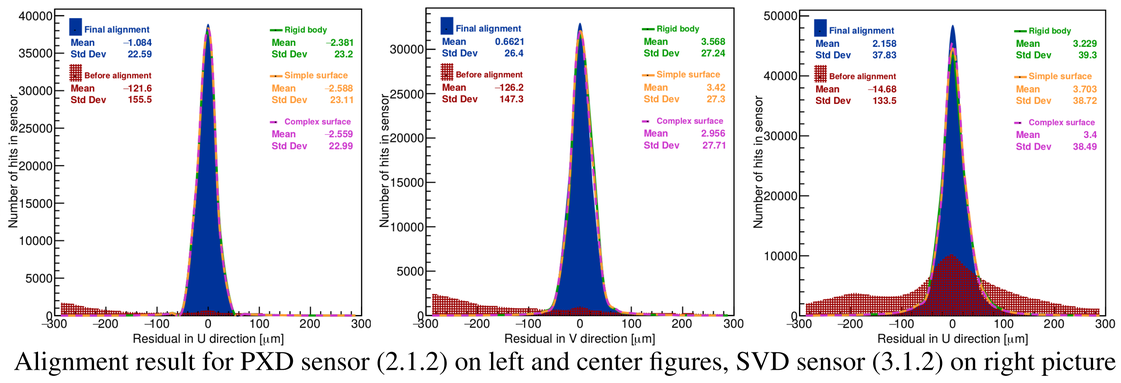
Monitoring tools of VXD alignment quality

- Monitoring is based on:

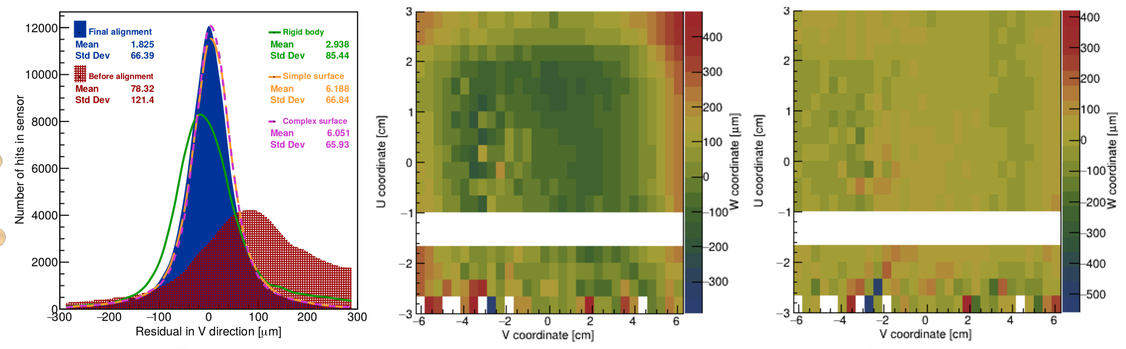
1. Track to hit residuals in directions of measurement (U, V)
2. Extrapolation to third local coordinate (W) of sensor:
   - Divide sensitive area of sensors to m × n cells
   - In each cell determine averaged extrapolated value using formula:
     $res_W = res_{[U,V]} / \tan \phi_{[U,V]}$, where $\tan \phi_{[U,V]}$ is slope of track in hit of sensor.

- Several initial misplacements, rotations or planar deformations were tested.
- Illustrative plots in "Legendre section" were done by our monitoring tool using MC.

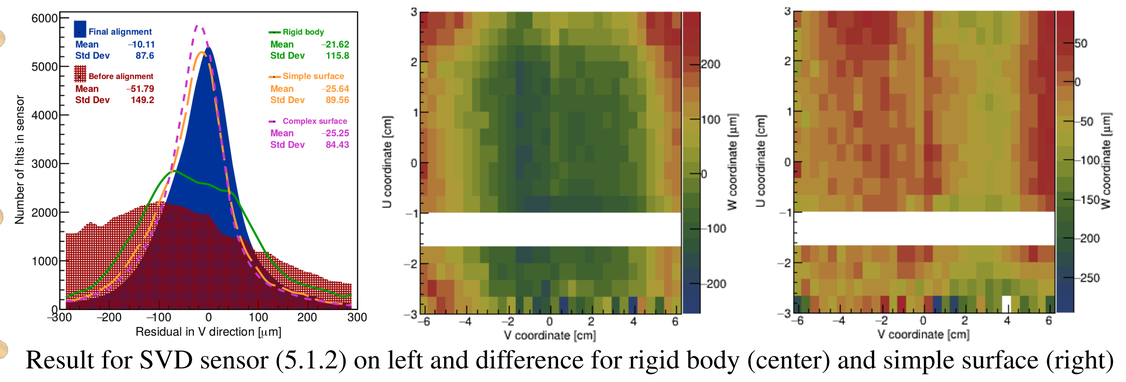
VXD alignment procedure results



Alignment result for PXD sensor (2.1.2) on left and center figures, SVD sensor (3.1.2) on right picture

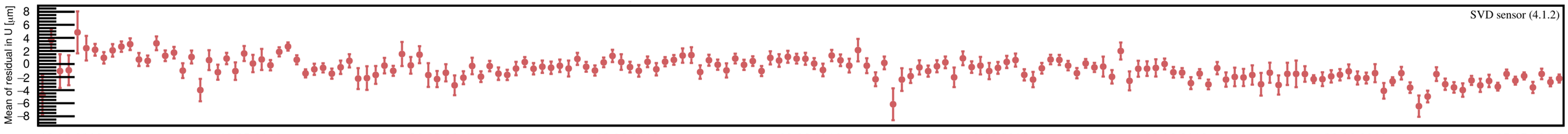


Result for SVD sensor (4.1.2) on left and difference for rigid body (center) and simple surface (right)



Result for SVD sensor (5.1.2) on left and difference for rigid body (center) and simple surface (right)

Time dependent VXD alignment validation



Connecting the Dots & Intelligent Trackers in Valencia, 1 - 4 th April 2019