Modeling and Analysis of Ionization Laser Calibration for the DUNE Time Projection Chamber

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DUNE Introduction

- The Deep Underground Neutrino Experiment (DUNE) is a forthcoming neutrino experiment designed to address a broad spectrum of physics goals.

- DUNE’s far detector will have a total volume of approximately 70 kilotonnes of liquid argon (LAr).

- Large-scale prototyping efforts (in a 760 tonne detector called ProtoDUNE) are ongoing at CERN.

For more on these goals, visit: DUNEScience.org
DUNE TPC Introduction

DUNE’s Far Detector:
- Four modules
- Largest Liquid Argon Time Projection Chambers (LAr TPCs) ever assembled

Calibration challenges:
- Massive scale
- Deep underground location
- Stringent systematics requirements
Time Projection Chambers: An Introduction

TPCs are particle detectors that use gas or liquid and electromagnetic fields to perform a three-dimensional reconstruction of particle interactions.

ProtoDUNE is a large-scale prototype TPC located at CERN aimed to inform the design and construction of DUNE.
Spatial Calibration Motivation

- Position reconstruction is vital to DUNE’s science goals
- Particle identities are derived from spatial patterns.
External Calibration Motivation

Previous LAr TPCs (including ProtoDUNE!) rely on cosmics for spatial calibration - DUNE can’t do this!

1480m

Image Courtesy: SURF

Figure 49. Spatial distortions normal to the top detector face (upper left), bottom detector face (upper right), upstream detector face (lower left), and downstream detector face (lower right) in ProtoDUNE-SP data. The color axis represents the additive correction (in cm) one must apply to the start/endpoint of a track passing through the given detector face in order to correct its position to the true entry/exit point at the side of the detector.
Ionization Laser Concept

IoLaser System injects tracks with known trajectories into TPC Active Volume.
Ionization Laser Calibration Overview

- IoLaser System Injects linear tracks of known trajectory into TPC
- Signals are distorted by non-uniformities in the TPC’s drift field
- Tracks are reconstructed under the assumption of field uniformity
- With the difference between the True trajectory and the Reconstructed trajectory, we can discern these non-uniformities!
Laser Measurements

The goals for IoLaser as a calibration & diagnostic tool are broad. IoLaser enables a suite of detector physics measurements:

- E-field non-uniformity
- Drift velocity
- Wire response uniformity

We will also explore:

- Electron recombination
- LAr purity measurements

MicroBooNE successfully deployed an IoLaser system and performed calibration measurements:
[MicroBooNE collab JINST 15 (2020) 07, P07010]
Simulation Introduction

Using **LArSoft**, a cross-collaboration software tool for physics simulations in Liquid Argon Detectors, muons are used to emulate laser tracks with scattering and decay physics removed to ensure track linearity.

Tracks:

- Distorted based on model data for charge accumulation.
- Reconstructed with assumption of uniformity
- Corrections are derived by comparing this to the known track geometry!
Methodological Challenges

Naive Method - Closest Point Projection

- Problem: Introduces track angle dependency
- Solution: Overlapping Laser Coverage
  - Iterative Mixing of data from two laser systems

An illustration of track-angle-dependence [MICROBOONE-NOTE-1055-PUB]
Drift Field Extraction

Regions with poor track coverage require extending the available data.

- **Delaunay triangulation:**
  - Decide which points are relevant
- **Barycentric weighting:**
  - Interpolate between them.
Summary + Next Steps

IoLaser can help overcome DUNE’s calibration challenges by injecting tracks with known trajectories into DUNE, providing a robust suite of detector measurements.

Both IoLaser’s hardware and this analysis is in a state of rapid development, with upcoming physics tests in ProtoDUNE-HD later this year.
Neutrino Science Goals in DUNE

Neutrino Oscillations:
Could leptonic Charge-Parity (CP) violation be the reason that the universe is made of matter rather than antimatter? What is the order of neutrino masses?

Nucleon Decay:
DUNE can search for signs of proton decay. This could reveal a relation between the stability of matter and the Grand Unification of forces.

Supernova Neutrinos:
DUNE’s observation of thousands of neutrinos from a core-collapse supernova in the Milky Way would allow us to peer inside a newly-formed neutron star and potentially witness the birth of a black hole.

For More on these goals, visit: DUNEScience.org