Liquid Argon Time Projection Chamber Trigger Development with MicroBooNE

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Abstract. The Micro Booster Neutrino Experiment (MicroBooNE) is a Liquid Argon Time Projection Chamber (LArTPC) neutrino detector at Fermilab that has been operating since 2015. It aims to perform ν-Ar cross-section measurements, explore the low-energy excess reported by the MiniBooNE experiment and perform a combined search for sterile neutrino oscillations as part of three LArTPCs that make up the Short Baseline Neutrino (SBN) Program at Fermilab. Since MicroBooNE is currently in an R&D phase, it offers a unique opportunity for the implementation and testing of TPC-based triggers as R&D towards the Deep Underground Neutrino Experiment (DUNE). One of the technical challenges of DUNE that we aim to address with this study is that of efficient self-triggering of a LArTPC utilizing TPC signal information. This capability will enable searches for rare processes in DUNE, such as neutrino interactions from a potential galactic supernova burst. This talk will describe the MicroBooNE TPC readout system and ongoing R&D efforts to develop and demonstrate TPC-based triggering.

1. Introduction

The groundbreaking discovery of neutrino oscillations, that implies the massive nature of neutrinos, has opened doors to exciting physics beyond the Standard Model. There are a variety of neutrino experiments studying neutrino oscillations in order to learn about the absolute mass and mass ordering of neutrinos, and to establish whether neutrinos violate charge-parity symmetry in the Universe. Additionally, there are some experimental hints for additional flavors of neutrinos (sterile neutrinos) beyond three weakly-interacting flavors which require further investigation [1]. One method to address this broad range of questions is to use an intense ν_μ beam combined with LArTPC detectors capable of producing high resolution images of neutrino interactions and which can in turn enable precision oscillation measurements.

The MicroBooNE detector [2], in addition to studying neutrino oscillations using beam neutrinos, also aims to study rare physics processes such as neutrinos from a Supernova (SN) burst [3], baryon number violating processes such as neutron-antineutron (n-nbar) oscillations and proton decay. These signatures are random in nature and there is no external timing information available to help identify them in raw data which make these searches a challenging task.

The objective of this study is to develop a TPC-based trigger (data-driven decision) in an attempt to select examples of such signatures. To perform this task, data must be processed continually in real-time to implement the trigger techniques online. This is one of the first demonstrations of TPC-based self-triggering with a real LArTPC using the MicroBooNE detector. Due to its smaller size and ambient backgrounds because of its on-surface location, MicroBooNE will not have much sensitivity to these rare processes, but serves as an important R&D step in developing the trigger techniques towards future large detectors such as DUNE [4]. DUNE′s massive LArTPC detector offers a great opportunity to search for proton decay and other baryon number violating processes as well as to study a potential galactic supernova burst with the detection of up to thousands of supernova electron neutrinos interacting in its far detector, providing an unprecedented look into supernova dynamics [5] [6].

2. The MicroBooNE Detector

The MicroBooNE is a LArTPC detector, comprising 89 tons of active LAr volume, located in the Booster Neutrino Beam at Fermilab and has been operational since October 2015 [2]. Each charged particle produced from a neutrino interaction with LAr leaves a trail of ionization electrons which drift, under the effect of uniform electric field, with a maximum electron drift time of 2.3 ms towards anode wire planes. There are two induction wire planes with 2400 wires each and one collection wire plane with 3456 wires, with a 3mm wire pitch, to detect the ionization electrons. Additionally, ν-Ar produces scintillation light which is detected by 32 PMTs located behind the anode wire planes. The light information provides a trigger signal used in coincidence with the beam signal to open a readout window of 4.8 ms. Light information complements the TPC wire information to help achieve 3D particle reconstruction. Data collected during beam-on periods (4.8 ms time window around the trigger) is used for oscillation physics analysis and to make ν-Ar cross-section measurements. Additionally, MicroBooNE also has a continuous data stream, as discussed in the following subsection, which is used to search for the rare (off-beam) events.

2.1. MicroBooNE Readout Electronics

The readout electronics are responsible for digitally processing the anode wire signals and send the processed data to the downstream data acquisition (DAQ) system which assembles events and writes the triggered events to the disk.

The data (signals) from 8256 TPC wires are distributed among 9 readout electronics crates [2]. Each crate has multiple digitizer boards where a single digitizer board takes data from a group of 64 wires. The digitizer board is responsible for digitizing the data using a 16 MHz 12-bit Analog to Digital converter (ADC). The Field Programmable Gate Array (FPGA, Altera Stratix III) downsamples the data to 2Hz and writes it in channel order to Static RAM. The data is then read-back, in time order, by the same FPGA. Further, FPGA splits the data into two streams and stores it in multi-buffer Dynamic RAM.

On receiving an external trigger via a controller module in each crate, 4.8 ms of data around the trigger is read out through the NU (triggered) stream which has losslessly compressed data. In parallel, data is streamed out continuously via the SN (continuous) stream, where Regions of Interest (ROIs) [3] are extracted whenever a waveform crosses a threshold as shown in Figure 1. This zero-suppressed, baseline-subtracted data is used to search for off-beam events [3]. Both of these data streams are read out via a transmitter module and are sent to Sub Event Buffer (SEB) machines via PCI Express cards. The NU stream data from nine SEB machines is transferred to the Event Builder (EVB) machine where the events are built and checked for consistency and written to local disk on the EVB before being sent offline for further processing. For the SN stream, data is temporarily stored in hard-disk drives for 48 hours and sent for permanent

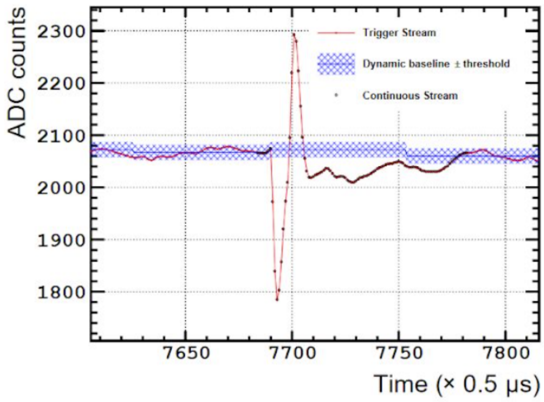

Figure 1. Figure showing a zero-suppressed waveform in the SN stream data, overlaid on the same waveform from the NU stream data.

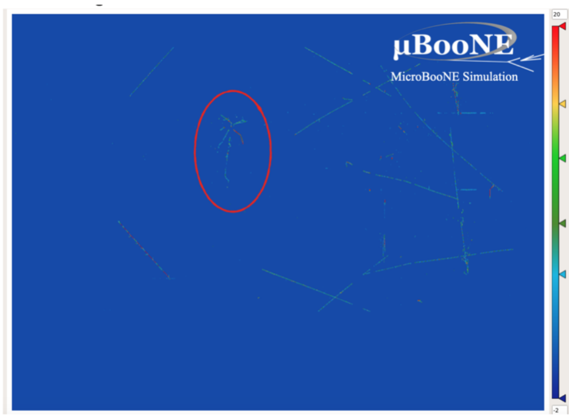

Figure 2. Event display showing neutron-antineutron oscillation simulated event in MicroBooNE which illustrates the characteristic spherical topology of an annihilation signal event, compared to the ambient cosmogenic background.

storage only upon receiving an external Super Nova Early Warning System (SNEWS) alert [7]. After data is written to disk, it is copied to another server where the raw data is further compressed and stored on tape for doing offline analysis.

3. TPC-based Trigger

Studying off-beam physics processes requires a continuous readout with 100% live time. In MicroBooNE, the detector's raw data rate is roughly 33 GB/s without applying any compression or down-selection. For future massive detectors like DUNE where the TPC will have of order of 1 million of readout channels, data rates can go up to >5TB/s. Storing such a large volume of data is prohibitive. The solution is to devise triggers in order to select particular events of interest and save only those, while discarding everything else, permanently. MicroBooNE, located on-surface, benefits from a plethora of types of cosmogenic activity one may target with dedicated triggers, as can be seen in Figure 2. We aim to select interesting events like the one shown in red circle which is a simulated neutron-antineutron oscillation event. Another such interesting topology for triggering is stopping muon events shown in Figure 4 where, a cosmic muon comes to a stop in the detector and decays into an electron. We make use of both topological and calorimetric information to develop the techniques to trigger on these interesting events.

Following the DUNE trigger strategy [4], Trigger Primitives (TP) are constructed from the SN ROIs (Figure 1). TP generation, on a per-channel basis, has been implemented in FPGA (Arria II GX EP2AGX65DF25I3) for real-time implementation where TPs are defined to include the following information: integral of the ROI waveform (absolute area under the curve), the maximum amplitude of the ROI waveform, and the time over threshold of the ROI waveform (length of the ROI). The start time of the ROI and the ROI channel number is also recorded as a part of TP. This data stream will be read out via a transmitter module and sent to different SEB machines via PCI Express cards where TPs are re-organized and clustered together to construct higher level triggered objects. An algorithm is developed to identify stopping muon events using TPs where both topological (existence of kink with change in linearity) and calorimetric

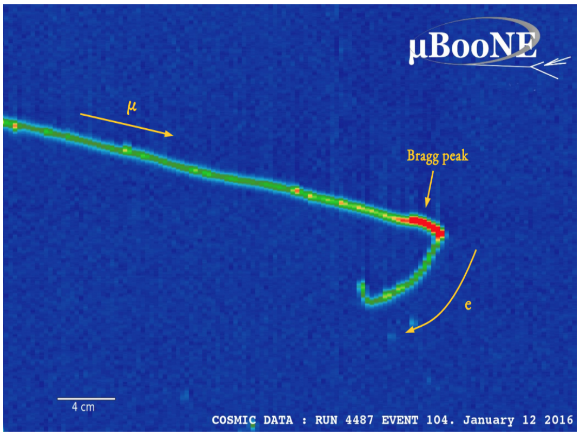

Figure 3. MicroBooNE event display showing a stopping muon topology.

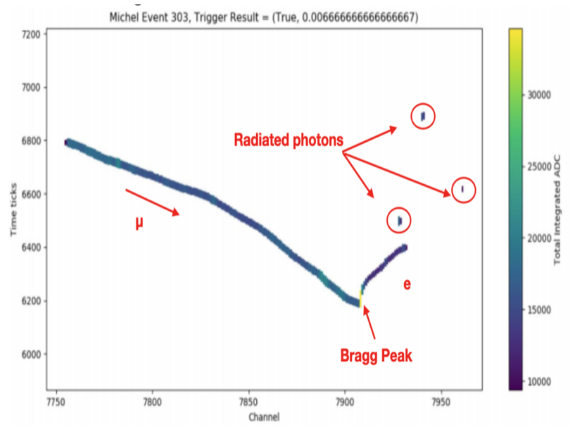

Figure 4. An example showing a stopping muon event triggered by an algorithm developed using Trigger Primitives.

information (change in dE/dx at Bragg peak) are used as a part of algorithm to identify such events. One such example of triggered stopping muon event is shown in Figure 4, which was found using an offline simulation of the trigger algorithm.

Furthermore, there is also a possibility of exploring image classification, rather than having to cluster TPs to reconstruct a track to generate higher level triggered objects such as trigger decision. This is a machine learning based trigger approach, where an image like the one shown in Figure 4 can be fed into a Convolution Neural Network (CNN) for interaction type classification [8].

4. Conclusions

With the currently operating MicroBooNE LArTPC detector, we are developing and testing real-time TPC-based trigger techniques. This is one of the first demonstrations with a real LArTPC for TPC-based self-triggering. We are developing two different trigger approaches, one is the traditional approach which works by clustering the TPs to construct higher level triggered objects and another based on machine learning algorithms, both using the DUNE TP-based data selection strategy. The analysis developed with MicroBooNE TPC-data, and, in the near future, with SBND will serve as an important proof-of-principle for future detectors like DUNE.

Acknowledgements

This material is based upon work supported in part by the National Science Foundation under Grant PHY-1753228.

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