LMU LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

# Track Fitting in Belle II

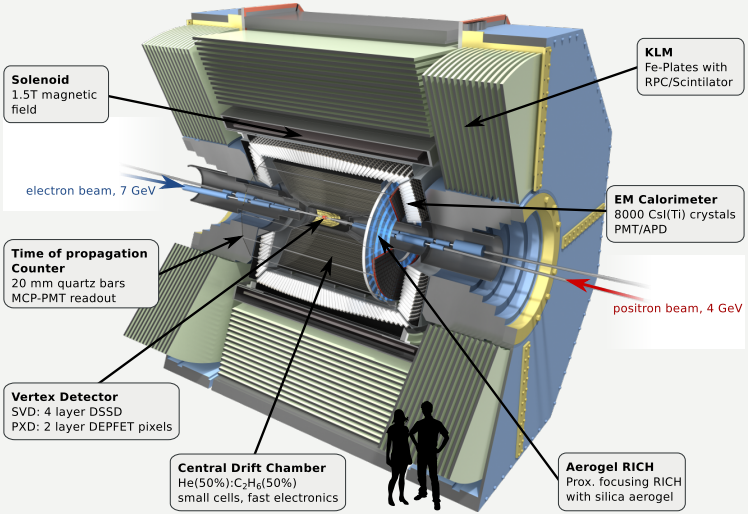
## The GENFIT LIBRARY AND ITS PERFORMANCE

Tobias Schlüter, LMU München

EPS-HEP 2015 (Vienna)
2015-07-25

TUM LMU Excellence Cluster Universe

# The Belle II Experiment

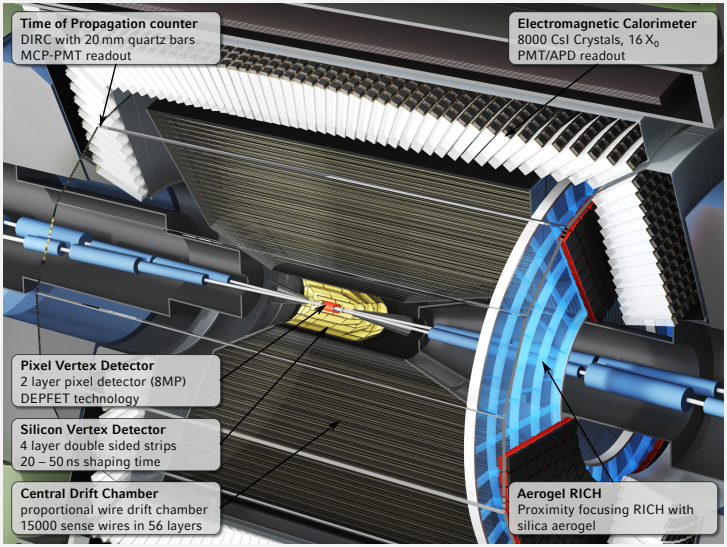



Currently being set up at KEK, Japan.

- $B$-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



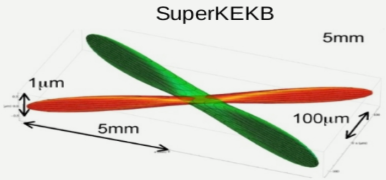

Aims:

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

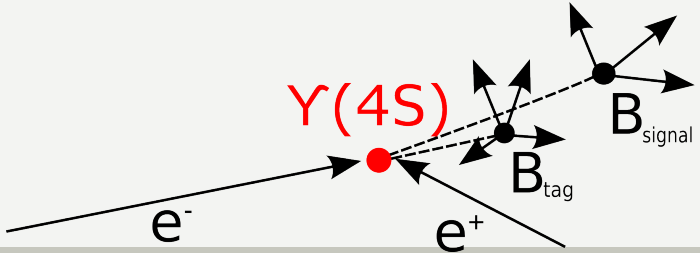
Detector choices:

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

# Event Topology

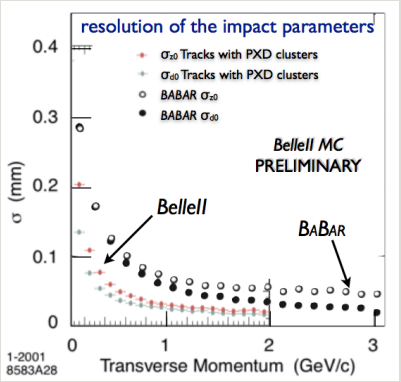



- $e^+e^-$ are brought into collision in the tiny beamspot (``nanobeam'')
- $\Upsilon(4s)$ is produced, decays into $B\bar{B}$ pair
- these propagate $O(100\,\mu\text{m})$ ($p_{\text{LAB}} = 1.5\,\text{GeV}$) …
- …before decaying into a total of $O(10)$ tracks
- most important observable: separation 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

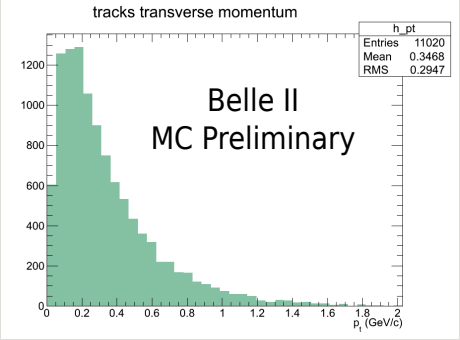
## Resolution




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, 15 kHz high-level trigger, 10 kB/ev recorded

### Offline

Stand-alone trackfinding in subdetectors

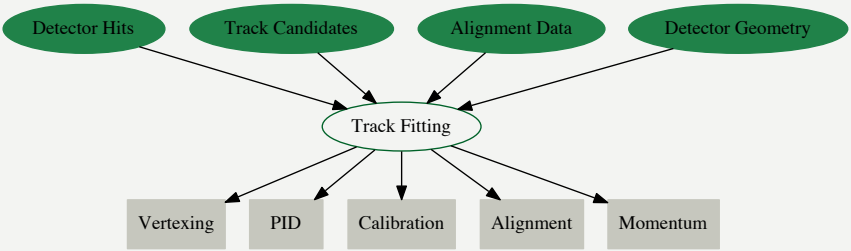
- vertex detector: cellular automaton, Hopfield network for candidate evaluation
- drift chamber: Legendre-based global track finder, cellular automaton-based local track finding

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

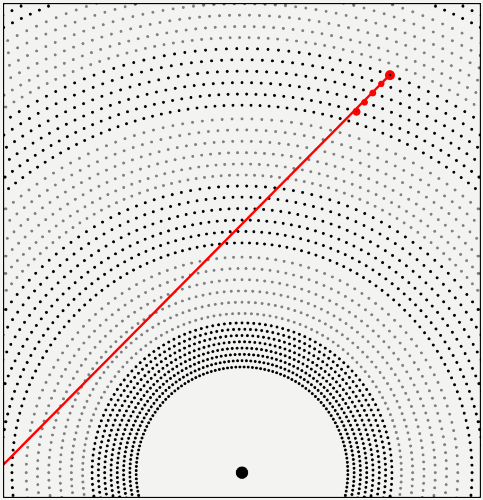
In 2014 we had a beam test where we could successfully establish the complete dataflow for the vertex detector including online reconstruction. (G. Casarosa, C. Li's talks)

### 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

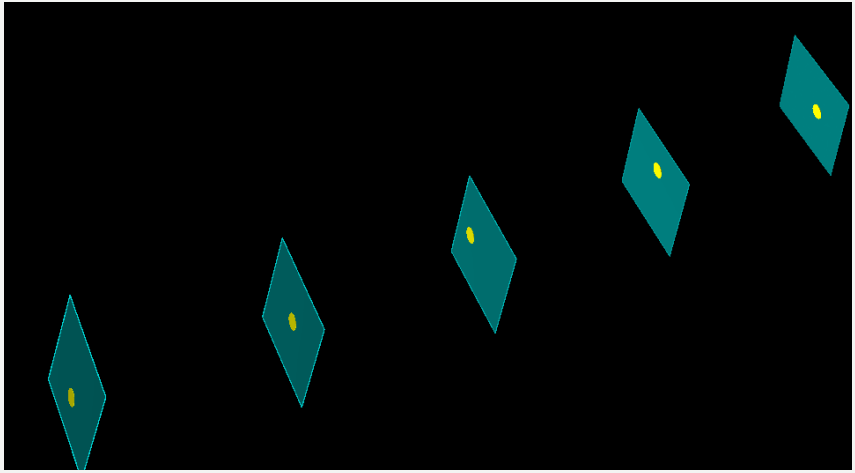
## Deterministic Annealing Filter (DAF)

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

## Generalized Broken Lines

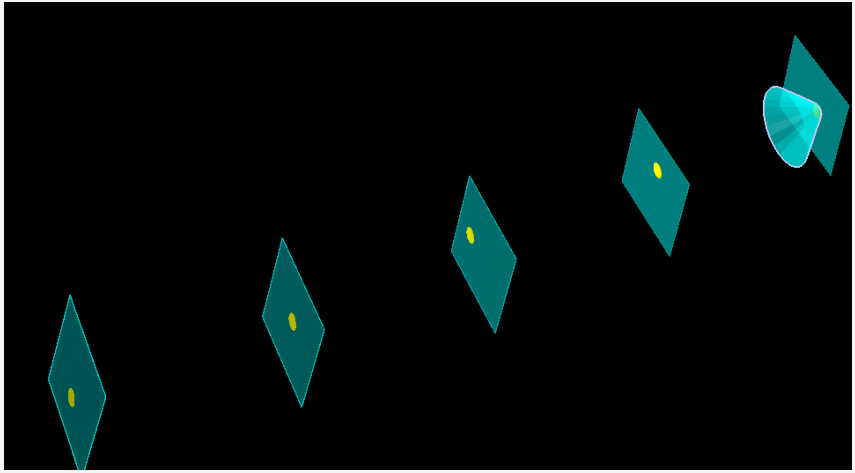
- alternative to Kalman filter
- well-suited to Millipede II alignment
- treats track as a whole

# Illustration of the Kalman Filter



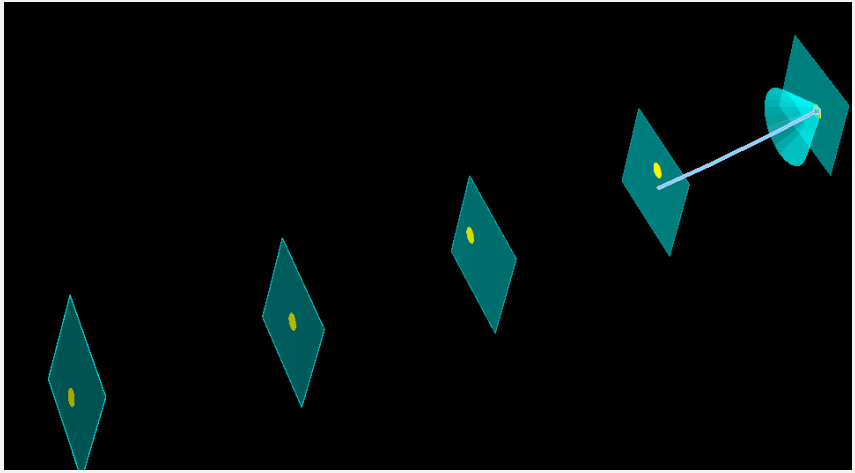
Series of noisy measurements.

# Illustration of the Kalman Filter



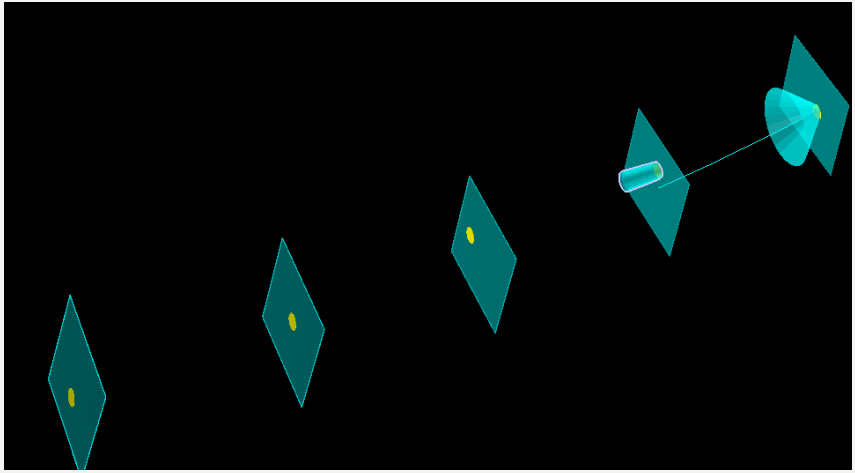
First update of the forward fit.
Position determined by first measurement.

# Illustration of the Kalman Filter



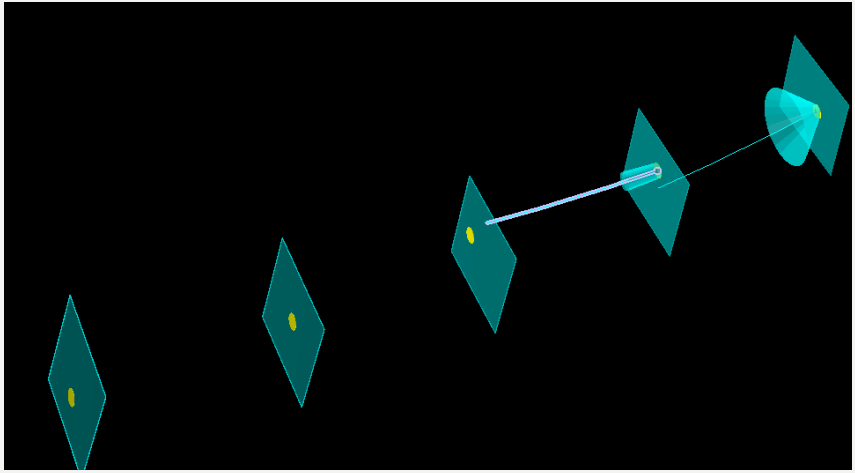
Prediction.

# Illustration of the Kalman Filter



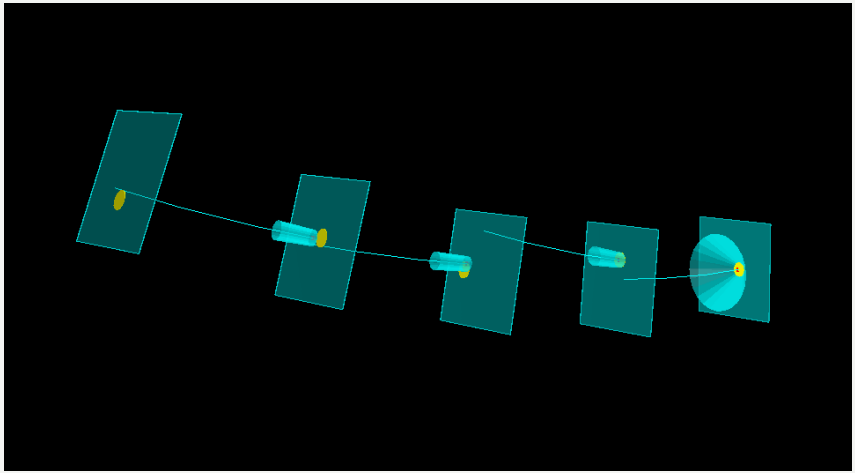
Update.
Direction determined by fist two measurements.

# Illustration of the Kalman Filter



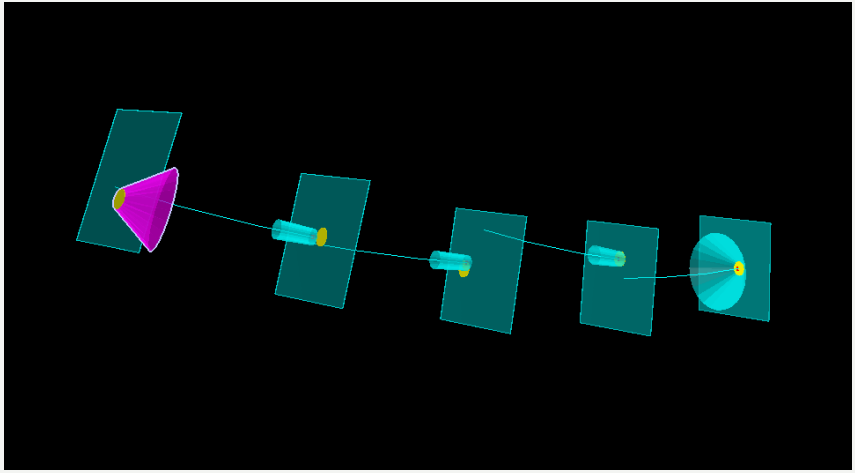
Prediction.

# Illustration of the Kalman Filter



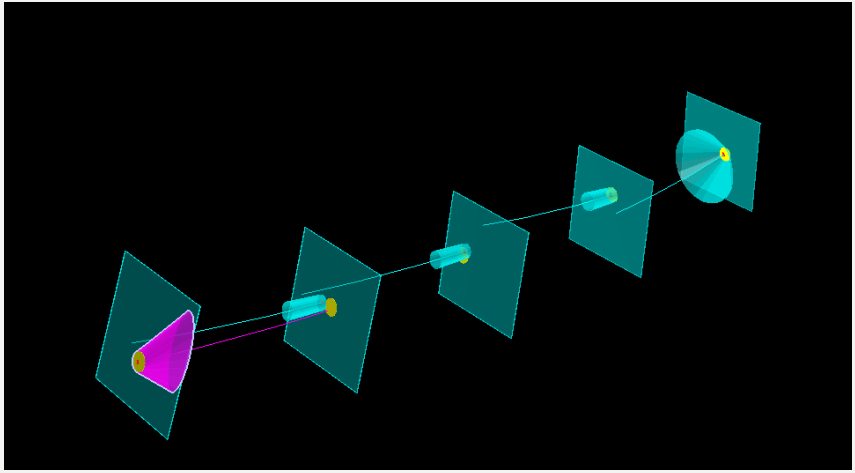
Forward fit.

# Illustration of the Kalman Filter



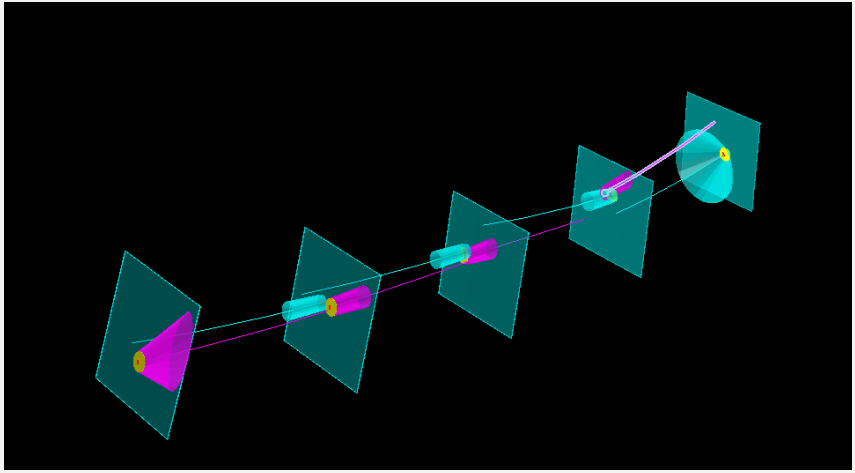
First update of the backward fit.
Direction and momentum from forward fit used as starting value.

# Illustration of the Kalman Filter



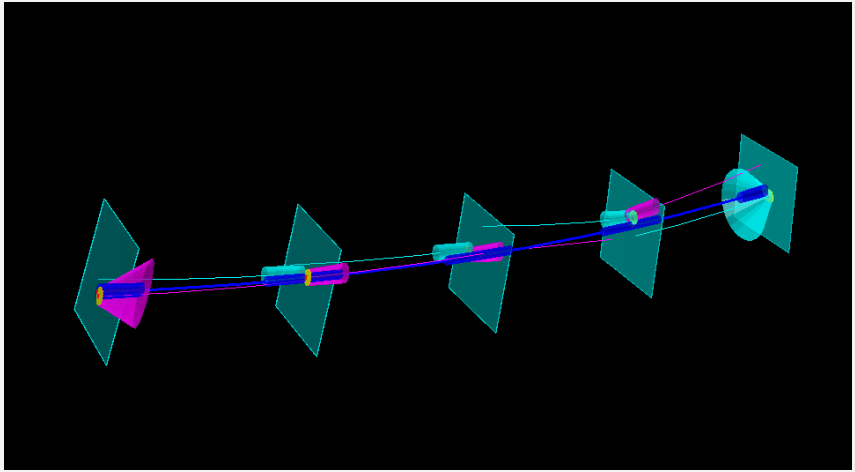
Prediction.

# Illustration of the Kalman Filter



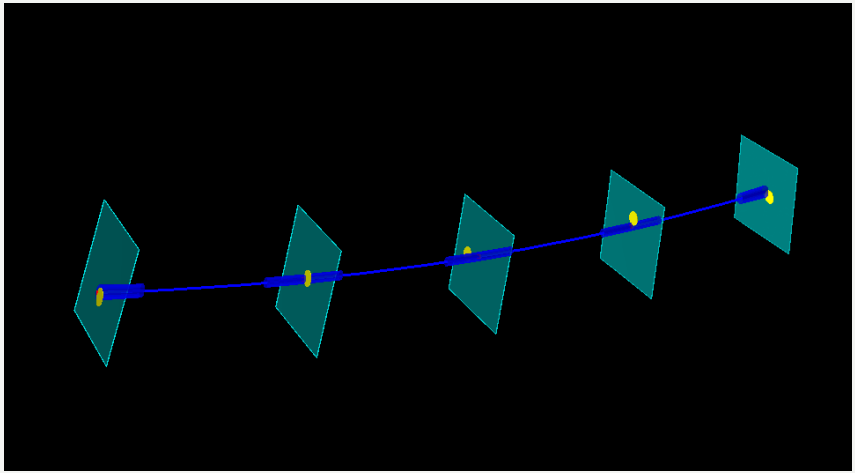
Prediction.

# 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.

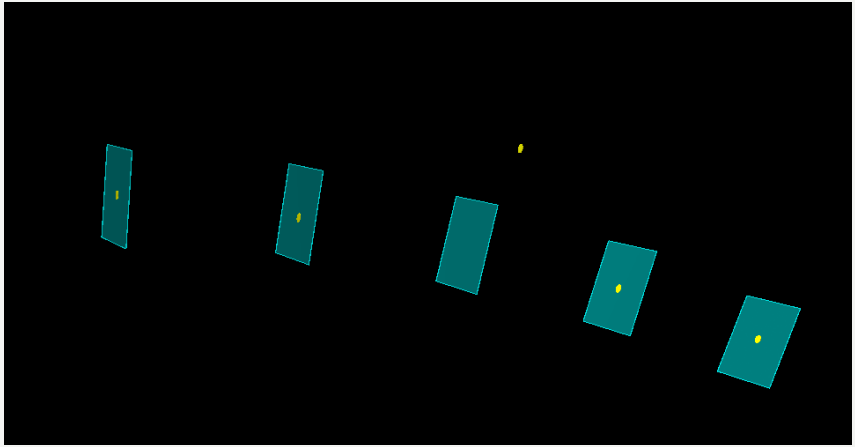
## The Deterministic Annealing Filter

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

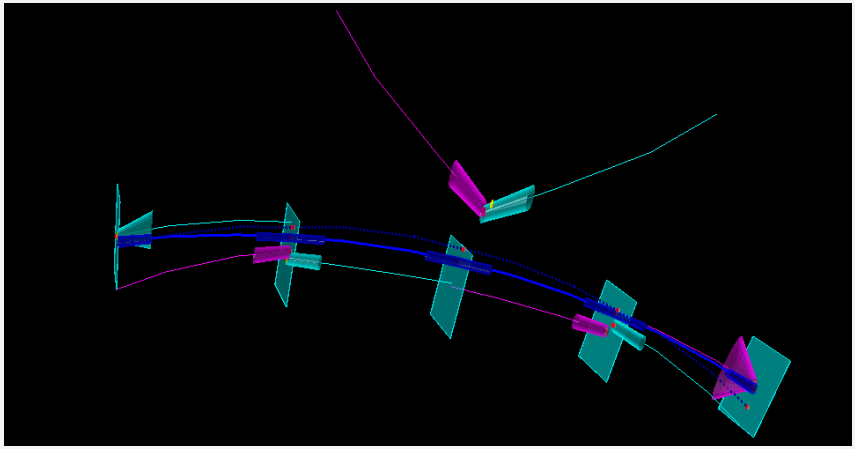
On the next slides: an example

# 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 |

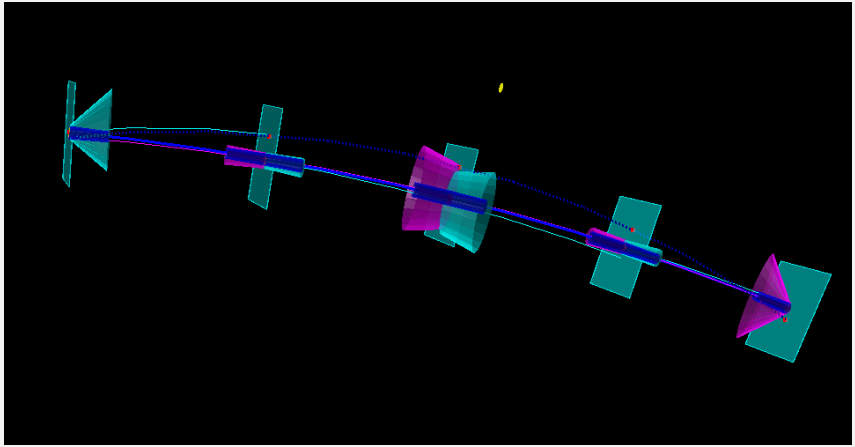
# Outlier - Fitted with the DAF



After the first Kalman fit.

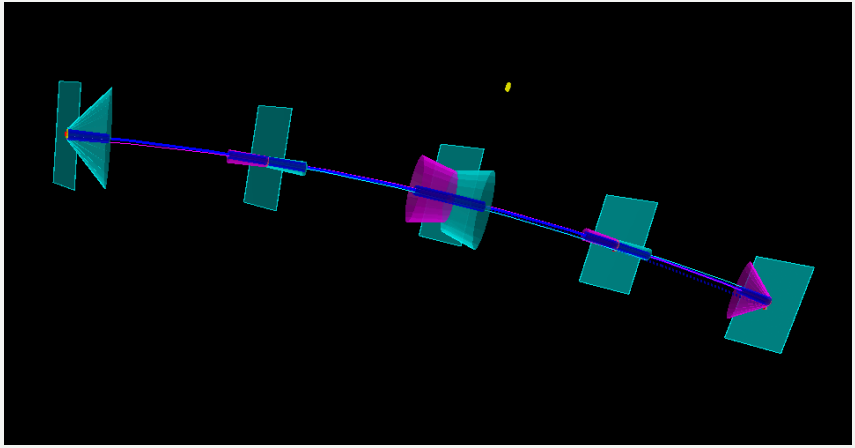
| | | | | | | |
|---|---|---|---|---|---|---|
| $\beta = 17.78$ | initial weights: | 0.4960 | 0.4238 | 0.1940 | 0.4310 | 0.5003 |
| $\log_{10}\beta = 1.25$ | new weights: | 0.5426 | 0.3640 | $6.052e-6$ | 0.3913 | 0.5470 |

# Outlier - Fitted with the DAF



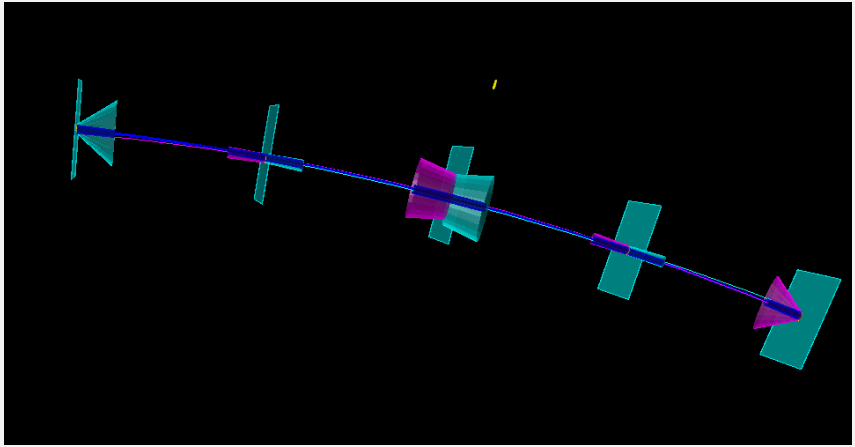
| | | | | | | |
|---|---|---|---|---|---|---|
| $\beta = 3.162$ | initial weights: | 0.5426 | 0.3640 | $6.052e-6$ | 0.3913 | 0.5470 |
| $\log_{10}\beta = 0.5$ | new weights: | 0.8111 | 0.8093 | $4.106e-52$ | 0.8099 | 0.8109 |

# Outlier - Fitted with the DAF



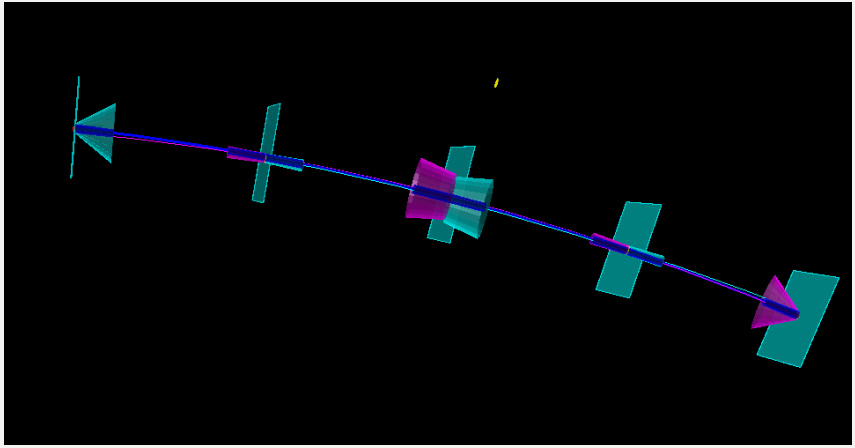
| | | | | | | |
|---|---|---|---|---|---|---|
| $\beta = 0.5623$ | initial weights: | 0.8111 | 0.8093 | $4.106e-52$ | 0.8099 | 0.8109 |
| $\log_{10}\beta = -0.25$ | new weights: | 0.9997 | 0.9997 | $1.725e-290$ | 0.9997 | 0.1000 |

# 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 |

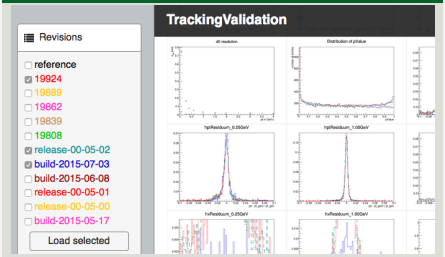
# Outlier - Fitted with the DAF



| | | | | | | |
|---|---|---|---|---|---|---|
| $\beta = 0.1$ | 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