RESEARCH AREAS: **B, C, D**

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Neural Network Z-Vertex Trigger for Belle II

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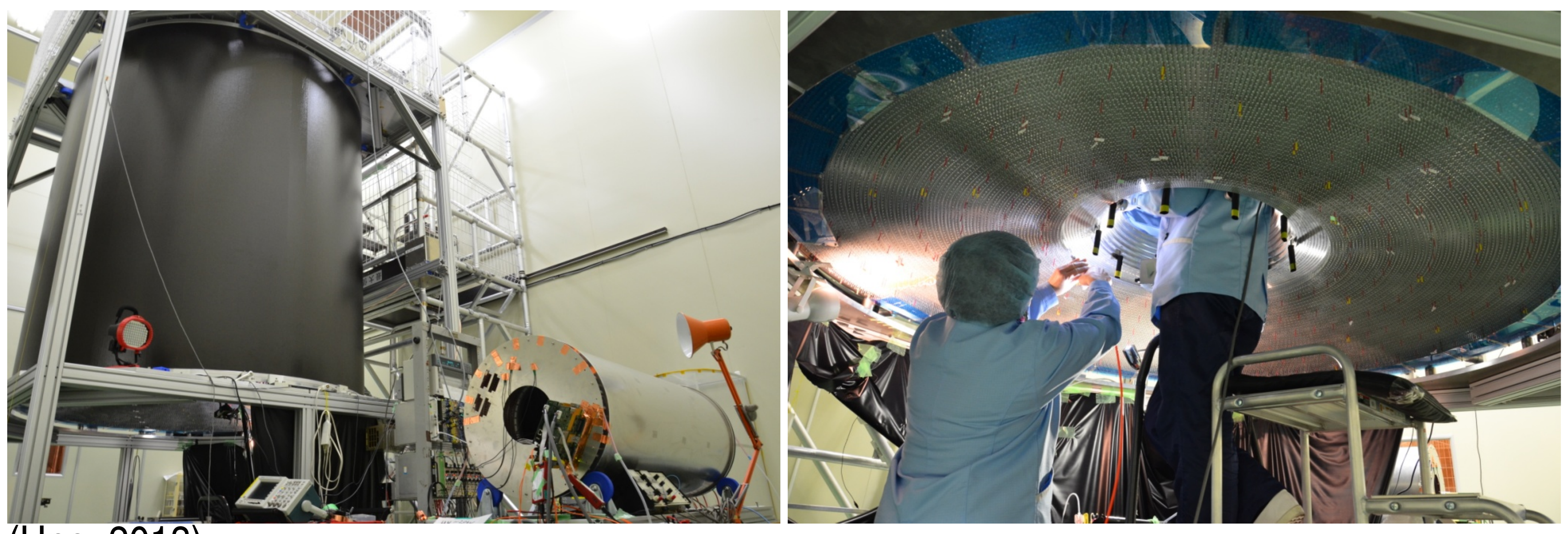
Triggering in a particle physics experiment is a fast "hardwired" online event selection and data reduction mechanism where interesting physics events are identified and unwanted background is rejected. This data reduction task is crucial as the full data rate generated by the different detector components is too large to be stored for a later offline analysis. Recent studies for the Belle II detector, which is currently under construction at the SuperKEKB B-Factory in Tsukuba, Japan, have demonstrated the possible benefits of using a neural network approach in the trigger system. By using neural networks the difficult 3D reconstruction problem of finding the z-coordinate of the vertex position can be solved with a high accuracy.

Belle II CDC Trigger

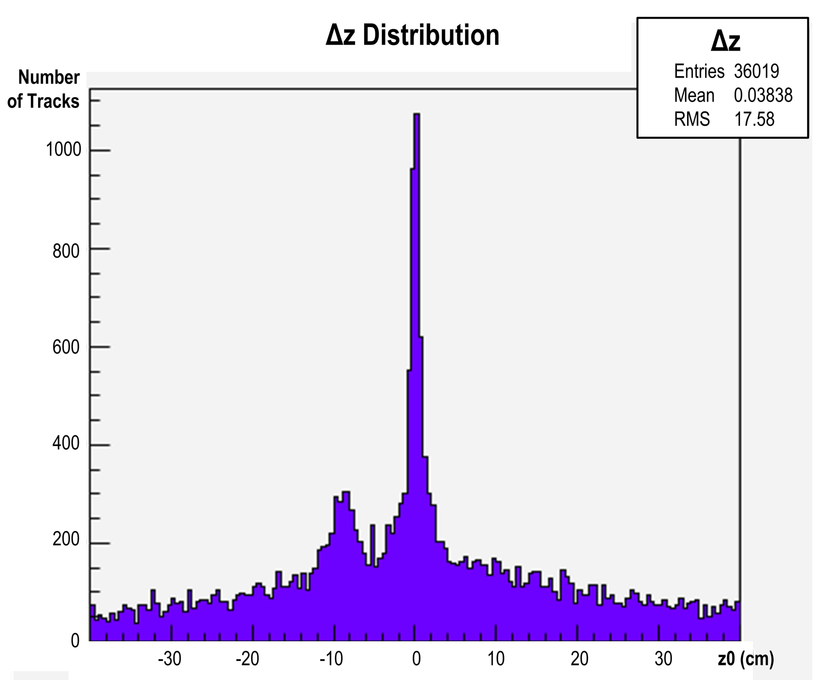
The Belle II trigger has several pipelined sub-triggers at the first trigger level, operating in parallel. One of the sub-trigger components is the Central Drift Chamber - CDC trigger, which is used to select events based on charged particle tracks. The CDC is a wire chamber with ca. 15000 sense wires which are arranged in axial wires parallel to the beamline, alternating with inclined ("stereo") wires. It has a sufficiently short readout time to meet the high demands on execution speed for the whole trigger system (only 5 μs are allowed to provide a decision). Due to the slight differences in the stereo angles of the wires combined with the drift times (a distance measure of a track to a wire) , this detector allows a 3D reconstruction of the tracks.



(Uno, 2013).

Figure 1: Construction of the Central Drift Chamber - CDC for the Belle II detector at KEK. Axial wires are stringed into the cylindrical support structure of the CDC.

Z-Vertex Resolution



Although the CDC allows a 3D reconstruction of the tracks in principle, the high demands on a short deterministic runtime do not allow to use complex tracking algorithms or iterative fitting procedures such as used for offline analysis. In the Belle experiment this problem lead to the unfortunate z-vertex resolution in the collected data depicted in Figure 2.

Figure 2: (Abe & et al., 2010, p. 366) Distribution of the z-vertex position in Belle experiment #57 and #59. Only the narrow peak around $z = 0$ cm corresponds to the interesting physics signal.

The Neural Network Approach

Neural Networks refer to a variety of machine learning techniques that are inspired by the biological operation of the brain. An established type is the Multi Layer Perceptron - MLP, which is a directed acyclic graph. Each node calculates the weighted sum over its inputs and evaluates this by an activation function to produce one output value. The information is stored in the weights of the connections, which are trained with a supervised learning algorithm. For the three layer MLP there even exists a theorem that proves its capabilities to approximate any continuous bounded function (Hecht-Nielsen, 1989).

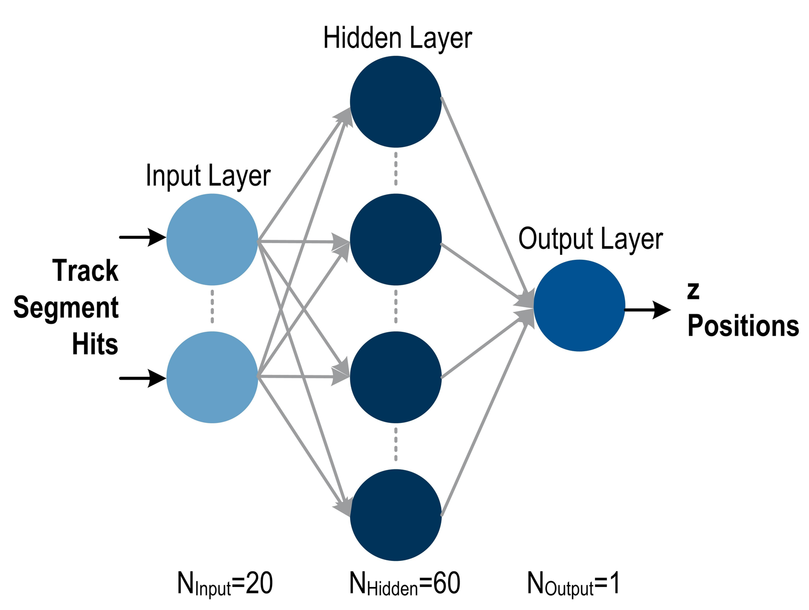
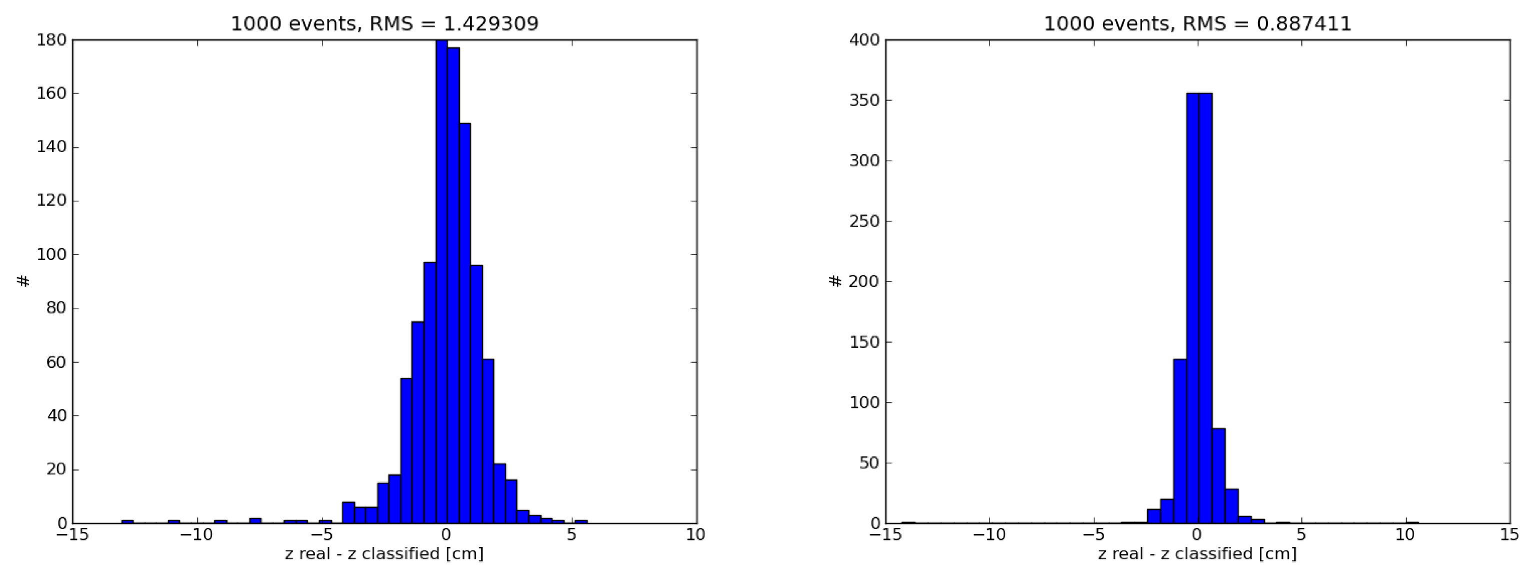


Figure 3: Schematic drawing of the MLP structure.

Experimental Evidence

Recent studies with the MLP were carried out on simulated Belle II single track events. The input to the MLP consists of the drift times for the set of wires being hit by the track. Based on solely this information, the MLP could be trained to estimate very accurately the z-vertex position (see Figure 4). For multi-track events the set of wires to be used must be known for each track. For Belle II, such a priori information can be provided by the 2D trigger and a table lookup.This encourages to implement many specialized MLPs, where each MLP is an "expert" for a different p_T, ϕ, θ sector.



(Skambraks, 2013).

Figure 4: MLP in two p_T sectors. Track parameters: $\phi \in [0, 1]°$; $\theta \in [45, 46]°$; $z \in [-10, 10]$ cm. Left: $p_T = 0.2$ GeV → Δ z: 1.4 cm. Right: $p_T = 7$ GeV → Δ z: 0.9 cm.

Hardware Implementation

The feasibility of a fully parallelized FPGA implementation of the proposed MLP-based method for z-vertex estimation has been confirmed in a first study following the computation architecture of the target FPGA. The resulting logic resource consumption assumes a hardware solution with readily available off-the-shelf components. A custom designed universal trigger board (UT3) with massive parallel optical transceivers enables real-time transmission of all the required track segment signals to the neural network.

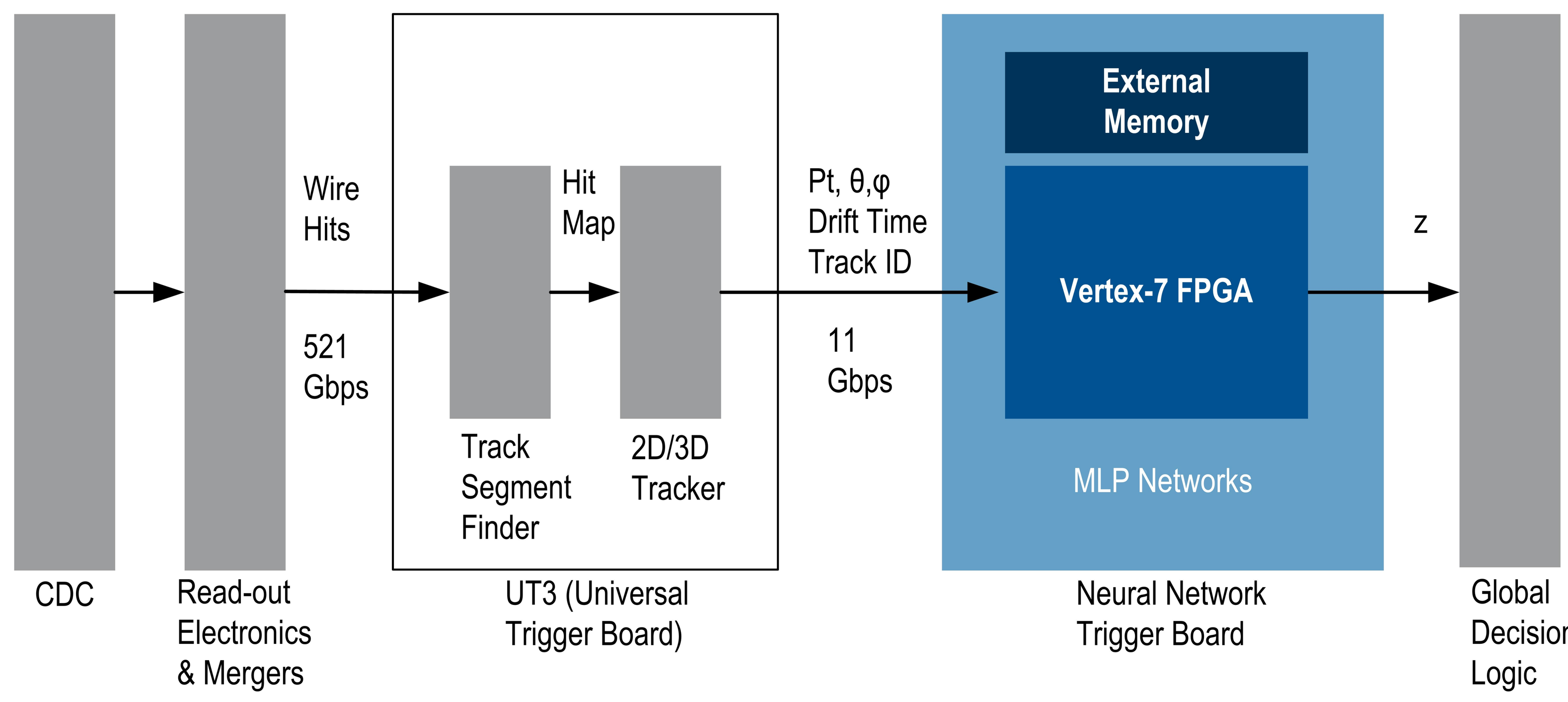


Figure 5: System diagram of the CDC Trigger and Neural Network z-Trigger subsystem.

Outlook

- The MLP approach will be generalized to the full CDC acceptance region.
- To meet the stringent real-time requirements an ultra high bandwidth memory access scheme will be developed.
- The Neural Network trigger implementation will be prototyped on FPGA boards.
- An alignment to the 32 ns clock of the input stream will be done by designing a pipelined version of the network architecture.

Acknowledgments

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