Ionization Laser Calibration for the DUNE Time Projection Chamber

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Fermilab New Perspectives

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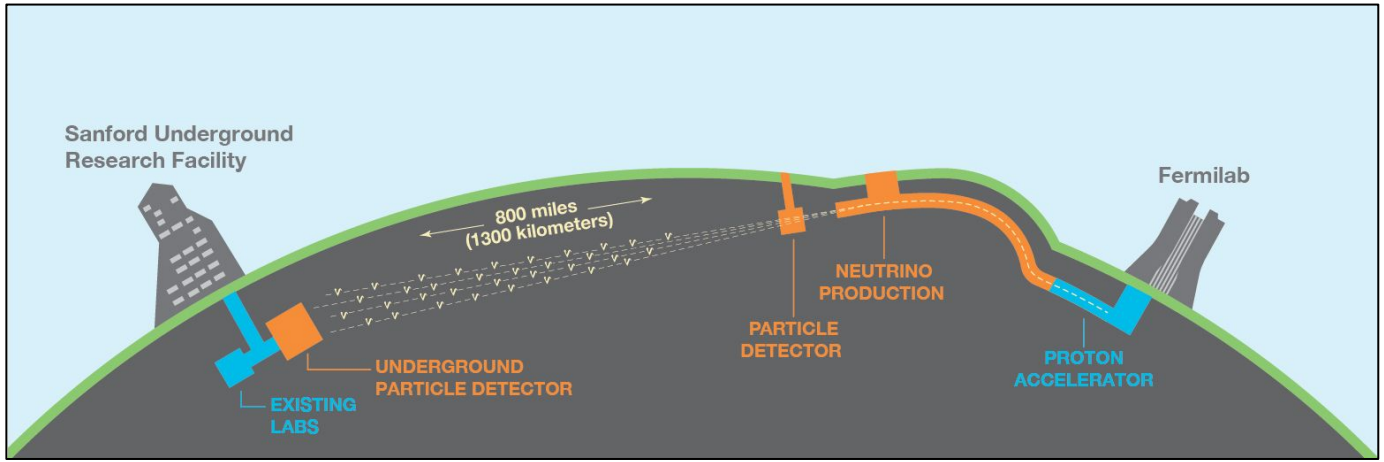
Introduction: DUNE

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

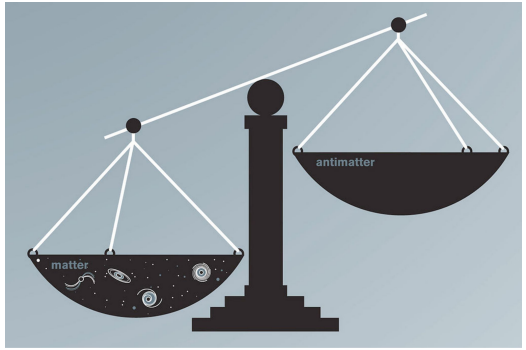


[1] "An International Experiment for Neutrino Science" *Deep Underground Neutrino Experiment*, http://www.dunescience.org/.

DUNE Physics Goals

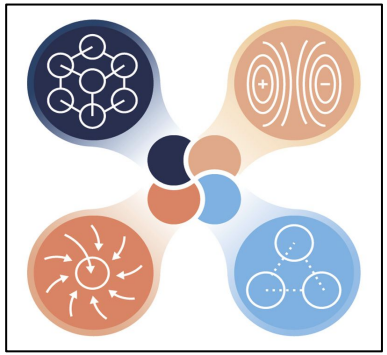
For More on these goals, visit: DUNEScience.org

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



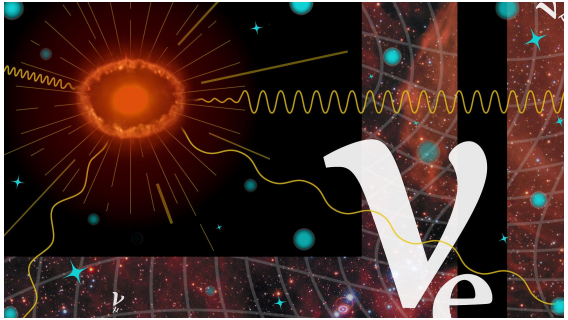
Neutrino Oscillations [3] [4]

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 is to measure the *neutrino mass hierarchy.*



Nucleon Decay [1]

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



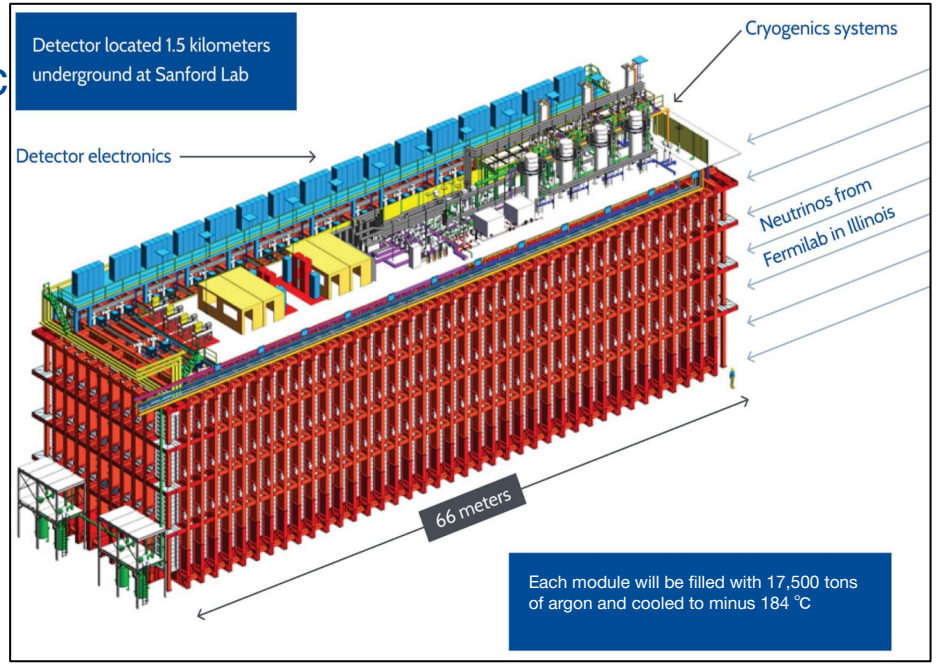
Supernovae [5]

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

[1] "An International Experiment for Neutrino Science"
[3] "CP Violation" *Symmetry Magazine*
[4] "What is the neutrino mass hierarchy?" *Hyper-Kamiokande*
[5] "The supernova that keeps on giving" *Symmetry Magazine*

DUNE Far Detector

- 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

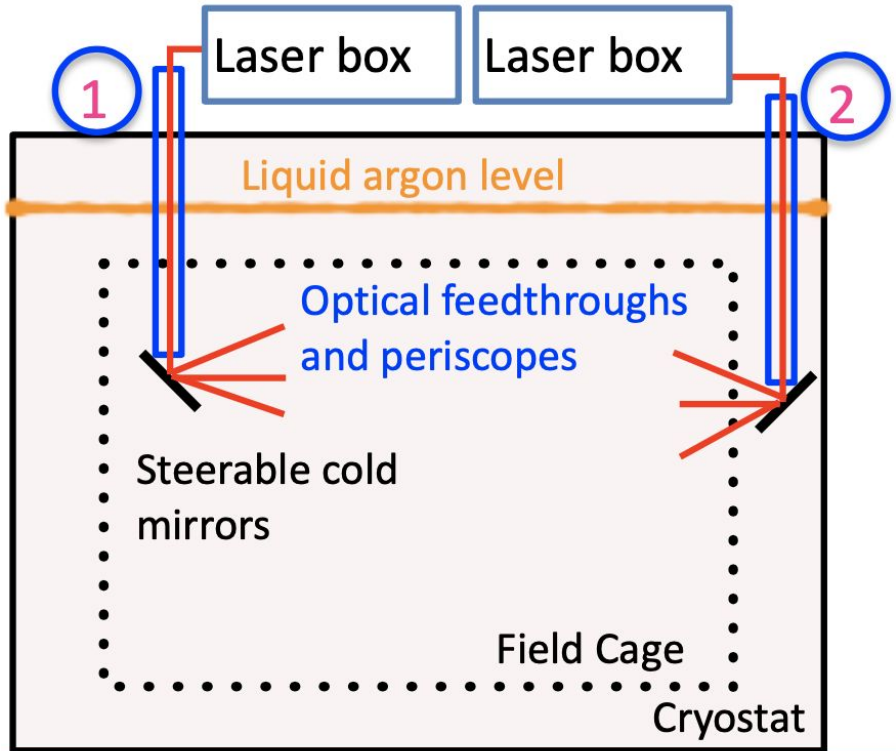


[2] B. Abi, R. Acciarri, & et. al.. (2020). Deep Underground Neutrino Experiment (DUNE), Far Detector Technical Design Report, Volume IV: Far Detector Single-phase Technology.

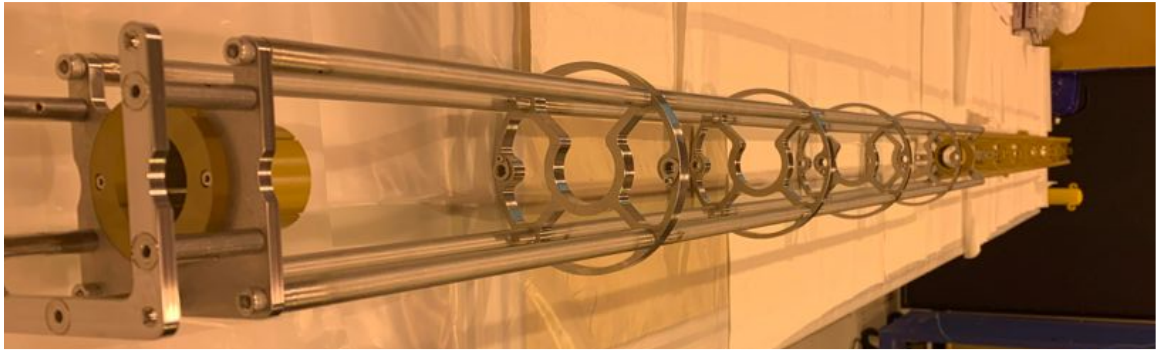
Ionization Laser System

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

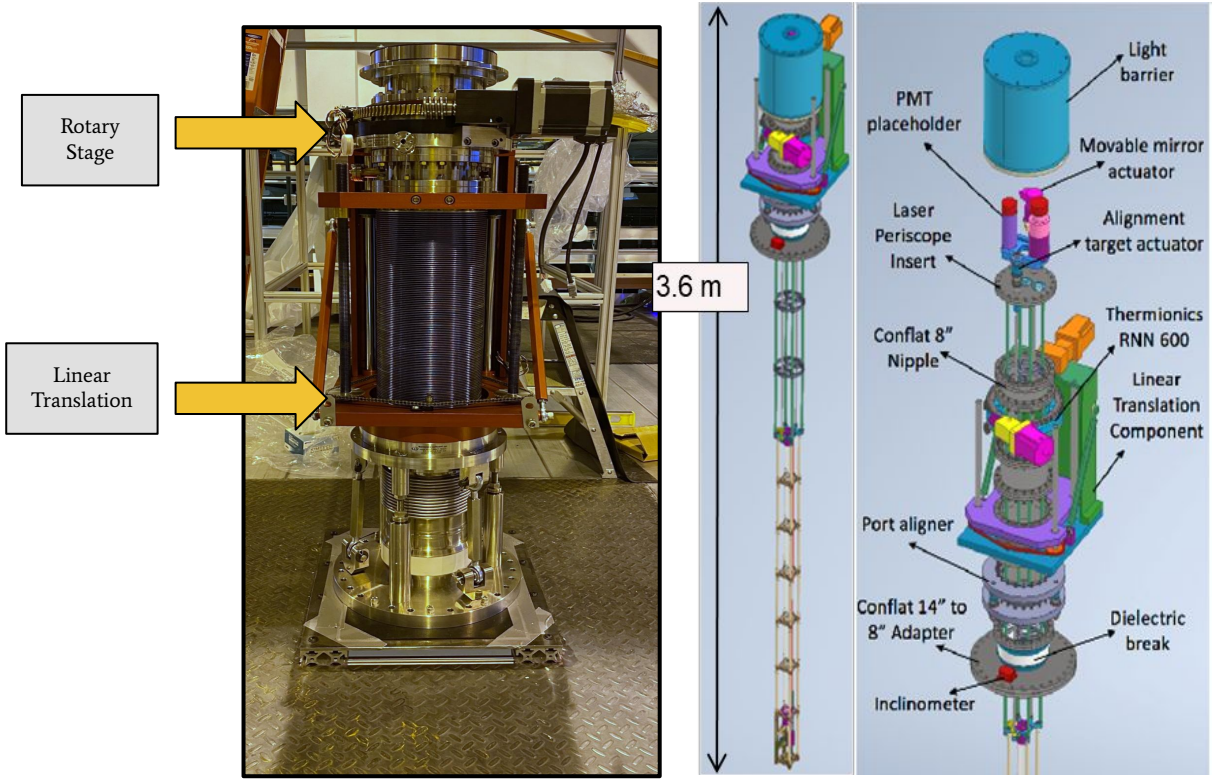
Periscope assembled in test stand

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



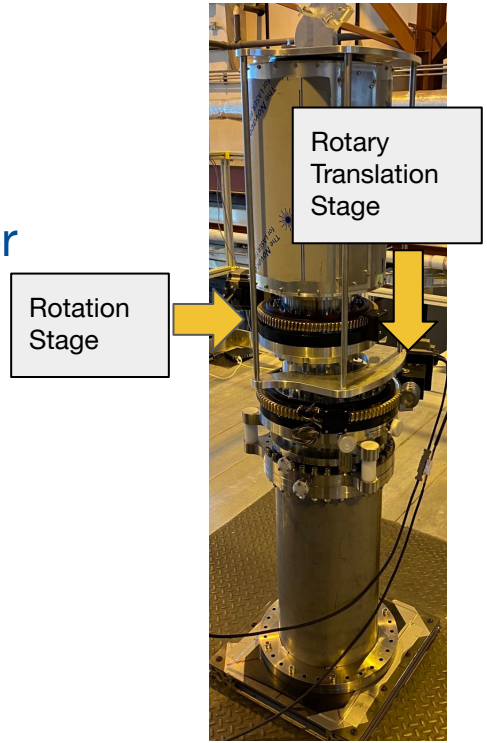
Periscope 1 (Interior)

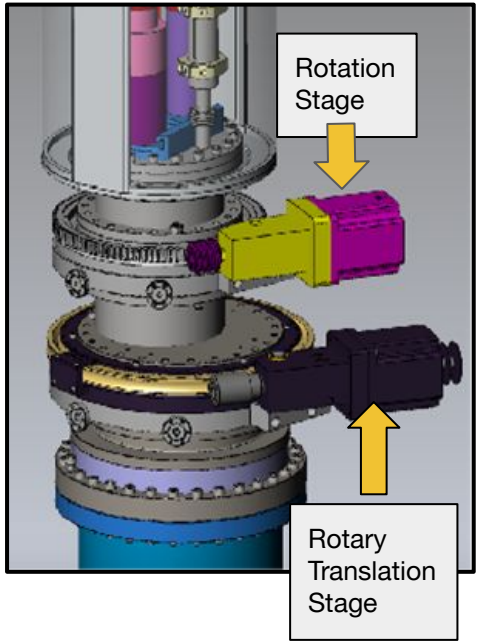
End Wall Periscope

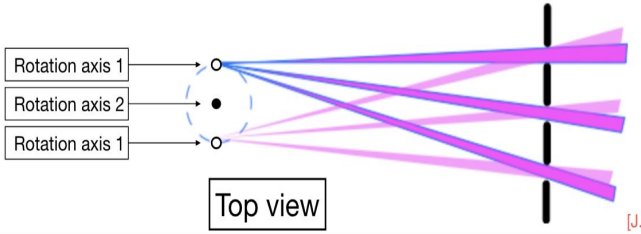
★ Design is external to detector field cage

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







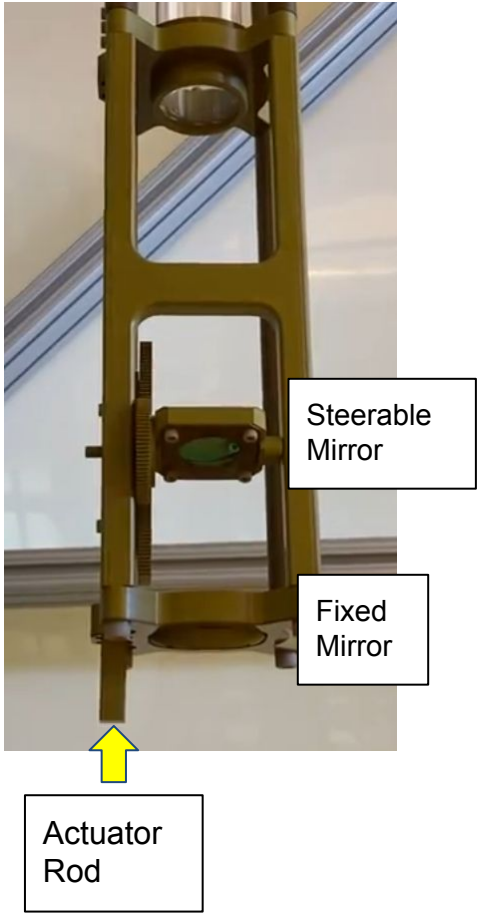
[J. Maneira, LIP]

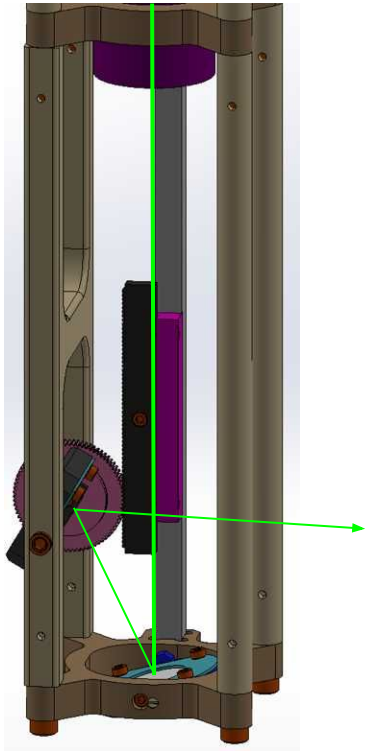
Rotary Stage Motion

Steerable Mirror

★ 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 on to steerable mirror
- Linear actuator rod moves rack and gear, steering the mirror and directing the laser



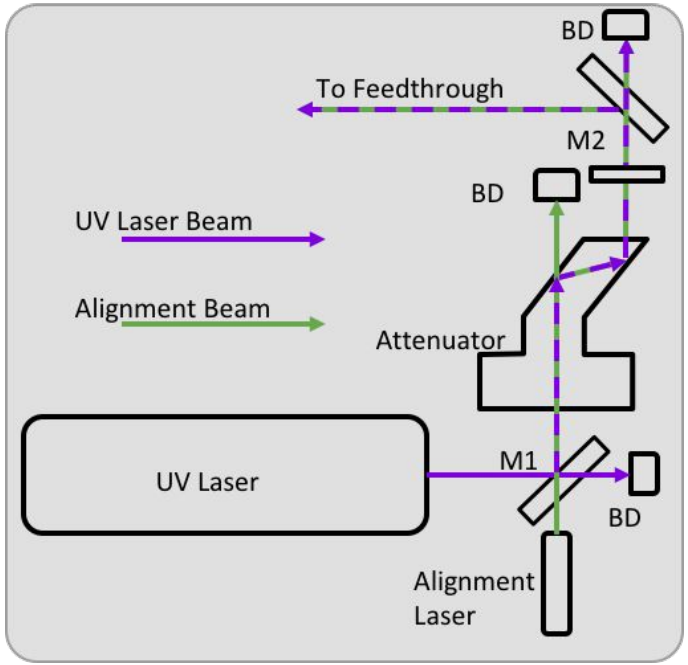


Steerable Mirror Motion

Beam Conditioning

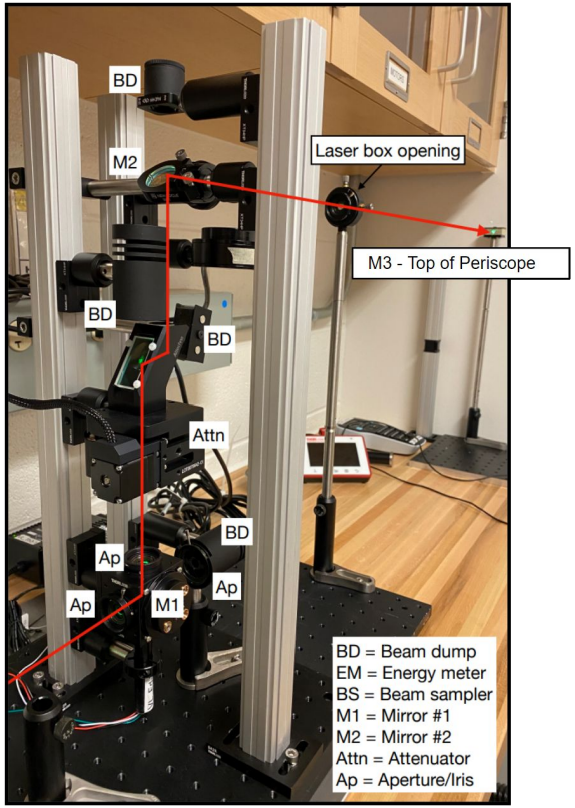
An intense narrow beam of pure 266 nm (UV) light with a stable energy and profile is needed to ionize the LAr.

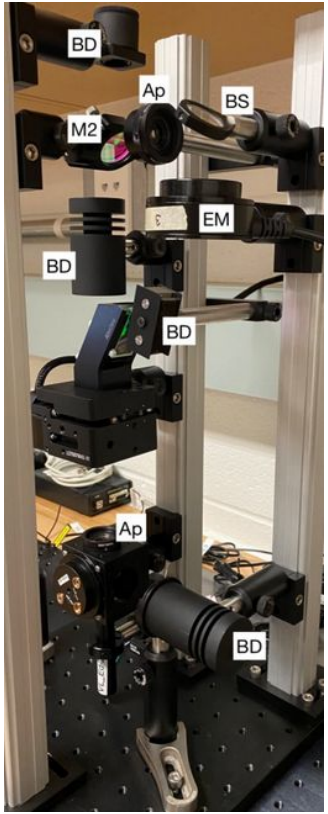
- Harmonic Splitting optics - purifies beam composition
- Attenuator - controls beam energy
- Apertures - truncates beam width
- Beam Sampler and Energy Meters - monitors laser energy

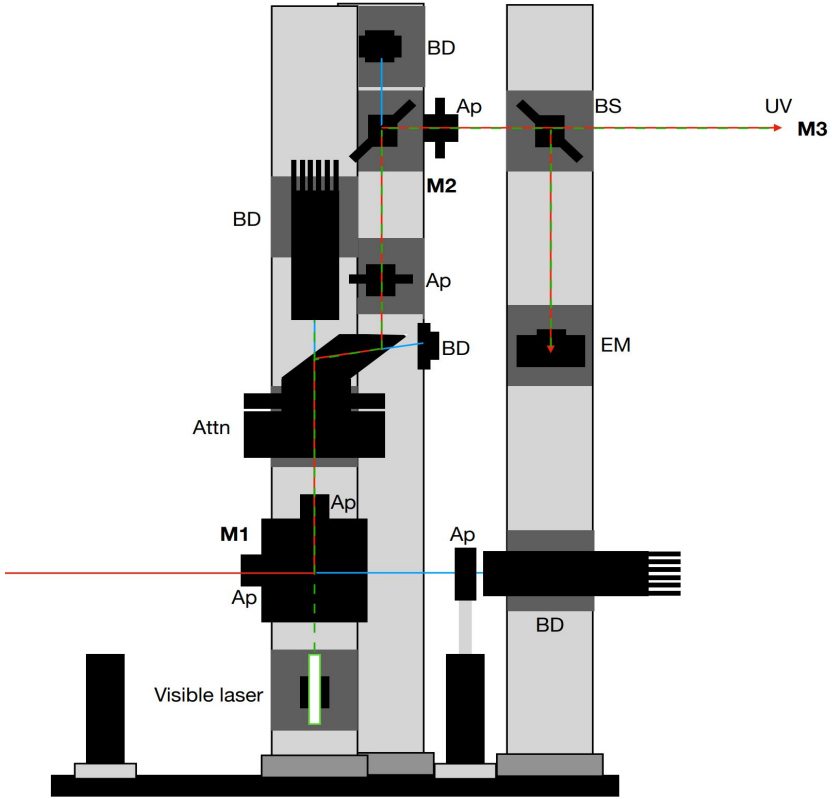


BD = Beam Dump
M1 = Mirror 1
M2 = Mirror 2

Optical Setup Photos



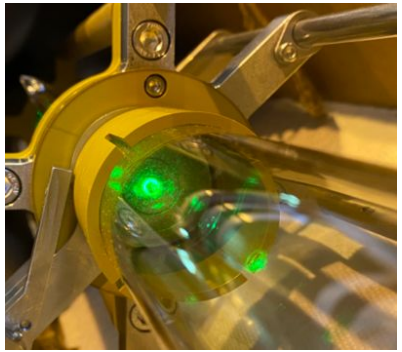




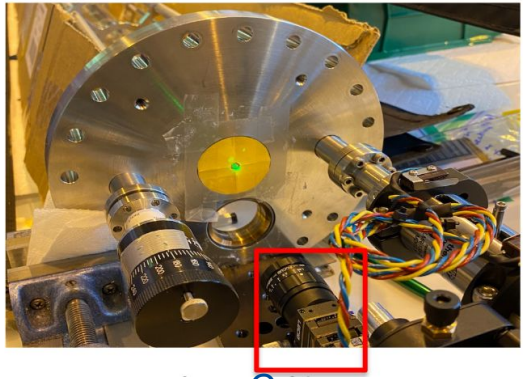
Laser Alignment

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



Visible laser aligned with middle target

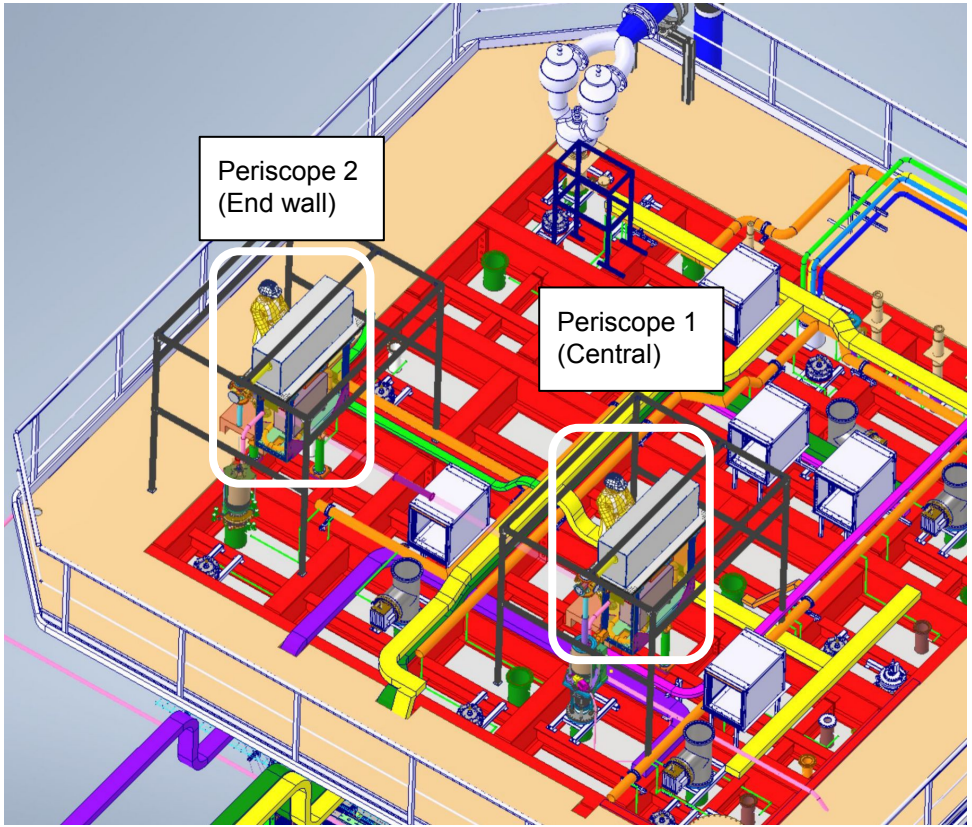


Camera

Not-aligned → Aligned

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 (ProtoDUNEs), 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

[1] “An international experiment for neutrino science” *Deep Underground Neutrino Experiment*, http://www.dunescience.org/.

[2] B. Abi, R. Acciarri, & et. al.. (2020). Deep Underground Neutrino Experiment (DUNE), Far Detector Technical Design Report, Volume IV: Far Detector Single-phase Technology. *4*

[3] “CP Violation” *Symmetry Magazine*, 1 Oct. 2005, https://www.symmetrymagazine.org/article/october-2005/explain-it-in-60-seconds

[4] “What is the neutrino mass hierarchy?” *Hyper-Kamiokande*, http://www.hyper-k.org/en/physics/phys-hierarchy.html

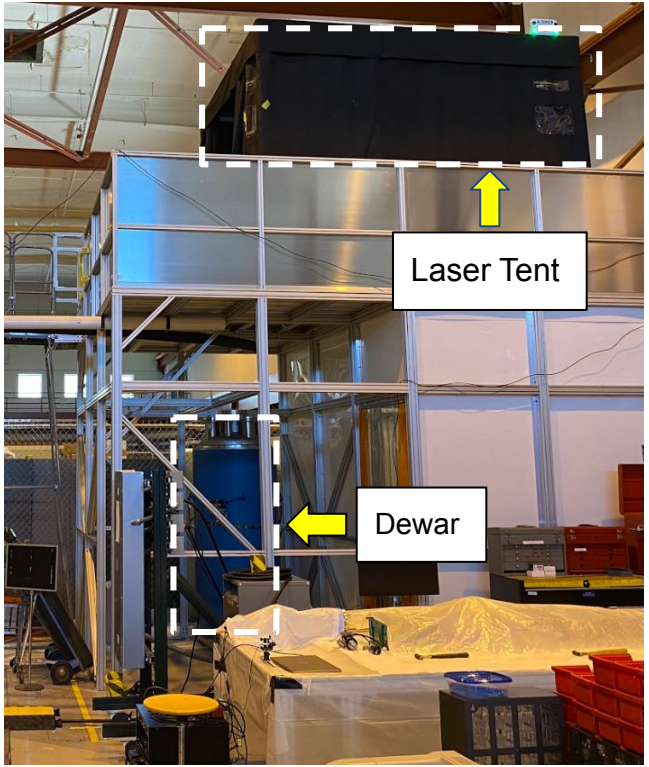
[5] “The supernova that keeps on giving” *Symmetry Magazine* 28 Apr. 2020, https://www.symmetrymagazine.org/article/the-supernova-that-keeps-on-giving-sn1987a

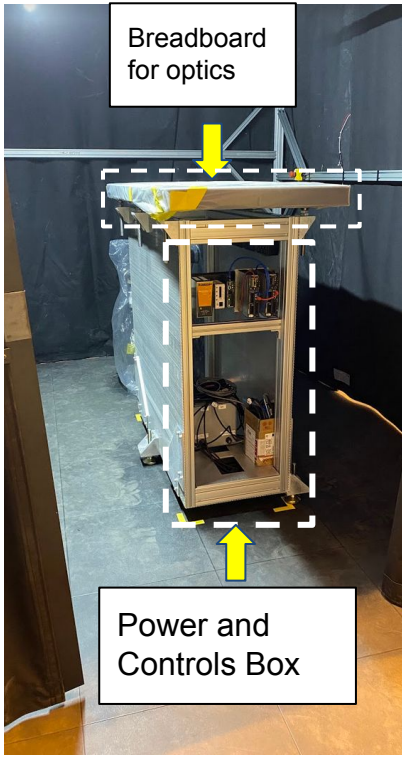
[6] B. Abi, R. Acciarri, & et. al.. (2020). Deep Underground Neutrino Experiment (DUNE), Far Detector Technical Design Report, Volume IV: Far Detector Single-phase Technology. *2*

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*(GeV) events: ~1-2%

- Energy response parameters are given by:

$$E'_{rec} = E_{rec} \times (p_0 + p_1\sqrt{E_{rec}} + \frac{p_2}{\sqrt{E_{rec}}})$$

- Different response uncertainties for various particles:

Particle	p_0	p_1	p_2
all (except muons)	2%	1%	2%
μ (range)	2%	2%	2%
μ (curvature)	1%	1%	1%
p, $\pi^{\pm}$	5%	5%	5%
e, γ, π^0	2.5%	2.5%	2.5%
n	20%	30%	30%