LMU LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

Track Fitting in Belle II

The GENFIT LIBRARY AND ITS PERFORMANCE

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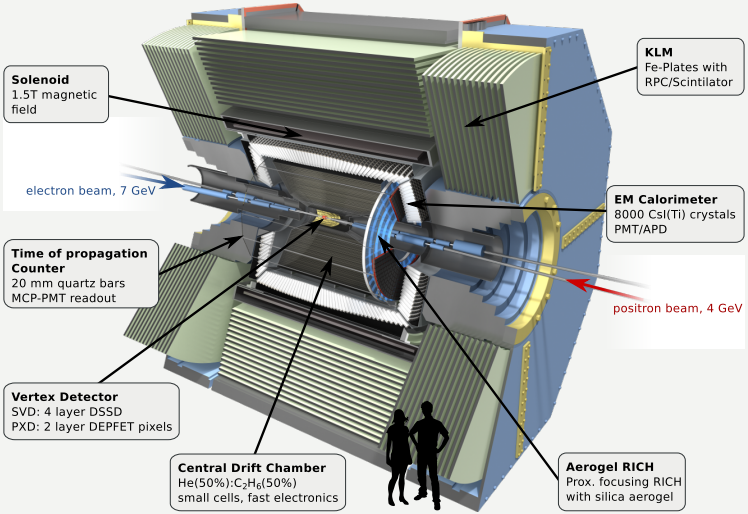
2015-07-25

The Belle II Experiment

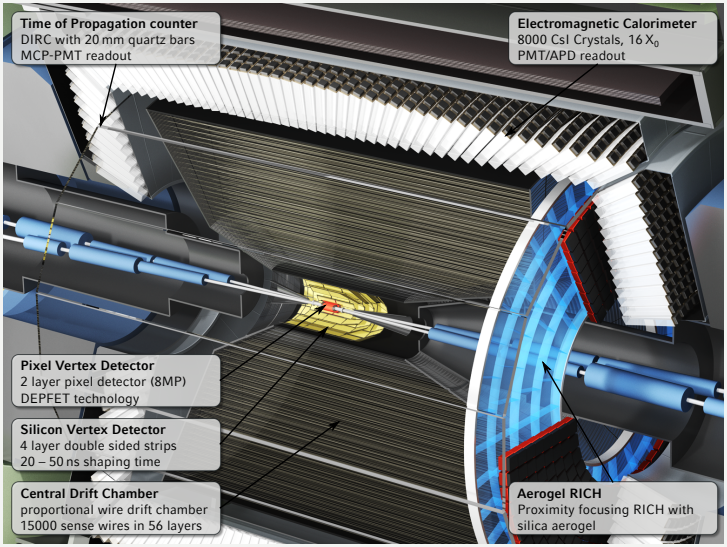


Currently being set up at KEK, Japan.

- B-factory experiment
- first beam 2016
- physics from 2018
- instantaneous luminosity goal $L = 8 \times 10^{35}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$ (40 times Belle, KEKB)

Talk by J. Wiechczynski (now)

Tracking Detectors in Belle II



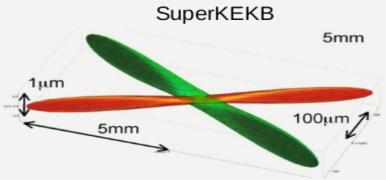
Aims:

- Momentum range: 50 MeV – 5 GeV
- background resistant
- high resolution

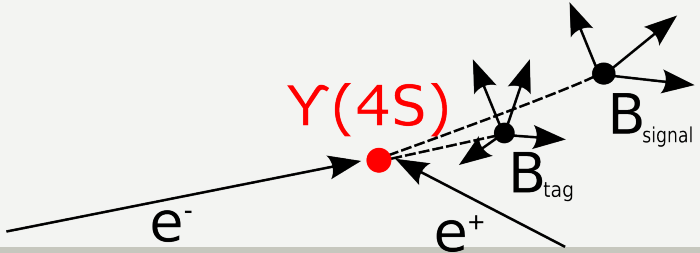
Detector choices:

- six-layer Si vertex detector (G. Casarosa's talk)
- drift chamber: 56 wire layers, divided into 9 superlayers

Event Topology

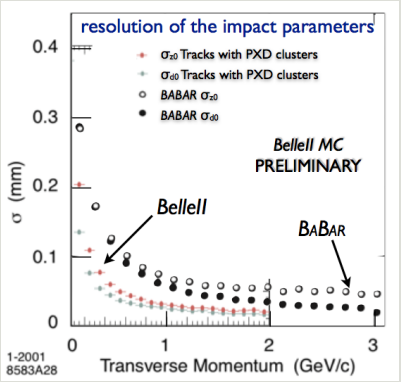


- e^+e^- are brought into collision in the tiny beamspot (``nanobeam'')
- $\Upsilon(4s)$ is produced, decays into $B\bar{B}$ pair
- these propagate $O(100\,\mu\text{m})$ ($p_{\text{LAB}} = 1.5\,\text{GeV}$) …
- …before decaying into a total of $O(10)$ tracks
- most important observable: separation of B decay vertices along boost direction
- nanobeam requires smaller boost ($\beta\gamma = 0.3$) than previous B-factories ($\beta\gamma = 0.425$), need to compensate with higher resolution



Requirements

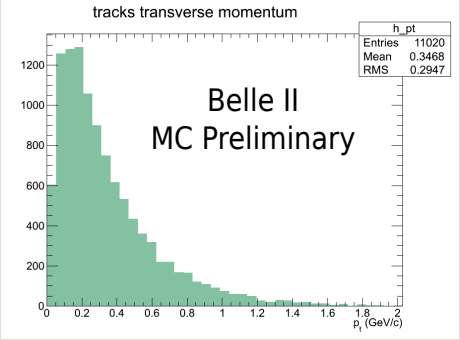
Resolution



High resolution even in presence of backgrounds and at low transverse momenta

(courtesy of G. Casarosa)

Interesting momenta



Event characteristics:

- $O(10)$ tracks per event
- large fraction of momenta below 200 MeV

Track Finding

Online, Offline

Trigger, Readout (See C. Li's talk)

- low-level trigger does coarse tracking
- reconstruction in high-level trigger, also for data reduction / background suppression in pixel vertex detector
- 30 kHz low-level trigger, 10 kHz high-level trigger, 300 kB/ev recorded

Offline

Stand-alone trackfinding in subdetectors

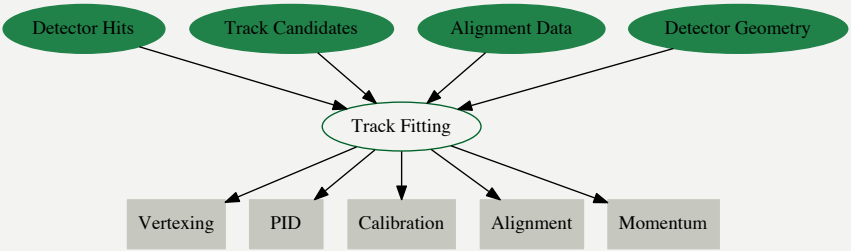
- vertex detector: cellular automaton, Hopfield network for candidate evaluation
- drift chamber: Legendre-based global track finder, cellular automaton-based local track finding

Combination of subdetectors

- found tracks are merged if fitted parameters agree at subdetector boundary
- cross-detector searches, extrapolations for additional hits (combinatorial kalman filter, under development)

Convergence Point

Track fitting is the convergence point of many things.



Convergence Point

Track fitting is the convergence point of many things.

The Genfit Library

- Belle II initially based its track fitting on the experiment-independent, open source (LGPL) Genfit library (arXiv:0911.1008)
- this turned out to be fairly limited, the track fitting software was essentially rewritten while keeping in spirit with the original library
- the new Genfit library is now used by the Belle II collaboration as well as the PANDA and SHiP collaborations (arXiv:1410.3698)

The Complete Track Fitting Package

GENFIT handles all aspects of track fitting

Inputs

- flexible hit classes
- track candidate handling
- interfaces for interaction between hits, tracks, alignment info (e.g. wire sag)
- detector geometry (TGeo, Geant4)

Processing

- extrapolation code
- pluggable fitting algorithms (Kalman filter, DAF, GBL)
- combined handling of several particle hypotheses

Output

- flexible convergence criteria (e.g. were there rejected outliers?)
- storage with configurable detail (ROOT)
- interfaces to Millipede II (alignment), RAVE (vertexing)
- visualization

All Detectors Tested

Vertex Detector Data Processing

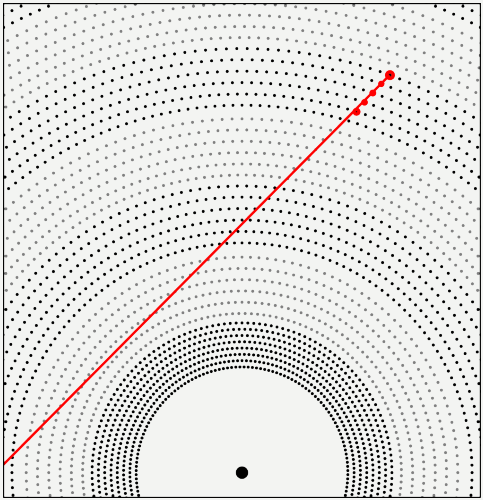
In 2014 we had a beam test where we could successfully establish the complete dataflow for the vertex detector including online reconstruction. (G. Casarosa, C. Li's talks)

Drift Chamber Data

This year, we are having a cosmic ray test of the drift chamber.

- very promising, data from a single read-out board could be reconstructed successfully
- track data through the entire detector expected later this year

GENFIT can handle real detector data, even unaligned and uncalibrated .



Actual Cosmic Data with Track Candidate

Track Fitting Algorithms

Kalman Fitter

- standard track fitting algorithm
- sequential
- equivalent to least squares method

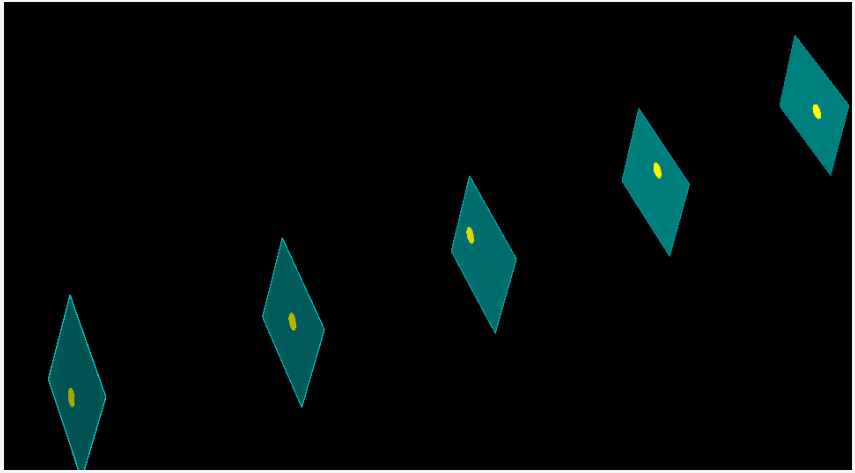
Deterministic Annealing Filter (DAF)

- sequence of Kalman filters
- annealing procedure for outlier rejection, ambiguity resolution

Generalized Broken Lines

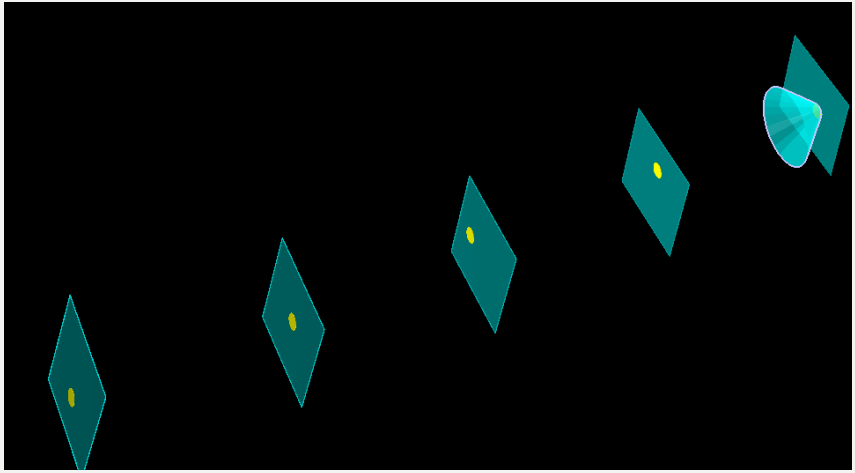
- alternative to Kalman filter
- well-suited to Millipede II alignment
- treats track as a whole

Illustration of the Kalman Filter



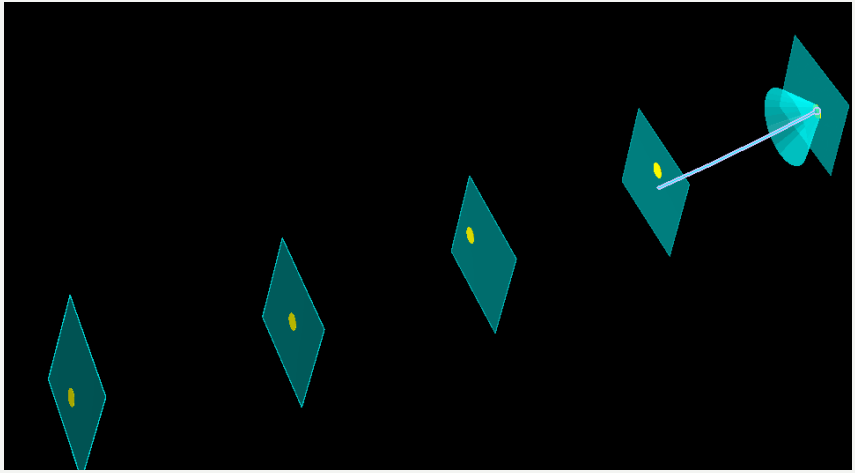
Series of noisy measurements.

Illustration of the Kalman Filter



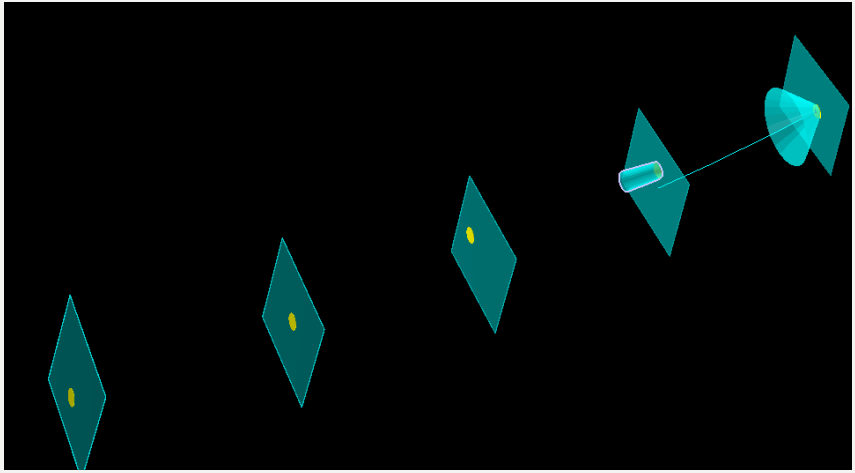
First update of the forward fit.
Position determined by first measurement.

Illustration of the Kalman Filter



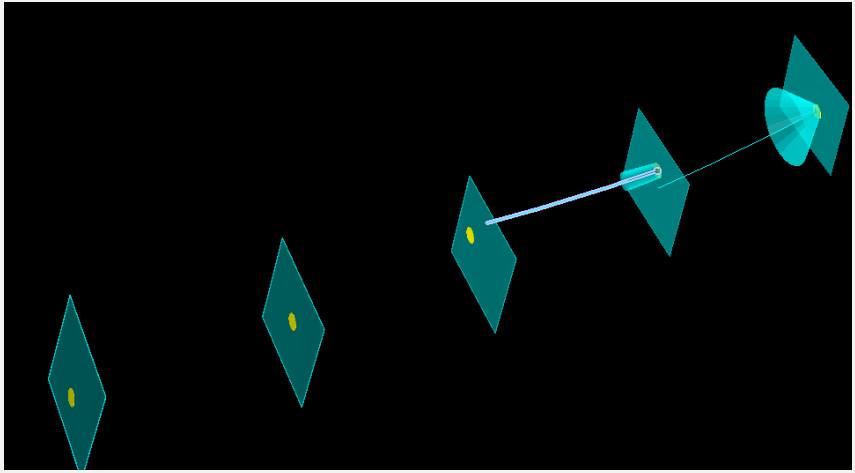
Prediction.

Illustration of the Kalman Filter



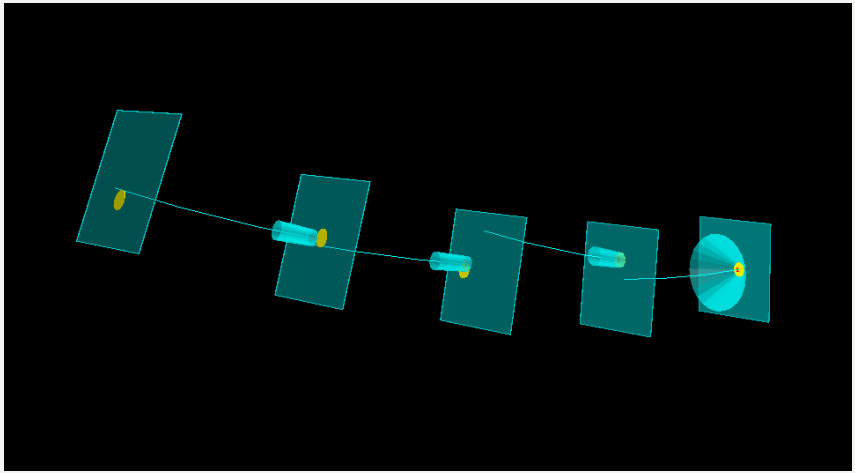
Update.
Direction determined by fist two measurements.

Illustration of the Kalman Filter



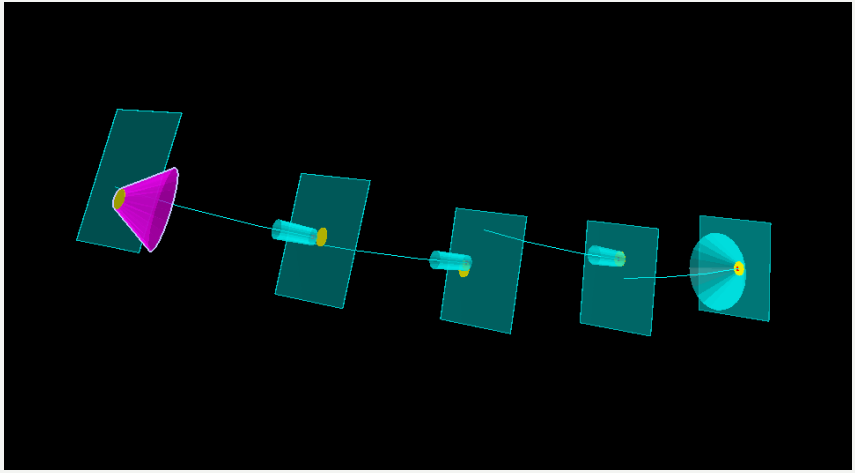
Prediction.

Illustration of the Kalman Filter



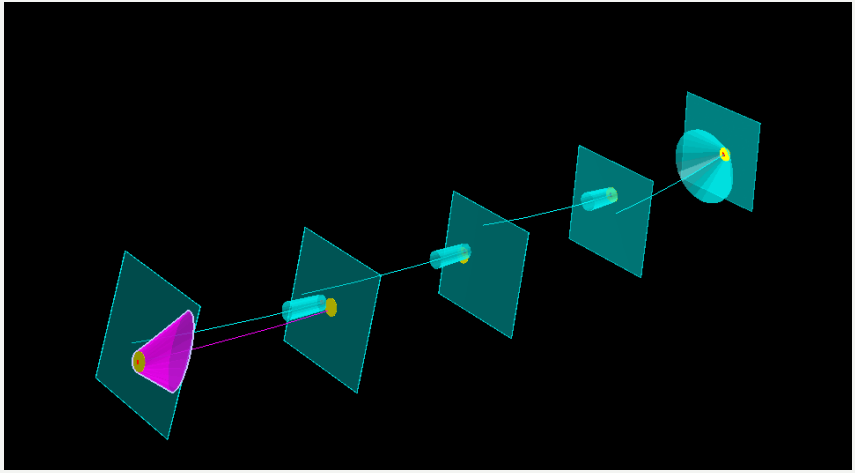
Forward fit.

Illustration of the Kalman Filter



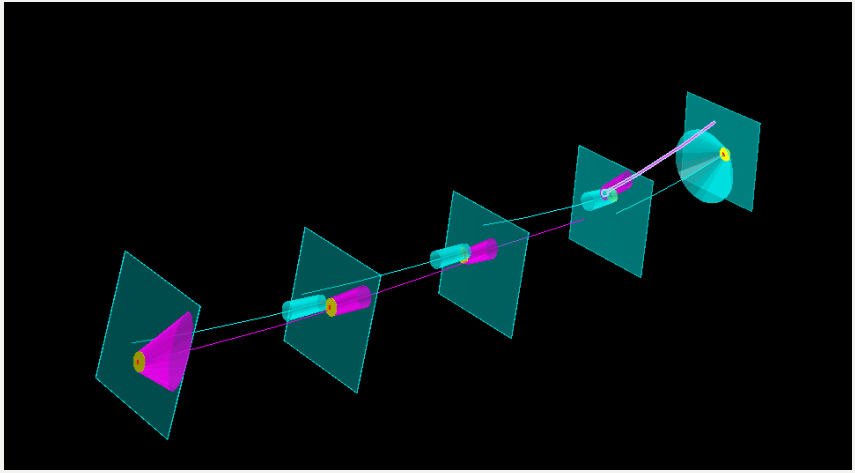
First update of the backward fit.
Direction and momentum from forward fit used as starting value.

Illustration of the Kalman Filter



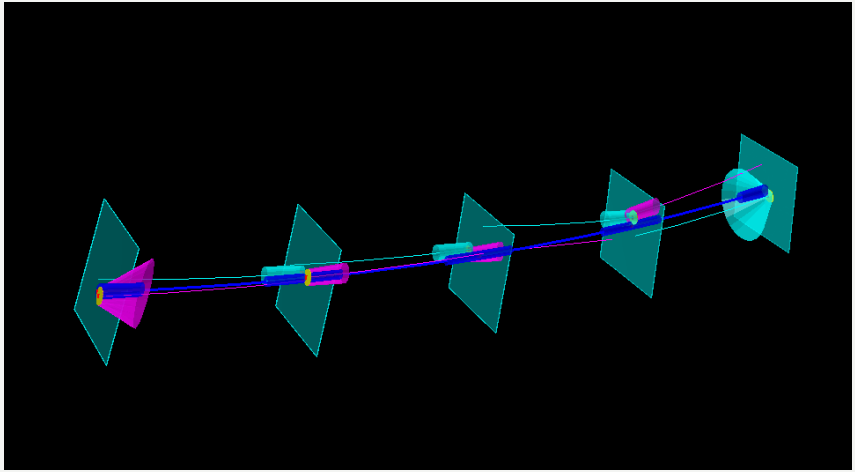
Prediction.

Illustration of the Kalman Filter



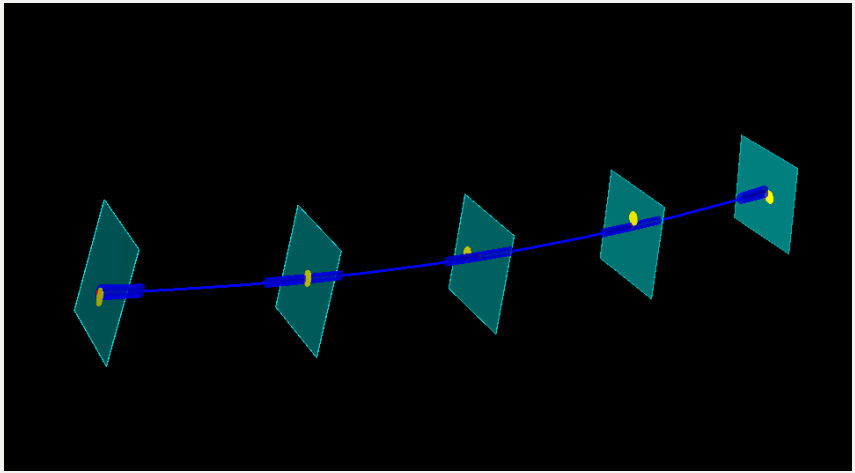
Prediction.

Illustration of the Kalman Filter



Smoothed track: weighted average between forward fit and backward fit.

Illustration of the Kalman Filter



Smoothed track.

Outlier Rejection, the DAF

Outliers, Ambiguities

The Kalman fit has no means of dealing with wrong hit assignments or with wrong assumptions about wire passage.

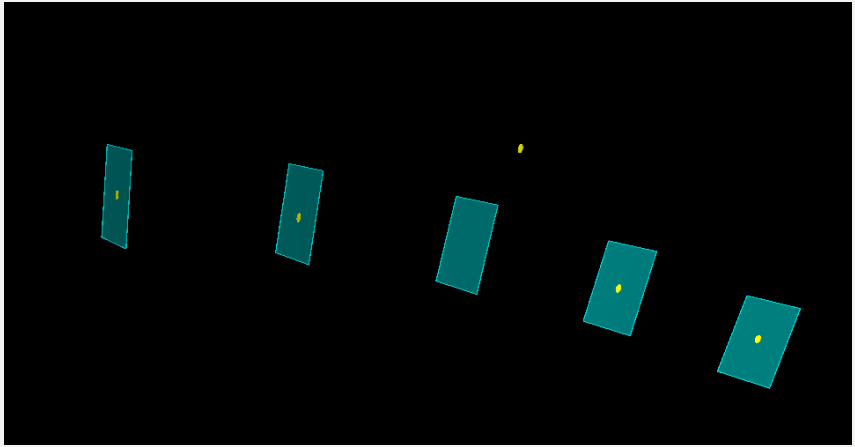
The Deterministic Annealing Filter

To deal with these problems, Belle II uses the Deterministic Annealing Filter (DAF) by default.

- points are weighted according to their residual to the smoothed track
- an annealing procedure is used to suppress hits with large residuals
- several hits can compete for one slot (e.g. left/right ambiguity in drift chamber

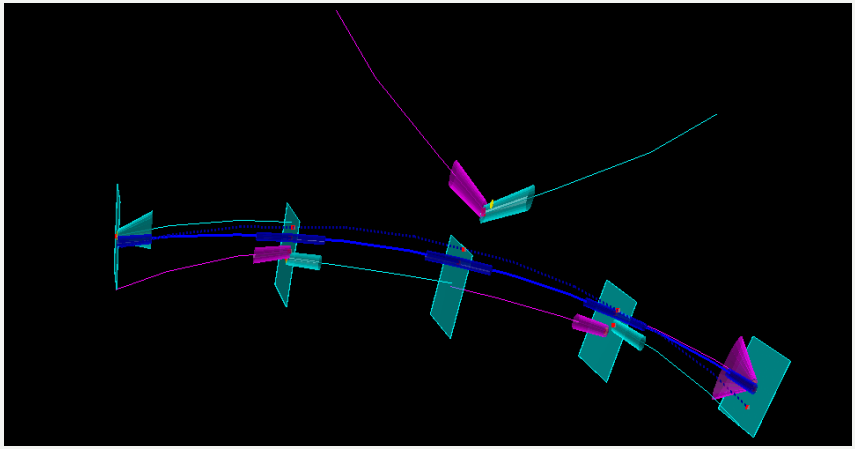
On the next slides: an example

Outlier - Fitted with the DAF



$\beta = 100$	initial weights:	1	1	1	1	1
$\log_{10}\beta = 2$	new weights:	0.4960	0.4238	0.1940	0.4310	0.5003

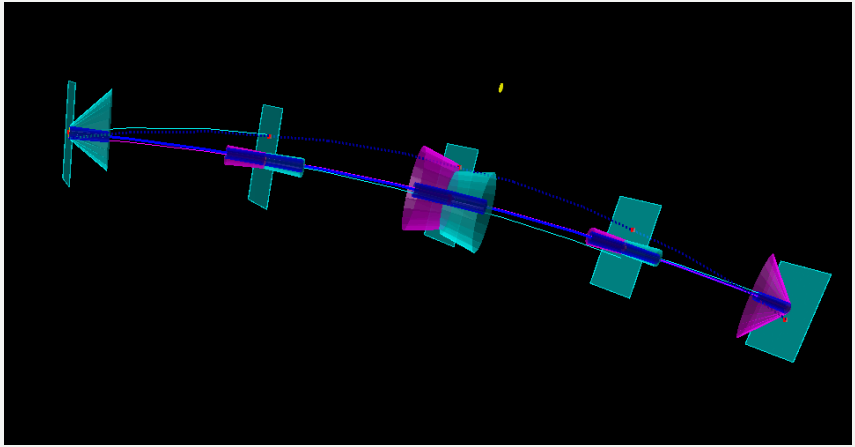
Outlier - Fitted with the DAF



After the first Kalman fit.

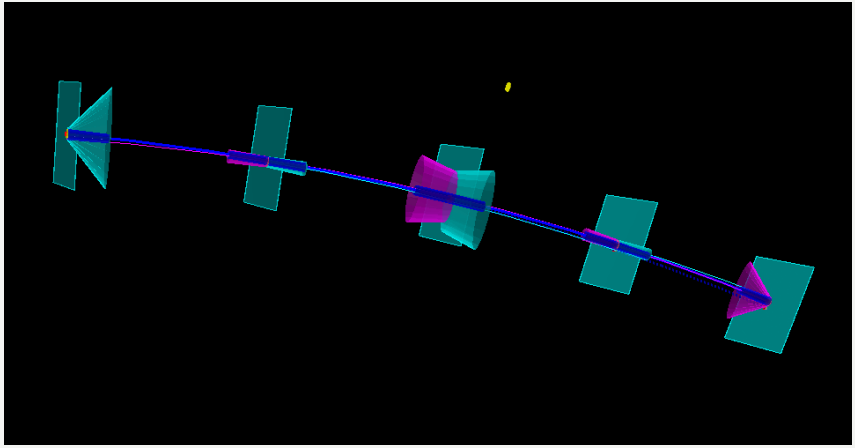
$\beta = 17.78$	initial weights:	0.4960	0.4238	0.1940	0.4310	0.5003
$\log_{10}\beta = 1.25$	new weights:	0.5426	0.3640	$6.052e-6$	0.3913	0.5470

Outlier - Fitted with the DAF



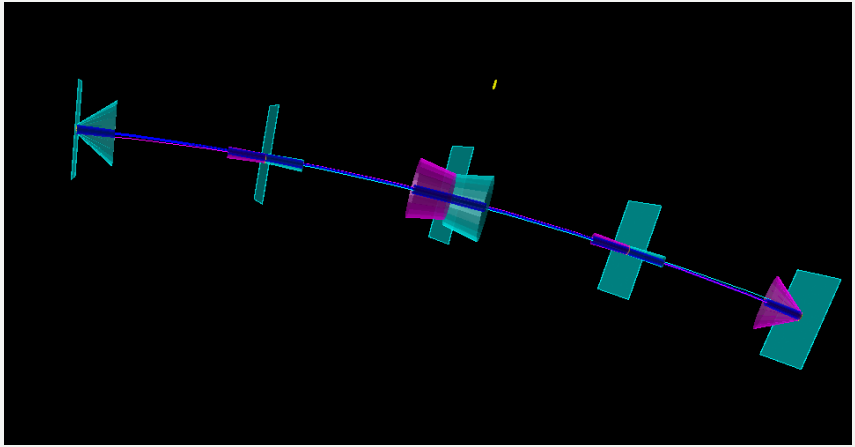
$\beta = 3.162$	initial weights:	0.5426	0.3640	$6.052e-6$	0.3913	0.5470
$\log_{10}\beta = 0.5$	new weights:	0.8111	0.8093	$4.106e-52$	0.8099	0.8109

Outlier - Fitted with the DAF



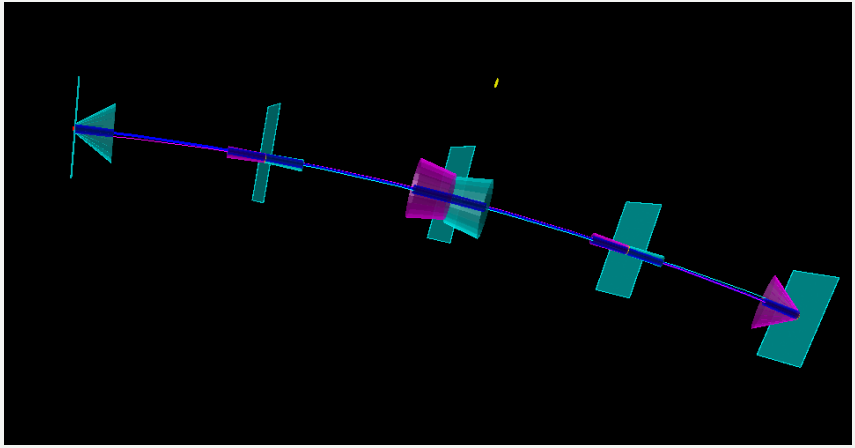
$\beta = 0.5623$	initial weights:	0.8111	0.8093	$4.106e-52$	0.8099	0.8109
$\log_{10}\beta = -0.25$	new weights:	0.9997	0.9997	$1.725e-290$	0.9997	0.1000

Outlier - Fitted with the DAF



$\beta = 0.1$	initial weights:	0.9997	0.9997	$1.725e-290$	0.9997	0.1000
$\log_{10}\beta = -1$	new weights:	1	1	0	1	1

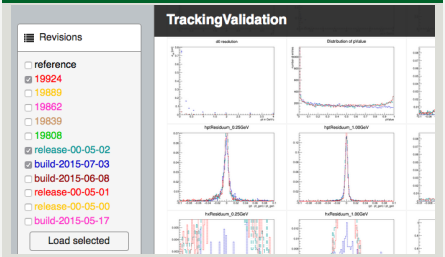
Outlier - Fitted with the DAF



$\beta = 0.1$	initial weights:	1	1	0	1	1
$\log_{10}\beta = -1$	new weights:	1	1	0	1	1

Summary, Figures of merit

Constantly Validated



Software quality is constantly monitored in order to catch regressions early.

A Few Numbers

- Time per track: 20 ms (dominated by geometry)
- full Belle II track with all fit information: 70 kB/track
- only information needed for further processing: 1.3 kB/track
- for comparison: mDST format: 170 bytes/track

Features of the GENFIT Package

- experiment-independent, open-source track-fitting package
- interfaces and (example) implementation for everything from detector hits over track-fitting and vertexing to alignment interfaces and visualization