Background Suppression with the Belle II Neural Network Trigger

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Neuro Team
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Outline

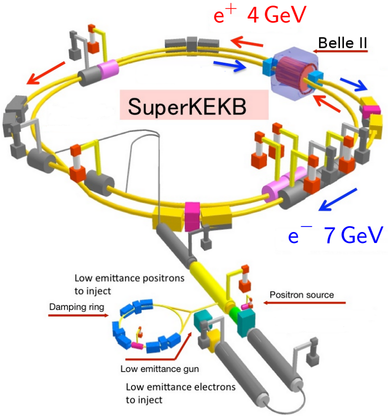
Introduction - Belle II at SuperKEKB

located in Tsukuba, Japan at **KEK**

高エネルギー加速器研究機構

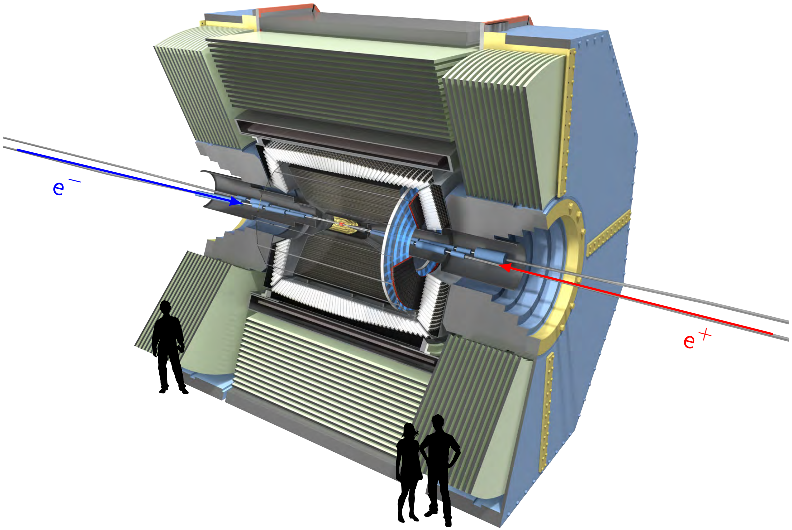
Kō **E**nerugī **K**asokuki kenkyū kikou

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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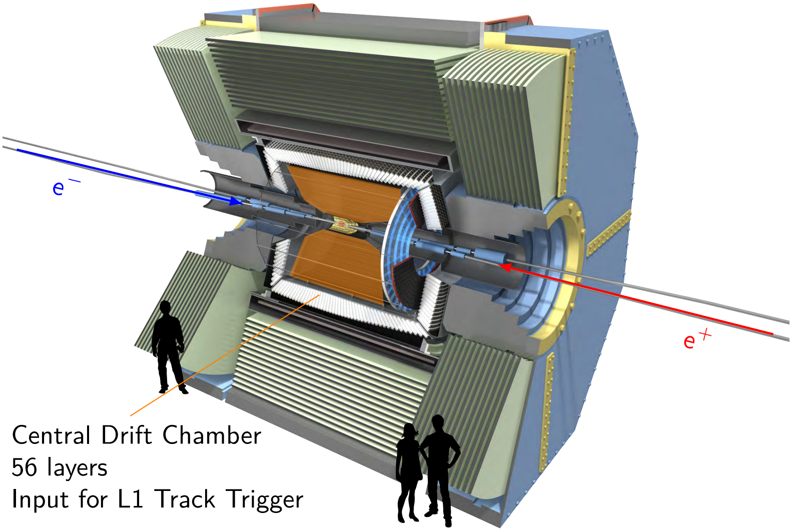
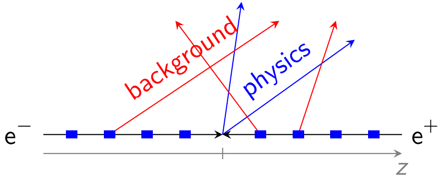


Central Drift Chamber
56 layers
Input for L1 Track Trigger

Introduction - Belle II Background

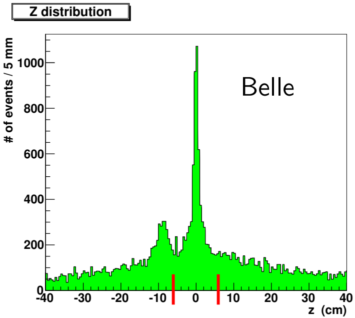
Beam Background Tracks



- 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

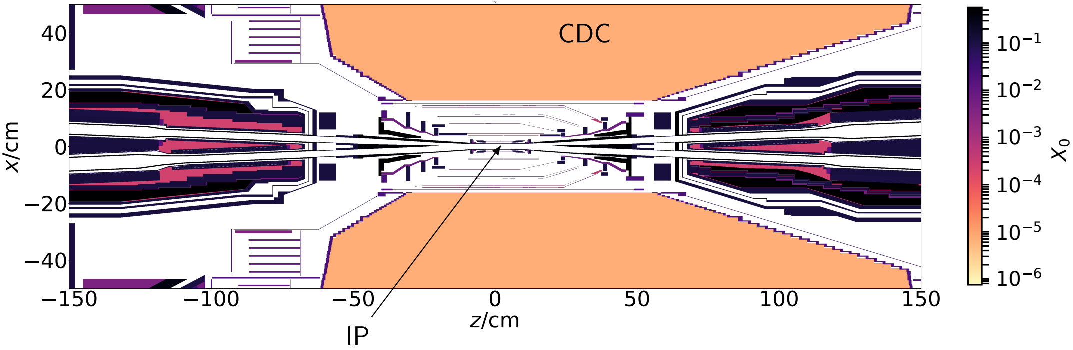
- reject tracks from $z \neq 0\,\mathrm{cm}$
- single track z-vertex resolution $< 2\,\mathrm{cm}$
- latency $< 1\,\mu\mathrm{s}$



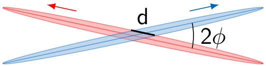
$\Rightarrow$ need z vertex reconstruction at 1st trigger level

Introduction - Interaction Region

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



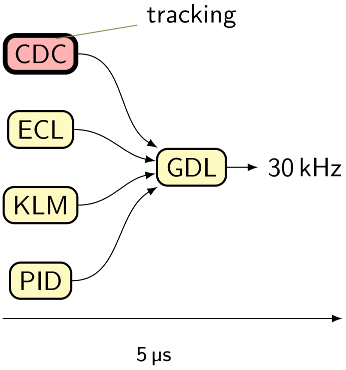
Bunch crossing:



Nano-Beam scheme

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

Introduction - Belle II First Level Trigger



Requirements

- 30 kHz trigger rate
- 5 μs latency

⇒ deadtime-free pipelined operation

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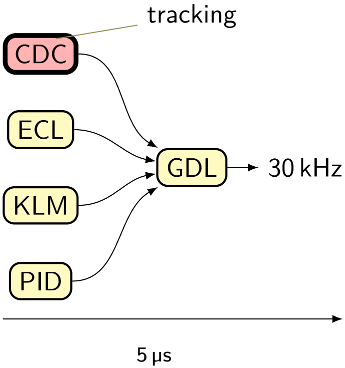

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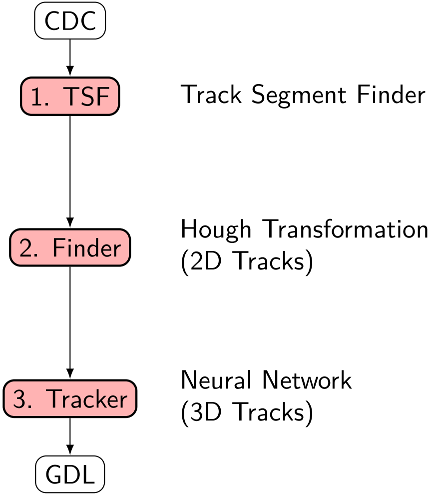
CDC Trigger Pipeline



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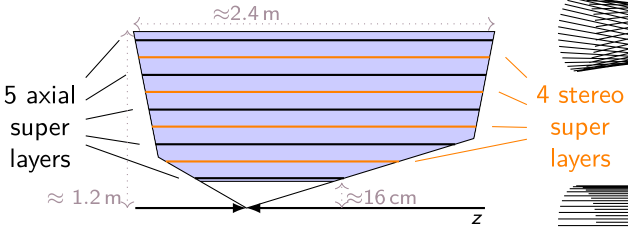
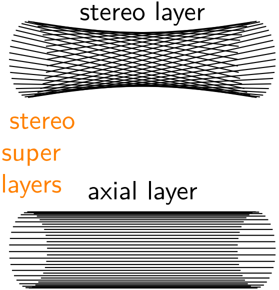


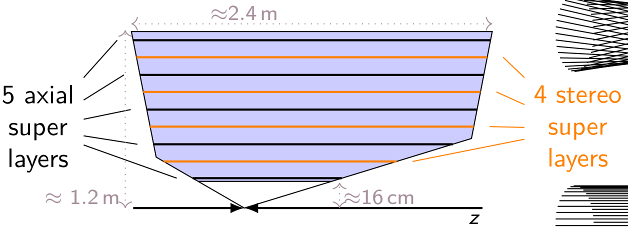


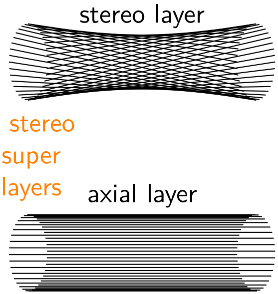
- 56 layers combined to 9 super layers (SL)
- 2336 track segments (TS) in 9 SL

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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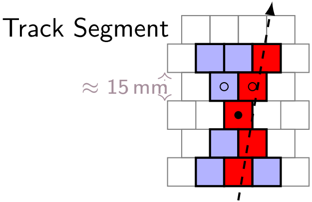
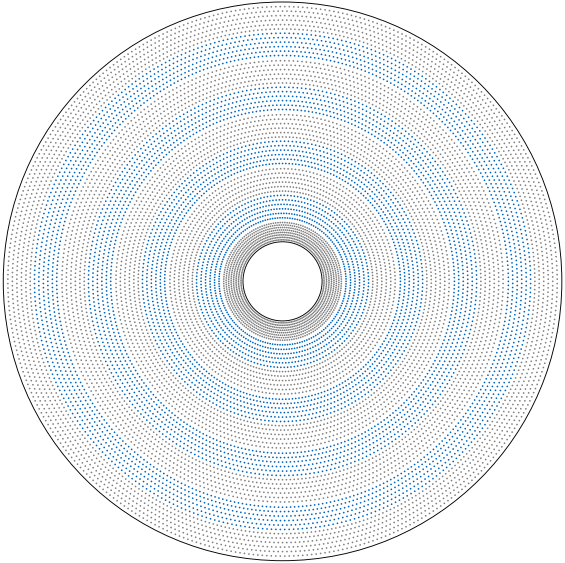


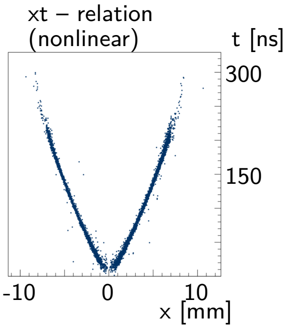
NeuroTrigger Input

- 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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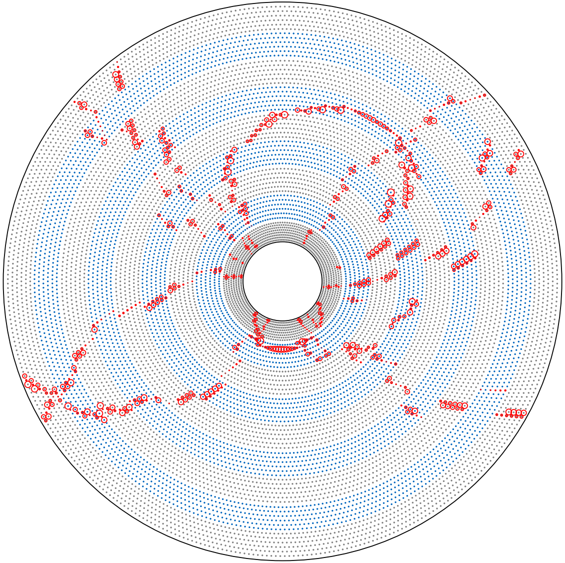
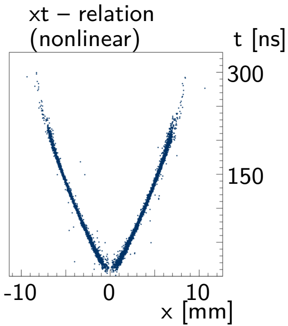


- axial layers
- stereo layers
- $\Upsilon(4S)$ Event



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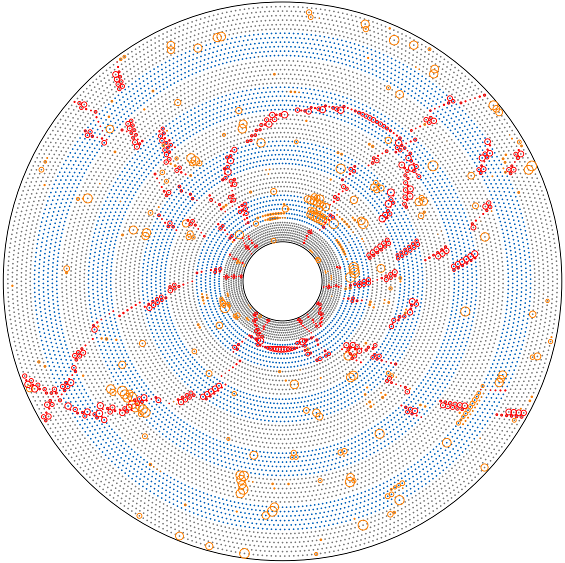
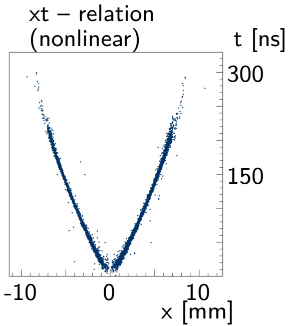


- axial layers
- stereo layers
- $\Upsilon(4S)$ Event
- background noise



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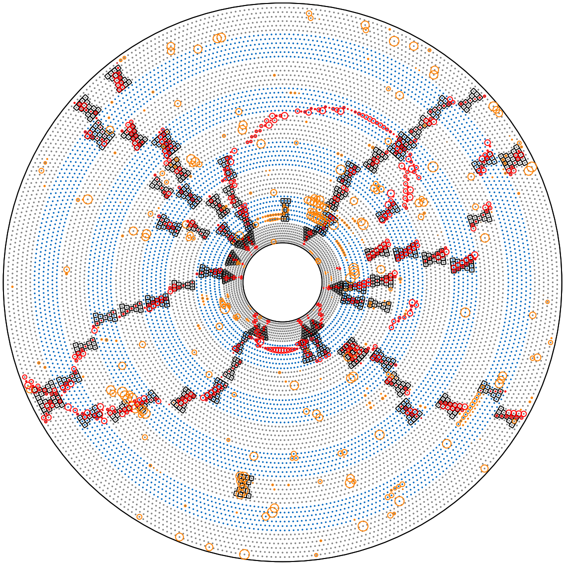
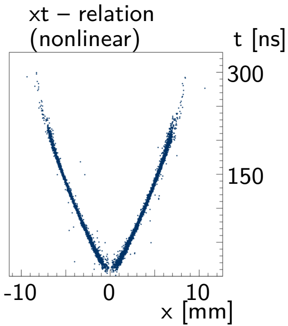


- axial layers
- stereo layers
- $\Upsilon(4S)$ Event
- background noise
- track segments (TS)



NeuroTrigger - Multi Layer Perceptron

Properties

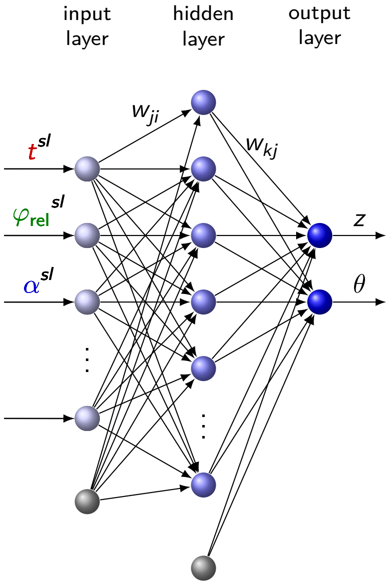
- robust function approximator
- massively parallel processing
- short deterministic runtime
- neuron: $y = \tanh(w_i x_i + w_0)$
- network: $z_k = f(w_{kj} f(w_{ji} x_i))$

Training

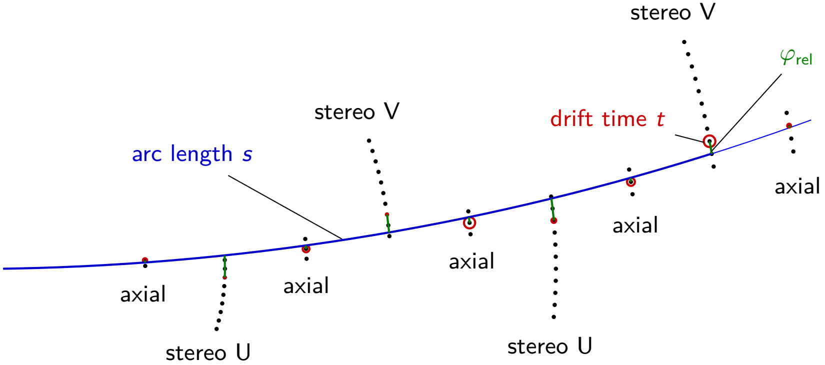
- minimize $\sum_i \left(z_i^{\text{True}} - z_i^{\text{Net}}\right)^2$
- RPROP (backpropagation)

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

output z, θ estimate



NeuroTrigger - Input Representation



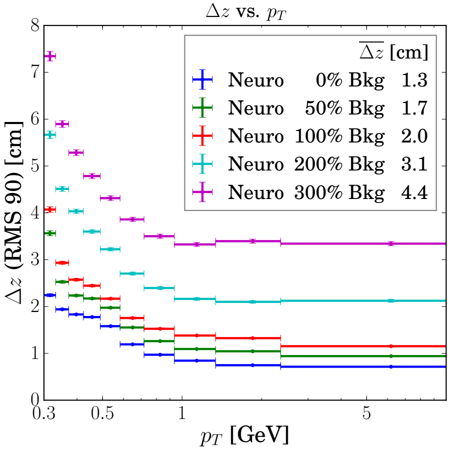
φ_{rel} : TS position relative to 2D track

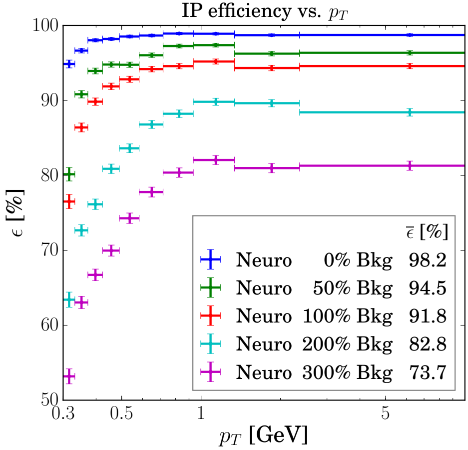
α : $\dfrac{\text{2D arc length to TS}}{r_{2D}}$

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

NeuroTrigger - Accuracy

- 5 networks total (for missing stereo hits)
- different bkg noise levels
- IP efficiency: flag IP events with $z \in [-6, 6]$ cm

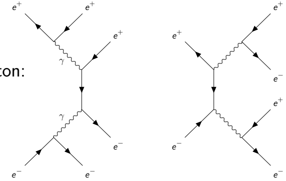




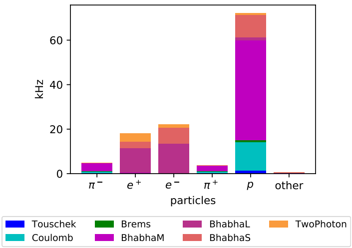
Background Simulation

	background	process	2D trigger rate
Luminosity	TwoPhoton	$e^+e^- \underbrace{\rightarrow}_{e^+e^-\gamma\gamma} e^+e^-e^+e^-$	6 kHz
	Bhabha S	$e^+e^- \rightarrow e^+e^-\gamma$	20 kHz
	Bhabha M		52 kHz
	Bhabha L		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

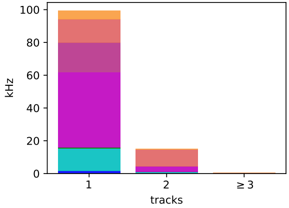
Two Photon:



Triggered Particles



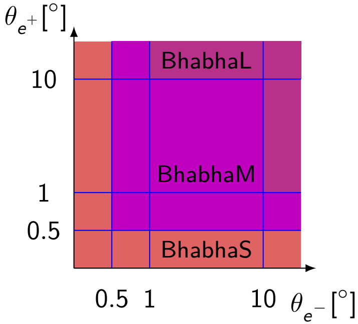
Track Multiplicity

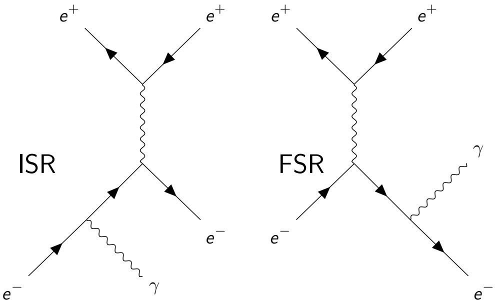


Luminosity Background - Radiative Bhabha

largest contribution

- initial state radiation (ISR) (t-channel)





Bhabha Simulation

3 Bhabha cases:

- small angle (BhabhaS)
- medium angle (BhabhaM)
- large angle (BhabhaL)

Bhabha cross section strongly depends on scattering angle (t-channel)

Machine Background

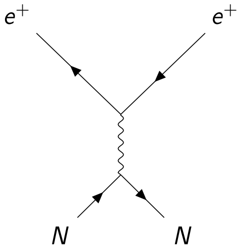
Touschek

elastic inner beam

- $e^{\pm}e^{\pm} \rightarrow e^{\pm}e^{\pm}$

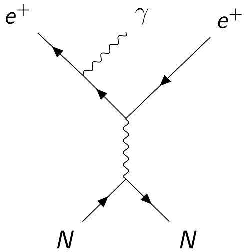
Coulomb

elastic beam gas



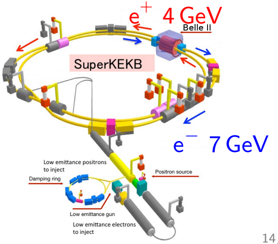
Brems

inelastic beam gas



Simulation

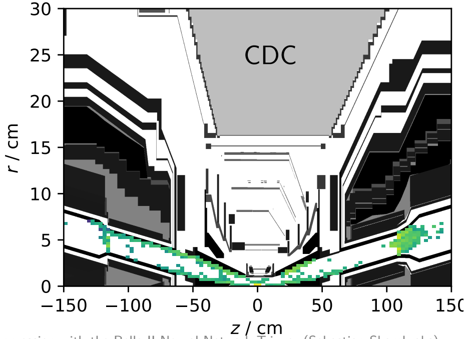
1. calculate deviations of beam particles from the nominal beam orbit
2. track these particles until they get lost
3. loss positions are input to detector simulation



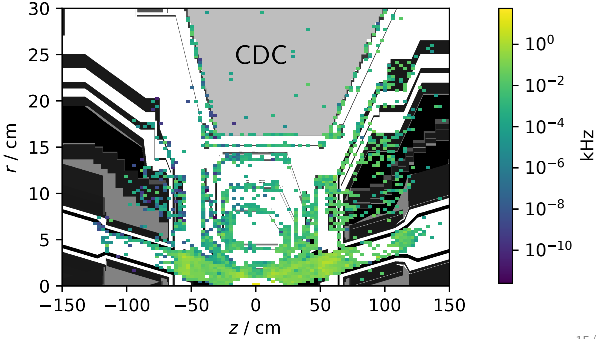
Background - Material Scattering

- initial particles from
  - beam pipe (machine background)
  - IP (luminosity background)
- scattered particles show detector structure and beam pipe
- backscatters: reducible with track trigger
- tracks from the IP: irreducible QED
  - prescaled with Bhabha veto (combine track & calorimeter information)

Initial Particles



Track Vertices



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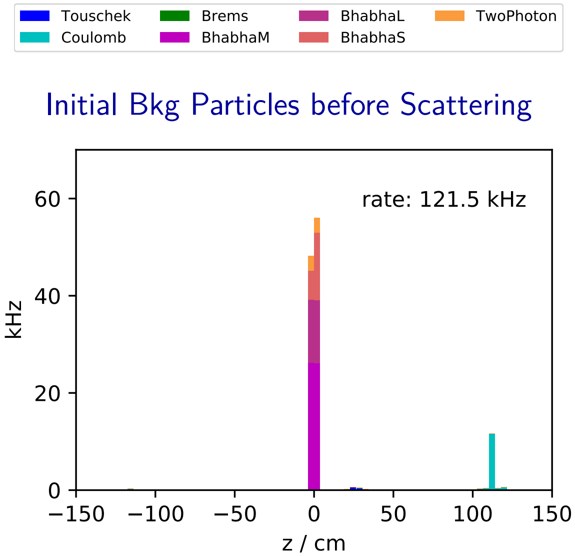
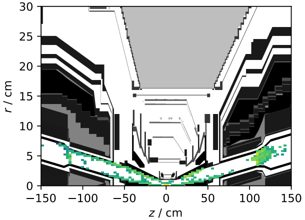
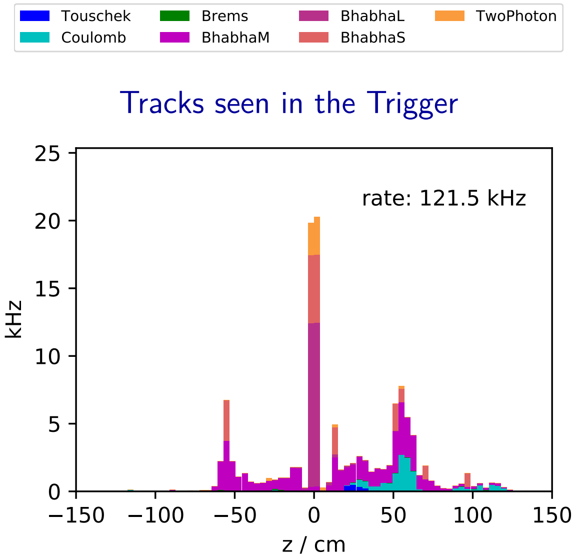


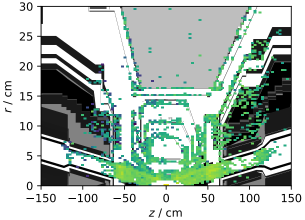


- primary particles from the bkg generators
- only events with a 2D trigger
- luminosity bkg only from the IP

Background - Material Scattering

Tracks seen in the Trigger



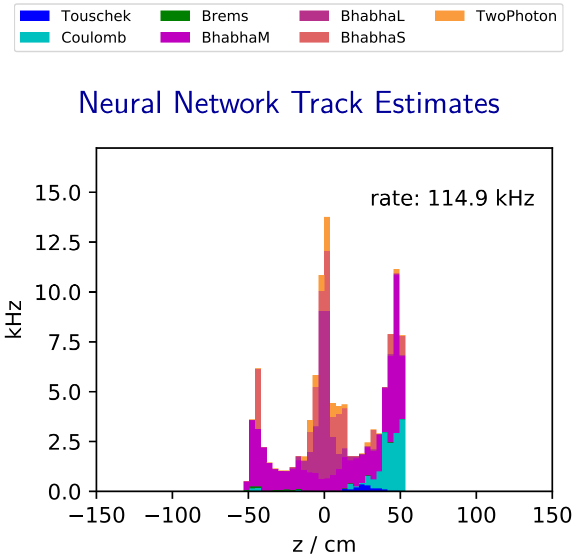


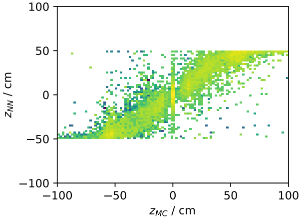
- particles after detector simulation
- bkg particles matched to 2D trigger tracks

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

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

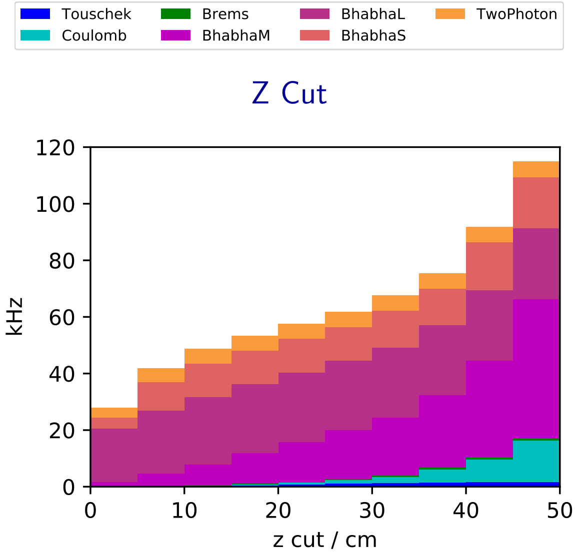
Background - Reconstruction

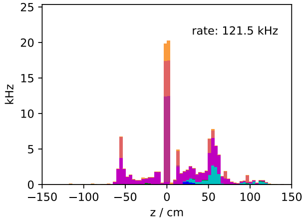




- 3D reconstructed bkg with the neural network
- neuro z range limited to $[-50, 50]$ cm

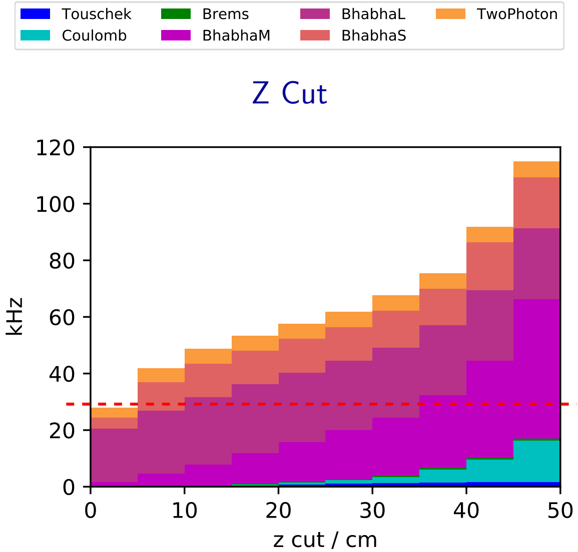
Background - Suppression

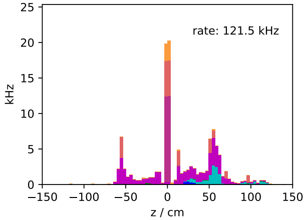




- cumulative bkg rate after a cut on the neural network z
- z_{cut} is varied in 5 cm steps

Background - Suppression





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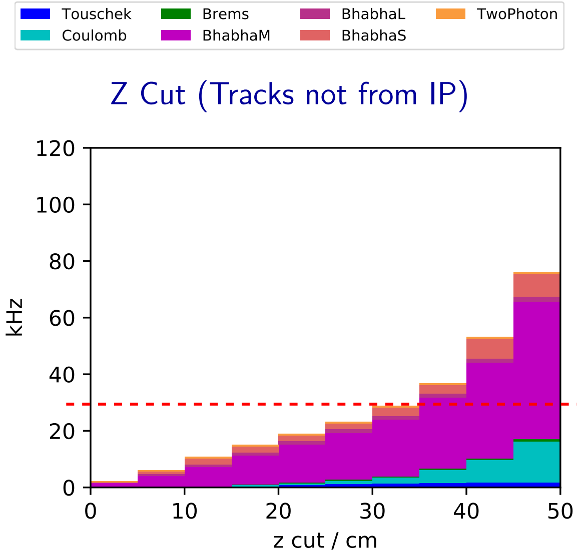
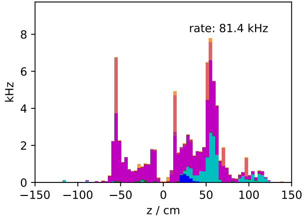




- only tracks with $|z_{MC}| \geq 1\,\text{cm}$
- cumulative bkg rate after a cut on the neural network z
- z_{cut} is varied in 5 cm steps

Conclusion

Background

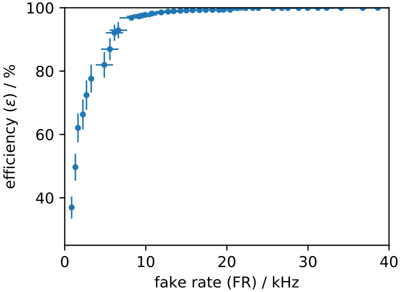
- 2 background types: luminosity background (generated at the IP) and machine background (generated at the walls of the beam pipe)
- scattering of background tracks at material leads to spread in z
- $\approx$ 82 kHz reducible background (tracks not from the IP) and $\approx$ 40 kHz irreducible background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



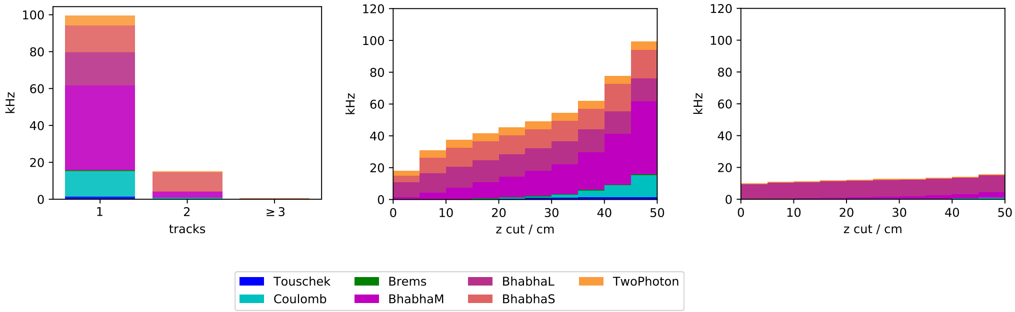
z_{cut}/cm	FR /kHz	ε / %
9	5.6	89.5
16	10.9	98.5
22	15.6	99.3
28	20.3	99.9

- 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

Multiplicity | Single Track | Multi Track



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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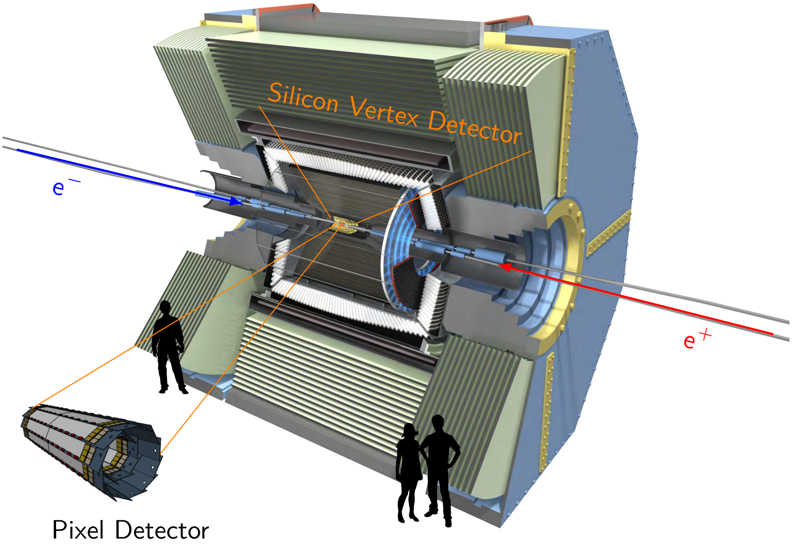

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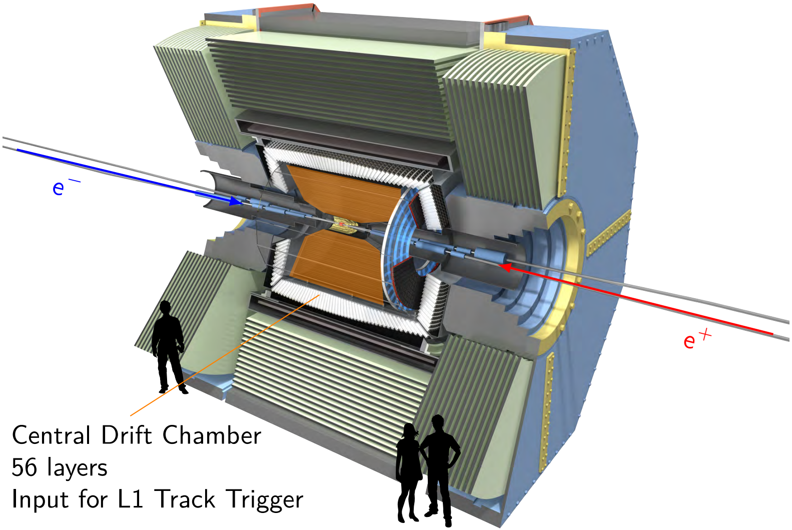

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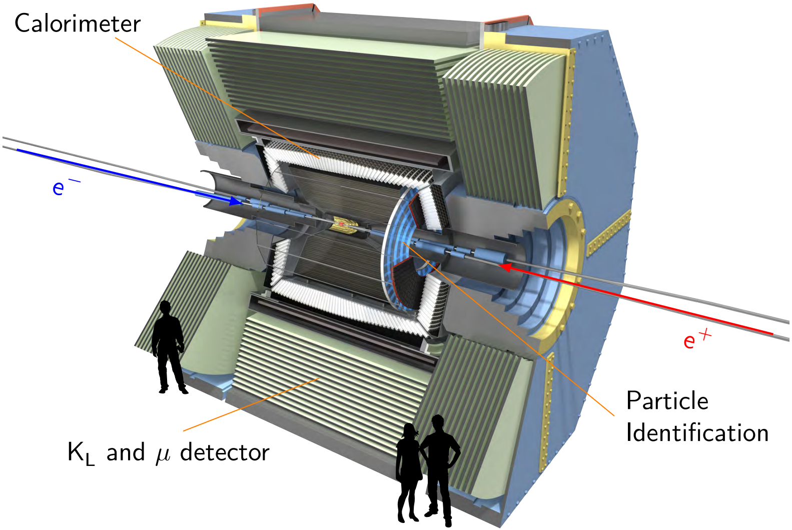
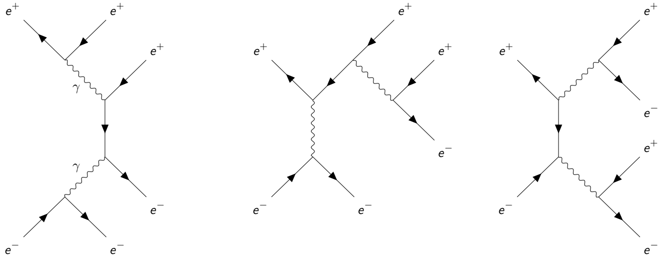
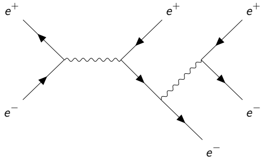


TwoPhoton



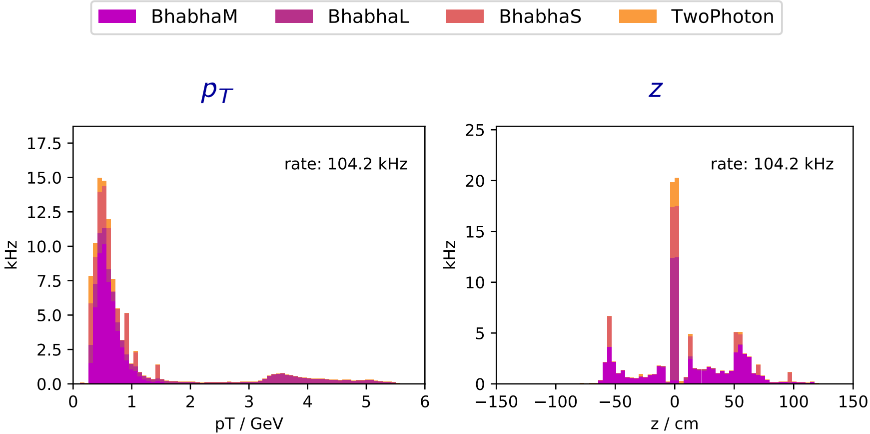
t channel



s channel

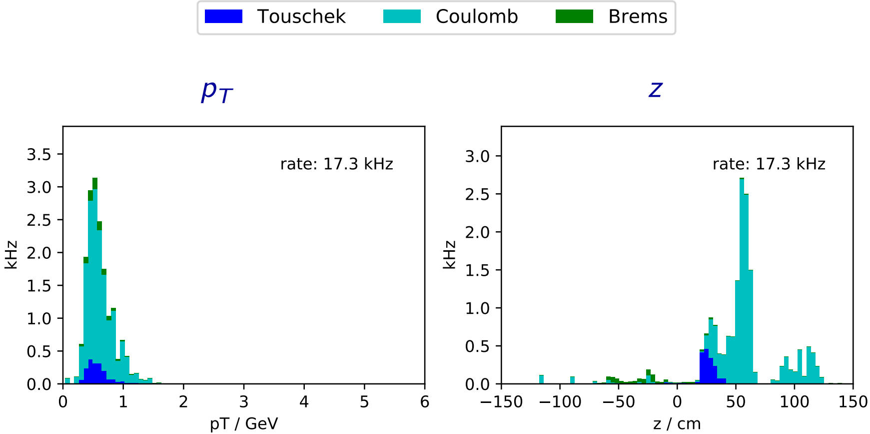
Luminosity Background

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



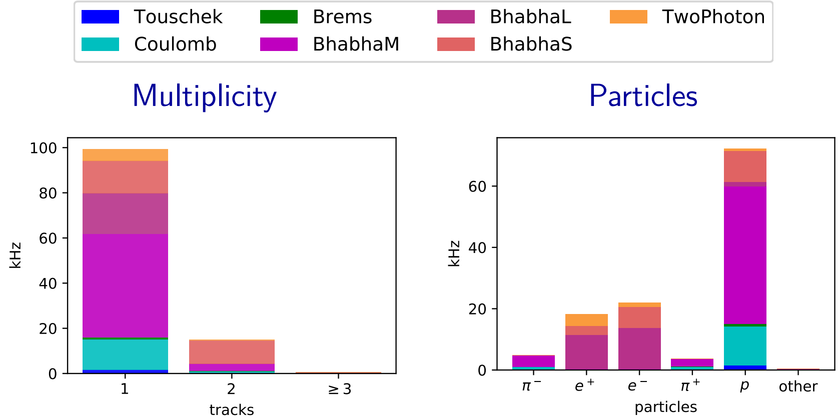
Machine Background

- 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



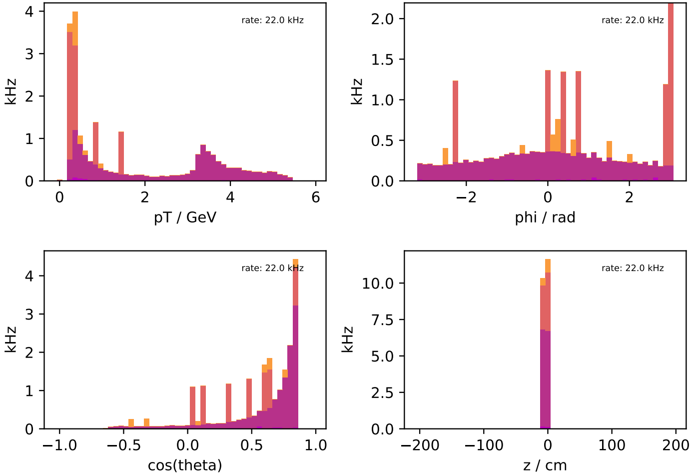
Background - Track Properties

- ≈ 106 kHz single track background
- ≈ 16 kHz multi track background
- most scattered particles: protons (from nuclear spallation)



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

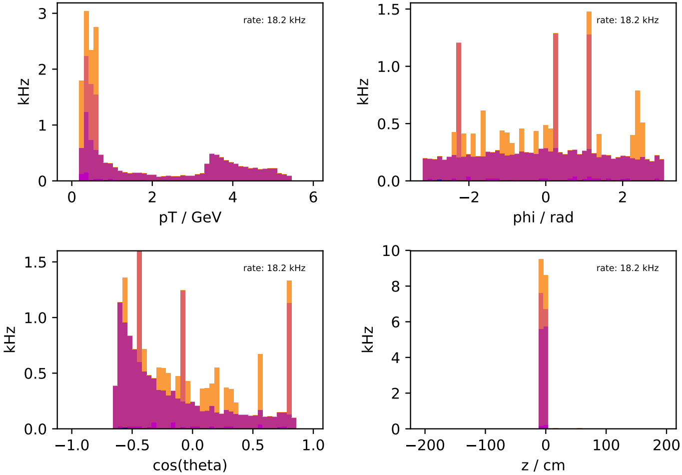
final state e^-



Touschek
Coulomb
BhabhaM
BhabhaL
BhabhaS
TwoPhoton

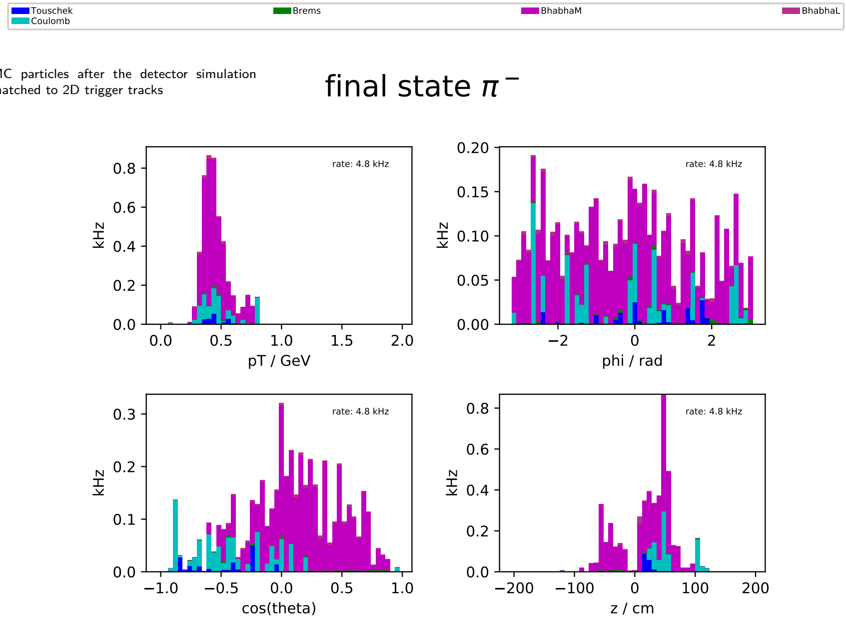
MC particles after the detector simulation matched to 2D trigger tracks

final state e^+



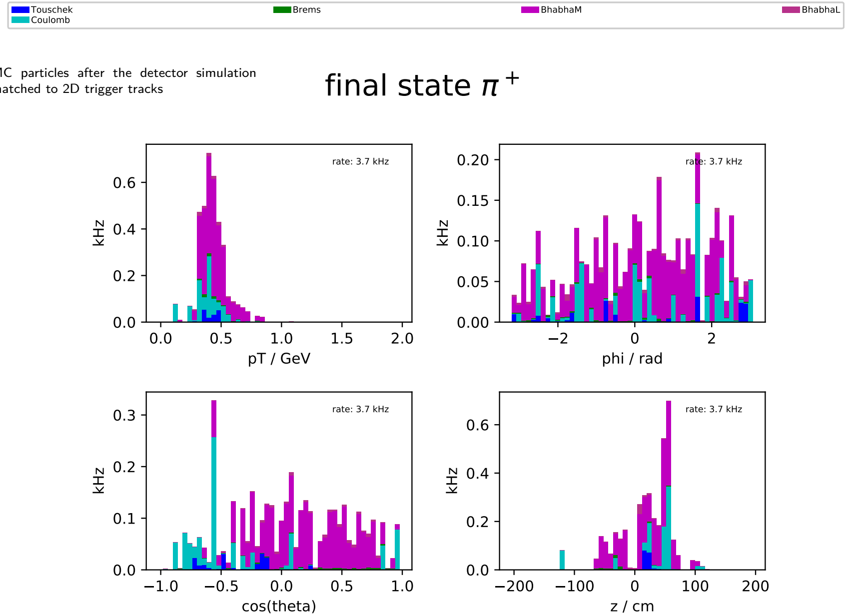
MC particles after the detector simulation matched to 2D trigger tracks

final state π^-



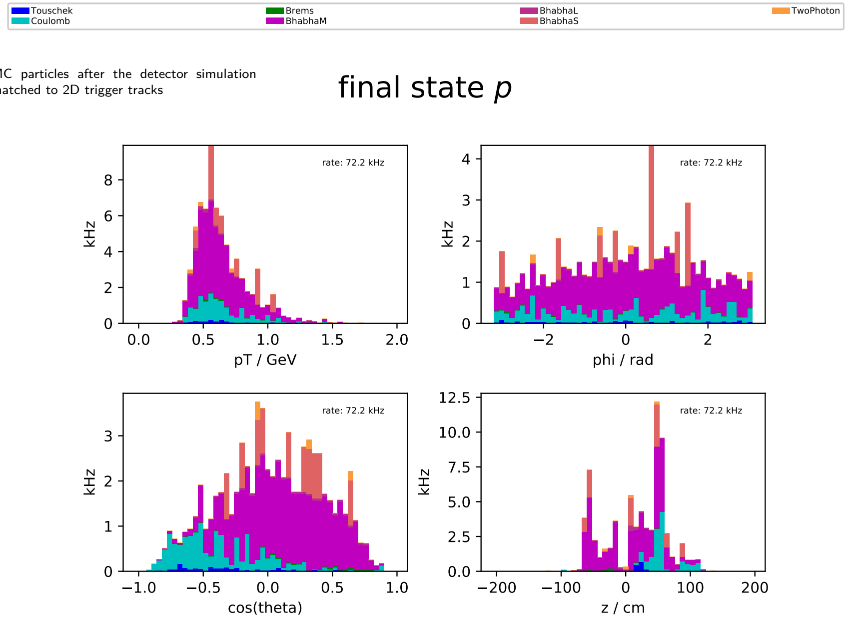
MC particles after the detector simulation matched to 2D trigger tracks

final state π^+



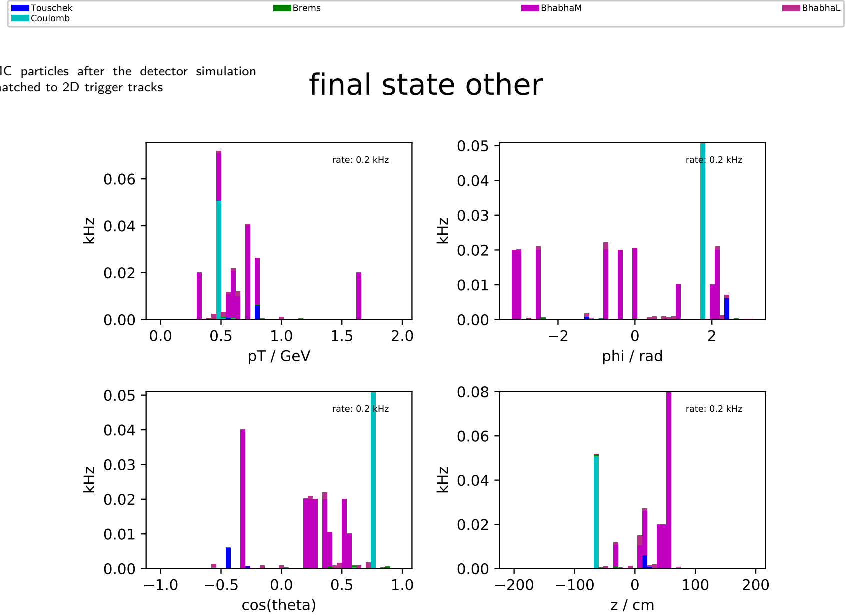
MC particles after the detector simulation matched to 2D trigger tracks

final state *p*



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

final state other



Generator particles scattering to final states