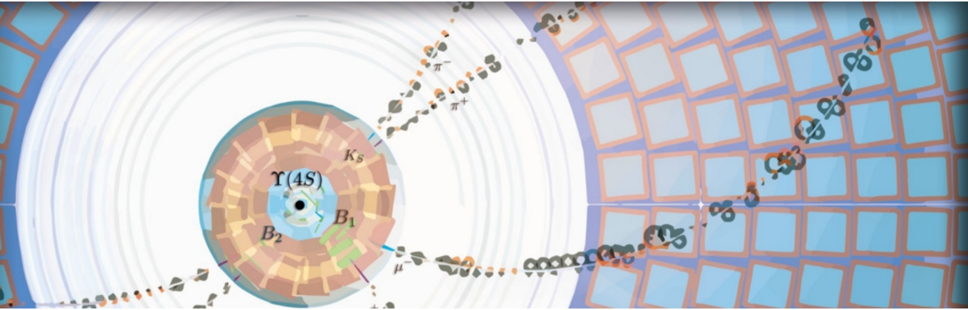
Cellular Automaton based Track Finding for the Central Drift Chamber of Belle II.

OIST, Okinawa - CHEP 2015



Oliver Frost on behalf of the Belle II collaboration
Deutsches Elektronen-Synchrotron (DESY)
2015-04-13

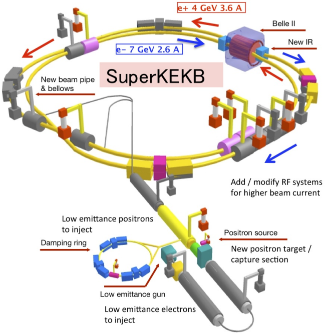
DESY
HELMHOLTZ ASSOCIATION
Belle II

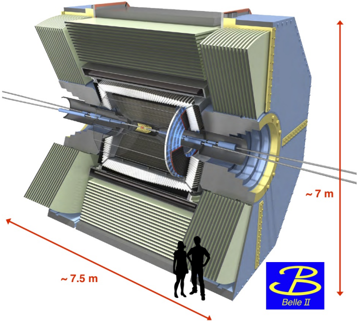
Overview

- Belle II and the Central Drift Chamber
- Weighted Cellular Automaton
- Concrete Application

Belle II and the Central Drift Chamber

SuperKEKB und Belle II



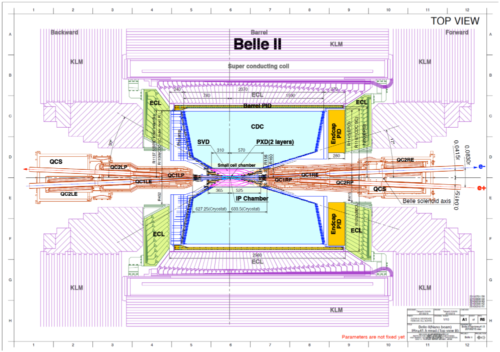


Experimental agenda

- B-Factory : Asymmetrical $e^{+}e^{-}$-Collider mainly running on the Υ(4S)-Resonance
- Search for new physics by precision measurements
- 50 ab^{-1} from 2018 until 2025
- Exceed the world record luminosity by a factor of 40.

Tracking detector components

- Silicon pixel detector (PXD)
- Silicon strip detector (SVD)
- Central drift chamber (CDC)



Offline tracking reconstruction

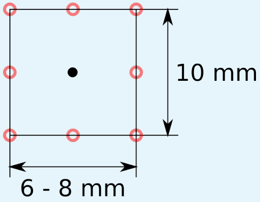
1. Standalone finder for PXD + SVD
   - Cellular automaton / Hopfield-Network finder
2. Standalone finder for the CDC
   - Legendre finder for high momentum tracks
   - **Weighted cellular automaton** finder for lower momentum range, decays in flight and comics tracks
3. Merging of silicon and drift chamber tracks
4. Cross detector searches and extrapolations for additional hits
5. Final track fit with GENFIT Kalman filter or DAF from seed delivered by the finders

Structure and detection principle

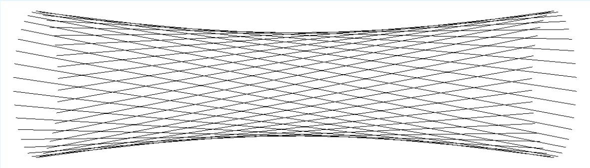
- 14336 drift cells with sense wires in hexagonal near ordering
- Gas mixture $He - C_2H_6$ with $v_{drift} = 0.04 \frac{mm}{ns}$
- Two drift times / radii per wire
- 56 concentric layers in 9 super layers alternating

axial	parallel to the beam line
stereo	slightly twisted enabling reconstruction into the third dimension (see below)

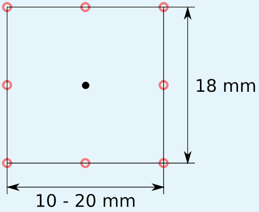
Small cells SL 0



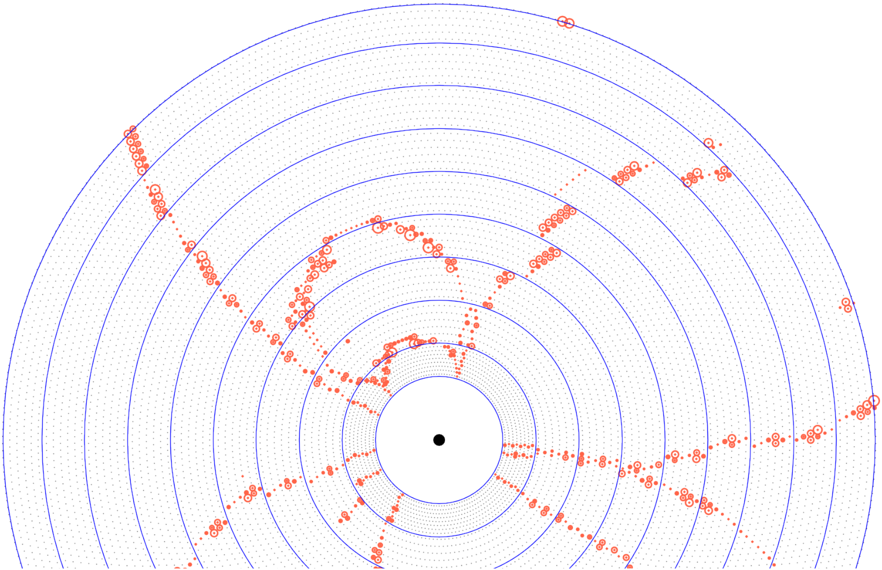
Stereo layers - twist exaggerated for illustration



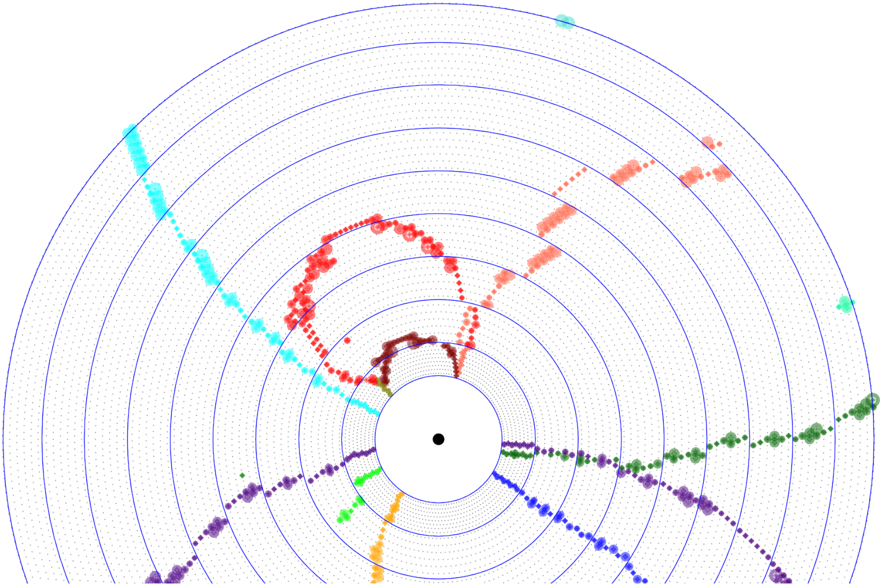
Regular cells SL 1 - 8



Track finding in the Central Drift Chamber. Turn unmarked hits ...



...into groups caused by the same particle.



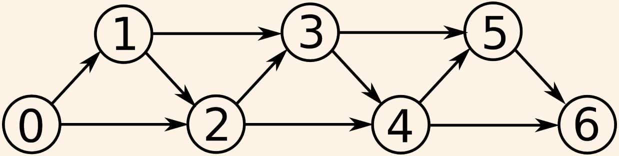
Weighted Cellular Automaton

Classical cellular automaton

Introduced at DESY

Discrete form of (Denby-Patterson-)Hopfield-Network in CATS (Cellular Automaton for tracking in Silicon) by Kisel for HERA-B

Graph diagram



- *Loop-free* directed graph - assuming a forward direction
- Vertices / cells represent suspected positions
- Edges / neighbors represent suspected propagations
- Evaluation rule designed for *non-floating* point hardware

$$E_i = \max_{\text{neighbor } j} (E_j + 1) = \sum_{\text{best path to } i} 1$$

Weighted cellular automaton

Approximate the Hopfield-Network more closely

- Allowing weights on vertices θ_i and edges w_{ij}
- Weighted evaluation rule picking the neighbor with highest weight gain

$$E_i = \theta_i + \max_{\text{neighbor } j} (w_{ij} + E_j) = \sum_{\text{best path to } i} w_{ij} + \sum_{\text{best path to } i} \theta_i$$

Inherited properties

- High evaluation speed by single pass over the graph (forward pass, $O(n)$ - algorithm)
- Generation of valuable tracks following cells with highest state (backward pass)
- Iteration for additional disconnected tracks
- Emphasis on local connections - robustness against separated background and energy loss
- Agnostic to start position and direction of flight - seeding phase unnecessary

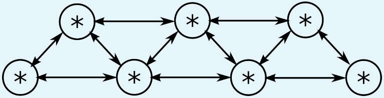
Upgraded properties

- Refined track model by encoding probability of positions and propagations into the weights

Comparison to Hopfield-Network

Hopfield-Network

- *Symmetrical* graph

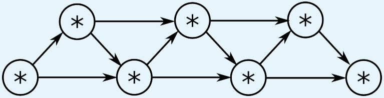


- *Minimized* energy function

$$E = -\frac{1}{2}\sum_{i,j} w_{ij} \cdot s_i \cdot s_j - \sum_i \theta_i \cdot s_i$$

Weighted cellular automaton

- *Directed loop free* graph



- *Maximized* energy function

$$E_{i,\text{highest}} = \sum_{\text{best path to } i} w_{ij} + \sum_{\text{best path to } i} \theta_i$$

Quality of the approximation

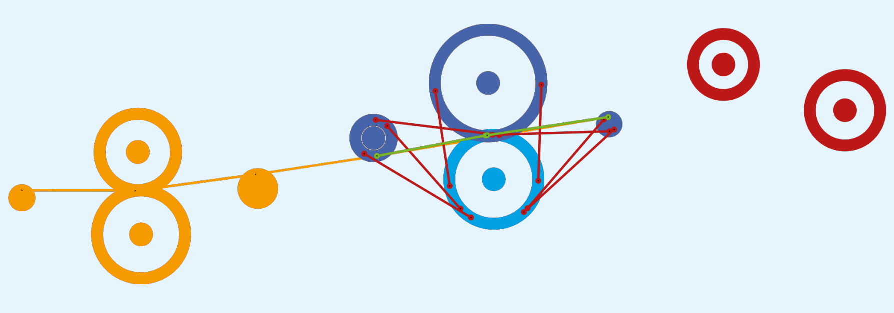
Weighted cellular automaton optimizes the same energy function as the Hopfield-Network assuming

- The symmetry of the graph can be broken to a forward direction (as it is applicable in tracking applications).
- The activation of the Hopfield-Cells is $s_i = 1$ on the sought track and $s_i = 0$ elsewhere.

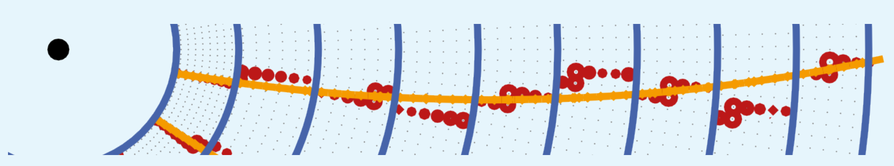
Concrete Application

Two weighted cellular automata at different level of detail

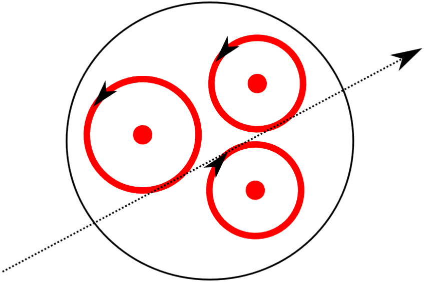
Build segments from individual hits in each super layer

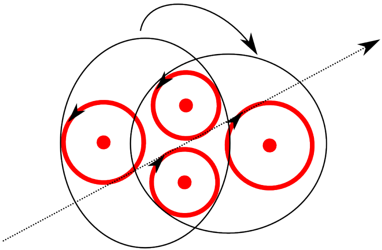


Build tracks from segments



Segment building stage - components of the graph





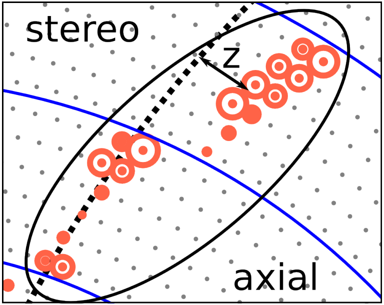
Vertices - θ_i

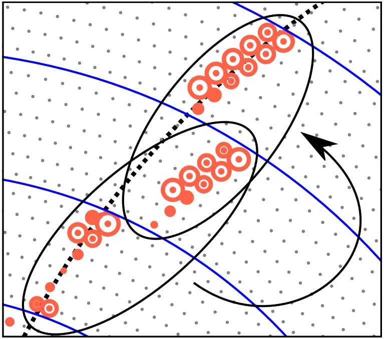
- Ordered triple of close by hits triangulating the suspected position
- Assumed right left passage hypotheses for unique trajectory
- *Linear trajectory* by least square method

Edges - w_{ij}

- Neighboring triplets share two hits
- Loose feasibility cuts
- Judging compatibility by combined χ^2 of the trajectories

Track building stage - components of the graph





Vertices - θ_i

- Ordered pairs of segments axial $\leftrightarrow$ stereo
- Least square circle fit by Riemann technique (Frühwirth et al.) + linear fit of reconstructed z-coordinates over travel distance s
- $\rightarrow$ full helix trajectory with uncertainties

Edges - w_{ij}

- Neighboring segment pairs share one segment
- Loose feasibility cuts
- Judging compatibility by combined χ^2 of the trajectories

Conclusion

Algorithm

- Bottom-up track finding in two stage utilizing a graph of suspected positions and transitions
- Generation of long paths with the generalization of the classic cellular automaton with weights
- Detailed modeling of the physical particle movement can be encoded by the weights.
- Automatic filtering of beam backgrounds
- Low susceptibility against energy loss along the track

Outlook

- Best weighting model under investigation
- First application to the data from cosmic data taking starting this spring