Tracking in drift chamber of Belle II

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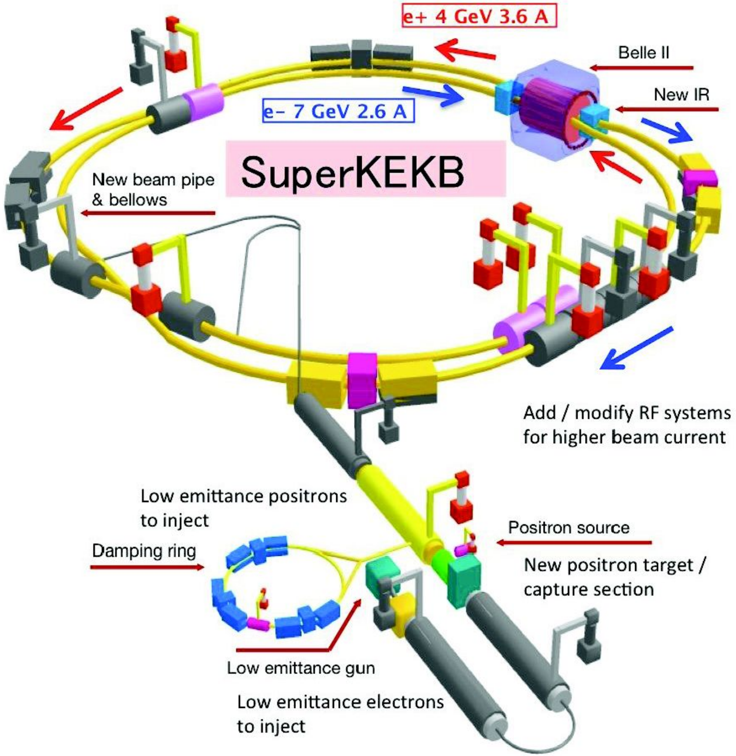
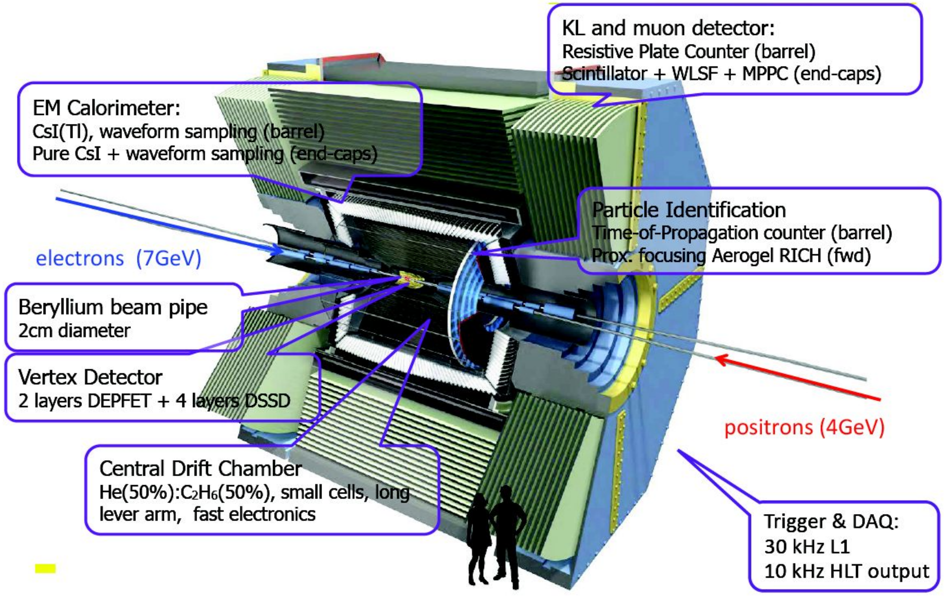
Belle II tracking group

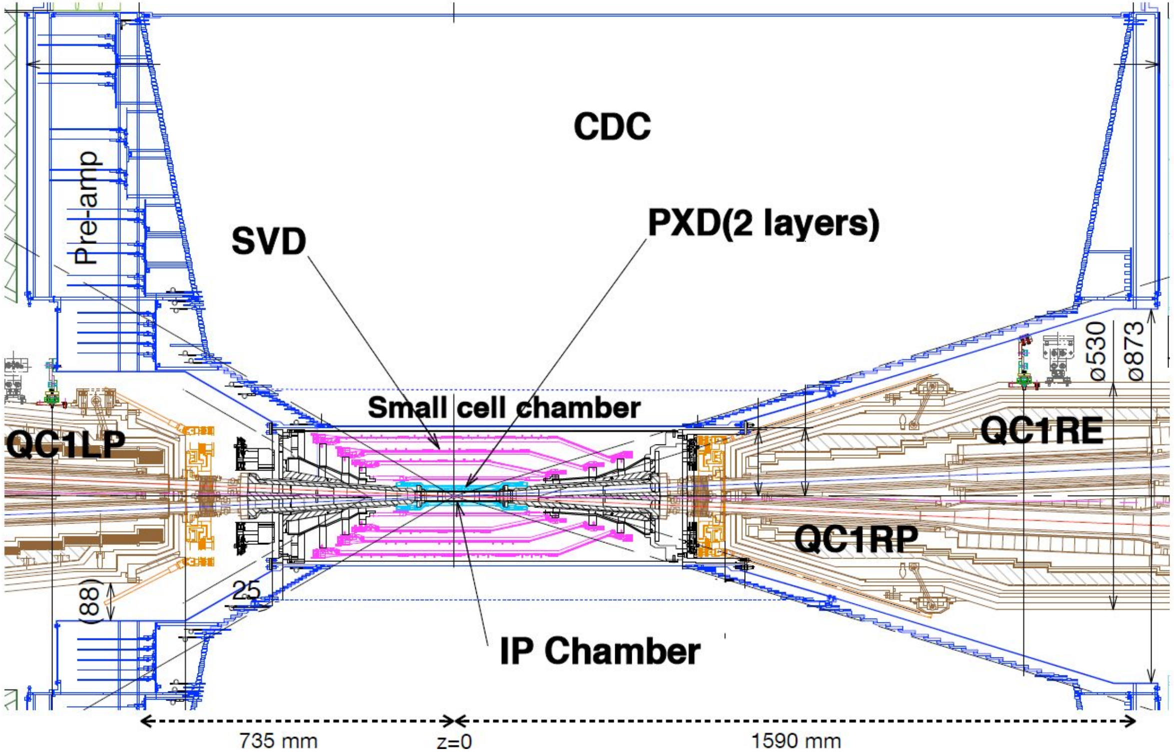
Belle II and SuperKEKB





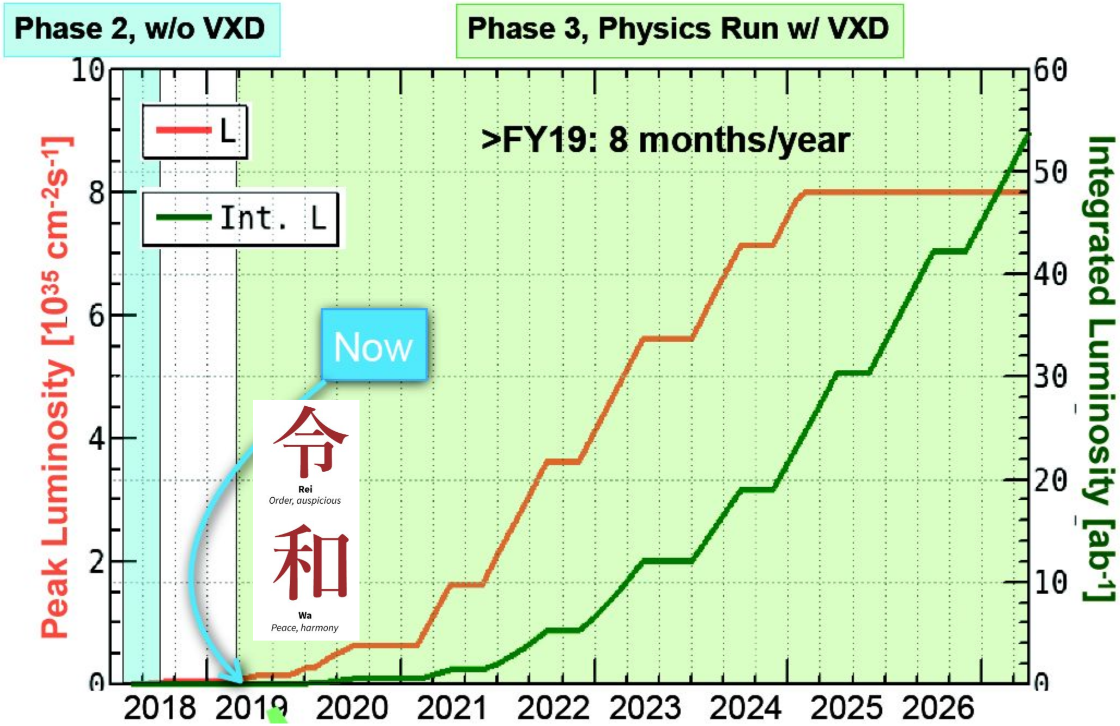
Asymmetric e+ - e- B-factory to study CP violation and rare decays.

Tracking system of Belle II



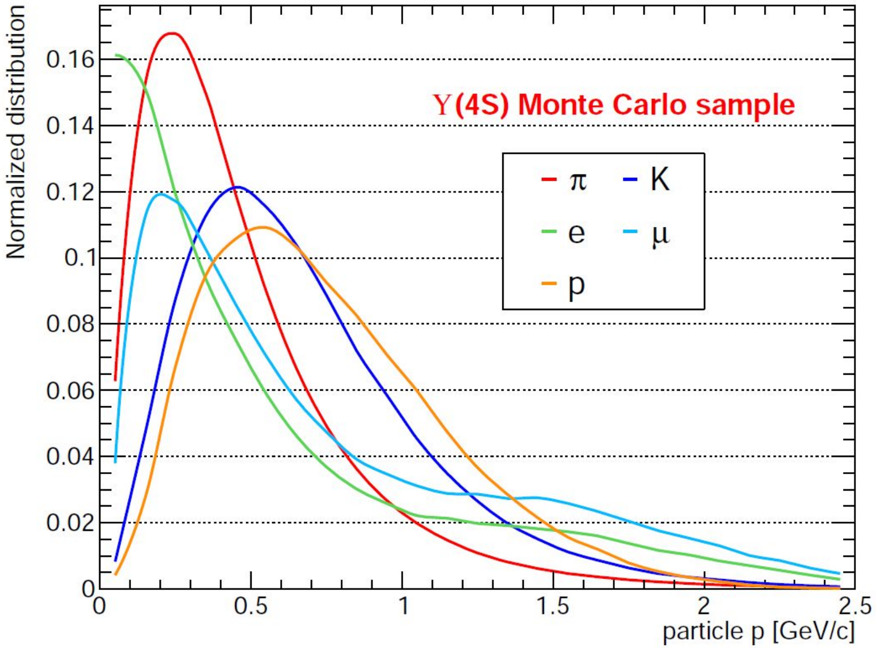
- 1.5T solenoid and final focusing magnets inside detector volume (moderate non-uniformity of the B-field)
- Asymmetric vs IP due to different beam energies
- Vertex detector with SVD and PXD (talk of Guilia Casarosa)
- Central drift chamber with 56 layers arranged in superlayers of axial and stereo wires

Belle II and SuperKEKB status



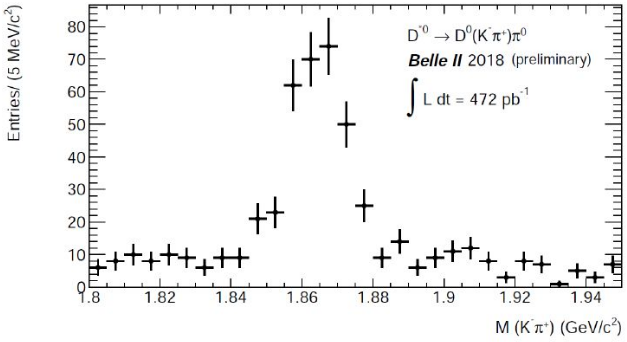
- 2018 -- “phase 2” run, with one sector of VXD installed
- 2019 -- “phase 3” run, with full coverage of VXD. Getting to nominal luminosity by 2024
- First collisions in phase 3: last weekend

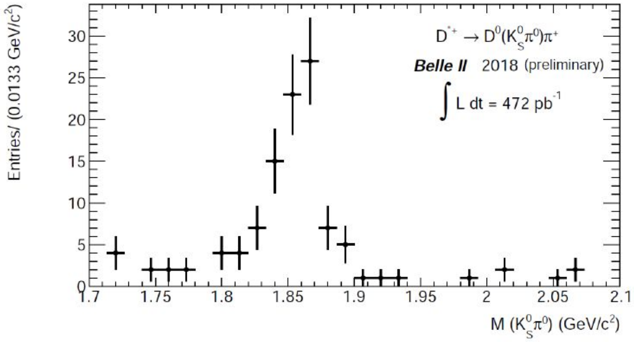
Event properties and background



- Average track multiplicity for Y(4S) events is about 11 tracks
- B/D meson tagging requires both high efficiency and purity of the tracks
- Many tracks are at low momentum
- Sizable machine background

Decay chains reconstruction in Belle II

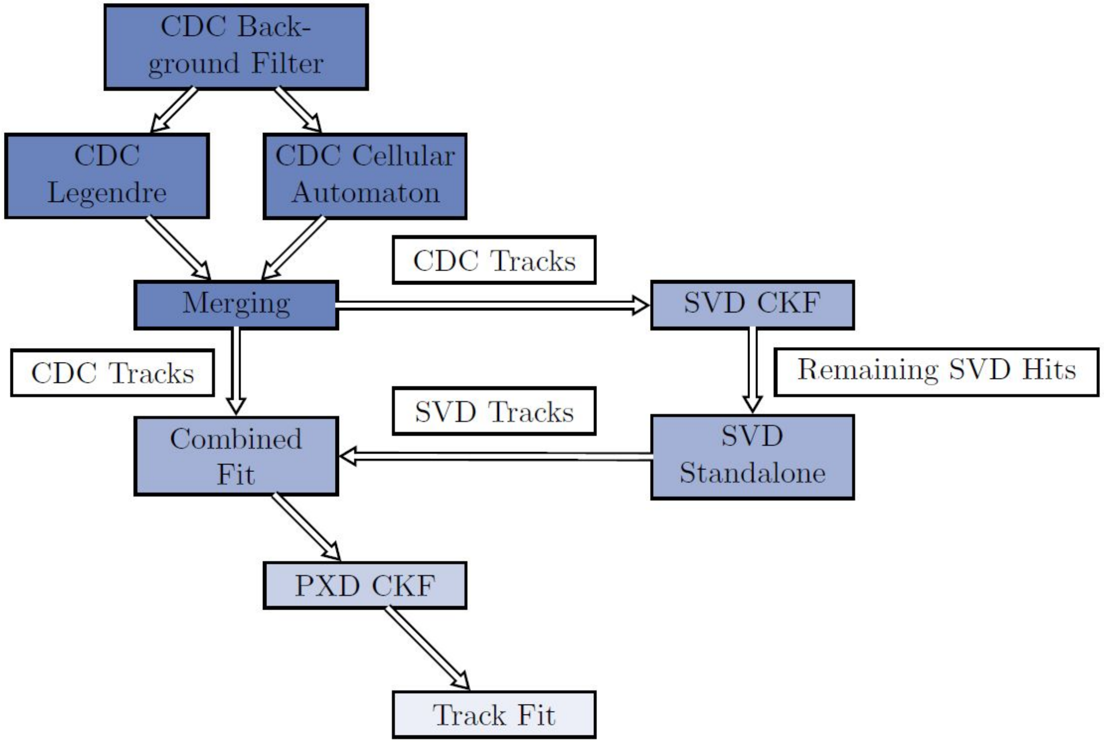




- D^* mesons are reconstructed from $D^{*0} \to D^0\gamma, D^0\pi^0$ and $D^{*+} \to D^+\pi^0, D^0\pi^+$ while D are from $D^0 \to K^0_S\pi^0$, $\pi^+\pi^-, K^-\pi^+, K^+K^-, K^-\pi^+\pi^0, K^0_S\pi^+\pi^-, K^0_S\pi^+\pi^-\pi^0, K^-\pi^+\pi^+\pi^-$, $D^+ \to K^0_S\pi^+, K^0_S K^+, K^0_S\pi^+\pi^0, K^-\pi^+\pi^+, K^+K^-\pi^+, K^-\pi^+\pi^+\pi^0$, $K^0_S\pi^+\pi^+\pi^-$
- Many of the channels are "rediscovered" at Belle II.
- With increased statistics, different channels provide important systematic check.

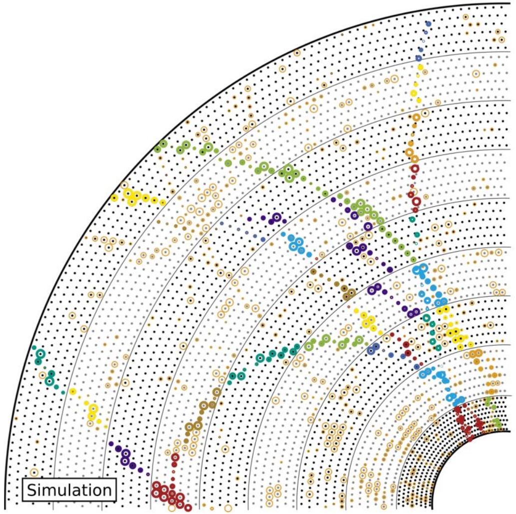
→ High efficiency and purity are essential for track reconstruction at Belle

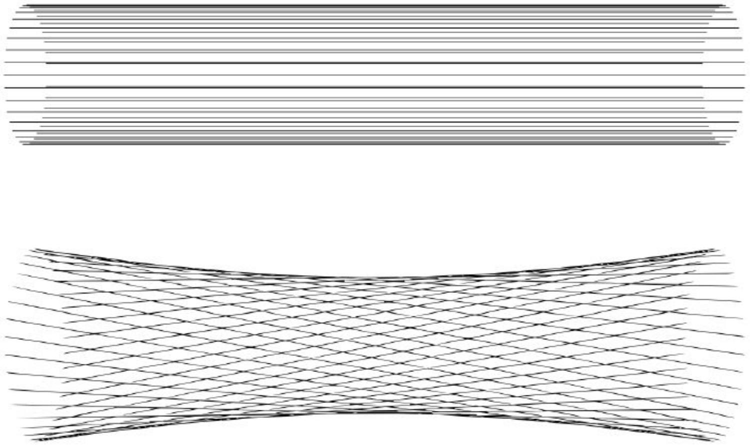
Scheme of Belle II tracking



- Modulare code structure, with different possibilities for reconstruction sequence
- At the moment, use CDC track finding as the main, supplemented by SVD tracking. PXD is attached to reconstructed tracks

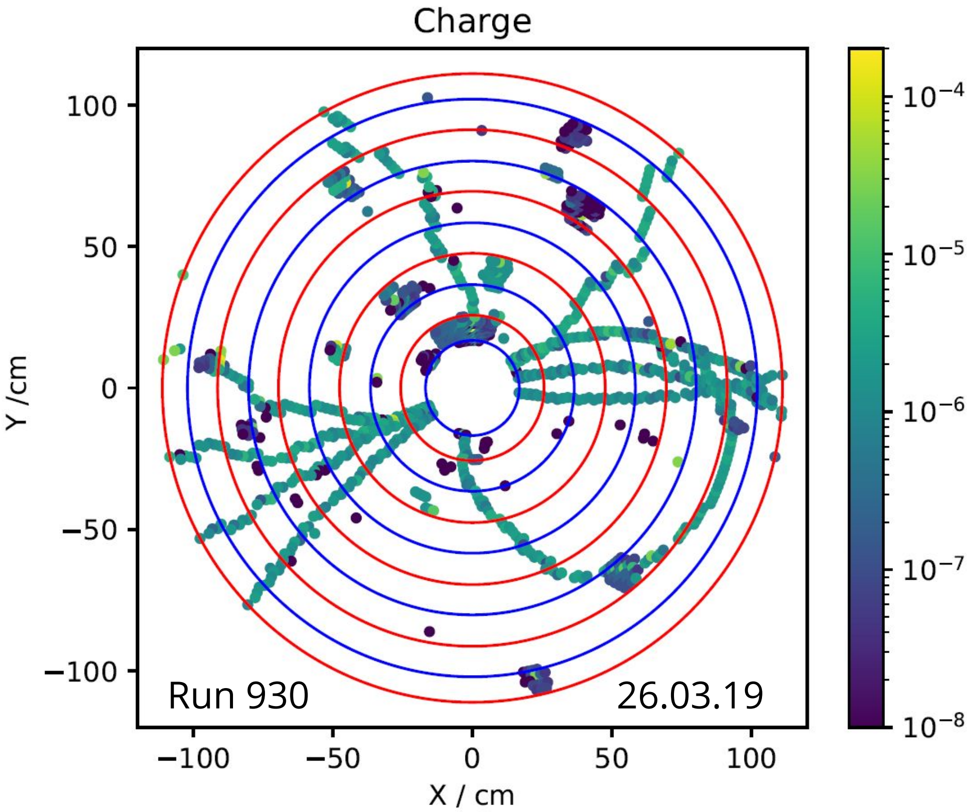
CDC tracking





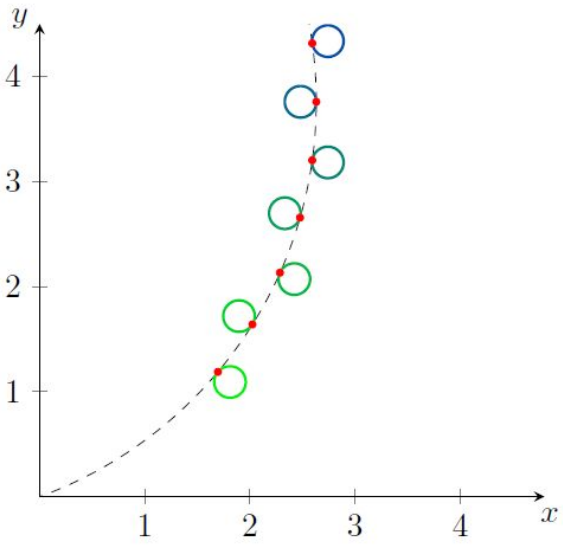
CDC consists of 56 layers, arranged in superlayers of axial and stereo wire orientation. Global track finding stats in x-y, followed by s-z reconstruction. Local track finding starts with building segments in superlayers, and then connecting them

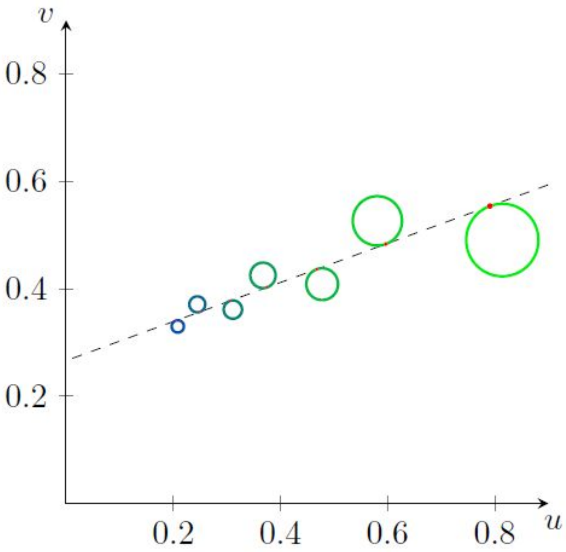
Background filtering



- Significant background from beam-related sources
- Impact of the background amplified by electronic cross talk
- MVA filter trained on MC → simple filter based on deposited charge information

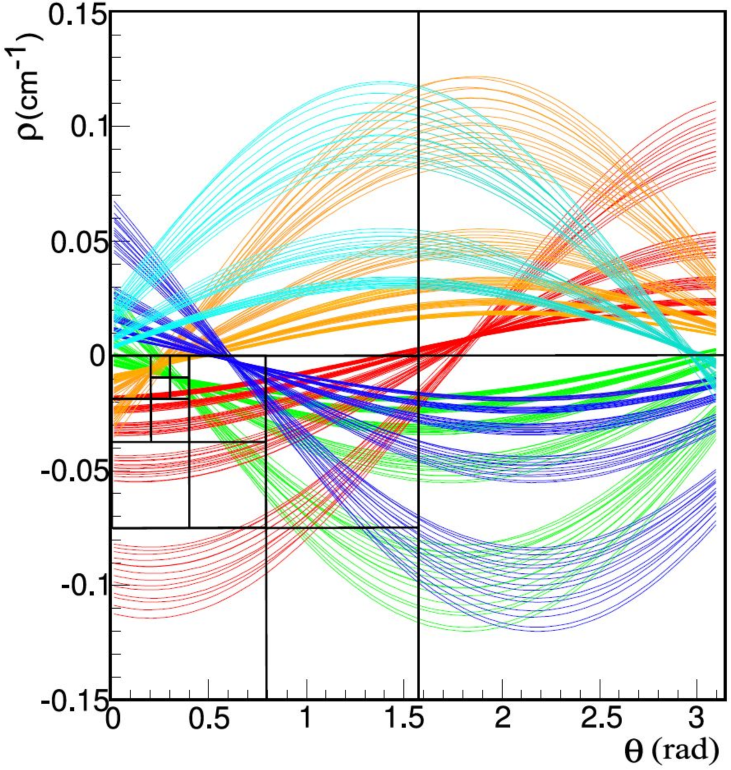
Conformal - Legendre transformation





Conformal map to transform circular in x-y trajectories to straight lines. Drift circles transform to circles. Track finding reduces to finding common tangent to the set of circles.

Binary search in rho - theta plane

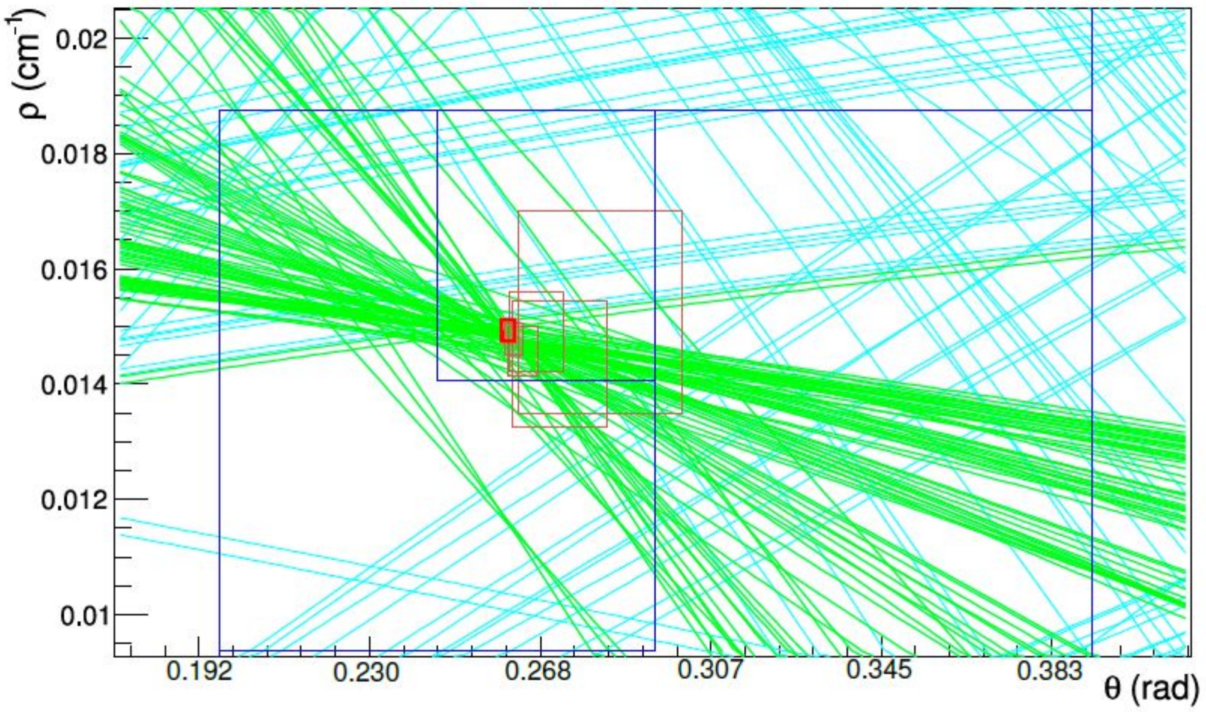


- The equation of tangent to a drift circle in conformal space is

$$\rho = x_0 \cos\theta + y_0 \sin\theta \pm R_{\mathrm{dr}}$$

- Determine a point of maximal density in the parameter space
- Can use 2D binary search algorithm, with dedicated “quadtree” structure for efficient update of the results

Sliding windows



- Improve the algorithm by using bins with overlap
- Helps to avoid splitting of the maximal density among bins.
- Bins tend to “slide” towards region of maximal density

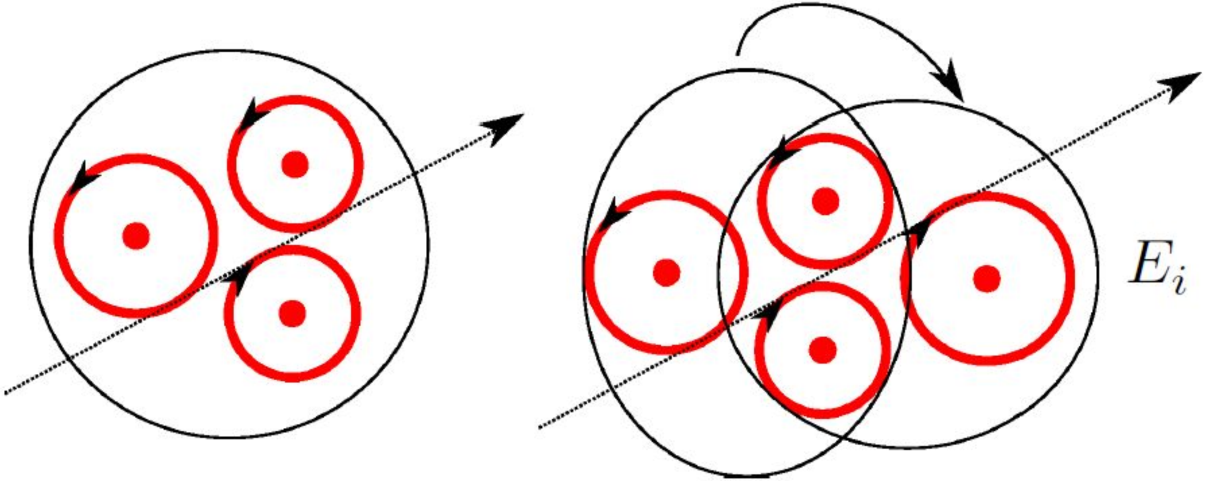
Post processing and S-Z search

- Multiple track candidates are found iteratively, removing found tracks. High momentum tracks are searched for first, followed by curlers and tracks leaving CDC acceptance
- Found track candidates fitted in x-y space using fast Riemann method. Closeby tracks are merged to reduce clone rate.
- Z information is added using stereo wire hits. Track search is reduced to straight line fit with tracks defined as

$$z_0 = z_{\mathrm{rec}} - \tan\lambda \cdot s_{\mathrm{rec}}$$

- Same quadtree algorithm is re-used for that.

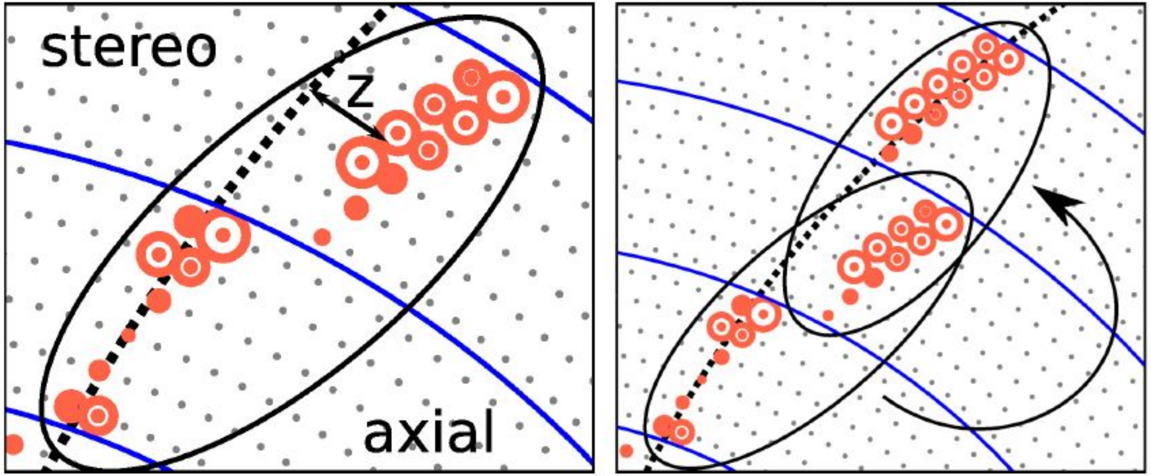
Local track finding: segment building



$$E_i = \sum w_{ij} + \sum \Theta_j$$

Cellular automaton with vertices associated to triplets of hits with and a linear track-element trajectory. Edges are from neighboring triplets, sharing two hits. Weights are based on a quality of the common fit

Local track finding: track-candidate building

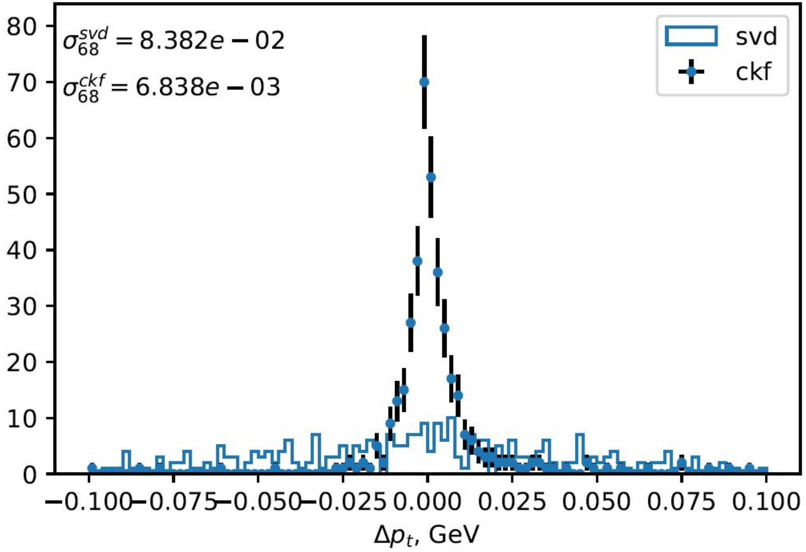


Cellular automaton with vertices from a pair of segments in axial+stereo layers. Segments that share common segment form edges. Weights based on Riemann fit in x-y and linear fit in s-z space.

Track-candidate merge and fit

- Both global and local track finding use full CDC hit set.
- For the combination, global TF is used as the baseline.
- Track segments are combined based on MVA estimators trained using simulation, this is important for curling tracks in particular.
- Additional MVA filters are applied on the found set of tracks and hits belonging to tracks
- The found track-candidates are fitted using GENFIT2 DAF algorithm, for different mass hypotheses, including material effects and non-uniformity of the magnetic field.

CKF from SVD

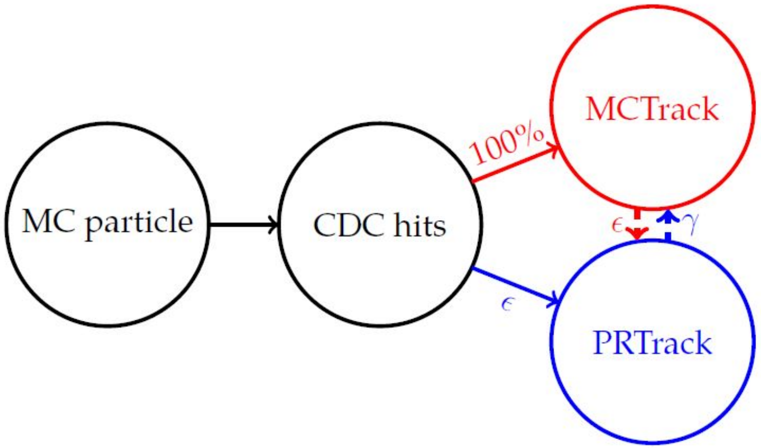


Similar performance vs standard tracking chain. Other seeding mechanisms: self-seeding, ECL cluster seeding (under development)

- For small/large angles tracks may not be reconstructed in CDC (too few hits)
- SVD tracking is more robust vs background
- SVD tracking is accurate for impact parameter resolution, but momentum resolution can be improved with CDC

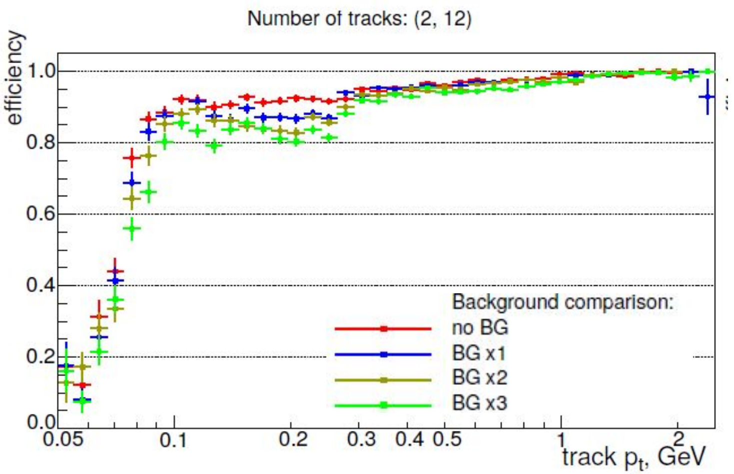
→ Combinatorial Kalman Filter seeded by SVD tracks

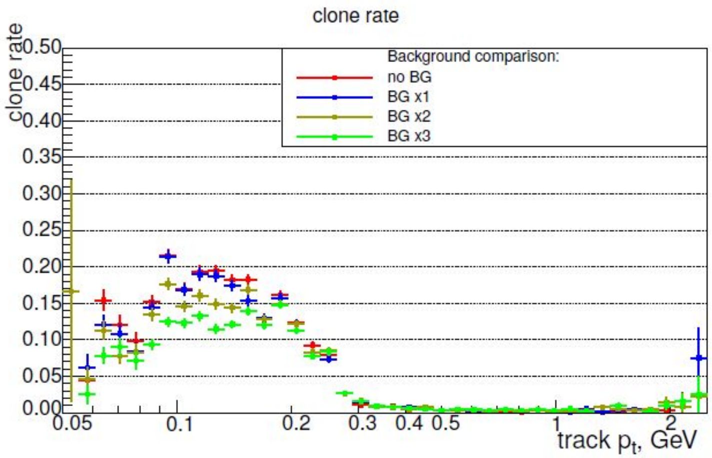
Measuring performance



- Measure performance of pattern recognition (PR) tracking using Monte Carlo tracks
- PR tracks are matched to MC based on maximal common hits
- Hit efficiency is a fraction of MC-hits found in PR track
- Hit purity is fraction of correct MC-hits in PR track
- MC Track is defined as found in PR if purity exceeds 66%
- If there are two PR tracks with purity >66% for a single MC track, the track with lower purity is defined as “clone”

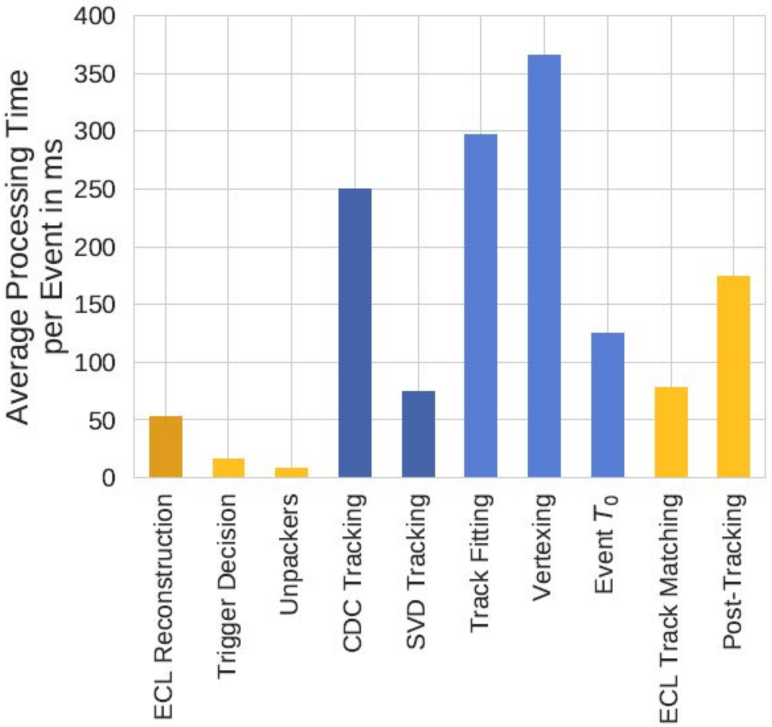
Efficiency, clone rate vs background level





Significant dependence of the track finding efficiency on the background. Clone rate at 15% level for curling low Pt tracks. Results depend strongly on BG simulation. (KIT PhD thesis, V. Trusov)

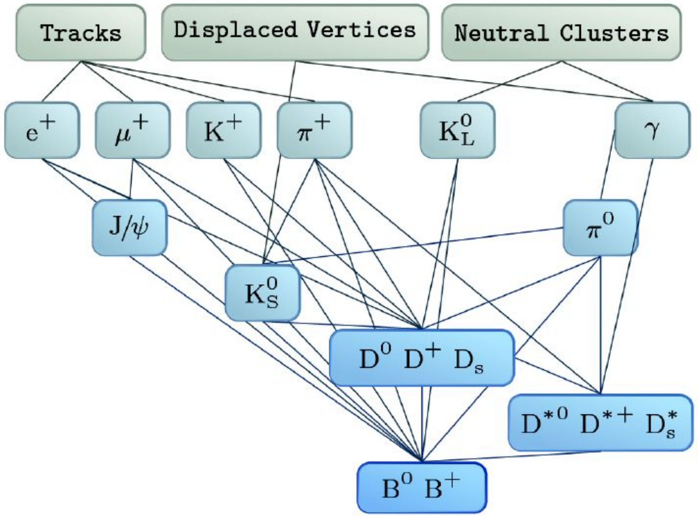
Performance on HLT

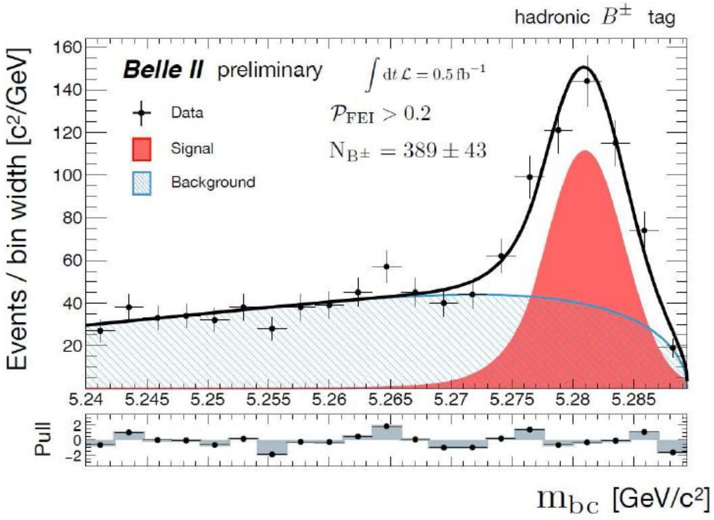


- Track reconstruction takes significant time on HLT
- For Υ(4S) events, CDC tracking, fitting and vertexing take most of the time
- At the moment, 1 sec per event in tracking is OK, can be improved with more performant fitting algorithms.

B-meson reconstruction in phase 2

Tracking in phase 2 data overall behaves as expected





- Hierarchical approach using several stages to construct full decay chains of B^0, B^+ mesons.
- Heavy use of ML methods (BDT) leads to improvement vs previous methods.

FEI, T. Keck, et al. Comput Softw Big Sci (2019) 3:

Summary and outlook

- Modular track finding approach, combining several algorithms for track finding in CDC
- Performing well for early data from phase II and phase III operation of SuperKEKB
- Further improvements and adjustments are possible, depending on machine background and performance requirements.