Adaptive Track Fitting in the Inner Tracking Detector of Belle II

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The Belle II experiment and its tracker

- Successor to Belle experiment. Under construction at KEK, Japan
- The upgraded accelerator called SuperKEKB aims at instantaneous luminosity increase from $2.11 \cdot 10^{34}$ to $80 \cdot 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$
- Minimal requirement for tracking system is to cope with that
- Additionally better vertex resolution and reconstruction of lower momentum tracks is anticipated
- The tracking system has (starting from inside) 2 layers of pixel sensors (PXD), 4 layers of double sided strip sensors (SVD), and a central drift chamber (CDC)

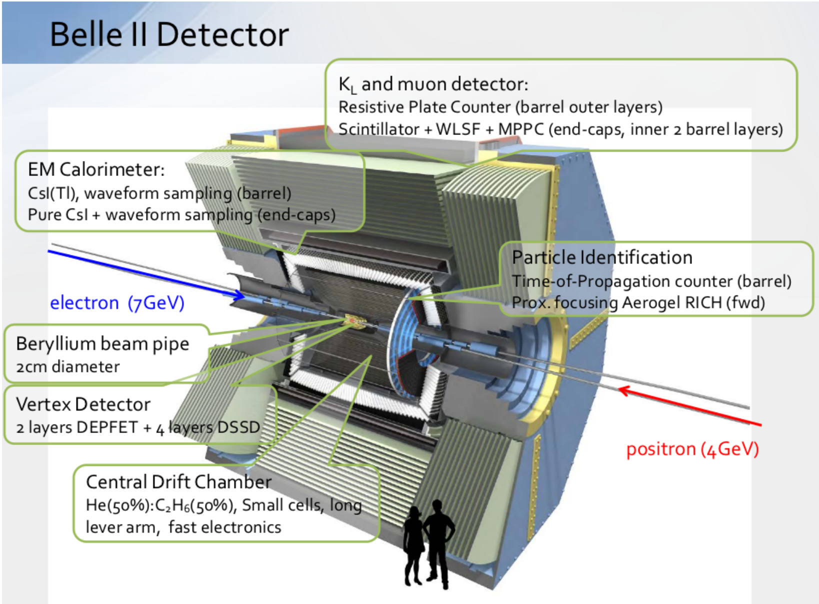


Illustration of the Belle II detector.

Software challenges for new inner tracker

- Very low momentum (below p_T of 100 MeV) tracks are only seen in inner tracker (PXD + SVD)
- For that a SVD only track finding was developed (see poster 74 in afternoon session)
- These tracks suffer from very strong material effects
- Additionally very high background levels are anticipated
- From the track fit side testing and improving modern adaptive track fit algorithms is a natural first step to deal with this environment
- This talk presents the background detection performance of the Deterministic Annealing Filter (DAF) using only measurements from the 6 layers of the inner tracker

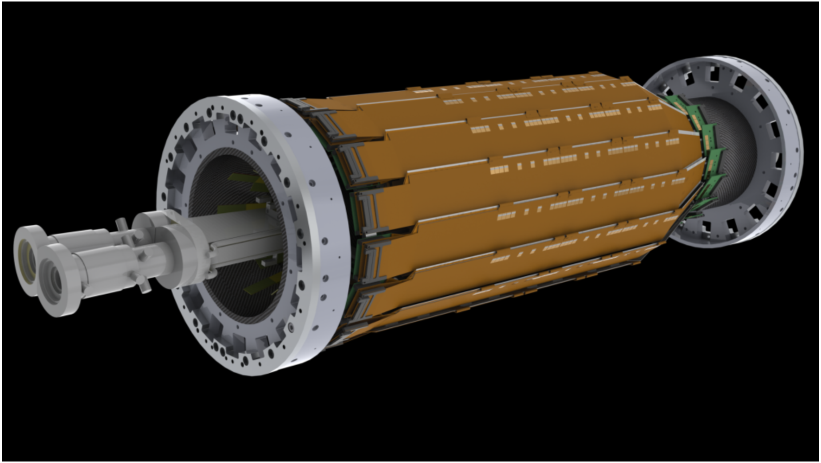


Illustration of inner tracker. The beam pipe and the outer most Si sensor layer are visible. Diameter of the inner tracker $\approx 30\,\mathrm{cm}$, length $\approx 65\,\mathrm{cm}$

basf2

- The Belle II collaboration develops and uses the Belle analysis software framework 2 (basf2)
- basf2 started as a new project, is inspired by other HEP frameworks but not based on any legacy code base
- Modules can be wirtten in C++ or Python, steering files are Python source files
- It uses Geant4 for simulation of particle trajectories, Root for the I/O data format
- Genfit (developed at TU Munich, see poster 448 in afternoon session) is used as its track fit tool kit. A Kalman filter and DAF are already implemented in Genfit.
- Both are still in debugging / validation phase

Track fit algorithms: Kalman filter

- A Kalman filter is an iterative linear estimator
- Standard method of track fitting in HEP
- Starts with a priori track parameters $\boldsymbol{x}$ and covariance matrix $\boldsymbol{C}$
- Proceeds by alternating prediction and update steps
- Prediction means propagation of $\boldsymbol{x}$ to next measurement plane and linear error propagation of $\boldsymbol{C}$
- Any material crossed leads to additional manipulation of $\boldsymbol{x}$ and $\boldsymbol{C}$ according to material model
- Update means correction of prediction with new measurement information

Track fit algorithms: DAF

- The DAF is an iterated Kalman filter with weights and annealing
- Designed for robust track fitting in presence of outlier and background hits
- The weights can be interpreted as probabilities of hits belonging to the track
- The annealing makes it possible to find a globally optimal solution even when the a priori information is bad or first few hits are outliers
- Hits do not have to be removed from tracks and will all contribute according to their estimated weight (soft assignment)

General approach

- First a track sample was simulated and fitted with Kalman filter under perfect conditions
- Then to the same sample artificial background was added and fitted with the DAF
- For different kinds of background the fraction of correctly identified background hits and real hits falsely identified as background hits were calculated
- The impact parameters estimated with and without background were compared
- Parameters for simulation and fitter were not chosen for maximal realism but validation of DAF implementation

Generation of track sample

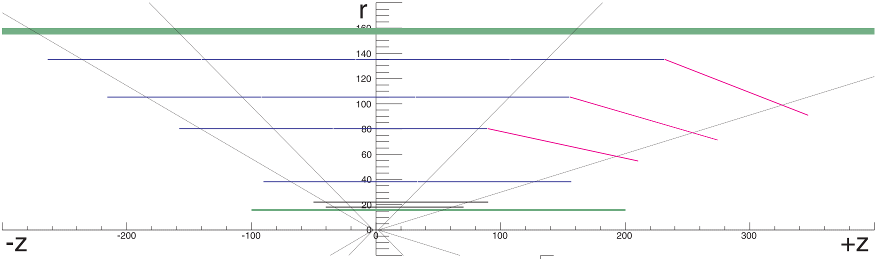
Particle gun, simulation and fitter setup

- Momentum fixed at 1 GeV or 100 MeV, $\Phi \in [0^\circ, 360^\circ]$ uniformly distributed, $\theta = 90^\circ$
- Either μ^+, μ^- uniformly distributed
- Pefect conditions: only Gaussian smearing, truth information used as starting values for track fit and "pattern recognition", homogeneous magnetic field
- Annealing scheme of DAF: 1, 1, 1 ($\Longrightarrow$ no annealing)
- Only tracks with exactly one hit in every layer ($\Longrightarrow$ same information in specific layer for all tracks)
- $\approx$ 3800 Tracks per sample

Parameters of inner tracker as implemented in basf2

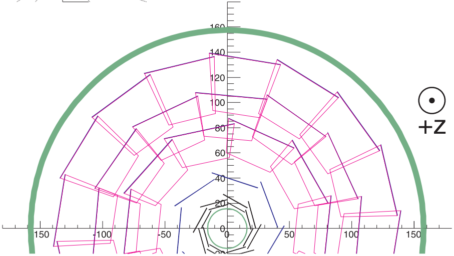
Layer	R [mm]	σ_u [µm]	σ_v [µm]	t [mm]
1	14	14	16	0.42
2	22	14	25	0.42
3	38	15	45	0.32
4	80	22	69	0.32
5	105	22	69	0.32
6	135	22	69	0.32

- From left to right: layer number, layer radius R, measurement resolution in u and v direction, thickness t of the silicon sensors
- u and v are the local coordinates on the sensor planes. v is parallel to beam.
- The measurement resolutions are simply pitch size over $\sqrt{12}$. Real resolutions should be a bit better.




```
conf120510.dat
W -300 400 -20 180 1
B       0.0 0.0 15.0 16.5 -100.0 200.0  0 0 0
O 0.0 0.0 155.0 160.0 -400 800    0 0 0
C       17   150 0.0   2.0       200.0
C       45   135 0.0   2.0       200.0

X  0.3  140.0   22.0        22.0   -50.0     3    1   0.35   -5.0    8
R  0.3  122.8   38.4        38.0   -90.0     1    2   0.4   -6.0    7
R  0.3  122.8   57.6        80.0   -157.6    1    2   0.83   -6.0   10
R  0.3  122.8   57.6       105.0   -215.4    1    3   0.83   -6.0   12
R  0.3  122.8   57.6       135.0   -263.2    1    4   0.6   -7.0   16
S  0.3  122.8   57.6  38.4  135.0    232.0  -21.1      0.6   -7.0   16
S  0.3  122.8   57.6  38.4  105.0    156.0  -16.0      0.83   -6.0   12
*** Total Sensor area=1.1388 / m2 ***
```

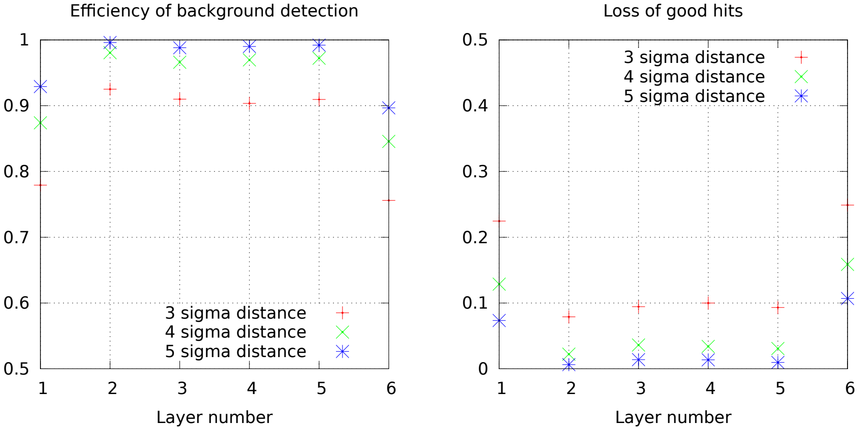


Schematic drawing of PXD and SVD sensor layers. Scale in mm.

Generation of background

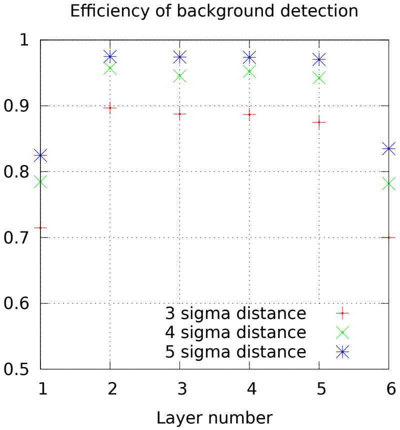
- First an artificial background generation module for basf2 was implemented
- A BG hit was generated with:
  $u_{\mathrm{BG}} = u_{\mathrm{true}} + a\sigma_u \sin(\phi)$
  $v_{\mathrm{BG}} = v_{\mathrm{true}} + a\sigma_v \cos(\phi)$
- $\phi \in [0^\circ, 360^\circ]$ uniformly distributed
- For one track sample a was set to one of 3 fixed values: 3, 4, or 5
- Two different kinds of track samples were prepared:
  either 1 BG for every hit in one specific layer was added $\Longrightarrow$ one BG hit per track
  or 1 BG for every hit in one track was added $\Longrightarrow$ 6 BG hits per track
- After track fitting a hit with a weight under 0.5 was counted as "declared to be background by the DAF" in following results.

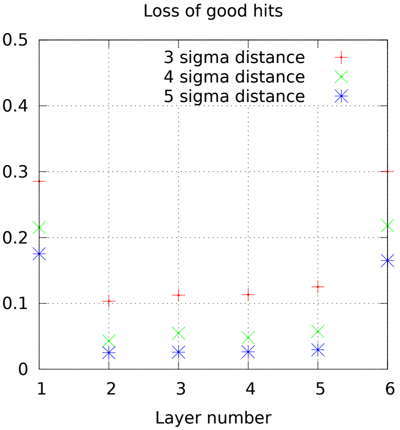
Background hit detection at 1 GeV I



Results from samples with 1 BG hit per track. Each data point stands for a whole track sample.

Background hit detection at 1 GeV II





Results from samples with 6 BG hit per track. Each colour stands for a whole track sample.

Comparison with background free tracks at 1 GeV I

Standard deviation of the impact parameters at point of closest approach to true track origin of tracks with 1 BG hit per track.

para.	no BG	L1	L2	L3	L4	L5	L6
x in µm	17	20	17	18	18	17	17
y in µm	18	20	18	18	18	18	18
z in µm	23	27	23	23	23	23	23
p_x in MeV	30.2	30.6	29.7	31.1	31.3	30.2	30.0
p_y in MeV	29.7	30.2	29.7	31.6	31.0	29.9	30.4
p_z in MeV	1.0	1.0	1.0	1.0	1.0	1.0	1.0

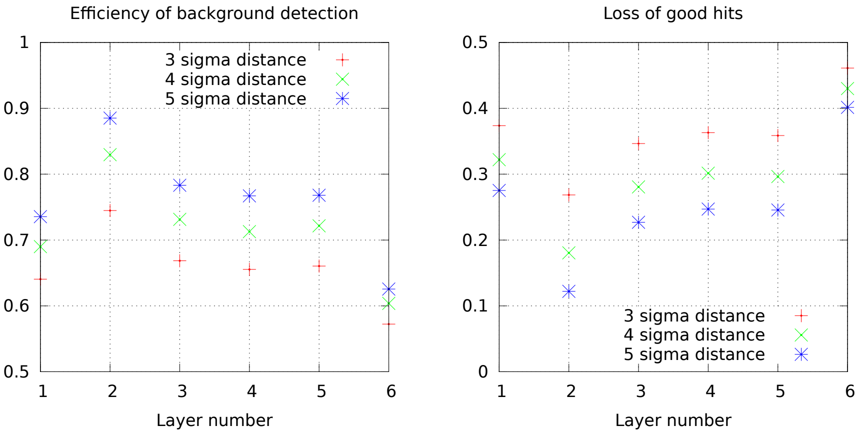
- BG hits have $3\sigma_{\text{meas}}$ distance to true hit
- Other distances ($4\sigma_{\text{meas}}$ and $5\sigma_{\text{meas}}$) give nearly identical result

Comparison with background free tracks at 1 GeV II

Standard deviation of the impact parameters at point of closest approach to true track origin of tracks with 6 BG hits per track.

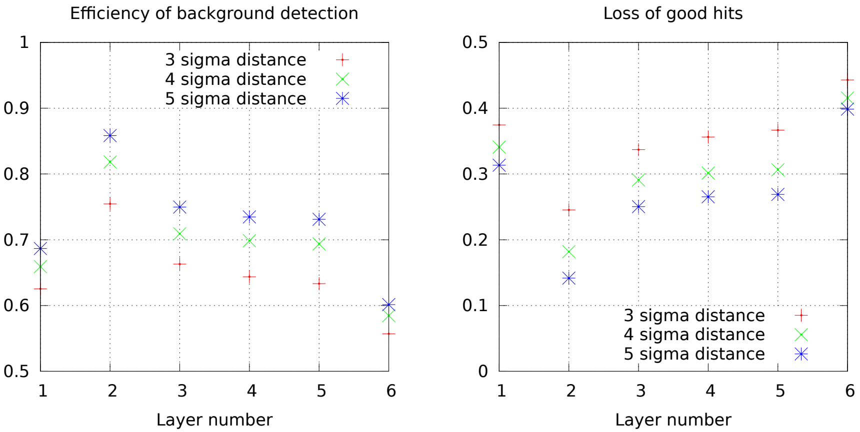
para.	no BG	$3\sigma_{\text{meas}}$ BG	$4\sigma_{\text{meas}}$ BG	$5\sigma_{\text{meas}}$ BG
x in µm	17	22	24	24
y in µm	18	22	24	25
z in µm	23	28	30	31
p_x in MeV	30.2	34.0	35.7	36.1
p_y in MeV	29.7	34.2	36.0	36.8
p_z in MeV	1.0	1.1	1.1	1.1

Background hit detection at 100 MeV I



Results from samples with 1 BG hit per track. Each data point stands for a whole track sample.

Background hit detection at 100 MeV II



Results from samples with 6 BG hit per track. Each colour stands for a whole track sample.

Comparison with background free tracks at 100 MeV I

Standard deviation of the impact parameters at point of closest approach to true track origin of tracks with 1 BG hit per track.

para.	no BG	L1	L2	L3	L4	L5	L6
x in µm	71	106	73	100	75	81	77
y in µm	71	80	76	79	79	80	76
z in µm	99	143	123	139	132	144	130
p_x in MeV	3.6	5.6	7.0	3.5	7.3	7.2	6.8
p_y in MeV	3.7	7.2	9.5	3.5	9.8	9.8	9.0
p_z in MeV	0.7	1.5	1.6	0.8	1.8	1.9	1.6

- BG hits have $3\sigma_{\text{meas}}$ distance to true hit
- Other distances ($4\sigma_{\text{meas}}$ and $5\sigma_{\text{meas}}$) give nearly identical result

Comparison with background free tracks at 100 MeV II

Standard deviation of the impact parameters at point of closest approach to true track origin of tracks with 6 BG hits per track.

para.	no BG	$3\sigma_{\text{meas}}$ BG	$4\sigma_{\text{meas}}$ BG	$5\sigma_{\text{meas}}$ BG
x in µm	71	79	83	86
y in µm	71	76	80	84
z in µm	99	123	128	130
p_x in MeV	3.6	7.4	7.6	7.8
p_y in MeV	3.7	10.2	10.4	10.8
p_z in MeV	0.7	1.9	1.9	2.0

Summary of results

- At moderate track energies BG detection works very well even if a track candidate contains as much BG as real hits and the σ of Impact parameters is only increased by 13 % to 20 %
- A single BG hit per track in any layer besides layer 1 has virtually no effect on the impact parameters.
- At low track energies the picture is worse. The main reason is the strong MSC.
- BG detection very different depending on layer: 2 still quite good, 6 comes close to random guessing

Outlook

- Instead of adding BG hits to the track before fitter it should be done before track finding. DAF must only be able to identify background the track finder could not exclude.
- Investigate how additional information from CDC can improve BG detection in inner tracker
- Investigate impact of additional hits from overlaps and curling tracks on BG detection
- Improve the current implementation of the annealing scheme