Background Suppression with the Belle II Neural Network Trigger

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Neuro Team
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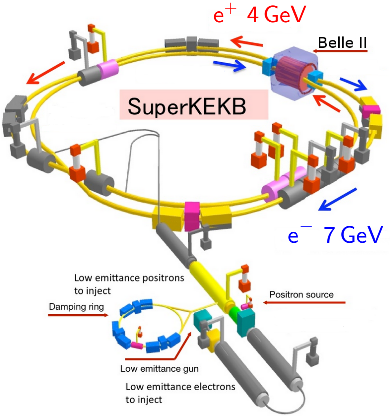
Outline

Introduction - Belle II at SuperKEKB

located in Tsukuba, Japan at **KEK**

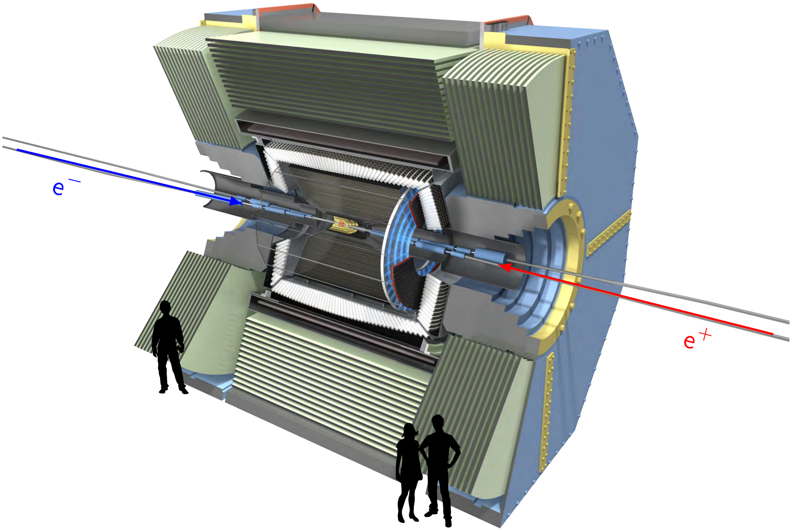
高エネルギー加速器研究機構
Kō **E**nerugī **K**asokuki kenkyū kikou

High Energy Accelerator Research Organization



- asymmetric $e^+ e^-$ collider
- $\Upsilon(4S)$ resonance
  ↳ $B^0\,\overline{B}^0 / B^+\,B^-$
- $\mathcal{L} = 8 \times 10^{35}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ (40× KEKB)
- average p_T: 500 MeV
- average track multiplicity: 11

Introduction - The Belle II Detector



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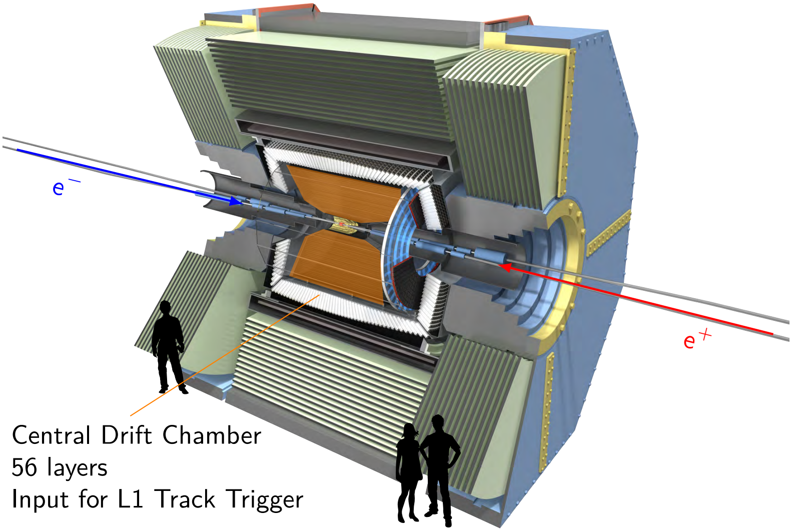
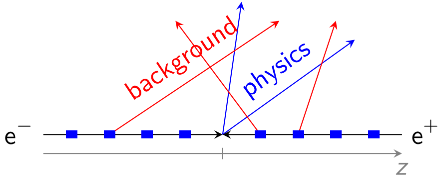


Central Drift Chamber
56 layers
Input for L1 Track Trigger

Introduction - Belle II Background

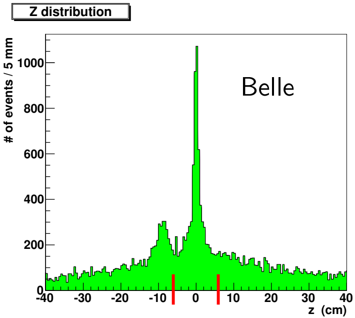
Beam Background Tracks



- 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

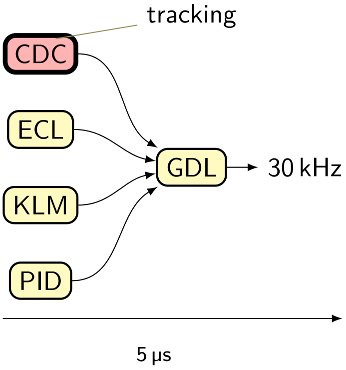
NeuroTrigger Goals

- 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

Introduction - Belle II First Level Trigger



Requirements

- 30 kHz trigger rate
- 5 μs latency

⇒ deadtime-free pipelined operation

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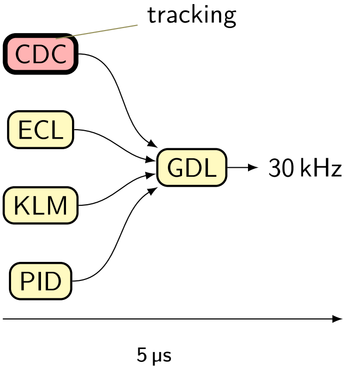
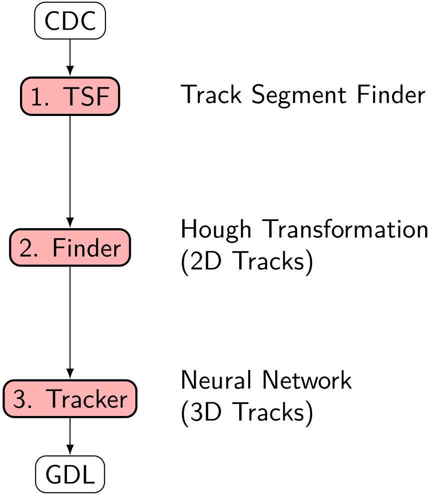


CDC Trigger Pipeline



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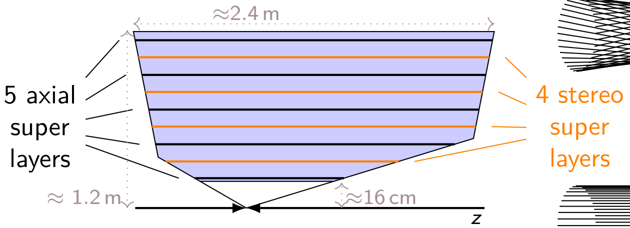
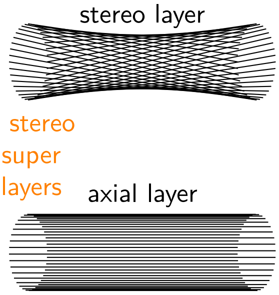


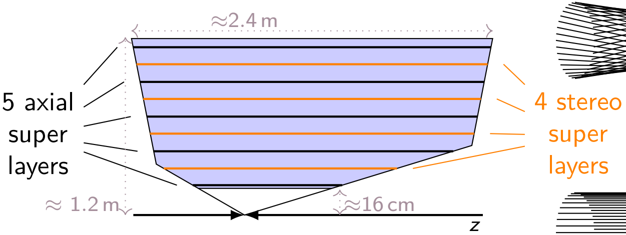


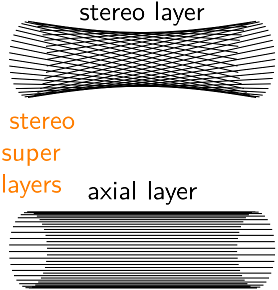
- 56 layers combined to 9 super layers (SL)
- 2336 track segments (TS) in 9 SL

SL	angle (mrad)
2	45.4 – 45.8
4	-55.3 – -64.3
6	63.1 – 70.0
8	-68.5 – -74.0

Stereo SL configuration

Introduction - CDC Trigger





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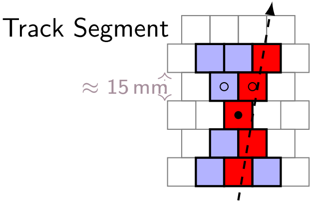
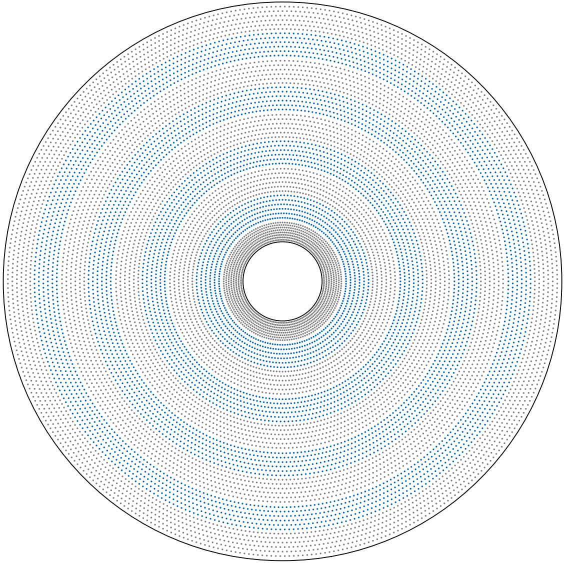


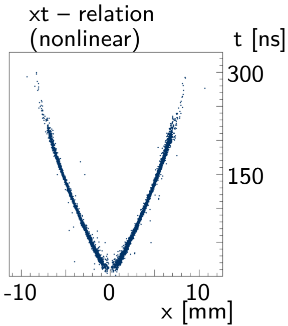
NeuroTrigger Input

- position, drift time and left/right information of TS priority wires
- 2D track estimates (p_T, φ)

Introduction - CDC Trigger



- axial layers
- stereo layers



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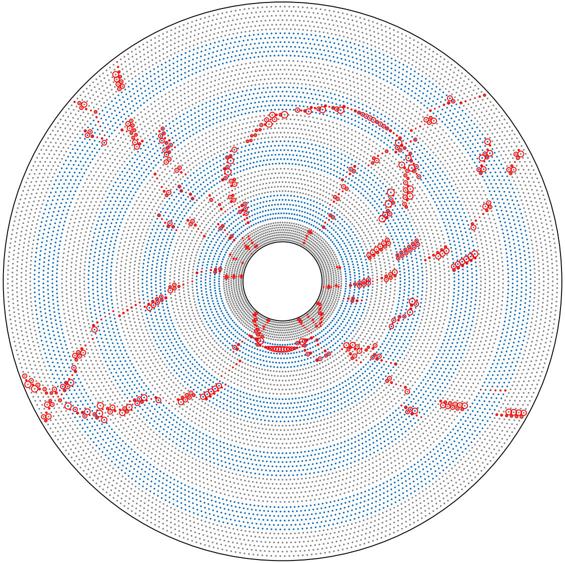
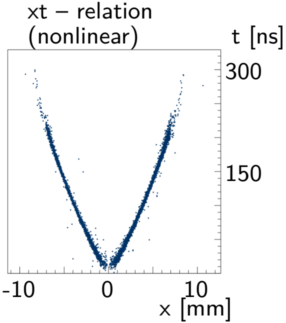


- axial layers
- stereo layers
- $\Upsilon(4S)$ Event



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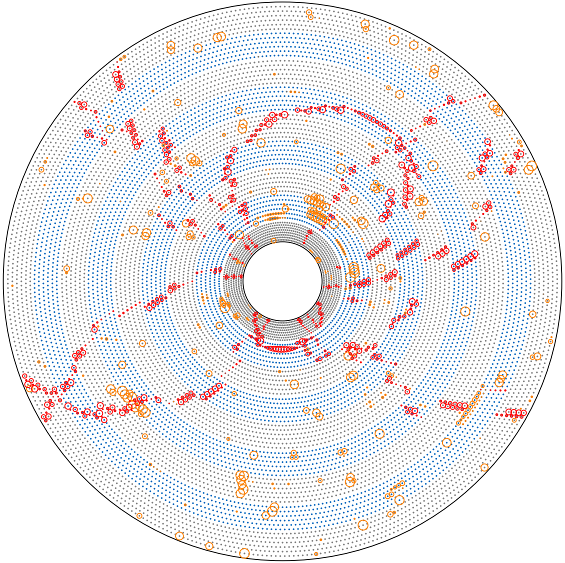
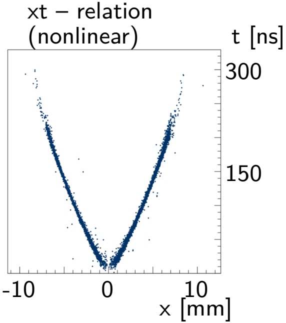


- axial layers
- stereo layers
- $\Upsilon(4S)$ Event
- background noise



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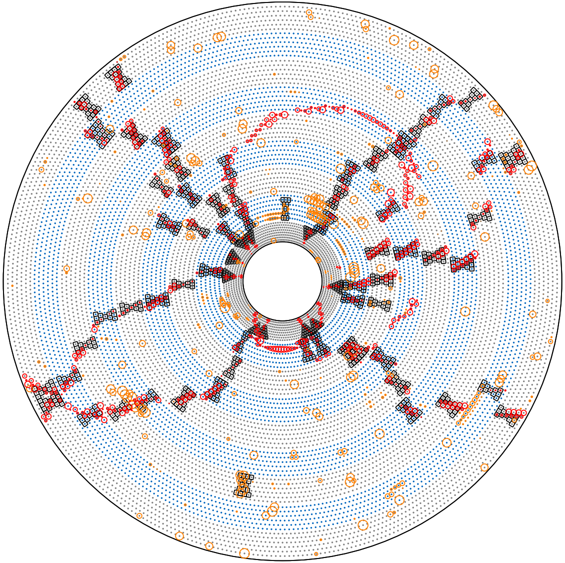
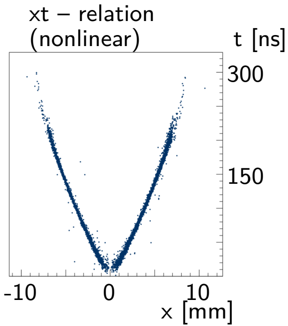


- axial layers
- stereo layers
- $\Upsilon(4S)$ Event
- background noise
- track segments (TS)



NeuroTrigger - Multi Layer Perceptron

Properties

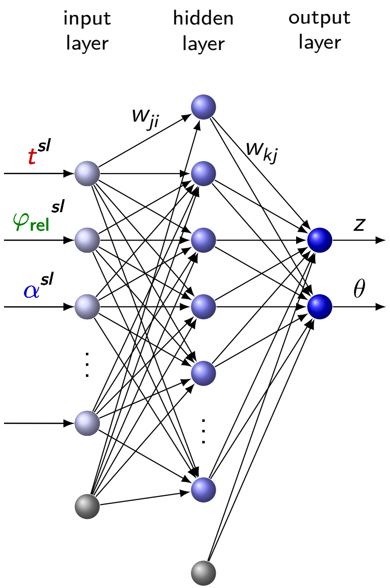
- robust function approximator
- massively parallel processing
- short deterministic runtime
- neuron: $y = \tanh(w_i x_i + w_0)$
- network: $z_k = f(w_{kj} f(w_{ji} x_i))$

Training

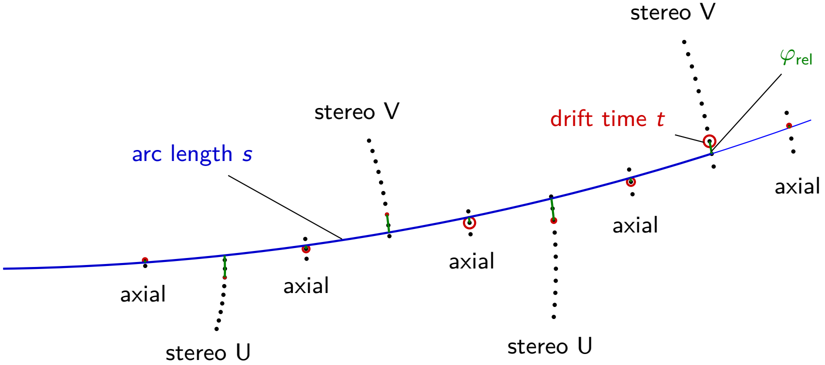
- minimize $\sum_i \left(z_i^{\text{True}} - z_i^{\text{Net}}\right)^2$
- RPROP (backpropagation)

input one TS Hit per SL per track (position φ_{rel}, α and time t)

output z, θ estimate



NeuroTrigger - Input Representation



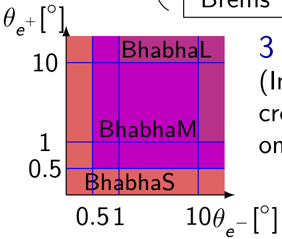
φ_{rel} : TS position relative to 2D track

α : $\frac{\text{2D arc length to TS}}{r_{2D}}$

- use track estimates provided by 2D finder
- 3 inputs per SL, values: $(t, \varphi_{rel}, \alpha)$
- dedicated networks for missing hits

Background Simulation

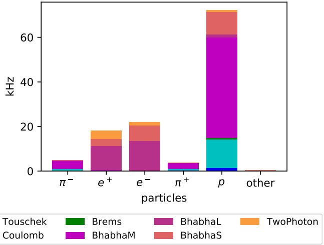
	background	process	2D trigger rate
Luminosity	TwoPhoton	$e^+e^- \underbrace{\rightarrow}_{e^+e^-\gamma\gamma} e^+e^-e^+e^-$	6 kHz
	Bhabha S Bhabha M Bhabha L	$e^+e^- \rightarrow e^+e^-\gamma$	20 kHz 52 kHz 26 kHz
Machine	Touschek	intra bunch scatt.	2 kHz
	Coulomb	$e^{\pm}N \rightarrow e^{\pm}N$	15 kHz
	Brems	$e^{\pm}N \rightarrow e^{\pm}N\gamma$	1 kHz



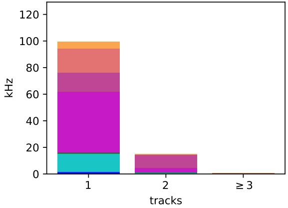
3 Bhabha cases

(In the dominating t-channel, the Bhabha cross section strongly depends on the scattering angle)

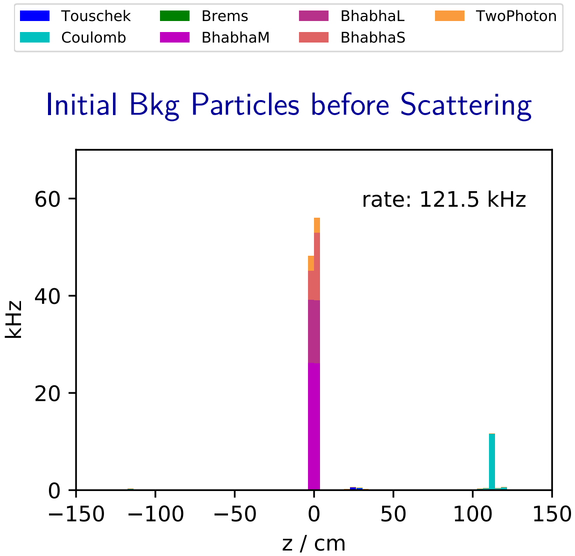
Triggered Particles

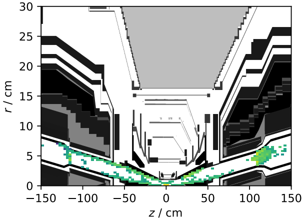


Track Multiplicity



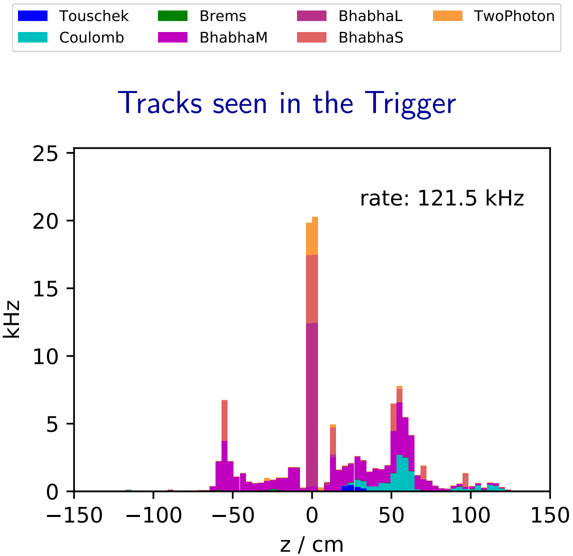
Background - Material Scattering

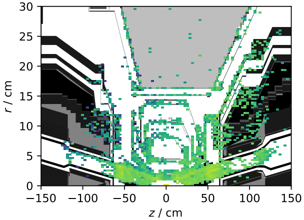




- primary generated bkg particles
- only events with a 2D trigger
- luminosity bkg only from the IP
- machine bkg from the beam pipe

Background - Material Scattering





- particles after detector simulation
- bkg particles matched to 2D trigger tracks

$\approx$ 80 kHz reducible $(z \neq 0)$

$\approx$ 40 kHz irreducible $(z = 0)$

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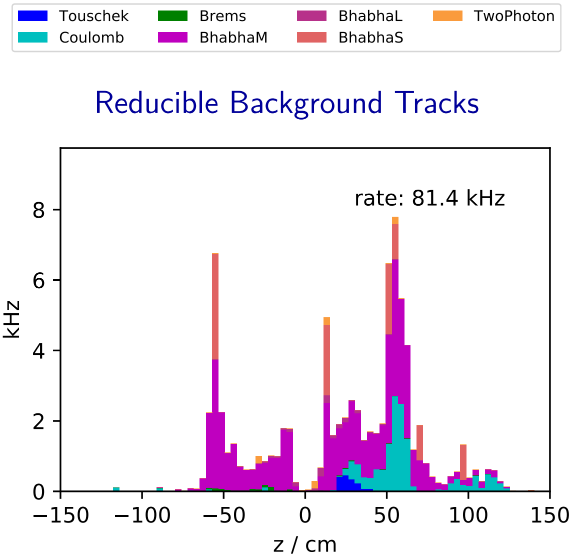

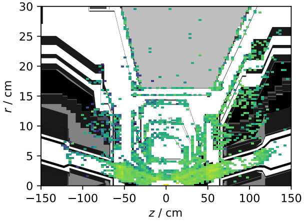

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$\approx$ 80 kHz reducible $(z \neq 0)$

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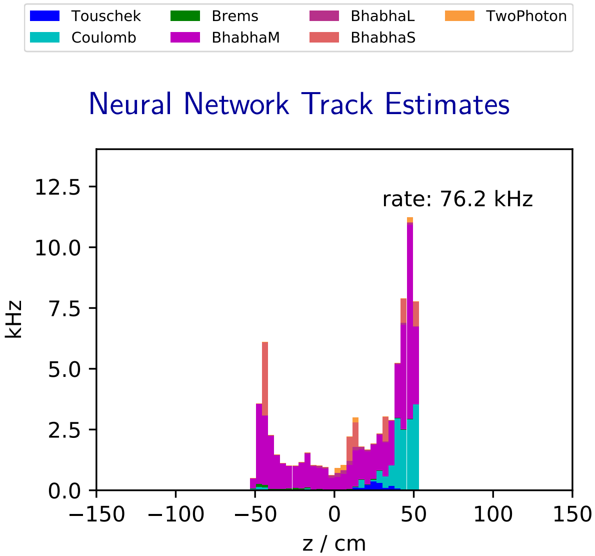
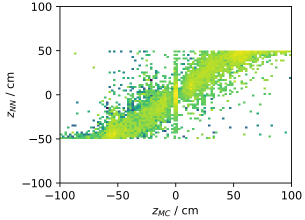
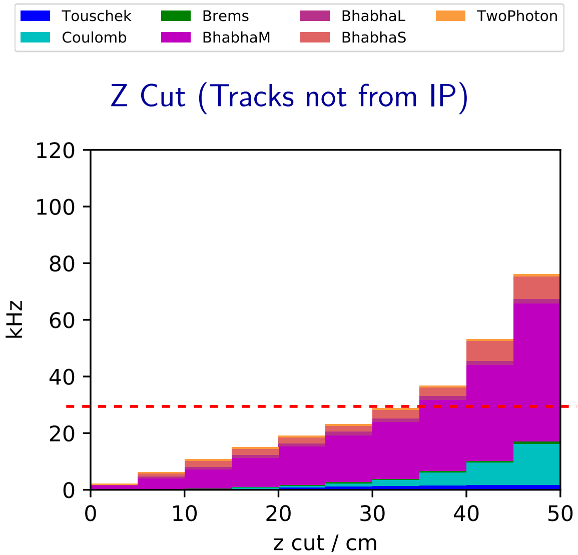
Background - Reconstruction

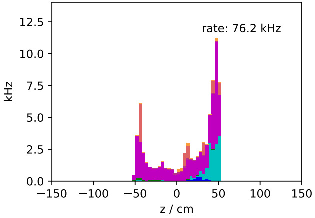




- 3D reconstructed bkg with the neural network
- neuro z range limited to $[-50, 50]$ cm

Background - Suppression





- 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

Conclusion

Background

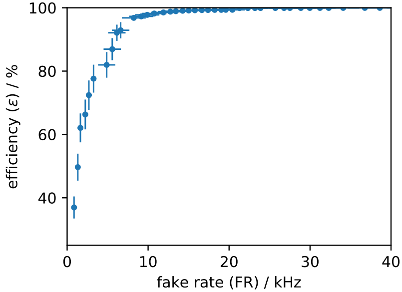
- 2 background types: luminosity background (generated at the IP) and machine background (generated at the walls of the beam pipe)
- scattering of background tracks at material leads to spread in z
- $\approx 82\,\text{kHz}$ reducible background (tracks not from the IP) and $\approx 40\,\text{kHz}$ irreducible background (tracks from the IP)

Neural Network Trigger

- robust z-vertex estimation with the neural networks
- significant background reduction with z cut
- allows to consider a single track trigger

Backup

IP Efficiency

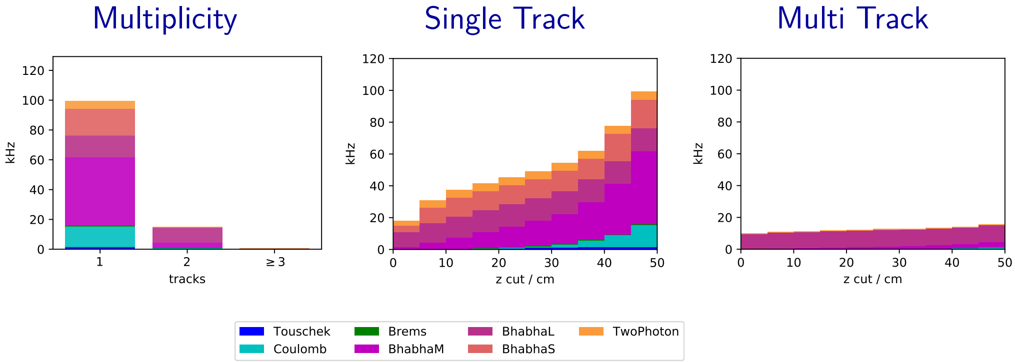


z_{cut}/cm	FR /kHz	ε / %
9	5.6	89.5
16	10.9	98.5
22	15.6	99.3
28	20.3	99.9

- efficiency ε:
  efficiency to correctly flag tracks from the IP
- fake rate FR:
  rate of tracks wrongly flagged as IP tracks

- split background data in
  - "ip-tracks": $z \in [-1, 1]$ cm
  - "displaced": $z \notin [-1, 1]$ cm
- vary z_{cut} in 1 cm steps ($z_{cut} \in [1..50]$)

Background - Suppression



rate [kHz]	= 1 track	≥ 2 tracks
lumi. bkg	89.7	14.5
machine bkg	16.1	1.2
total	105.8	15.7

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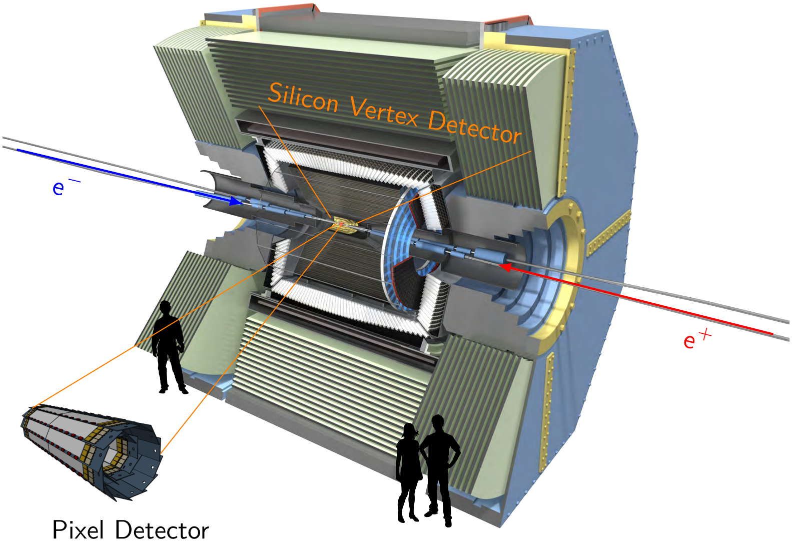

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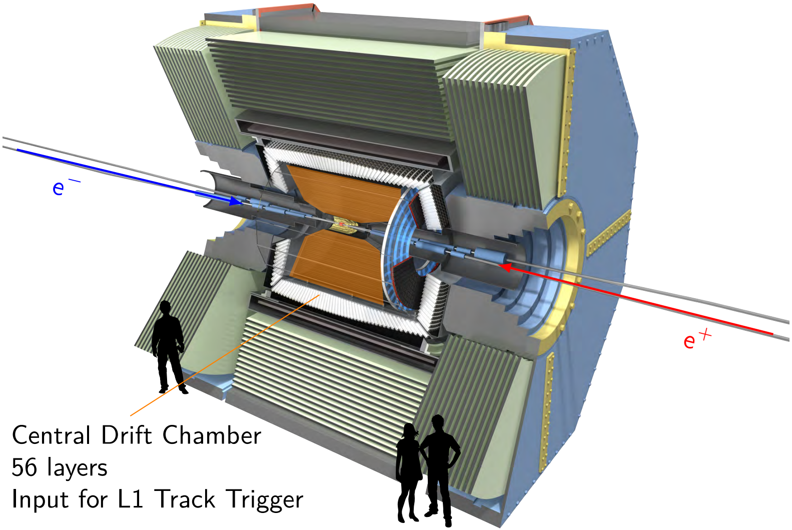

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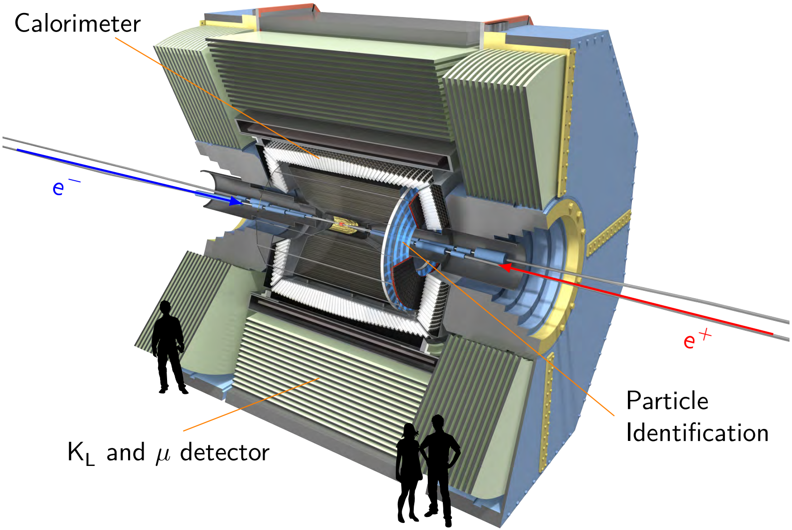
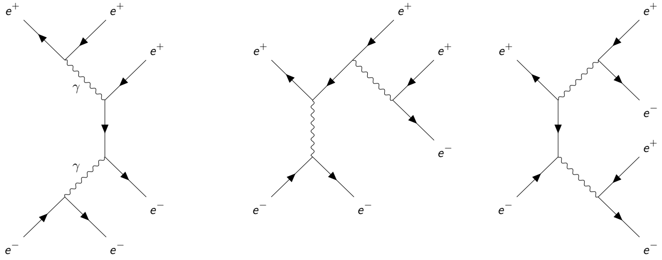
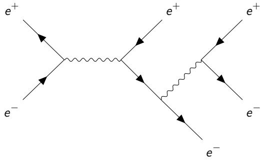


TwoPhoton



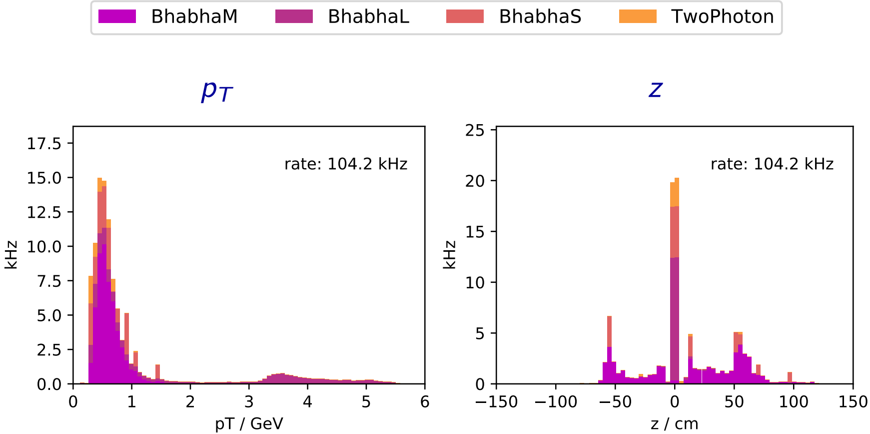
t channel



s channel

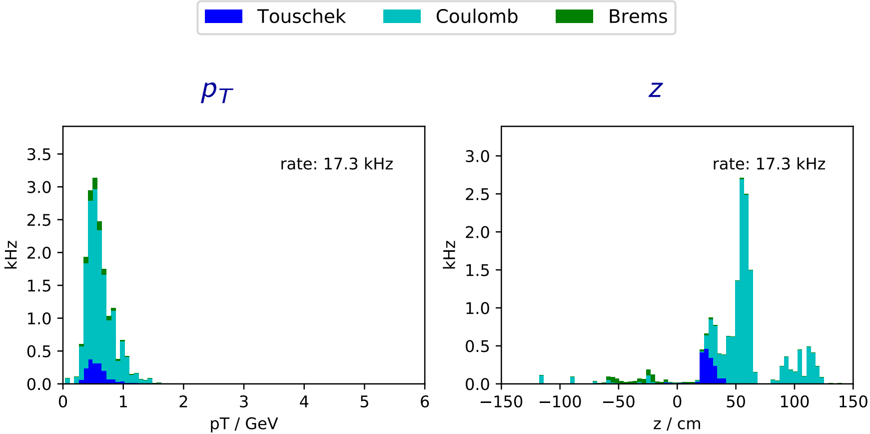
Luminosity Background

- primary vertex at the IP ($z = 0$)
- e^+e^- from the IP directly hit the CDC
- back scattered particles hit the CDC



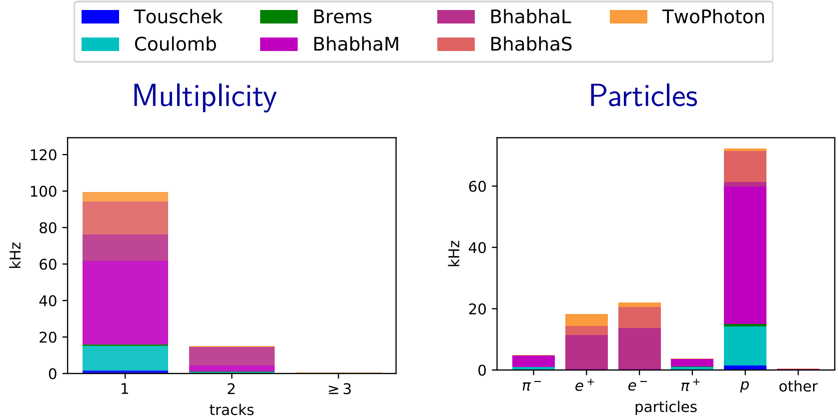
Machine Background

- Touschek increase via nano beam scheme
- small beam pipe ($r \approx 1\,\mathrm{cm}$), resulting in worse vacuum conditions
- beam gas scattering increased via bad vacuum in the beam pipe



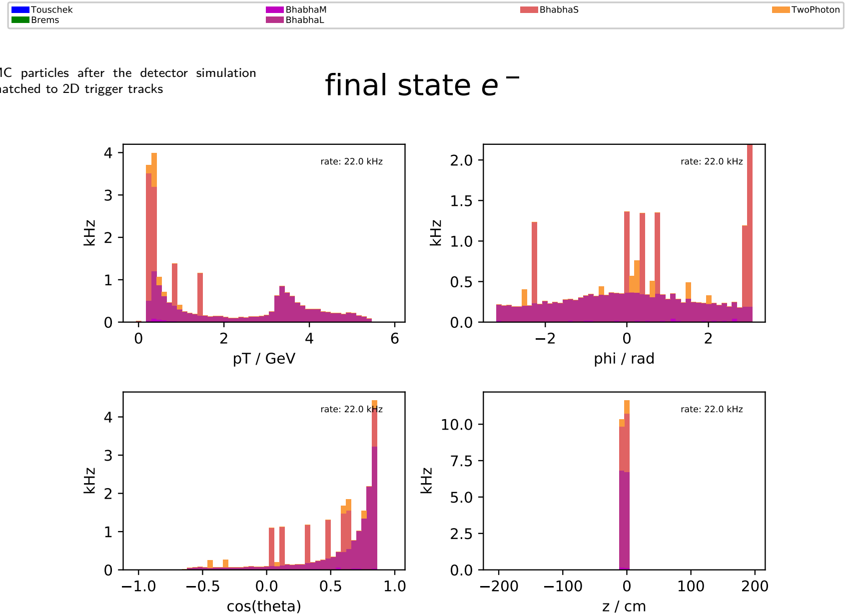
Background - Track Properties

- $\approx 106\,\mathrm{kHz}$ single track background
- $\approx 16\,\mathrm{kHz}$ multi track background
- most scattered particles: protons (from nuclear spallation)



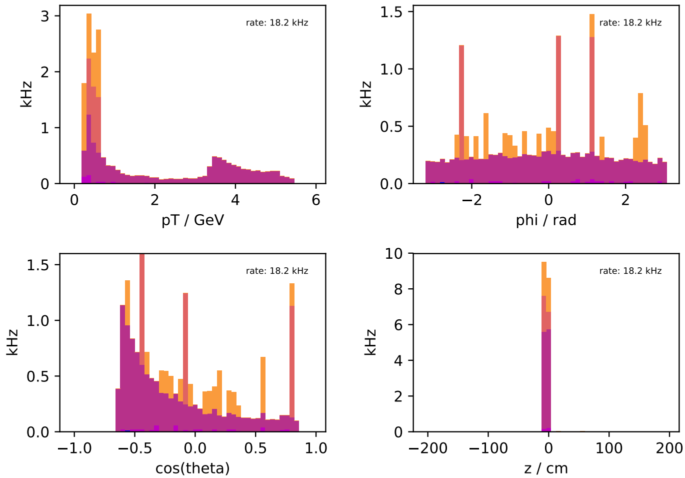
MC particles after the detector simulation matched to 2D trigger tracks

final state e^-



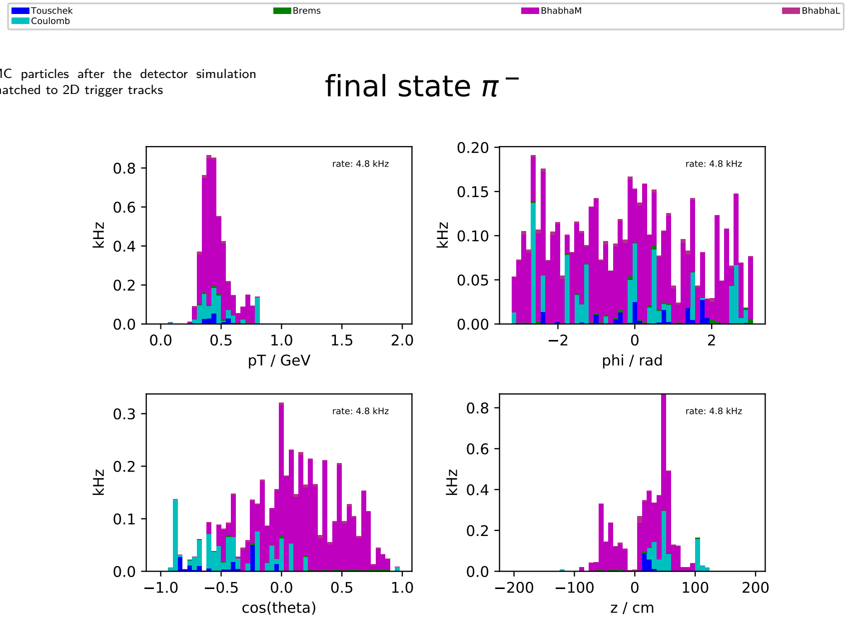
MC particles after the detector simulation matched to 2D trigger tracks

final state e^+



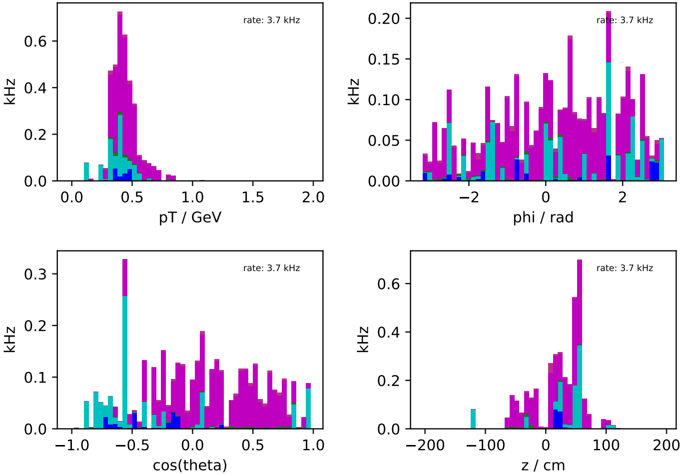
final state π^-

MC particles after the detector simulation matched to 2D trigger tracks



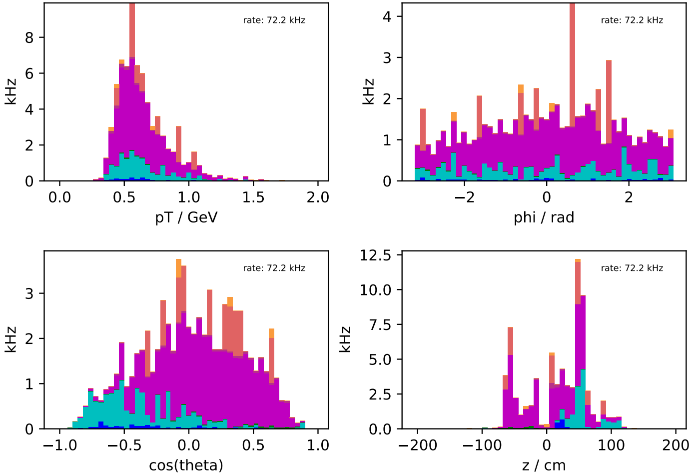
MC particles after the detector simulation matched to 2D trigger tracks

final state π^+



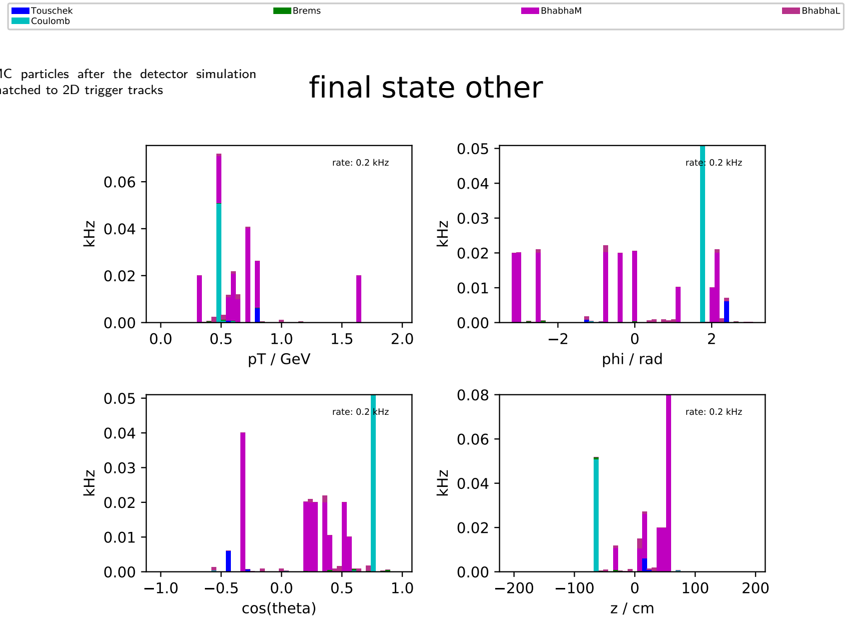
MC particles after the detector simulation matched to 2D trigger tracks

final state *p*



final state other

MC particles after the detector simulation matched to 2D trigger tracks



Generator particles scattering to final states