Background suppression with neural networks at the Belle II trigger

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March 28, 2017

Outline

Introduction
- Motivation
- Trigger

NeuroTrigger

Background

Neuro Team
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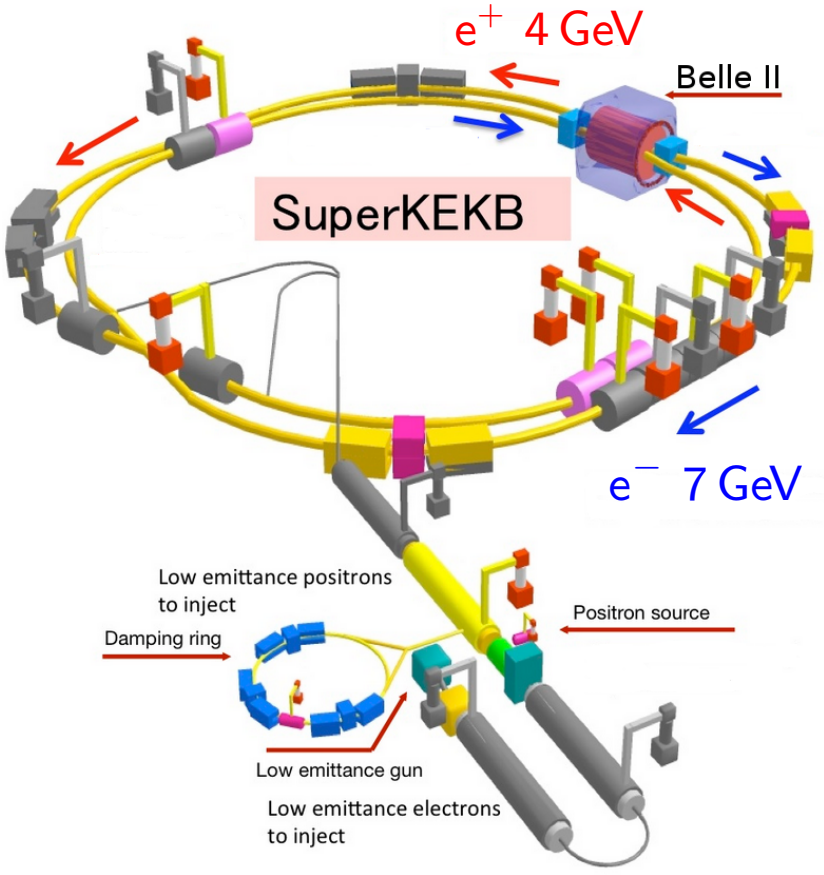
Introduction - Belle II at SuperKEKB

located in Tsukuba, Japan at **KEK**

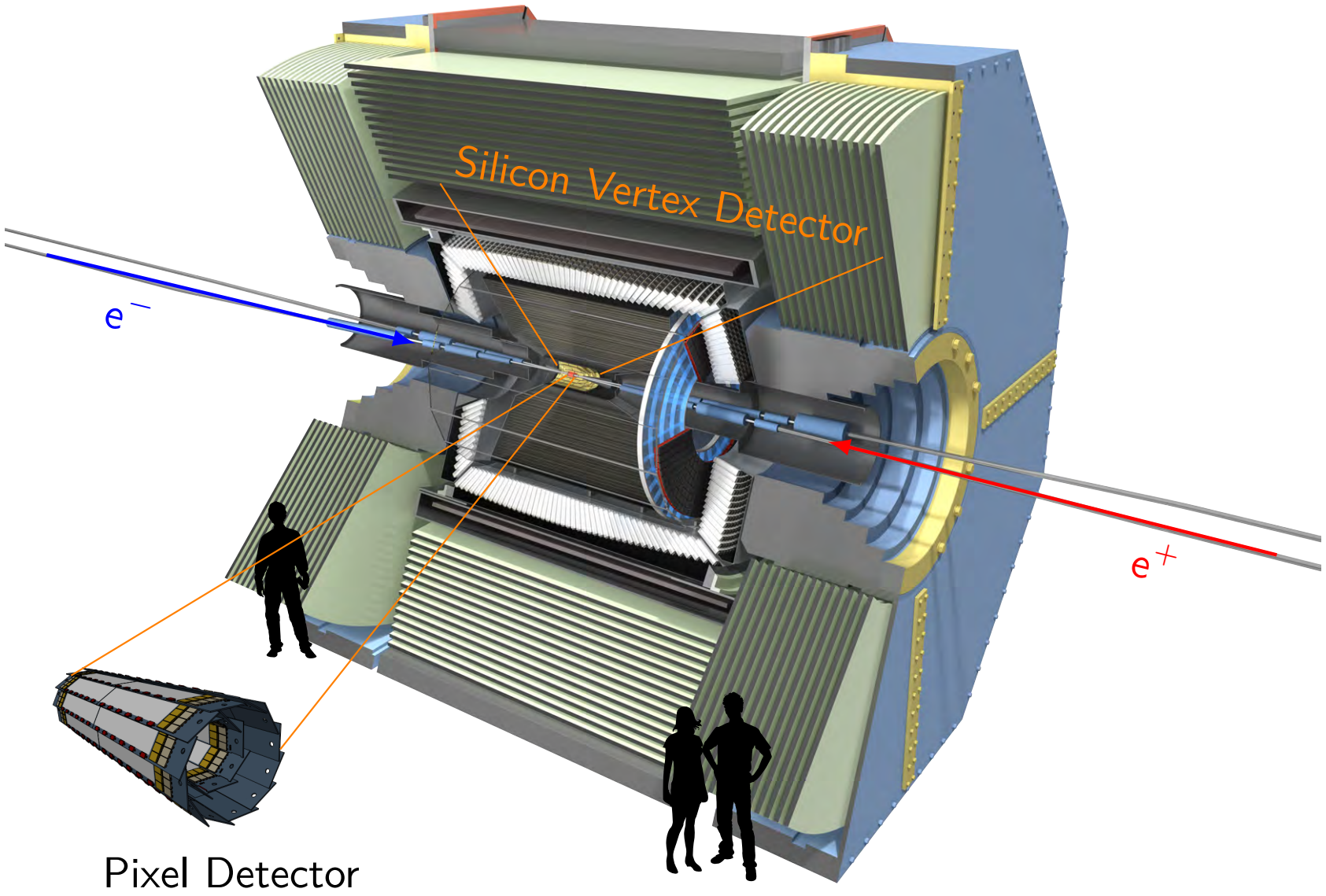
Kō **E**nerugī **K**asokuki kenkyū kikou

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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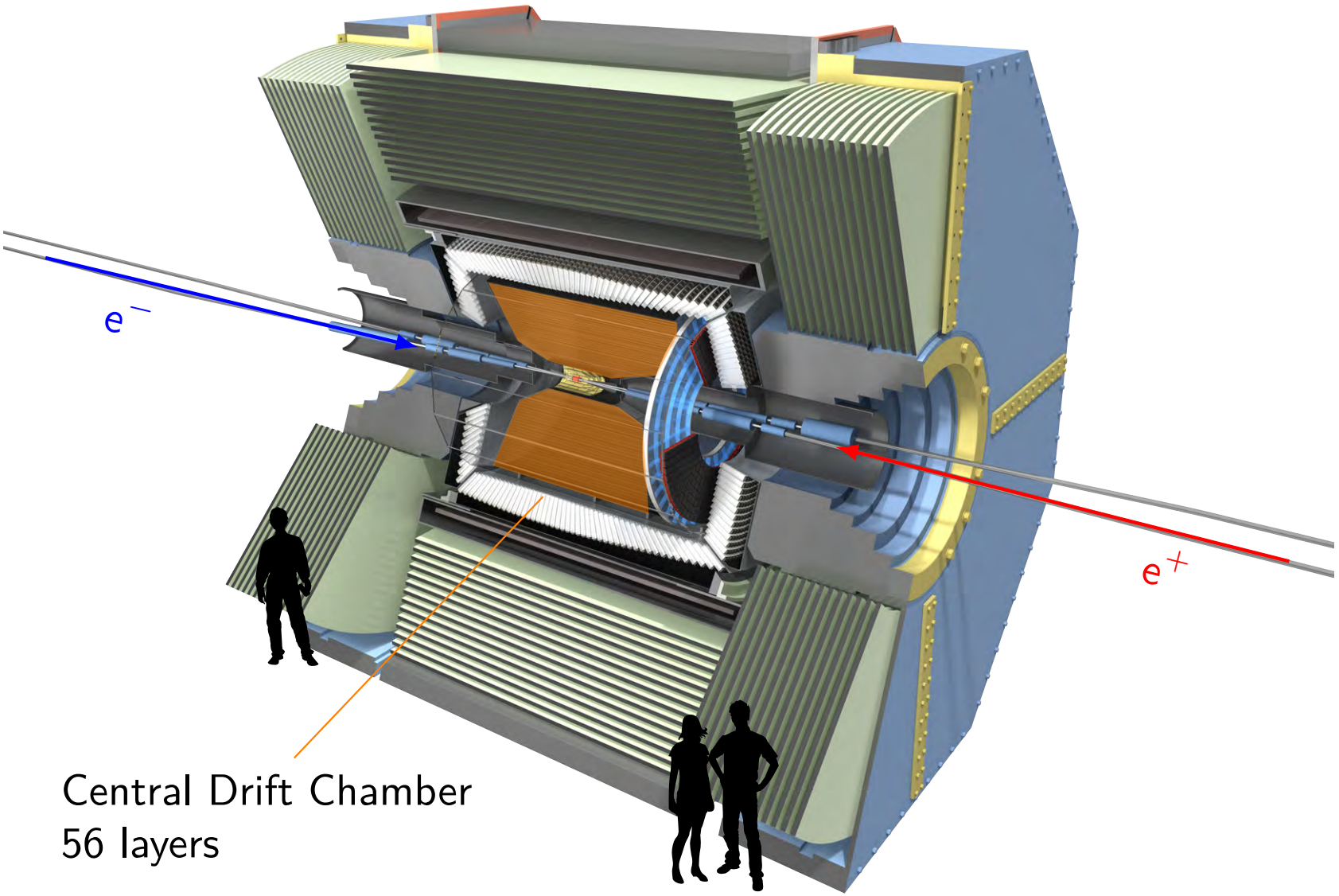

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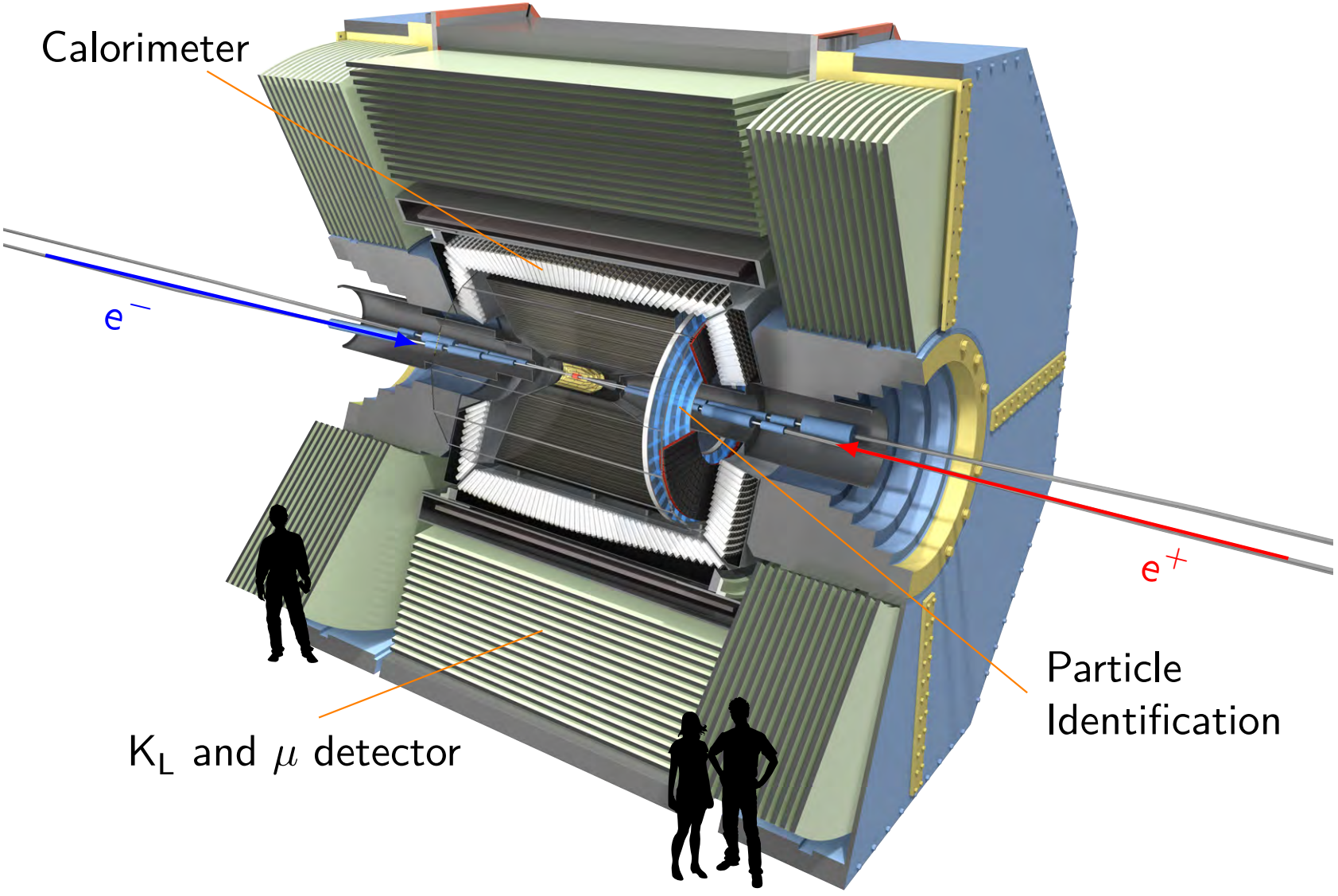
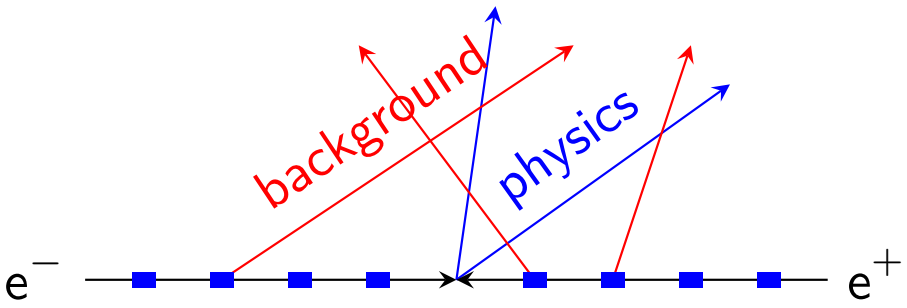


Introduction - Belle II Background

Beam Background Tracks

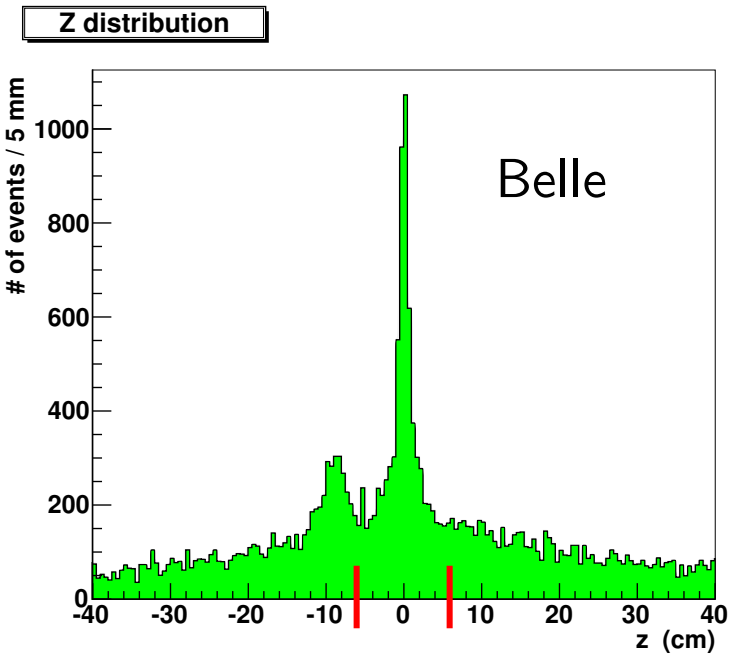


- increase with luminosity
- tracks from the beamline with displaced z vertices
- main processes:
  - Touschek Effect
  - Radiative Bhabha
  - Beam Gas

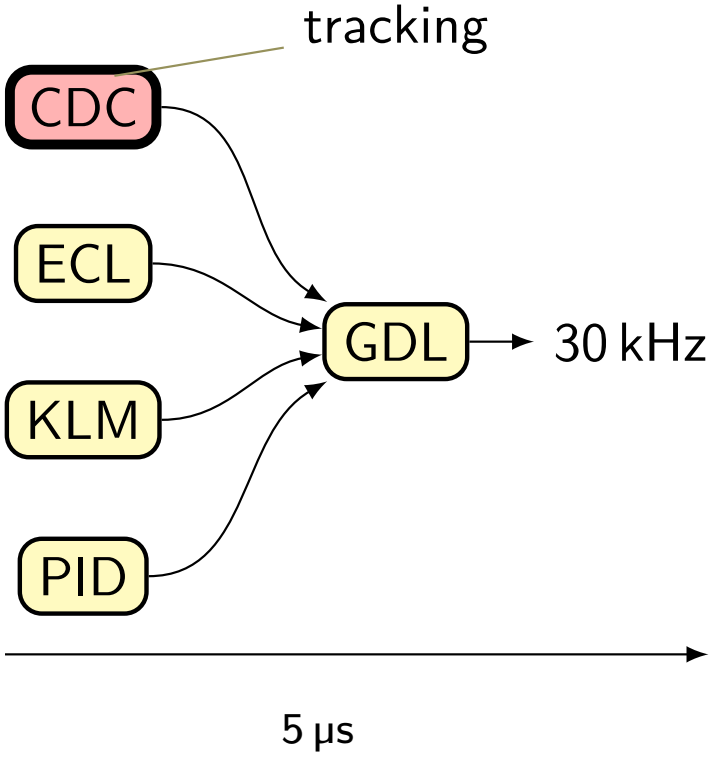
$\Rightarrow$ need z vertex reconstruction at 1st trigger level

NeuroTrigger Goals

- suppress machine background
- reject tracks from $z \neq 0\,\text{cm}$
- single track z-vertex resolution $< 2\,\text{cm}$
- time window $< 1\,\mu\text{s}$



Introduction - Belle II First Level Trigger

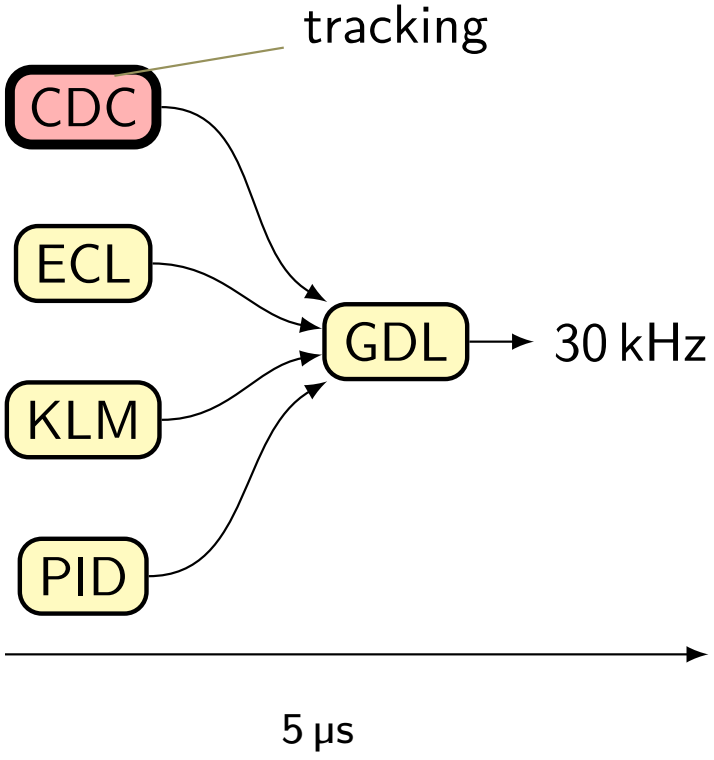


Requirements

- 30 kHz trigger rate
- 5 µs latency
- 200 ns event separation

$\Rightarrow$ pipelined operation

Introduction - Belle II First Level Trigger



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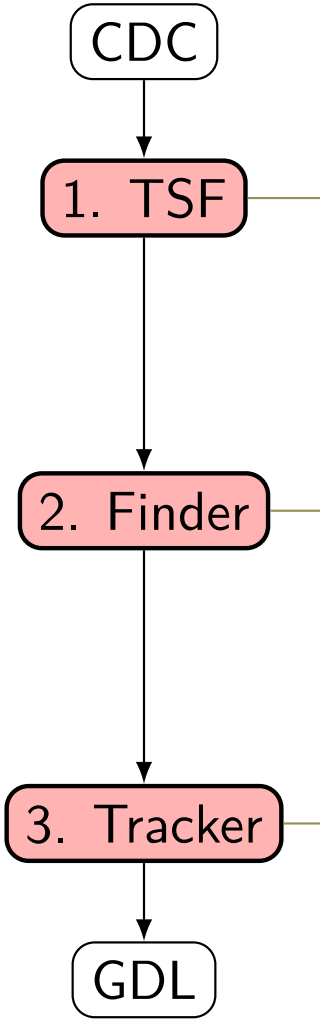
CDC Trigger Tracking

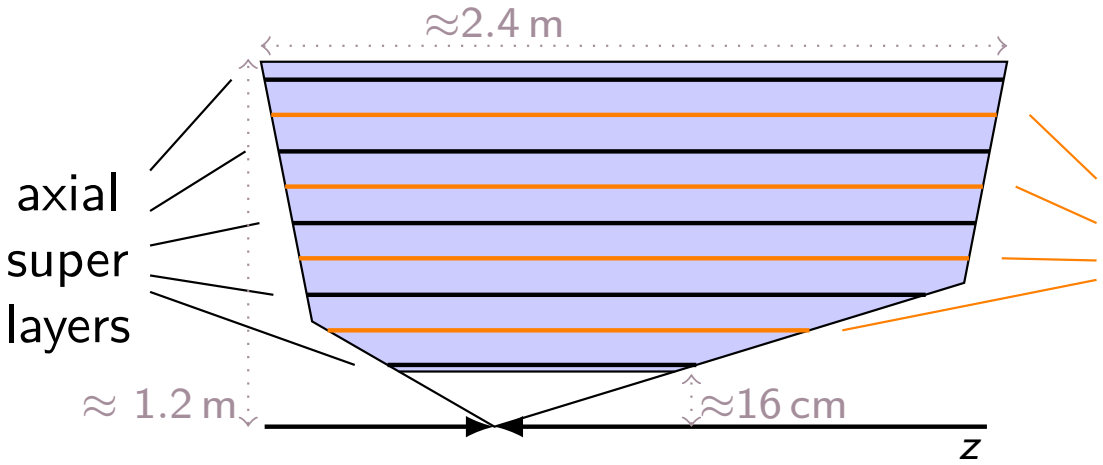


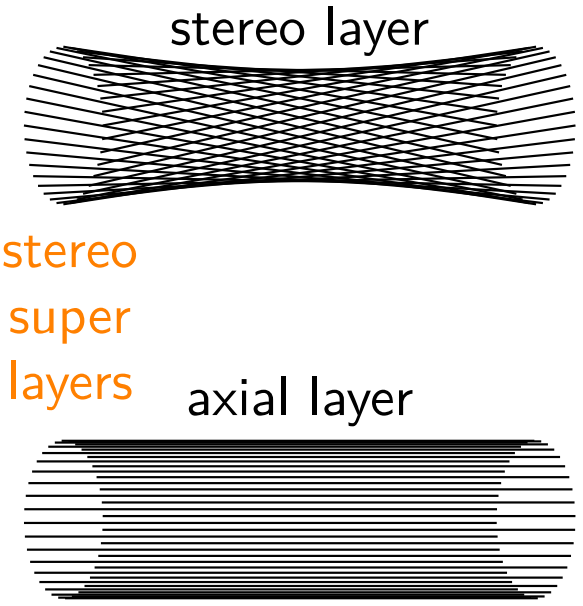
Track Segment Finder

Hough Transformation

- Least Square Fit
- Neural Network

Introduction - CDC Trigger



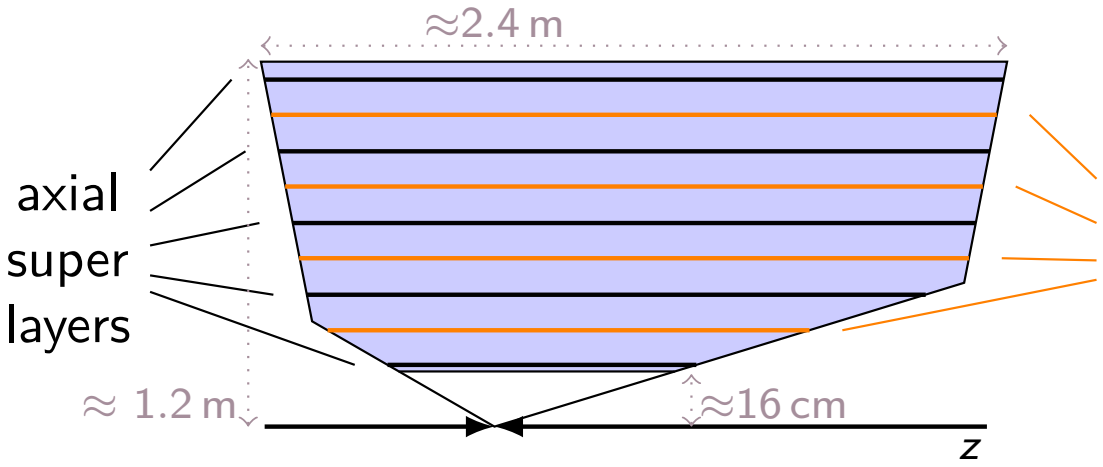


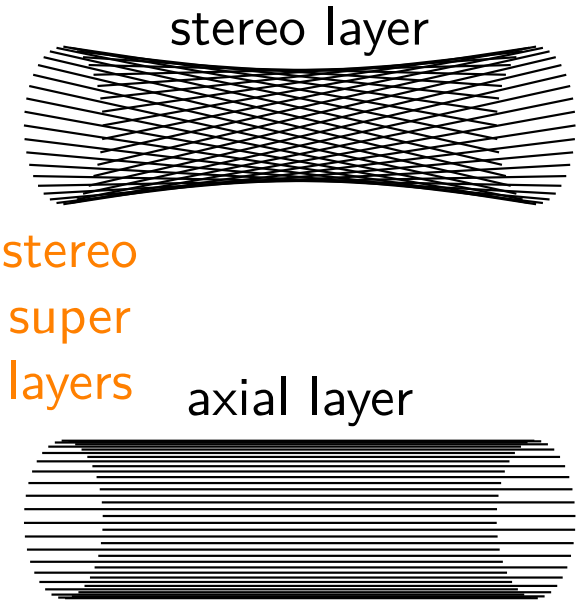
- 56 layers combined to 9 super layers (SL)
- 2336 track segments (TS) in 9 SL

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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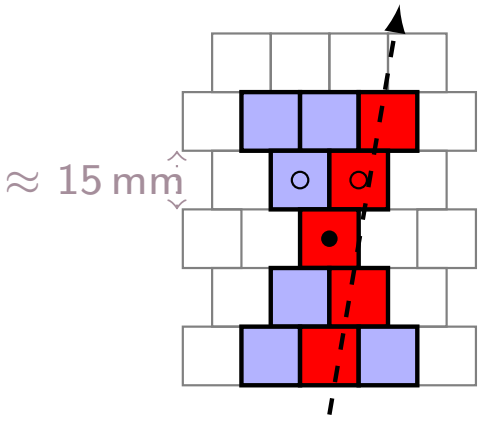
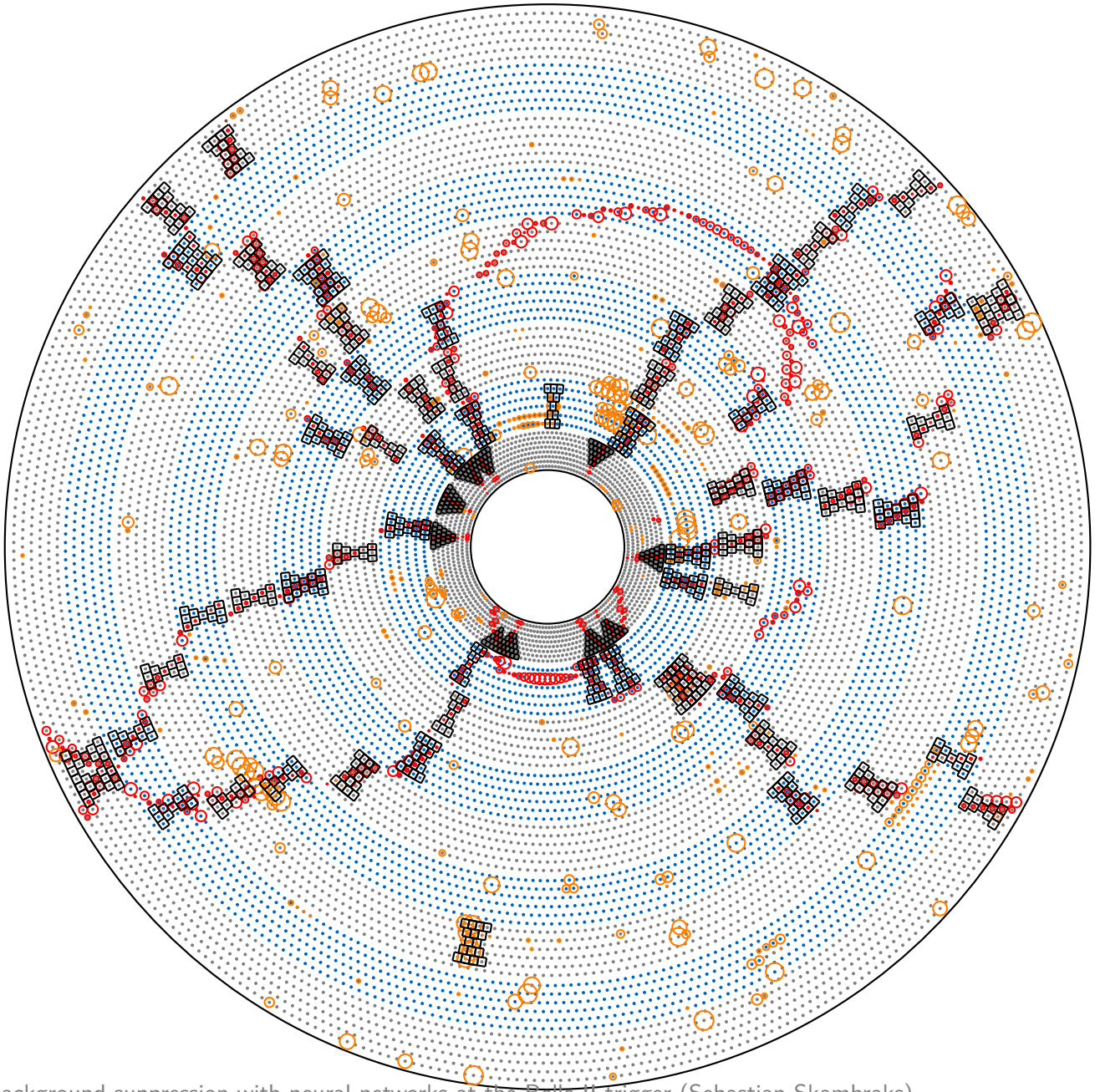
Track Segment



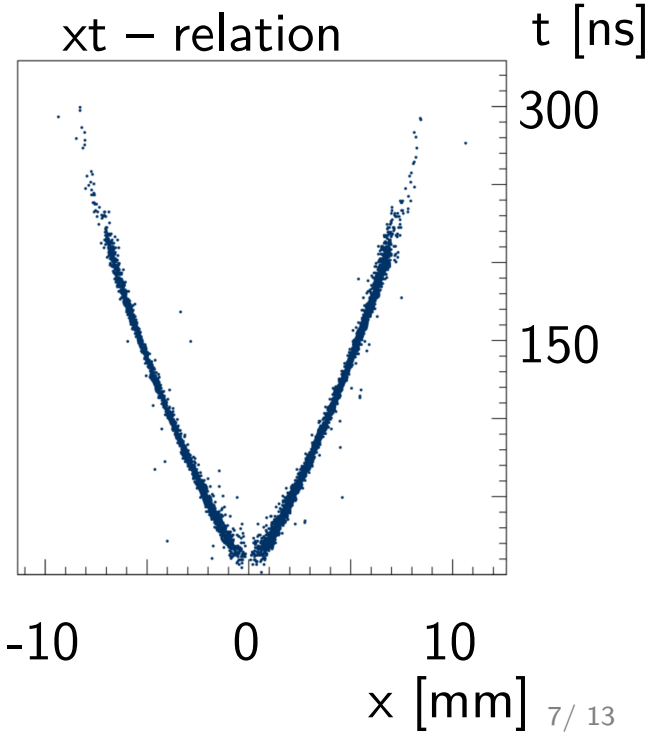
NeuroTrigger Input

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

Introduction - CDC Trigger



- $\Upsilon(4S)$ Event
- Bkg overlay
- track segments (TS)
- axial layers
- stereo layers



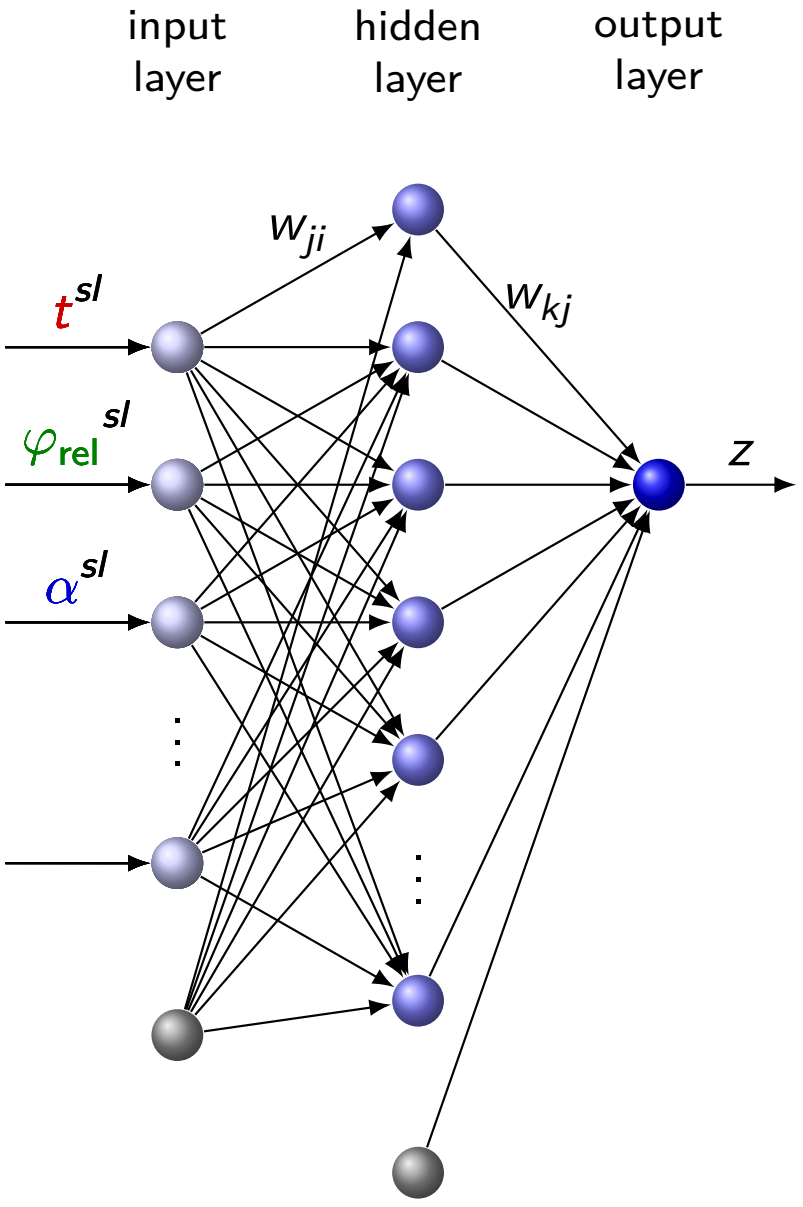
NeuroTrigger - Multi Layer Perceptron

Properties

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

Training

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

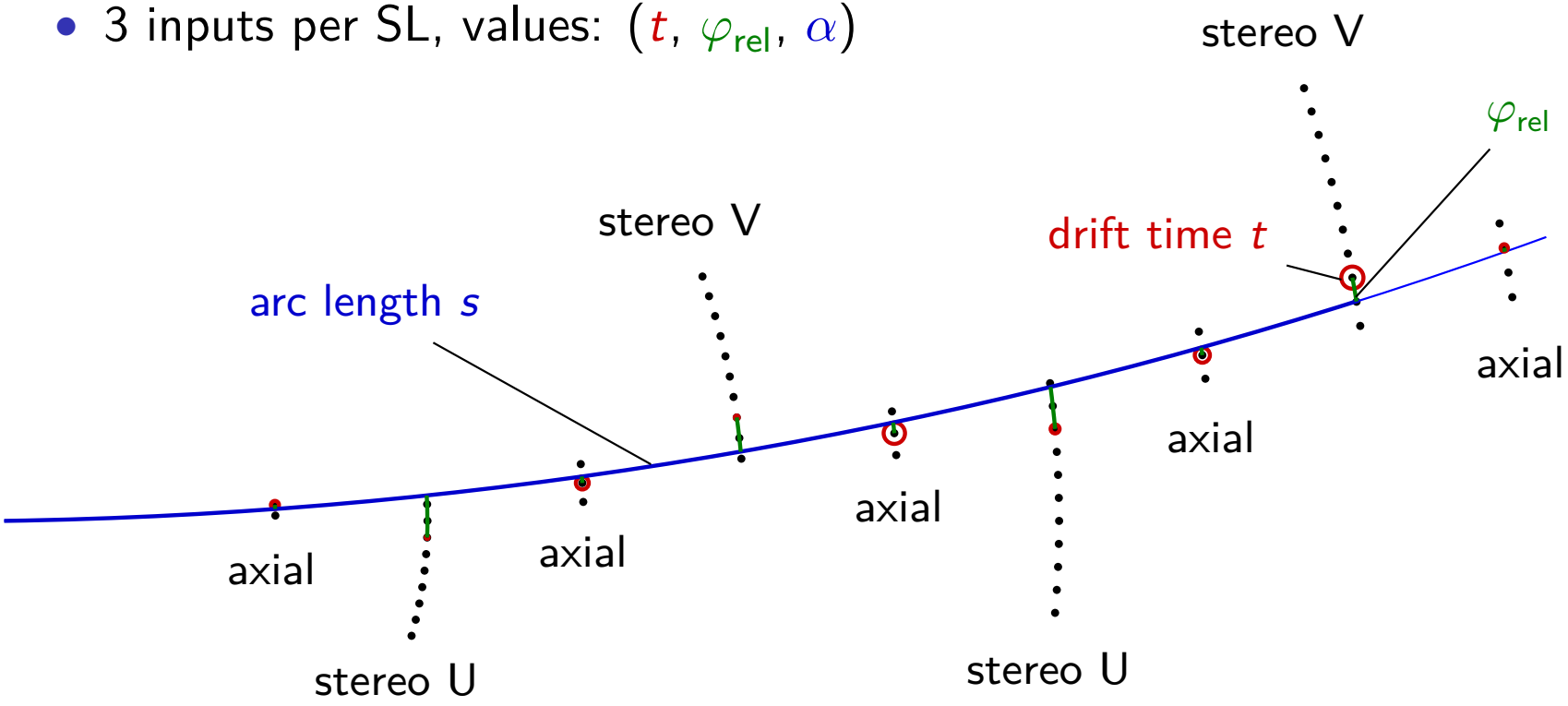


input one TS Hit per SL per track (positions: φ_{rel}, α and drift times: t)

output z estimate

NeuroTrigger - Input Representation

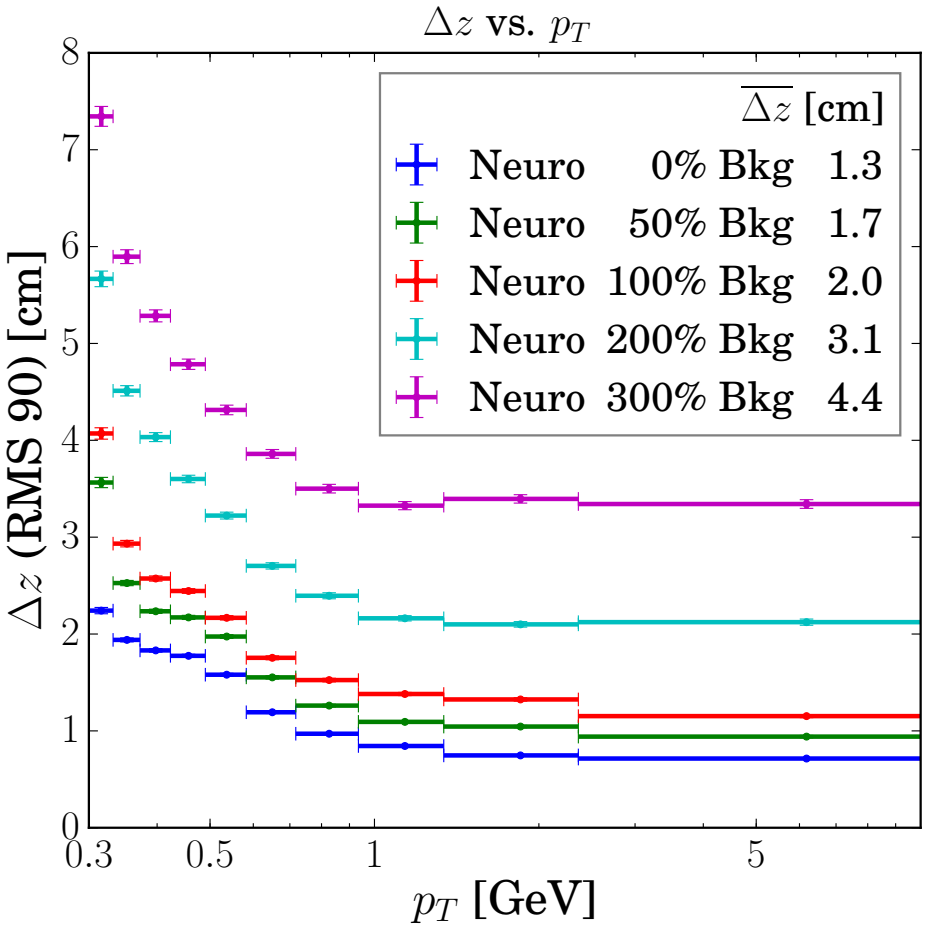
- use track estimates provided by 2D finder
- 3 inputs per SL, values: (t, φ_{rel}, α)

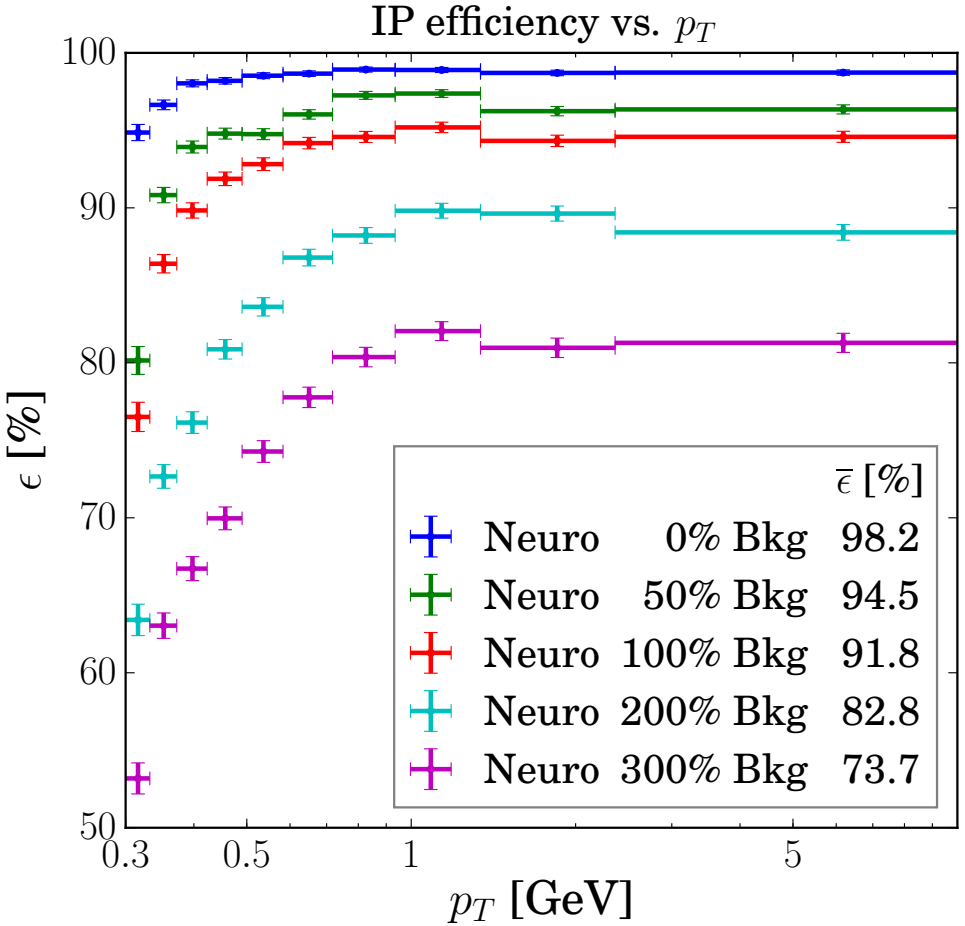


- φ_{rel} TS position relative to 2D track
- α $\dfrac{\text{2D arc length to TS}}{r_{2D}}$
- dedicated networks for missing hits

NeuroTrigger - Results Full Acceptance

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

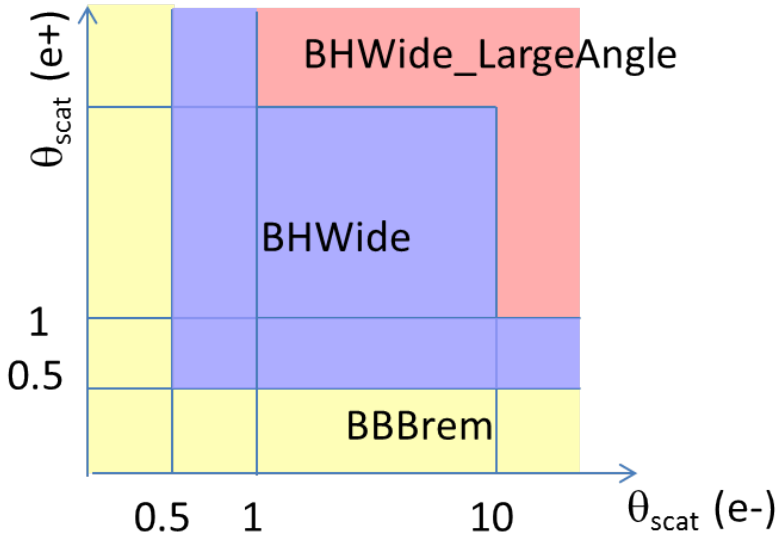




Background Simulation

background	generator	process
TwoPhoton	Aafh	$e^+e^- \underbrace{\rightarrow}_{e^+e^-\gamma\gamma} e^+e^-e^+e^-$
Bhabha	BBBrem BHWide	$e^+e^- \rightarrow e^+e^-\gamma$
Touschek	SAD	$e^\pm e^\pm \rightarrow e^\pm e^\pm$
Coulomb	SAD	$e^\pm N \rightarrow e^\pm N$
Brems	SAD	$e^\pm N \rightarrow e^\pm N\gamma$

Bhabha Generation



3 Bhabha cases:

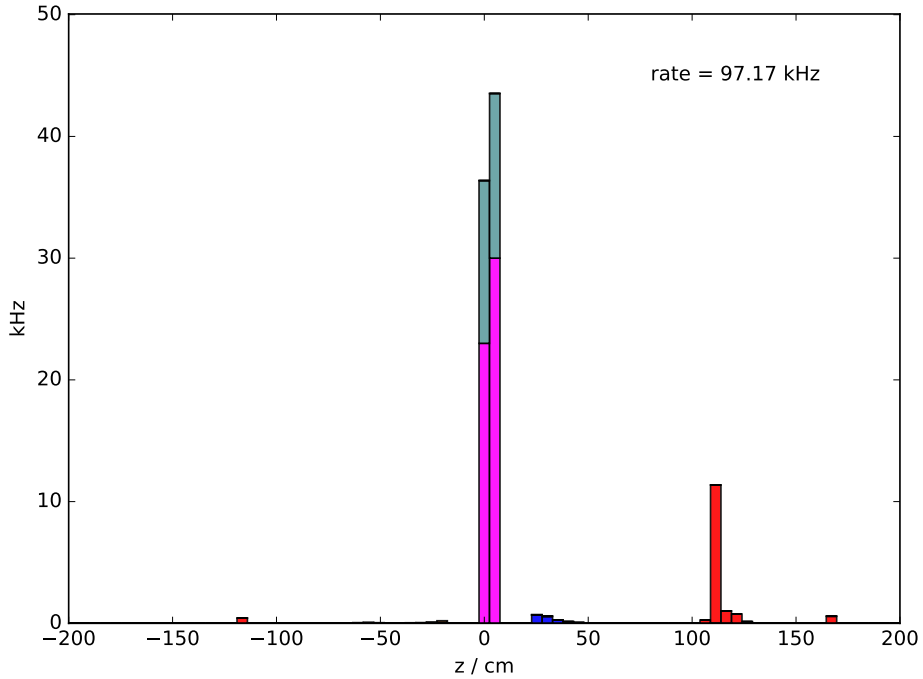
- small angle (BhabhaS)
- medium angle (BhabhaM)
- large angle (BhabhaL)

"Bhabha cross section depends on scattering angle"

Background Simulation

TwoPhoton
Touschek
Coulomb
BhabhaS
BhabhaM
BhabhaL
Brems

MC z of initial particles



Background Simulation

TwoPhoton
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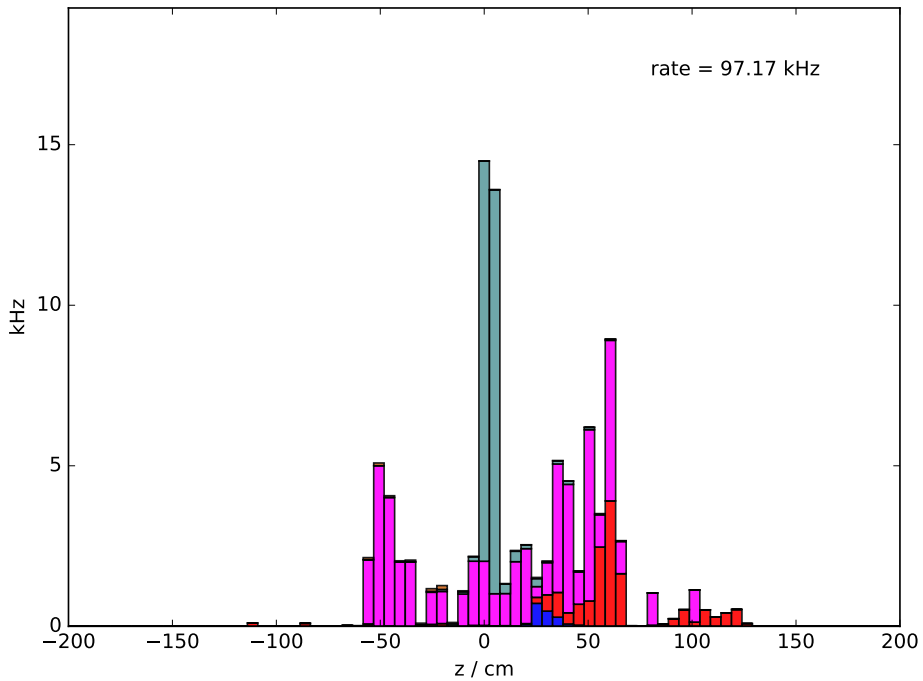
MC z of BG trigger tracks



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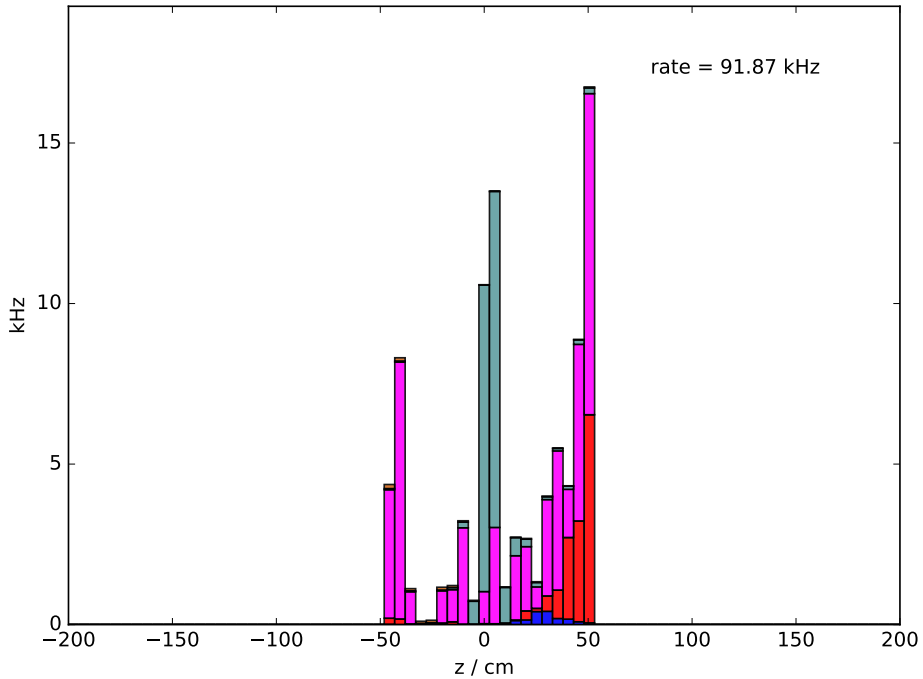
neural network z estimates



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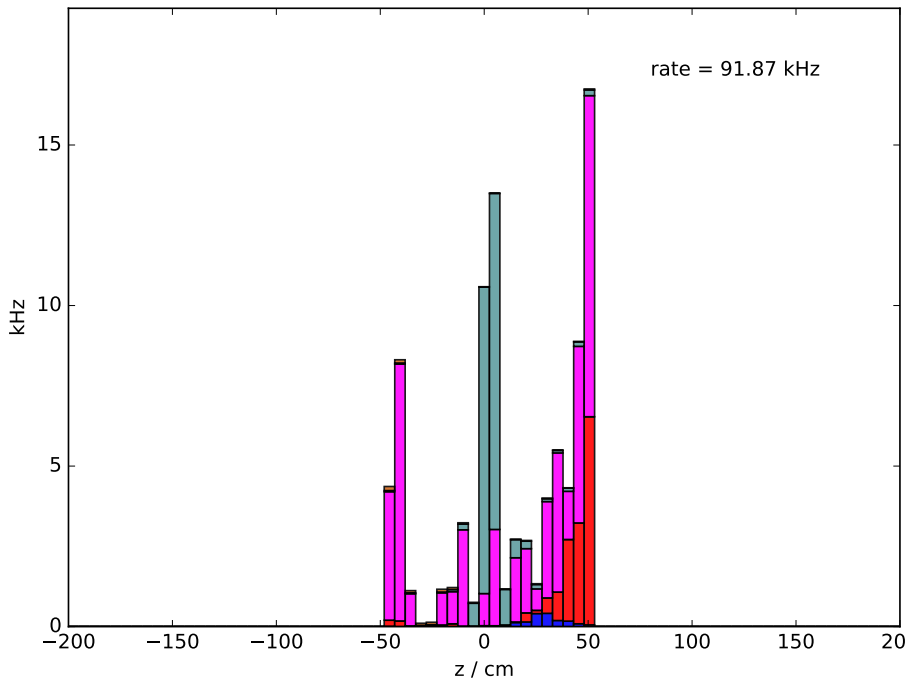
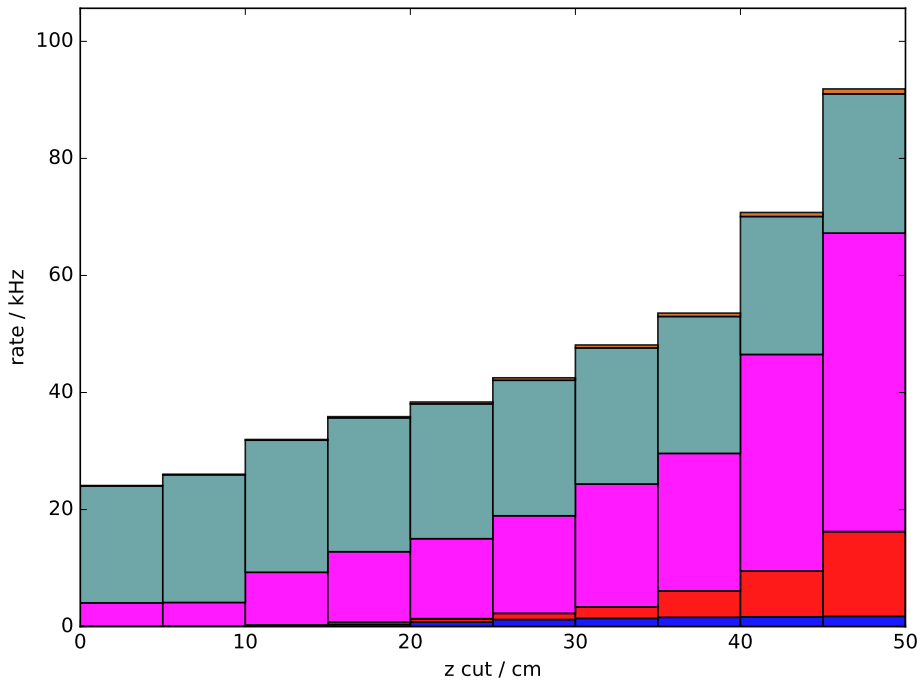


neural network z cut



Conclusion

"a z-vertex trigger is essential for Belle II"

NeuroTrigger

- noise robust
- depends on preprocessing
  (track finding & hit selection)

Background

- trigger background rate:
  - $\approx 17\,\text{kHz}$ (Coulomb/Touschek/Brems)
  - $\approx 80\,\text{kHz}$ (BHWide/BHWideLA)
- good BG reduction with Neural Network z cut