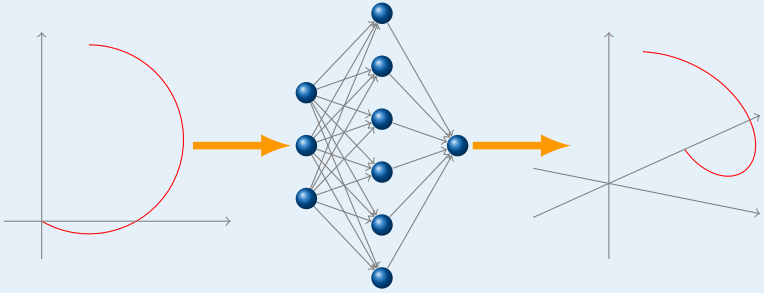
Track vertex reconstruction with neural networks at the first level trigger of Belle II

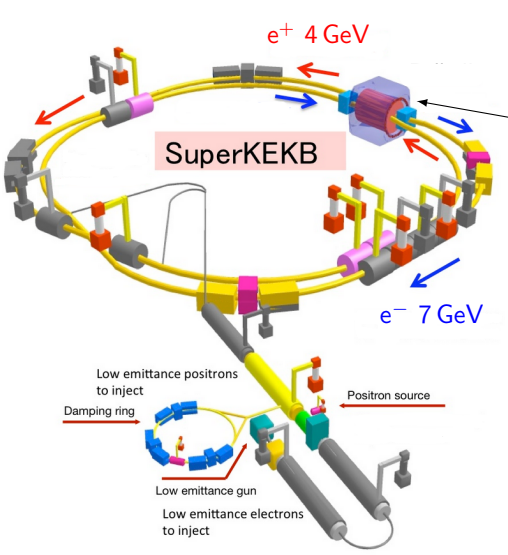
Connecting the Dots / Intelligent Trackers 2017

Mar 6 – 9, 2017

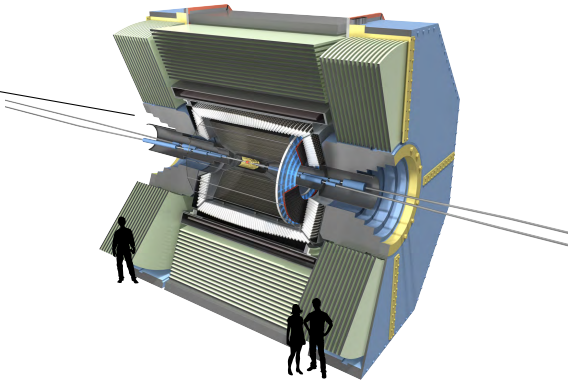


S. Neuhaus, S. Skambraks, C. Kiesling
Max Planck Institute for Physics

The Belle II experiment

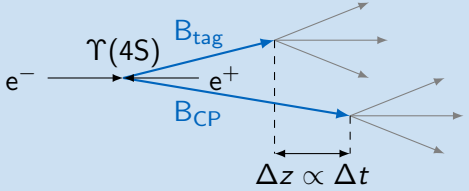


Belle II



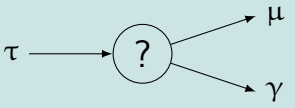
- asymmetric e^+e^- collider
- B factory: $\Upsilon(4S) \rightarrow B\overline{B}$
- $\mathcal{L} = 8 \times 10^{35}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$

Task for the first level trigger



- time dependent CP violation in $B\overline{B}$
- typically $\approx 3 - 9$ tracks

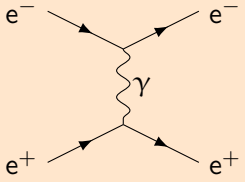
low track multiplicity: $e^+e^- \to \tau^+\tau^-$



- lepton flavor violation
- genuine 2 track trigger

max. trigger rate 30 kHz
total latency 5 µs
pipelined, FPGA

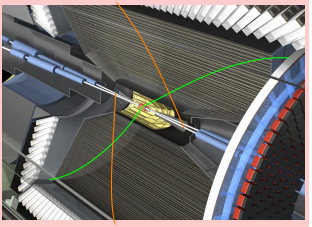
Bhabha scattering



- for calibration
- needs to be prescaled
- Bhabha veto

machine background

- z-vertex $\neq 0$
- suppression requires 3D tracking



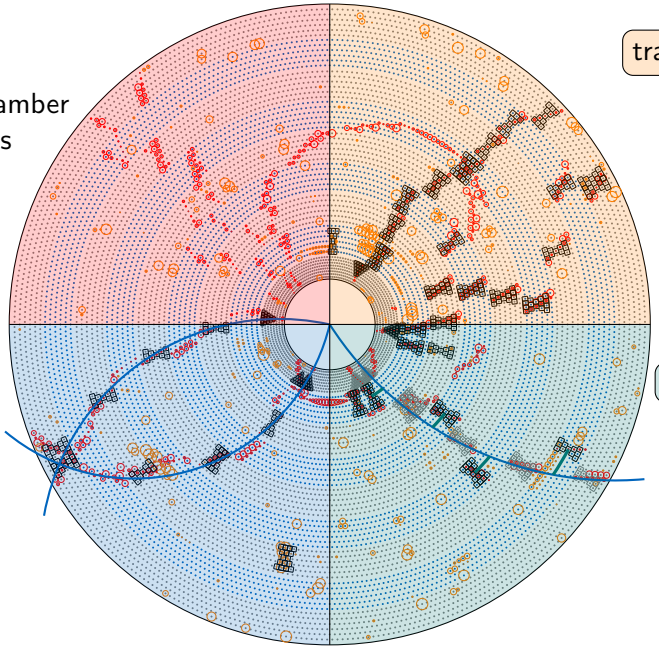
Track trigger – overview

input: CDC hits

Central Drift Chamber
14336 sense wires
56 layers

track segment finder

combine hits
2336 segments
9 super layers



2D track finder

circles in
$x - y$ plane
Hough transform

3D reconstruction

2 methods:
neural network
least squares fit

Track trigger – input

input: CDC hits

Central Drift Chamber
14336 sense wires
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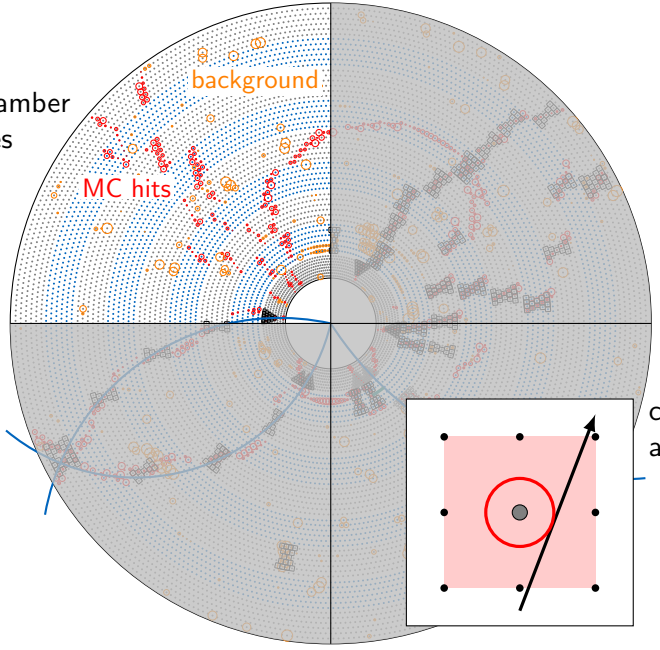

Track trigger – input

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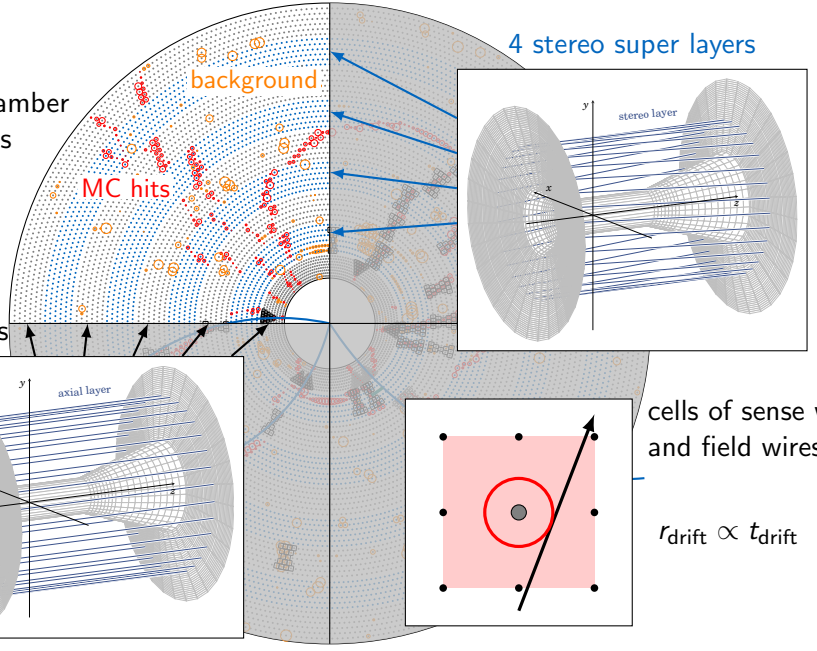
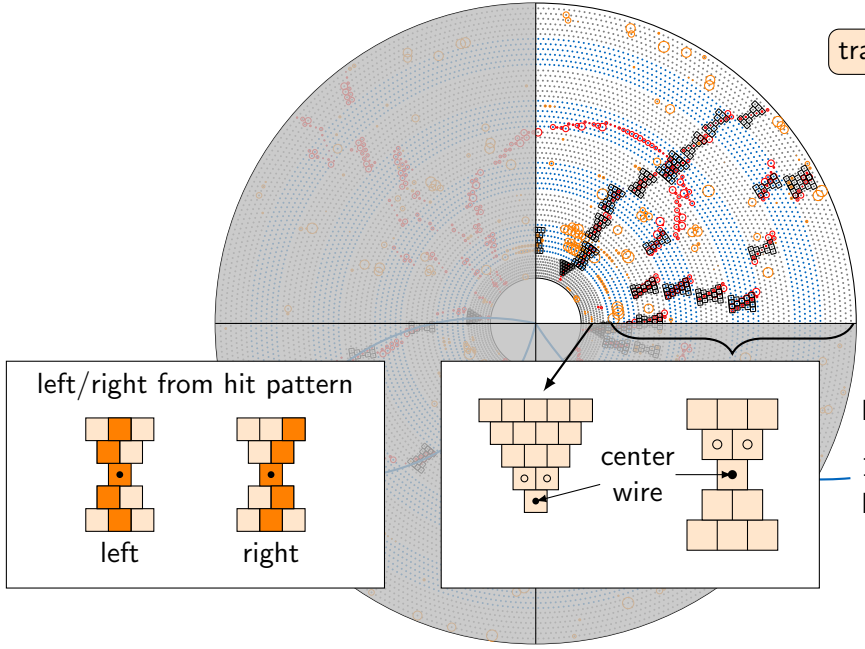


Track trigger – track segment finder



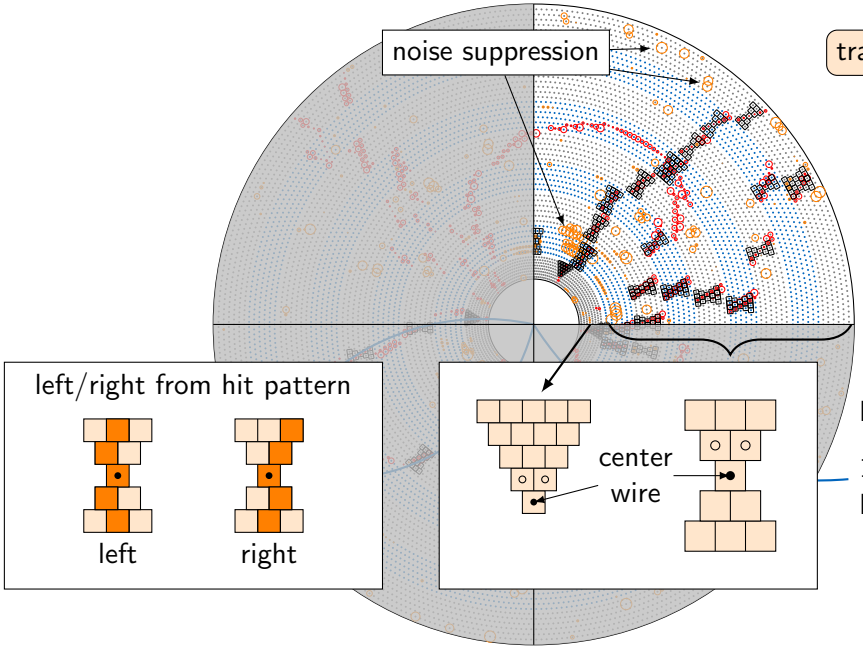
track segment finder

combine hits
2336 segments
9 super layers
→ "layers"

hits in ≥ 4 layers

1 t_{drift} value
left/right passage

Track trigger – track segment finder



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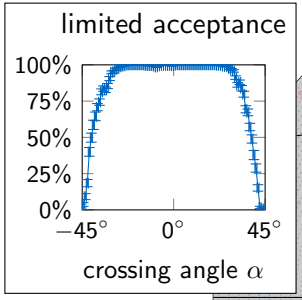
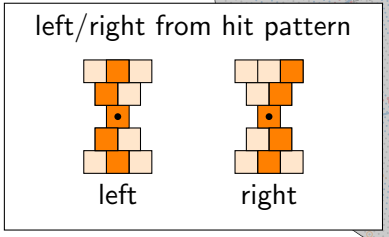
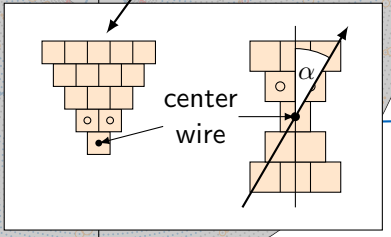


noise suppression

track segment finder

combine hits
2336 segments
9 super layers
→ "layers"





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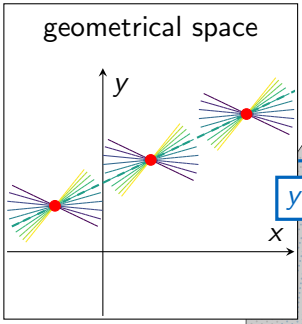
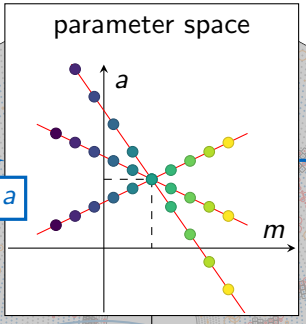
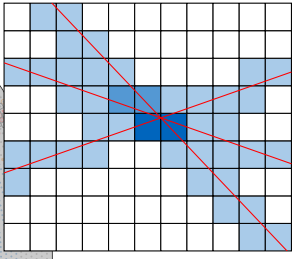
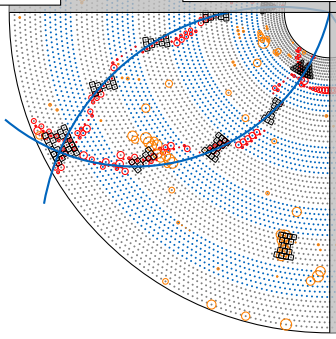
Track trigger – 2D track finder



$y = mx + a$





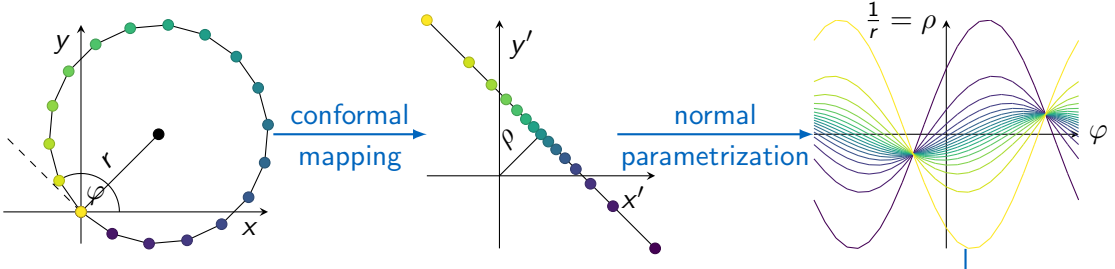


2D track finder

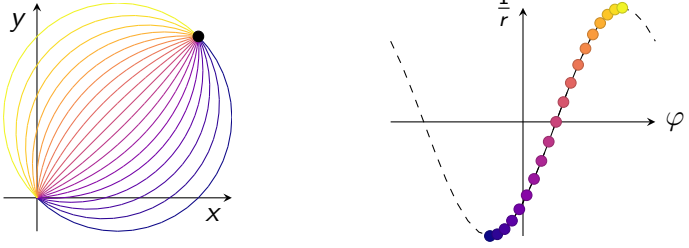
circles in
$x - y$ plane
Hough transform

- track segments from axial layers
- grid in parameter space
- count lines from different layers
- cluster center gives track parameters

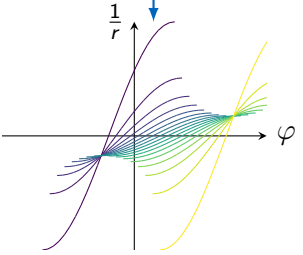
Hough transform for circles



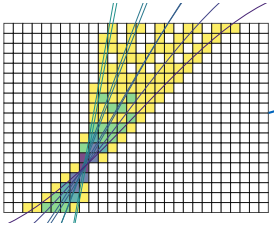
outgoing tracks ≡ rising half of Hough curve



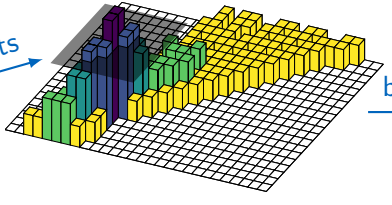
only outgoing tracks



Parallel clustering

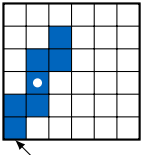


≥ 4 hits

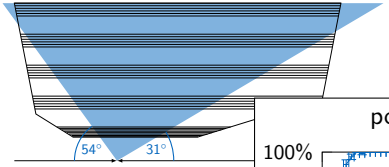


binary grid

cluster area 6×6



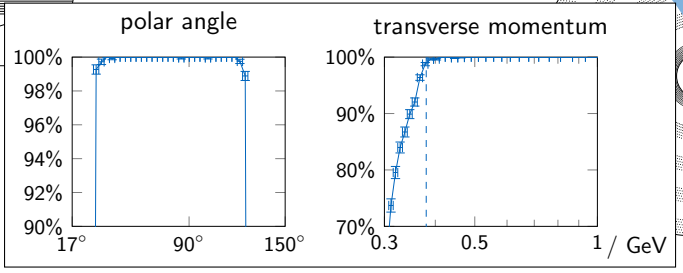
seed: isolated corner

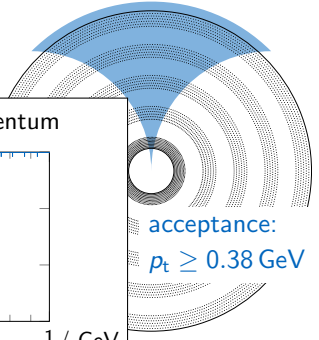


acceptance:

$\theta \in [31°, 126°]$

track finding efficiency

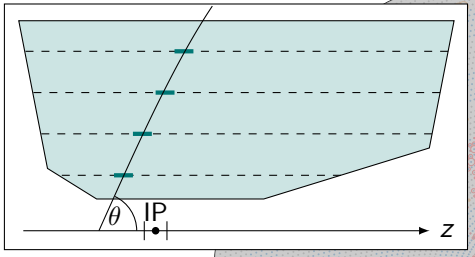


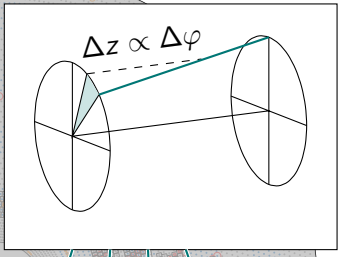


acceptance:

$p_t \geq 0.38\,\text{GeV}$

Track trigger – 3D reconstruction





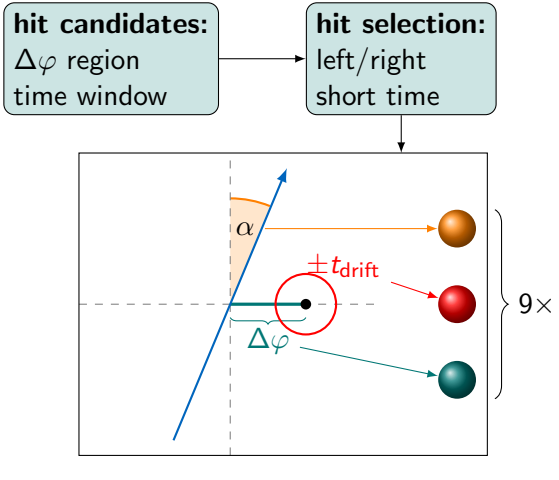
4 z-coordinates from stereo hits and 2D tracks

- precise position: drift time
- event time determined parallel to track finding
- problems with fit: approximations, background

3D reconstruction

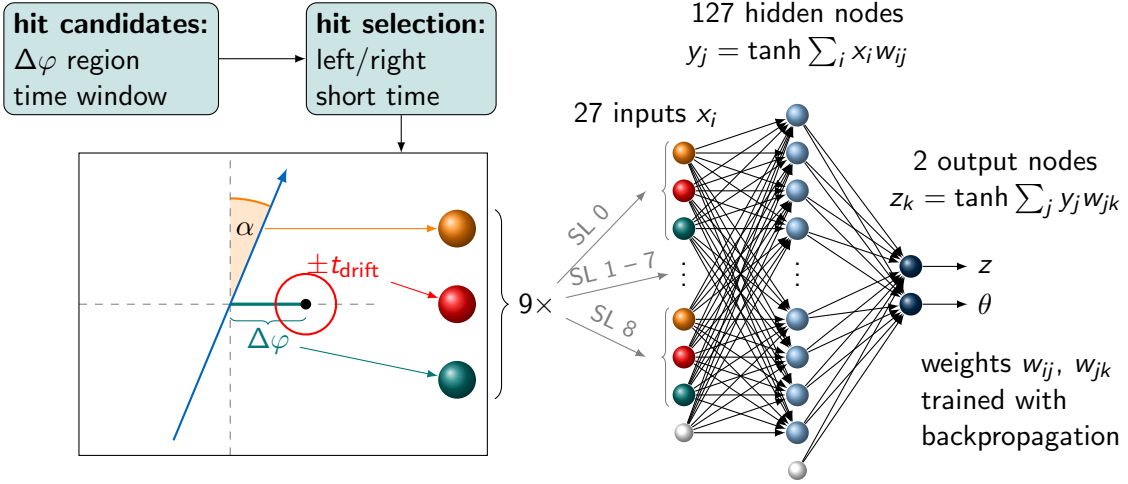
2 methods: neural network least squares fit

Neural network



- drift time separately → nonlinear corrections
- crossing angle α: track curvature
- axial inputs: 2D track corrections

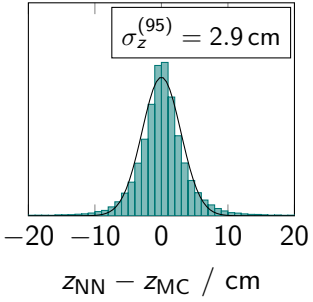
Neural network

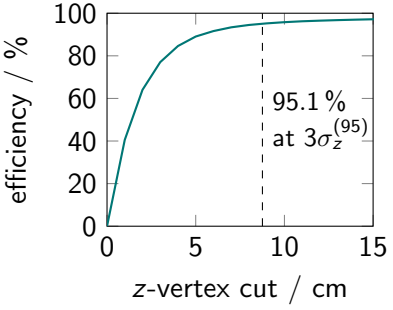


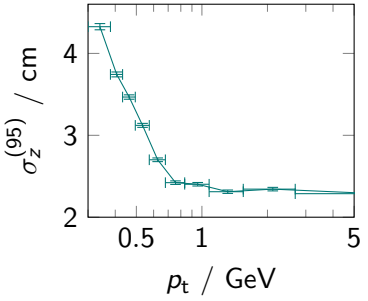
- drift time separately → nonlinear corrections
- crossing angle α: track curvature
- axial inputs: 2D track corrections

- missing axial hit:
  default inputs $(0, 0, 0)$
- missing stereo hit: expert network

z-vertex resolution

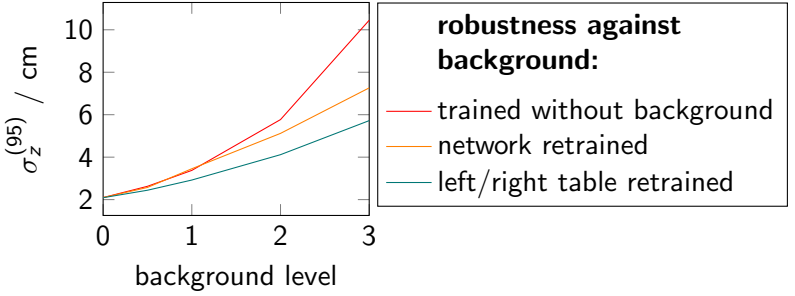




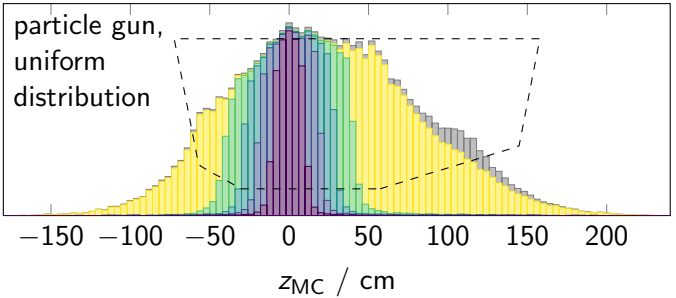


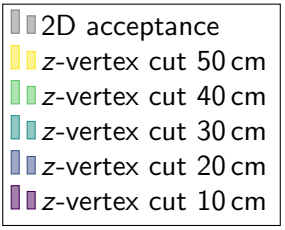
resolution depends on

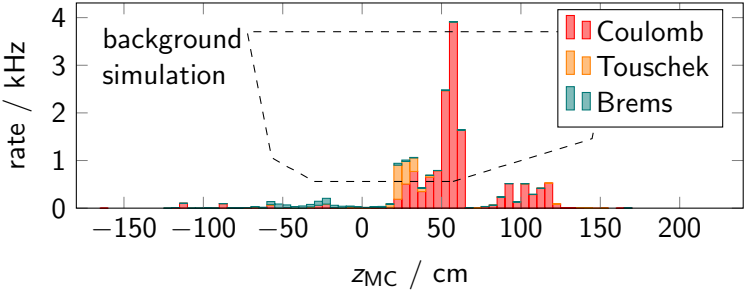
- missing hits
- track curvature
- background hits

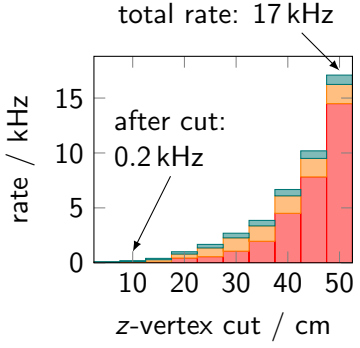


Background rejection



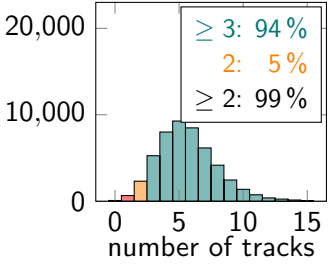




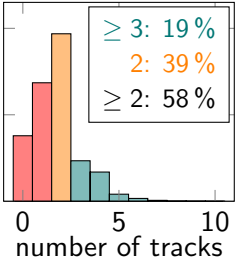


Track trigger efficiency

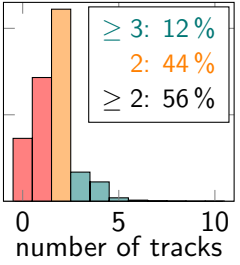
$B\overline{B} \rightarrow$ generic



$\tau^+\tau^- \rightarrow$ generic



$\tau \rightarrow \mu\gamma$



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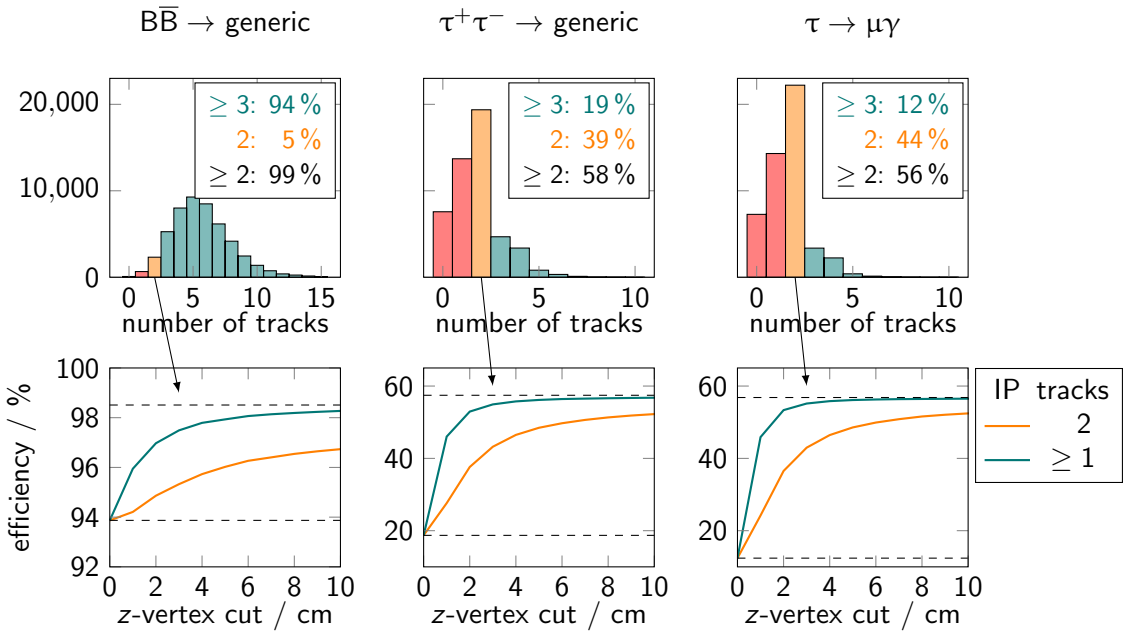
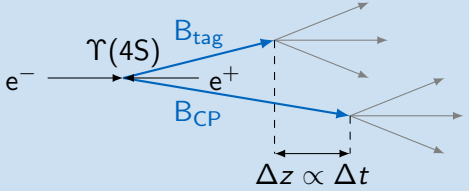


Summary



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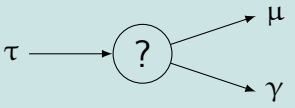
- typically $\approx 3 - 9$ tracks

1. track segments
2. 2D tracks: Hough
3. z-vertex: neural network

low track multiplicity: $e^+e^- \to \tau^+\tau^-$



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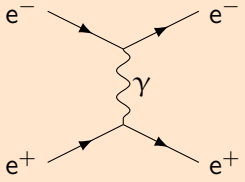
Bhabha scattering



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- Bhabha veto

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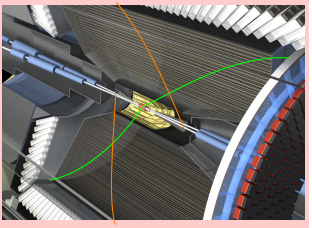
- z-vertex $\neq 0$
- suppression requires 3D tracking



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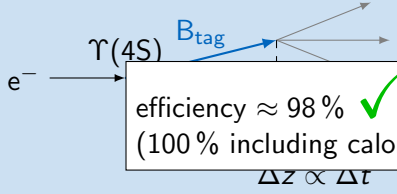

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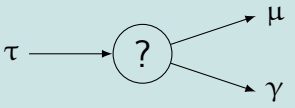

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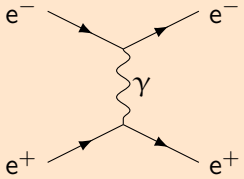

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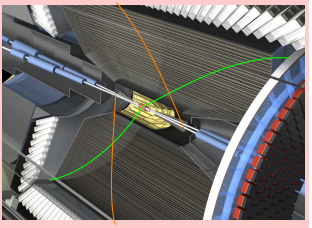

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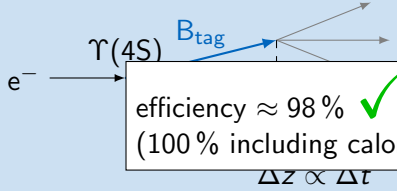

- time dependent CP violation in $B\overline{B}$
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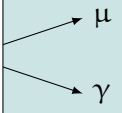
low track multiplicity: $e^+e^- \to \tau^+\tau^-$

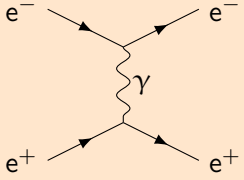
efficiency $\approx 56\,\%$
(12 % for ≥ 3 tracks)
$\to$ gain factor **4.7**



- lepton flavor violation
- genuine 2 track trigger

1. track segments
2. 2D tracks: Hough
3. z-vertex: neural network

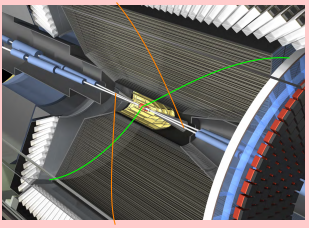
Bhabha scattering



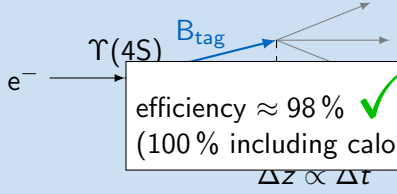
- for calibration
- needs to be prescaled
- Bhabha veto

machine background

- z-vertex $\neq 0$
- suppression requires 3D tracking



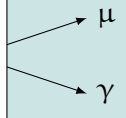
Summary



- time dependent CP violation in $B\overline{B}$
- typically $\approx 3 - 9$ tracks

low track multiplicity: $e^+e^- \to \tau^+\tau^-$

efficiency $\approx 56\,\%$ ✓
(12 % for ≥ 3 tracks)
$\to$ gain factor **4.7**



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- genuine 2 track trigger

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2. 2D tracks: Hough
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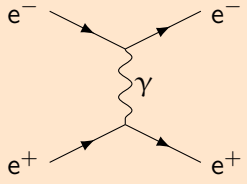
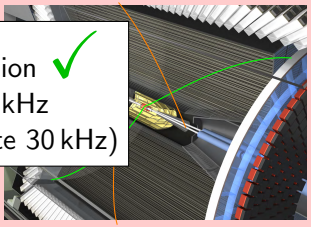
Bhabha scattering



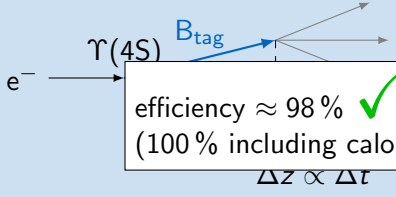
- for calibration
- needs to be prescaled
- Bhabha veto

machine background

efficient rejection ✓
17 kHz $\to$ 0.2 kHz
(maximum rate 30 kHz)



Summary



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μ

γ

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- genuine 2 track trigger

1. track segments
2. 2D tracks: Hough
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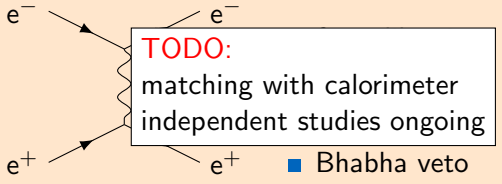
Bhabha scattering



- Bhabha veto

machine background

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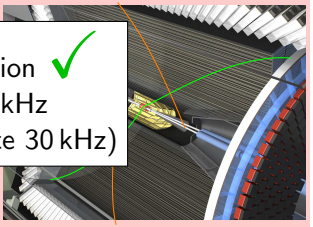
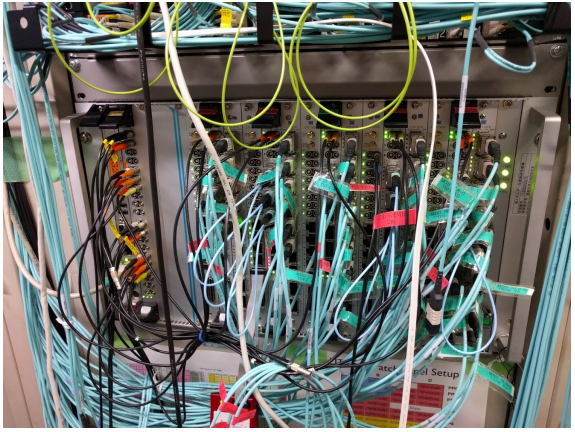


Hardware is waiting for first tests. . .



Hardware team:
S. Bähr, J. Becker

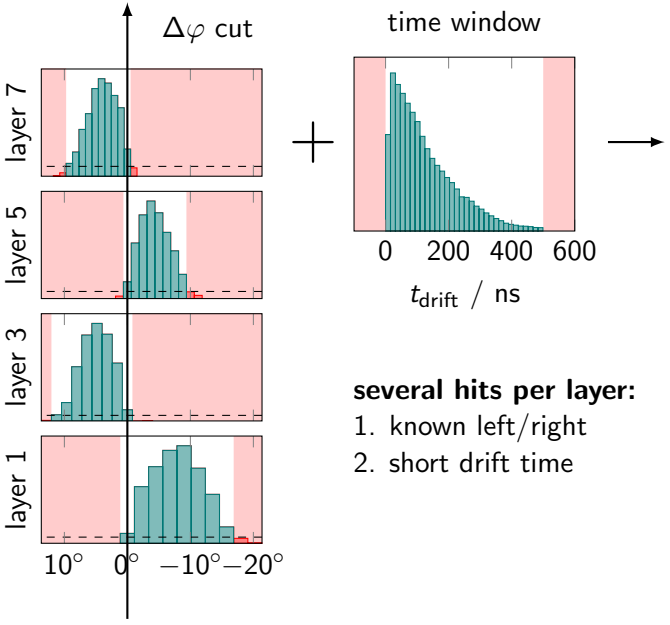
Karlsruhe Institute of Technology

- neural networks implemented on FPGA
- logic tests with simulated input
- installation planned in spring 2017
- cosmic ray tests in summer 2017

Thank you for your attention!

Backup

Hit and network selection



hit in layer 1/3/5/7				expert
✓	✓	✓	✓	#1
✓	✓	✓	—	#2
✓	✓	—	✓	#3
✓	—	✓	✓	#4
—	✓	✓	✓	#5

several hits per layer:

1. known left/right
2. short drift time