Ionization Laser Calibration System for DUNE

Darcy Newmark - Los Alamos National Laboratory
On behalf of the DUNE collaboration
Deep Underground Neutrino Experiment (DUNE)

- DUNE consists of a near and far detector and an intense muon neutrino beam from Fermilab
- Next generation long-baseline experiment
- Construction will start in 2024 and neutrino data taking expected in late 2020s

Physics Goals:
- Understand neutrino mass hierarchy
- Measure charge-parity violating phase ($\delta_{cp}$)
- Supernova neutrino burst searches and proton decay
- Other Beyond Standard Model physics
Far Detector at SURF

- Far detector will include 4 liquid argon time projection chamber (LArTPC) detectors with 70-kt total mass
- Largest LArTPC detectors ever to be built

Diagram showing the layout of the detectors with dimensions: 18 m x 19 m x 66 m, and a 17 kton module (10 kton active volume).
Liquid Argon Time Projection Chamber (LArTPC)

https://www.youtube.com/watch?v=R5G1_hW0ZUA
Challenges in Calibrating DUNE

Understanding the response of the detector is important to achieve the needed energy scale and resolution:

- GeV-scale oscillation physics: energy scale uncertainty < 2% for leptons and < 5% for hadrons
- MeV-scale low E physics (e.g. supernovae, solar): energy resolutions ~20-30%

- Challenge due to huge size
- Segmented detector: 4 drift volumes, many thousands of channels/wires etc.
- Low cosmic ray muon rates due to deep underground location
Calibration Systems

- Three calibration systems planned for DUNE - ionization laser system is the primary one
- Laser calibration system will create straight and well-defined ionization tracks for calibration
- Independent fine grained measurement of detector parameters
  - eg: drift velocity and electric field distortions
- Can help diagnose detector issues such as anode/cathode tilts
Laser Ionization of LAr

- 266nm (equivalent to $E_{\gamma} = 4.67$ eV) laser light ionizes LAr through 2-photon excitation followed by single-photon ionization.

- Electron yield goes with square of photon intensity (in typical regime).

Laser Ionization System Overview

1. Class IV laser
   - High intensity (60 mJ) UV laser

2. Optical bench
   - Modulate intensity and remove lower harmonics (e.g., visible and infrared)

3. Periscope
   - Direct and rotate laser beam into LAr detector
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## Laser and Optical Bench

<table>
<thead>
<tr>
<th>Component</th>
<th>Purpose</th>
</tr>
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<tbody>
<tr>
<td>Surelite I10 Nd:YAG class IV Laser</td>
<td>Emits beam of 266 nm, 532 nm, and 1064 nm light</td>
</tr>
<tr>
<td>Low power visible laser</td>
<td>For alignment</td>
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<tr>
<td>Beam splitter mirrors</td>
<td>Separate 266 nm light from other frequencies</td>
</tr>
<tr>
<td>Dual band mirror</td>
<td>Transfer both 266 nm light and 532 nm light</td>
</tr>
<tr>
<td>Attenuator</td>
<td>Control laser energy and rotate linear polarization of beam</td>
</tr>
<tr>
<td>Iris</td>
<td>Reduce beam diameter</td>
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</tbody>
</table>
Optical Bench at LANL
Optical Bench at LANL

From laser bench

To Beam dump

Attenuator
Preliminary Results and Next Steps for Optical Bench

- Characterized first laser, currently testing second laser
- Characterized other optical components such as attenuator, mirrors, etc.
- Isolated pure beam of 266nm light
- Moving to vertical setup towards a more compact design
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Optical Feedthrough and Periscope

- Two periscope designs to maximize coverage of the detector

- One for the central region (penetrates the TPC top field cage and includes a retraction device for safety)

- One for the end-wall region (send light from outside the field cage using a dual rotary motion)

- Periscope designs final, procurement and fabrication ongoing at LANL and LIP (Portugal)
Leak Testing

- Periscope includes a number of seals to the cryostat which need to be tested for leak tightness
- Helium leak testing of components (e.g. rotary stages, flange view ports) ongoing at LANL and LIP (Portugal)
- Leak rate specification for DUNE/ProtoDUNE is $10^{-6}$ mbar·l/s for the whole cryostat and $10^{-8}$ mbar·l/s for local leaks
  - RNN-600 rotary stage is within range; leaks on the order of $10^{-9}$ mbar·l/s
  - MDC viewport flanges are both within range; leaks on from $10^{-9}$ to $10^{-10}$ mbar·l/s
Summary and Next Steps

- Developing laser ionization calibration system for fine grained measurements of detector parameters to understand + diagnose detector behavior
- Testing + finalizing design of optical components and periscope feed through
- Will soon be testing laser, optical bench, and periscope on cryogenic test stand at LANL
- Two full prototype laser systems will be built and installed in DUNE’s 419-ton (active) Prototype detector (ProtoDUNE) at CERN in early 2022
Thank you for listening!