ML Pileup Rejection at the ATLAS High Level Trigger (HLT) based on Hit-Level Information

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The Large Hadron Collider (LHC) at CERN is designed to generate particle collisions to acquire a high-statistic measurement of the electroweak sector of the Standard Model. Due to the low total cross section of a proton collision the protons are arranged in bunches of $2 \cdot 10^{11}$ protons, which are scheduled to collide every 25 ns. It is likely that not only one proton pair of the colliding bunches is interacting, instead there are multiple proton collisions in the same bunch crossing which is called pile-up.

Pile-up has severe consequences for the experiments searching for interesting signatures. In the case of the ATLAS experiment pile-up should be identified by the event trigger system consisting of the hardware-based Level-1 trigger and the software-based High Level Trigger (HLT). An example for an interesting signature is the Di-Higgs process, since measuring the HHH interaction vertex is equivalent to measuring the shape of the Higgs potential. The dominating decay channel for the Higgs boson is $H \to b\bar{b}$ ($\approx 60\%$). For the Di-Higgs process the dominating decay channel is hence $HH \to b\bar{b}b\bar{b}$. This final state signature containing four hadronic jets can be imitated by two djet events originating from pile-up. One possibility to discriminate the signal to the background is an estimation of the primary vertex (PV) of each individual jet. If the primary vertices of the jets are consistent with each other within some uncertainty the event is classified as signal, otherwise as background.

In ATLAS the primary vertex estimation of each jet is performed in the HLT using tracking, i.e. combining the detector hits in the inner detector as well as the calorimeter information to reconstruct the particle tracks in a jet. The main bottleneck of the HLT are limited CPU resources, thus the CPU-intensive full-scan tracking algorithms that cover the entire detector area are rather disadvantageous.

This project therefore aims to evaluate whether the prediction of the z-coordinate of the primary vertex (PVz) for each jet is possible using only hit-level information of the inner detector. If this is possible, tracking will not be necessary for some events. This enables a potential reduction of the CPU consumption in the HLT as well. In order to perform a Gaussian regression for PVz, a transformer neural network is implemented: it uses the position of the hits associated with one jet as well as the jet p_T and η as inputs; the output prediction consists of an estimator of PVz as well as a Gaussian uncertainty.

After training the neural network it is possible to evaluate its predictive power by plotting the truth-level PVz and the predicted PVz for each jet in a histogram (Figure 1). This shape is clearly approaching a diagonal line, further observations show that also the uncertainties are realistic.

In order to perform pile-up rejection it is necessary to combine the jet-by-jet prediction on an event-by-event basis. Since this project is primarily aimed to be used in a Di-Higgs setup, the final state is assumed to contain four signal jets. The basic idea of the event-wise combination is to multiply the individual Gaussian predictions and use the maximum of the resulting function to classify the event as signal or background. This algorithm is called MLPL(n,m), with n being the number of signal jets (here $n = 4$) and m being the number of considered jets, i.e. MLPL(n,m) returns the best n-jet combination out of the m leading p_T jets. The results of this pile-up rejection are displayed in Figure 1. It is clearly visible that it is possible to reject pile-up using only hit-level information, in conclusion this can potentially save CPU consumption in the HLT by avoiding tracking for some events.

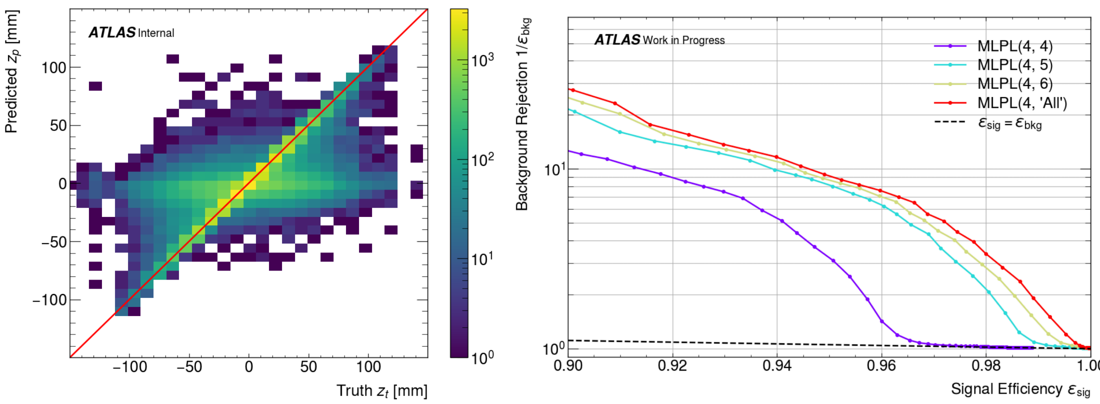

Figure 1: Results of the HitZ algorithm. The figure on the left shows the jet-by jet performance of the network by plotting the prediction z_p and the truth-level value z_t in a histogram. The plot on the right shows ROC curves of the HitZ algorithm with a different number of jets m considered in the calculation of MLPL(4,m). It is visible that considering more jets results in a better background rejection. With a signal efficiency of 98% a background rejection factor of 3 is possible.