DUNE Far Detector Calibrations

- Calibration Thoughts
- Overview of Preliminary Charge
- Organization and Work

First WG Call 9/24/2015

Calibrations: Overview

Calibrations have 4 basic goals:

- To generate *corrections*: e.g., conversion of ADC counts to charge.
  Usually applied to data
  Example: Pulser

- To measure *parameters*: e.g., electron lifetime, diffusion. (could also be response functions)
  Usually provide inputs to simulation model
  Example: Laser source

- To measure *acceptances*: e.g., Cut acceptance, fiducial volume.
  Usually included in normalizations and background estimation
  Example: Sample of cosmic muons?

- To provide *tests*: Comparison of model prediction to data, reconstruction response
  Usually provide estimations of systematic uncertainties
  Examples: Sample of cosmic muons? Radioactive source?

Calibrations: Overview

Calibrations have 4 basic goals:

1. To generate *corrections*.
2. To measure *parameters.*
3. To measure *acceptances.*
4. To provide *tests.*

Depending on philosophy and needed precision, some of these elements can be used in place of others.

Ex 1. Fiducial volume (3) can be predicted by a calibrated model (2), rather than measured. Uncertainties on model can be measured via cosmics (4) or by varying uncertainties from measurements in (2).

Ex 2. Drift correction could in principle be mapped (1) by a source, or parameters like E field (2) could be measured and drift correction predicted. Uncertainties could come from cosmics (4).

Calibrations: Overview

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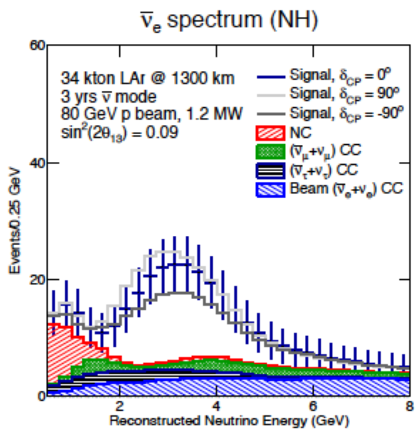
Top-down example: Where will NC background estimate come from?



a. Could be a calibrated full simulation model
b. Could be from fast MC or analytic calculation with measured response functions

(b) Requires careful handling of correlations and extrapolations

Calibrations: Overview

Simulation model of detector includes:

- ν interaction cross sections ($d\sigma(E_\nu)/dE_e d\Omega_e$)
- Particle propagation through LAr (e.g., GEANT4)
- Ionization and any non-linearities
- Detector geometry
- Creation of scintillation light
- Electron drift including speed, diffusion, lifetime, etc.
- Response of TPC wires and front-end electronics
- Response of light detection system and associated electronics

Model needs to be valid for all times, all energies, and positions and directions within detector.

Calibrations: Overview

- Ideally, the model should be over-constrained.
- It will be *necessary* to also test the model, independent of parameter constraints

Calibrations: Overview

Detector model will rely on parameters provided by:

- Benchtop measurements
- DUNE prototypes
- Other experiments
- Other detectors (e.g., near detector, beam monitors)
- Analyses of *in-situ* physics events in Far Detector
- Explicit *in-situ* calibration systems in Far Detector

Some parameters are universal:

- Cross sections
- Ar ionization energies
- Particle passage through argon

Here, protoDUNE and other detector measurements play a big role.

Calibrations: Overview

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Other parameters are detector-dependent:

- Drift velocity, diffusion….
- Reconstruction efficiency
- Particle ID

protoDUNE helps verify model of detector
But hard to see how to avoid *in-situ* tests…

Calibration Working Group

Preliminary Charge Elements

Calibration WG will:

1. Provide complete list of parameters, corrections, efficiences/acceptances to be measured
2. Generate requirements for calibration system(s)
3. Design a calibration program to meet requirements
    - May include analyses of data (cosmics, tagged events…)
    - May include explicit sources
        - Laser?
        - Cosmic tagger?
        - Radioactive sources
        - Radioactive spikes

Charge---Scope?

As it stands, charge includes

- Electronics corrections and response functions (pedestals, ADC…)
- Photon system response (light yield, timing…)
- TPC response (electron lifetime, drift velocity, diffusion…)
- Detector geometry (e.g., wire positions)
- High-level acceptances such as fiducial volume and uncertainties

Other elements of the model are *not* in our scope:

- Neutrino cross sections
- Beam flux and flavor composition
- Particle propagation through LAr

Calibration Working Group
Deliverables

- Requirements for calibration program
- Requirements for any necessary instrumentation
- Outline of how calibrations will be integrated into analysis path
- Analyses demonstrating how program will constrain parameters as well or better than physics requirements for all physics topics of interest

Calibration Working Group
Inputs and Foundations

Calibration WG will need:

- Input from all Physics WG on what requirements are on knowledge of detector response
- Simulation of Far Detector
- Reconstruction and analysis tools

Path Forward

Are we done already?

Date: 8-8-12 **Date revised:** 10-04-2012 J. Dolph

Risk Title: The LAr Detector lacks an adequate calibration system
Risk Description: A calibration system is required to measure the neutrino energy to the required accuracy.
Detailed Risk Cause: Temporal and/or spatial variations of impurities or positive ions due to the high flux of cosmic rays.
Detailed Risk Effect: The energy deposition in the detector cannot be adequately measured.
WBS Affected: 1.4
Other WBS Affected:

Actual Start Date (when available from schedule)	**Actual Finish Date (when available from schedule)**

Initial Risk Analysis – (description of selection of impacts and probability, text length commensurate with risk complexity):

The need for a calibration has yet to be demonstrated. ANSYS simulations of fluid flow indicate that impurities and positive ions would be mixed to some extent in the cryostat. In principle, the large flux of cosmic rays would provide sufficient calibration although this has not been demonstrated. It is highly desirable to have an independent means of calibrating the detector however, for instance by providing a laser calibration system.

As a point of reference, The MicroBooNE experiment, which plans to operate on the surface with a 2.5 m drift, has decided to include a laser calibration system in the project cost.

Path Forward

Are we done already?

130.05 DUNE **BASIS of ESTIMATE (BoE)** **for** ***130.05.05.04 Laser Calibration***		**Date of Estimate:** 6 / 29 / 2015 **Prepared by:** Gus Sinnis Contributing Authors: Qiuguang Liu Reviewed by: Jim Stewart **Docdb #:** 10606
WBS number: 130.05.05.04	**WBS Title :** Calibration	**Control Account:** ____________

WBS Dictionary Definition:

Laser Calibration System: Design, procurement, and construction of all Laser Calibration system components, including the UV laser, cold and room temperature optics, laser optical feedthroughs, an automation system, and safety systems. Includes system checkout prior to commissioning.

Supporting Documents (including but not limited to):

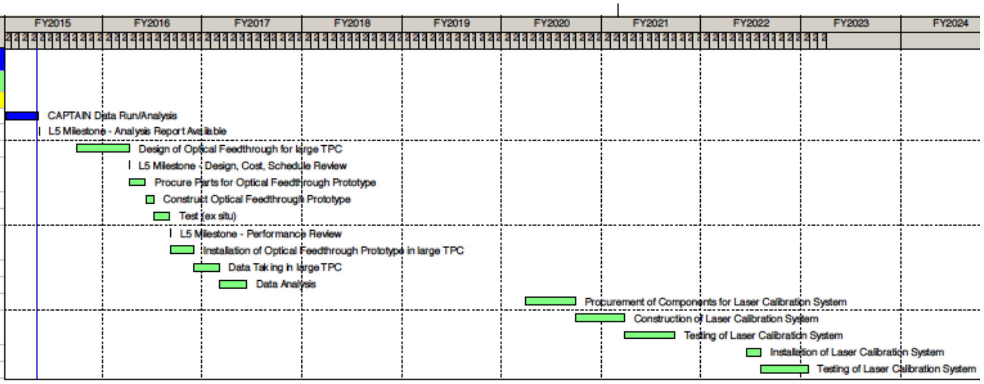
see Electronic BOE file (docdb10606) for supporting documentation.
Estimate based on R&D experience with full-scale PD module assembly. No supporting documentation supplied beyond this BOE.

Assumptions:

Path Forward

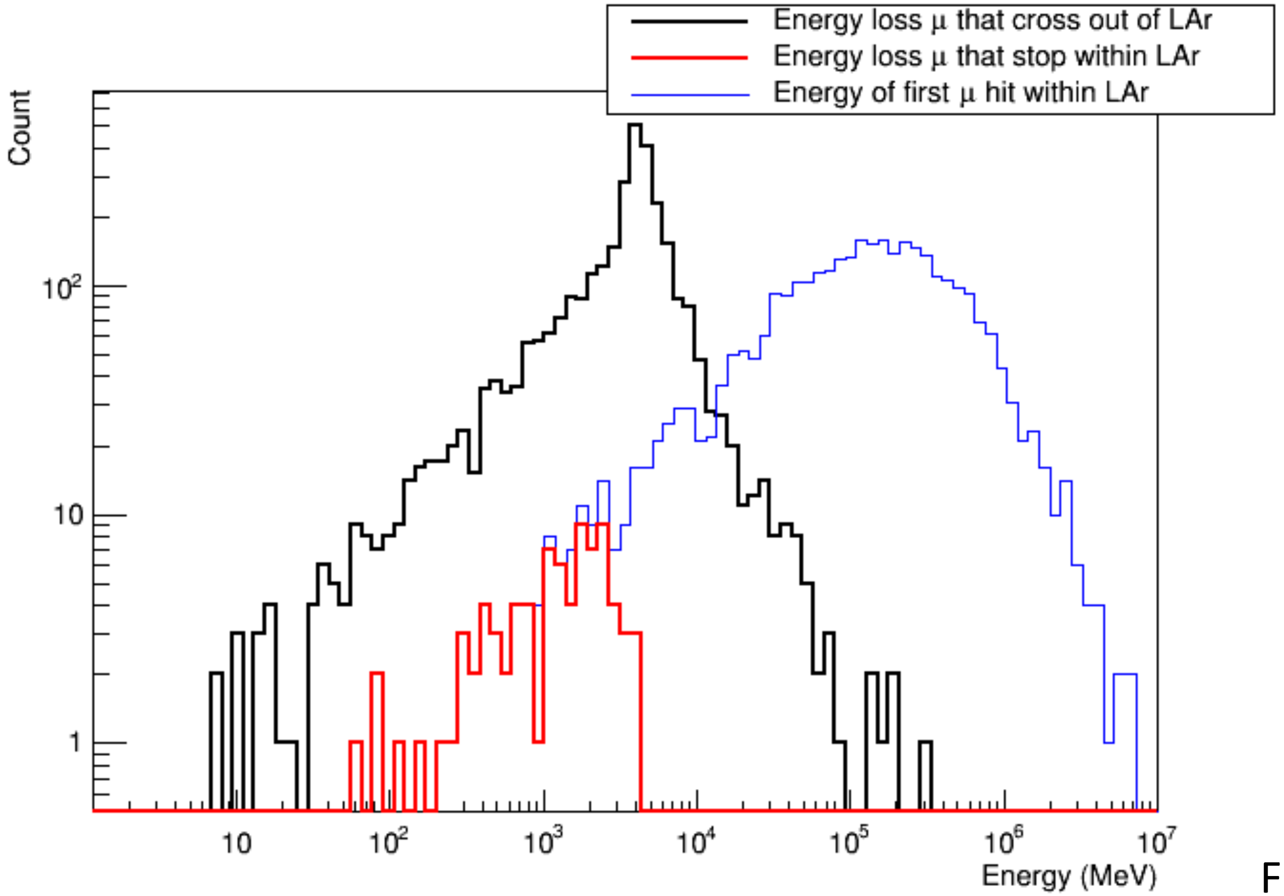
Are we done already?

Activity ID	Activity Name	Funding Type	Planned Duration	Start	Finish
130.05 Far Detector			2019	14-Oct-14 A	26-Oct-22
130.05.05 DAQ & Monitoring			2019	14-Oct-14 A	26-Oct-22
130.05.05.04 Calibration			2019	14-Oct-14 A	26-Oct-22
13005.05.04.05	CAPTAIN Data Run/Analysis	DOE.HEP.LNI.PED	80	14-Oct-14 A	10-Feb-15
13005.05.04.06	L5 Milestone - Analysis Report Available		0	11-Feb-15	11-Feb-15
13005.05.04.10	Design of Optical Feedthrough for large TPC	Non-DOE	126	02-Jul-15	05-Jan-16
13005.05.04.12	L5 Milestone - Design, Cost, Schedule Review		0	06-Jan-16	06-Jan-16
13005.05.04.14	Procure Parts for Optical Feedthrough Prototype	Non-DOE	43	06-Jan-16	07-Mar-16
13005.05.04.16	Construct Optical Feedthrough Prototype	Non-DOE	21	08-Mar-16	05-Apr-16
13005.05.04.18	Test (ex situ)	Non-DOE	42	06-Apr-16	03-Jun-16
13005.05.04.20	L5 Milestone - Performance Review		0	06-Jun-16	06-Jun-16
13005.05.04.22	Installation of Optical Feedthrough Prototype in large TPC	Non-DOE	60	06-Jun-16	29-Aug-16
13005.05.04.24	Data Taking in large TPC	Non-DOE	65	30-Aug-16	01-Dec-16
13005.05.04.26	Data Analysis	Non-DOE	65	02-Dec-16	09-Mar-17
13005.05.04.28	Procurement of Components for Laser Calibration System	Non-DOE	127	26-Dec-19	24-Jun-20
13005.05.04.30	Construction of Laser Calibration System	Non-DOE	125	25-Jun-20	22-Dec-20
13005.05.04.32	Testing of Laser Calibration System	Non-DOE	125	23-Dec-20	23-Jun-21
13005.05.04.34	Installation of Laser Calibration System	Non-DOE	40	14-Mar-22	06-May-22
13005.05.04.36	Testing of Laser Calibration System	Non-DOE	120	09-May-22	26-Oct-22



Path Forward

Are we done already?



From Vitaly

Three different sets of code give agreement on muon spectrum at 4850 ft to ~2%

Path Forward

Are we done already?

LBNE Calibration Module
User Manual

J. T. Anderson, P. De Lurgio, Z. Djurcic,
G. Drake, A. Kreps, M. Oberling

Argonne National Laboratory

Path Forward

Are we done already?

But DUNE FD will be different in many ways:

- Neutrino energy spectrum
- Much smaller number of cosmics/APA
- Probably too big for single laser
- Illumination and understanding of dead regions
- Very different primary physics program
- Broader physics program than other detectors
- PDS likely to be different

Path Forward

Many Questions…

- How much of detector should a laser illuminate, and how much can it reasonably do? Are we happy to get our ADC-to-energy conversion based on the agreement of 3 simulations of muon spectra?
- How are things like "fiducial volume" and/or its uncertainty measured?
- Do we need a way of independently tagging/measuring cosmics?
- Do we need low-energy calibration sources?
- How well do we need to know front-end response so that deconvolutions are accurate?
- How often do we need to measure detector response?
- How do we know mis-ID efficiencies?
- …

Answers to these and many others must be demonstrated solutions (And not "We'll just…").

Path Forward

One suggestion: Start from the top-down

How have far detectors for other LBL experiments been calibrated, and how have the calibrations been used?

How have LAr-TPCs been calibrated, and how have those calibrations been used?

What are the outlines of DUNE physics analyses, and what assumptions do they make?

What uncertainties are important for DUNE physics programs?

Path Forward

In next several meetings, need to hear from:

- MINOS, NOvA, T2K
- Argoneut, ICARUS, MicroBooNE, SBND
- 35t, protoDUNE
- Physics WGs (maybe summary from Detector Performance?)
- Photon System
- Electronics

Path Forward

Near-term deliverable will be list of all parameters that must be measured, in-situ or not, how often, how many places within the detector.

Energy associated to a given hit is related to the collected charge by

$$E = C\frac{W}{R}e^{(t-t_0)/\tau}Q \qquad (1)$$

YES—but predicted exactly? → C Calibration factor ($C = [152 \pm 2] \times 10^{-4}$ fC/[ADCxsampling time]). Describes the linear relation between the hit amplitude and the charge injected into the electronics. Should be determined for every detector. Could it change over time?

NO → W Average energy necessary to create an electron-ion pair in LAr ($W = 23.6^{+0.5}_{-0.3}$ eV).

YES—pos/time? → R Electron recombination factor.

$(t - t_0)$ Drift time of the electrons.

τ Drift electron lifetime.

YES, but tiny uncertainties relative to ms

YES---pos/time dependent?

N. Barros, LBNE DocDB#9262

Path Forward

Near-term deliverable will be list of all parameters that must be measured, in-situ or not, how often, how many places within the detector.

- Charge loss due to recombination (quenching) - Birk's Law
  - Electrons recombine with argon ions, leading to loss of charge.
  - Variation of Birk's law:

$$Q = A\frac{Q_0}{1 + k_Q \frac{dE}{dx}} \quad , \quad k_Q = \frac{k}{\xi} = 0.097 \pm 0.001 (g/cm^2)/MeV \text{ at } 0.5kV/cm \quad (3)$$

YES? A Normalization parameter (from ICARUS: $A = 0.800 \pm 0.003$).

YES? k From ICARUS: $k = 0.0486 \pm 0.0006 \left[\frac{kV}{cm}\right] \left[\frac{g}{cm^2 MeV}\right]$

YES--- idendent of drift velocity? → ξ Electric field

NO $\frac{dE}{dx}$ Stopping power

We need a table of all of these.

N. Barros, LBNE DocDB#9262

Path Forward

A first (and inconsistent) start:

A	B	C	D	E	F	G	H	I	J	K
Parameter/Function	**Definition**	**In-situ**	**protoDUNE**	**35 t**	**Universal**	**Calibration**	**Position Dep?**	**Time Dep?**	**Test**	
W	ionization energy	No	No	No	Yes	Benchtop	No	No	Cosmics	
C	ADC/charge map	Yes	No	No	No	Electronics cals.	Yes	Yes	Laser?	
R	electron recombination	Yes	No	No	No	Purity monitor?	Yes	Yes	Cosmics	
τ	Electron lifetime	Yes	No	No	No	Purity monitor?	Yes?	Yes?	Laser?	
A	Birk's Normalization	No?	Yes	No	Yes?	protoDUNE	No	No	cosmics	
k	Birk's constant	No	Yes	No	Yes	ICARUS?	No	No	protoDUNE	
E	electric field	Yes	No	No	No	Laser	Yes	Yes?	Cosmics?	
vd	Drift velocity	Yes	No	No	No	Laser?	Yes	Yes?	Cosmics w/ tag?	
(x,y,z)	Wire positions	Yes	No	No	No	Survey?	Yes	No?	Laser	
d	electron diffusion	Yes	No	No	No	Laser?	Yes	Yes	Cosmics?	
σt	time resolution	No	No	No	No	Clock spec.	No	Weakly	Laser	
σt0	T0 resolution	Yes	No	No	No	LED?	Yes	Weakly	Beam time profile	
N	PDS light yield	Yes	No	No	No	LED?	Yes	Yes	Stopping μs?	
ε	Trigger Efficiency/non-beam	Yes	Yes?	Yes?	No	Source?	Yes	Yes	Beam events	
Vf	Fiducial volume	Yes	No	No	No	Model prediction?	Yes	No?	Cosmics w/tag?	
ρe(E-Er)	e Energy response function	Yes	Yes	No	No	Model/protoDUNE?	Yes	Yes	protoDUNE	
$\rho\gamma$(E-Er)	γ Energy response function	Yes	Yes	No	No	Model/protoDUNE?	Yes	Yes	protoDUNE	
σr	Recon precision	Yes	Yes	No	No	Laser?	Yes	Yes	Cosmics	
Δr	Recon bias	Yes	Yes	No	No	Laser?	Yes	Yes	Cosmics	

Path Forward

Schedule

We (unfortunately) also have to deal with project/schedule realities:

- Need to ensure calibration needs of protoDUNE are in hand
- Need to ensure that measurements by protoDUNE will provide needed calibrations input for DUNE
- Need to provide specifications for DUNE FD conventional facilities
  - How many lasers, mirrors, feedthroughs…?

These are all needed before end of this CY(?)

Organization

- Given potential breadth of charge, we are very manpower-limited
- Some things will proceed by themselves (e.g., 35t calibrations already ongoing)
- Probably don't have time for separate subgroup phone calls
    - But "obvious" subgroups are protoDUNE, 35 t right now
    - Later might be instrumentation, in-situ analyses, etc.
- Will meet biweekly at first, may move to monthly as things settle down
- Need to define available manpower for work:
    - Cosmic-ray calibration studies
    - Tagged beam-event studies
    - Simulations of PDs (from PD WG)
    - Laser studies---how much illumination?