Photon Detection System Calibration for DUNE

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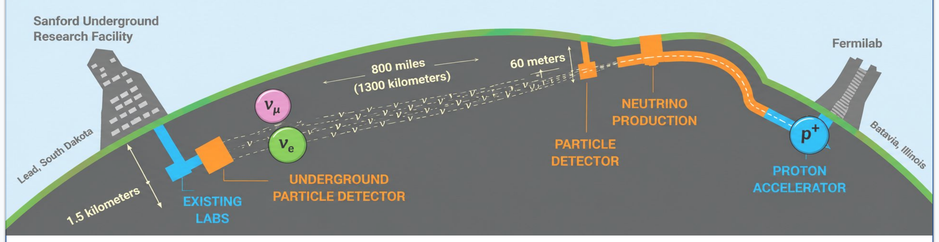
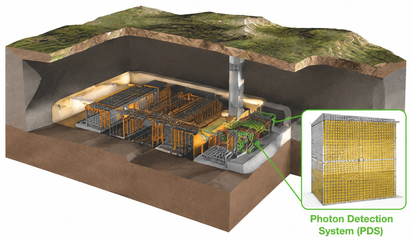
SOUTH DAKOTA MINES

DEEP UNDERGROUND NEUTRINO EXPERIMENT

Deep Underground Neutrino Experiment (DUNE)



Far Detector Facility

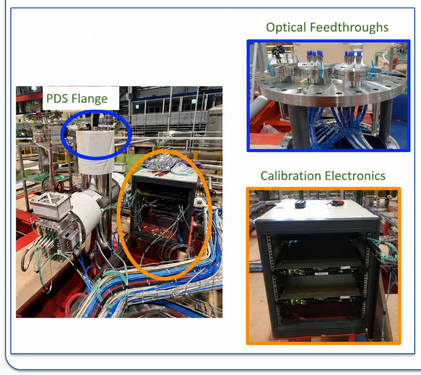


Near Detector (ND) and Far Detector (FD)

- DUNE will use a near detector and a far detector at the Sanford Underground Research Facility (SURF) in South Dakota to measure neutrino oscillations.
- The ND will be located approximately 60 m underground at Fermilab while the FD will be located ~1.5 km underground and ~1,300 km from the ND.
- Each of the four FD modules will contain approximately 17kt of liquid argon.
- DUNE goals include Supernova physics, neutrino oscillations, CPV, MO and searches BSM.

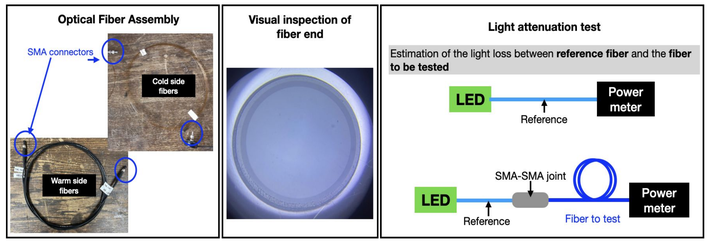
UV Light Calibration System (UV LCS)

- **Goal:** A system that uniformly illuminates the surface of the DUNE [1] photon detection system (PDS) X-ARAPUCAs [2], calibrates gain, verifies time resolution, and can monitor the stability of the PDS components (i.e. pTP layer, lightguide, and SiPM).
- System electronics developed by Argonne National Laboratory is interfaced to timing/DAQ, transmits UV-light at selected pulse width (4 – 80 ns), repetition rates (1 – 1000 Hz), in a single or double pulse modes, independently for 12 channels.
- Successful installation, commissioning, and operation of the UV LCS in DUNE prototypes located at CERN.

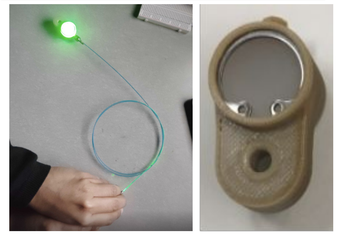


Optical Fibers and Light Diffusers

- Ultraviolet-grade optical fibers are used to deliver calibration light into the detector.
- The amount of transmitted light decreases with fiber length and depends on wavelength.
- Fiber transmission is measured relative to a reference fiber to quantify attenuation.
- Developed QA/QC procedures to ensure consistent optical performance.



- Diffusers are used to spread UV light and illuminate large detector areas uniformly.
- UV-grade fused-silica diffuser elements are used to ensure high transmission at short wavelengths
- Diffuser housings were designed and 3D-printed in the lab using PEEK for cryogenic compatibility.



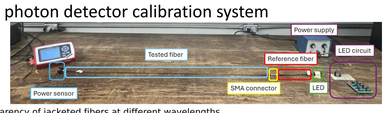
Characterization of UV Optical Components for Photon Detector Calibration in Liquid Argon TPCs

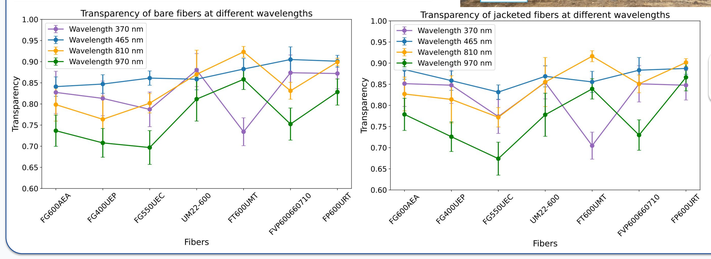
JINST 21 P06013 (Published in June 2026)

Light transmission

Fiber Tag (Supplier)	Core Diameter [μm]	Cladding Diameter [μm]	Coating Diameter [μm]	Coating Material	Operating Temperature [°C]	Numerical Aperture	Operating Wavelength [nm]
FG600AEA (Thorlabs)	600 ± 12	660 ± 6	750 ± 20	Acrylate	−40 to 85	0.22 ± 0.02	180 to 1200
FG400UEP (Thorlabs)	400 ± 8	440 ± 9	480 ± 7	Polyimide	−65 to 300	0.22 ± 0.02	400 to 2400 (Low OH) 250 to 1200 (High OH)
FG550UEC (Thorlabs)	550 ± 19	600 ± 10	630 ± 10	TECS Hard Fluoropolymer	−60 to 125	0.22 ± 0.02	400 to 2200 (Low OH) 250 to 1200 (High OH)
UM22-660 (Thorlabs)	600 ± 10	660 ± 10	710 ± 10	Polyimide	−65 to 300	0.22 ± 0.02	180 to 850
FT600UMT (Thorlabs)	600 ± 10	630 ± 10	1040 ± 10	Tefzel	−65 to 135	0.39	400 to 2100 (Low OH) 300 to 1200 (High OH)
FVP600660710 (Molex)	600 ± 10	660 ± 10	710 ± 10	Polyimide	−65 to 300	0.22 ± 0.02	180 to 1150 (High OH)
FP600URT (Thorlabs)	600 ± 10	630 ± 10	1040 ± 30	Tefzel	−40 to 85	0.50	300 to 1200 (High OH)

- **14 multimode fused-silica optical fibers** (7 bare and 7 jacketed) were characterized.
- **Light transmission (transparency)** was measured at 370, 465, 810, and 970 nm to identify optical fibers suitable for reliable UV light delivery in DUNE photon detector calibration system

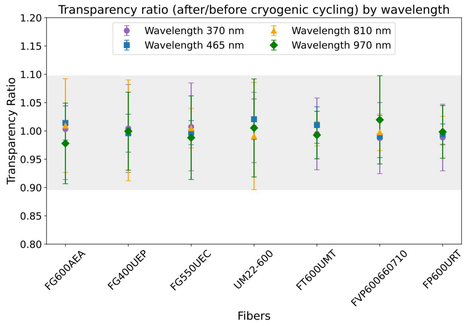




Transparency equation

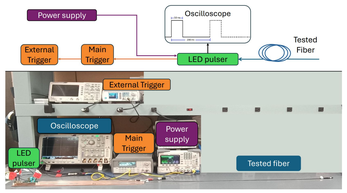
$$T = \frac{P_{\text{tested fiber}}}{P_{\text{reference}}}$$

Optical fiber thermal cycling in cryogenic conditions



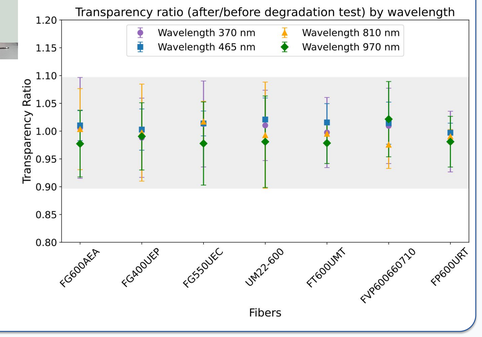
- 30 cryogenic thermal cycles were performed to simulate thermal stresses on optical fibers.
- Transparency ratios remained consistent with unity across all tested wavelengths and fiber types.
- The results indicate that the tested fibers maintain stable optical performance after repeated cryogenic exposure.

Test of potential fiber degradation caused by a long UV light exposure

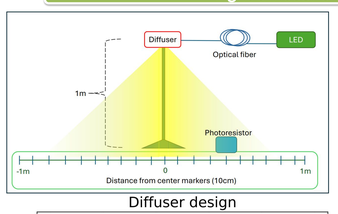


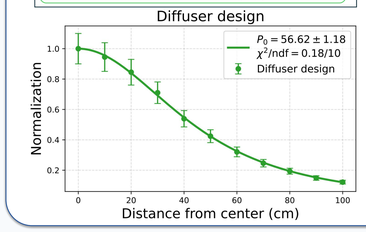
- Optical fibers were exposed to 275 nm UV light levels corresponding to extended detector operation.
- Transparency ratios remained consistent with unity across all tested fibers types and wavelengths.
- No statistically significant UV-induced degradation was observed

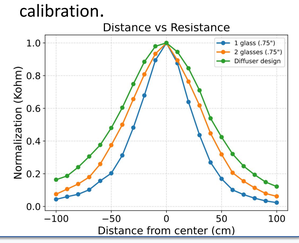
- These results demonstrate the viability of long-term use of the tested fibers in DUNE photon detector calibration system.



Light diffuser characterization

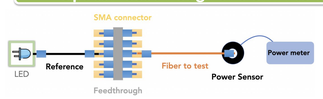


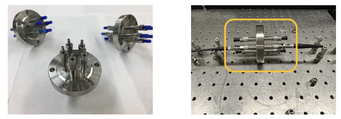




- Compact, palm sized light diffuser housing 3D printed in PEEK was designed.
- The diffuser design produced a near-Lambertian light distribution, providing broad and uniform illumination for photon detector calibration.

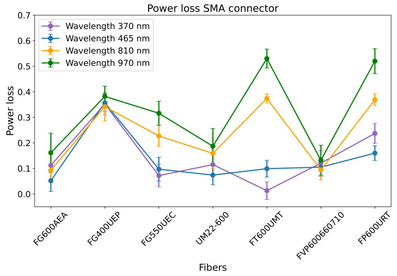
Optical feedthrough and SMA-to-SMA connector interface loss





- Optical feedthroughs allow the interface of the warm and cryogenic regions of the detector through SMA-terminated fiber interfaces.
- Connector losses were quantified by isolating the contribution of a single SMA-to-SMA interface from full-chain transmission measurements.

- SMA connectors were identified as a significant and wavelength-dependent source of optical loss that must be considered in light calibration system design.



Summary

- No statistically significant optical degradation was observed after cryogenic thermal cycling.
- No measurable UV-induced degradation was observed after prolonged light exposure.
- The customized diffuser achieved a near-Lambertian light distribution suitable for uniform detector illumination.
- SMA-to-SMA connector interfaces were found to be a major source of wavelength-dependent optical loss.
- Successful deployment of UV LCS in DUNE prototypes at CERN established the path for the deployment of the system in the DUNE Far detectors.

References

[1] DUNE Far Detector Technical Design Report, JINST 15 T08008.
[2] The X-ARAPUCA: an improvement of the ARAPUCA device, JINST 13 C04026
[3] Characterization of UV optical components for photon detector calibration in liquid argon TPCs, JINST 21 P06013

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