The z-Vertex Trigger for Belle II

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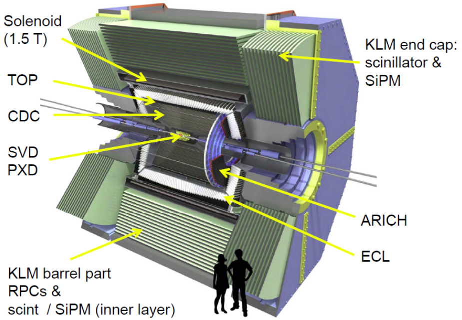
Outline



Neuro Team

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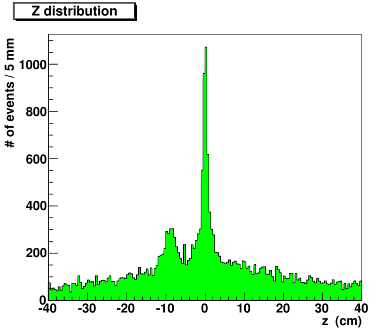
Introduction

Goals

- build a z-vertex track trigger
- achieve high precision
  (spatial resolution $\Delta z \approx 2\,\mathrm{cm}$)
- get a fast decision ($< 1\,\mu\mathrm{s}$)

Method

- Input:
  - CDC Track Segment data
    [IDs & clock cycle (2 ns timing)]
- Algorithms:
  1. Bayes Classifier / Hough Transformation
     (pattern recognition)
  2. LS - Least Square fit
     (linear estimation)
  3. MLP - Multi Layer Perceptron
     (nonlinear correction)



Offline z distribution in the Belle Experiment[a].

a) T. Abe et al., *Belle II Technical Design Report*, KEK-REPORT-2010-1, arXiv:1011.0352v1 [physics.ins-det] (2010).

Main approach

Pattern recognition - Bayes Classifier / Hough Transform

sectorize Input in the track parameters $(p_T, \varphi, \vartheta)$

$$P(Sector|Hits) = P(Hits|Sector) \cdot \frac{P(Sector)}{P(Hits)} \tag{1}$$

Fitter - Least Squares

$$\vec{n} = (\mathbf{X}^T\mathbf{X})^{-1}\mathbf{X}^T\vec{y} \tag{2}$$

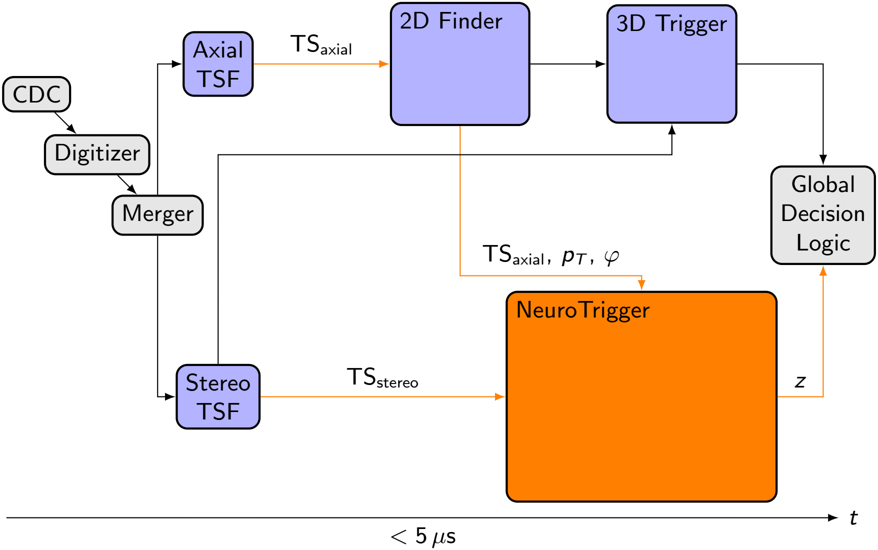
$\mathbf{X}$ and $\vec{y}$ contain the hits, $\vec{n}$ defines a track parameter sector

Neural Network - MLP

$$z(Hits, p_T, \varphi, \vartheta) = NN(f(Hits, p_T, \varphi, \vartheta)) \tag{3}$$

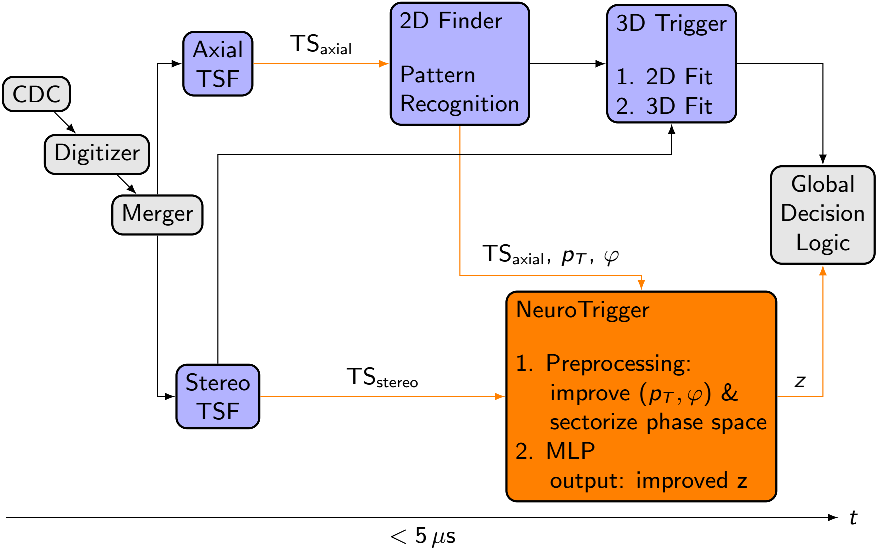
- output float value interpreted as scaled z-position
- NN input transformation (function f) requires preprocessing

Signal flow in the CDC Trigger



→ The neural network trigger will be implemented on a Virtex 7 FPGA

Signal flow in the CDC Trigger



$\rightarrow$ The neural network trigger will be implemented on a Virtex 7 FPGA

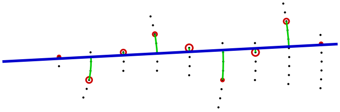
MLP - Multi Layer Perceptron

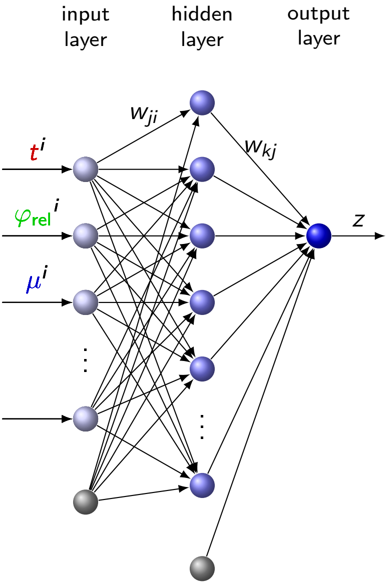
Properties

- supervised machine learning
- function approximation
- short deterministic runtime
- one neuron:
  $y = \tanh(\sum_{i=1} w_i \cdot x_i + w_0)$

Input

3 nodes per SL (t, φ_{rel}, μ)
with t: drift time, φ_{rel}: relative wire position, μ: 2D arc length

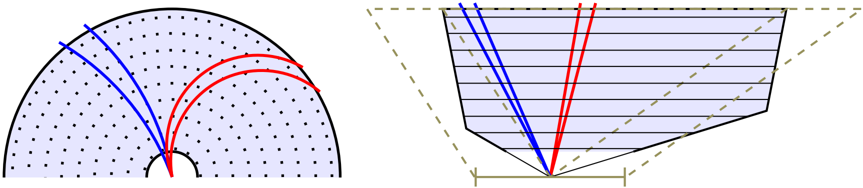




MLP - Setup

Sectorization

- the track parameter space is sectorized in $(p_T, \varphi, \vartheta)$
- for each sector an expert MLP is trained
- asymmetry in ϑ, and p_T can be taken into account
- preprocessing selects the proper MLP



Two different sectors in (p_T, φ) (left) and in ϑ (right).

“Expert” MLP - Capabilities

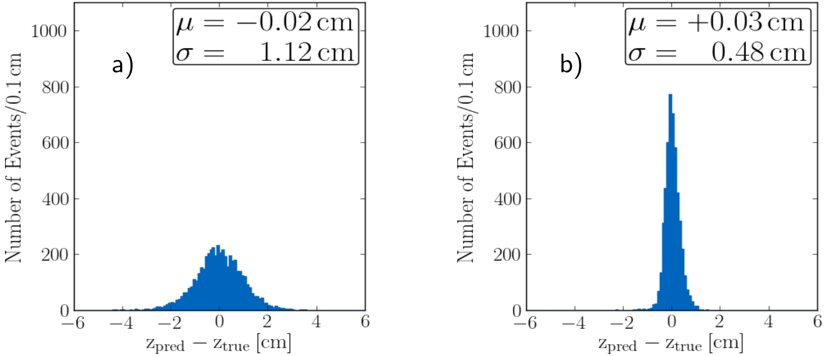


Figure: z-vertex prediction with an “expert” MLP for a small sector in two p_T regions with $\phi \in [0, 360]^\circ$, $\theta \in [56, 62]^\circ$ and $z \in [-10, 10]$ cm.
a) $p_T \in [0.3, 0.317]$ GeV. b) $p_T \in [3.5, 9.625]$ GeV.

! high accuracy on the z-vertex within a small sector

Preprocessing

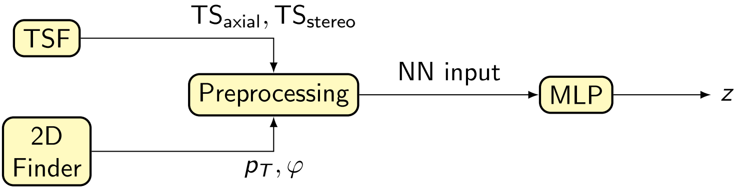


Figure: Information flow in the NeuroTrigger

Tasks

1. match Track Segments to tracks
2. improve (p_T, φ) estimate (2D fit)
   $\rightarrow$ Least Squares fit including drift times
3. provide 3D estimate (ϑ, z)
4. prepare Neural Net Input (& choose sector)

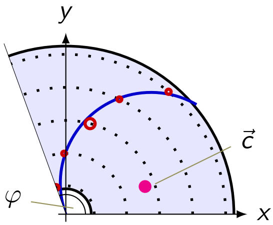
Preprocessing - Least Square fit

solve the linear equation $\vec{y} = \mathbf{X} \cdot \vec{n}$ by: $\vec{n} = (\mathbf{X}^T\mathbf{X})^{-1}\mathbf{X}^T\vec{y}$

2D fit

circle fit; center at $\vec{c}$; track from origin.
$p_T, \varphi \leftarrow c_x, c_y$
x_i, y_i: cartesian coordinates of axial hits in the (r, φ) plane.

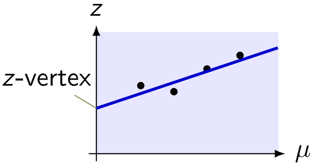
$$(x_i^2 + y_i^2) = 2c_x \cdot x_i + 2c_y \cdot y_i$$



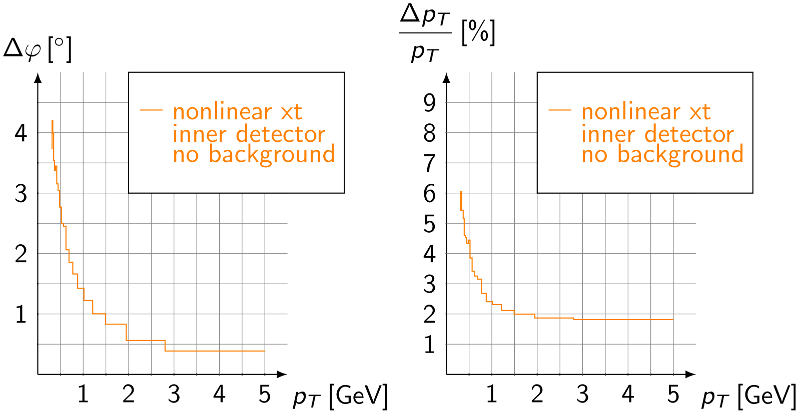
3D fit

line fit in the (μ, z) plane.
μ_i, z_i: stereo hits transformed by 2D fit result.

$$z_i = cot(\vartheta) \cdot \mu_i + z_0$$

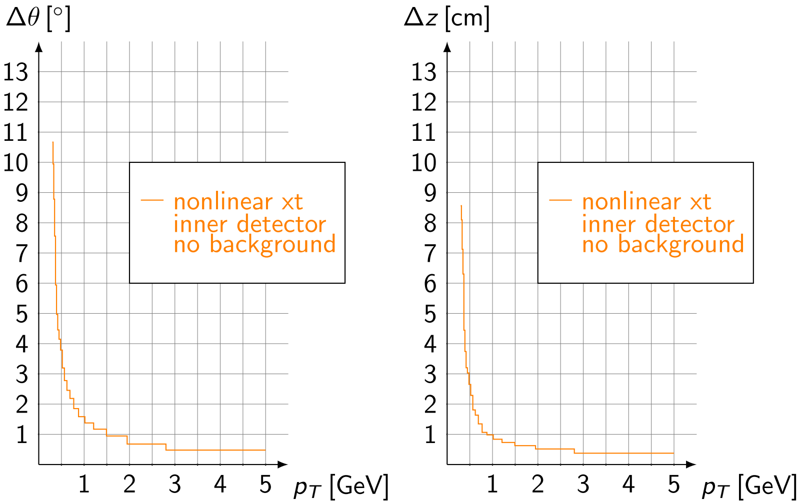


Results - 2D LS Fit (φ, p_T) 90% RMS



$p_T \in [0.3, 5]$ GeV	$\varphi \in [0, 90]^\circ$	$\vartheta \in [35, 123]^\circ$	$z \in [-50, 50]$ cm

Results - 3D LS Fit (ϑ, z) 90% RMS

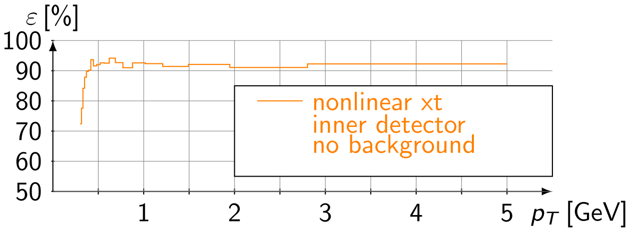


$p_T \in [0.3, 5]$ GeV	$\varphi \in [0, 90]^\circ$	$\vartheta \in [35, 123]^\circ$	$z \in [-50, 50]$ cm

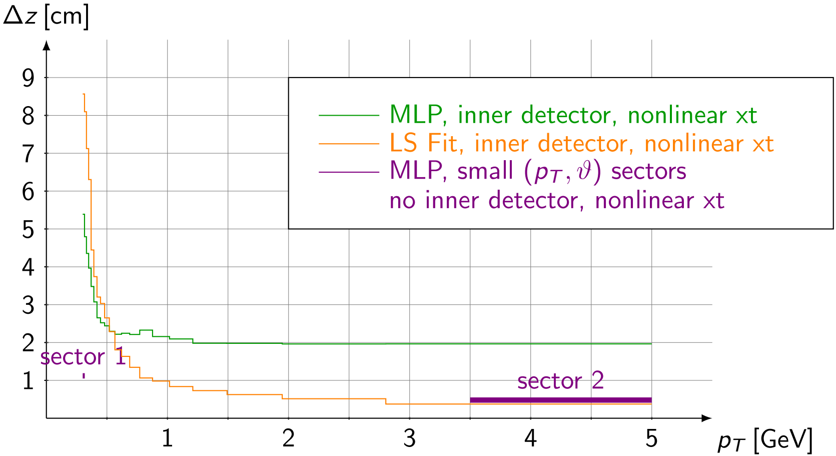
LS Fitter efficiency

Cuts lead to efficiency decrease

- min 3 axial hits in different layers
- max 10 axial hits total
- min 2 stereo hits in different layers
- max 8 stereo hits total
- min 5 hits total



z-90% RMS with LS fit and MLP



$p_T \in [0.3, 5]$ GeV	$\varphi \in [0, 90]^\circ$	$\vartheta \in [35, 123]^\circ$	$z \in [-50, 50]$ cm

Conclusion

MLP

- MLP requires preprocessing
- MLP can improve z-RMS in low pt region
- Sectorization improves MLP prediction

Preprocessing

- LS fit useful for preprocessing
- LS fit achieves good z-RMS for high p_T tracks

Outlook

- MLP optimization for low p_T tracks
- further preprocessing studies
- hardware implementation on Virtex 7 FPGA