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 VXD in \( r-z \) (top) and \( r-\phi \) (bottom) plane. VXD consists of PXD (black), SVD trapezoidal wedge (pink) and SVD rectangular (blue) sensors.

Dimensions are in millimeters.

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

\[
\chi^2(\tau, \alpha) = \sum \left( \frac{r_i(\tau, \alpha) - u^0_i}{\sigma_i} \right)^2
\]

where \( u^0_i \) is a recorded measurement of hit \( i \) on the track \( j \), \( \sigma_i \) is the uncertainty of measurement, \( u^0_i \) is a predicted measurement from track model dependent on track parameters \( \tau \) and alignment parameters \( \alpha \).
- 212 sensors \( \times \) 6 parameters = 1272 alignment parameters + deformation of sensors \( \Rightarrow \) We need a rich set of tracks of different types.
- \( \chi^2 \) 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.

Effects of alignment on physical analysis
- What is the impact of alignment on physical analyses?

Physical analysis
- Golden process: \( B^+ \rightarrow J/\psi + K^0_S \)
- Comparison between Monte Carlo and reconstructed information
- Comparison between distributions of nominal and misaligned geometry

Alignment studies
- What are the properties of alignment? What is the result of an alignment study?
- Datasets consist of tracks from lower mass 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.
- \( \chi^2 \) invariant modes are successfully eliminated.
- The presented result uses in total \( \sim 1 \) M tracks.

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

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

Effects of weak modes on distribution of \( \Delta z \) (left) and more detailed for \( z \) expansion (right).

Effects of misalignment on position vertex \( B^+ \) (left) and \( \Delta z \) (right).

Effects of weak modes on vertex position \( B^+ \) (left) and \( K^0_S \) (right).

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