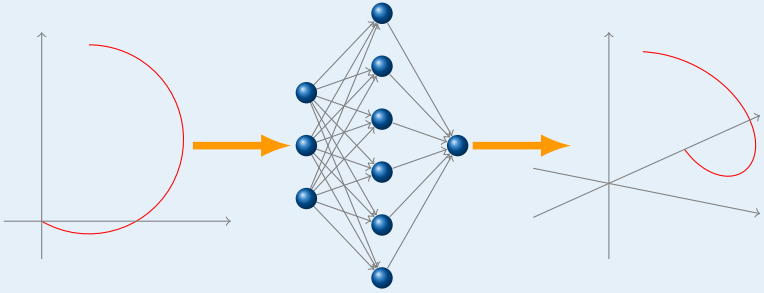
Track vertex reconstruction with neural networks at the first level trigger of Belle II

11th Terascale Detector Workshop 2018

Mar 2, 2018

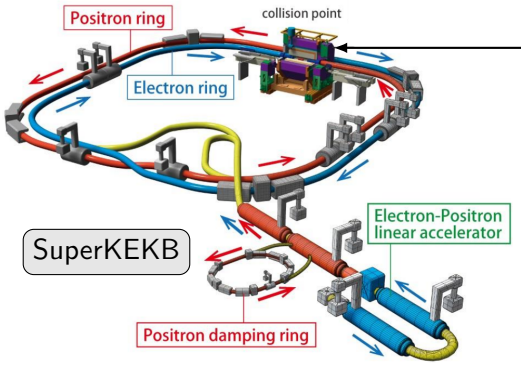


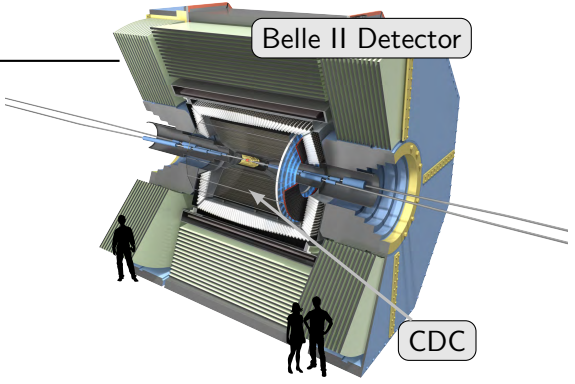
S. Pohl, S. Skambraks, C. Kiesling (MPI)
S. Bähr, J. Becker, F. Bernlochner, T. Reuter, R. van Tonder (KIT)
A. Knoll (TUM)

The Belle II experiment

located at **KEK** in Tsukuba (Japan) (**K**ō **E**nerugī **K**asokuki kenkyū kikou)

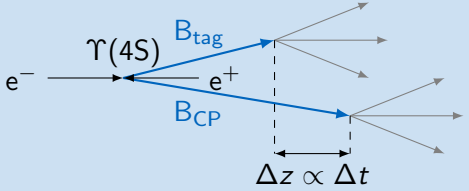
(≡ high energy accelerator research organization)





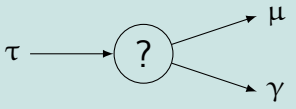
- asymmetric e^+e^- collider (e^-: 7 GeV, e^+: 4 GeV)
- B factory: $\Upsilon(4S)$ resonance, decay $\rightarrow B\overline{B}$
- Luminosity $\mathcal{L} = 8 \times 10^{35}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$, integrated $50\,\mathrm{ab}^{-1}$

Task for the first level trigger



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

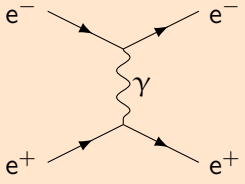
low track multiplicity: $e^+e^- \to \tau^+\tau^-$



- lepton flavor violation
- genuine 2 track trigger

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

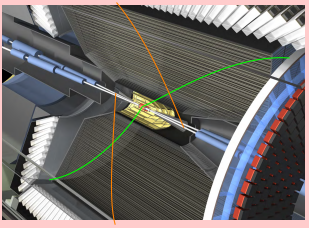
Bhabha scattering



- for calibration
- needs to be prescaled
- Bhabha veto

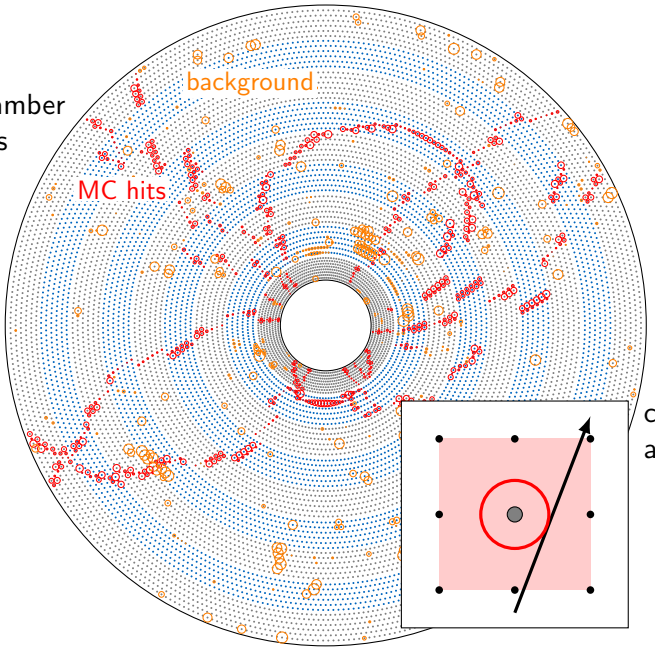
machine background

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



input: CDC hits

Central Drift Chamber
14336 sense wires
56 layers



cells of sense wires
and field wires

$r_{\text{drift}} \propto t_{\text{drift}}$

Track trigger – input

input: CDC hits

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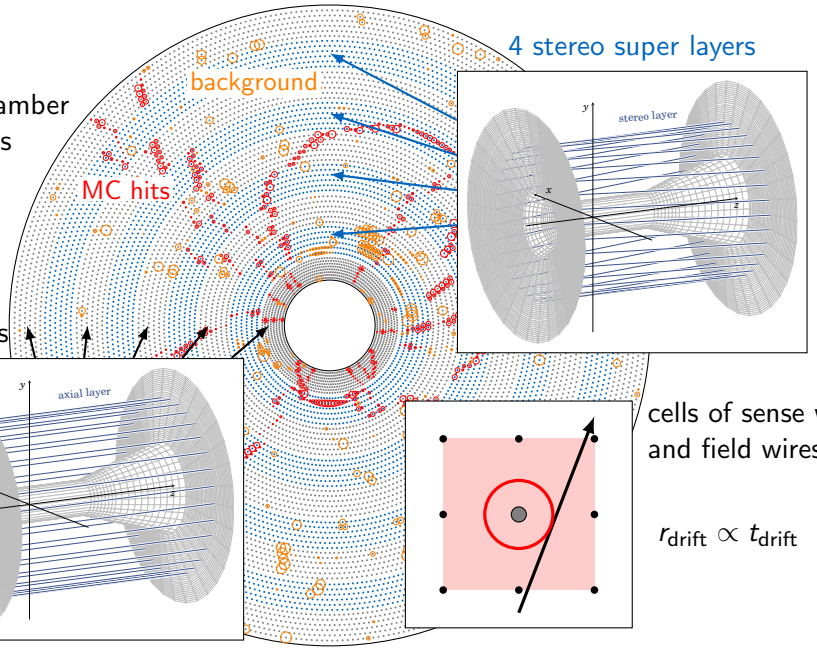


Track trigger – track segment finder

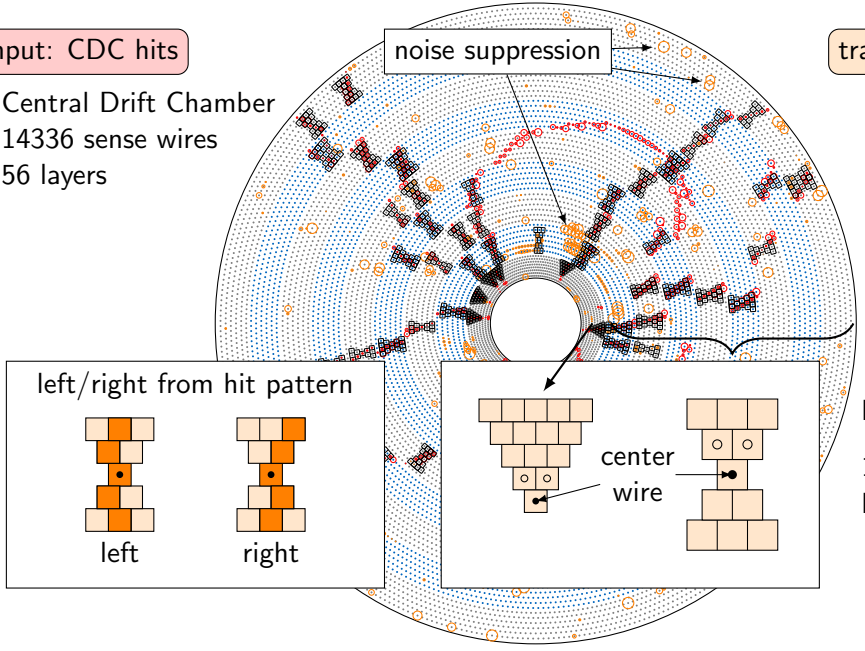
input: CDC hits

Central Drift Chamber
14336 sense wires
56 layers

noise suppression

track segment finder

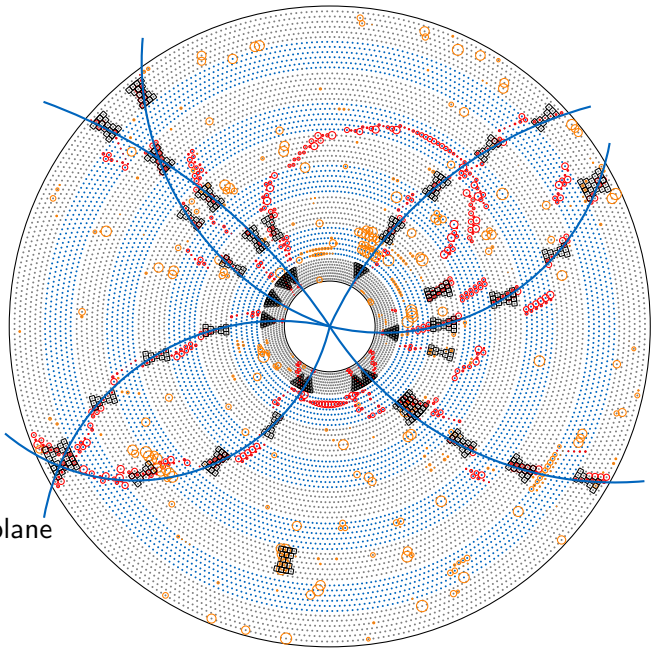
combine hits
2336 segments
9 super layers



hits in ≥ 4 layers

1 t_{drift} value
left/right passage

Track trigger – 2D track finder



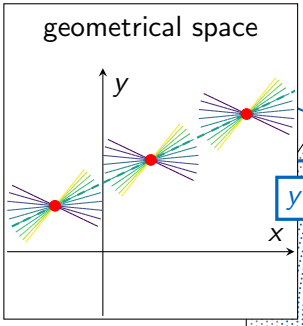
2D track finder

track segments from axial layers

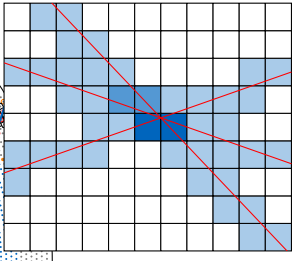
circles in $x - y$ plane

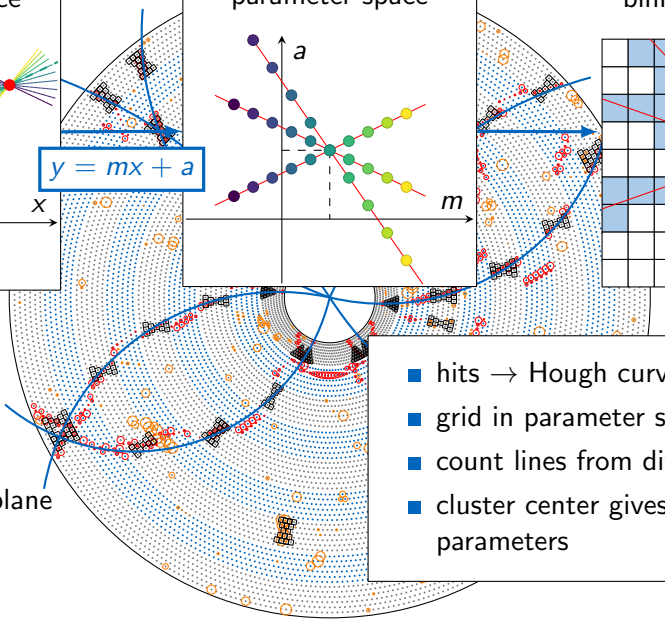
Hough transform

Track trigger – 2D track finder



$y = mx + a$





2D track finder

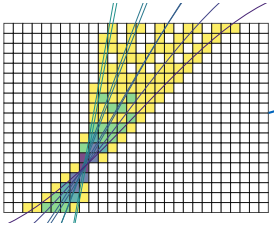
track segments from axial layers

circles in $x - y$ plane

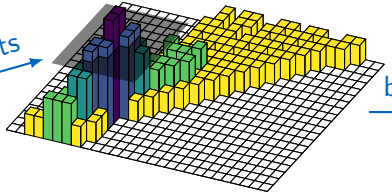
Hough transform

- hits → Hough curves
- grid in parameter space
- count lines from different layers
- cluster center gives track parameters

Parallel clustering

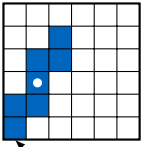


≥ 4 hits

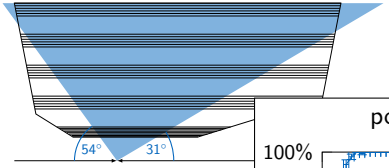


binary grid

cluster area 6×6



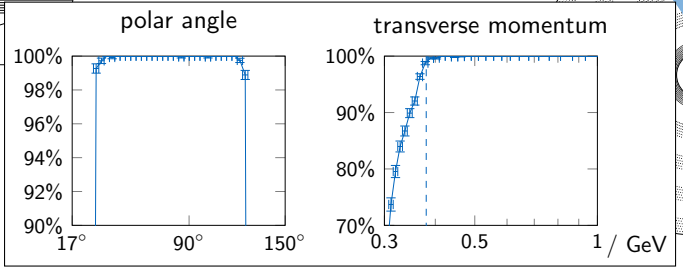
seed: isolated corner

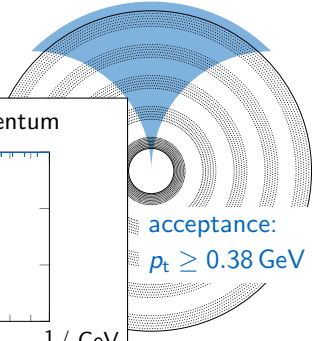


acceptance:

$\theta \in [31°, 126°]$

track finding efficiency

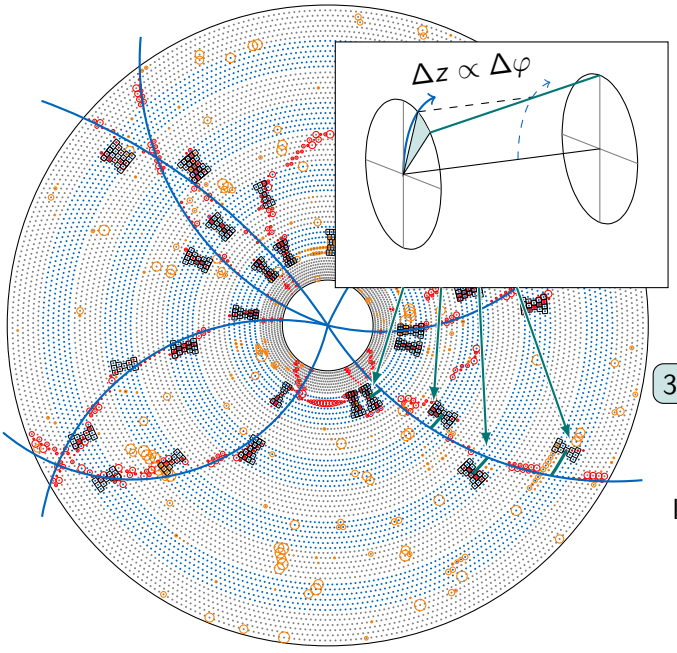




acceptance:

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

Track trigger – 3D reconstruction

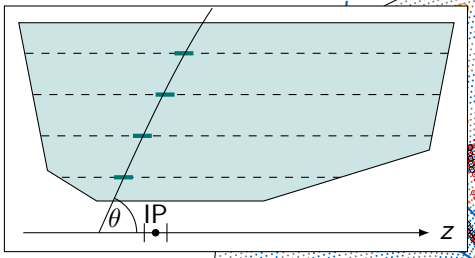


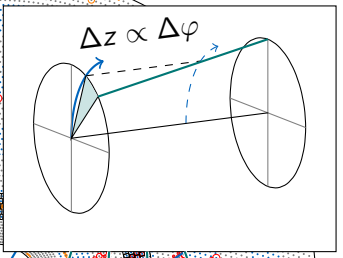
4 z-coordinates from stereo hits and 2D tracks

3D reconstruction

2 methods:
neural network
least squares fit

Track trigger – 3D reconstruction





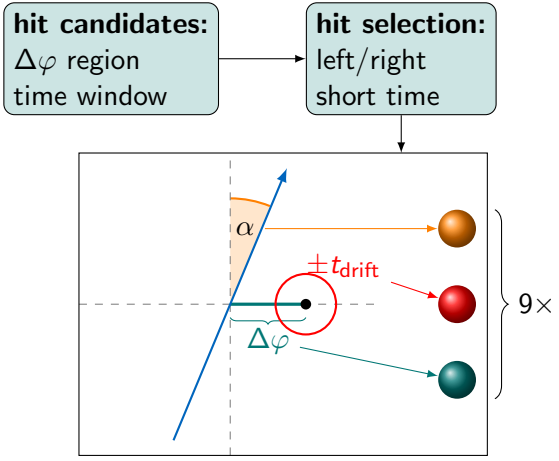
4 z-coordinates from stereo hits and 2D tracks

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

3D reconstruction

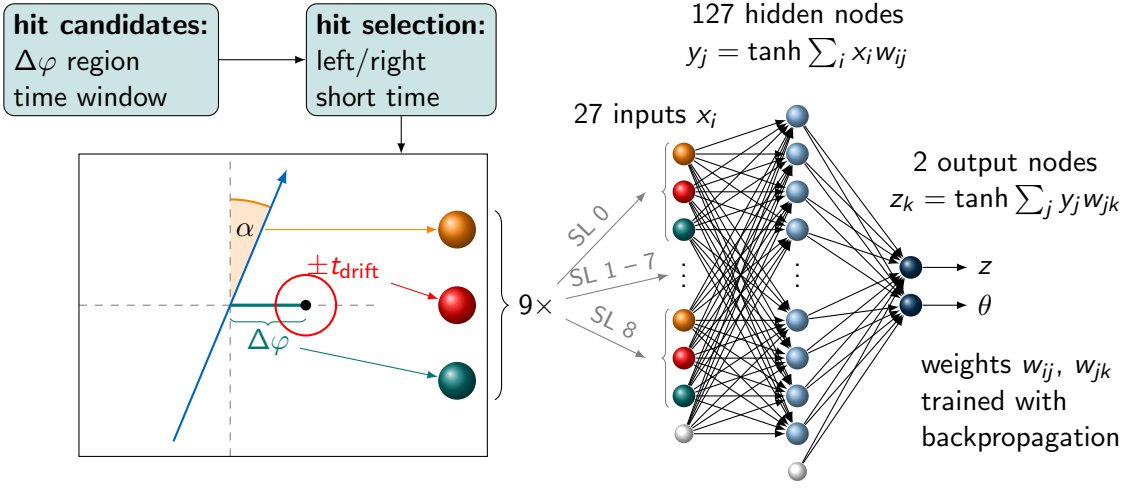
2 methods: neural network least squares fit

Neural network



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

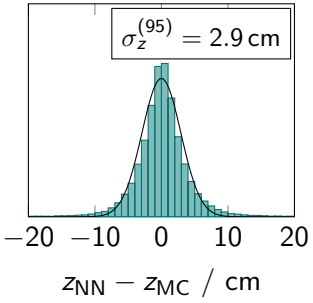
Neural network

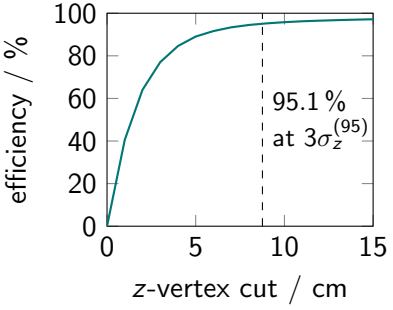


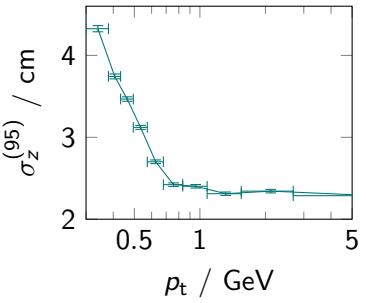
- drift time separately → nonlinear corrections
- crossing angle α: track curvature
- axial inputs: 2D track corrections

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

z-vertex resolution

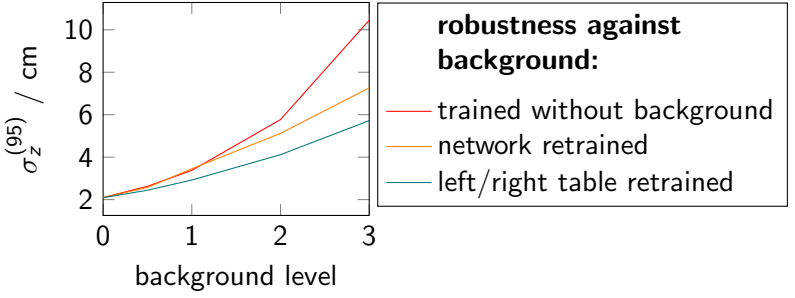




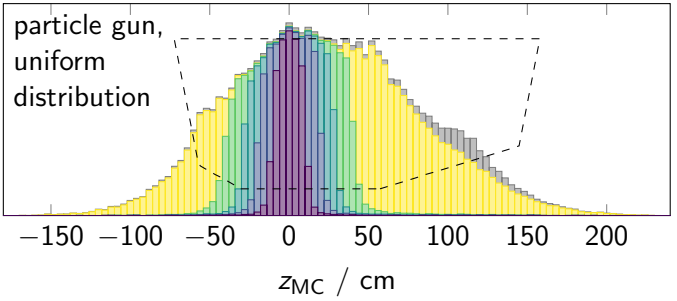


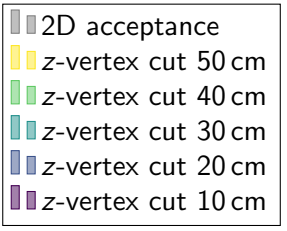
resolution depends on

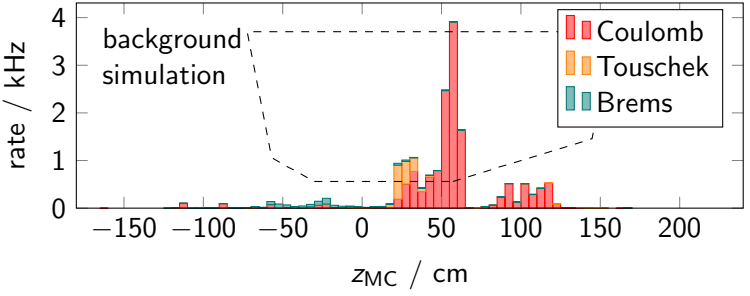
- missing hits
- track curvature
- background hits

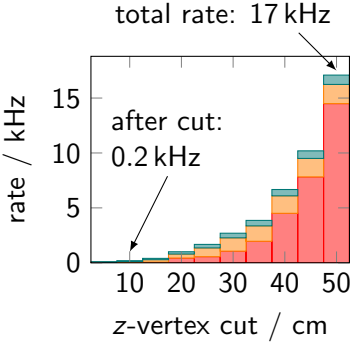


Background rejection



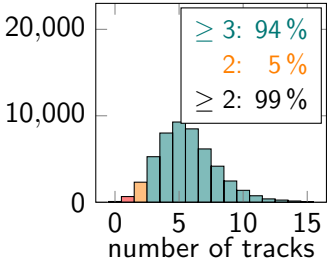




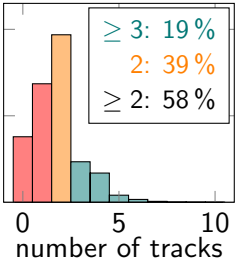


Track trigger efficiency

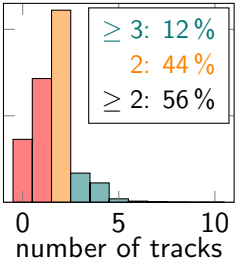
$B\overline{B} \rightarrow$ generic



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



$\tau \rightarrow \mu\gamma$



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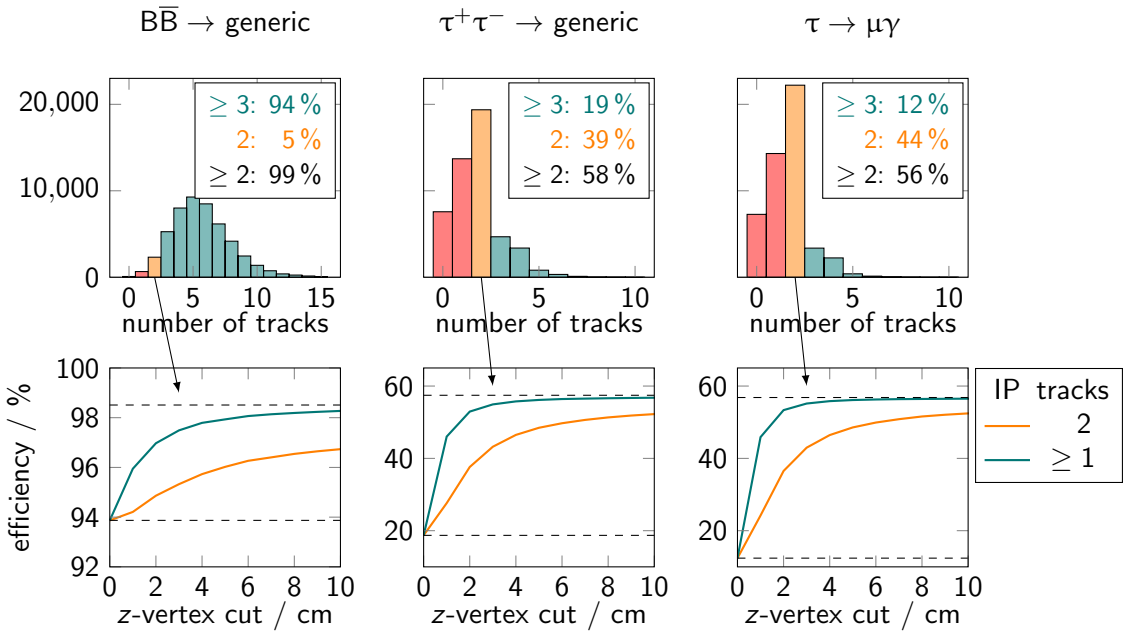
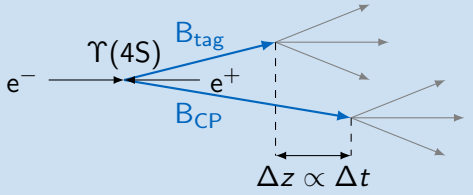


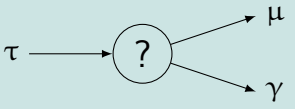
Summary



- time dependent CP violation in $B\overline{B}$
- 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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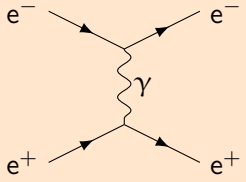
Bhabha scattering



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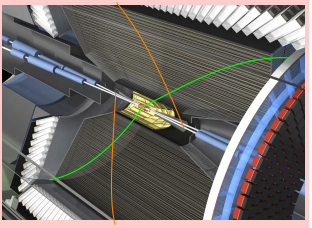

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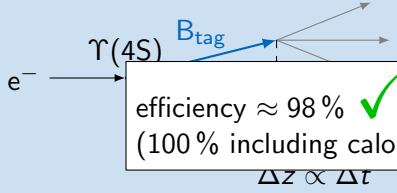

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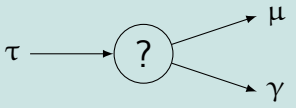

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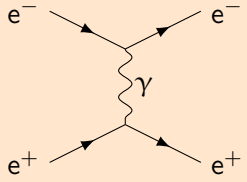

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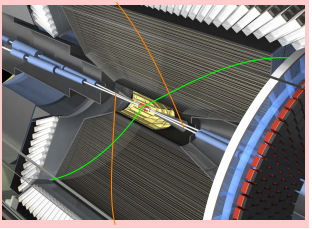

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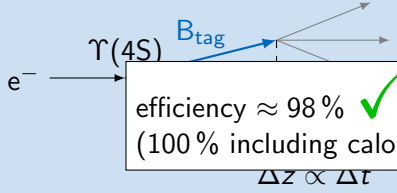

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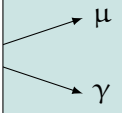
(12 % for ≥ 3 tracks)
$\to$ gain factor **4.7**



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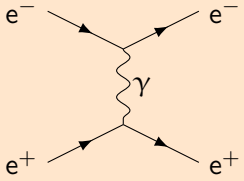

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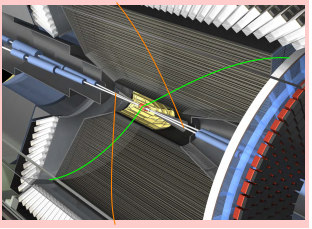

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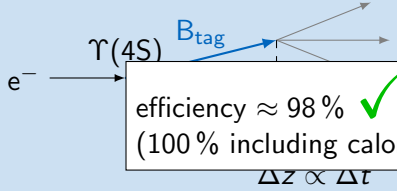

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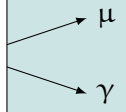

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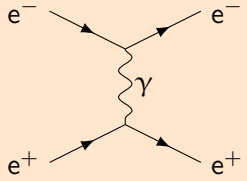
3. z-vertex: neural network

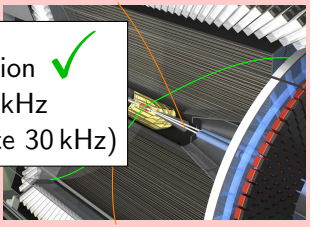
Bhabha scattering



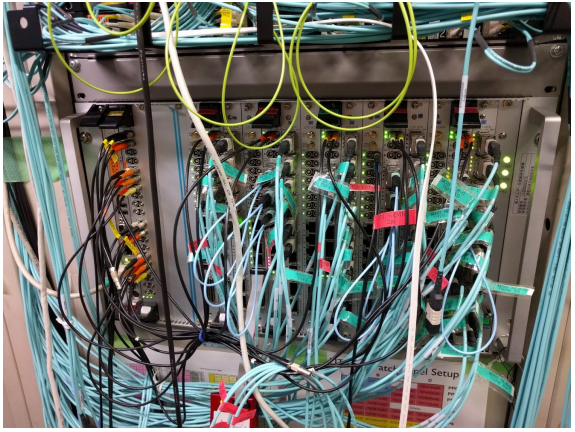
- for calibration
- needs to be prescaled
- Bhabha veto

machine background

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



Hardware is looking at first data...



Hardware team:
S. Bähr, T. Reuter,
J. Becker

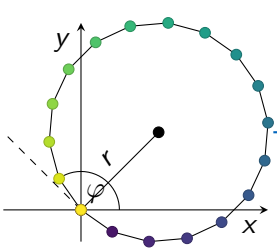
Karlsruhe Institute of Technology

- neural networks implemented on FPGA
- tests with cosmic rays ongoing
- hardware results and simulation agree
- next step:
  comparison to reconstructed tracks
- first collisions in April 2018

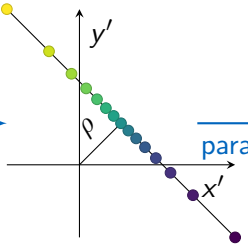
Thank you for your attention!

Backup

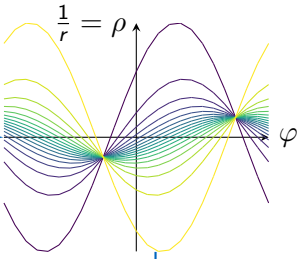
Hough transform for circles



conformal mapping

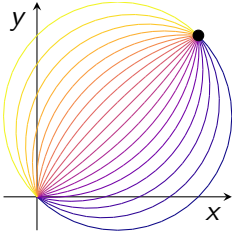


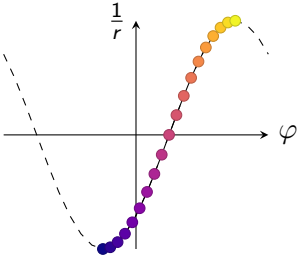
normal parametrization

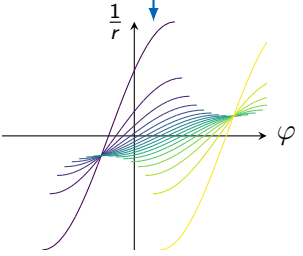


only outgoing tracks

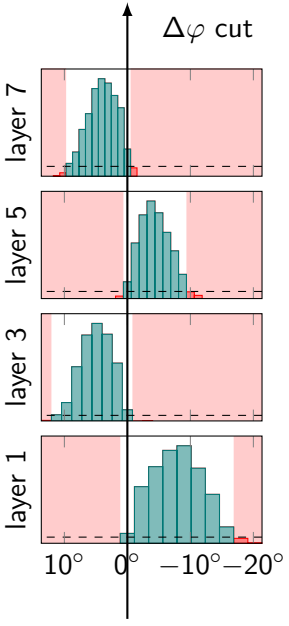
outgoing tracks ≡ rising half of Hough curve

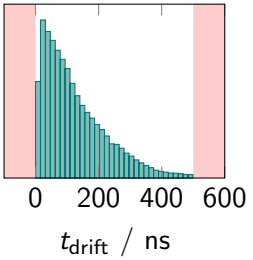






Hit and network selection





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