Comments on μBooNE DAQ Challenges

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Some LArTPC Facts for μBooNE

Drift velocity v ~ 1.6 mm/μs @ 500 V/cm.

Drift distance = 2.6 m; drift time = 1.6 ms.

Active LAr volume = 2.6 m (x) x 2.6 m (y) x 12 m (z) = 81.1 m^3.

3 wire planes: U, V, X with U, V at $\theta = \pm 60°$ to the vertical (X).

Wire length = 2.6 m for X, and 5.2 m for U/V.

Nominal wire spacing d = 3 mm.

Total number of wires = 12 [1/d + 2/(d / cosθ)] + 2.6 [2 / (d / sinθ)] = 28.503 / d = 9,500.
[4000 X wires, 2250 each for U and V.]

The induced (bipolar) signal waveforms have characteristic width Δt ~ d/v ~ 2 μs.
(99% of frequency content below 2 MHz).

Nominal time sampling is 5 MHz ⇒ 10 samples per characteristic width. [Is this enough/too much?]

Number of time samples = 8,000 per wire during drift time of 1.6 ms.

Argon purity: Nominal electron lifetime of 1.5 ms ⇒ only 1/3 of original signal left after 2.6 m drift.

Horizontal minimum ionizing track, 2.6 m from readout ⇒ ~ 6000 electron signal.

Electronic noise on a 5-m-long wire (with cold front-end transistor near end of wire) ~ 500 e.

S/N only 12:1 for long drift (36:1 close for track close to readout plane).

ADC bits: 1 (bipolar) + 5 (MIP close in) + 5 (slow protons/multiple tracks up to 32 x MIP) = 11 (i.e., 12).

Cosmic Ray Rates in μBooNE

[Refer to DocDB #198 for "theory".]

R_H = 200 /m²/s of cosmic rays crossing a horizontal plane at the Earth's surface.

$R_V = R_H/\pi$ = 63 /m²/s of cosmic rays crossing a vertical plane (from one side) at the Earth's surface.

Active volume = 2.6 m (x) x 2.6 m (y) x 12 m (z).

Total rate of muons entering this volume is R_{total} = 11,000 / s (1 muon every 90 μs).

⇒ 1.1 e4 x 1.6 e-3 = 18 muons cross the detector during one readout time of 1.6 ms.

The average path length of a muon crossing this volume is 2.2 m.

The average projection of this path onto the long (z) axis of the TPC is about 1.1 m,

⇒ 1.1 / 0.003 = 367 vertical (X) wires "struck" by a muon on average.

The signal from a wire from a single particle is significant over about ± 1 cm along the drift direction (see Argoneut events), ⇒ ~ 70 readout "pixels" @ 5 MHz.

⇒ 367 x 70 = 2.6 e4 pixels occupied by each muon, on average.

Total number of X pixels during one readout time is 4000 x 8000 = 3.2 e7.

⇒ Fraction of X pixels occupied during one readout time = 18 x 2.6 e4 / 3.2 e7 = 1.5%.

Occupancy of U and V pixels is about double that of X pixels, ~ 3%.

Average occupancy of pixels by muons is ~ 2.5%.

[An overburden of 15 feet(?) of dirt would cut the occupancy in half. The liquid argon is also self shielding to some extent, so the above estimate is a bit high.]

Triggers

1. Beam trigger.
   - 67 ms between beam pulses; 15 Hz maximum trigger rate, < 10 Hz average.
   - Booster beam spill ~ 1.6 μs long, so an LAr scintillation trigger would fire only 1.6/90 = 1.7% due to cosmics.
2. "Random" trigger for diagnostic purposes.
   - Most beam triggers will not contain neutrino events, even if use scintillator trigger, so most beam triggers are in effect "random" triggers.
   - For diagnostics, record "all" data.
3. Supernova trigger.
   - Given an external trigger from some supernova watch, record "all" data in the detector for the next ~ 5 sec.

What Data Can/Should We Record?

- 9500 wires x 8000 times samples over full drift length x 2 bytes/sample ⇒ 160 MB / trigger. [If concerned about effects of partial tracks from earlier muons, also record data from up to 1 drift time earlier, ⇒ 320 MB / trigger. *No need to record data from later than 1 drift time.*]
- Can use lossless (Huffman = gzip) encoding to reduce data size by ~ 10 ⇒ 16 (32) MB / trigger. [With ~ 3% occupancy, barely pays to do "zero suppression" compared to Huffman coding.]
- If transfer this data "on the fly", instantaneous rate = 16 (32) MB / 1.6 ms = 10 (20) GB/s
- If buffer data on detector and read out over 67 ms, rate = 16 (32) MB / 67 ms = 240 (480) MB/s.
- If 64 wires per readout channel, have 150 channels (front-end readout boards), with readout rates of 67 (134) MB/s per channel "on the fly" (or 1.6 (3.2) MB/s per channel if over 67 ms).
- If record all beam triggers @ 10 Hz average with Huffman coding, have average data rate of 160 (320) MB /s .
- If only record beam triggers with prompt LAr scintillation, average date rate is 3.2 (6.4) MB/s.
- For supernova trigger, buffer 5 sec of data on the detector. With Huffman coding, this is 50 GB. If stored in 150 memories, each is only 1/3 GB ⇒ single 512 MB chip per readout board.

There is no serious technical challenge to record "all" data for all beam triggers, and for occasional supernova triggers as well.

And, no reason not to record only beam triggers with prompt LAr scintillation to cut total data by ~ 50.

Event Building: Switch + PC Farm

- If combine the data from 150 channels (readout boards) into events "on the fly", need a switch that can handle rates of 10 GB/s. This is doable, but at a visible cost.
- If buffer data on detector and read out over 67 ms, need only a 240 MB/s switch (whose cost would hardly be visible).
- Option: Do event building in stages, with a small PC farm at the intermediate stage. This farm could (perhaps) makes cuts based on information from partial events to reduce the data size by ~ factor of 10. [No algorithm to do this has been suggested, and it is not so easy to imagine what it would be.]
- After the main switch, have full events available to individual PCs, and the main data analysis can begin.

Personal view: there is no harm in organizing the switch in 2 stages with a small PC farm in between, but there is also no obvious gain in doing this.

Next Step: Electronics/DAQ Meeting

- Would be good to hold a 1-day meeting before next Collaboration Meeting.
- Possible location: Nevis
- Possible date: Tuesday Dec. 2 (Only Tue and Thu good for KTM).