A z-Vertex Trigger for Belle II

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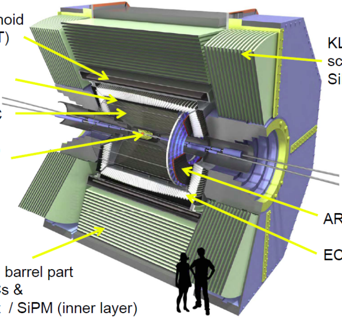
Outline

Belle II Detector



Neuro Team

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Introduction

Goals

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

Methods

- CDC Track Segment data as input [IDs & clock cycle (2 ns timing)]
- current approaches:
  - MLP - Multi Layer Perceptron
  - Cascade prediction

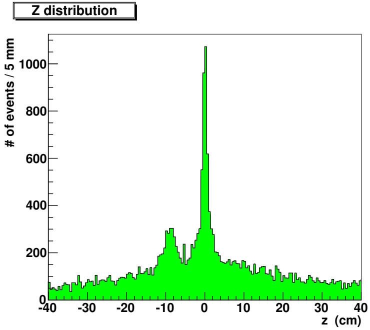


Figure: Offline z distribution in the Belle Experiment[a].

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

Main approach

- sectorize input in (p_T, ϕ, θ)-Sectors
- many MLPs (one for each Sector)
- Hits are TS-IDs & drift times (2 ns resolution from TSF clock)

Look Up Table - Bayes

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

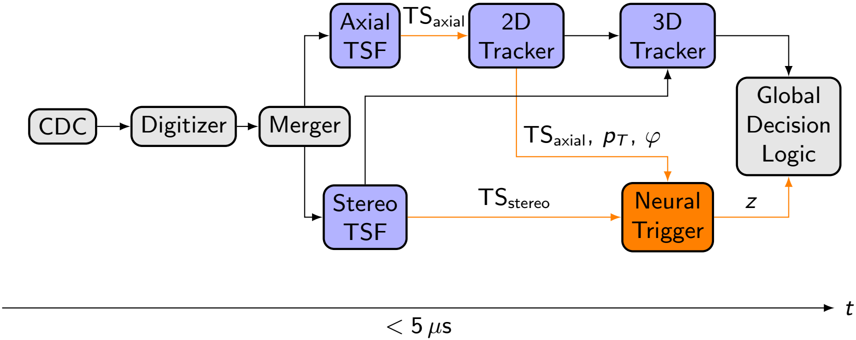
- modeled as nD array
- used to predict Sector & used to generate NN input

MLP

$$z(Hits, p_T, \phi, \theta) = NN_{p_T,\phi,\theta}(Hits) \tag{2}$$

- output float value interpreted as scaled z-position

Signal flow in the CDC Trigger

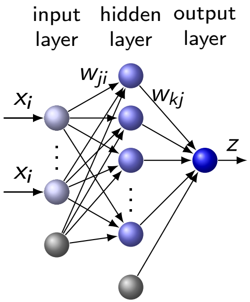


→ The neural network trigger will be implemented on a Virtex 7 FPGA

MLP - Multi Layer Perceptron

Motivation

- supervised machine learning
- universal real valued function approximation[b]
- short deterministic runtime



Basic Setup

- one neuron: $y = \tanh(\sum_{i=1} w_i \cdot x_i + w_0)$
- 3 layers, fully forward connected, hidden layer: $N_{hidden} = 3 \cdot N_{input}$
- 1 output node, output value interpreted as scaled z-vertex position
- train size $\approx Ndof \cdot 10$
- training with rprop algorithm (backpropagation)

b) R. Hecht-Nielsen, Theory of the Backpropagation Neural Network, IEEE first Annual Int. Conf. on Neural Networks, 593 - 605, 1989

Sectorization & TS selection

Sectorize input in p_T, ϕ, θ

all 2336 Track Segments (TS) as input is too much for one MLP

- constraint in (ϕ, θ) to shoot always in the same direction
- constraint in p_T to have the same curvature for the tracks

$\longrightarrow$ subset of relevant TS for each $(\phi,\ \theta,\ p_T)$ region

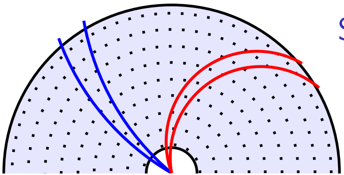


Figure: Two different $p_T - \phi$ sectors.

Selection criteria

- require >p% of the events to be covered by TS selection (chosen on a per superlayer basis)

$\rightarrow$ per sector $\approx$ 20 TS are used as input

“Relevant” Track Segments

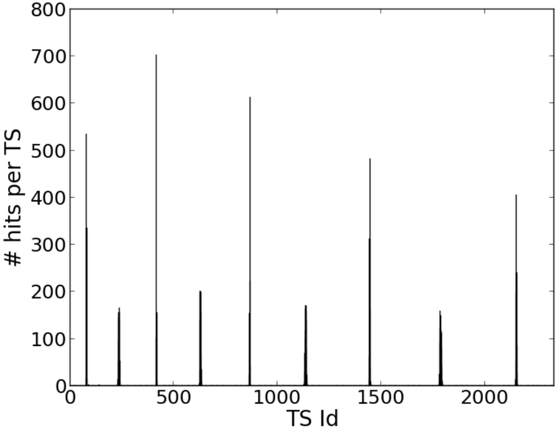


Figure: Hit distribution for events within a $p_T - \phi$ sector.

Track Parameters

$pt \in [1.43, 1.67]$ GeV	$\phi \in [180, 181]^\circ$	$\theta \in [35, 123]^\circ$	$z \in [-50, 50]$ cm

"Expert" MLP - Capabilities

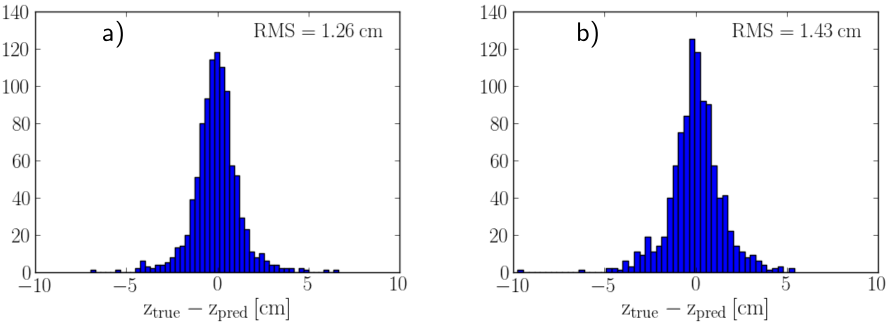


Figure: z-vertex prediction with an "expert" MLP in two p_T regions with $\phi \in [180, 181]^\circ$, $\theta \in [56, 62]^\circ$ and $z \in [-10, 10]$ cm.
a) $p_T \in [1.6, 1.67]$ GeV. b) $p_T \in [4.2, 4.8]$ GeV.

! high accuracy on the z-vertex within a small sector
→ construct one MLP for each sector ("expert")
→ find optimal solution to determine the sectors (preprocessing)

Preprocessing

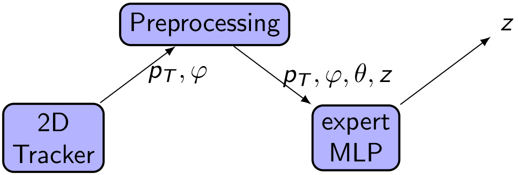


Figure: The $p_T - \phi$ from the 2D Tracker is enriched with $\theta - z$ information by the preprocessing to allow the selection of an "expert" MLP.

- $\mathcal{O}(10^6)$ sectors in total
- preprocessing determines correct sector
- "expert" MLP provides z-vertex value
- MLP is main candidate for preprocessing
- several rounds in the preprocessing might be required (ideal: 1 round)

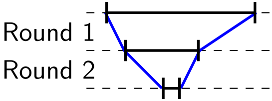


Figure: Incrementally shrink the sector size in the preprocessing.

θ Sector Finding with a MLP

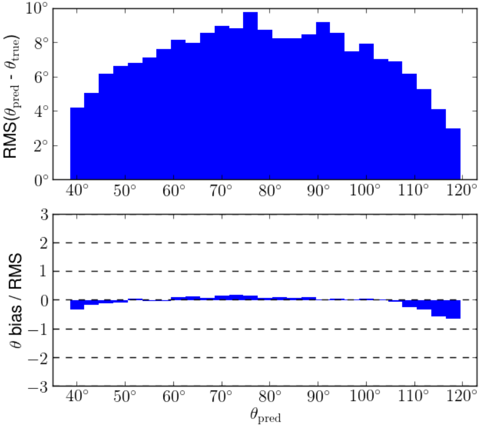


Figure: RMS of θ prediction in θ-bins.

- bins are assigned using the prediction θ_{pred}

$\rightarrow$ RMS is θ dependent: RMS(θ)

$\rightarrow$ MLP suitable for θ prediction

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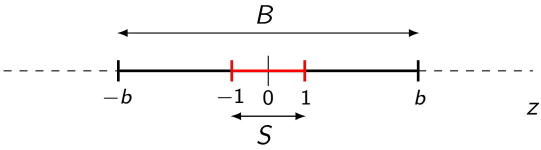
z Sector Finding with a MLP - Efficiency Analysis

a high efficiency for Interaction Region (IR) events is required
→ for the experiment, define two z-bins around IR ($z = 0\,\text{cm}$):

small $S = [-1, 1]\,\text{cm}$
big $B = [-b, b]\,\text{cm}$



b is varied in the experiment

Contingency Table

	$z_{\text{true}} \in S$	$z_{\text{true}} \notin S$
$z_{\text{pred}} \in B$	TP	FP
$z_{\text{pred}} \notin B$	FN	TN

Table: The prediction z_{pred} and true value z_{true} are evaluated in two different bins.

Efficiency

- efficiency

$$EFF = \frac{TP}{TP + FN} \tag{3}$$

- false positive rate

$$FPR = \frac{FP}{FP + TN} \tag{4}$$

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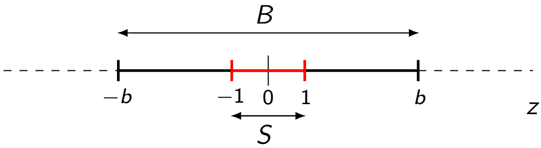

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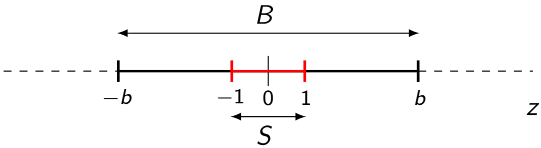

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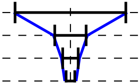
3 Round z Prediction Chain Experiment

In each round b is set such that $EFF > 99\%$

$\rightarrow$ use more specialized predictor in next round



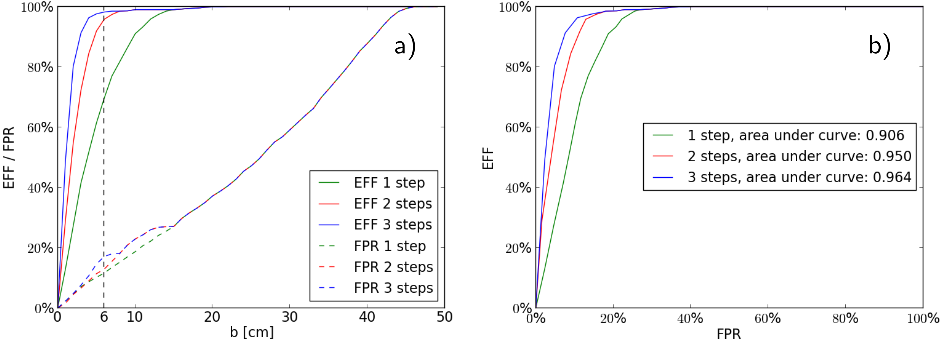


Figure: a) *EFF* and *FPR* of all 3 rounds vs. the half bin size b.
b) *EFF* vs. *FPR* as overall measure of the classification.

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Conclusion

“expert” MLP

- “experts” are specialized to phase space sectors
- high z-resolution with $RMS < 2\,\text{cm}$
- sectorized solution requires $\mathcal{O}(10^6)$ “expert” MLP

Preprocessing

- preprocessing necessary for the sector finding
- MLP is good candidate for preprocessing
  (can predict θ and z in given $p_T - \phi$ sectors)

Outlook

- need generalization experiment to full detector acceptance region
- for hyper parameters and efficiency in the preprocessing further optimization is required
- Virtex 7 FPGA implementation anticipated

Thank you for your attention!