A Community Effort

Workshop on Calibration and Reconstruction for LArTPC Detectors

December 10-11 @ Fermilab, Batavia, IL

LarIAT / ArgoNeuT

MicroBooNE

protoDUNE

ICARUS
A Community Effort

A venue for the LArTPC neutrino community to exchange ideas and start developing a collaborative strategy working to meet stringent requirements on neutrino event reconstruction and detector calibrations.

30+ contributions with 60+ participants
Question for this audience as topics are reviewed: what have we missed?
TPC Calibrations

TPC calibrations:

i. noise
ii. electronics response
iii. ADC calibrations
iv. wire field response

Impact of noise filtering:

i. model noise in MC?
ii. signal efficiency
iii. charge bias

Move to protoDUNE / DUNE:

Less extrinsic noise.

Plan: use data-driven spectrum and simulated pick-up noise to study impact on DUNE CP violation measurement
TPC Calibrations

TPC calibrations:
  i. noise
  ii. electronics response
  iii. ADC calibrations
  iv. wire field response

Useful knowledge from MicroBooNE experience:

i. stability within 0.2% over two years.
ii. few percent variation in channel response.
iii. differences in cold / warm response: ~few %.
iv. impact of signal transport / attenuation for absolute calibration.

Lots of activity on ADC front in LArTPC community:

MicroBooNE: warm ASIC.
SBND: cold ASIC, commercial.
ProtoDUNE: cold ASIC, custom.

ProtoDUNE making rapid progress in understanding cold ASIC behavior.

Questions for DUNE:

Is the electronics response calibration system sufficient? Charge injection at wire?
TPC Calibrations

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Anisotropy of TPC wire readout causes large variations in response which impact absolute energy scale measurement.

Numerous competing processes impact signal shape: [wire-response, diffusion, noise, topology]

Current state-of-the-art extracts field response and phase-space dependence using ab-initio analytic calculation with Garfield.

Validation performed matching charge across planes and comparing DATA/MC waveform shapes.

Discussion topics:

i. 3D field calculation.
ii. Test-stand planning@ BNL (LarFCS by Chao Zhang)

Questions for DUNE:

i. How to estimate the tolerance of DUNE analyses to phase-space dependent variations in response?
ii. Is current level of data/MC agreement satisfactory?
Photo Detection Calibrations

PMT calibrations:
   i. Gain and quantum efficiency
   ii. Light transport modeling
   iii. Energy reco with PDS

Use of light signals at an early stage (for neutrino physics) in large LArTPCs.

This is changing as PD systems become more sophisticated, and as low-threshold / beam triggering become more important.

Contributions by:

Matt Toups, FNAL
Diego Garcia-Gamez, Granada
Will Foreman, UChicago

Take-aways:

- Test stand experiments [PAB] have been leading the way on such measurements

- Uncertainties in Rayleigh scattering measurements need to be resolved. Important for large-volume detectors.

- What level of detected PE / MeV is needed to achieve the physics? What enhancements do improvements bring?
Photo Detection Calibrations

PMT calibrations:

i. Gain and quantum efficiency
ii. Light transport modeling
iii. Energy reco with PDS

Exciting presentation by Will Foreman, [UChicago, LArIAT] demonstrating improvement in energy reconstruction for Michel electrons employing light information.

LarIAT achieves a uniform and large PE / MeV yield by using reflective foils. Will be employed in SBN.

\[
E = \frac{Q}{\langle R \rangle} \times W_{ion}
\]

\[
E = (Q + L) \times W_{ph}
\]
Calibration Sources

Calibration Sources:

i. $\pi^0$ mass
ii. stopping tracks
iii. Michel electrons
iv. argon-39
v. neutrons
vi. laser system

Energy

MeV GeV

coverage [stats / uniformity]

$\text{Ar}^{39}$ stopping $\mu/p$

6.1 MeV

neutrons

Michel stopping $\mu/p$

$\pi^0$

MicrBooNE

MicroBooNE Preliminary

Threshold: 1500 e$^-$
Threshold: 2200 e$^-$

Reconstructed Electron Kinetic Energy [kV]

Number of Candidates

$\text{ENDF} - \text{W} - \text{GEL}
\text{J} - \text{DRN} - \text{JRT}$

Continuum Surelite I-10

DUNE FD Calibrations group – January 8th 2019
Calibration Sources:

i. $\pi^0$ mass
ii. stopping tracks
iii. Michel electrons
iv. aron-39
v. neutrons
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Pi0s offer one of the few available “standard candles”.

Statistics limit extent of available studies: $O(100)$ in ICARUS [LNGS / Pavia], not much more in past ArgoNeuT, current MicroBooNE xsec [arXiv:1811.02700].

Expand knowledge of EM interactions via protoDUNE beam sample / upcoming SBN results / cosmics?

General question of how to relate knowledge of gamma showers to much more rare electrons.

Presentation by Alessandro Menegolli, Pavia, Pi0s at ICARUS.
Calibration Sources:

i. π⁰ mass  
ii. stopping tracks  
iii. Michel electrons  
iv. aron-39  
v. neutrons  
vi. laser system

Discussed the possibility of Ar39 as a multi-purpose calibration tool:

i. recombination and electron lifetime effects in a combined fit.  
ii. Monitor / measure wire response.  
iii. Measure diffusion constants.

These measurements rely on their cumulative effect on the Ar39 spectrum. A question of:

1) how well can the effects be disentangled.  
2) How does the selection impact the measurement?

Can we extrapolate to DUNE FD by applying appropriate thresholds / cuts in the analysis?
Calibration Sources:

- π⁰ mass
- stopping tracks
- Michel electrons
- aron-39
- neutrons
- laser system

Presentation on stopping track calibrations:

LarIAT:

Beam provides source of mu/π/p/K. Beamline instrumentation provides momentum.

Focus has been on producing a calibration for the purpose of achieving LarIAT’s physics goals.

Worth turning around and asking how good can we do?

Michel electrons:

Overview of current status, advocating for new effort on this front to test detector and reconstruction limitations of energy reconstruction in an important energy range.
"External" sources

Calibration Sources:

i. $\pi^0$ mass  
ii. stopping tracks  
iii. Michel electrons  
iv. aron-39  
v. neutrons  
vi. laser system

Challenge of aligning timeline for current results and decision-making for DUNE planning.

LASER calibrations:
Extensive experience installing / operating hardware at Bern and in MicroBooNE.
First laser calibrations from MicroBooNE underway. Results soon.

Transferring current knowledge to DUNE:
  i. hardware / installation very different.  
  ii. current surface analysis focus is space-charge.

Neutron source:
Unique opportunity to investigate few-MeV energy scale.
DUNE-focused effort.
Results from ACED useful to:
  i. Inform simulations on $\gamma$-cascade.  
  ii. First XSEC on argon.
Addressing low-energy physics, not relativistic neutrons.

Presentations by Yifan Chen [Bern] on laser system and Jingbo Wang [UC Davis] on neutron sources.
High Level Calibrations

i. space-charge effects
ii. Ion recombination
iii. TPC alignment
iv. Neutrino energy reconstruction
v. MicroBooNE detector calibration

It’s a matter of strategy! Ample room for discussing and shaping procedure.

At the workshop we heard:

- MicroBooNE’s current all-in-one calibration procedure.
- step-by-step calibrations currently available/being performed.
High Level Calibrations

i. space-charge effects
ii. Ion recombination
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iv. Neutrino energy reconstruction
v. MicroBooNE detector calibration

MicroBooNE current calibration implementation presented by Varuna Meddage [Kansas State].

Relies on cosmic through-going and neutrino stopping muons to calibrate relative dQ/dx and absolute dE/dx scales respectively.

“All-in-one” calibration accounting for lifetime, wire response, and other detector effects.

This calibration gives O(3%) accuracy w/ few systematic effects.
High Level Calibrations

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Discussion: as we learn more about the various effects impacting TPC signals, does it become advantageous to correct effects individually?

Discussion: How to separate the measurement of an effect from its calibration in an analysis? Value of external / test-stand measurements.

How will DUNE’s workflow proceed? Current strategies cosmics-dominated.

Need to build expertise on a complex chain of events. Many effects, many experts, make sure work is well coordinated.

Electronics and field-response effects were discussed earlier in the day. Spent the rest of the session discussing various detector effects.
High Level Calibrations

i. space-charge effects
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Ion recombination: nice introduction and overview of current state by Bruce Baller [FNAL].

LarTPCs rely on ArgoNeuT and ICARUS past measurements.

Challenge in extracting/validating a recombination model in a surface TPC with several effects compounded.

• Is current knowledge adequate?
  o OK for discriminating protons from pions/muons
  o Not OK for pion – muon or proton – kaon discrimination
  o Golden proton decay channel $p \rightarrow K^+ \nu$ requires high confidence PID at all angles

• Significant differences are expected between real world recombination ($\mu$m scale), simulation (sub-mm scale) and reconstruction (dx is sub-cm scale)

• ArgoNeuT angular dependence should be confirmed …
  o In a short drift LArTPC to mitigate space charge E-field variations
  o In a test beam with known particle types
  o Mounting LArIAT on a turntable would be ideal
High Level Calibrations

DUNE FD Calibrations group – January 8th 2019

High Level Calibrations
i. space-charge effects
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Space-charge and DUNE. A complicated relationship...

Still a “fresh” subject. First quantitative measurements underway @ MicroBooNE and now protoDUNE.

Working to integrate these calibrations in general analysis chain.

Marginal effect at DUNE FD, but impactful for all calibration measurements to come until FD turns on.

Mike Mooney, Colorado State, *Space Charge*

<table>
<thead>
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<th>Experiment</th>
<th>E Field</th>
<th>Drift Length</th>
<th>Max E Field Distortion</th>
<th>Max Spatial Distortion</th>
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<td>~15%</td>
<td>~15 cm</td>
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<td>SBND</td>
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<td>~5%</td>
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<td>ProtoDUNE-SP</td>
<td>500 V/cm</td>
<td>3.6 m</td>
<td>~15%</td>
<td>~20 cm</td>
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</table>
High Level Calibrations

i. space-charge effects
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iii. TPC alignment
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v. MicroBooNE detector calibration

TPC alignment: a “new” challenge arising from larger, segmented detector.

Presentation by Tom Junk @ FNAL, TPC Alignment.

Preliminary qualitative results from protoDUNE. A significant calibration task which deserves dedicated effort [i.e. from a student]
High Level Calibrations

Putting it all together: neutrino energy reconstruction!

Presentation by Jianming Bian, UC Irvine focused on DUNE neutrino energy reconstruction performed with CNN (comparing to kinematic methods).

Good opportunity to step back and view detector calibrations in the bigger context of neutrino energy reconstruction uncertainty caused by e.g. uncertainties in hadronic portion of interaction.

e.g. weigh neutron detector response vs. neutron production knowledge.

Summary: status of neutrino energy reconstruction matches TDR expectation in MC. Now is where the work of a calibrations group comes to play.

In the short term use protoDUNE for data-driven validations. How? Recover known beam energy from re-interacting particles?
Beyond the workshop

Challenges of DUNE calibration
what is needed ex-situ?

• What does a complete (realistic) calibration program look like? **Tools, techniques and analysis validation via publications:**
  - What seems to work well and at what level? with cosmics/pi0/decay electrons/39 Ar?
  - What parameterization is used?

• **Design validation:** ideally needed for March 2019
  - uB laser system, (joint with CISC) protoDUNE fluid flow simulations and monitor validation of those simulations
  - Plan to deploy systems in a dedicated protoDUNE run; important to test the whole design and readout

Closed with a “call to arms” by Kendall

How can you help DUNE?

• **Two primary areas you can help:**
  - Help “outside” of DUNE from other experiments (as presented in previous slide)
  - Help “inside” DUNE on two aspects:
    - DUNE targeted studies that demonstrate the limitations of intrinsic sources (e.g. theoretically Ar39 can provide lifetime monitoring but need studies to demonstrate achievable granularity”)
    - Studies on DAQ challenges for both intrinsic and dedicated systems to support calibration (e.g. Ar39 DAQ)
Beyond the workshop

Plan to produce proceedings of the workshop, as a JINST technical publication.

Twofold goal:

1) Benchmark of current status of calibration / reconstruction in LarTPCs.
2) Documentation as a pedagogical reference.

Would be beneficial to have a section focused on what DUNE needs are, based on the current status. In my opinion this provides a useful summary to a general reader on what to focus on moving forward.

Possible next steps:

- Pick several detector effects measured by other TPCs, based on expected impact and feasibility of implementation, and push into DUNE simulation to estimate impact on physics.

Workshop contributions at https://indico.fnal.gov/event/18523/
Backup
# protoDUNE event rates

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From email by Roberto Acciarri to DUNE list 11/12/2018