Alignment and physics performance of the Belle II vertex detector

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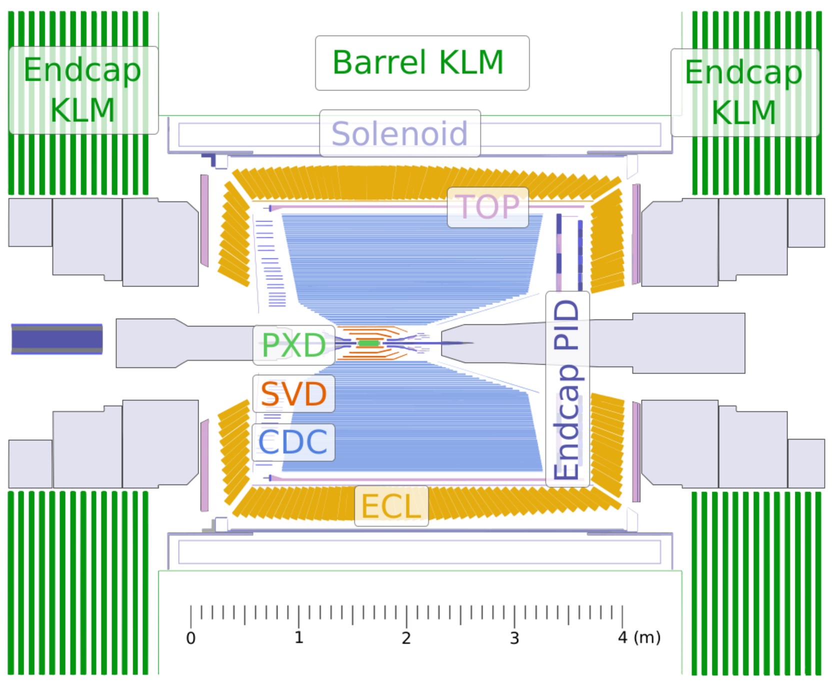
more information in presentations "Belle II Physics prospects" by Elisa Guido and "SuperKEKB / Belle II Status" by Riccardo de Sangro at Friday morning

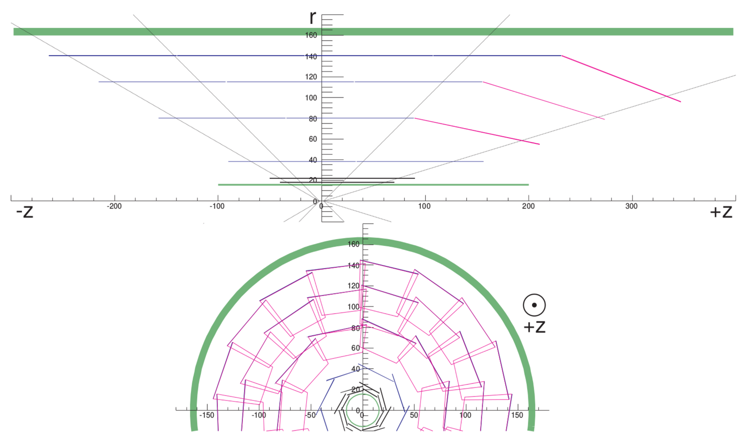
Belle II vertex detector

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
- 212 sensors in 6 layers
- The first layer is 14 mm from IP



Cross-section of Belle II detector



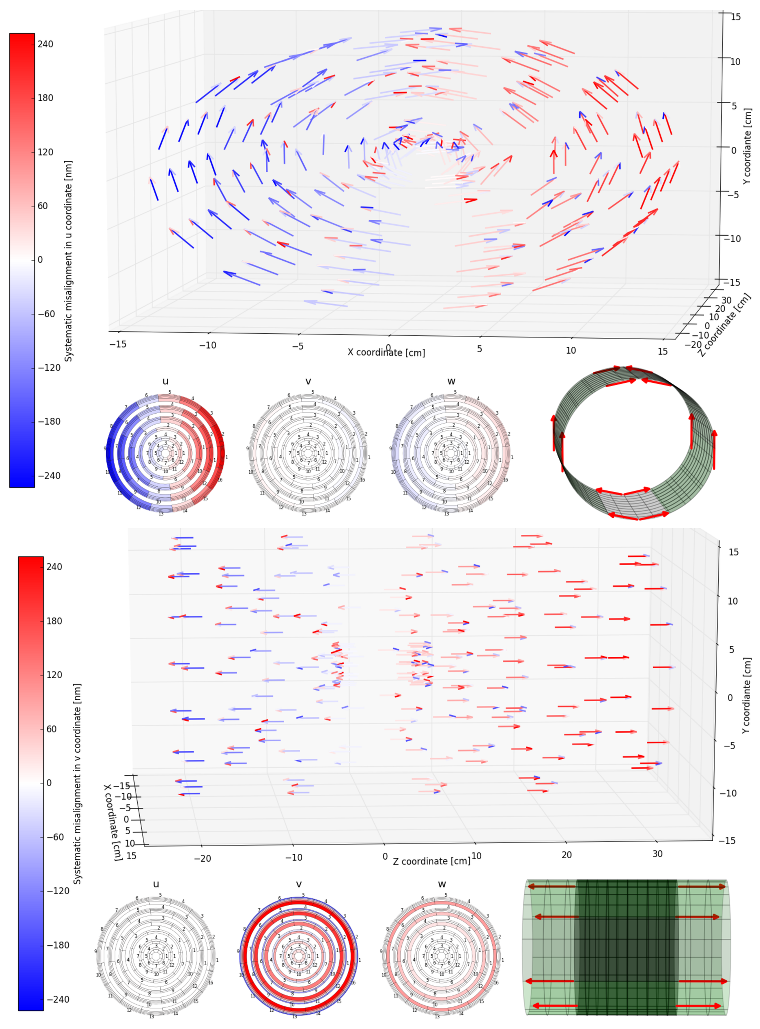
Cross-section of VXD in r-z (top) and r-ϕ (bottom) plane. VXD consists of **PXD** (black), **SVD trapezoidal wedged** (pink) and **SVD rectangular** (blue) sensors. Dimensions are in milimeters.

Misalignment

- Misalignment as initial realistic misplacement of sensors in simulation of the vertex detector

1. Random misalignment is generated using zero-mean normal distribution for each VXD sensor in rotations and shifts. The standard deviation is used as a measure of the size of the misalignment.
2. Systematic misalignment is classified as weak modes of VXD detector:

	Δr	$r\Delta\phi$	Δz
r	**Radial expansion** $\Delta r = c_{scale} \cdot r$	**Curl** $r\Delta\phi = c_{scale} \cdot r + c_0$	**Telescope** $\Delta z = c_{scale} \cdot r$
ϕ	**Elliptical expansion** $\Delta r = c_{scale} \cdot \cos(2\phi) \cdot r$	**Clamshell** $\Delta\phi = c_{scale} \cdot \cos(\phi)$	**Skew** $\Delta z = c_{scale} \cdot \cos(\phi)$
z	**Bowing** $\Delta r = c_{scale} \cdot \|z\|$	**Twist** $r\Delta\phi = c_{scale} \cdot z$	**Z expansion** $\Delta z = c_{scale} \cdot z$

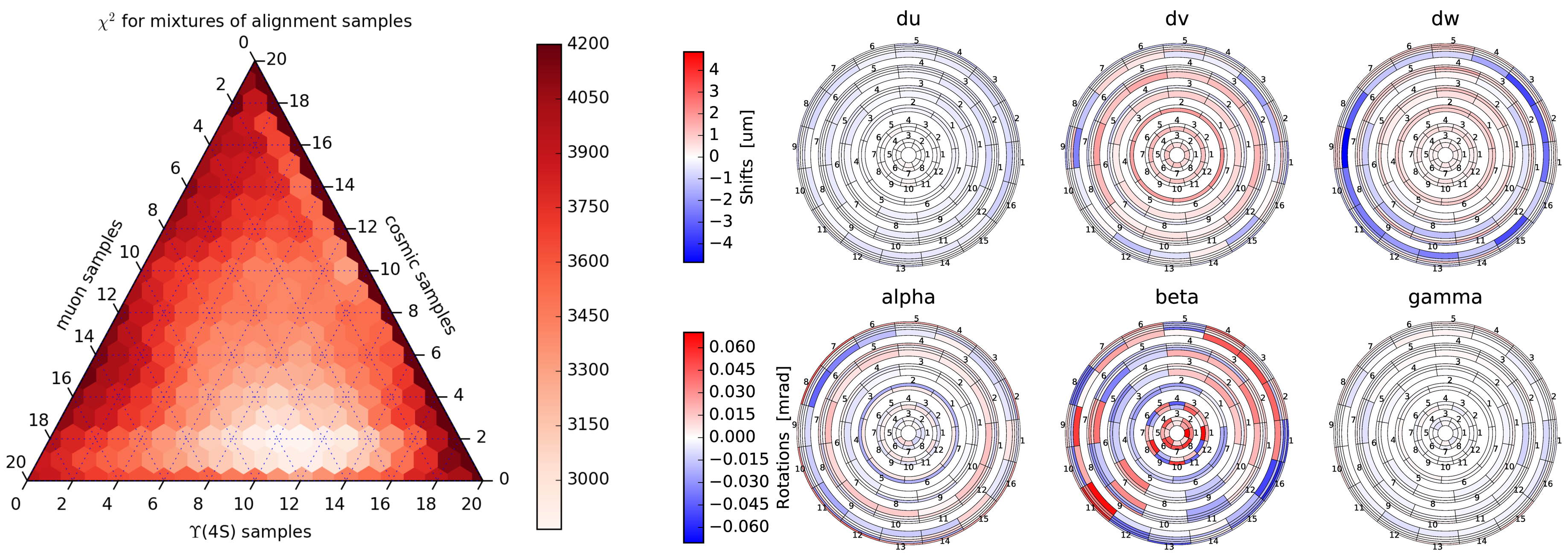


Weak modes of the VXD detector: Systematic deformations (left) are coherent movements of individual sensors which can be parametrized by displacements in global coordinates (columns) depending on the location of the sensor (rows). Each cell of the table shows the name of the weak mode (top), its parametrization (middle) and schematic plot (bottom). Clamshell (right top) and z expansion (right bottom) are shown more detailed.

Alignment studies

- What are the properties of alignment? What is the result of an alignment study?
- Datasets consist of tracks from $\Upsilon(4S)$ resonance decay, cosmic muons, and muons pairs.
- A simple constraint: *Sum of alignment corrections per each rigid body parameter is zero.*

Finding the optimal sample
- Datasets are mixed in different ratios in an MC study to reach the best result. The best mixture is composed of single charged tracks from $\Upsilon(4S)$ resonance, cosmic muons recorded without magnetic field and vertex constrained muon pairs in ratios 11:2:7.
- χ^2 invariant modes are successfully eliminated.
- The presented result uses in total $\sim$ 1 M tracks.



The ternary plot (left) shows χ^2 for all mixtures of the three datasets. The best choice is the mixture of 11 $\Upsilon(4S)$, 2 cosmic and 7 muon samples. All alignment parameters (right) are shown for the best mixture. Largest residual misalignments are visible in the β parameter and wedge sensors.

Random misalignment and alignment
- What is the radius of convergence alignment?
- Misaligned VXD sensors by applying random shifts and rotations
- Residual misalignment as comparison between initial and aligned geometry

Initial	Shifts [μm]	0.00	10.2	157.7	0.0	0.0	215.7
	Rotations [mrad]	0.000	0.000	0.000	0.247	3.040	3.467
Residual	Shifts [μm]	4.62	4.11	4.06	4.15	4.09	4.35
	Rotations [mrad]	0.086	0.106	0.106	0.104	0.104	0.104

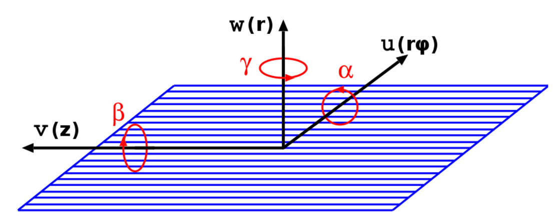
Convergence of alignment using large scaled misalignment: Shown values are maximal distances (radius) of shifts, resp. rotations from 0 in positive or negative direction.

Alignment of vertex detector

- Precise determination of positions and orientations of sensors in space ⇒ precise measurement of vertex position
- Position of sensors estimated from tracks
- Hits are detected in <u>local frame</u> of sensors, tracks are calculated in <u>global frame</u> ⇒ transformation ⇒ alignment parameters (3 rotation and 3 position parameters per sensor)
- Tracks are fitted by minimizing:

$$\chi^2(\boldsymbol{\tau}, \boldsymbol{a}) = \sum_{j}^{tracks} \sum_{i}^{hits} \left(\frac{r_{ij}(\boldsymbol{\tau}_j, \boldsymbol{a})}{\sigma_{ij}} \right)^2 \qquad r_{ij}(\boldsymbol{\tau}_j, \boldsymbol{a}) = u_{ij}^m - u_{ij}^p(\boldsymbol{\tau}_j, \boldsymbol{a})$$

where u_{ij}^m is a recorded measurement of hit i on the track j, σ_{ij} is the uncertainty of measurement, u_{ij}^p is a predicted measurement from track model dependent on track parameters $\boldsymbol{\tau}_j$ and alignment parameters **a**.
- 212 sensors $\times$ 6 parameters = 1272 alignment parameters + deformation of sensors ⇒ We need a rich set of tracks of several different types.
- χ^2 invariant modes are combination of alignment parameters that cannot be estimated from the given set of tracks.
- For better result we define constraints, e.g. physical symmetries, same vertex position of tracks, sum of rotations and shift should be zero.
- The solution to the linearised alignment problem is obtained by the Millepede II [1] integrated in the Belle II software and calibration framework basf2. The software:
  - re-fits the track with General Broken Lines,
  - produces binary data for Millepede II, and
  - calculates the corrections to alignment parameters which are stored in a database

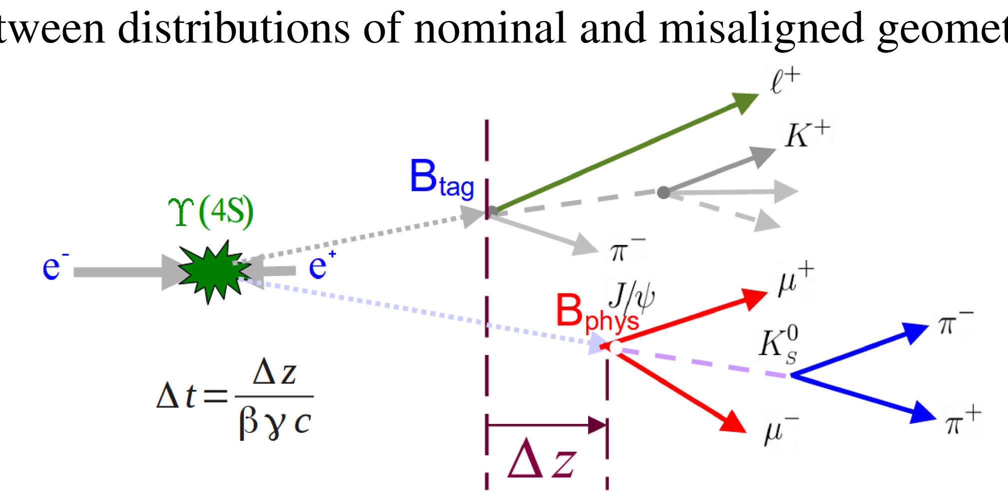


Alignment parameters of a planar sensor

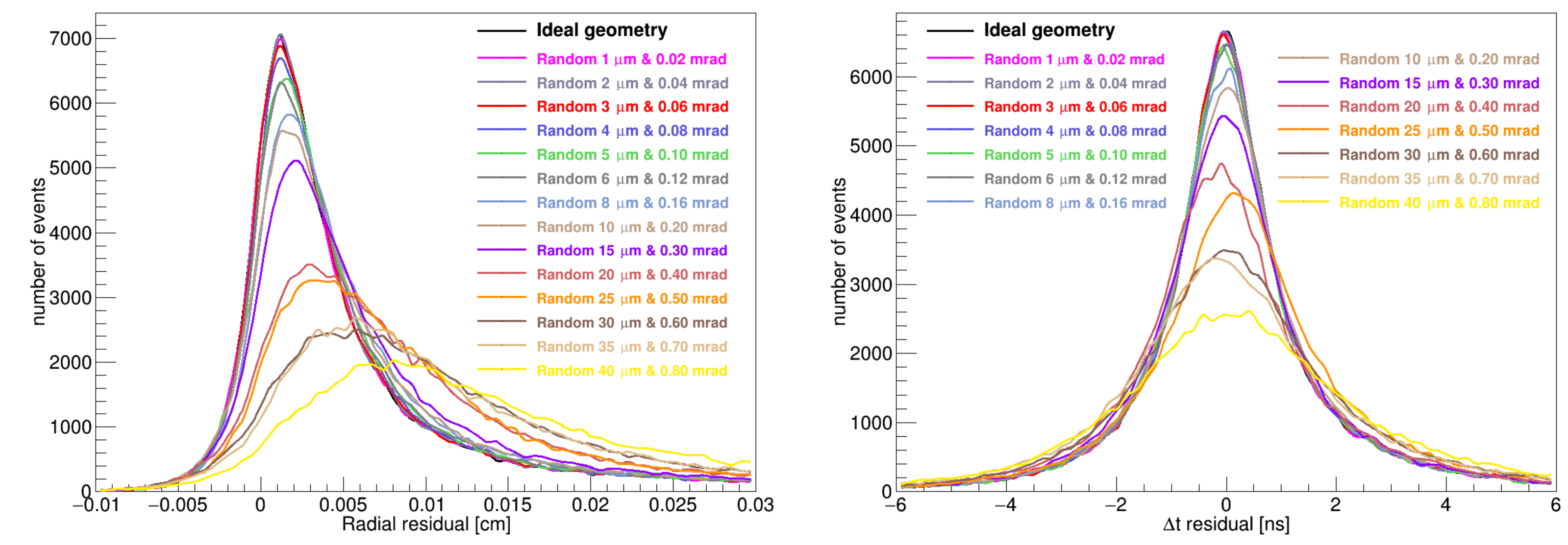
Effects of misalignment on physics analysis

- What is the impact of misalignment on physical analysis?

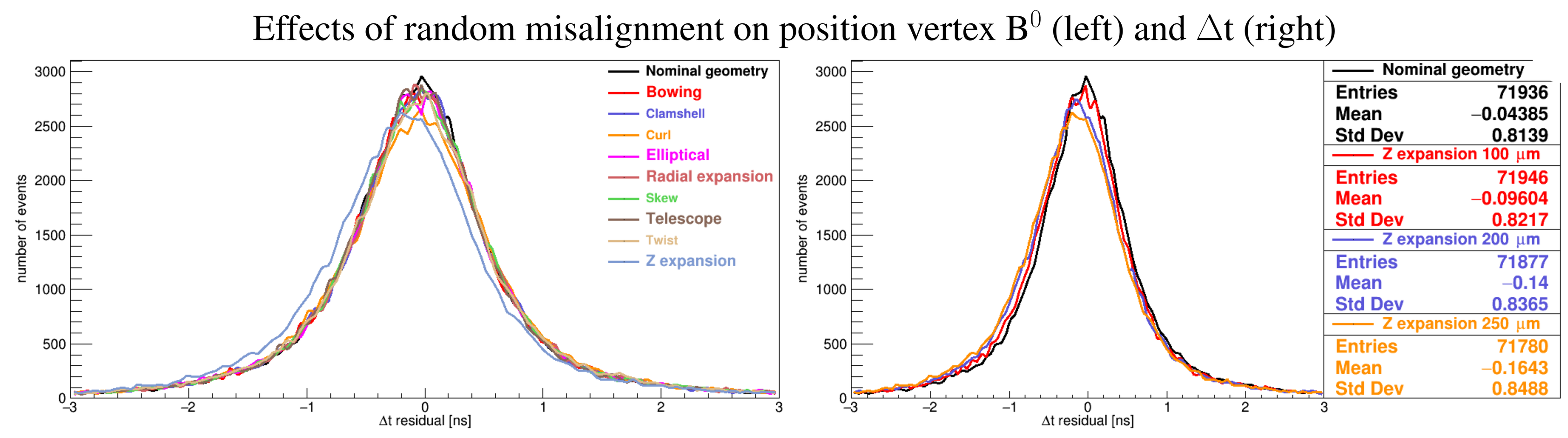
Physical analysis
- Golden process: $B^0 \rightarrow J/\Psi + K_S^0$
- Comparison between Monte Carlo and reconstructed information
- Comparison between distributions of nominal and misaligned geometry



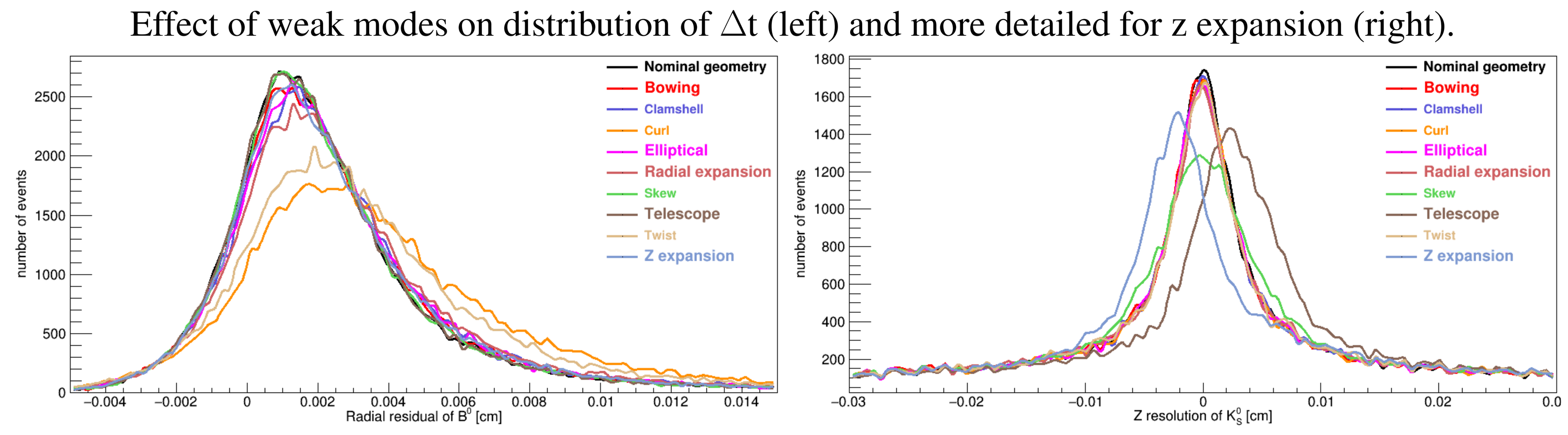
Schematic plot for event with decay channel $B^0 \rightarrow J/\Psi + K_S^0$



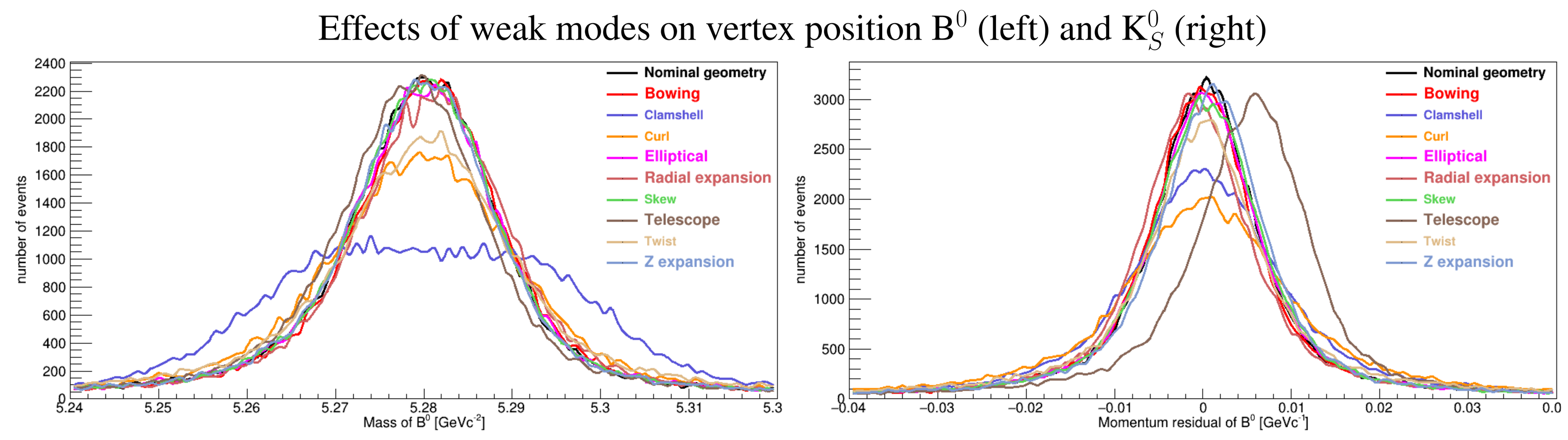
Effects of random misalignment on position vertex B^0 (left) and Δt (right)



Effect of weak modes on distribution of Δt (left) and more detailed for z expansion (right).



Effects of weak modes on vertex position B^0 (left) and K_S^0 (right)



Effects of weak modes on mass (left) and momentum (right) of B^0.

Status and Plans

- Alignment study using weak modes is progressing.
- Validation and monitoring of alignment procedure will be based on tracking information, process with high counting rate and cosmic rays in magnetic field.

Reference

[1] *V. Blobel, C. Kleinwort* A new method for the high-precision alignment of track detectors, arXiv:hep-ex/0208021

Flavor Physics & CP Violation in Prague, 5th June 2017