R&D of Power Over Fiber in harsh environments and its novel application for the DUNE FD-VD Photon Detection System

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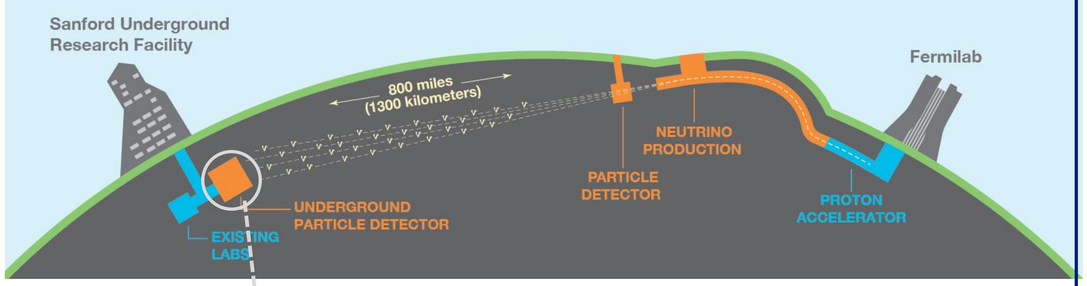
The Deep Underground Neutrino Experiment

Physics Goals: neutrino oscillations, CP violation, supernova physics, proton decay searches, BSM physics

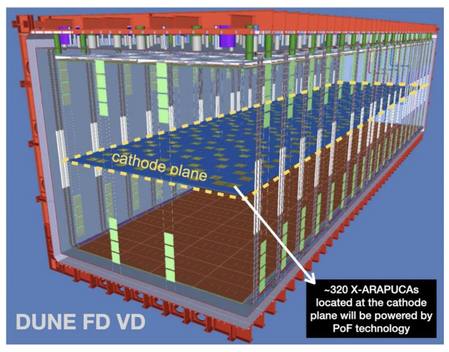


- **Near Detector:** Located ~60m underground at Fermilab.
- **Far Detector:** Located ~1.5 km underground and ~1,300 km from the ND to the SURF in South Dakota. DUNE far detector will utilize 17k kt LArTPC modules.

Far Detector Vertical Drift and Motivation

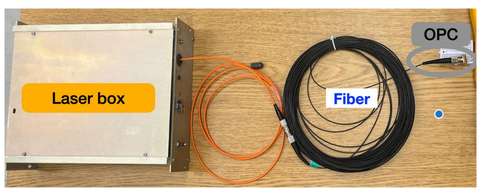
The DUNE FD-VD will utilize a vertical drift cathode arrangement that includes photon detectors (X-ARAPUCAs) embedded in the cathode at HV (~300kV).

Because of the HV involved, conventional copper cables are not feasible for powering the PDS.



Power over Fiber Technology (PoF)

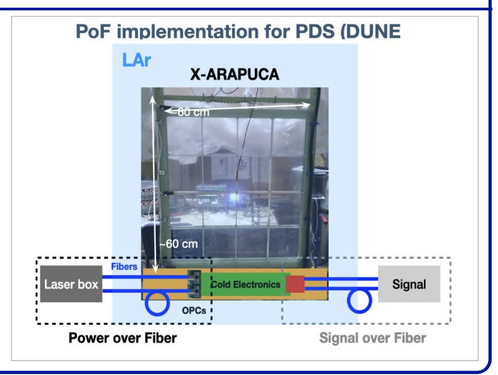
The PoF system is composed of three components: an infrared laser source, optical fibers to carry the optical power, and optical power converter (OPC) to convert optical power into electrical power.



Warm Side PoF challenges:
- Designed to be repaired
- Reduce production cost
- Operational capability & loss budget for Cold-Plus system

Cold Side PoF challenges:
- Designed for reliable operation with a 20-year viability!
- To have redundancy for the system
- Low noise performance
- Ensuring non-contamination of LAr

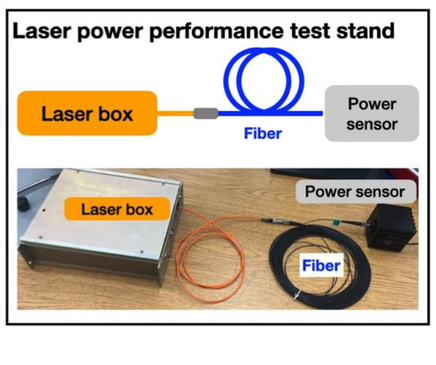
As of today, DUNE FD-VD will be the first particle physics experiment employing PoF technology operating at cryogenic temperatures and HV environment to power supply the PDS (X-ARAPUCAs).

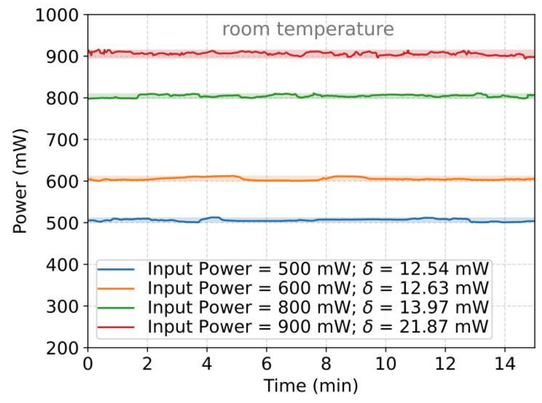


Laser Transmitter Modules

The PoF laser box units contains a gallium arsenide (GaAs) 808-nm laser-transmitter module that transmits optical power through the optical fiber.

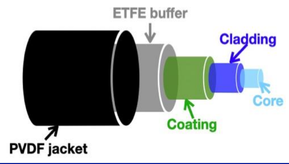
A power stability test was conducted to monitor the output power of the GaAs laser transmitter. Power fluctuations are less than 3% wrt to the input power.





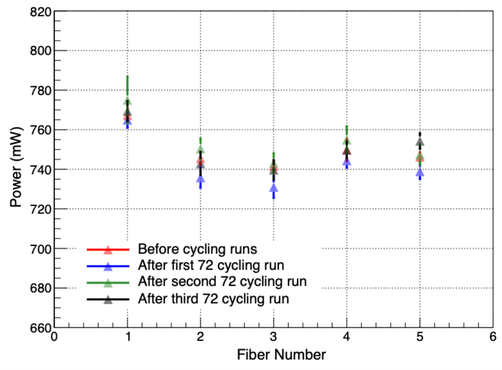
Optical Fiber Selection

The selection of optical fibers for PoF technology took about 3 years. The selected optical fibers are unique and have large cladding, a double jacket (buffer + jacket) that helps to contain light leakage.

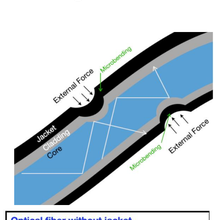


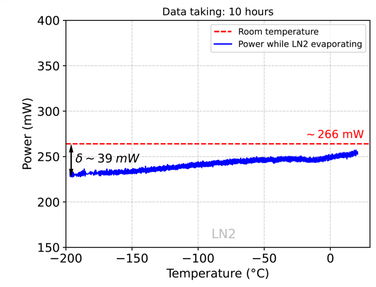
- *LN2 tests:* thermal stress, power loss a function of the temperature, tensile strength and more

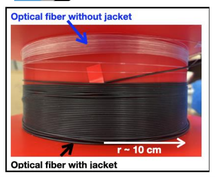
Thermal stress did not impact the functionality of the fibers.
Example: input power of 0.8W



Low temperatures can induce thermal contraction along the fiber, leading to microbending, which causes power loss

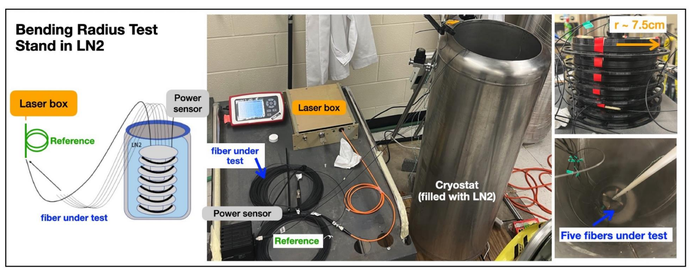


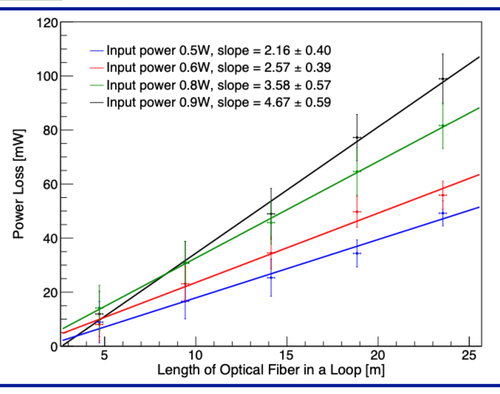




Fiber type	Input Power (mW)	Power loss per meter (mW/m)
With Jacket	500	1.74 ± 0.28
Without Jacket		0.56 ± 0.21
With Jacket	800	3.14 ± 0.51
Without Jacket		1.06 ± 0.48

- *Bending radius tests:* study of power loss in the optical fiber as function of the bending radius

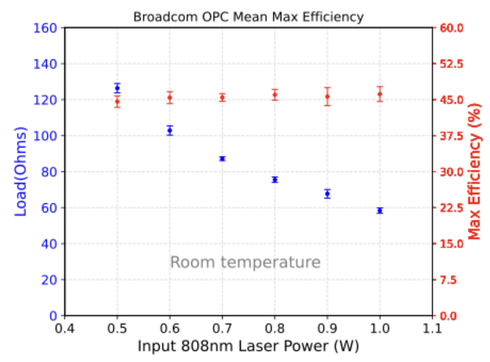


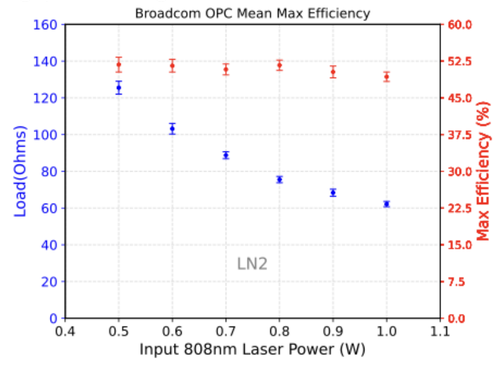


Optical Power Converter

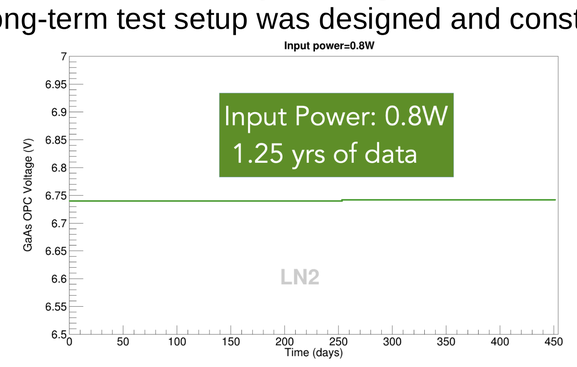
The OPC converts the optical energy of radiation into electric energy through the internal photoelectric effect in semiconductors.

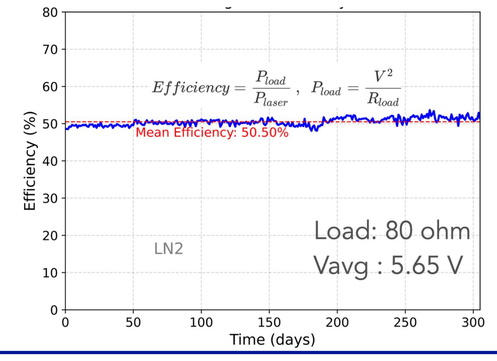
- Two types of OPCs have been tested (Si and GaAs)
  - Silicone: Cheap, Low Efficiency, 977 nm Laser
  - GaAs: Medium Price, Low Efficiency, 808 nm Laser
- Partnership between FNAL and Broadcom to improve efficiency:
  - *Broadcom*: Improved efficiency through packaging (Focal length, Material Size/Power Handling)





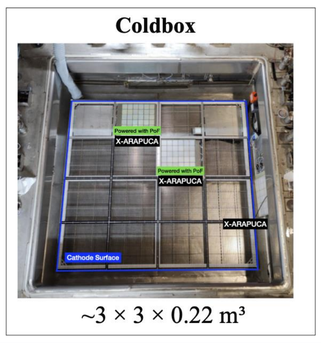
To assess the feasibility of using OPCs under cryogenic conditions for extended time periods, a long-term test setup was designed and constructed.

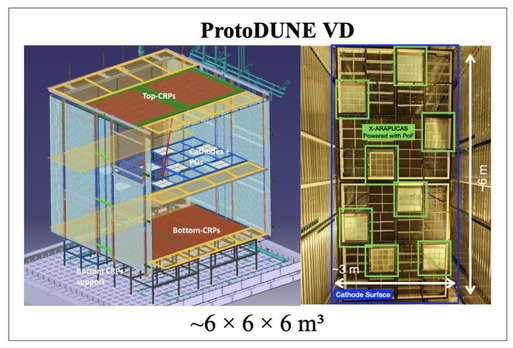


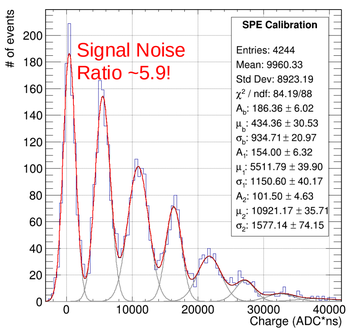


Prototypes Detectors using PoF technology

After validating and optimizing the PoF components through multiple test stands, the PoF components have been installed in Coldbox and ProtoDUNE VD at CERN.

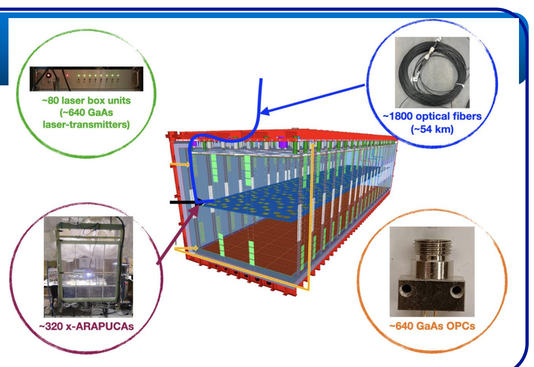






Conclusion and References

- PoF technology offers a new opportunity for supplying electrical power to electronics operating in HV at cryogenic temperatures
- First ever application of PoF technology in a particle physics experiment operating in HV and at cryogenic temperatures



[1] M.A. Arroyave *et al*. "Characterization and novel application of power over fiber for electronics in a harsh environment "*JINST* **19** P10019 (2024)
[2] https://www.dunescience.org
[3] http://neutrinos.ciemat.es/es/dune-es
[4] Abi, Babak, et al. "Volume I. introduction to DUNE." *Journal of instrumentation* 15.08 (2020)
[5] https://ep-news.web.cern.ch/content/dune-prototype-activities-neutrino-platform

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