A 3D Track Finder for the Belle II CDC L1 Trigger

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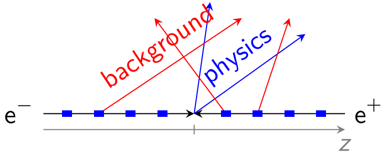
Outline

Introduction - Belle II Background

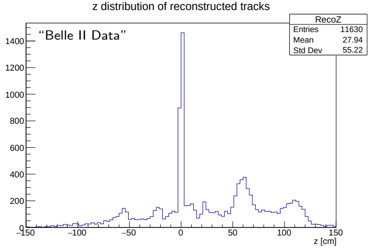
Beam Background Tracks

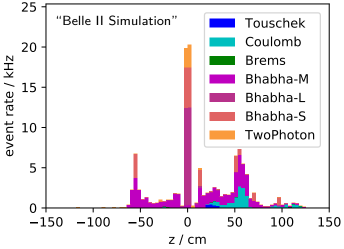


- tracks generated at the beam-line & -wall with vertices $z \neq 0\,\mathrm{cm}$
- increase with luminosity
- main processes:
  - Touschek effect
  - radiative Bhabha back scatters
  - beam gas

NeuroTrigger Goals

- reject tracks from $z \neq 0\,\mathrm{cm}$
- single track z-vertex resolution $< 2\,\mathrm{cm}$
- latency $< 1\,\mu\mathrm{s}$



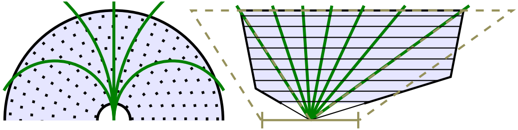


$\Rightarrow$ need z vertex reconstruction at 1st trigger level

3D Hough Finder $(p_T, \varphi, \vartheta)$

Motivation

- include CDC stereo hits
- improve track finding efficiency
- get NN hit selection in one step (axial & stereo)
- estimate ϑ (allow NN sectorization)



Sectors in p_T (left) and in ϑ (right).

Track Finder Concept

Bayes'ian estimation

$$P(tracks|hits) = \frac{P(hits|tracks) \cdot P(tracks)}{P(hits)}$$

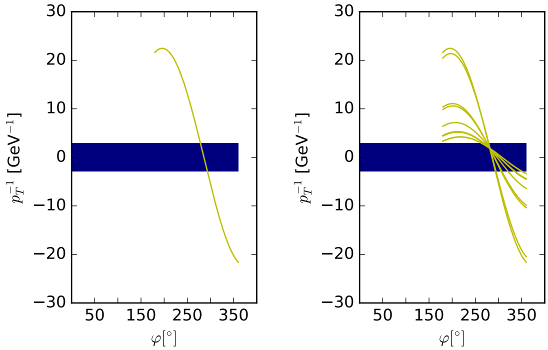
with a set *tracks* and a set *hits*.

- general approach
- allows easy change of the track and hit parametrization
- results equivalent to a Hough transformation

2D Hough Transformation

Hits in Parameter Space

1. conformal mapping: $x' = \frac{2x}{x^2 + y^2}; y' = \frac{2y}{x^2 + y^2}$
2. Hough transform: $p_T^{-1}(\varphi) = C \cdot (x' cos(\varphi) + y' sin(\varphi))$



- hits are sine curves in the p_T^{-1}, φ space
- tracks are intersections
- blue region: $p_T > 350\,\mathrm{MeV}$

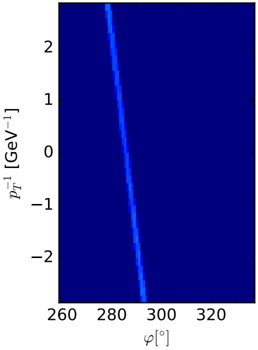
Discrete 2D Hough Space

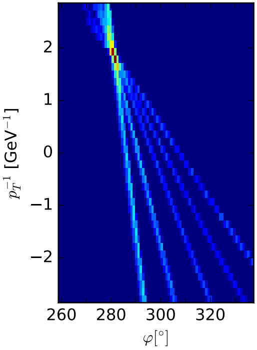
binning of track parameters (φ, p_T)

Construct Houghplane

$$H(t|hits) = \sum_{h \in hits} P(t|h)$$

$P(t|h)$ single hit contributions. $H(t|hits)$: Houghplane for all hits.

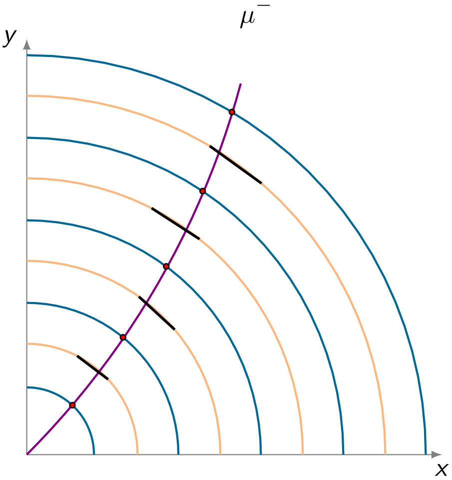




Cluster Peaks

- identify tracks
- are local maxima
- have a minimum weight

Transverse Hit Positions



- axial hits appear as points
- stereo hits as line segments
- ϑ binning allows to represent stereo hits as points

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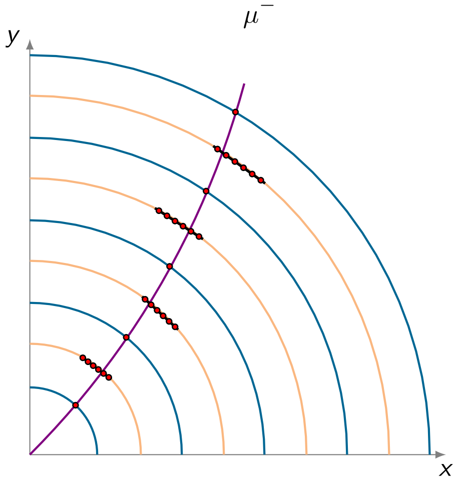

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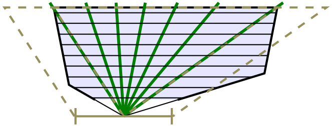
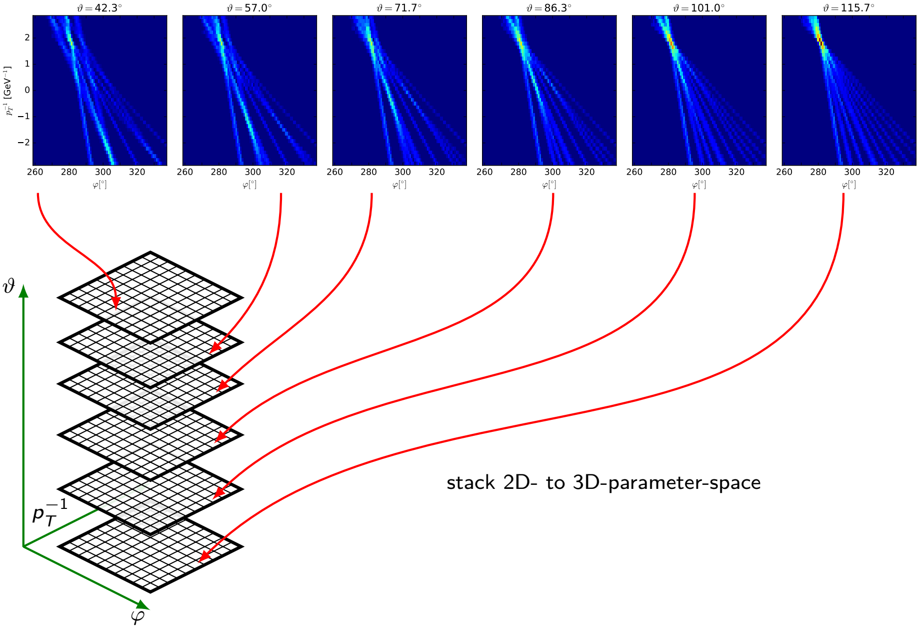


3D Hough Finding



stack 2D- to 3D-parameter-space

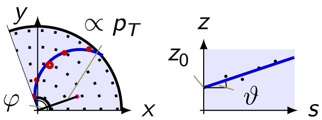
3D Finder Setup

$$H(t|hits) = \sum_{h \in hits} P(t|h)$$

weights for all possible tracks t given a set $hits$.

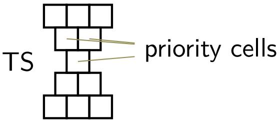
Track Phase Space

- $p_T^{-1}, \varphi, \vartheta$



Hit Phase Space

- TS-id, priority



$P(t|h)$

- approximated by a 5D array A (stored as lookup table)
- A can be trained using Monte Carlo

	p_T	φ	ϑ	id	prio
bins	40	384	6	2336	3

Table: size of the array A

3D Finder Training

Filling

for each track

1. find related hits: h
2. bin track parameters: t
3. increment $A[t, h]$ for all pairs $[t, h]$

Normalization

normalize A for all tracks t ($\equiv$ all tracks are equally probable)

$$A[t, h] = \frac{A[t, h]}{\sum_{\text{all} h} A[t, h]}$$

Set Bit Width

- adjust maximum bit width of each cell in A
- currently 3 bits are used

Track Finding

Construct “Houghplane“

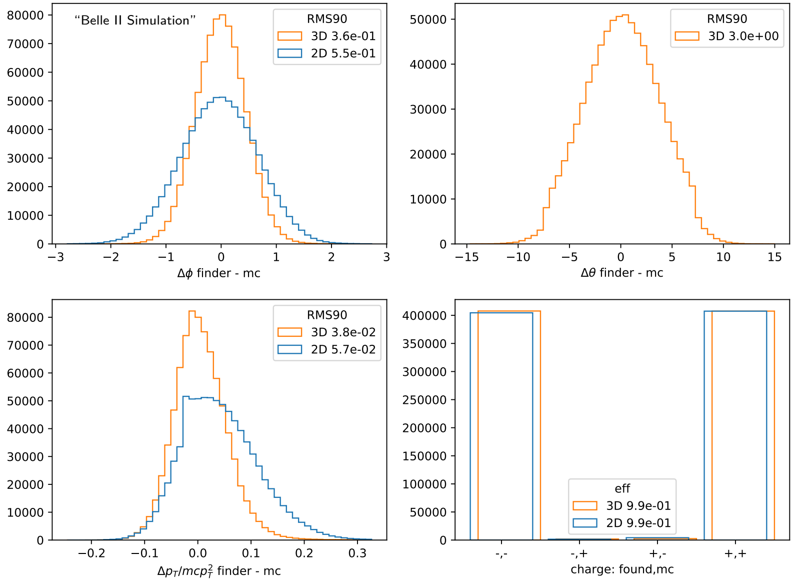
$$H[tracks] = \sum_{h \in hits} A[tracks, h]$$

for an event with a set *hits*, *tracks* are peaks in H

Clustering and Track Estimation

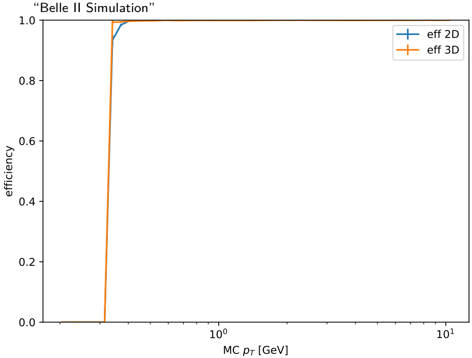
1. find clusters
   density based clustering algorithm (DBSCAN)
   require cluster cells to have a minimum weight: $\texttt{minweight} = 24$
2. select contributing hits
   hits with high weight contribution to the cluster
   require a minimum number of hits related to a cluster: $\texttt{minhits} = 4$
3. calculate track parameters
   weighted mean of cluster cells close to the peak
   require cells to have a minimum weight $> \texttt{thresh} \times$ *peakweight:* $\texttt{thresh} = 0.85$

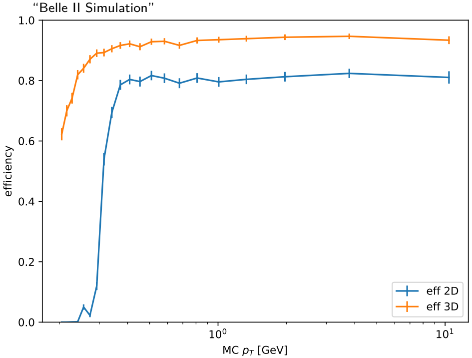
Accuracy



- single $\mu^{\pm}$ IP tracks
var	range
p_T	$[0.35, 7]$ GeV
ϕ	$[0, 360]^{\circ}$
z	$[-1, 1]$ cm
ϑ	$[35, 123]^{\circ}$
- 3D resolution $\Delta\vartheta \approx 3^{\circ}$

Track Finding Efficiency





- tracks in the acceptance region
- $\mu^{\pm}$ track parameters

p_T [GeV]	ϕ [°]	z [cm]	ϑ [°]
[0.35, 7]	360	[−1, 1]	[35, 123]

- tracks with low p_T and ϑ
- $\mu^{\pm}$ track parameters

p_T [GeV]	ϕ [°]	z [cm]	ϑ [°]
[0.2, 7]	360	[−1, 1]	[19, 140]

Summary

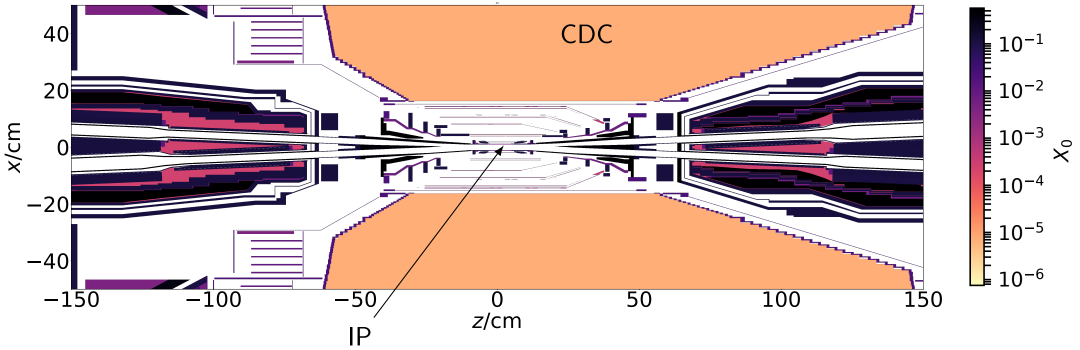
3D Track Finder

- high track finding efficiency
- improves efficiency for tracks with low p_T and flat θ angles
- improves 2D track parameter accuracy
- provides ϑ estimate
- directly relates stereo hits to tracks
- Hough map construction implemented in HW
- HW clustering under investigation

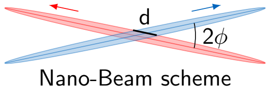
Backup

Introduction - Interaction Region

- scattering at material $\rightarrow$ background tracks
- two separate rings with different energies

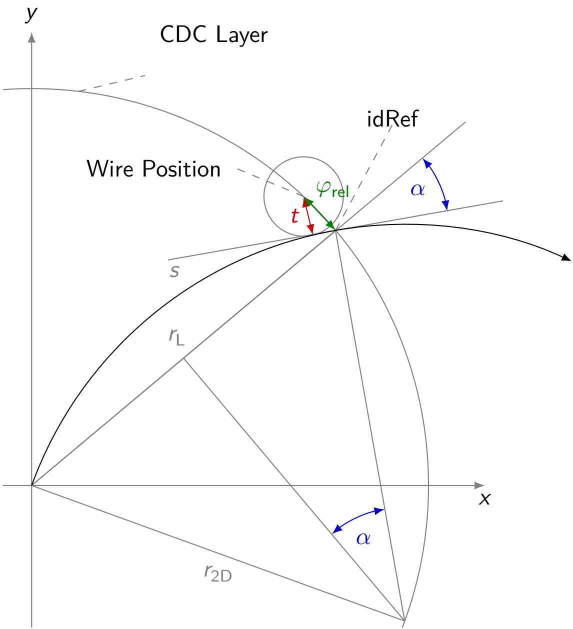


Bunch crossing:



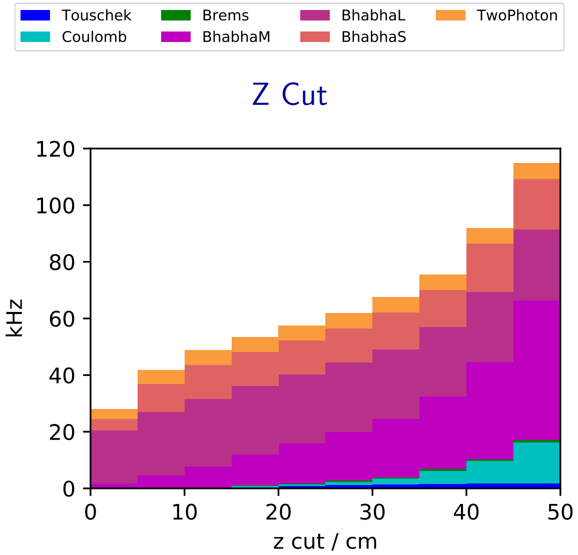
$\sigma_{x,y,z}$	beam size	$\sigma_y \approx 60\,\text{nm}$
ϕ	crossing angle	$\phi \approx 40\,\text{mrad}$
$d = \frac{\sigma_x}{\phi}$	eff. bunch length	$d \approx 0.2\,\text{mm}$

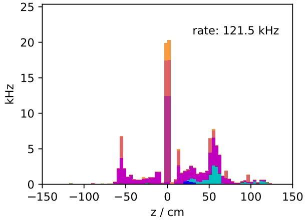
NeuroTrigger - Input Representation



- idRef: crossing point of the track with the layer
- α: crossing angle of the track with the layer
- φ_{rel}: distance of the wire position to idRef
- t: drift time

Background - Suppression





- cumulative bkg rate after a cut on the neural network z
- z_{cut} is varied in 5 cm steps

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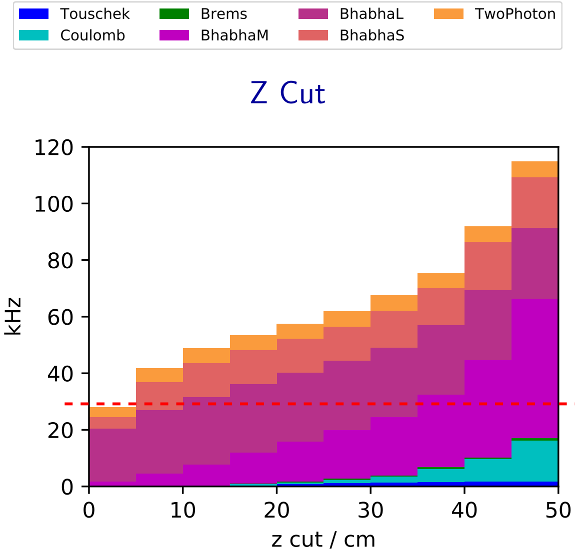

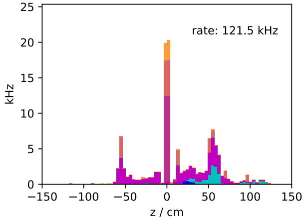

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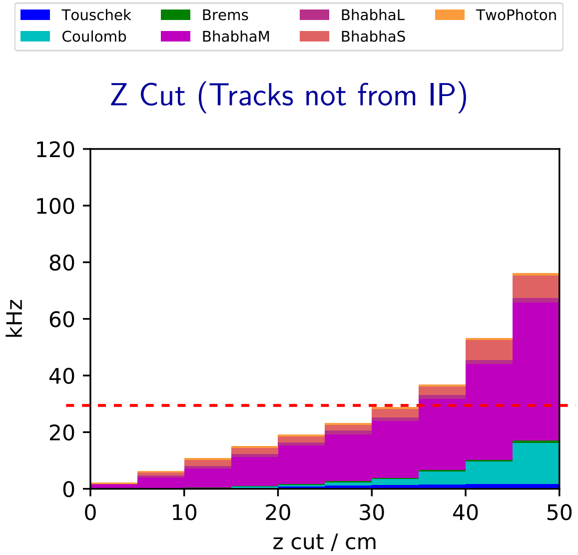

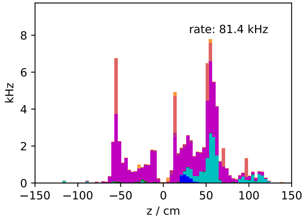

- only tracks with $|z_{MC}| \geq 1\,\text{cm}$
- cumulative bkg rate after a cut on the neural network z
- z_{cut} is varied in 5 cm steps