Liquid Argon Detectors for Particle Physics

Why Liquid Argon?

- Bright scintillator (40,000 photons/MeV)
- Free electrons drift meters under electric fields of ~ kV/cm
- density of 1.4 ton/m^3
- readily available
- Boiling point of 87K, possible to refrigerate with liquid nitrogen.

Neutrino Interactions

Studying the properties of neutrinos will shed light on the origin of the matter/antimatter asymmetry in the universe

The next generation of experiments requires a large volume of material (10-100 kton) that serves as both target and detector.

Liquid Argon Time Projection Chambers (LArTPC) can produce 3D event images with topology *and* ionization density

- Identify particle (e,μ,p,γ, . . .)
- Measure particle trajectory
- Measure particle energy

Dark Matter Searches

Dark matter constitutes ~25% of the mass-energy in the universe, but what is it? Axions? WIMPs?

The time development of the light pulse and the ratio of the amount of free charge to light produced by interactions in Argon provide powerful rejection of electron and photon backgrounds for WIMP searches

REFERENCES

1. Distillation: arXiv:1204.6024, arXiv:1204.6061, arXiv:1204.6011.
2. ArgoNeuT: Phys. Rev. Lett. **108** 161802 (2012), arXiv:1205.6747, arXiv:1205.6702.

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PURITY DEMONSTRATOR

All existing LArTPC detectors have been evacuated before filling. Not practical for kiloton detectors.

- Goal: Demonstrate good purity (life-time) in an industrial vessel without evacuation.
- First multi-ton purification system designed and built at Fermilab.

Stage 1 (2011)
bare tank and instrumentation

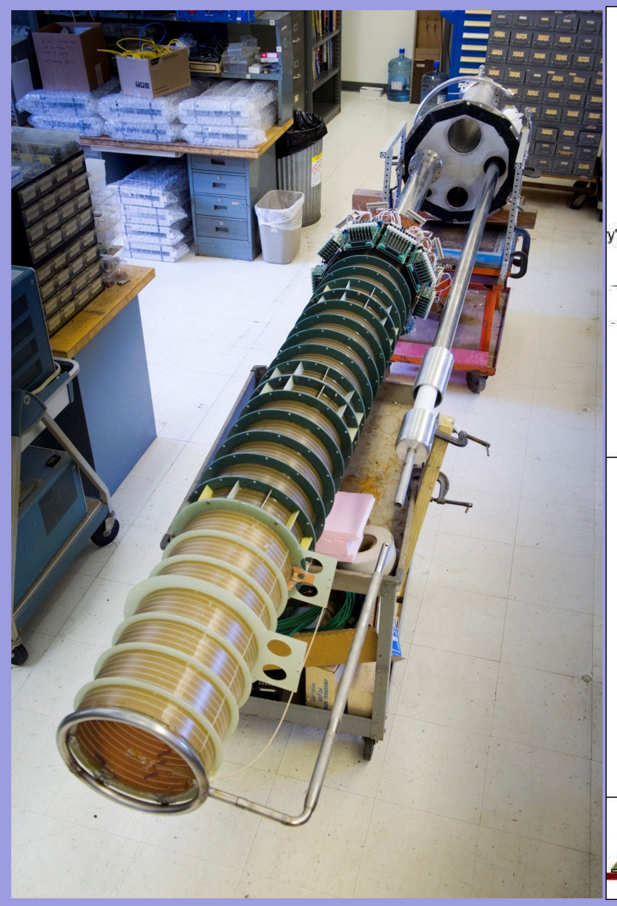
- Sniffers for evolution of gas purge
- Analyzers for O_2, N_2, and H_2O levels
- RTDs – for temperature (gradients)
- Purity Monitors for drift-lifetime

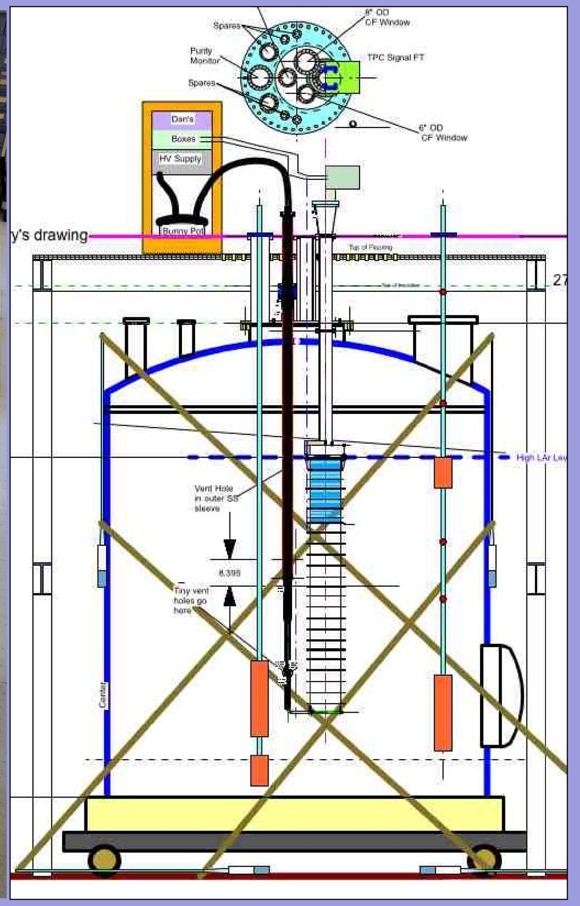
2011: SUCCESS! Measured electron drift lifetime >3 ms (Contaminants <100 ppt O_2 equivalent)

LONG DRIFT DEMONSTRATION

Stage 2 (Winter 2012-13)

- 150 kV feedthrough voltage already achieved
- The response of a 2m long TPC to cosmic ray muons is a sensitive purity measurement
- Fully characterize filter sizing and material performance
- Study the effect of varying the recirculation rate on the drift lifetime
- Perform studies of how quickly lifetimes can be recovered from (intentional) poisoning of the Argon





ELECTRONICS IN LIQUID ARGON

MSU and FNAL

For multi-kiloton LAr TPCs, there are significant advantages in putting the electronics in the liquid argon and multiplexing the signals before transmitting them out of the cryostat.

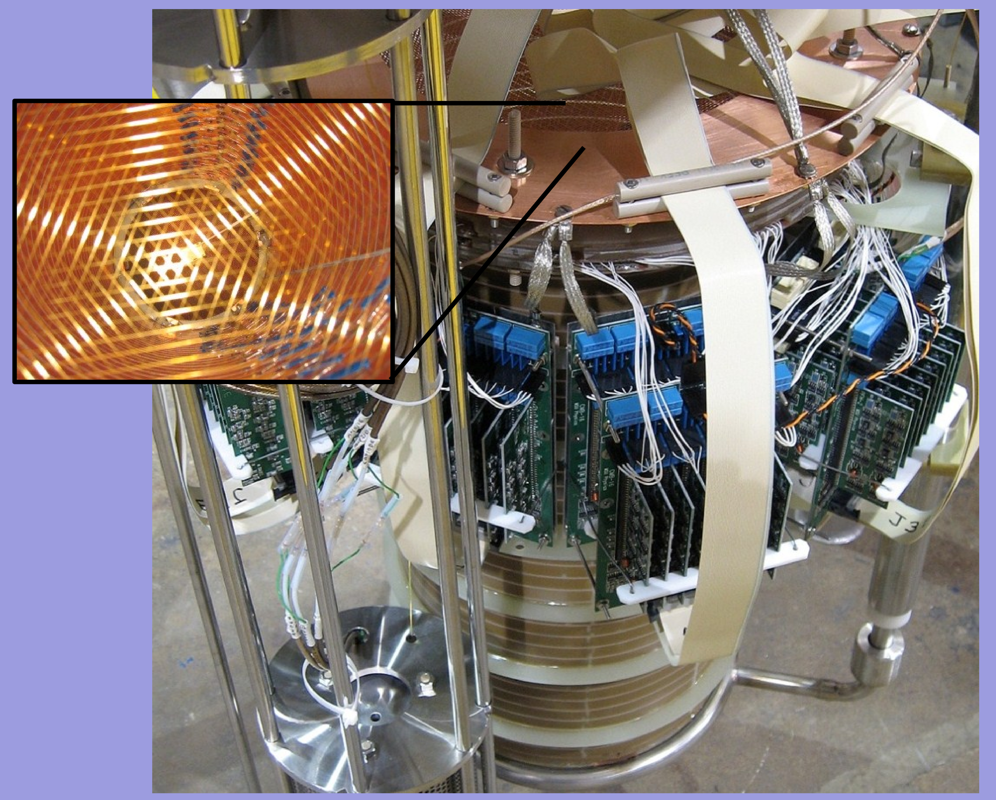
Advantages:

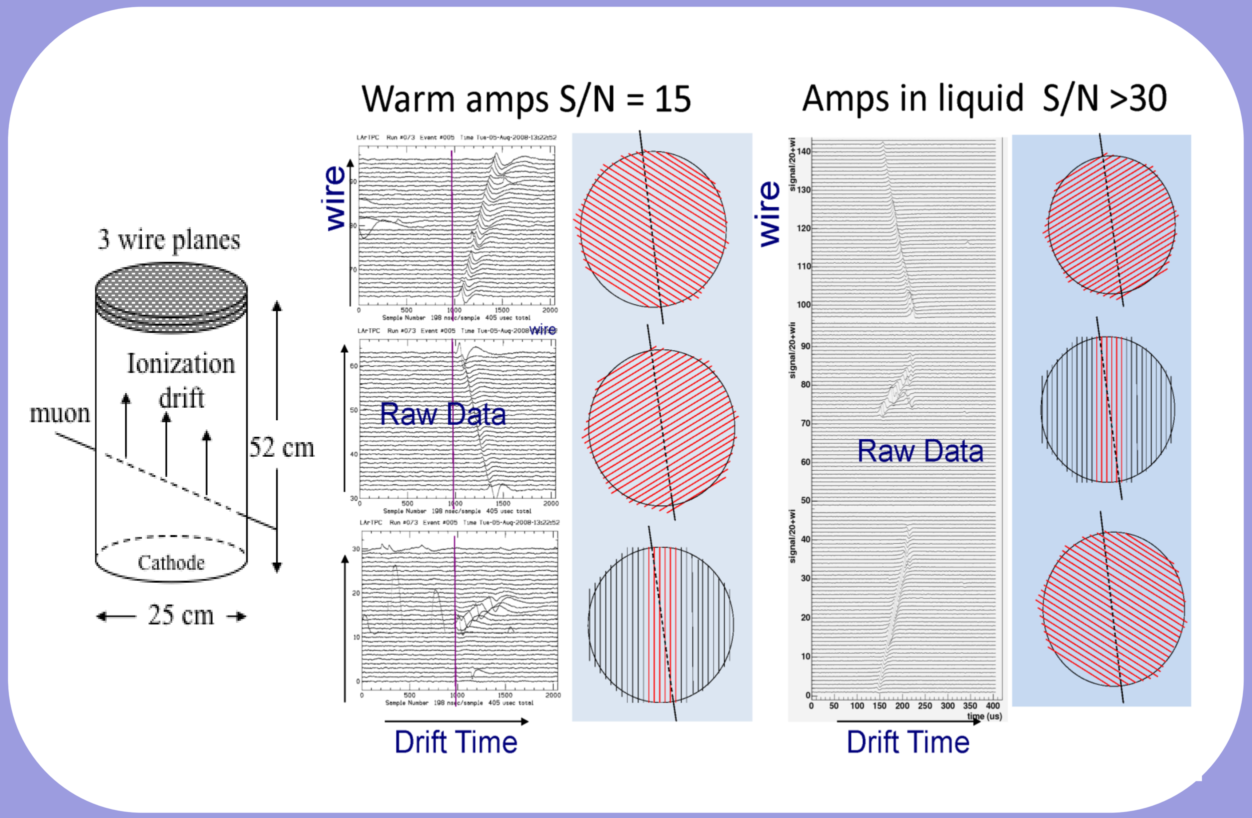
- Lower capacitance seen by an amplifier close to the TPC wire can improve signal to noise compared to amplifier some meters from the wire.
- Ability to put amplifiers anywhere on the TPC avoids having to bring the signals to top of detector, or to have feed-throughs in liquid.
- Multiplexing signals inside the cryostat reduces the number of feed-throughs reducing cost and chance of leaks.
- Multiplexing signals reduces cable plant inside detector and thus reduces sources of contamination and out-gassing.

Challenges:

- Passive components require careful selection.
- Connectors and cabling need careful testing.
- All connections need robust mechanics.

2011: First in-liquid CMOS electronics on a LArTPC

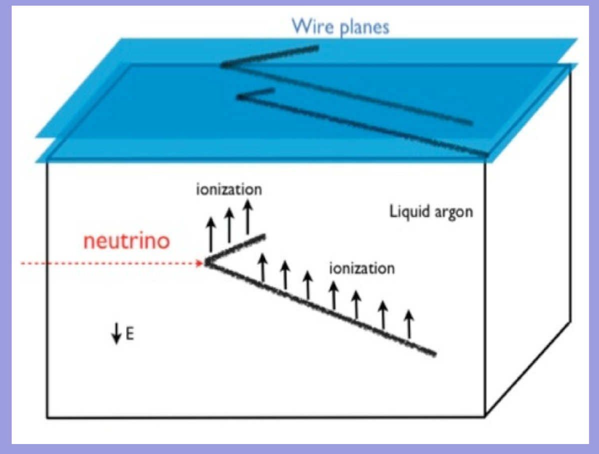


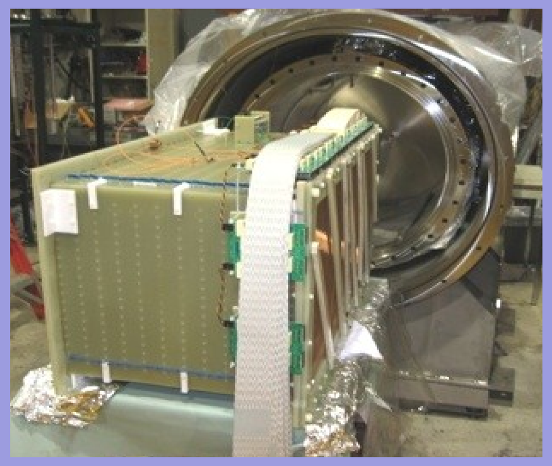


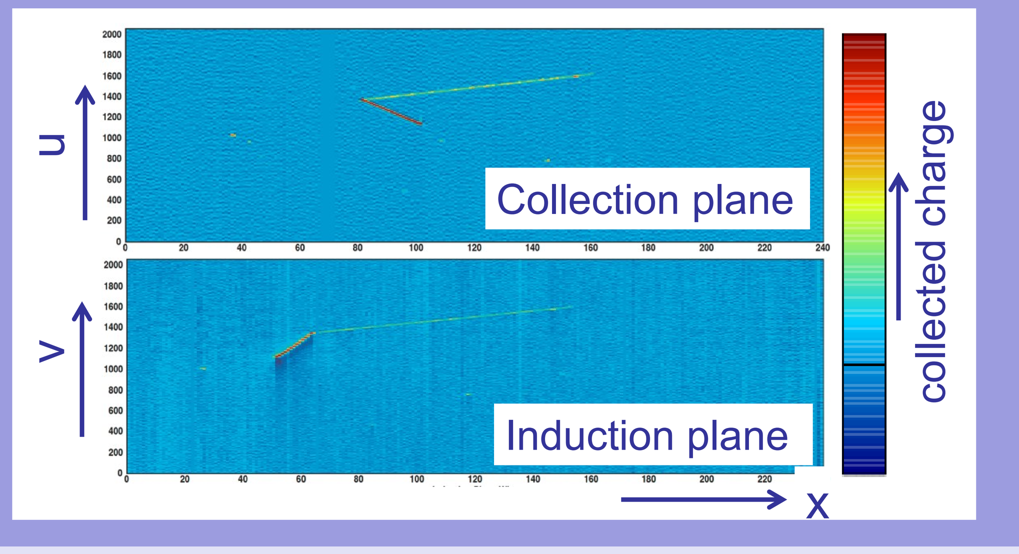
ARGONEUT

Bern (CH), FNAL, Italy, KSU, MSU, Syracuse, Texas, and Yale

- First U.S.-based LArTPC in a low energy (~3 GeV) neutrino beam (NUMI)
- 1m x 50 cm x 50 cm, external (warm) electronics
- 2 wire planes +/- 30^0 to vertical, 480 channels total

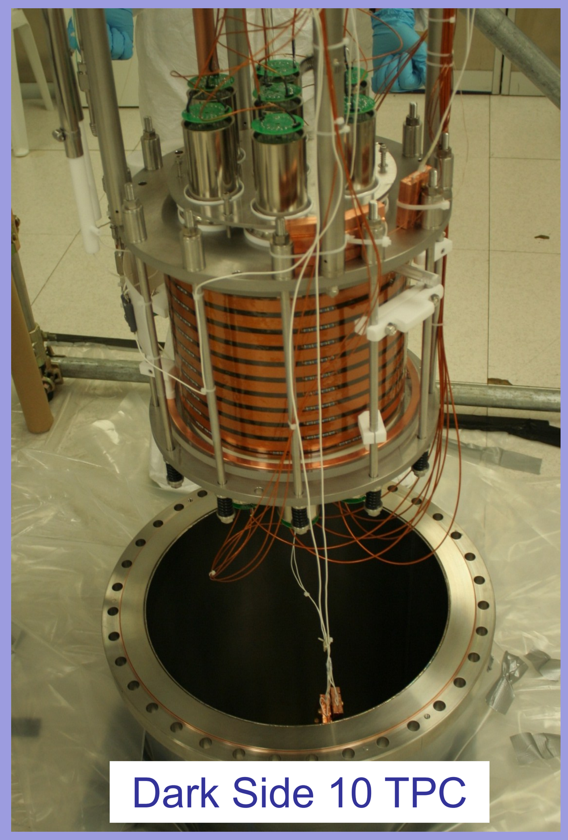


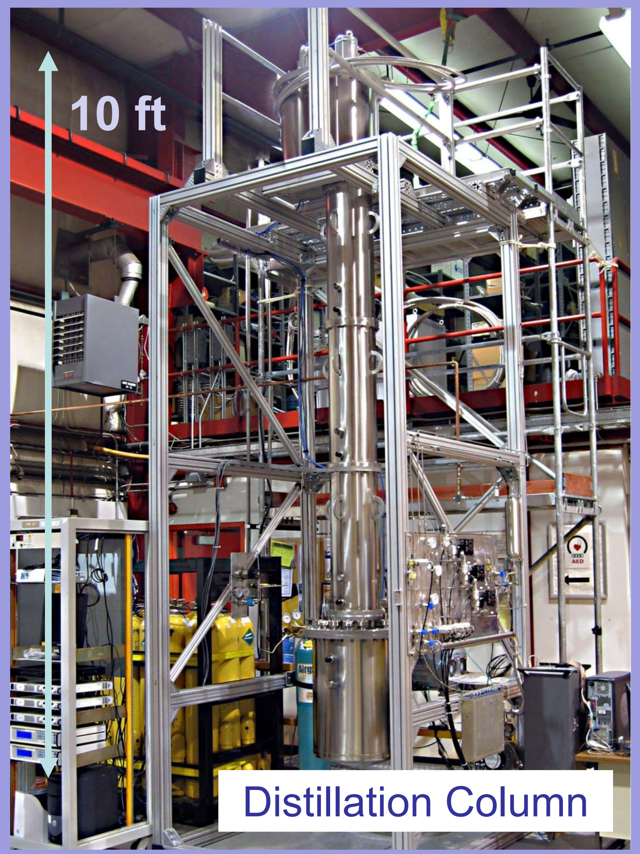




2012: First measurement of inclusive muon neutrino charged current differential cross sections on Argon

DISTILLATION OF UNDERGROUND ARGON





- The size of dual phase TPCs for dark matter searches is limited by backgrounds from ^{39}Ar decay
- Atmospheric argon emits ~1 Bq/kg while mantle argon has <0.01 Bq/kg (measured)
- Gas from CO_2 wells is 96% CO_2, 2.4% N_2, 0.57% CH_4, 0.43% He, 0.06% Ar, and 0.21% H_2
- After VPSA (molecular sieve): 3% Ar, 27% N_2, 70% He
- Distill out N_2 and He, <10 ppm achievable

2011: Distillation column commissioned at Fermilab
Total of 15 kg low activity Ar distilled and stored to date.