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Trigger Primitive Generation using FELIX FPGA system: A Case Study for DUNE

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DUNE will be a long baseline neutrino experiment with a broad physics program, including neutrino oscillation, proton decay, and supernova studies. The detector, located 1,500 m (4,850 ft) underground at SURF, South Dakota, will be 1,300 km (810 mi) away from the ultimate 2.4 MW proton beam source at Fermilab. Four far detector modules, of 17 kt total mass of liquid argon each, will produce ionization data at a rate of 1-2 TB/s per module, while in total 30-60 PB/year can be permanently stored. The data reduction occurs in real time via triggering the collection of data only for interesting detector regions and time windows, which are identified by using beam timing and isolated energy depositions (trigger primitives) as seeds to more complex selection algorithms. An active and rigorous prototyping program has been carried out to tackle the most challenging task of trigger primitive finding. This contribution presents the design and operational performance of a trigger primitive generation (TPG) algorithm implemented on FPGAs using the ATLAS FELIX readout interface in the DUNE Trigger and DAQ system. Although in parallel a software-based TPG was developed and delivered as the baseline solution, we demonstrate that the FPGA-based system was successfully integrated and put into operation. We describe the firmware TPG pipeline, its verification in software with an emulation approach, and we present the results obtained from a sample of real muons collected during various tests of the first detector prototypes.

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1. Introduction

The Prototype Deep Underground Neutrino Experiment (ProtoDUNE) [1] Data Acquisition (DAQ) system required the ability to generate Trigger Primitives (TPs) from the ADC waveforms that represented particle detection signals from the Anode Plane Array (APA) wires generating approximately 80 Gbps of data per APA. A Field Programmable Gate Array (FPGA) PCIe card was used for ADC data ingest to a readout server and it was demonstrated that TP generation could be performed in the same FPGA device.

2. Design and Implementation

The Firmware (FW) Trigger Primitive Generation (TPG) design consisted of multiple modular FW blocks to handle various aspects of data processing to extract TP information from raw ADC data. This included the reception of Warm Interface Board (WIB) packets containing ADC data and hit-finding operation on the ADC values to check they have not exceeded a programmable threshold limit. If the limit is exceeded, a TP data packet is produced. The FPGA card selected for the ProtoDUNE readout solution was a variant of the Front End LInk eXchange (FELIX)[2] system, namely the FLX-712. This card features an AMD® Kintex Ultrascale (XKCU115) FPGA. This card receives data on optical serial links at a line rate of 9.6 Gbps, with each link representing 256 channels from the APA. A readout software interface was developed to facilitate the movement of data out of the Direct Memory Access (DMA) buffers of the FELIX card and onto the host system for further processing. Processed TP data is then interfaced to the rest of the DUNE-DAQ system to allow for use in triggering decisions. A suite of simulation, plotting and analysis tools were also developed to allow for testing, performance benchmarking and validation of the FW TPG, an example of which can be seen in Figure 1.

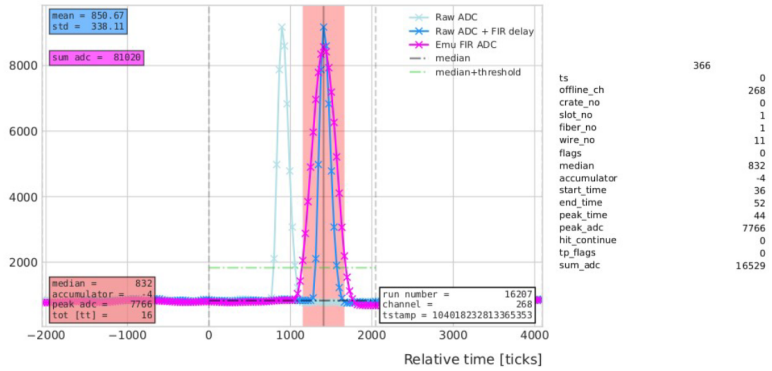

Figure 1: Plot shows a hit event from ADC data with overlaid information from the FW TP produced highlighted by the red band and a software emulation of the ADC data in magenta showing good agreement [3]

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3. Performance Evaluation

The FW TPG system was deployed during the ProtoDUNE-I operation and various test stands were set up in the lead up to ProtoDUNE-II operations. The largest variant of the design performed

TPG on 12 links of data from the Vertical Drift (VD), variant of the coldbox test platform [3]. This involves analysing 3072 channels across the Charge Readout Plane, (CRP) [3]. Successful physics event triggers with detector hardware were made with the greater DAQ system using FW TPs as shown in figure 2.

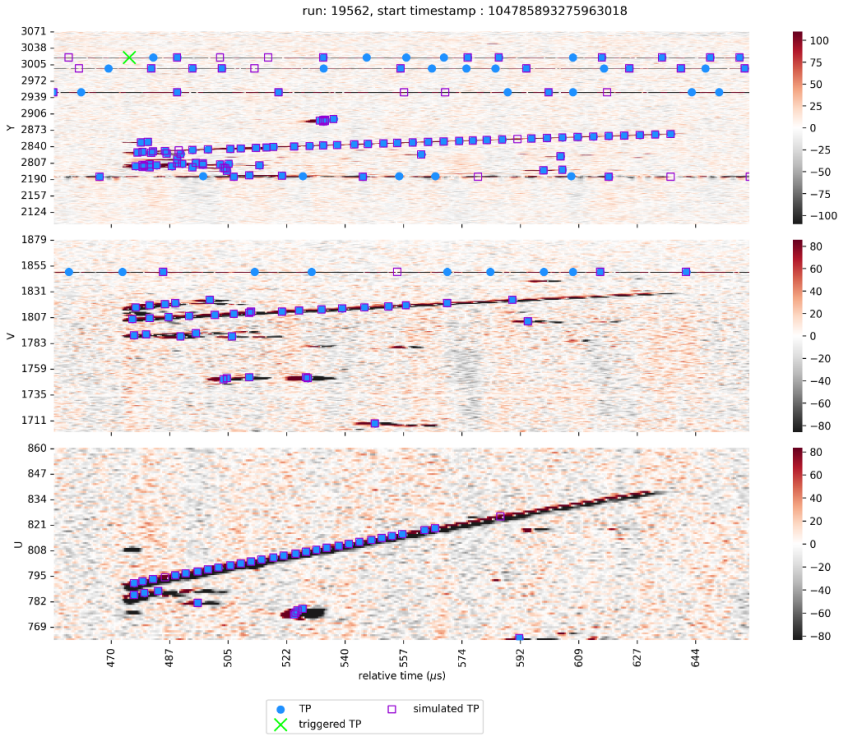

Figure 2: The plot is an event display of 3 ADC links of recorded VD data. This data was recorded with the use of a cosmic ray trigger algorithm, with the trigger being supplied TPs from the FW TPG [3]

4. Summary

The FW TPG successfully demonstrated operation during ProtoDUNE-I and was further developed to support various coldbox operations with a view to targeting and supporting ProtoDUNE-II operations. The FW TPG was discontinued in favour of a software-based TPG solution for ProtoDUNE-II and the full scale DUNE detector, however the work demonstrated as part of the FW TPG development proved it a viable option for TPG in large-scale detectors such as ProtoDUNE.

References

[1] B. Abi *et al.* [DUNE], Deep Underground Neutrino Experiment (DUNE) Far Detector Technical Design Report: FERMILAB-PUB-20-024-ND

[2] A. Borga *et al.* FELIX based readout of the Single-Phase ProtoDUNE detector: arXiv:1806.09194

[3] K. Manolopoulos *et al.* [DUNE], Firmware Trigger Primitive Generation in DUNE Data Acquisition System: DUNE-doc-29412-v1