Ionization Laser Calibration for the DUNE Time Projection Chamber

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(On behalf of DUNE Collaboration)
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Introduction: DUNE

The Deep Underground Neutrino Experiment (DUNE) is a next-generation, liquid argon time projection chamber (LArTPC) neutrino experiment - the largest of its kind.

- Near detector will be located at Fermilab
- Far detector will be located at the Sanford Underground Research Facility in South Dakota

DUNE Physics Goals

• DUNE is designed to address a large spectrum of physics goals

By exploring neutrino oscillations, DUNE can search for leptonic charge-parity (CP) violation, a potential reason there is more matter than antimatter in the universe. It will also allow us to measure the neutrino mass hierarchy.

DUNE can search for signs of proton decay, and other BSM physics processes.

Neutrinos produced from neutron star or black hole formation can be detected - allowing insight into the dynamics of these processes.

[4] “What is the neutrino mass hierarchy?” Hyper-Kamiokande
[5] “The supernova that keeps on giving” Symmetry Magazine
LArTPC experiments, particularly surface detectors, can utilize cosmic ray muons to calibrate the detector.

DUNE's FD will be located ~1,500m underground (few muons).

Other calibration sources are required.

DUNE will utilize an ionization laser (IoLaser) calibration system in order to meet stringent systematic requirements (1-2%).

- The Ionization Laser System will create tracks with known origin and direction in the TPC Volume.
- Two periscope designs, interior and exterior to detector field cage, will be installed in DUNE.
  - Overlapping coverage reduces uncertainty in reconstruction map.
Periscope Images

Looking down the periscope

Looking up the periscope

Periscope assembled in test stand
Interior Field Cage Periscope

★ Designed to penetrate the detector field cage

1. **Rotary stage** allows for rotation of the periscope

2. **Linear translation** stage allows for extension/retraction of the periscope
End Wall Periscope

- Design is external to detector field cage

1. **Rotation stage** allows for rotation of periscope

2. **Rotary translation stage** allows for periscope to move 6 cm, providing coverage around field cage obstacles
Rotary Stage Motion
Both periscope designs use a steerable mirror to provide wide azimuthal coverage.

- UV laser is aimed at fixed mirror at the end of the periscope.
- Laser is reflected onto steerable mirror.
- Linear actuator rod moves rack and gear, steering the mirror and directing the laser.
Steerable Mirror Motion
Beam Conditioning

An intense narrow beam of pure 266 nm (UV) light with a stable energy and profile is needed to ionize the LAr.

- **Harmonic Splitting optics** - purifies beam composition
- **Attenuator** - controls beam energy
- **Apertures** - truncates beam width
- **Beam Sampler and Energy Meters** - monitors laser energy
Laser Alignment

The UV laser must be aligned with optical equipment in order to maintain a consistent beam profile and direction.

- Detector must remain sealed, alignment cannot be visually validated
- Camera is placed near viewport at the top of the periscope, aimed at the mirror
- Will minimize reflections and deviations from alignment laser to align UV laser
Summary & Next Steps

• Periscopes assembled and successfully tested in air at Los Alamos National Lab

• Testing with class-IV laser beams and in LAr will start this month

• 700-ton LArTPC prototypes at CERN (ProtoDUNE), are used to validate technologies for DUNE

• Periscopes will be installed in the ProtoDUNE Horizontal Drift Module for Phase 2 operations in August to test technical and physics performance
Thank you!
References


Back-up Slides
Full System Tests at LANL

- Laser Tent contains optical equipment where laser will safely be contained and controlled from
  - Also contains computers to control laser and motors that operate periscope
- Periscopes mounted on test stand and will be fed into dewar below for cryogenic tests
Calibration Requirements [6]

- DUNE requires precise energy reconstruction for physics goals
  - For $O(\text{GeV})$ events: $\sim 1$-$2\%$

- Energy response parameters are given by:
  $$E'_{\text{rec}} = E_{\text{rec}} \times (p_0 + p_1 \sqrt{E_{\text{rec}}} + \frac{p_2}{\sqrt{E_{\text{rec}}}})$$

- Different response uncertainties for various particles:

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