SVD Timing in Tracking at Belle II

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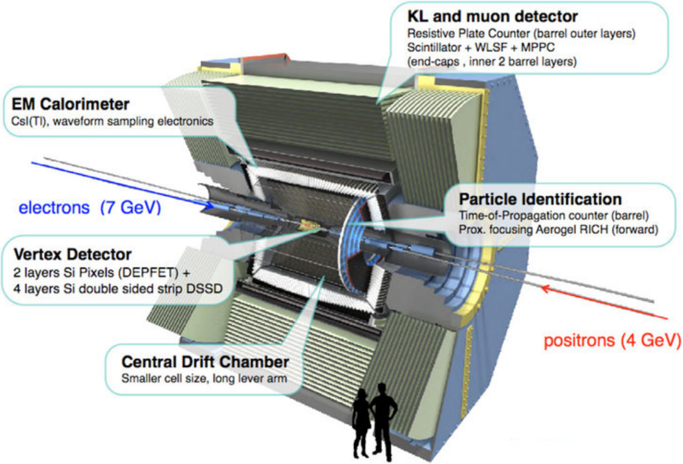
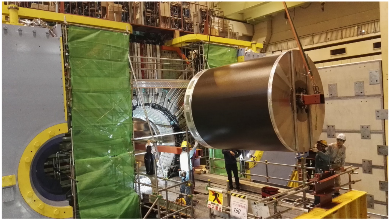
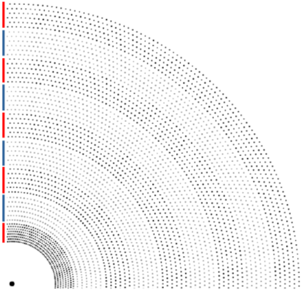
Belle II

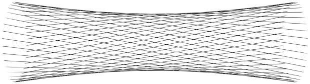

KL and muon detector
Resistive Plate Counter (barrel outer layers)
Scintillator + WLSF + MPPC
(end-caps , inner 2 barrel layers)
EM Calorimeter
CsI(Tl), waveform sampling electronics
electrons (7 GeV)
Particle Identification
Time-of-Propagation counter (barrel)
Prox. focusing Aerogel RICH (forward)
Vertex Detector
2 layers Si Pixels (DEPFET) +
4 layers Si double sided strip DSSD
positrons (4 GeV)
Central Drift Chamber
Smaller cell size, long lever arm

Central Drift Chamber (CDC)

- 14.2k wires in 56 layers radius 168 - 1111 mm
- arranged into 9 super layers of axial and stereo wires
- stereo wires skewed w.r.t. axial wires to get z information
- drift cell sizes from $\approx 1cm$ to $\approx 2cm$

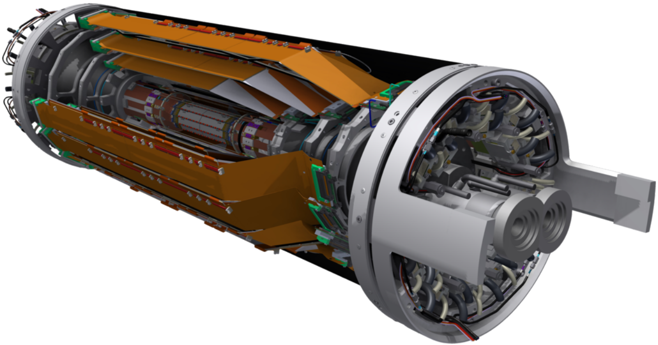






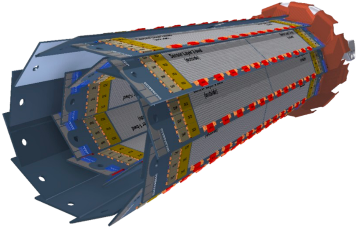
Silicon Vertex Detector (SVD)

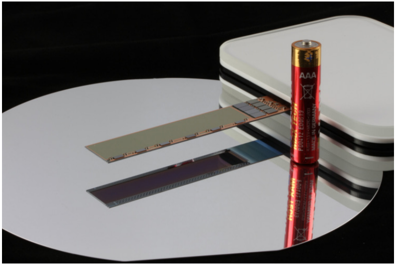
- 4 layers of double-sided silicon strip sensors (r=39, 80, 104, 135mm)
- 172 sensors, 220k readout strips
- strip distance between 50 and 240 μm
- strips are arranged perpendicular to get 2D information
- $< 1\% \ X_0$ per layer



Pixel Detector (PXD)

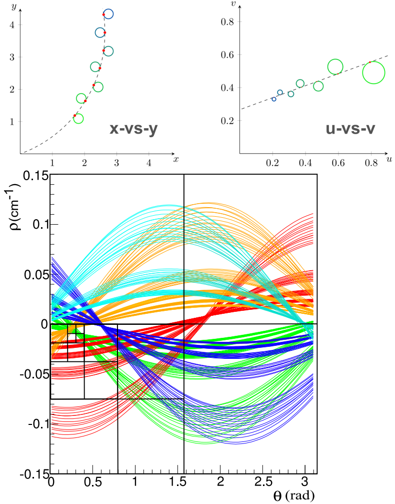
- 2 layers of DEPFET silicon pixel sensors (r = 14, 22 mm)
- pixel sizes 50x (55-85) μm
- 40 sensors
- in total 7.7 million pixels
- 20 μs integration time
- 0.2% X_0 per layer





Global CDC track finder

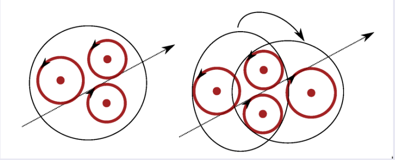
- tracks coming from IP
- conformal mapping:
  $u = \frac{x}{x^2+y^2}$; $v = \frac{y}{x^2+y^2}$
- Legendre transformation for Hough space:
  - parameter space representing all tangents to a drift circle
  - $\rho = x_0 \sin(\theta) + y_0 \cos(\theta) \pm R_{Drift}$
- Quad-Tree-Search for finding track parameters in Hough space



Local CDC track finder using Cellular Automaton (CA)

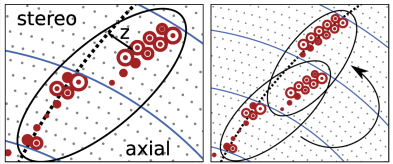
Cellular automaton for segment building in CDC

- segments: shorter track pieces (usually within one super layer)
- start combining triplets of hits assuming straight trajectory



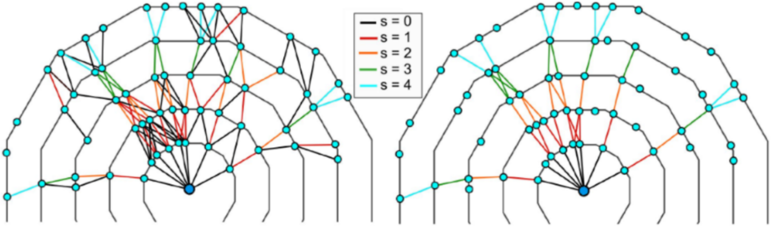
Cellular automaton for track building in CDC

- cell: pair of axial + stereo wire segments
- combining cells into tracks starting from a seed, by selecting longest path



SVD Standalone track finder (VXDTF2)

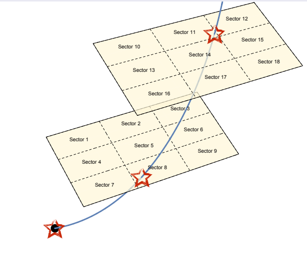
- local algorithm utilizing Cellular Automaton
- segments (cell): connection between hits on neighboring sensors
- connections of segments are filtered using simple requirements
- Cellular automaton collects longest paths
- start from outer - most hits due to less background



SVD track finder: Hit Filtering

- filter hits during CA step
- divide sensor into rectangular sectors (4x4 sectors per sensor)
- only hits on related sectors are considered
- selection of hit combinations:
  - consider 2-hit and 3-hit combinations of sectors
  - simple geometric quantities (angles, distances, radii) and hit times
  - individual cut values for each sector combination
- training on MC samples:
  - learn relations between sectors
  - learn cut values for each sector combination
  - use 13 mio MC events (mostly BB and some e^+e^- and $\mu^+\mu^-$)

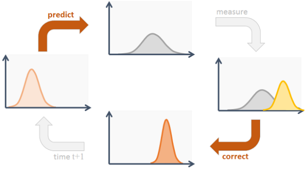
Illustration of the sector concept



Combinatorial Kalman Filtering (CKF) in Belle II tracking

Track Finding

- use found track as seed track
- extrapolate track into other sub-detector to look for hits
- from CDC to SVD and vice versa
- PXD hits only via CKF



Object-Tracking-Kalman-Filter-with-Ease

Track Merging

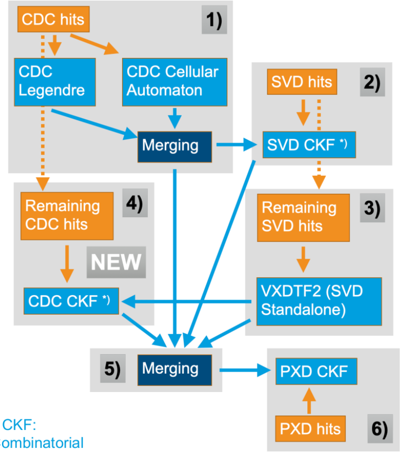
- one track as seed
- use CKF to update seed track with hits from other track

Deterministic Annealing Filter for Track Fitting

- iterate Kalman filtering for track candidate
- reject hits farthest away from track in each iteration

- use Genfit2 package for CKF algorithms

Bringing it all together



*) CKF: Combinatorial Kalman Filter

- 2 different tracking algorithms for CDC
- one stand alone algorithm for SVD
- have to combine tracks found in different detectors
- attach PXD hits to tracks

Usage of SVD time in track finding

- time information at the moment only for SVD track finding
- both SVD - standalone algorithm and CKF use space points as input

Space Point

- global 3D coordinates of hit
- SVD space point: combine positions of perpendicular Clusters (u,v)

- filter by time during space point creation:
  - absolute time for single hits: $|t_{u,v}| < 50ns$
  - time difference between u- and v-Clusters on same sensor: $|t_u - t_v| < 20ns$
- time filters applied during CA step of SVD track finding
  - time difference between u- and v-Clusters same sensor
  - time difference between Clusters from different sensors
  - cut values learned during training phase
  - individual cuts for different combination of sectors

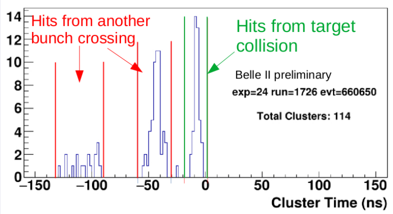
Other and future applications

- SVD time for Event T0 estimation
  - estimate Event T0 from time associated to SVD hits attached to tracks
  - only track candidates with $p_t > 250 MeV$ to avoid curling particles
  - on average less than 1 ns resolution on data
  - previous method based on CDC hits: 2000 x slower
- provide track time information (Luigi's slides) to analysts in future
  - included in new release
  - not yet used in MC production or data reprocessing
- replace time cuts by hit time grouping (see Luigi's slides)
  - currently cut on times for space point selection
  - grouping of SVD hit times promises improvement
- SVD hit times for CDC to SVD CKF hit selection
  - work in progress

Performance SVD hit time grouping

- finding efficiency for tracks normalized to MC based track finder (ideal track finder)
- fake rate: fraction of fake tracks and tracks from beam background
- clone rate: fraction of multiple tracks reconstructed per single particle (e.g. looper)
- selection on hit time grouping reduces fake rate by 50%

SVD hit time grouping: See Luigi's talk

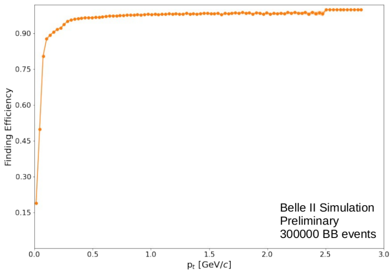


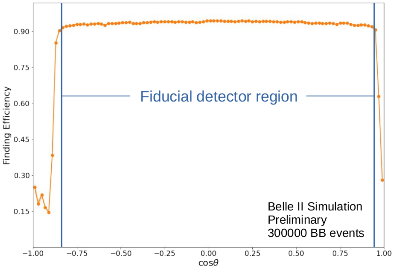
	Hit time grouping off	Hit time grouping on	Rel. difference
Track finding eff.	93.67 ± 0.24 %	93.69 ± 0.24 %	+0.02 %
Fake rate	9.55 ± 0.29 %	4.37 ± 0.20 %	-54.26 %
Clone rate	3.81 ± 0.19 %	3.56 ± 0.18 %	-6.62 %

Summary

- usage of SVD hit time during Belle II track finding:
  - so far only for SVD track finding
  - hit filtering before track finding
  - filtering of hit combinations during track finding
  - Event T0 estimation
- SVD hit time information powerful tool to reject beam background
- Belle II constantly increases luminosity
  - beam background will become more important in future
- future updates promise further improvement

Tracking Performance





Tracking Performance