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Power Over Fiber for the DUNE Vertical Drift PDS

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The DUNE experiment

The Deep Underground Neutrino Experiment (DUNE) is a next generation long-baseline neutrino experiment.

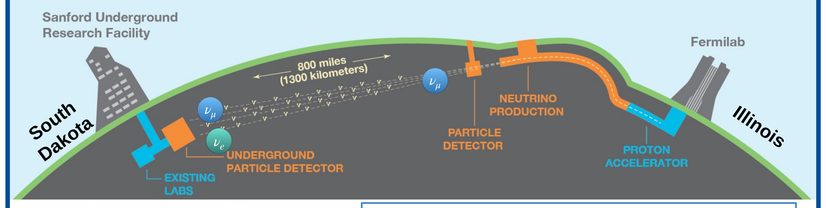
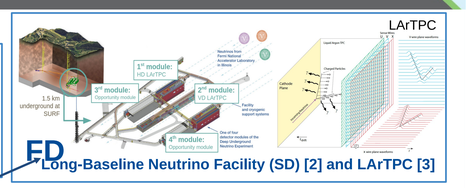


Diagram of DUNE experiment [1]

Near Detector (ND)

Located ~60 m underground at Fermilab



Long-Baseline Neutrino Facility (SD) [2] and LArTPC [3]

Far Detector (FD)

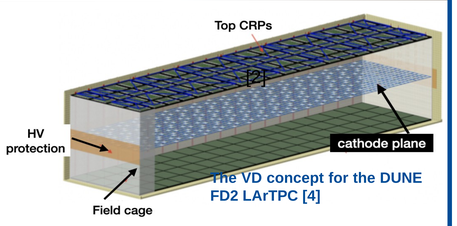
Located ~1.5 km underground and ~1,300 km from the ND to the SURF in South Dakota. DUNE consists of four LArTPC modules, each with a capacity of 17 kt.

Physics goals

- **Neutrino Oscillations**: Measurement of the CP violating phase and determination of the neutrino mass ordering
- **Supernova Physics**: Observation of neutrinos from core collapse supernovae
- **BSM Physics**: Search for nucleon decay channels and other BSM physics

The FD2 and Motivation

The second module (FD2) utilizes a vertical drift cathode arrangement that includes photon detectors (x-ARAPUCAs) embedded in the cathode at HV (~300kV).



The VD concept for the DUNE FD2 LArTPC [4]

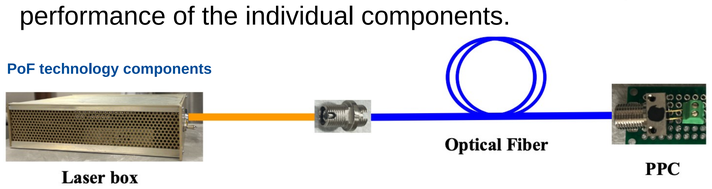
Because of the HV involved, conventional copper cables are not feasible for powering the PDS. Instead, Power over Fiber (PoF) has been proposed, which offers superior noise performance and immunity to EMF.

PoF Technology

A PoF system is composed of three components: an infrared **laser source**, an **optical fiber** to carry the optical power, and a photovoltaic power converter (**PPC**) to convert optical power into electrical power:

- A novel application of PoF technology for a particle physics experiment operating at cryogenic temperatures.
- Detailed R&D has been conducted to validate and optimize the performance of the individual components.

PoF technology components

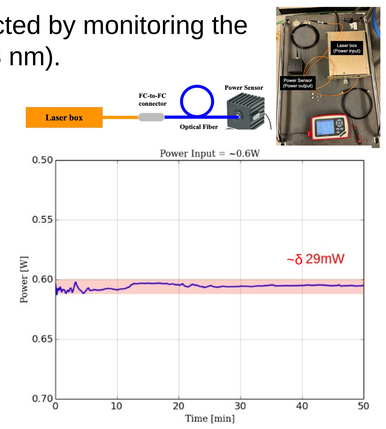


Laser Stability

A power stability test was conducted by monitoring the output power of the IR laser (808 nm).

This test, performed over an extended time period, allowed us to determine the power stability of the laser:

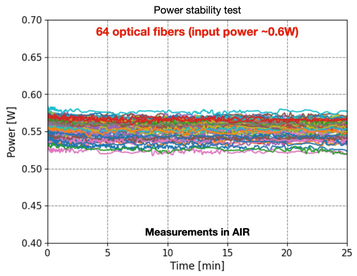
- Power fluctuations are not greater than 30mW (less than 3% wrt to the input power of 1W).
- No significant change in the output voltage of the PPC due to fluctuations in the IR laser's output power.

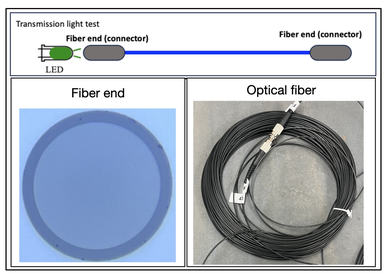


Optical Fiber QA/QC

In order to guarantee the effectiveness of optical fibers (62.5 um core) for PoF applications, we have established a QA/QC procedure.

1. Inspect fiber ends and jacket surface
2. Measure light transmission to ensure fiber continuity
3. Power stability test to ensure power transmission through the fiber





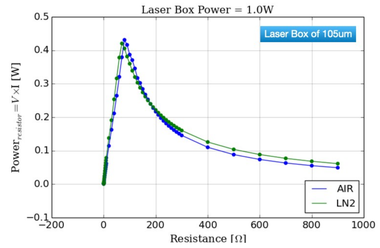
PPC Testing

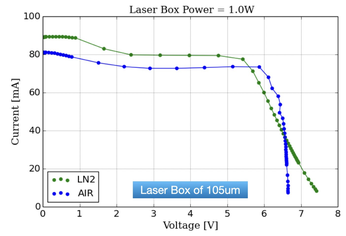
The PPC converts optical power (input power) into electrical power. The ability of the PPC to absorb the incident irradiance is correlated to the power conversion efficiency.

- PPCs are rated to operate effectively between -40 to 80°C.
- Load-resistor test let us to measure I-V curves and determine the PPC (Si) efficiency in AIR and LN2.

Table 1: Power output for laser box 105-µm core

PPC type	Input Power [W]	Current [mA]	Voltage [V]	Max output power [W]	Efficiency [%]
Si warm	1	73.4	5.87	0.431	43.1%
Si cold	1	79.2	5.42	0.429	42.9%

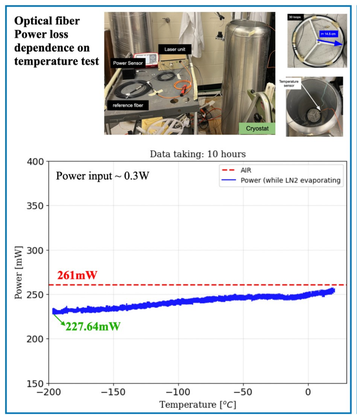


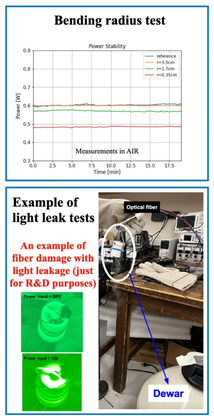


Optimization and Validation Testing

Almost three years of conducting tests and engaging in close collaboration with industry partners, we have optimized and validated various aspects of the PoF components:

- Durability in cryogenics was evaluated through thermal cycling test.
- Light leakage and power loss caused by fiber bending and optical fiber jacket contraction at low temperatures.
- Improving power conversion efficiency by employing GaAs PPC

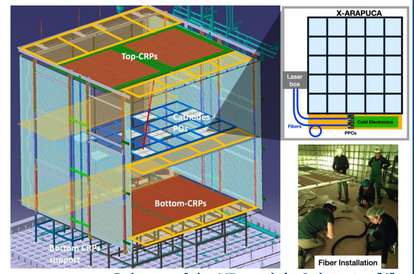




ProtoDUNE VD (Module-0)

After validating and optimizing the PoF components through multiple test stands, the PoF components will be installed, commissioned, and operated in the ongoing ProtoDUNE (Module-0) at CERN.

Goal: PoF will supply electrical power to the active elements in the cold electronics readout and photo-sensors of the PDS, located on the cathode plane, thereby increasing PDS coverage and enhancing energy resolution.



Scheme of the VD module-0 detector [4]

Conclusions and Next Steps

- PoF technology offers a new opportunity for supplying electrical power to devices operating in HV at cryogenic temperatures.
- Multiple tests of the individual components (lasers, fibers, and PPCs) have been performed over a period of ~3 years to validate and optimize this technology.
- Experience acquired with Module-0 will be critical in the application of PoF technology to power the PDS system located on the cathode plane for DUNE FD2.

Acknowledgments:
This work is supported by the U.S. Department of Energy Office of Science.

References:

[1] https://www.dunescience.org
[2] http://neutrinos.ciemat.es/es/dune-es
[3] Abi, Babak, et al. "Volume I. introduction to DUNE." *Journal of instrumentation* 15.08 (2020)
[4] https://ep-news.web.cern.ch/content/dune-prototype-activities-neutrino-platform