Liquid Argon Purity Monitoring for DUNE

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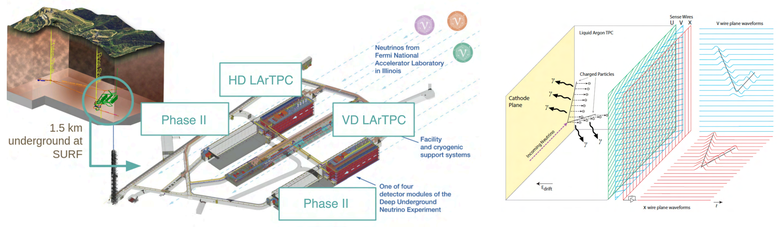
DUNE Deep Underground Neutrino Experiment

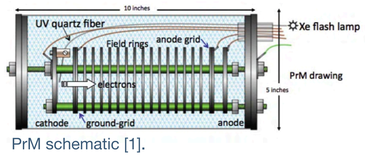
1. DUNE

- 1300 km baseline neutrino oscillation experiment.
- Four 17 kt modules with liquid argon time projection chambers.



2. Purity Monitoring Principles

- Electronegative impurities (e.g. O_2, H_2O) capture drift electrons.
- High purity liquid Ar with accurate purity measurements necessary for energy estimation.
- A purity monitor (PrM) is a miniature TPC.
- Electrons from source at cathode accelerated with uniform electric field toward anode.
- Charge collected at anode and cathode calculated from voltage pulses after RC fits.
- Detector's TPC 1/e electron lifetime calculated from ratio of charges and electron drift time.



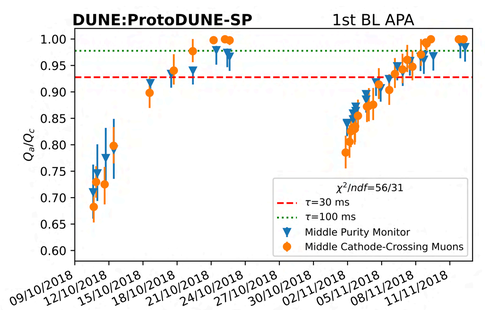
PrM schematic [1].

Example PrM pulses.

Drift Electron Lifetime: $\tau = -\dfrac{t_{\text{drift}}}{\ln(Q/Q_0)}$

3. Purity at ProtoDUNE

- ProtoDUNE detectors at CERN testing DUNE detector technology.
- PrMs of all technologies tested throughout ProtoDUNE operation.
- Good agreement with purity measurements from cosmic ray muons, which are rare underground.

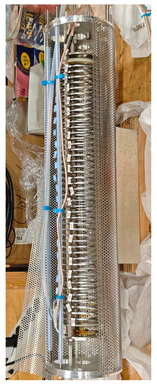


Purity measurements during ProtoDUNE Run 1 from PrMs and cosmic ray muons [2].

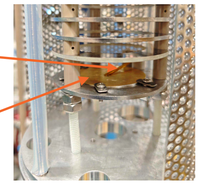
4. Technologies

- **Short** PrMs best for low purity (≲15 ms).
  - All electrons captured after short distance.
- **Long** PrMs best for high purity (≈1 ms — ≈70 ms).
  - Need long distance to observe loss of charge.
- **UV** PrM uses Xe flash lamp light delivered into detector through optical fibers aimed at photocathode for large electron signal.
- **Bi** PrM uses bismuth-207 radioactive source.
  - Monoenergetic 1.0 MeV internal conversion (IC) electrons used as source.
  - Dual-channel anode with inner and outer ring to separate IC electrons from γ-ray induced Compton electrons.
  - Anode-mounted cold amplifiers to read out small electron signal [3].

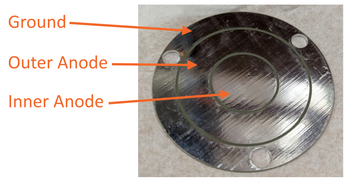
16 cm PrM.



50 cm PrM.

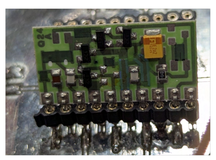


UV PrM cathode.

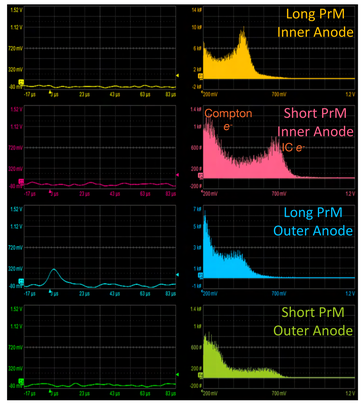


Dual channel anode.

Bismuth-207 source.



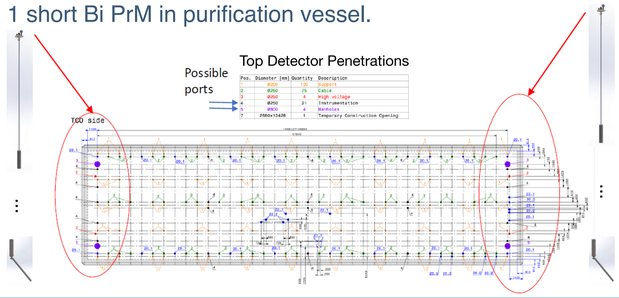
Anode-mounted cold amplifier.

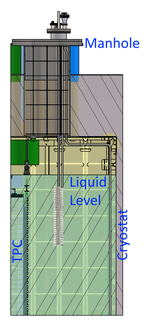


Example Bi PrM single pulse (left) and collected pulse height histograms (right) [4].

5. Nominal FD Plan

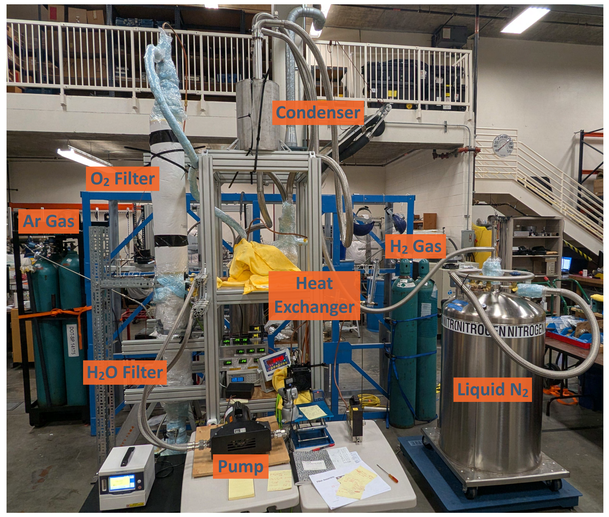
- 2 long UV PrMs on top, 2 long Bi PrMs on bottom, 1 short Bi PrM in purification vessel.

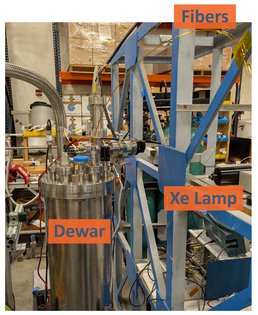




Top UV PrM mounting plan.

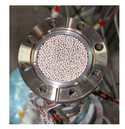
6. UCI LAr Test Facility





- Ar gas passed through 0.3 kg molecular sieve and 7.3 kg CuO catalyst to remove H_2O and O_2 contaminants, respectively.
- Cold N_2 gas passed through condenser and heat exchanger alongside Ar gas to condense Ar.
- Liquid Ar drips into dewar containing PrM.
- Pump and/or heater in dewar can recirculate Ar through filter for continuous purification.
- Heat strips and insulation around filter used to regenerate catalyst through reduction with H_2 [5].

CuO catalyst (O_2 filter).

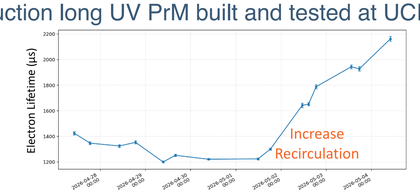


Molecular sieve (H_2O filter).

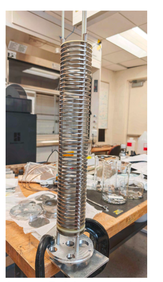
PrM mounting assembly.

7. Production Status

- First production long UV PrM built and tested at UCI.



- Long Bi PrM will be constructed next, followed by rest of PrMs for DUNE vertical drift module planned to begin operation in late 2029.



Long PrM assembly in progress.

References:
[1] M. Adamowski et al. "The Liquid Argon Purity Demonstrator". *JINST* **9**, P07005 (2014).
[2] S. Abbaslu et al (DUNE Collaboration). "Spatial and temporal evaluations of the liquid argon purity in ProtoDUNE-SP". *JINST* **20**, P09008 (2025).
[3] B. Baibussinov et al. "The ICARUS Front-end Preamplifier Working at Liquid Argon Temperature". arXiv:1108.3825.
[4] B. Baibussinov et al. "A novel liquid argon purity monitor based on ^{207}Bi". *JINST* **20**, P02011 (2025).
[5] A. Curioni et al. "A regenerable filter for liquid argon purification". *Nucl. Instr. and Meth. A* **605**, 306 (2009).

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