Liquid Argon TPC Trigger Development with MicroBooNE & SBND

Daisy Kalra

on behalf of MicroBooNE & SBND collaborations

Columbia University

CPAD-2021
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Contents

• Motivation
• Introduction to MicroBooNE and SBND
• TPC Readout Electronics
• TPC Trigger Strategy
• Trigger Approaches
• Future Possibilities
• Summary
Motivation

DUNE: World’s largest LArTPC neutrino experiment (once constructed), will start taking data ~2026.

Data rates in DUNE:
- up to >1 million readout channels
- 2 MHz x 12 bit ADC digitization
- >5 TB/s data rate!

- One of the DUNE physics goals is to search for non-beam events (rare events) such as neutrinos from Supernova burst,
  (up to ~few thousand interactions over first 10 seconds, but ~once per century)
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Requires continuous readout with ~100% live time and self-triggering.
Current LArTPC detectors such as MicroBooNE and SBND, which share functionally identical back-end readout electronics, can be exploited to demonstrate and develop TPC-based trigger.
Liquid Argon Time Projection Chamber (LArTPC)

- Neutrino interactions with Ar nuclei leave a trail of ionization electrons, drift towards anode under uniform electric field.

- Two induction planes (U & V) wires: orientation: @ 60° w.r.t vertical
  Collection plane (Y) wires: vertically oriented to enable 3D reconstruction of collected ionization tracks.

- PMTs located behind the anode planes capture prompt scintillation light and hence achieve 3D reconstruction along with the wire signal information.

- High spatial resolution and calorimetry for excellent particle identification.
MicroBooNE and SBND
Part of Short Baseline Neutrino Program at Fermilab

MicroBooNE

- 89 tons active* LAr volume
- 8256 TPC wires (2MHz)
- 32 8” PMTs (64 MHz digitization)
- Data Rates: 33 GB/s

SBND

- 112 tons active* LAr volume
- 11264 TPC wires (2MHz)
- 120 8” PMTs (500 MHz digitization)
- Data Rates: 45 GB/s

*Maximum volume that can be used for physics analysis.

Functionally identical back-end readout electronics (digital processing electronics) in both experiments.
**MicroBooNE and SBND**

Part of Short Baseline Neutrino Program at Fermilab

- **MicroBooNE**
  - 89 tons active* LAr volume
  - 8256 TPC wires (2MHz)
  - 32 8” PMTs (64 MHz digitization)
  - **Data Rates:** 33 GB/s

- **SBND**
  - 112 tons active* LAr volume
  - 11264 TPC wires (2MHz)
  - 144 8” PMTs (500 MHz digitization)
  - **Data Rates:** 45 GB/s

*Maximum volume that can be used for physics analysis.

MicroBooNE is currently in R&D measurement phase offers a unique opportunity to demonstrate and develop TPC self-triggering.
TPC Readout electronics (MicroBooNE)

The TPC readout electronics shapes, amplifies, digitizes and records the signal induced on anode wire planes and pass it to downstream data acquisition (DAQ) system.

**NU stream** Losslessly compressed data associated with event triggers.

**SN stream** Continuous data stream compressed with some data loss and is continuously readout frame by frame (1 frame = 1.6 ms).
TPC Readout electronics (MicroBooNE)

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Data Streams (MicroBooNE)

- ADC count
- Input
- NU stream
- SN stream
- Start of a run
- 1.6 ms frame
- Time tick

Cartoon display
Data Streams (MicroBooNE)

- NU stream: On receiving an external trigger, 4.8 ms of data is readout.
- SN stream: Regions of interest (ROI) are extracted, whenever a waveform crosses a certain threshold.

Cartoon display

External Trigger

1.6 ms

3.2 ms

Start of a run

Time tick

Channel dependent threshold

ADC count

Input

NU stream

SN stream

1.6 ms frame

3.2 ms

Cartoon display
Data Streams (MicroBooNE)

- NU stream: On receiving an external trigger, 4.8 ms of data is readout.
- SN stream: Regions of interest (ROI) are extracted, whenever a waveform crosses a certain threshold.
Data Streams (MicroBooNE)

- NU stream is saved every time there is a trigger and then is diverted to Sub Event Buffers (SEBs) and then to Event Builders to build events (Data used for beam physics measurements)

- SN stream is saved to drive and is written to disk on receiving a SuperNova Early Warning System (SNEWS) alert (Data to search for non-beam events).
Which events to trigger on?

MicroBooNE, being situated on-surface, has a lot of cosmogenic activities.
Interesting events to trigger

- Some of the interesting interactions to trigger on include stopping muons, cosmogenic anti-proton or anti-neutron annihilation.
TPC Trigger Strategy

• Following DUNE trigger strategy, trigger primitives (TPs) can be constructed from MicroBooNE’s SN stream ROIs.
TPC Trigger Strategy

- Following DUNE trigger strategy, trigger primitives (TPs) can be constructed from MicroBooNE’s SN stream ROIs.

TPs are defined as a “summary” of an ROI:

- Integral
- Amplitude
- Time over threshold
TPC Trigger Strategy

• Following DUNE trigger strategy, trigger primitives (TPs) can be constructed from MicroBooNE’s SN stream ROIs.

• TPs can be used to make an online TPC trigger decision (TD) (in CPUs or GPUs) by constructing higher-level TPC triggered objects.
Trigger Approaches

Michel electron candidate event display
(MicroBooNE’s ROI)

An example of applying TP generation to ROIs.
(ROI integral)

Hits are found by offline Gaussian Hit Finder Module
Current Status for Online Trigger Development

- TP generation has been implemented in FPGA for real-time implementation and testing in MicroBooNE (& SBND in near-future).

- Working towards TP processing software and algorithms for online trigger generation.
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<thead>
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<th>Header</th>
<th>Left 16bit</th>
<th>Description</th>
<th>Right 16bit</th>
<th>Description</th>
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<td>0xFFF00</td>
<td>contains upper 12 bits of number of ADC words from FEM for this event</td>
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6 32-bit FEM header words

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<th>Word # / Bit #</th>
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Channel header(0x1..),

TP header (0x[4..7]), unique Id

TP Payload

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$FFFFF F1E3FFF F6A8F001 F003F000 F002F000 F000F000 F000F000 107F4792
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E3FFF F6A8F001 F003F000 F002F000 F000F000 F000F000 10854991
```
Trigger Approaches

- TP generation has been implemented in FPGA for real-time implementation and testing in MicroBooNE (& SBND in near-future).

- Working towards TP processing software and algorithms for online trigger generation.

- TPs stream to DAQ servers for online processing with a goal of generating TD.

- TD can be used to select the buffered SN readout data for subsequent event building.
Trigger Approaches

• One can look for stopping muons, *by looking at straight tracks making use of topological (existence of kink) and calorimetric (change in dE/dx at bragg peak) information to trigger on.

• There is also a possibility of exploring image classification, rather than having to cluster TPs to make a track to construct high lever trigger objects.

*Michel Electron Reconstruction Using Cosmic Ray Data from MicroBooNE LArTPC (MicroBooNE Collaboration), JINST 12 (2017) 09, P09014
Machine Learning (ML) based Trigger Approach

Image classification

Classification will be done based on Activity

Low energy activity  \rightarrow \text{Low energy activity}

High energy Michel  \rightarrow \text{High energy Michel}

High energy Annihilation  \rightarrow \text{High energy Annihilation}

Low energy activity  \rightarrow \text{Supernova neutrino events}

High energy activity  \rightarrow \text{Michel electron, anti-neutron or anti-proton annihilation}
Future Possibility

• For future experiment such as DUNE, there is a possibility to use ML tools on specialized hardware like Field Programmable Gate Array (FPGA).

• Our group is also working on deploying CNN on FPGA (hardware stage of data selection, using HLS4ML tools*) as it is much more power efficient.

• Preliminary results on ROI downsized images.

*Please refer to the other talks in TDAQ Session of CPAD-2021 for more details
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<table>
<thead>
<tr>
<th>Sample</th>
<th>Train Size</th>
<th>Test Size</th>
<th>Accuracy (%)</th>
<th>Inference Time (ms)</th>
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</table>

NB: Noise & Background
LE: Low Energy
HE: High Energy

*Accelerating Deep Neural Networks for Real-time Data Selection for High Resolution Imaging Particle Detectors
https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=8909784&tag=1
Summary

With the currently & soon to be operating MicroBooNE & SBND LArTPCs, we have an exciting opportunity to:

- Carry out dedicated demonstrations for DUNE TPC trigger design.
- Develop novel (ML based) LArTPC trigger techniques for online or real-time data processing.
- Enhance future SBND and DUNE physics program.

Timeline:

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MicroBooNE: TPC trigger deployment

SBND: SBND Trigger Commissioning (beam, photon detectors) TPC trigger deployment
Thank you