A Neural Network z-Vertex Trigger for Belle II

Sara Neuhaus

Technische Universität München

1.9.2014

Neuro team

F. Abudinén (LMU), Y. Chen (TUM), M. Feindt (KIT),
R. Frühwirth (HEPHY), M. Heck (KIT), C. Kiesling (MPI), A. Knoll (TUM),
S. Neuhaus (TUM), S. Paul (TUM), T. Röder (TUM), J. Schieck (HEPHY),
S. Skambraks (TUM)

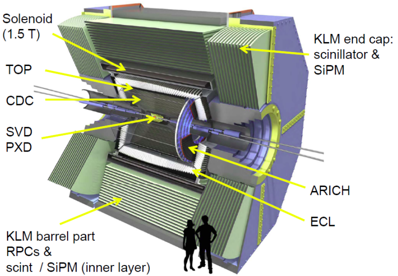
Outline

1 Goals and concepts

2 The neural z-vertex trigger
- Multi Layer Perceptron
- Input representation
- Cascade prediction

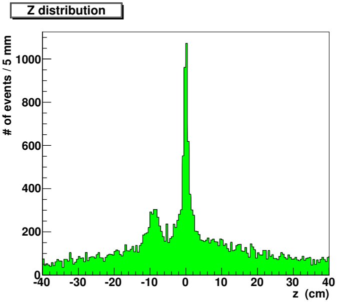
3 Conclusion

Belle II Detector



Goal: z-vertex track trigger for Belle II

- increasing luminosity and background compared to Belle
- new design of Central Drift Chamber (CDC)



z-vertex distribution in Belle

Requirements for z-vertex trigger

- reject events from $z \neq 0\,\mathrm{cm}$ at 1st level
- predict z-vertex with precision $< 2\,\mathrm{cm}$
- time window $< 1\,\mu\mathrm{s}$

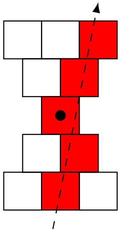
Concept of the neural network z-vertex trigger

Prediction of z-vertex with Multi Layer Perceptron (MLP)

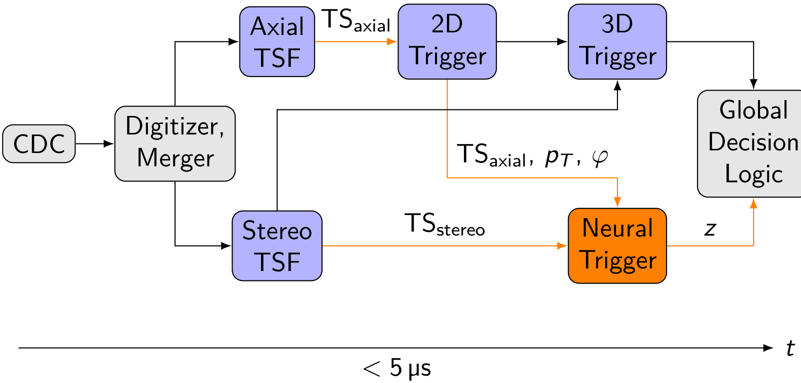
- supervised machine learning
- universal real valued function approximation
- short deterministic runtime

Input for the z-vertex trigger

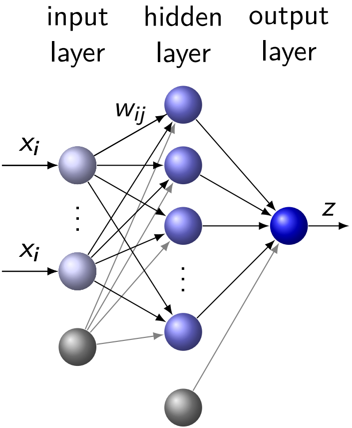
- 2336 track segments (TS) from the CDC
- position and drift time of central wires
- 3D information from stereo wires



Signalflow of the CDC trigger



Multi Layer Perceptron (MLP)

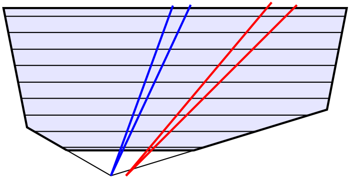


Basic setup

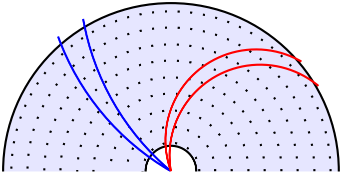
- 1 hidden layer: $N_{\text{hidden}} = 3 \cdot N_{\text{in}}$
- fully forward connected
- one neuron:
  $y_j = \tanh\left(\sum_i w_{ij} x_i + b_j\right)$
- training with rprop algorithm (back propagation)
- output interpreted as scaled z-vertex

Sectorization

- local experts for small sectors in phase space
- constraint in $(\varphi, \theta) \rightarrow$ fixed direction
- constraint in $p_T \rightarrow$ fixed curvature
- input for MLP: relevant track segments for (φ, θ, p_T)-sector



different sectors in θ and z

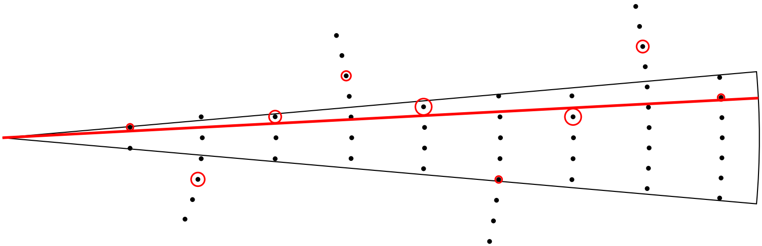


different sectors in p_T and φ

Input representation for neural network

Assign TS hits to input nodes

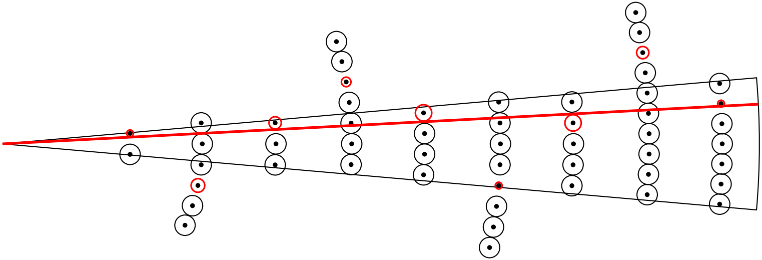
- ≈ 9 hits per track
- 20-50 track segments in a sector
- how to format the input for the network?



Input representation for neural network

Topological input distribution

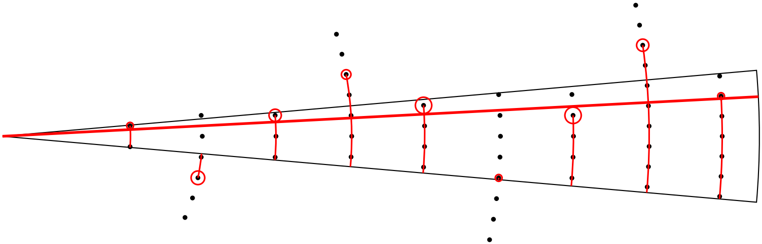
- one input node per relevant TS
- input value: scaled drift time t
- inactive TS: maximal drift time



Input representation for neural network

Wire coordinates as input

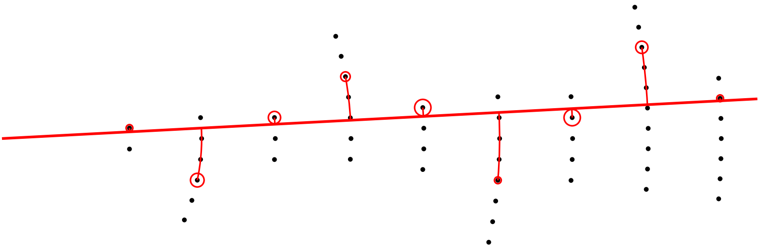
- 2 input nodes per superlayer
- input values: t, wire position φ_{wire}
- > 1 hit in SL: fastest hit, no hit in SL: default values



Input representation for neural network

Use cylindric symmetry and 2D results

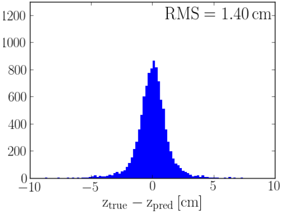
- 2 or 3 input nodes per superlayer
- t, **relative** wire position φ_{rel}, (helix parameter μ)
- > 1 hit in SL: fastest hit, no hit in SL: default values

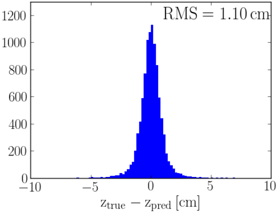


Resolution for small sectors (high p_T)

Sector ranges: $z \in [-10, 10]\,\text{cm}$, $\theta \in [50°, 60°]$
$\varphi \in [135°, 225°]/[180°, 181°]$, $\frac{1}{p_T} \in [0.2, 0.25]\,\text{GeV}^{-1}$

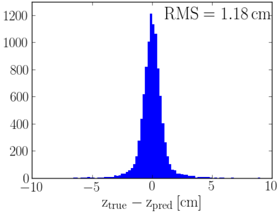
17 inputs:
$17 \cdot t$

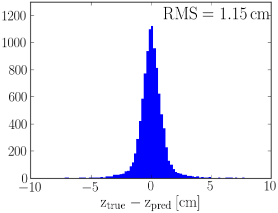




18 inputs:
$9 \cdot (t, \varphi_{\text{wire}})$

18 inputs:
$9 \cdot (t, \varphi_{\text{rel}})$



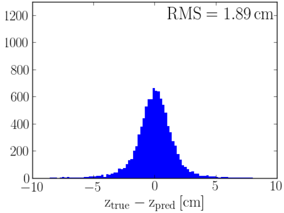


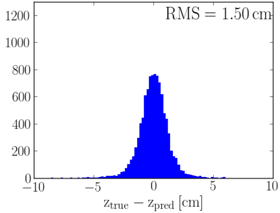
27 inputs:
$9 \cdot (t, \varphi_{\text{rel}}, \mu)$

Resolution for small sectors (low p_T)

Sector ranges: $z \in [-10, 10]\,\mathrm{cm}$, $\theta \in [50°, 60°]$
$\varphi \in [135°, 225°]/[180°, 181°]$, $\frac{1}{p_T} \in [1.95, 2.0]\,\mathrm{GeV}^{-1}$

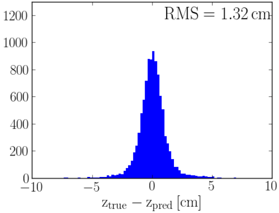
31 inputs:
$31 \cdot t$

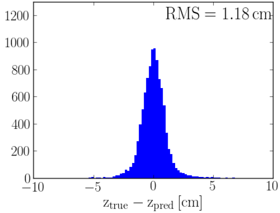




18 inputs:
$9 \cdot (t, \varphi_{\mathrm{wire}})$

18 inputs:
$9 \cdot (t, \varphi_{\mathrm{rel}})$

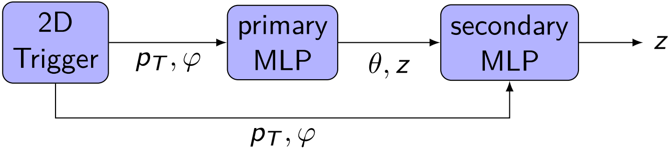




27 inputs:
$9 \cdot (t, \varphi_{\mathrm{rel}}, \mu)$

Sector finding

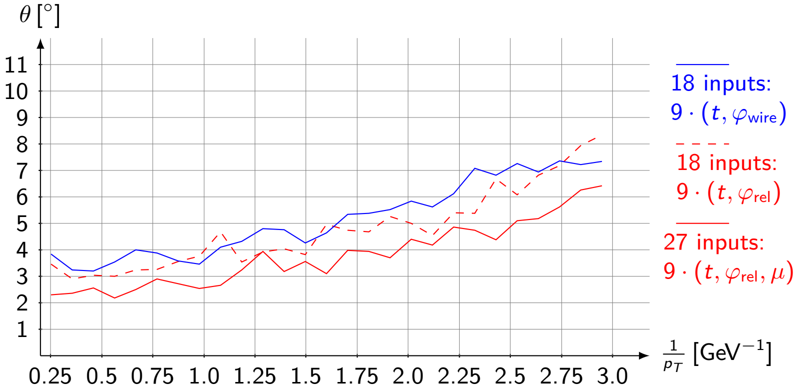
- sector in φ and p_T: 2D trigger
- task: find sector in $\theta \Rightarrow$ **cascade prediction**



- starting sector: small region in φ, p_T, full ranges in θ, z
- use MLP to predict θ, z
- reduced sector size in θ, first cut on z

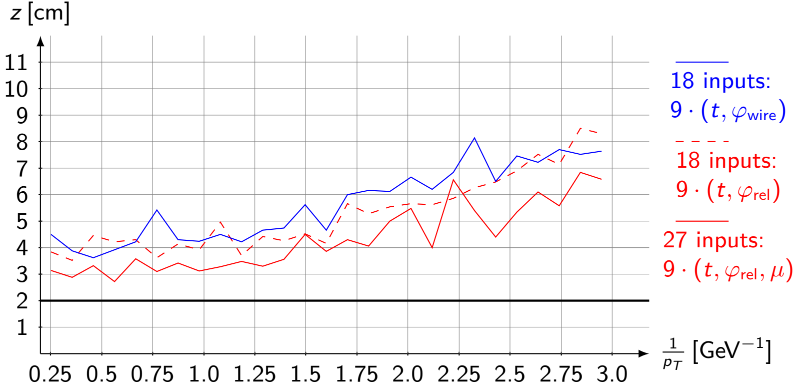
Experimental results: Primary MLP θ prediction

Sector ranges: $z \in [-50, 50]\,\text{cm}$, $\theta \in [35^\circ, 123^\circ]$
$\varphi \in [135^\circ, 225^\circ]/[179^\circ, 181^\circ]$, $\frac{1}{p_T} \in [0.2, 3]\,\text{GeV}^{-1}$ (9 sectors)
uncertainty in 2D values: $\Delta\varphi = 1^\circ$, $\Delta\frac{1}{p_T} = 0.1\,\text{GeV}^{-1}$



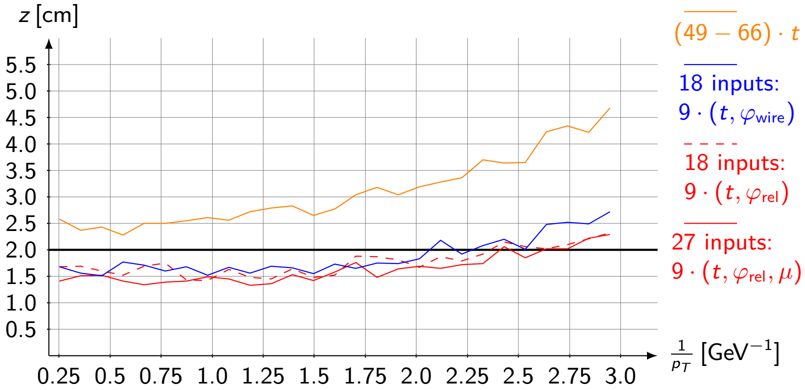
Experimental results: Primary MLP z prediction

Sector ranges: $z \in [-50, 50]$ cm, $\theta \in [35°, 123°]$
$\varphi \in [135°, 225°]/[179°, 181°]$, $\frac{1}{p_T} \in [0.2, 3]$ GeV^{-1} (9 sectors)
uncertainty in 2D values: $\Delta\varphi = 1°$, $\Delta\frac{1}{p_T} = 0.1$ GeV^{-1}



Experimental results: Secondary MLP z prediction

Sector ranges: $z \in [-15, 15]\,\mathrm{cm}$, $\theta \in [50^\circ, 60^\circ]$
$\varphi \in [135^\circ, 225^\circ]/[179^\circ, 181^\circ]$, $\frac{1}{p_T} \in [0.2, 3]\,\mathrm{GeV}^{-1}$ (9 sectors)
uncertainty in 2D values: $\Delta\varphi = 1^\circ$, $\Delta\frac{1}{p_T} = 0.1\,\mathrm{GeV}^{-1}$



Conclusion

L1 z-vertex trigger for Belle II with $\mathcal{O}$(cm) resolution

- MLPs specialized to sectors in phase space
- exploit detector geometry to reduce size of MLPs
- sector finding for θ: cascade prediction
- final z resolution of 1.3 cm (high p_T) – 2.3 cm (low p_T)

Future research

- optimization of low p_T region
- implementation on Virtex 7 FPGA