Brief Update on ProtoDUNE Calibration Plans

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Brief update today on update of ProtoDUNE calibration plans

Focus for now is development of calibration scheme

- Very soon this will translate to **tools development**

Hardest issues to tackle (in my view):

- Space charge effects
- ADC “features”

Also important to test out calibrations that we will want to carry out at the DUNE far detector

- **Example**: using $^{39}$Ar beta decays to measure electron lifetime in the far detector

More info in calibration document: **Doc DB #7222**
This document is organized by discussing individual calibration items of interest, grouped into sections by the type of data that would be utilized in order to carry out the calibrations. These categories are as follows:

- calibrations with noise data (data taken with the cathode and wire bias HV off),
- calibrations with pulser data (data taken as above but with signal calibration pulses injected into the electronics),
- calibrations with tracks \((t_0\)-tagged cosmic muons or beam muon halo), and
- calibrations with \(^{39}\)Ar beta decays.

♦ Above overview is from **calibration document**
♦ First bullet point first, then second; third and fourth can be carried out together
♦ In reality, we should be prepared to carry out the full chain relatively quickly (once we have the corresponding dataset)
Calibrations w/ Noise Data

Figure 1: Simulation of intrinsic electronics noise at ProtoDUNE using a data-driven noise spectrum derived from MicroBooNE (left), and modeling of a combination of broadband and narrowband coherent pick-up noise for use in the ProtoDUNE noise simulation (right).

- Find dead/noisy channels, populate database with information → channels tracking should ignore
  - Use tools created by Jingbo Wang for this
♦ Use calibration pulser signals (via DAC on ASICs, FPGA) to calibrate front-end electronics
  • Use MicroBooNE strategy – see paper (submitted to JINST) on signal processing performance (arXiv:1804.02583)

♦ CSU undergraduate Chris Alleman developing tools for ProtoDUNE – first results with test stand data
♦ Use calibration pulser signals (via DAC on ASICs, FPGA) to calibrate front-end electronics
  • Use MicroBooNE strategy – see paper (submitted to JINST) on signal processing performance (arXiv:1804.02583)
♦ CSU undergraduate Chris Alleman developing tools for ProtoDUNE – first results with test stand data
♦ ADC calibration: voltage → ADC

♦ We have two issues to deal with (hopefully only at ProtoDUNE):
  • Stuck codes – remove all ADCs from waveform at known stuck values, interpolate across corresponding time bins
  • Nonlinearity – use pulser signals with known voltage (various gains, shaping times), measure ADC value

♦ A lot of work being done by David Adams on this topic – see his past talks in Sim/Reco meetings

♦ Points of concern:
  • Will FE/ADC calibrations interfere? Iterative calib.?
  • Don’t know baseline voltage, but seems to be stable in time → perform nonlinearity calib. relative to baseline
Natural to target space charge effects first when looking at effects in TPC bulk

- Independent handle with only spatial information (no charge information needed)

Recent focus: studying SCE at MicroBooNE – first results with MC look promising (see above)

Soon: study effects of fluid flow at ProtoDUNE
Figure 4: Predictions of spatial distortions (in the vertical direction, $y$) due to space charge effects at the ProtoDUNE detectors and DUNE far detectors, making use of a dedicated simulation incorporated into LArSoft. Shown is a central...
SCE w/ Fluid Flow (35 ton)

\[ \Delta y \]
Without LAr Flow

\[ \Delta z \]
Without LAr Flow

\[ \sim 0 \]

\[ Q \text{ map from E. Voirin} \]

\[ \Delta y \]
With LAr Flow

\[ \Delta z \]
With LAr Flow

central z slice
♦ Last “major” calibration: electron lifetime
  • SCE impacts charge scale, so needs calibration first
♦ Multiple handles → enables a cross-check
  • Cosmic tracks (a la MicroBooNE)
  • $^{39}$Ar beta decays
♦ Latter method important to study for DUNE far detector (where cosmic ray rate will be low)
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BACKUP SLIDES
2 Calibrations with Noise Data

Key details:

- **Description of dataset:** ASIC LV on, cathode and wire bias HV off, external (pulser) triggers

- **Detector effects targeted:** intrinsic electronics noise spectrum, external pick-up noise spectrum, dead/noisy channel list

- **Involved collaborators:** Jyoti Joshi (BNL), Mike Mooney (CSU), David Rivera (UPenn), Jingbo Wang (UC Davis)

- **Progress so far:** simulation of imported data-driven noise model from MicroBooNE, simulation of coherent noise (both broadband and narrowband), development and exercise of coherent noise removal algorithm on simulated data containing coherent noise

- **Steps moving forward:** exercise interface to calibrations database (for dead/noisy channel list), add additional flexibility to coherent noise simulation, measure true noise spectra with first ProtoDUNE data
3 Calibrations with Pulser Data

Key details:

- **Description of dataset**: ASIC LV on, cathode and wire bias HV off, external (pulser) triggers, electronics calibration signals enabled (DAC on ASIC/FPGA)

- **Detector effects targeted**: FE ASIC gain and shaping time, ADC ASIC non-linearity and stuck codes

- **Involved collaborators**: David Adams (BNL), Chris Alleman (CSU), Brian Kirby (BNL), Ryan LaZur (CSU), Elizabeth Worcester (BNL)

- **Progress so far**: development of relevant techniques for FE ASIC calibrations with MicroBooNE data, preliminary studies of ADC ASIC calibrations with ProtoDUNE FEMB test stand data, preliminary simulation of ADC nonlinearity and stuck codes

- **Steps moving forward**: exercise interface to calibrations database (for FE ASIC gains and shaping times as well as ADC ASIC nonlinearity calibration), develop machinery to perform in-situ calibrations of FE ASICs and ADC ASICs, coordinate noise and ADC simulation developments
4 Calibrations with Tracks

Key details:

- **Description of dataset:** ASIC LV on, cathode and wire bias HV on, external (pulser) triggers and CRT triggers, tracks in question must be $t_0$-tagged

- **Detector effects targeted:** space charge effects, electron lifetime, wire field response, recombination, diffusion

- **Involved collaborators:** Bruce Baller (FNAL), Steven Green (Cambridge), Tom Junk (FNAL), Mike Mooney (CSU), Ajib Paudel (KSU), Xin Qian (BNL), Arbin Timilsina (BNL), Leigh Whitehead (CERN), Tingjun Yang (FNAL)

- **Progress so far:** development of relevant techniques for track-based space charge effect calibration and $dQ/dx$ uniformity cross-check with MicroBooNE data, study of wire field response simulation (to be used at ProtoDUNE) with MicroBooNE data, simulation of space charge effects for ProtoDUNE, development of CRT-TPC track matching algorithm and associated study of purity/efficiency/coverage, development of ProtoDUNE track-based purity monitoring tool (for online/nearline use), development of $t_0$-tagging tools

- **Steps moving forward:** exercise interface to calibrations database (for electron lifetime calibration), continue to build $t_0$-tagging tools, ensure track-stitching works across dead channels, import track-based space charge effect calibration scheme from MicroBooNE, import $dQ/dx$ uniformity cross-check from MicroBooNE, validate simulated wire field response with first ProtoDUNE data, development of CRT-TPC track matching using realistic data stream from CRT, develop strategy for pinning down TPC alignment, potential diffusion/recombination measurements
5 Calibrations with $^{39}$Ar Beta Decays

Key details:

- **Description of dataset:** ASIC LV on, cathode and wire bias HV on, external (pulser) triggers

- **Detector effects targeted:** electron lifetime, wire field response, recombination, diffusion

- **Involved collaborators:** Alex Flesher (CSU), Mike Mooney (CSU)

- **Progress so far:** demonstrated viability of technique with MicroBooNE data

- **Steps moving forward:** finish measurements at MicroBooNE (electron lifetime, recombination, longitudinal diffusion, transverse diffusion, and wire-to-wire field response variation), explore using technique in ProtoDUNE data, address needs with respect to DUNE far detector DAQ (e.g. zero suppression) to ensure enough data can be collected to perform necessary calibrations at desired level of spatial/temporal granularity
6 Studies of Standard Calibration Sources

This section is not yet complete. To be highlighted here are high-level studies that should be performed after the above calibrations have been carried out, including studying capabilities of particle reconstruction (e.g. charge clustering, particle identification, etc.) using standard calibration sources such as a sample of Michel decays in the LArTPC volume. Much insight has already been garnered at MicroBooNE and should continue to be developed with ProtoDUNE data; studies at ProtoDUNE have the added benefit of incorporating a detector response more similar to that of the DUNE far detector.

♦ Last section still being penned – will focus on high-level studies to be done once low-level calibrations complete (those that require pattern recognition, e.g. Michel electron reconstruction, PID, etc.)
Space charge effects: build-up of slow-moving argon ions in TPC volume due to large cosmic flux (afflicting near-surface LArTPCs, e.g. ProtoDUNEs)

- Observed at MicroBooNE: MICROBOONE-NOTE-1018-PUB
- Distorts E field (recombination smearing), leads to spatial distortions in position of reconstructed ionization charge
ProtoDUNE-SP @ 250 V/cm?

500 V/cm

$Y_{\text{reco}} - Y_{\text{true}} [\text{cm}]: Z = 3.60 \text{ m}$

~20 cm spatial distortions

250 V/cm

$Y_{\text{reco}} - Y_{\text{true}} [\text{cm}]: Z = 3.60 \text{ m}$

~60 cm spatial distortions
CRT Layout
♦ Muon halo can fill in gap (active volume in red, above)
♦ However, relative to cosmics, rate is low: \( O(100)/\text{spill} \)
♦ Need **CRT triggers** to save as many as possible
What about using other $t_0$-tagging methods to fill gaps?

For example, MicroBooNE’s anode/cathode piercers:

- See public note: MICROBOONE-NOTE-1028-PUB

But this sample still sees a gap in the middle of TPC...