The Neuro-Z-Vertex Trigger of the Belle II Experiment

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Outline

Belle II Experiment
NeuroTrigger
3D Track Finder

Neuro Team
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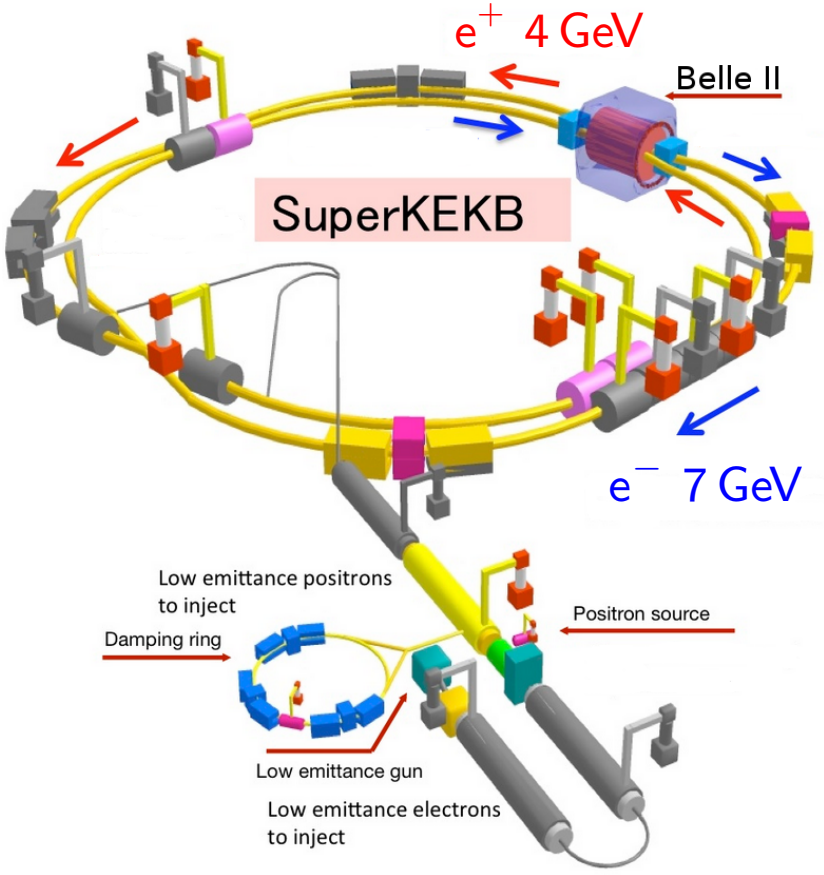
The Belle II Experiment at SuperKEKB

located in Tsukuba, Japan at **KEK**

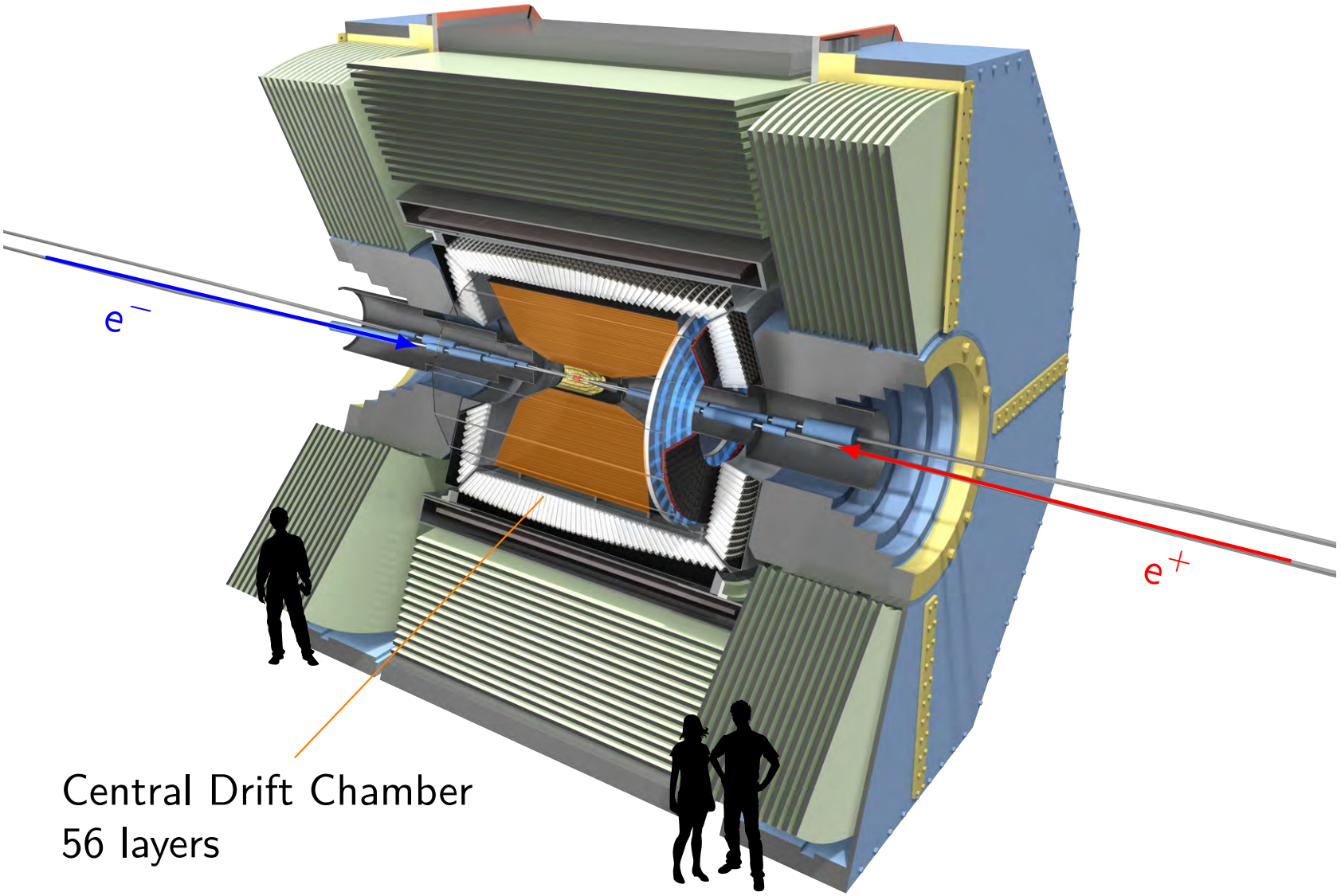
高エネルギー加速器研究機構　　**K**ō **E**nerugī **K**asokuki kenkyū kikou

High Energy Accelerator Research Organization



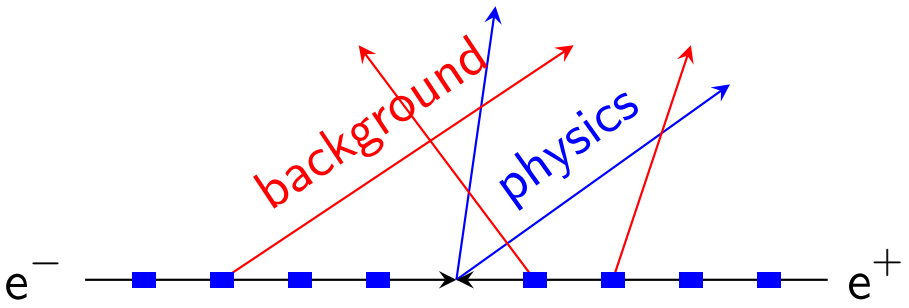
- asymmetric e^- e^+ collider
- $\Upsilon(4S)$ resonance
  ↳ B^0 $\overline{B}^0$ / B^+ B^-
- $\mathcal{L} = 8 \times 10^{35}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$
  (40× KEKB)
- average p_T: 500 MeV
- average track multiplicity: 11

The Belle II Detector



Belle II Background

Beam Background Tracks

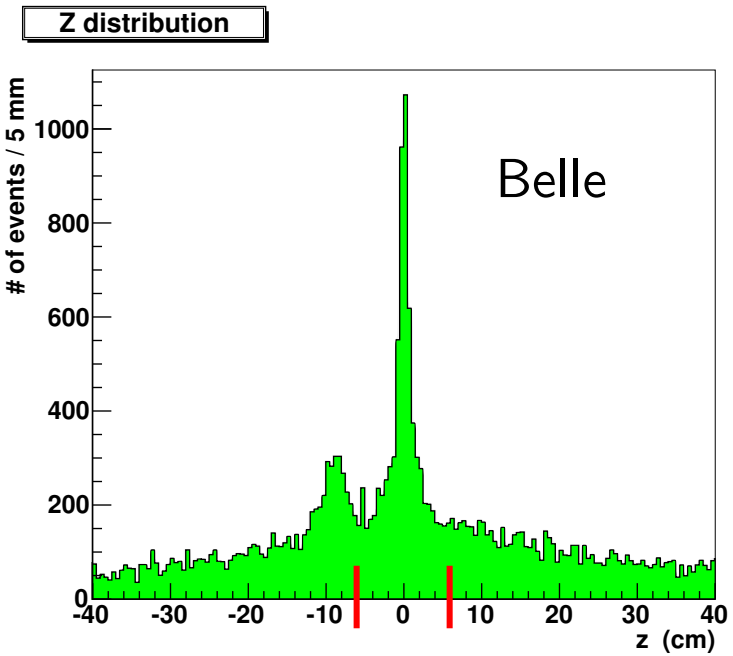


- increase with Luminosity
- tracks from the beamline with displaced z vertices
- main processes:
  - Touschek Effect
  - Radiative Bhabha
  - Beam Gas

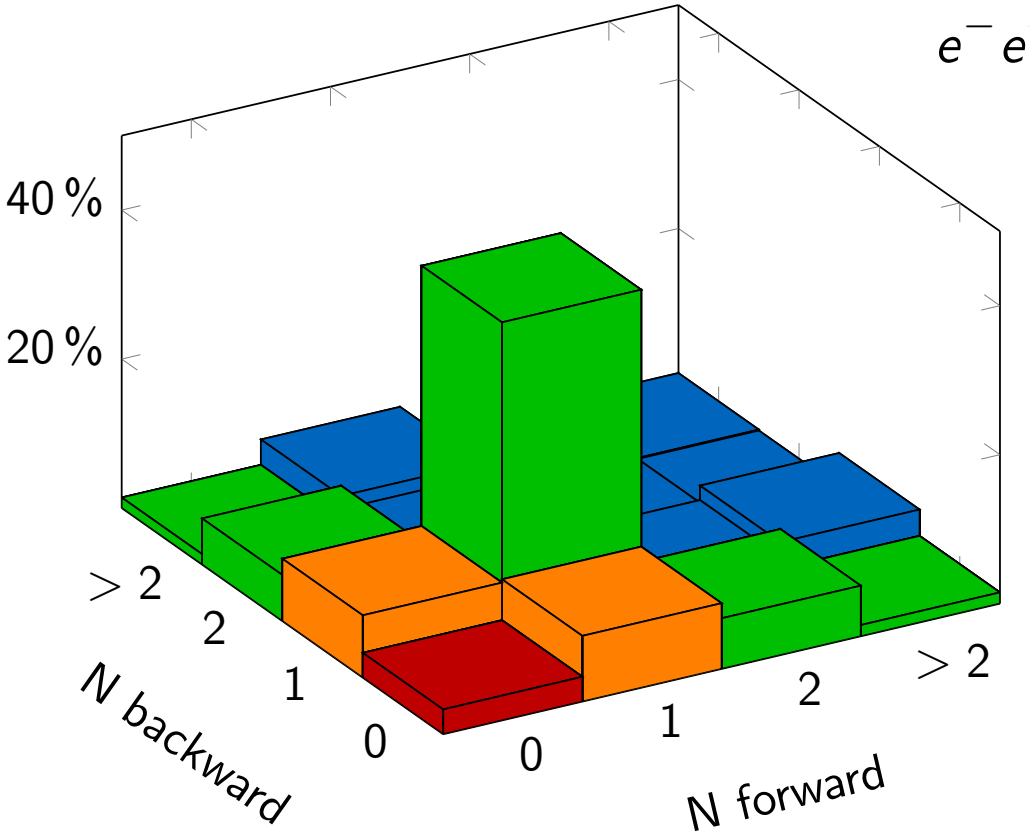
$\Rightarrow$ need z vertex reconstruction at 1st trigger level

NeuroTrigger Goals

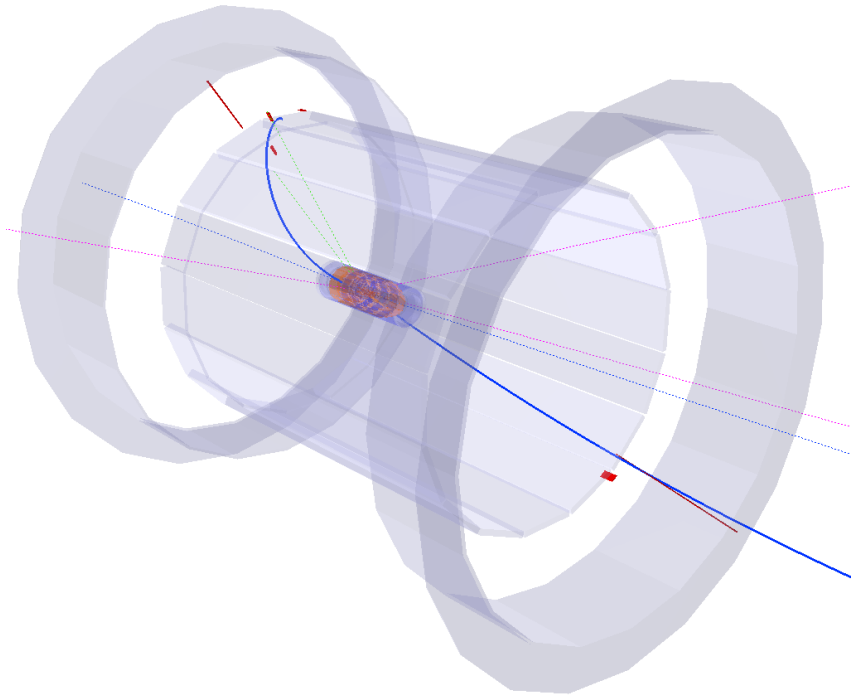
- suppress machine background
- reject tracks from $z \neq 0\,\text{cm}$
- single track z-vertex resolution $< 2\,\text{cm}$
- time window $< 1\,\mu\text{s}$



Benefits of a z-Vertex Trigger



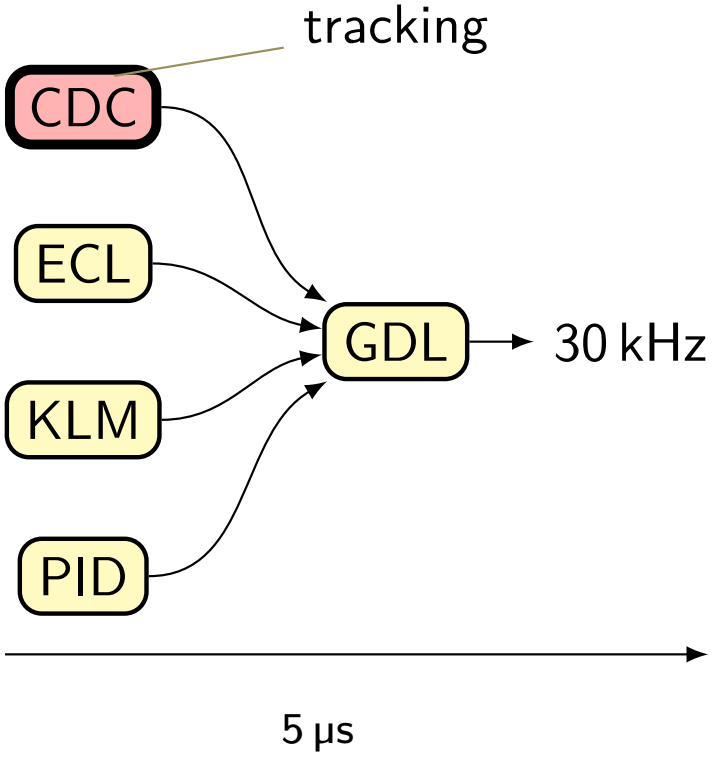
$e^- e^+ \longrightarrow \tau^- \tau^+$



- without z trigger: 3 tracks required (≥ 1 in each hemisphere)
- with z trigger: only 2 tracks required

- rescue low multiplicity events
- potential efficiency increase by factor 3.9

Belle II First Level Trigger

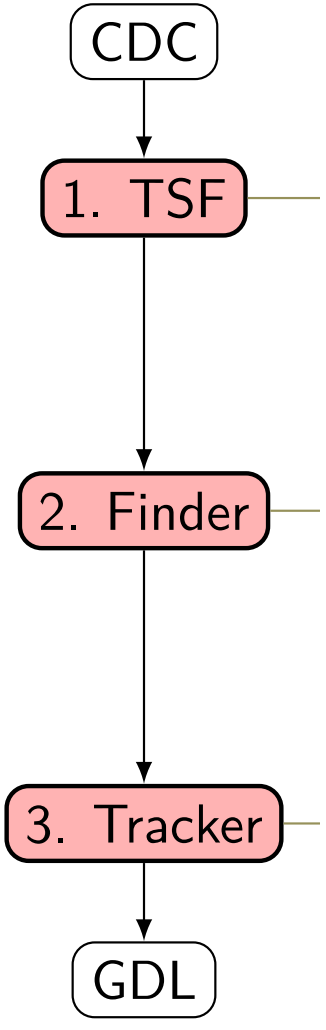


Requirements

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

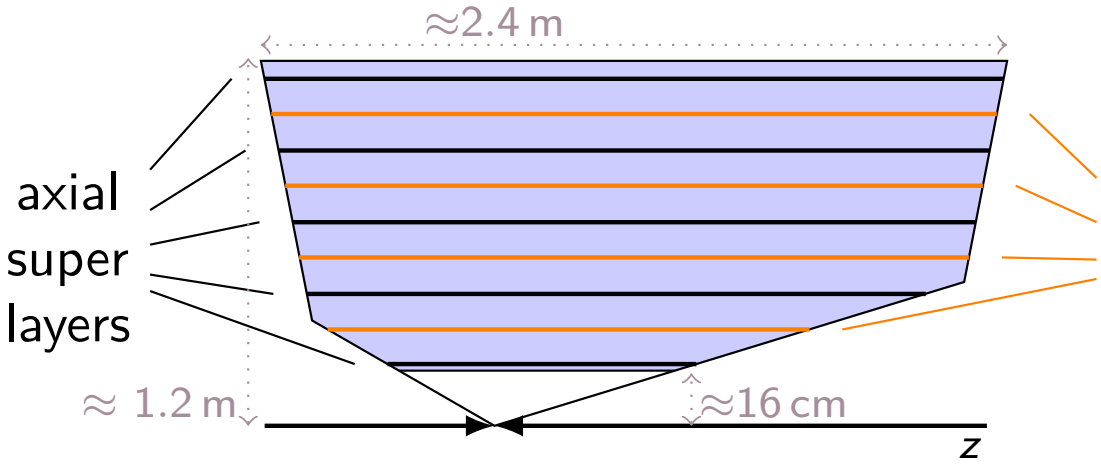
$\Rightarrow$ pipelined operation

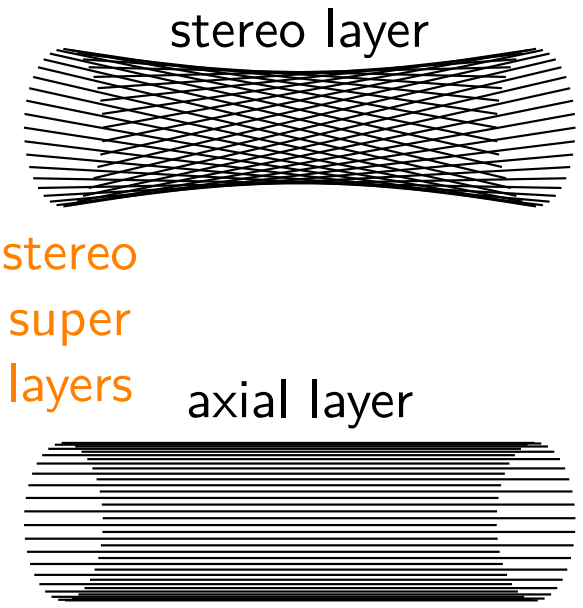
CDC Trigger Tracking



- Track Segment Finder
- Hough Transformation
- Least Square Fit
- Neural Network

CDC Trigger

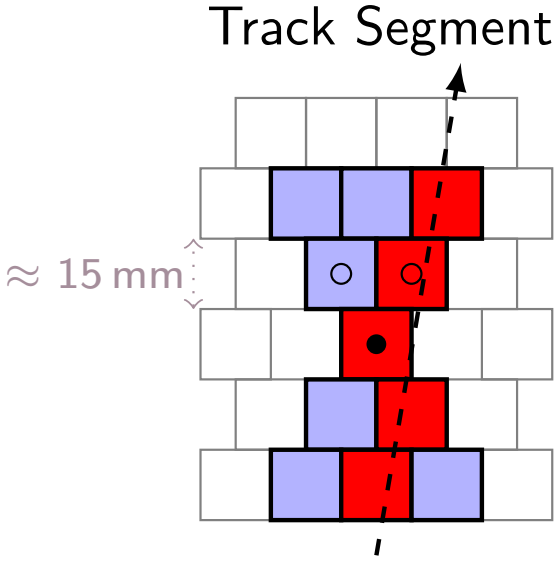




- 56 layers combined to 9 super layers (SL)
- 2336 track segments (TS) in 9 SL

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

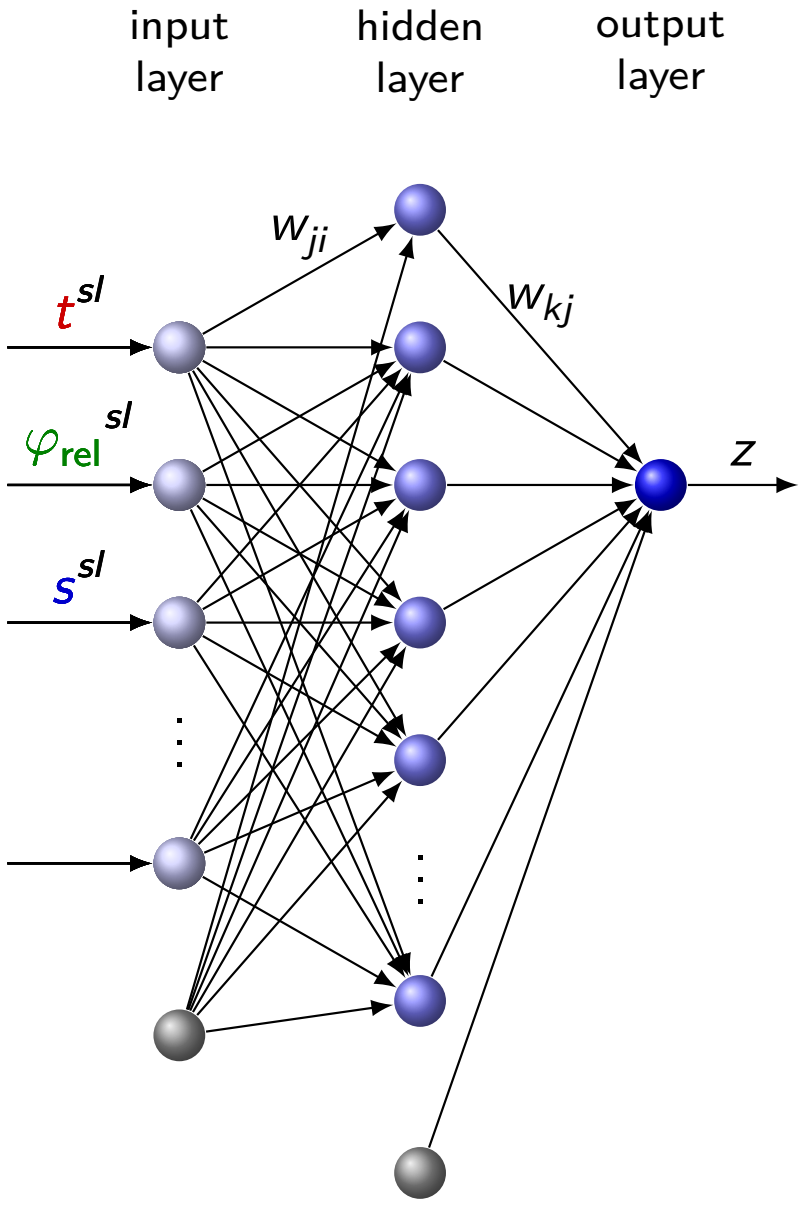
Stereo SL configuration



NeuroTrigger Input

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

NeuroTrigger - Multi Layer Perceptron



Properties

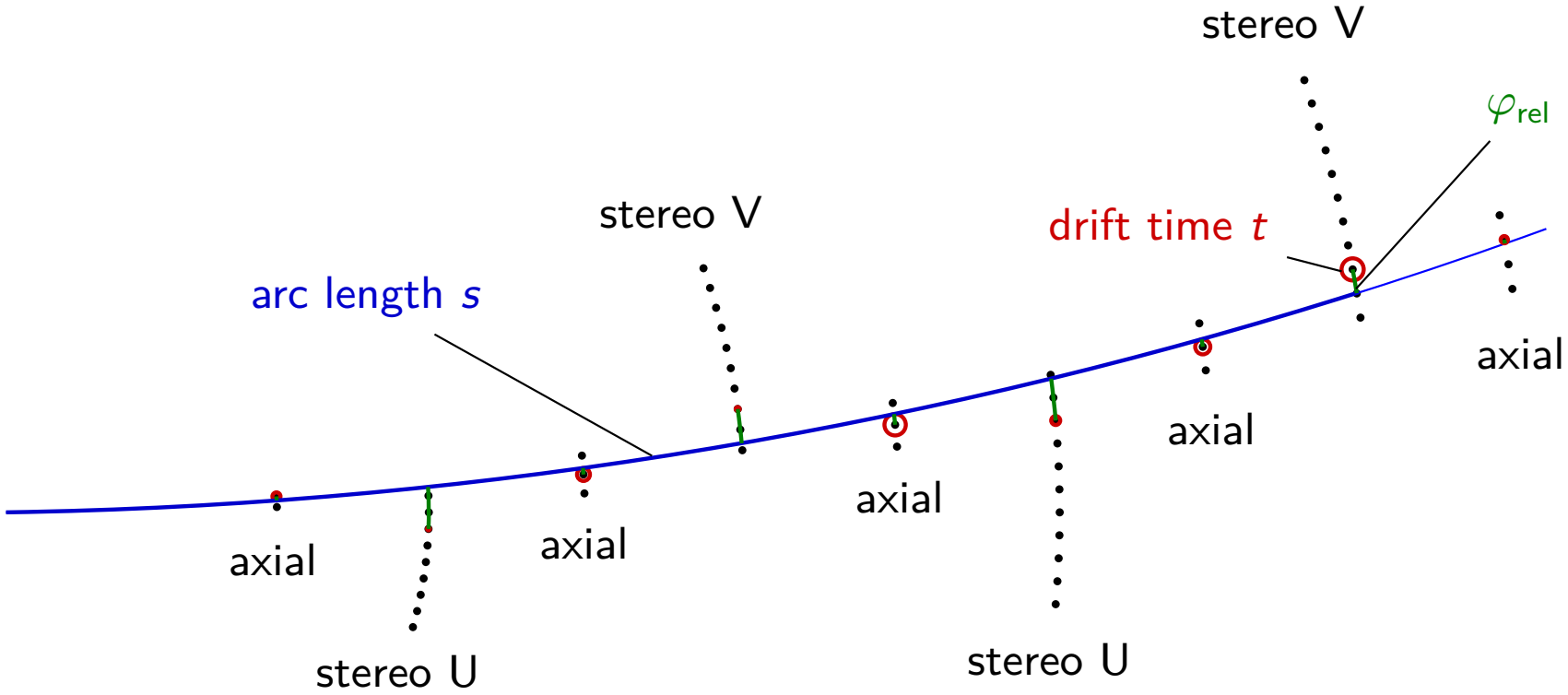
- supervised machine learning
- function approximation
- short deterministic runtime
- one neuron:
  $y = \tanh(\sum_i w_i \cdot x_i + w_0)$

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

output z estimate

Input Representation for the Neural Network

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



- φ_{rel} TS position relative to 2D track
- s 2D arc length to TS

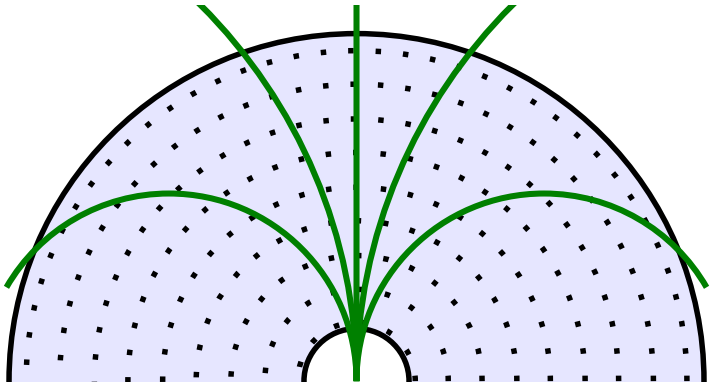
NeuroTrigger - Setup

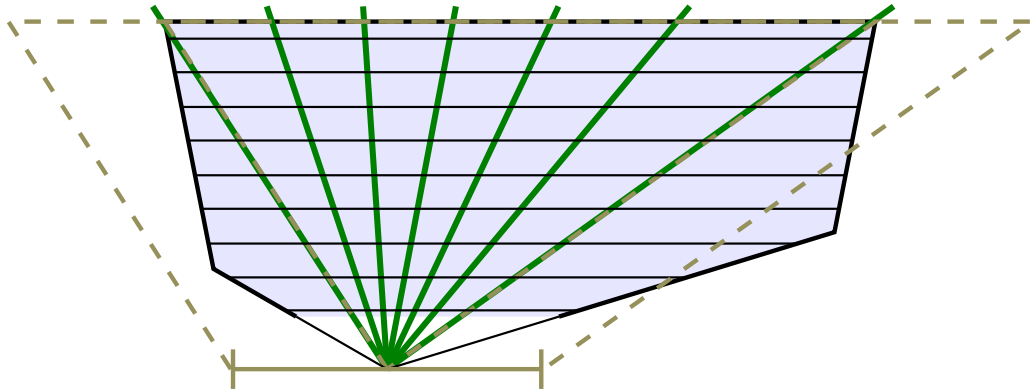
Sectorization

- sectorization in p_T, ϑ and missing hits
- one expert MLP per sector
- preprocessing selects the proper MLP

Training

- RPROP (backpropagation)
- monte carlo training data
- retraining with real data is planned

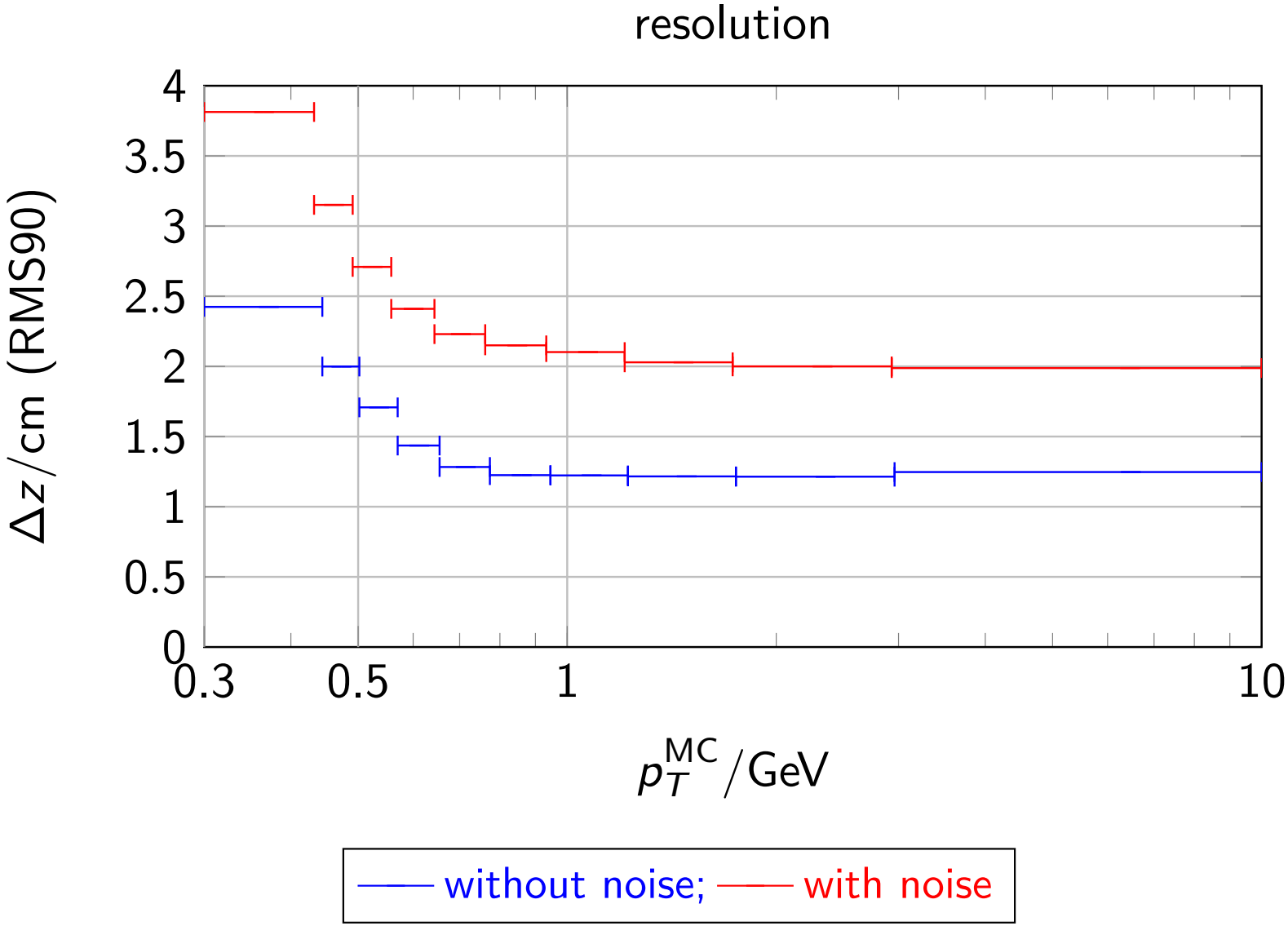




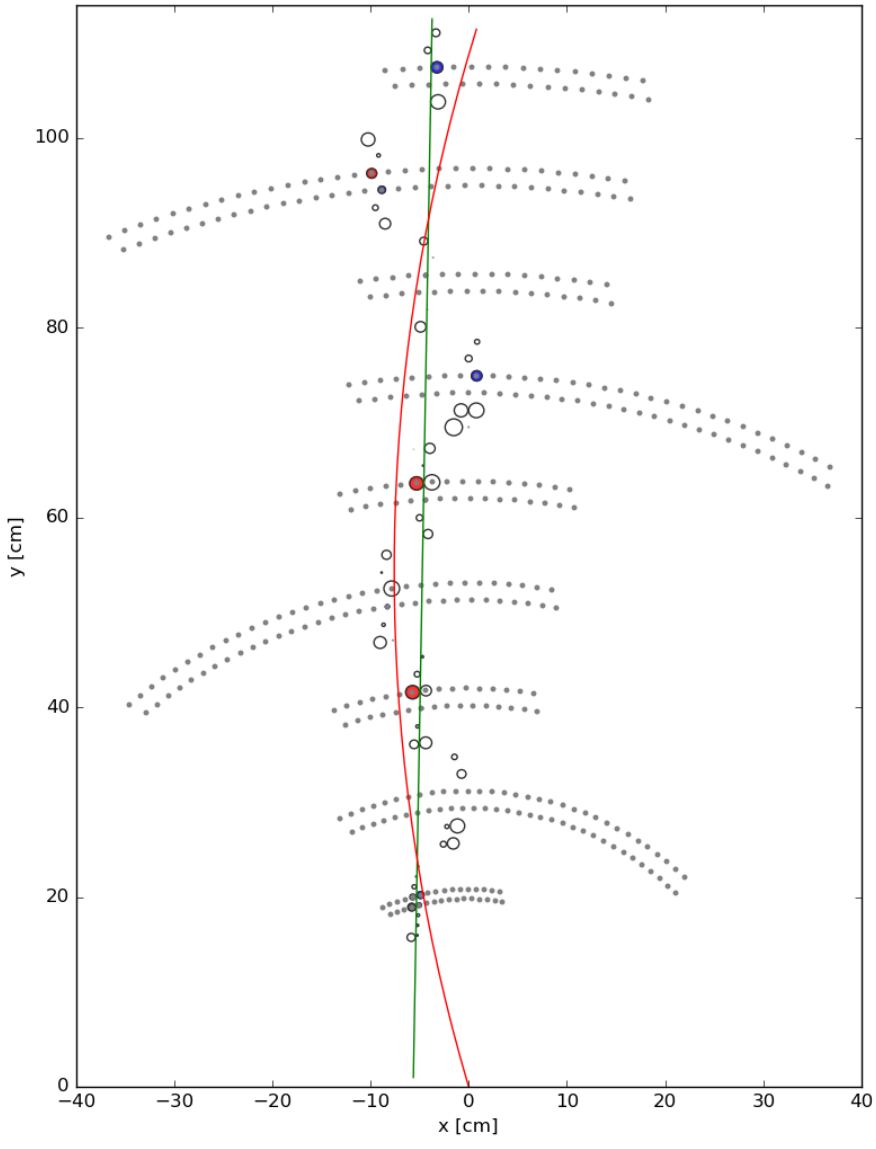
Sectors in p_T (left) and in ϑ (right).

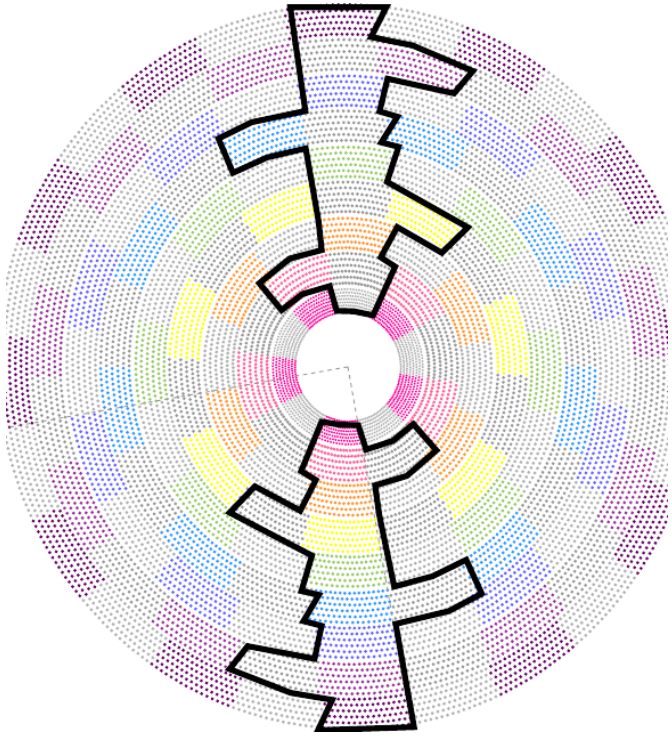
NeuroTrigger Resolution

- 2 networks for the full CDC (for +/- charge)



Cosmic Test - Geometry

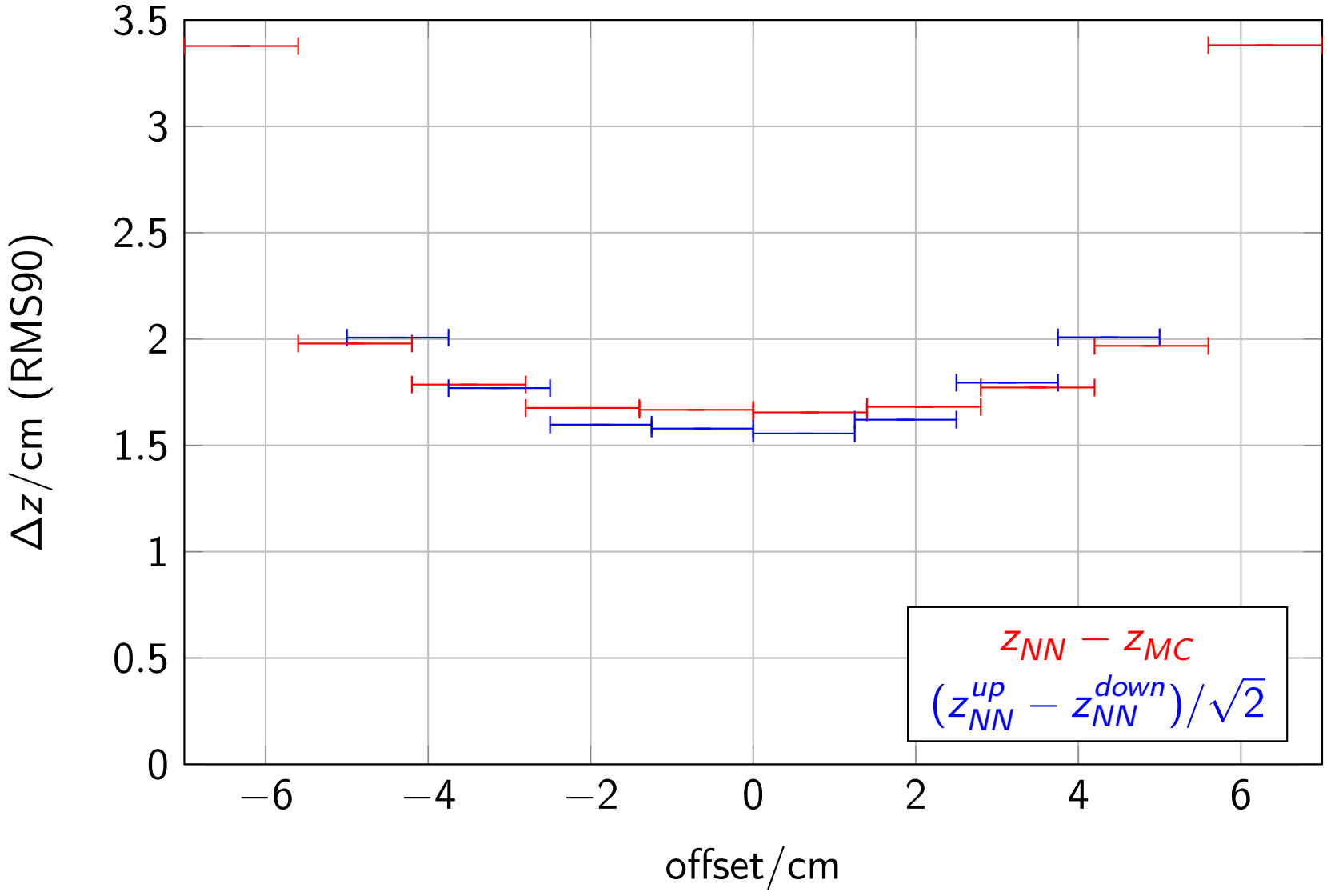




- no magnetic field
  $\rightarrow$ straight tracks
- transverse offset
- 2D Finder: origin constraint
  $\rightarrow$ apparent curvature
- $\approx$18% of CDC wires used

Cosmic Test - Neurotrigger Simulation

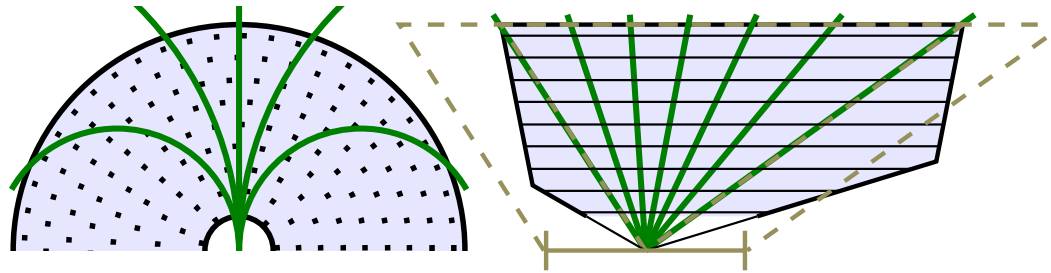
- resolution without MC: compare upper and lower CDC sector



3D Track Finder

Motivation

- improve 2D track finding
- use CDC stereo hits early
- get hit selection in one step (axial & stereo)
- allow ϑ sectorization



Sectors in p_T (left) and in ϑ (right).

Concept

Bayes'ian estimation

$$P(tracks|hits) = \frac{P(hits|tracks) \cdot P(tracks)}{P(hits)}$$

with a set *tracks* and a set *hits*.

- general approach
- allows change of track (and hit) parametrization (2D / 3D)

Track Finding

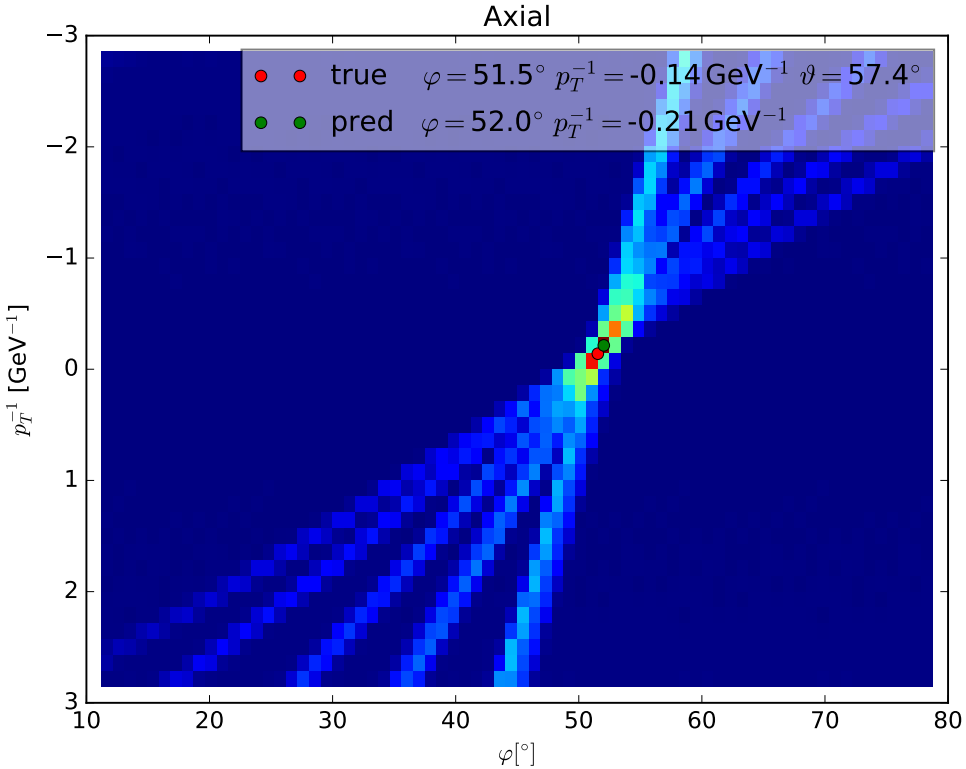
“Houghplane“

$$W(t|hits) = \sum_{h \in hits} P(t|h)$$

weights W for $t \in tracks$ and $h \in hits$. Tracks are peaks of $W(t|hits)$.

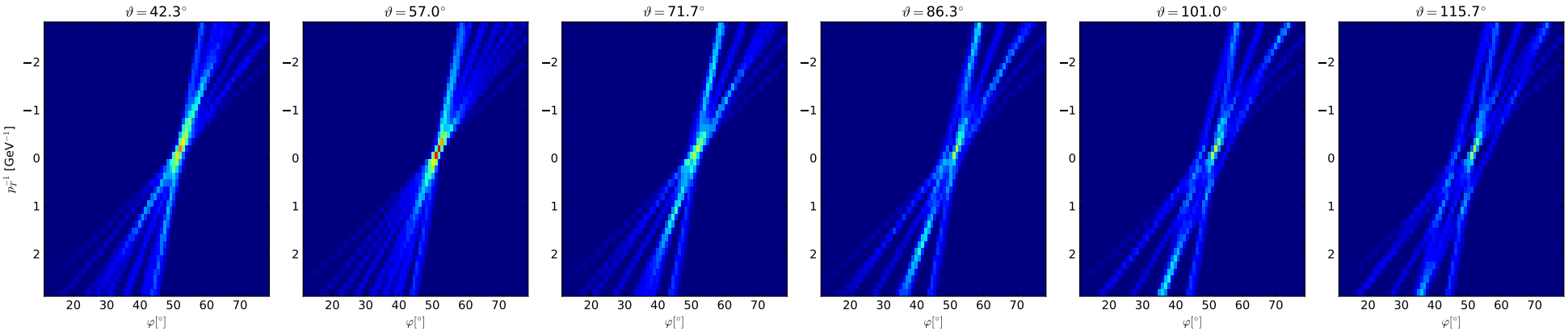
Peaks

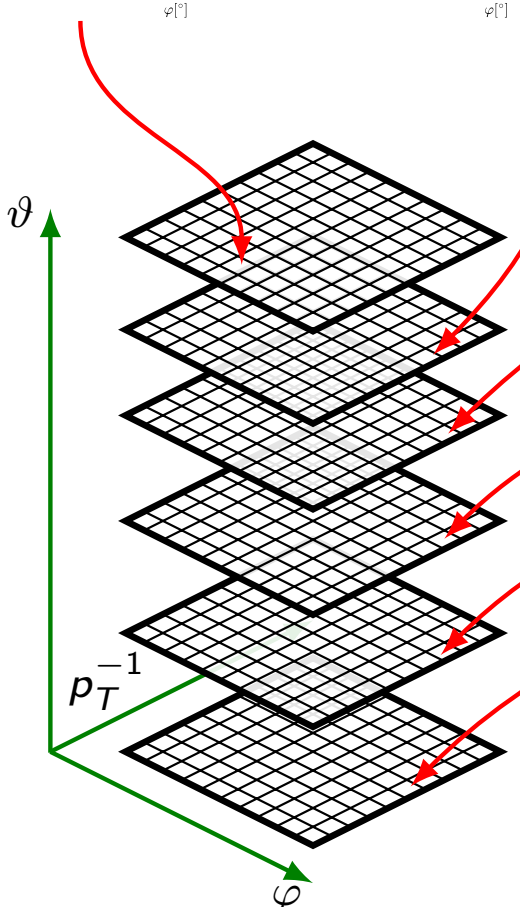
- are local maxima
- have a minimum weight
- identify tracks



2D finder using only axial hits

3D Track Finding





stack 2D- to 3D-parameter-space

Setup

$P(t|h)$

- approximated by a 5D array A (histogram)
- A is trained using monte carlo

	p_T^{-1}	φ	ϑ	id	prio
bins	40	384	6	2336	3

Table: size of the array A

Filling

for each track

1. bin track parameters t
2. increment $A[t, h]$ for all hits h

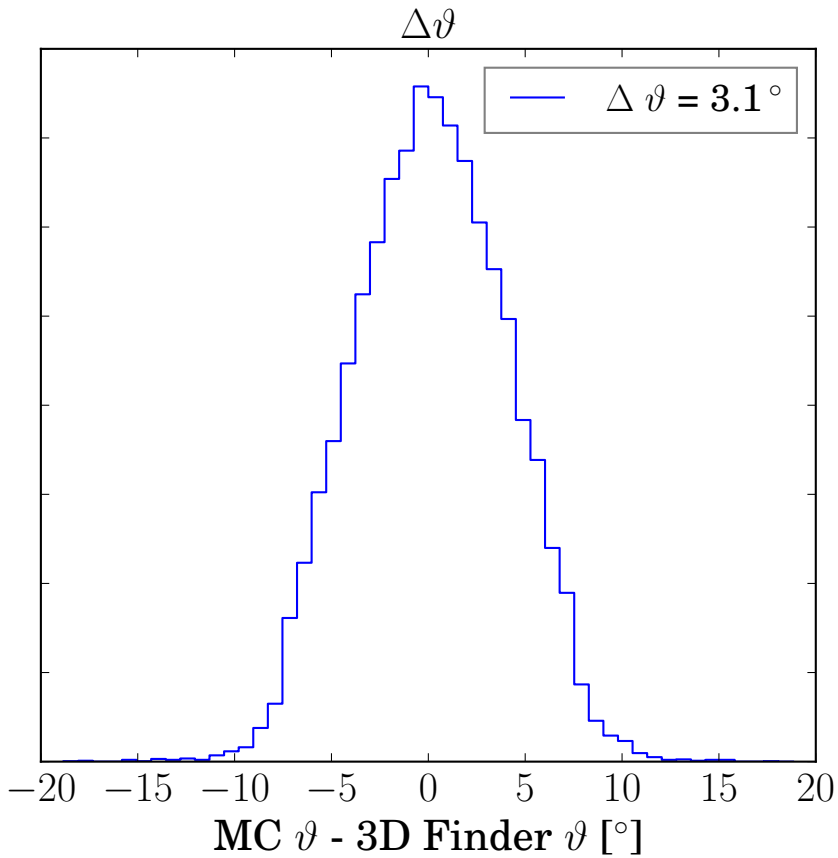
Normalization

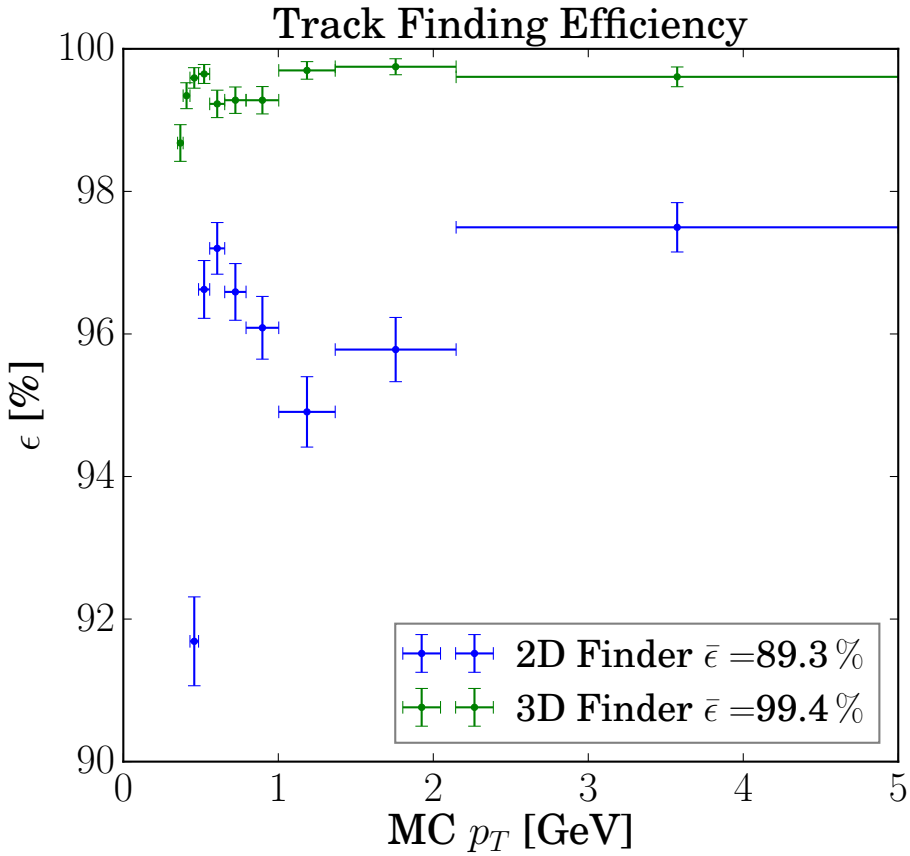
normalize A for all tracks t ($\equiv$ all tracks are equally probable)

$$A[t,h] = \frac{A[t,h]}{\sum_{\text{all}h} A[t,h]}$$

Results

- ϑ resolution (RMS90)
- track finding efficiency
- 10000 single track events





Summary

- a z-vertex Trigger is essential for Belle II
- the Neural Network is well suited

NeuroTrigger

- depends on preprocessing (Track Finding & Hit selection)
- upcoming hardware test with cosmics

Track Finding

- high accuracy 3D Pattern recognition possible
- improved 3D track finding efficiency

Backup - Track Finding

Construct "Houghplane"

$$H[tracks] = \sum_{h \in hits} A[tracks, h]$$

for an event with a set *hits*, *tracks* are peaks in H.

Algorithm

1. find clusters
   neighbours of the peaks with weight $> 90\%$ *peakweight*
2. select contributing hits
   hits with high weight contribution to the cluster
3. calculate track parameters
   weighted mean of selected cluster cells