

Machine learning: Hit Time Finding with a Neural Network

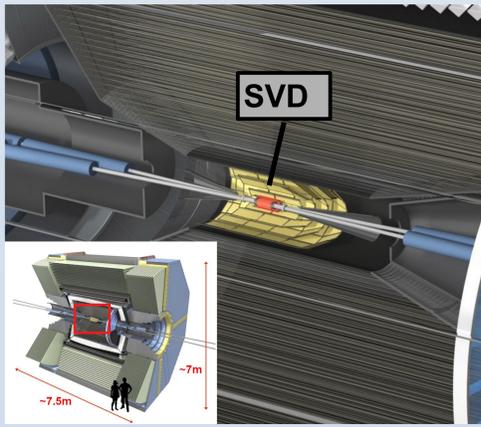


Figure 1: The Belle II Detector

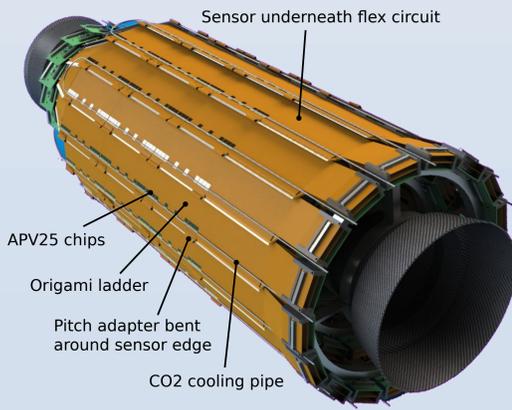


Figure 2: Belle II SVD

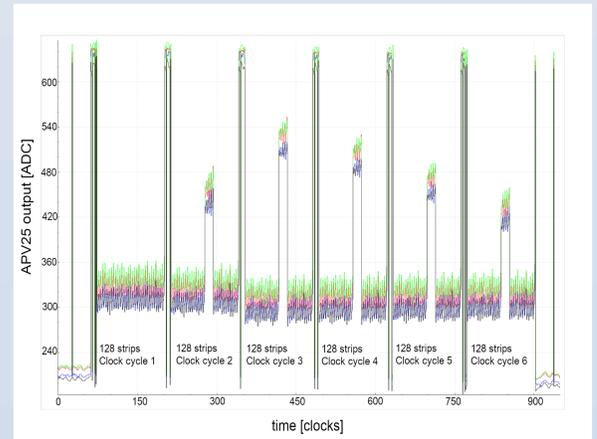


Figure 3: APV25 calibration pulse output

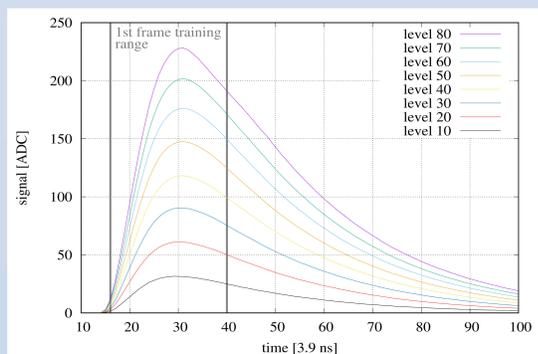


Figure 4: APV25 calibration pulses with different amplitudes

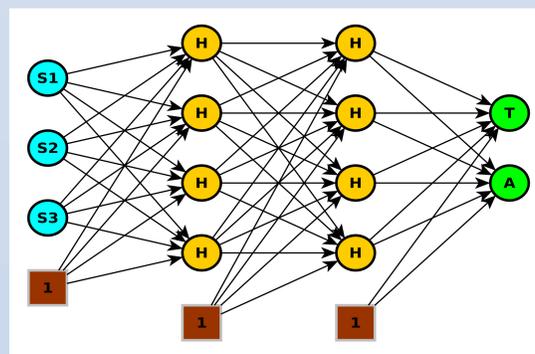


Figure 5: Neural network layout for hit time and amplitude

At the High Energy Accelerator Research Organization (KEK) in Tsukuba, Japan, the Belle II experiment (figure 1) will explore the asymmetry between matter and antimatter and search for new physics beyond the standard model.

One of its inner tracking systems is the Silicon Vertex Detector (figure 2), which consists of 172 orthogonal double-sided strip sensors. They are arranged cylindrically in four layers around the Pixel Detector to measure the tracks of the collision products of electrons and positrons.

These sensors are read out by 1748 APV25 chips, each for 128 silicon strips, which have a shaping time of about 50 ns and output a time-multiplexed signal for each event and strip.

The analog data are then sent out of the radiation zone to 48 custom-built VME modules which convert them to digital, where 3 or 6 values per event of each strip are sampled at a clock of 31.8 MHz.

FPGAs then compensate line signal distortions and reflections using digital finite impulse response (FIR) filters and detect data frames from the incoming stream.

Then they perform pedestal subtraction, common mode correction and zero suppression. And finally "Hit Time Finding", which will be implemented according to the findings below into the FPGA firmware: the determination of time and amplitude of the signal peaks of three selected samples of the APV25 outputs (figure 3) of each event on each silicon strip in real time using pre-trained neural networks.

Shown in this poster are preliminary studies to explore the possibility to implement in FPGAs an hit time finding algorithm.

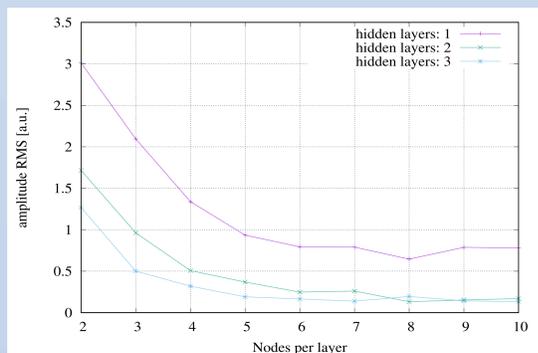


Figure 6: Training error on amplitude using avg. calibration pulse

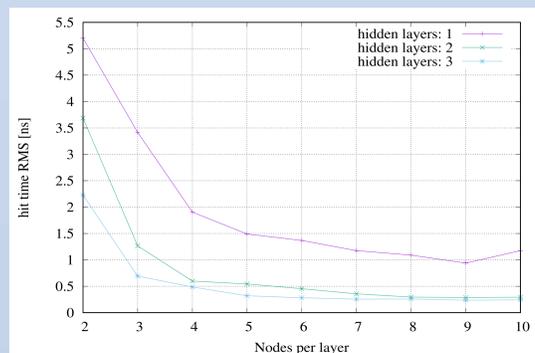


Figure 7: Training error on hit time using avg. calibration pulse

The APV25 has a so-called internal calibration circuit that is able to inject a configurable amount of charge into each pre-amplifier. The injected signal can be delayed in steps of 1/8th of a clock cycle (~3.9 ns). By scanning those parameters and trigger latency we can probe the calibration pulse at various timings and amplitudes (figure 4). The gray lines mark the training range, where the first frame signal is located at; the two following consecutive signals are ~32 ns apart.

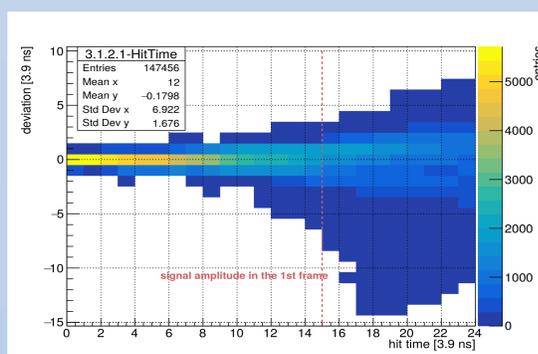


Figure 8: Hit time error after training with avg. calibration pulses

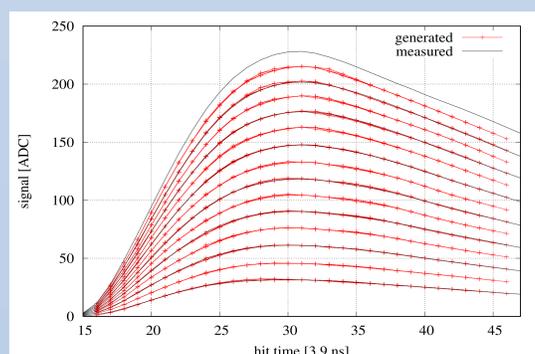


Figure 9: Generated pulses vs. averaged calibration pulses

For the network training we opted to use the averaged calibration pulse. Single strip pulses are used to verify the range of the output in order to check for over training. Both networks are optimized using online training: at each sample the weights are adjusted. The final accuracy of both networks is strongly dependent on the layout, see figures 6 and 7. With two hidden layers with four nodes each (figure 5) the precision is sufficient.

Figure 8 shows the accuracy of the hit-time/amplitude network with single strip data. Each strip has a slightly different amplitude, but overall the shapes of the calibration pulses are similar. The network is able to precisely estimate the hit time as long as the maximum signal is located at the second frame. However the accuracy drops when it moves to the first frame, which is indicated by the red vertical line in the figure. The verification network with hit time and amplitude as input is also able to generate strips signals similar to the training data (figure 9).

Once both networks have been sufficiently trained we applied data taken during BEAST phase 2 with particle collisions.

The verification network shows some deviation between the real-particle pulses and the calibration pulses, whereby the most visible effect has been observed at the lower amplitudes (figure 11); it is also seen in the hit-time distribution (figure 10), but no strong signal shape dependencies are present here.

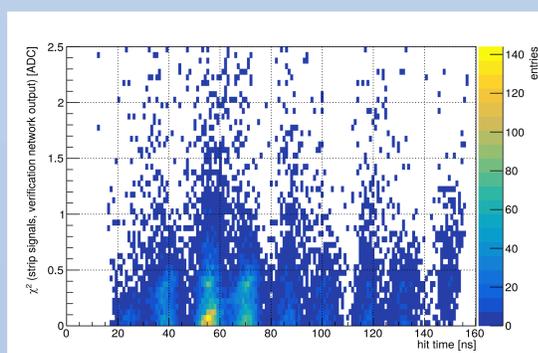


Figure 10: Signal deviations with different hit times

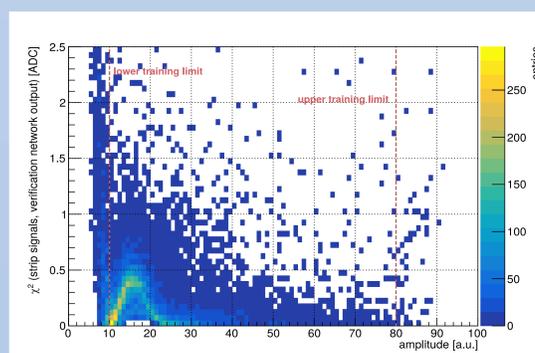


Figure 11: Signal deviations with different amplitudes

During the phase 2 run number 783 the beam bunches were synchronized with the APV25 clock in such a way that during one clock cycle two distinct bunches were able to collide. Due to trigger jitter we can also see smaller peaks at different trigger arrivals relative to the APV25 clock. The distances between each peak show good agreement with the bunch spacing at ~16 ns (figure 12).

The preliminary result also shows good agreement with the offline software analysis, which uses a center-of-gravity algorithm to determine the hit-time distribution (figure 13, which is before time-calibration).

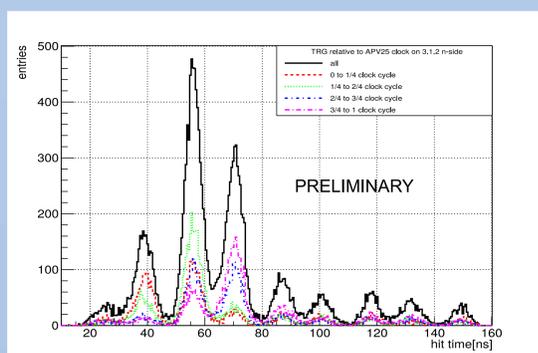


Figure 12: Hit time distribution with particle signals

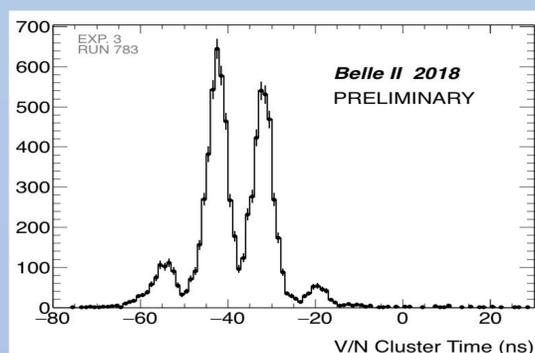


Figure 13: Hit time distribution using CoG algorithm