



Liquid Argon Projects at Fermilab

NNN10

Dec. 15, 2010

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Talk Outline

- Overview of development at Fermilab
 - ArgoNeuT
 - MicroBooNE
 - Argon Purity R&D
 - Large Detectors: LBNE



Introduction

- Liquid Argon Time Projection Chambers (LArTPCs) combine fine-grained tracking and calorimetry.
- U.S. efforts to develop LArTPCs have expanded significantly in recent years.
- These efforts are aimed at developing the technology for a multi-kiloton detector that could be used to do a variety of physics (accelerator neutrinos, proton decay, astrophysics, ...)
- Much progress to report since the last version of this talk (at NNN08).

LArTPC Work at Fermilab

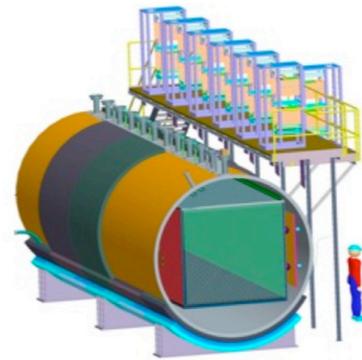
Materials/Electronics Test Stand



L.A.P.D.



ArgoNeuT



MicroBooNE

Refs:

- 1.) A Regenerable Filter for Liquid Argon Purification Curioni et al, NIM A605:306-311 (2009)
- 2.) A system to test the effect of materials on electron drift lifetime in liquid argon and the effect of water Andrews et al, NIM A608:251-258 (2009)

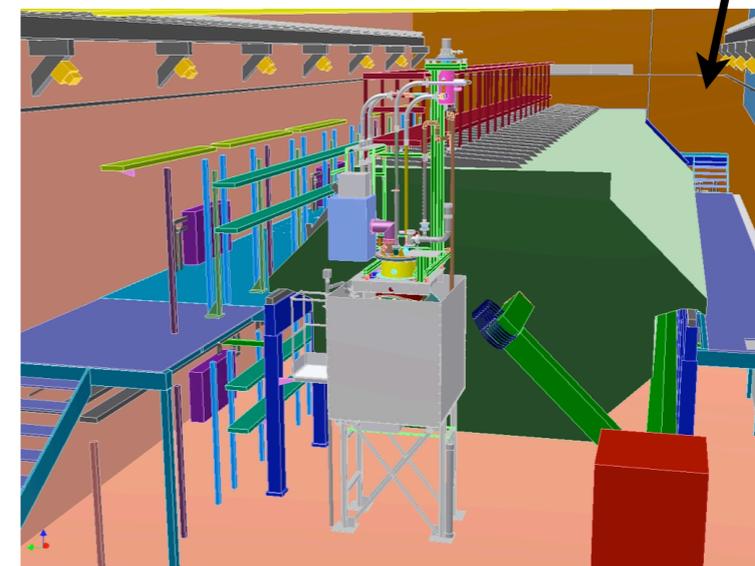
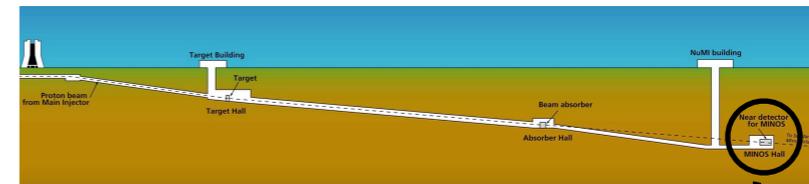


ArgoNeuT

- The ArgoNeuT (a.k.a. - Fermilab T962) project features a ~175 liter LArTPC
- Jointly funded by DOE/NSF
- Operated in NuMI beam at Fermilab, in front of MINOS near detector (to aid in muon reconstruction).
- Goals:
 - ▶ Gain experience building/running LArTPCs.
 - ▶ Accumulate neutrino/antineutrino events (1st time in the U.S., 1st time ever in a low-E beam).
 - ▶ Develop simulation of LArTPCs and compare with data.



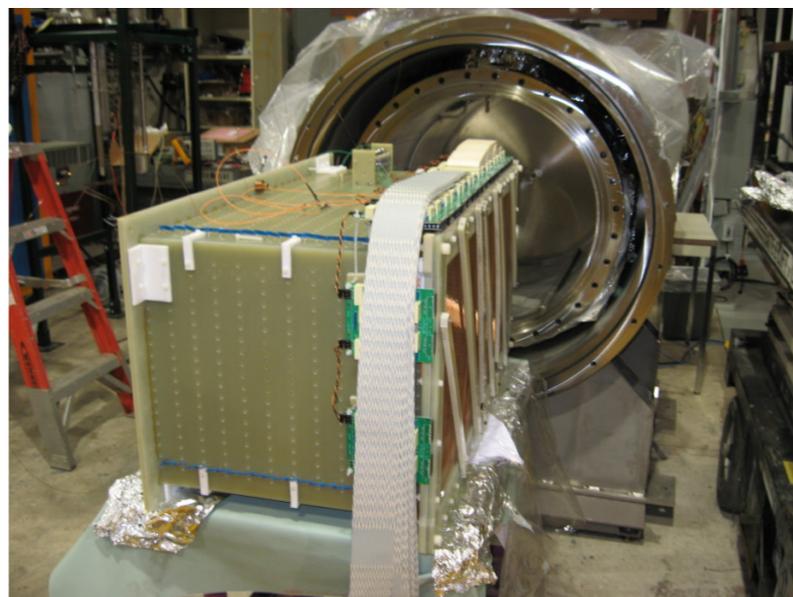
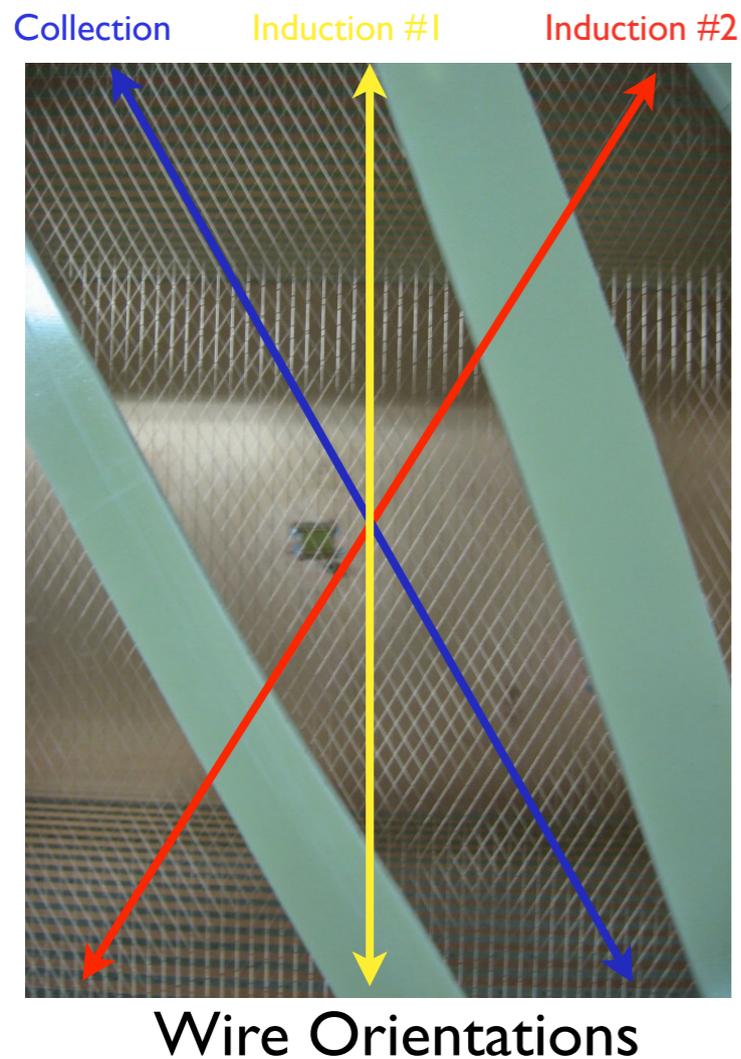
Fermilab



MINOS Hall at Fermilab

ArgoNeuT: TPC

Cryostat Volume	500 Liters
TPC Volume	175 Liters
# Electronic Channels	480
Electronics Style (Temp.)	JFET (293 K)
Wire Pitch (Plane Separation)	4 mm (4 mm)
Electric Field	500 V/cm
Max. Drift Length (Time)	0.5 m (330 μ s)
Wire Properties	0.15mm diameter BeCu



TPC outside cryostat

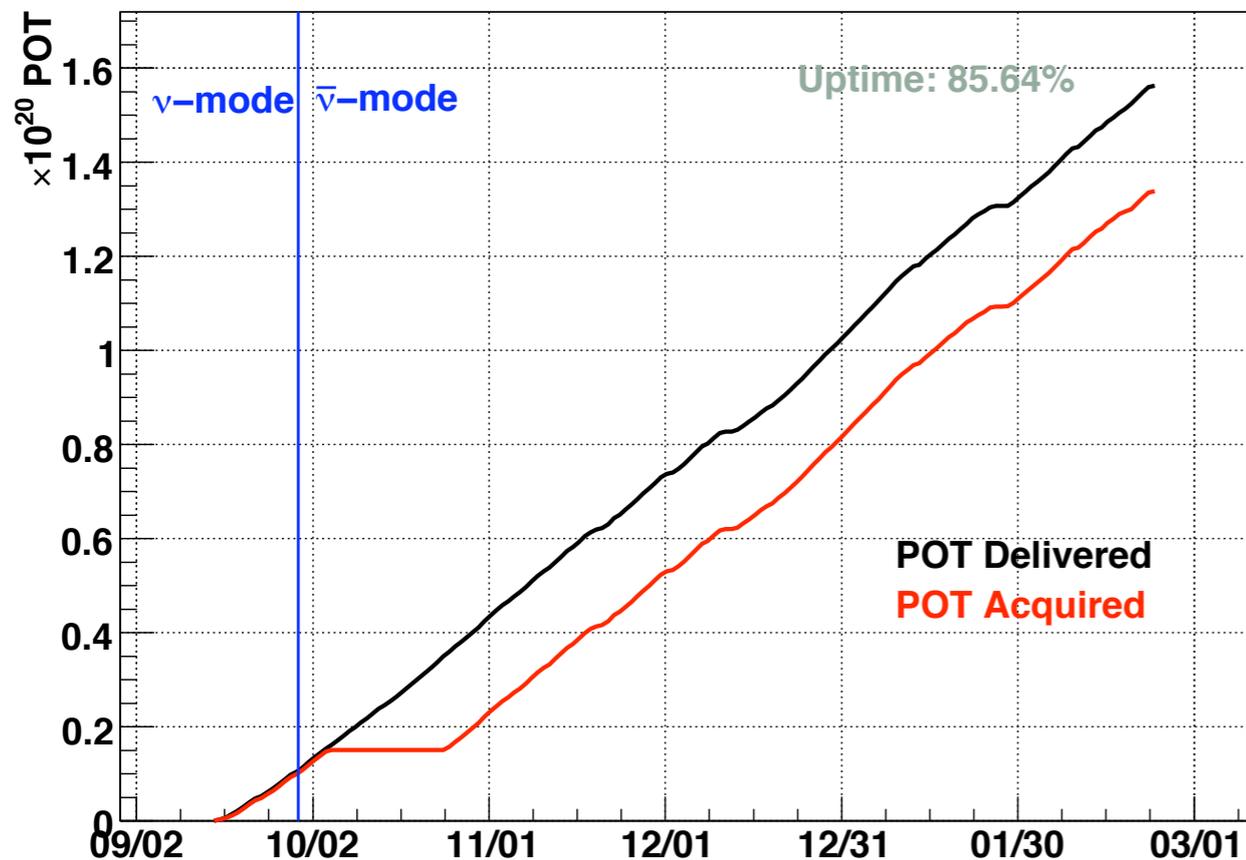


TPC Field Cage formed out of copper-clad G10 boards

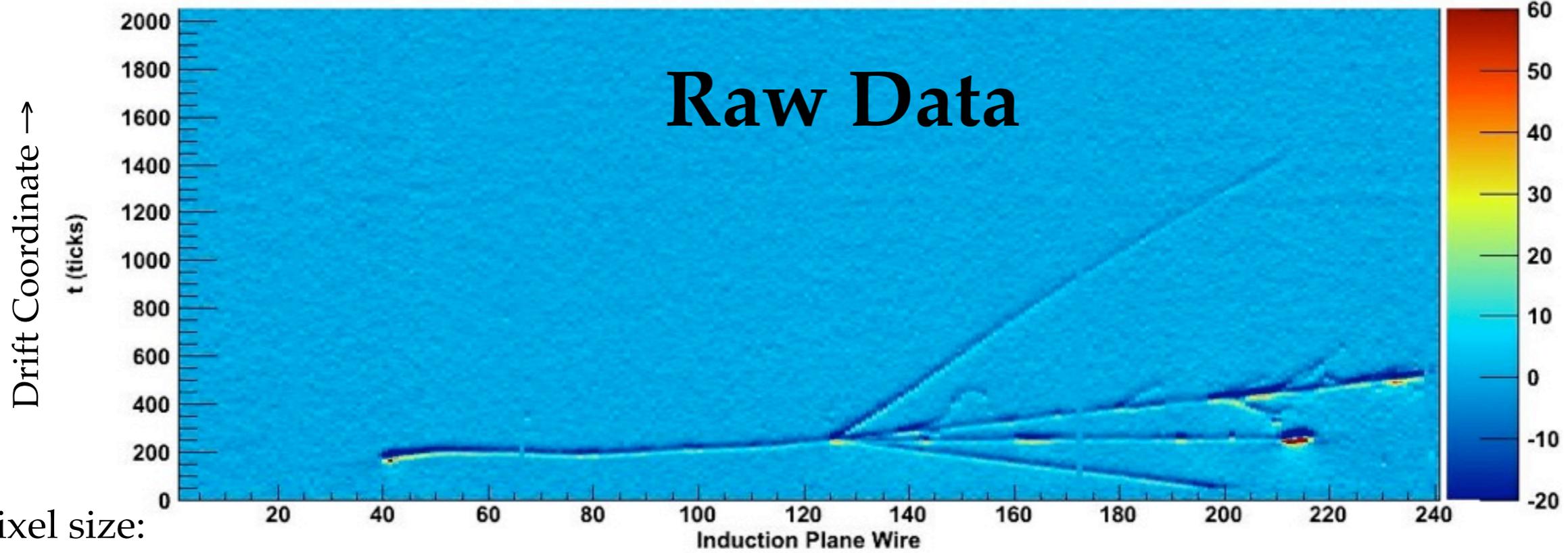
ArgoNeuT: NuMI Run

- Filled the detector underground on Friday, May 8, 2009
- Acquired neutrino data for ~1 month before summer 2009 shutdown...continued running in the Fall, mostly in antineutrino mode...run ended Feb. 22, 2010
- Cryo. system operated continuously since initial fill, (modulo cryocooler repair for ~2 weeks in October).
- ArgoNeuT acquired $\sim 1.4E20$ Protons On Target (P.O.T.) by the end of its run
- This data is being used to develop techniques for reconstructing events in 3D, and should allow us to perform several cross-section measurements.

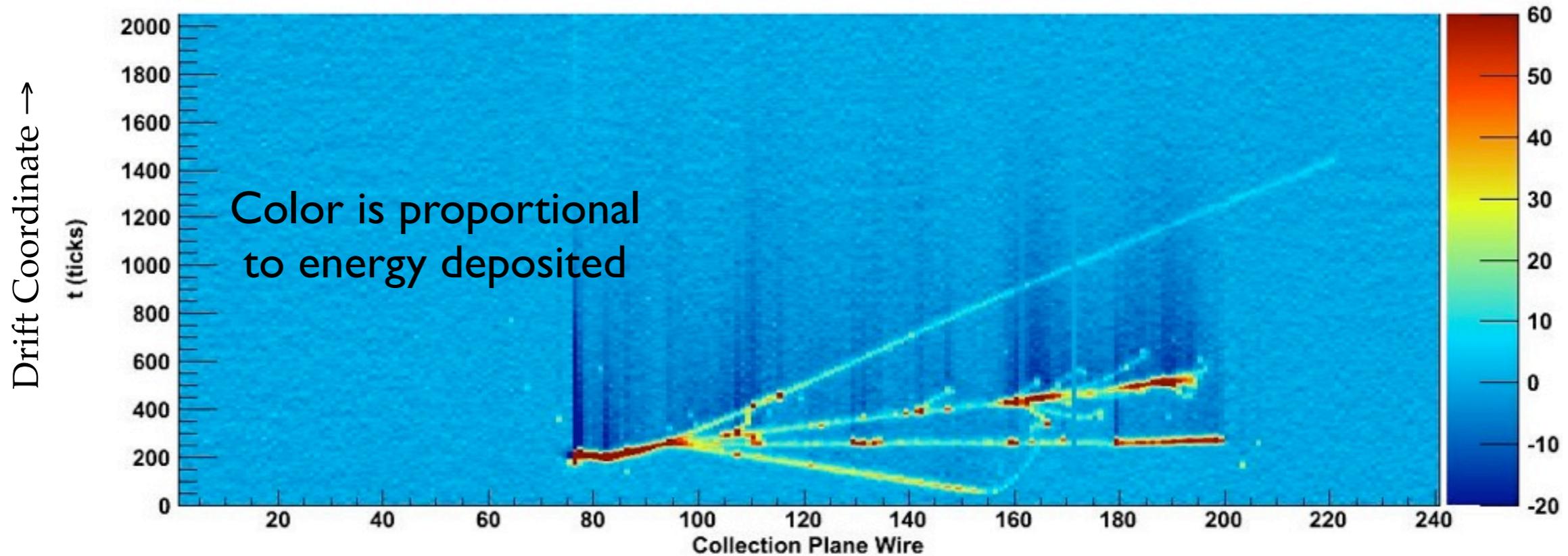
ArgoNeuT POT delivered and accumulated



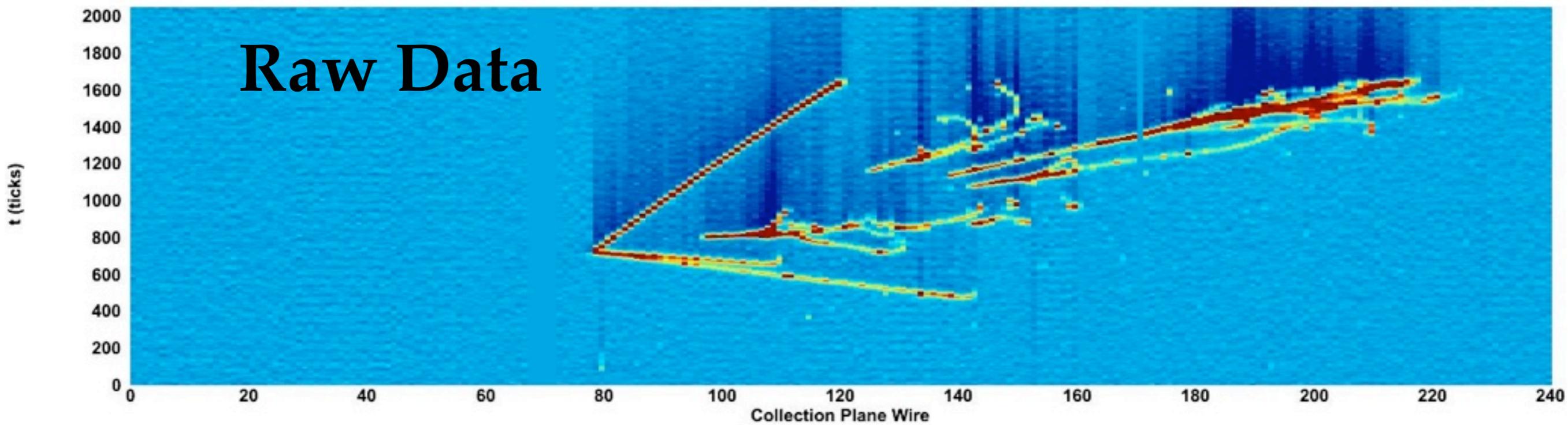
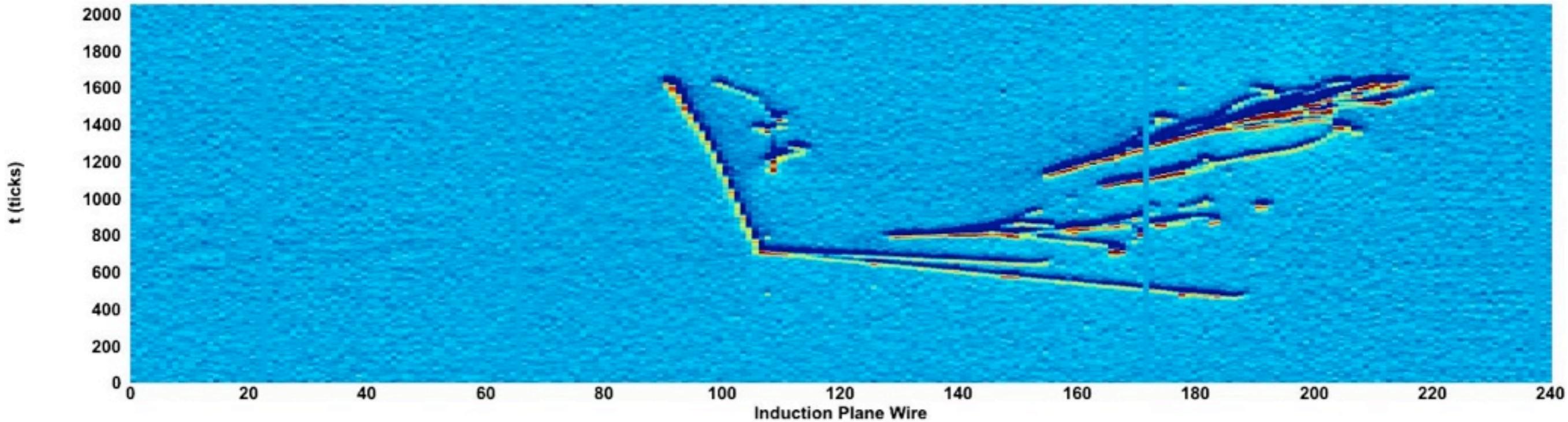
ArgoNeuT Neutrino Event



Pixel size:
4mm x 0.3mm

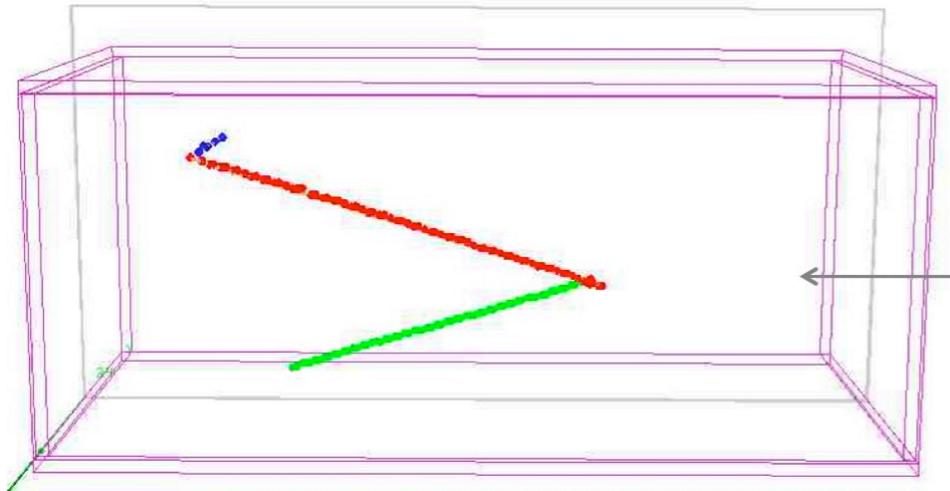


ArgoNeuT Neutrino Event

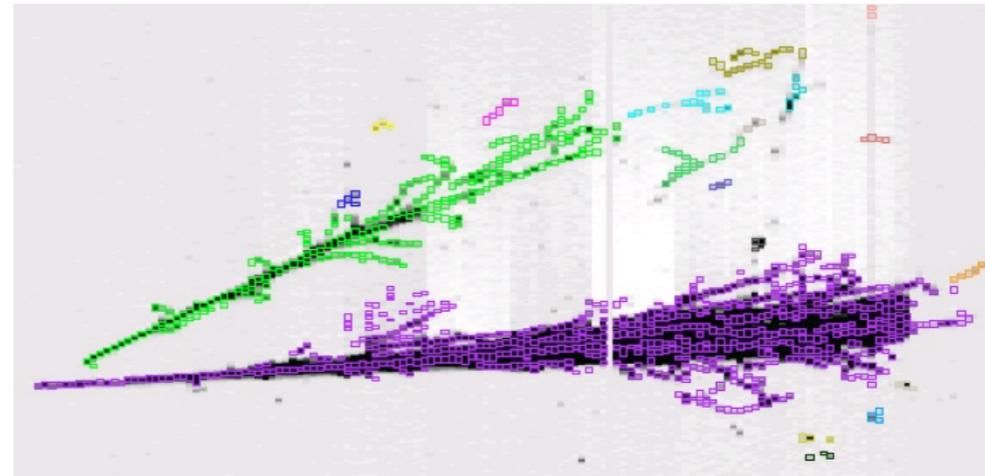


ArgoNeuT Software

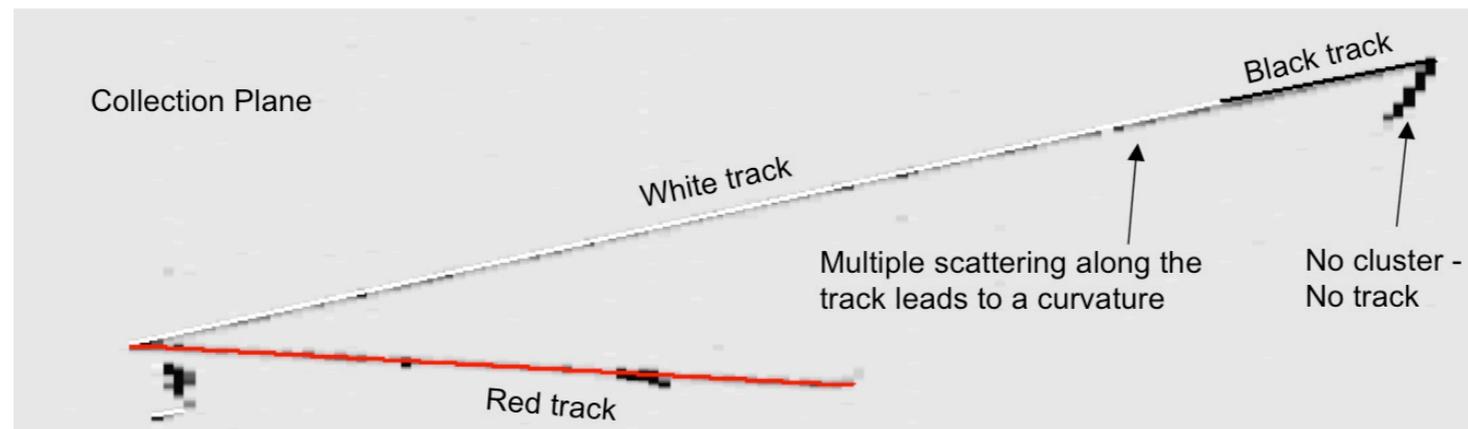
- ArgoNeuT (anti)neutrino data inspiring lots of software / analysis work.
- Creating a fully automated event reconstruction and analysis package for LArTPCs, called “LArSoft”
- LArSoft will be used for all U.S. LAr experiments.
- Example: Different reconstruction techniques being developed...



3D Reconstruction

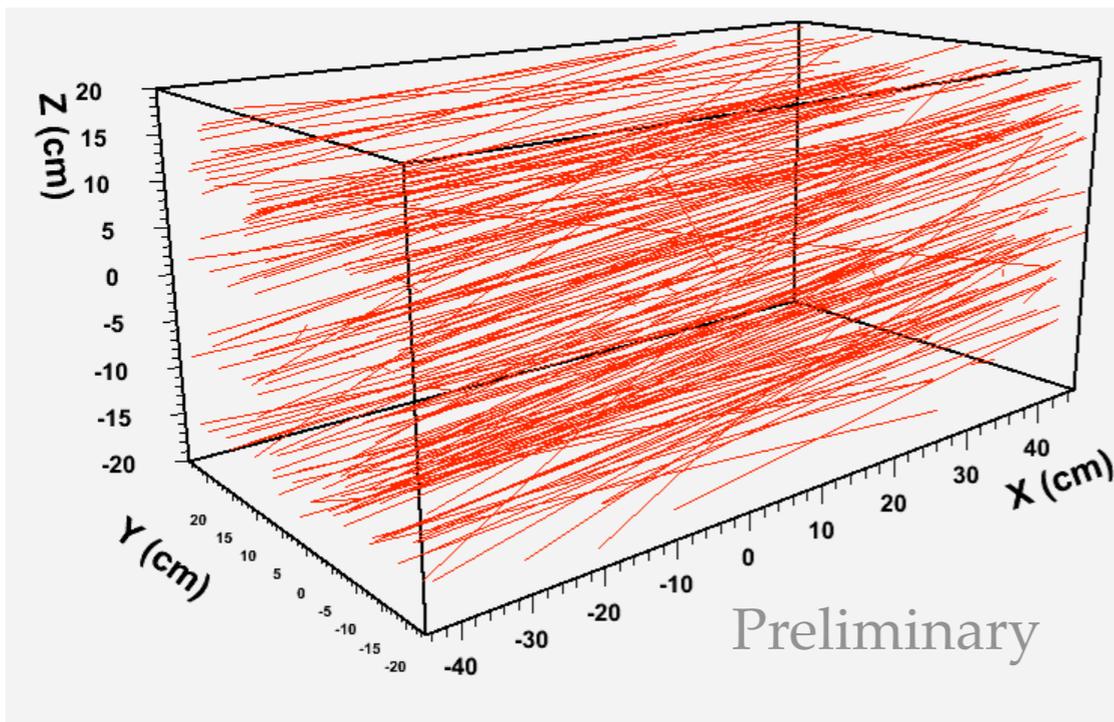


Density-based clustering.

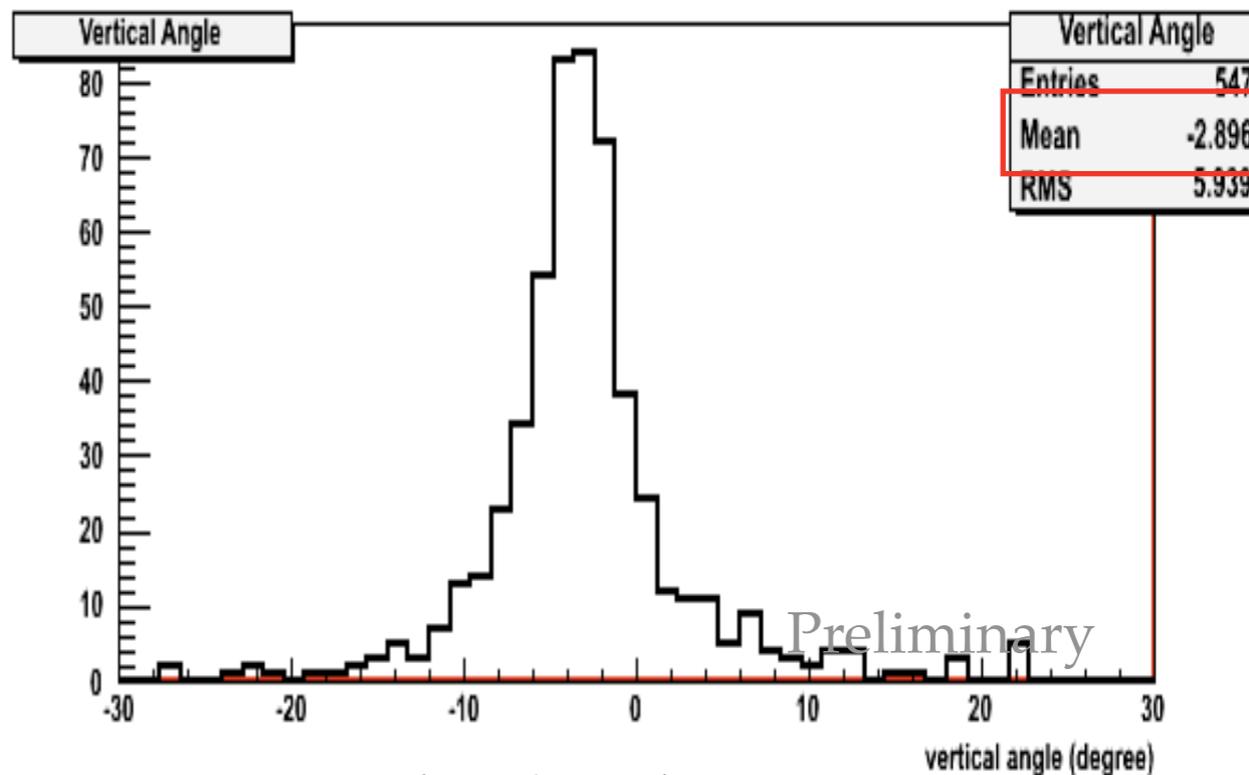


Straight-line reconstruction using
Hough Transform.

ArgoNeuT: Reconstruction

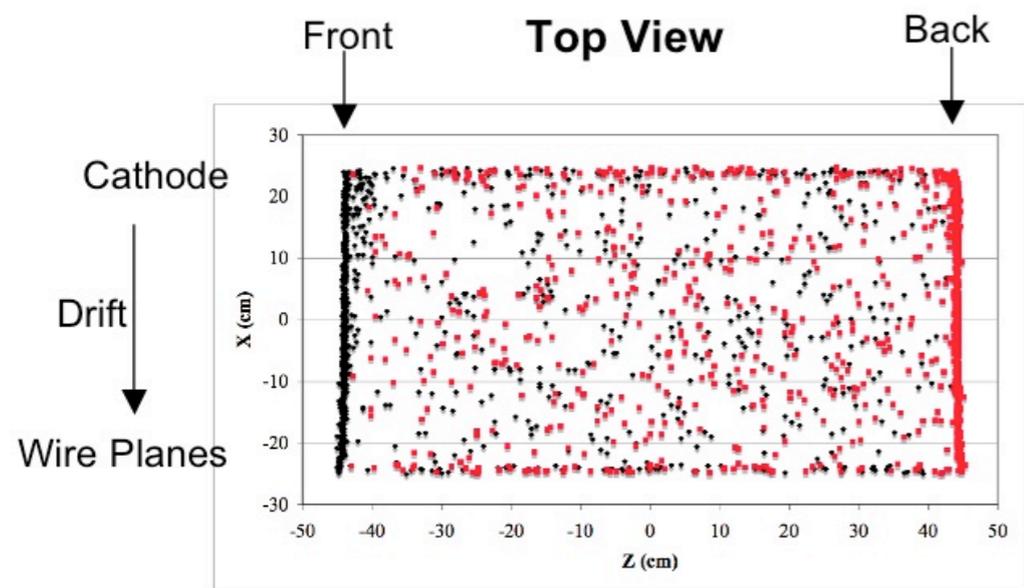


3D Reconstructed muons from few hours of running.

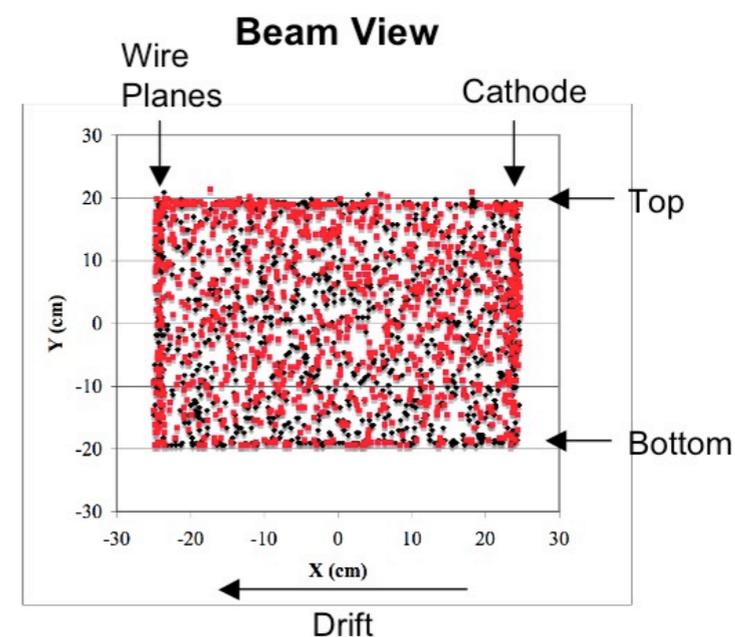


Angular distribution...NuMI

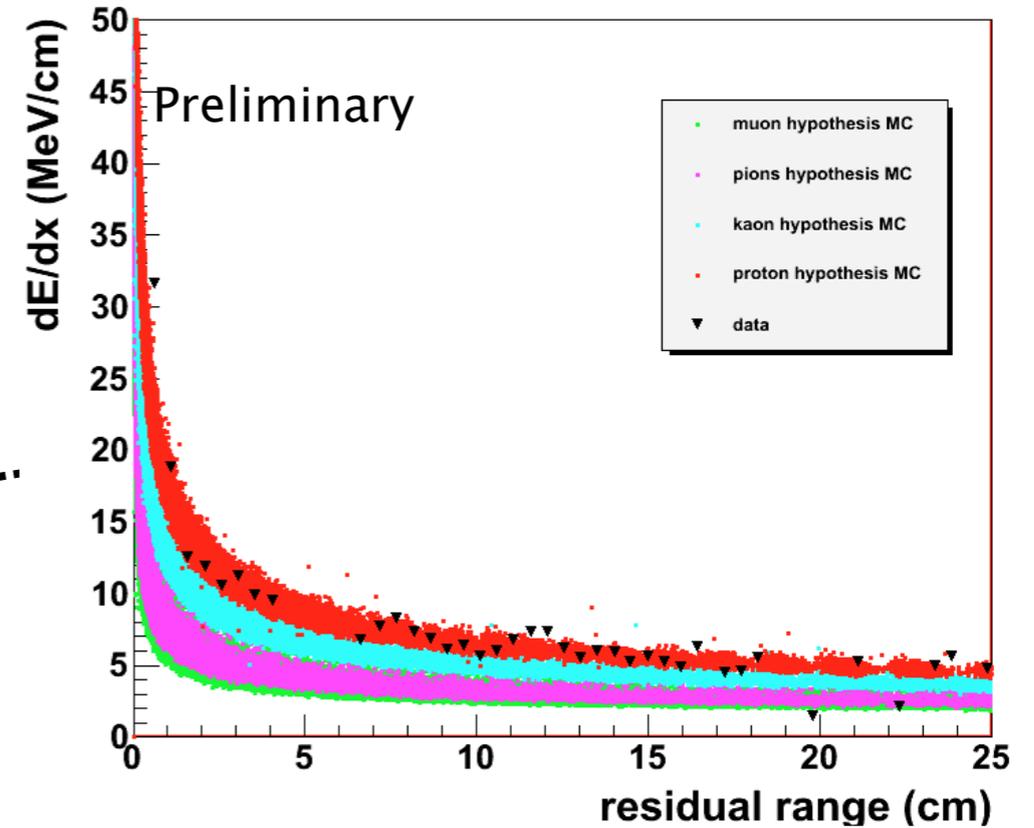
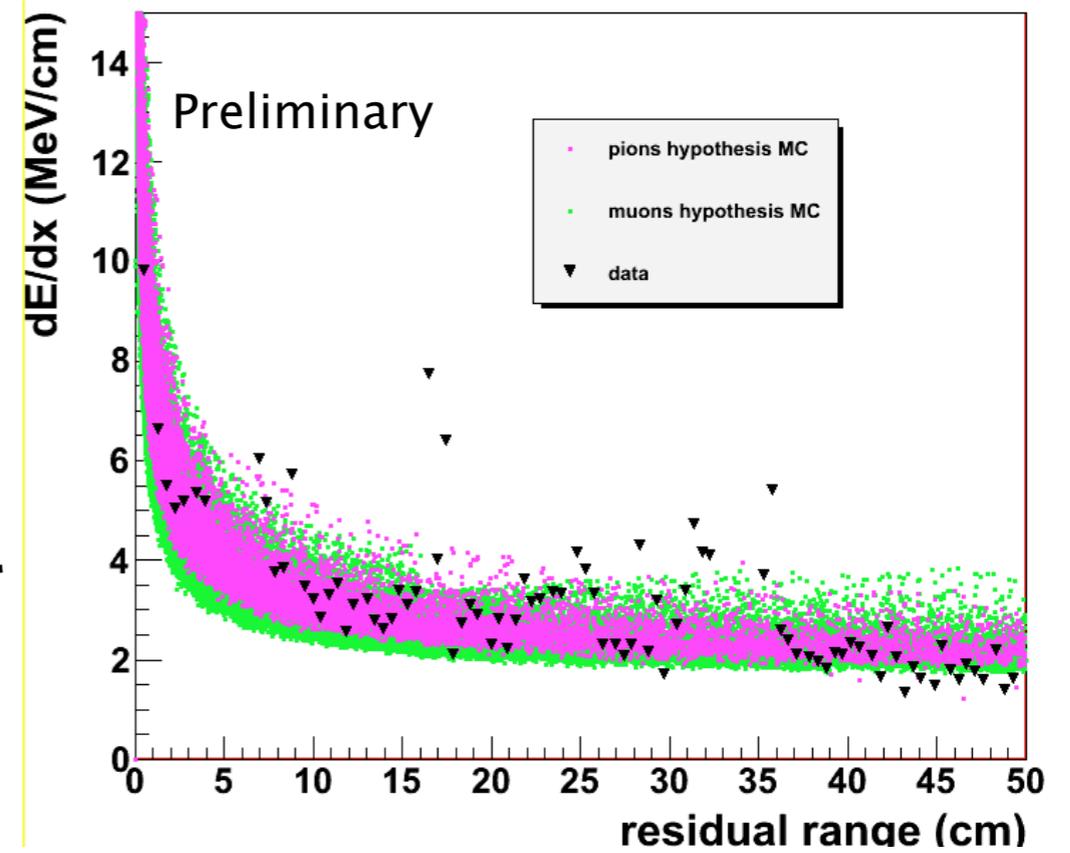
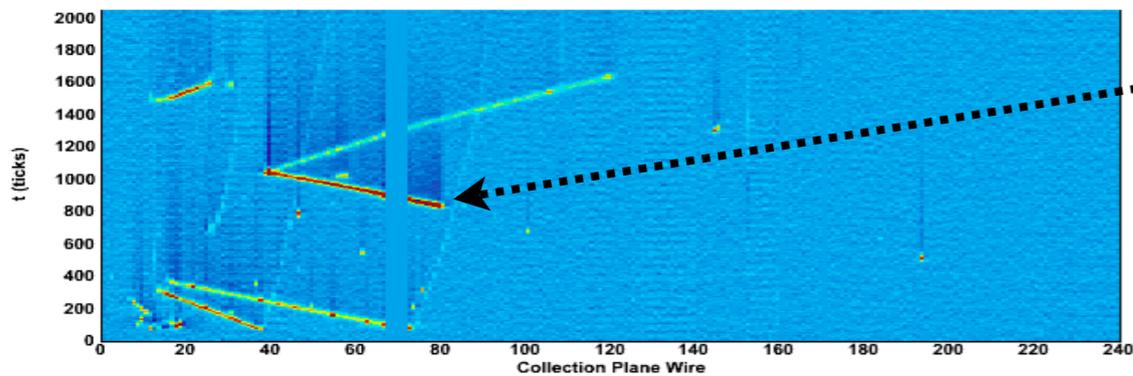
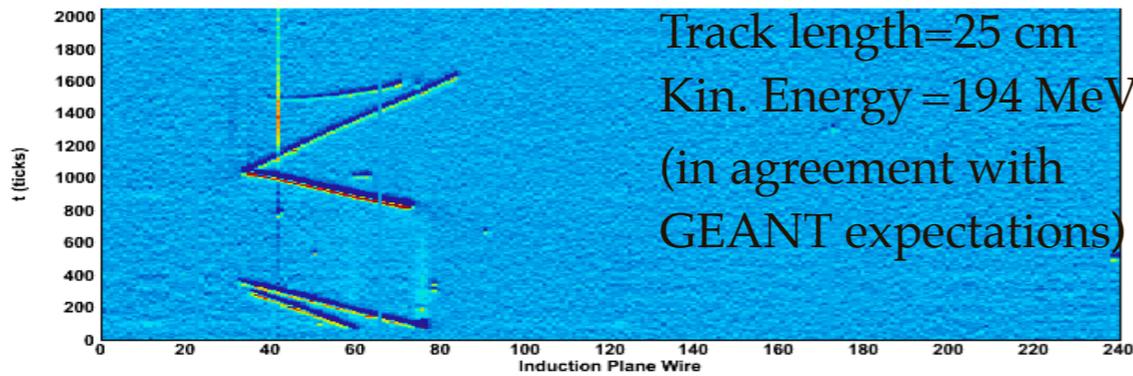
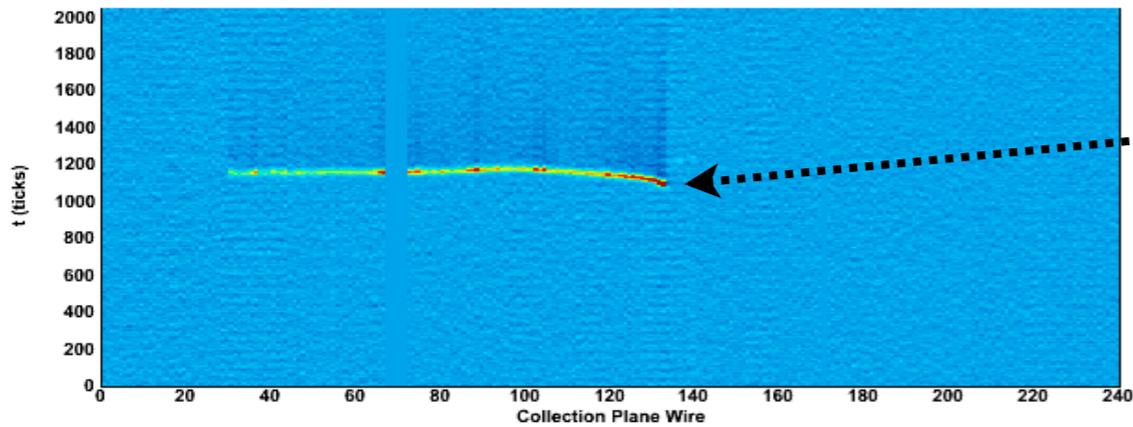
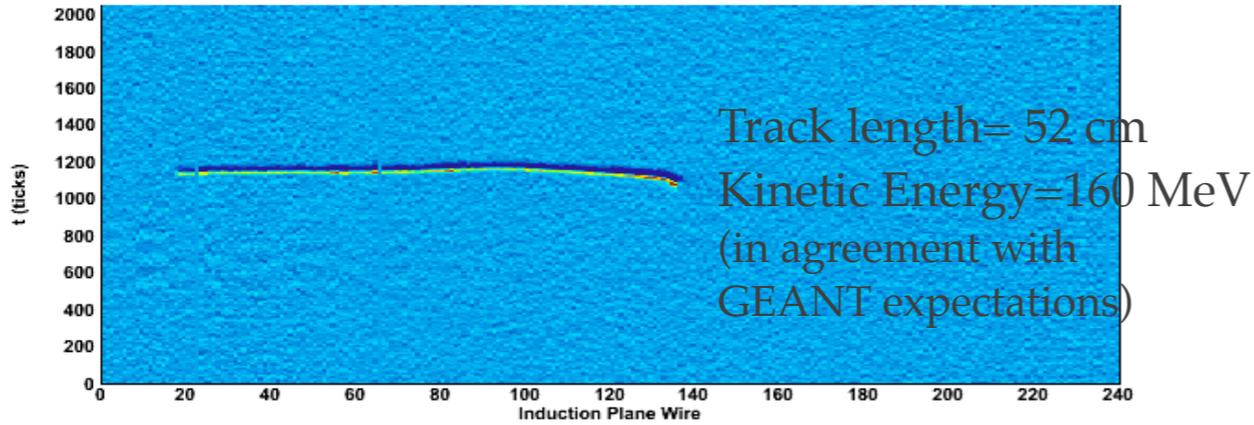
Beam is at -3°



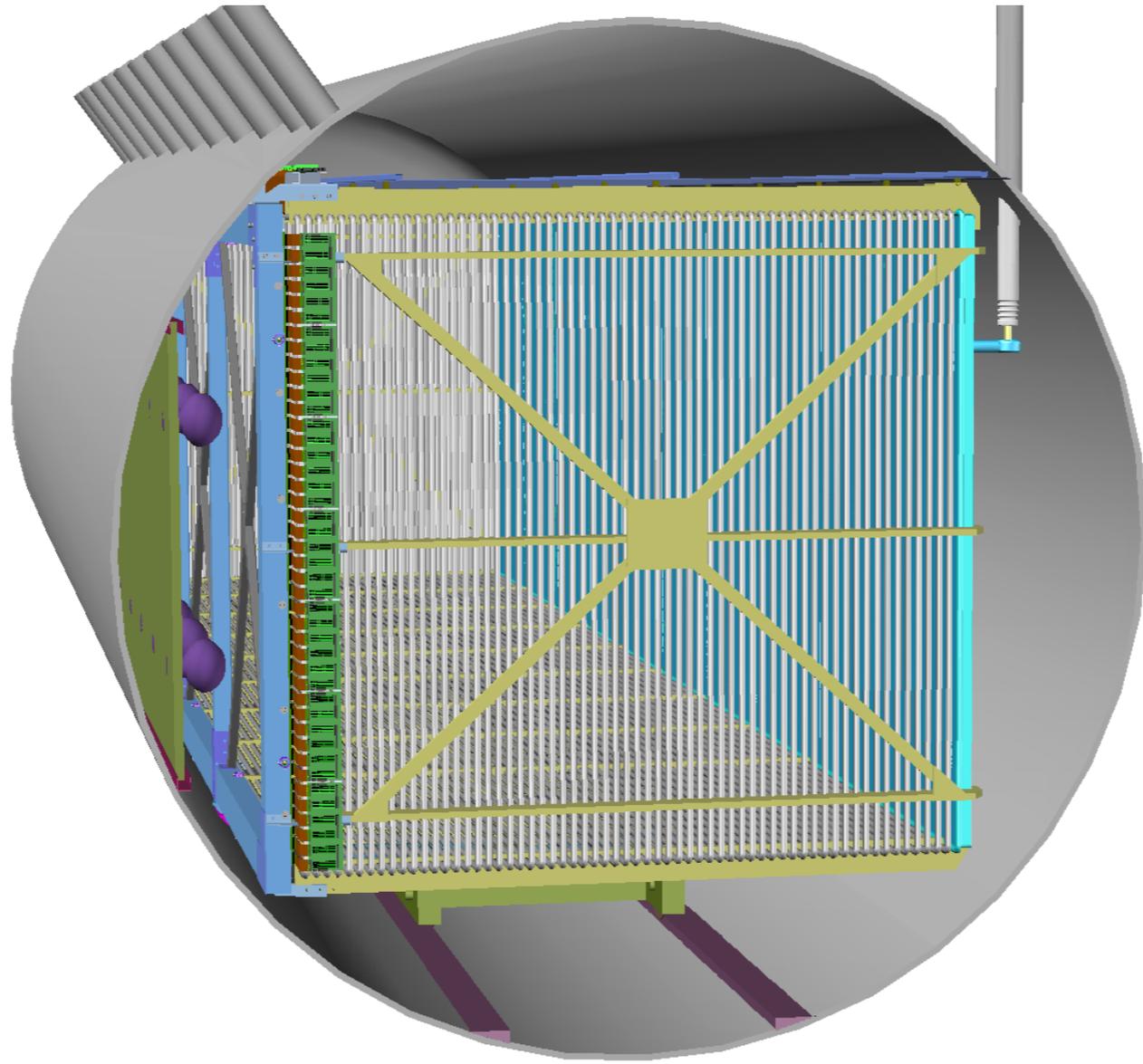
"X-ray" of detector boundaries showing **begin** and **end** of each muon track



ArgoNeuT: Calorimetry



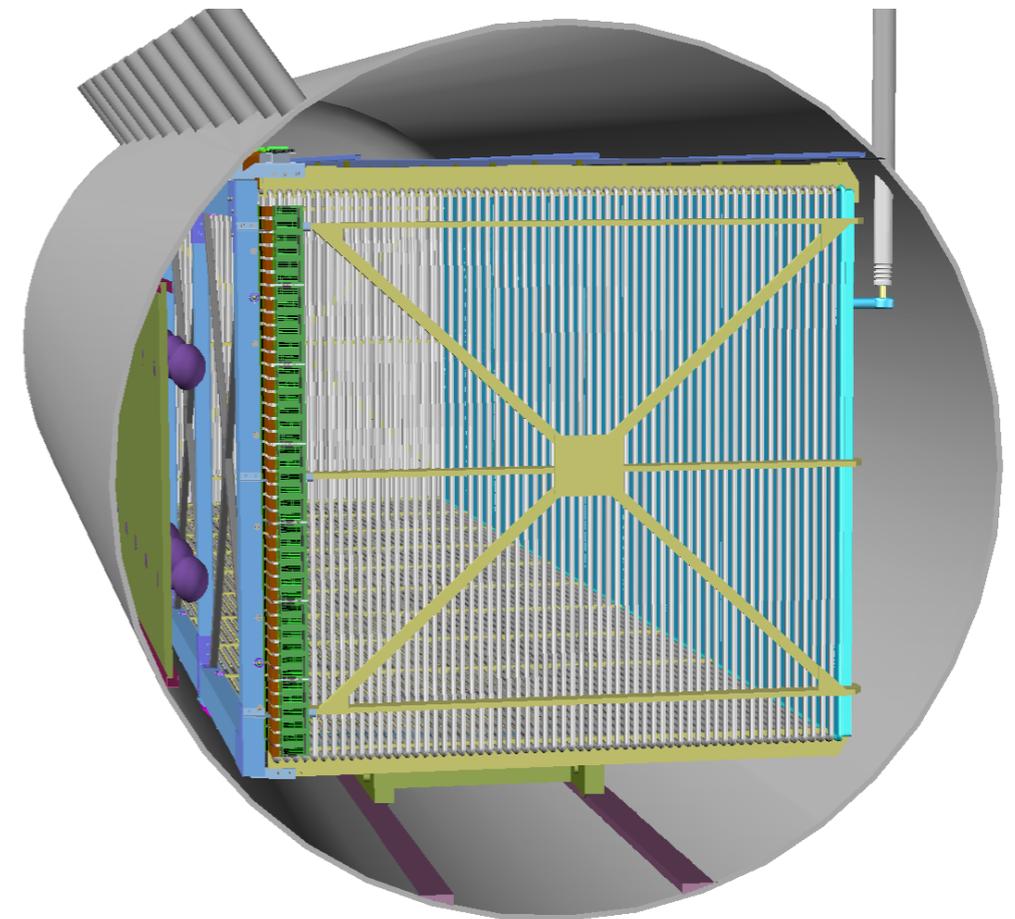
MicroBooNE



MicroBooNE

- Want to continue moving towards LArTPCs of larger sizes...
- MicroBooNE is a LArTPC experiment that will operate in the on-axis Booster neutrino beam
- Combines timely **physics** with **hardware** R&D necessary for the evolution of LArTPCs.
 - ▶ MiniBooNE low-energy excess
 - ▶ Low-Energy Cross-Sections
 - ▶ Cold Electronics (preamps in liquid)
 - ▶ Long drift (2.5m)

Cryostat Volume	150 Tons
TPC Volume (l x w x h)	89 Tons (10.4m x 2.5m x 2.3m)
# Electronic Channels	~8500
Electronics Style (Temp.)	CMOS (87 K)
Wire Pitch (Plane Separation)	3 mm (3mm)
Max. Drift Length (Time)	2.5m (1.5ms)
Wire Properties	0.15mm diameter SS, Cu/ Au plated
Light Collection	~30 8" Hamamatsu PMTs



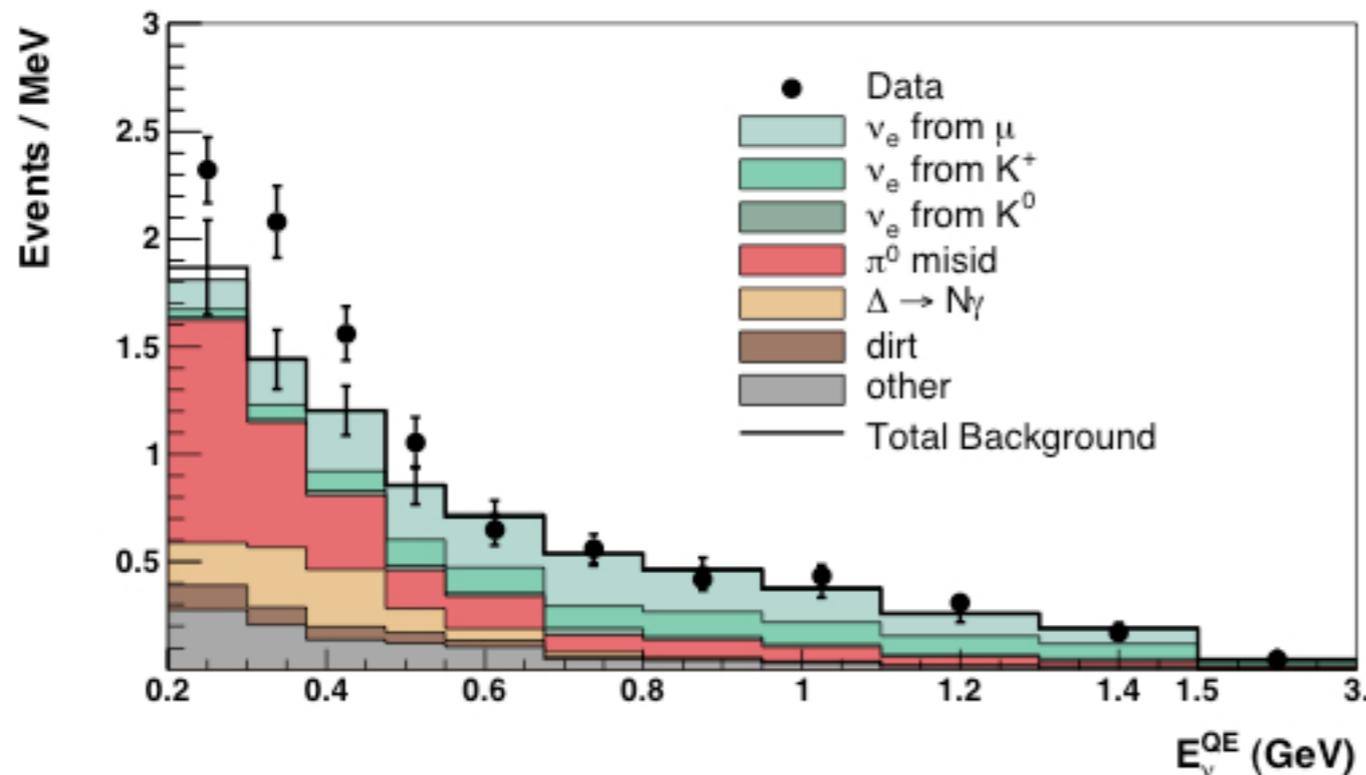
- ➔ Joint NSF / DOE Project
- ➔ \$1.1M NSF MRI for TPC, PMTs

- ★ Stage 1 approval from Fermilab directorate in June 2008
- ★ DOE CD-0 (Mission Need) in October 2009
- ★ DOE CD-1 June 2010
- ★ DOE CD-2 (early 2011)

MicroBooNE: Physics

- Address the MiniBooNE low energy excess
 - ▶ MiniBoone is a Cerenkov detector that looked for ν_e appearance from a beam of ν_μ
 - ▶ Does MicroBooNE confirm the excess?
 - ▶ Is the excess due to a electron-like or gamma-like process?
- Prove effectiveness of electron / gamma separation technique (using dE/dX information).
- Low Energy Cross-Section Measurements (CCQE, NC π^0 , $\Delta \rightarrow N\gamma$, Photonuclear, ...)
- Continue development of automated reconstruction (building on ArgoNeuT's effort).

MiniBooNE ν_e Appearance Result



MiniBooNE Result Excess

200-300MeV: 45.2 ± 26.0 events

300-475MeV: 83.7 ± 24.5 events

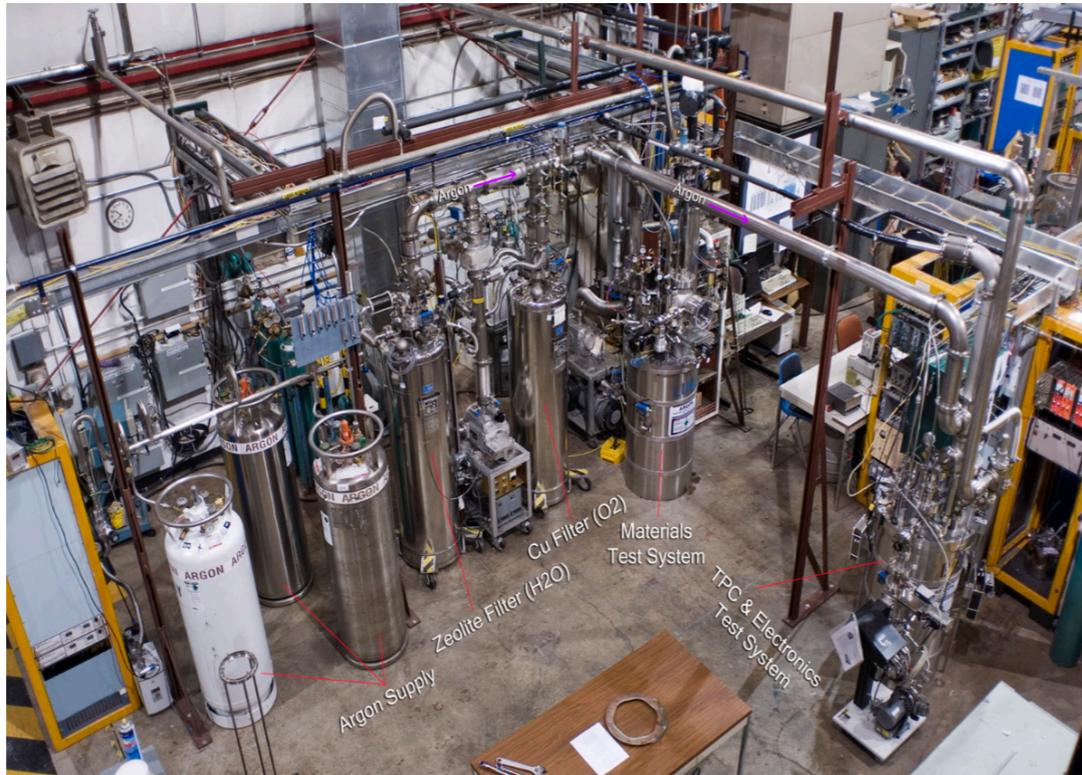
MicroBooNE will have 5σ significance for electron-like excess, 3.3σ for photon-like excess.

Refs:

1.) *Unexplained Excess of Electron-Like Events From a 1-GeV Neutrino Beam* MiniBooNE Collaboration, Phys. Rev. Lett. 102, 101802 (2009)

Liquid Argon Purity R&D

Purity Systems at Fermilab



Materials Test Stand at Fermilab



Cryostat for 30-ton test

- Controlling argon purity is vital for the LArTPCs to function.
- Fermilab group has two projects focused on better understanding argon purity.
 - ▶ Materials Test Stand is used to study the impact of different materials on argon purity.
 - ▶ Liquid Argon Purity Demonstrator will shed light on whether purity can be achieved starting from a non-evacuated environment.

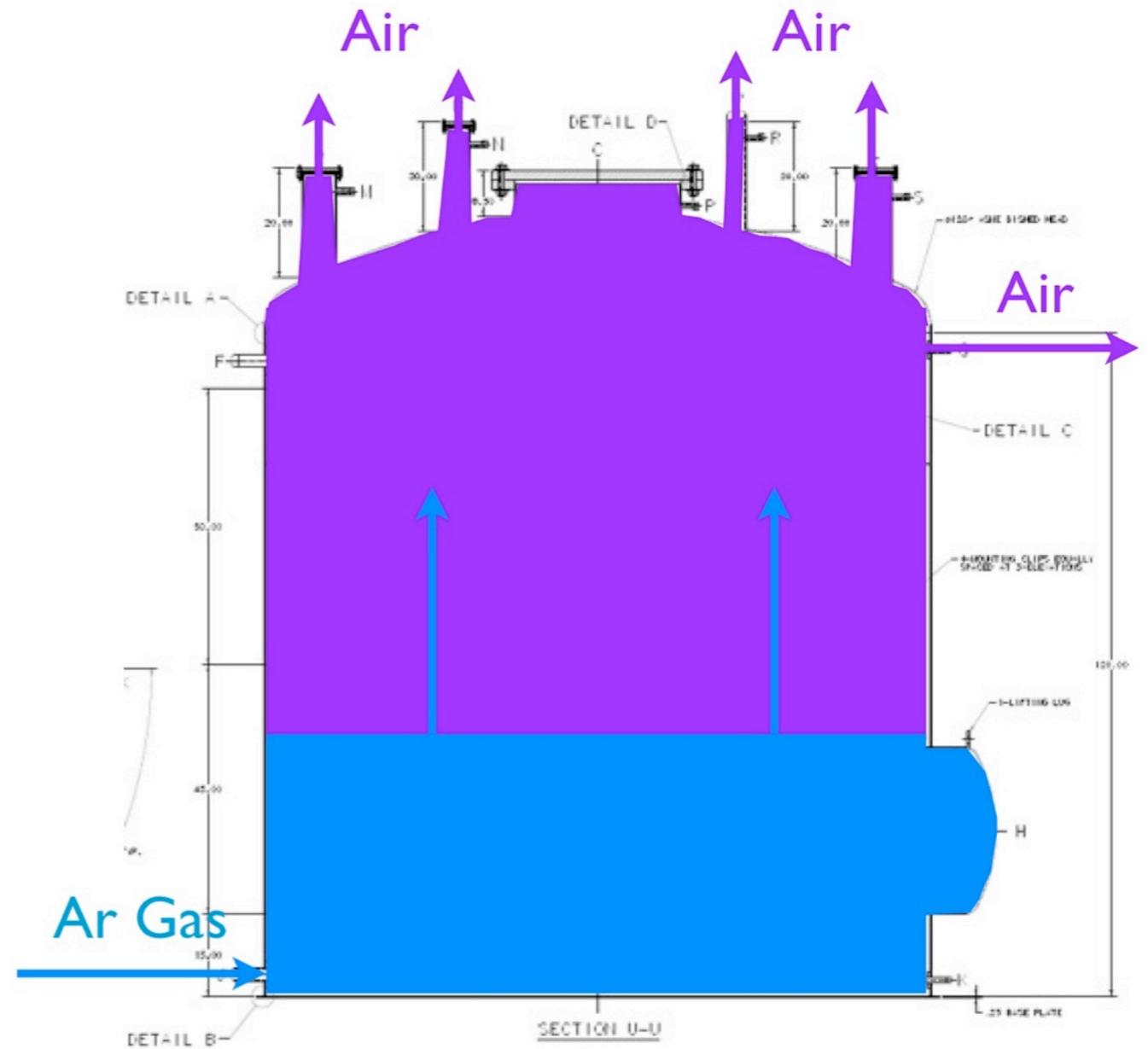
Liquid Argon Purity Demonstrator

- Looking into alternatives to evacuation for large vessels
- Primary goal: show required electron lifetimes can be achieved without evacuation in an empty vessel - Phase I
- Phase II will place TPC materials into the volume and show that the lifetime can still be achieved
- Will also monitor temperature gradients, concentrations of water, O₂



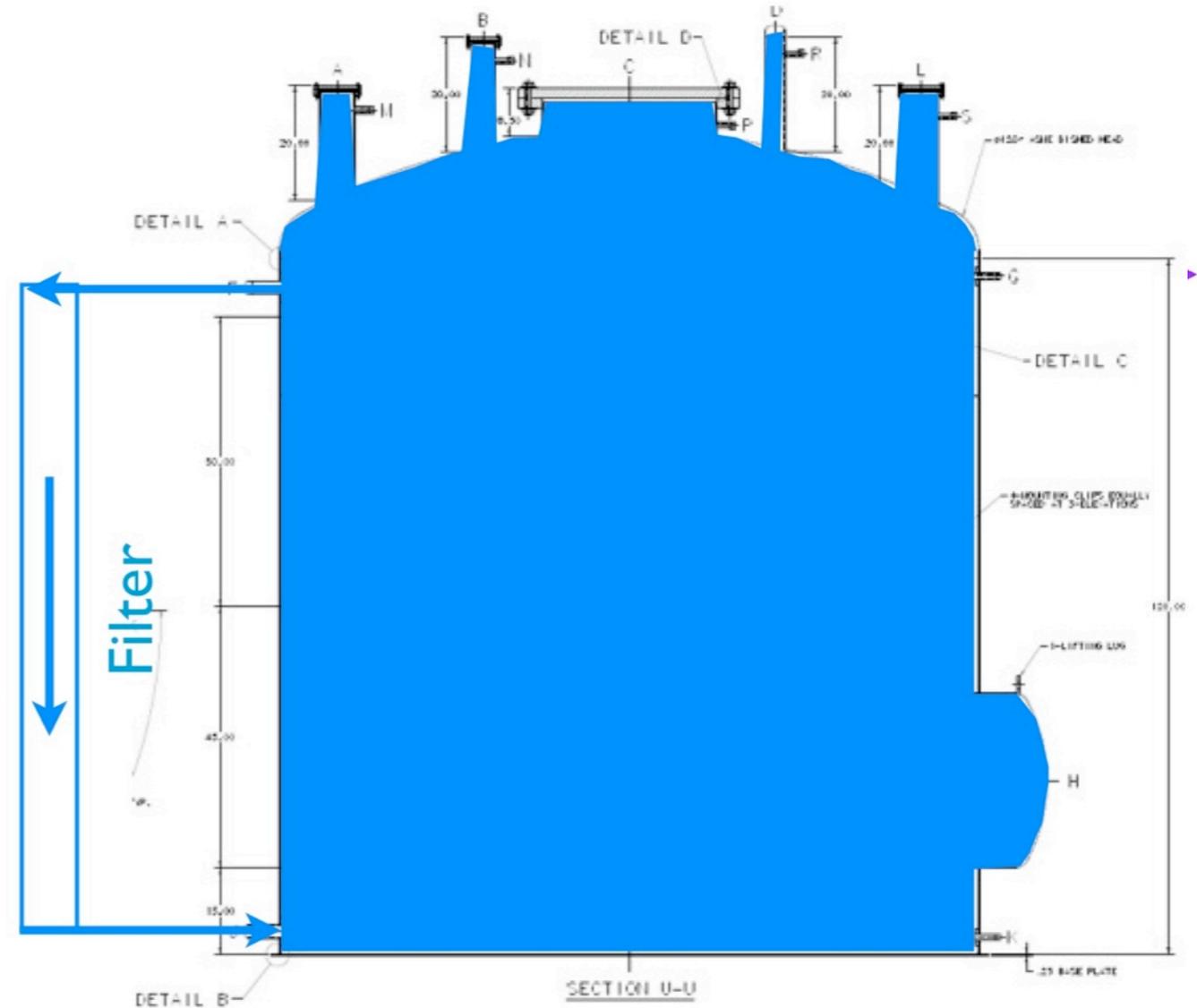
Liquid Argon Purity Demonstrator

- Use an argon piston for initial purification, followed by a few more volume exchanges
- Cycle a few volumes of clean, warm Ar gas through the volume to push out ambient air and dry out surfaces
- Then recirculate the gas through filter system to achieve <50 ppm contamination



Liquid Argon Purity Demonstrator

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Liquid Argon Purity Demonstrator

- One goal of LAPD is to understand how to scale the cryogenics system up for a multi-kiloton scale detector
- Will do studies of:
 - ▶ Oxygen concentration at various depths in the tank vs time during purge - will compare vs ANSYS models to verify modeling for large detectors
 - ▶ Number of LAr volume exchanges needed to reach necessary lifetime for 2.5m drift
 - ▶ Rate of volume exchanges necessary to maintain lifetime
 - ▶ Filter capacity as a function of flow rate
 - ▶ Ability to recover from intentional contamination

Liquid Argon Purity Demonstrator

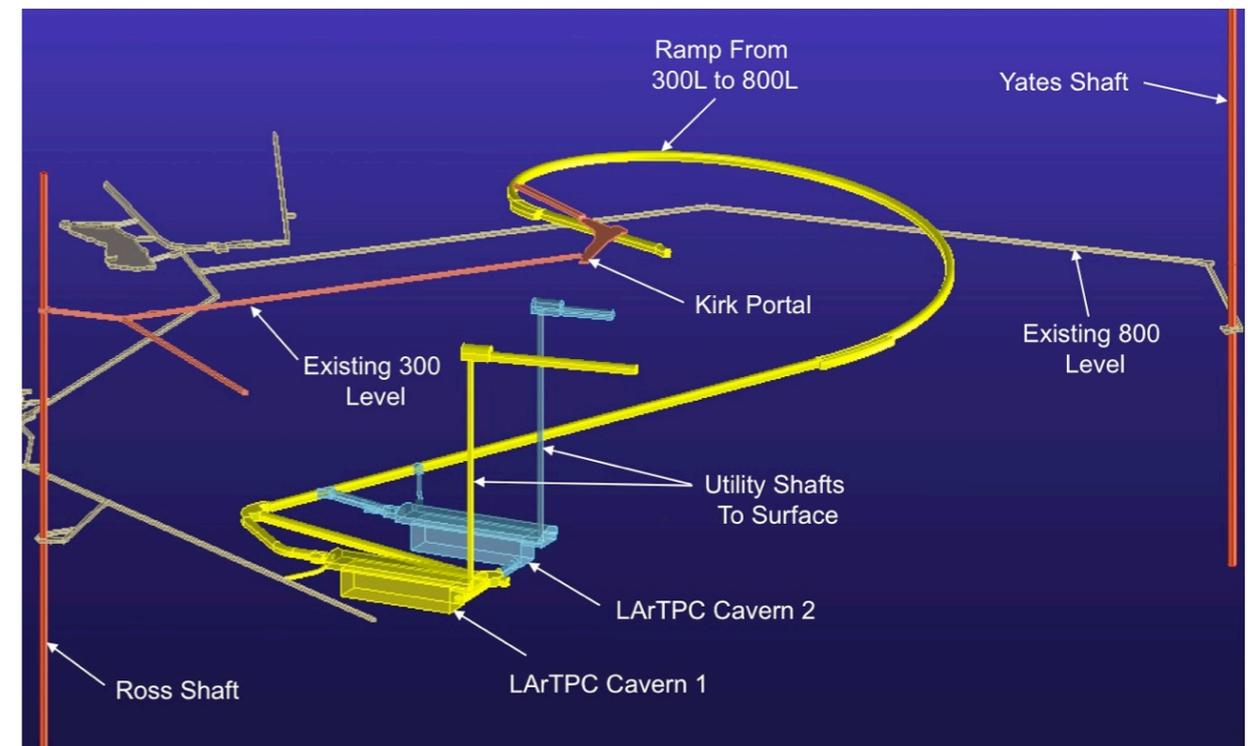
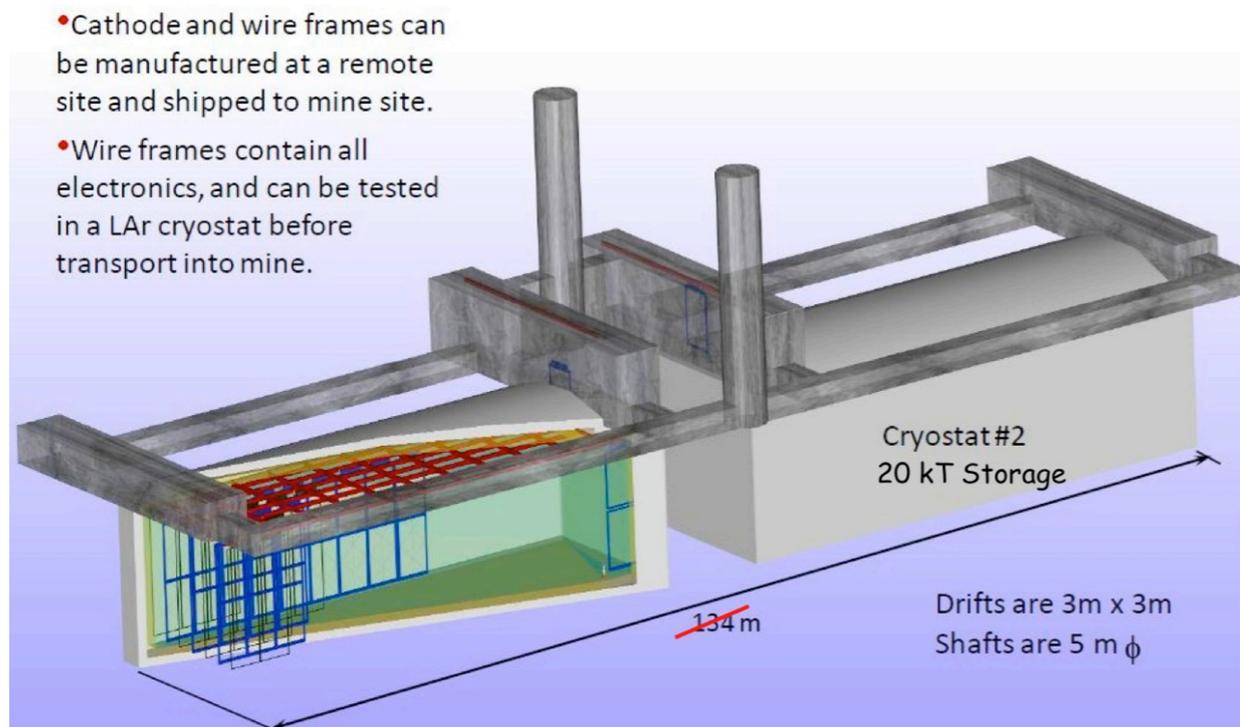
- Tank delivered September 1, 2009
- Placed in PC4 - (fixed target enclosure at Fermilab)
- Completely insulated with foam board, 45 W/m² heat leak
- Filling scheduled to start in January 2011



Massive Liquid Argon Detectors

Massive LArTPC Detectors

- Description here is the Reference design for the LBNE project.
- LArTPC at DUSEL could be two ~20 kTon modules.
- Focusing on locating this detector at the 800ft level at DUSEL.



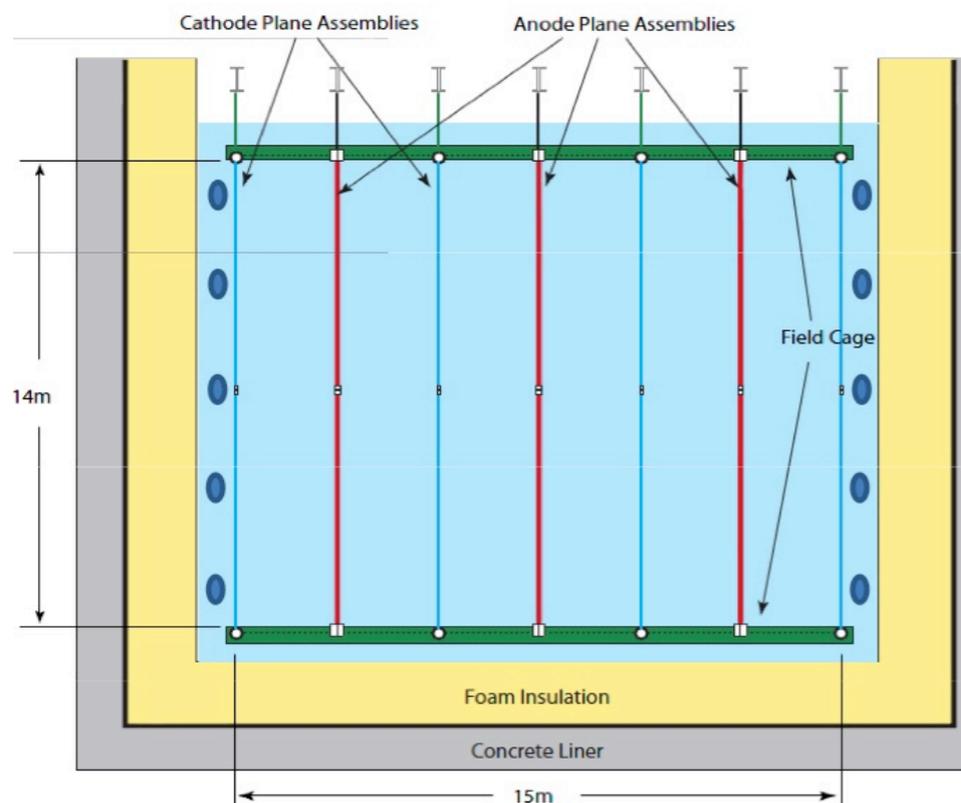
~20 kTon LArTPC module(s)

800-ft. level layout.

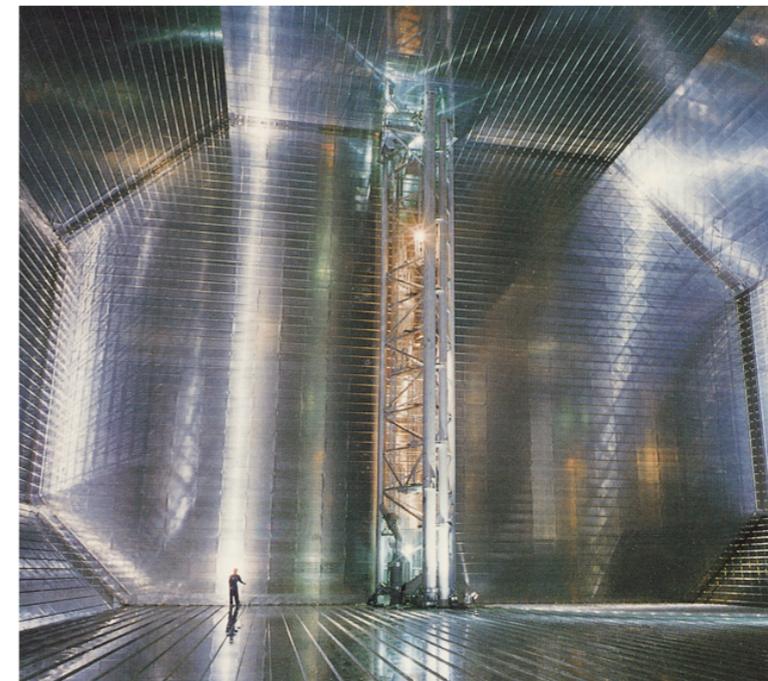
Cryostat Volume	~25 kTons
TPC Volume	~16.7 kTons
# Readout Wires	~645000 (128:1 MUX)
Wire Pitch	~3 mm
Electronics Style (Temp.)	CMOS (87 K)
Max. Drift Length	~2.5m
Light Collection	TBD

Massive LArTPC Detectors

- Storage of many kilotons of cryogenic liquids not such a crazy idea...storage of many kilotons of ultra-high purity liquid is the major unknown.
- Industrial companies use ocean liners to transport Liquefied Natural Gas (LNG) in “membrane” cryostats fitted to the hull.
- Liquid space would be divided up into regions with drift length $\sim 2.5\text{m}$ by hanging vertical cathode/anode plane assemblies from the ceiling of the cryostat.



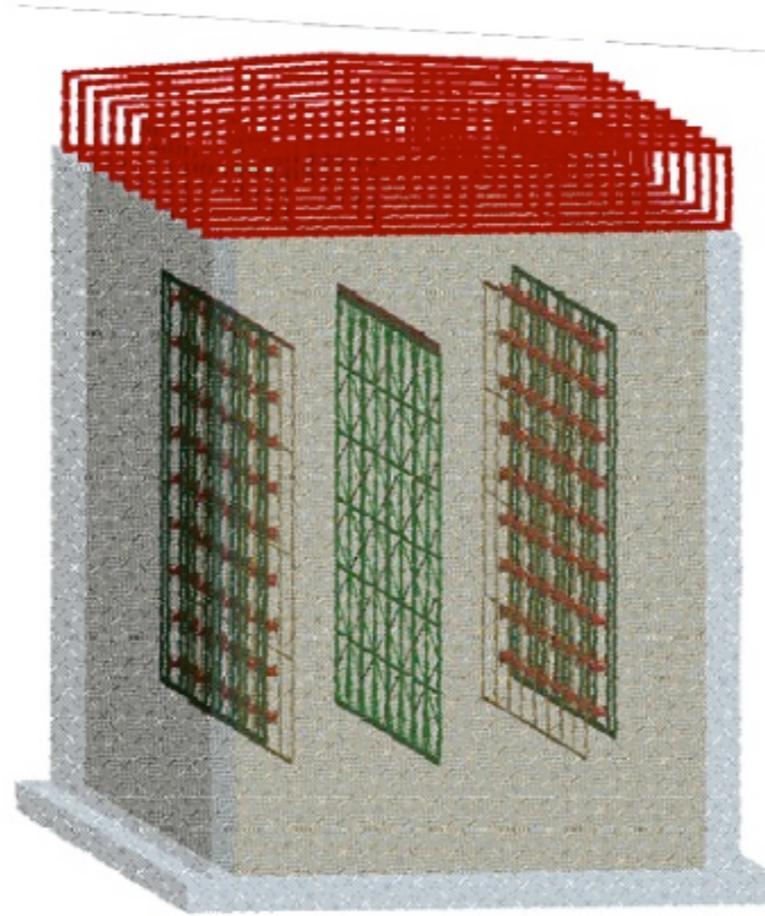
Example layout of LAr20



Membrane Interior

Massive LArTPC Detectors R&D

- Plan is being developed to conduct R&D for using membrane cryostats in the LBNE LArTPC.
- This plan includes:
 - Repeat LAPD using a ~30 ton membrane style cryostat.
 - Build an “engineering prototype” with a membrane style cryostat:
 - ▶ 830 tons LAr total
 - ▶ Three TPC cells
 - ▶ 480 tons LAr active



830 ton prototype

Conclusion

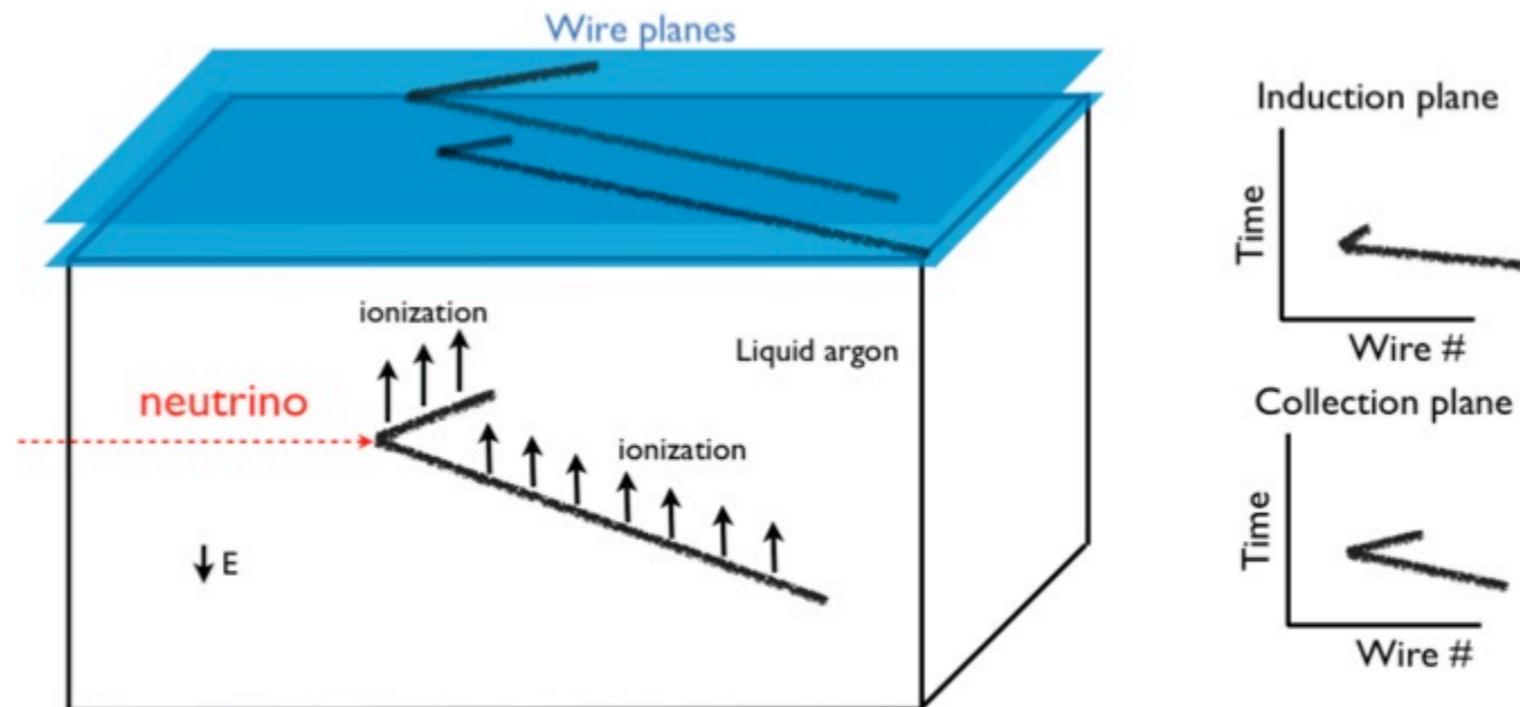
- Liquid Argon detectors provide exceptional capabilities for neutrino physics, and there is significant R&D ongoing at Fermilab to develop this technique for very large scales.
- Several different projects are part of this R&D:
 - ▶ ArgoNeuT - small scale LArTPC to develop reconstruction tools using real neutrino data. Completed operations in 2010.
 - ▶ MicroBooNE - 89 ton LArTPC to do physics as well as hardware R&D (cold electronics, purge test, long drift). Operational in 2013.
 - ▶ Liquid Argon Purity Demonstrator (LAPD) - 30 ton vessel to test whether purity can be achieved without evacuation. Operational in early 2011.
 - ▶ LAr20 - Option for LBNE LArTPC...plan is forming for R&D to conduct on a “smaller” (30-1000 ton) scale.

Back-Up Slides

LArTPC Principle

TPC = Time Projection Chamber

- Neutrino interactions within the TPC produce charged particles that ionize the argon as they travel ($55k e^- / \text{cm}$).
- Ionization is drifted along E-field to wireplanes, consisting of wires spaced a few millimeters apart.
- Location of wires within a plane provides position measurements...multiple planes give independent views.
- Timing of wire pulse information is combined with drift speed to determine drift-direction coordinate.
- Scintillation light also present, can be collected by Photomultiplier Tubes and used in triggering.



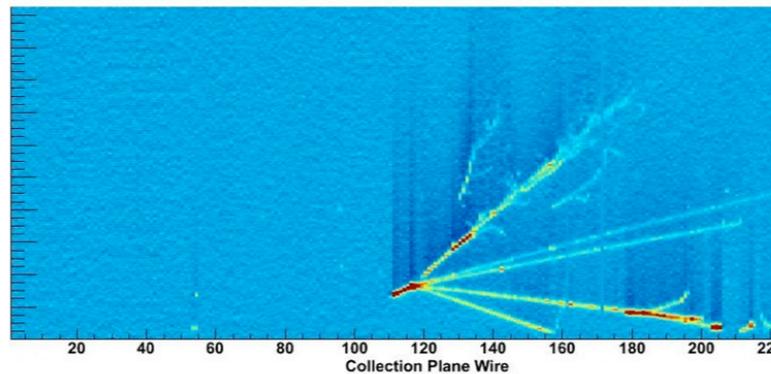
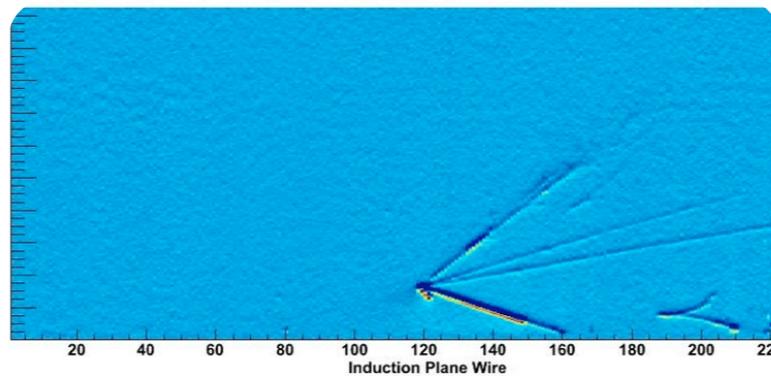
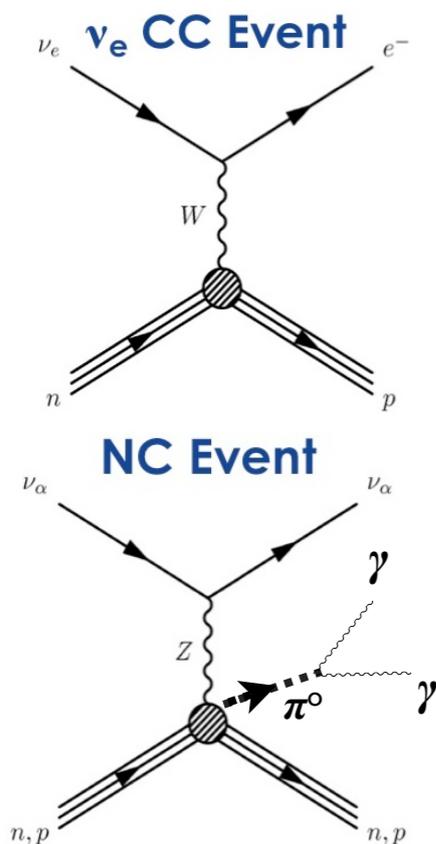
Refs:

1.) *The Liquid-argon time projection chamber: a new concept for Neutrino Detector*, C. Rubbia, CERN-EP/77-08 (1977)

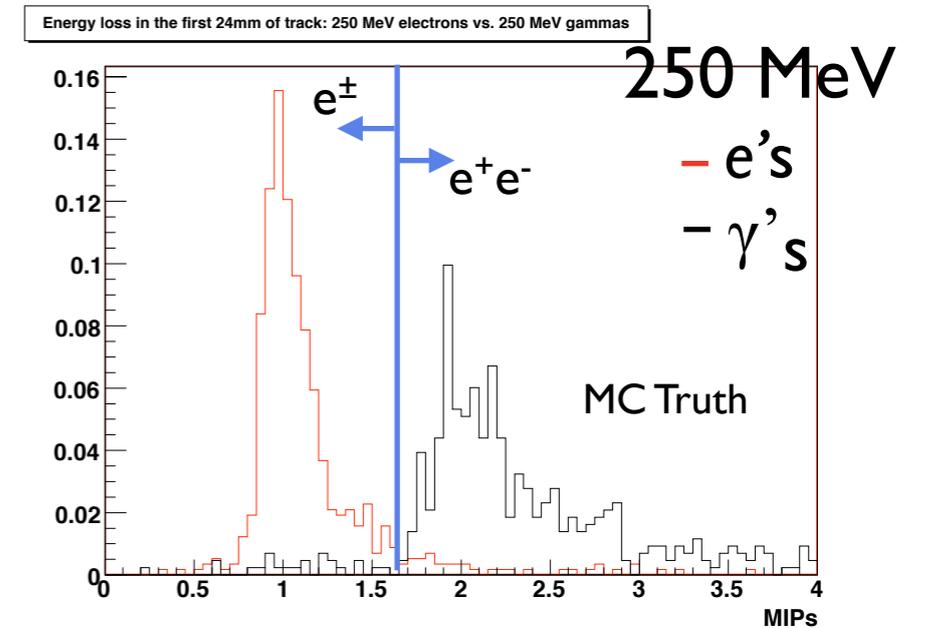
LArTPC Advantages

excellent e/γ separation \rightarrow superior background rejection

- Particle identification comes primarily from dE/dx (energy deposited) along track.
 - ▶ Millimeter wire spacing plus rapid sampling provides fine-grained resolution
- ν_e appearance: Excellent signal (CC ν_e) efficiency and background (NC π^0) rejection
 - ▶ Topological cuts will also improve signal/background separation
- Appear scalable to large sizes.
- Beautiful, bubble-chamber like events!



ArgoNeuT Event

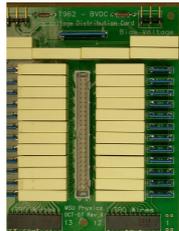


dE/dx for electrons and gammas in first 2.4 cm of track

Materials Test System at Fermilab



BNL 4-ch Amp

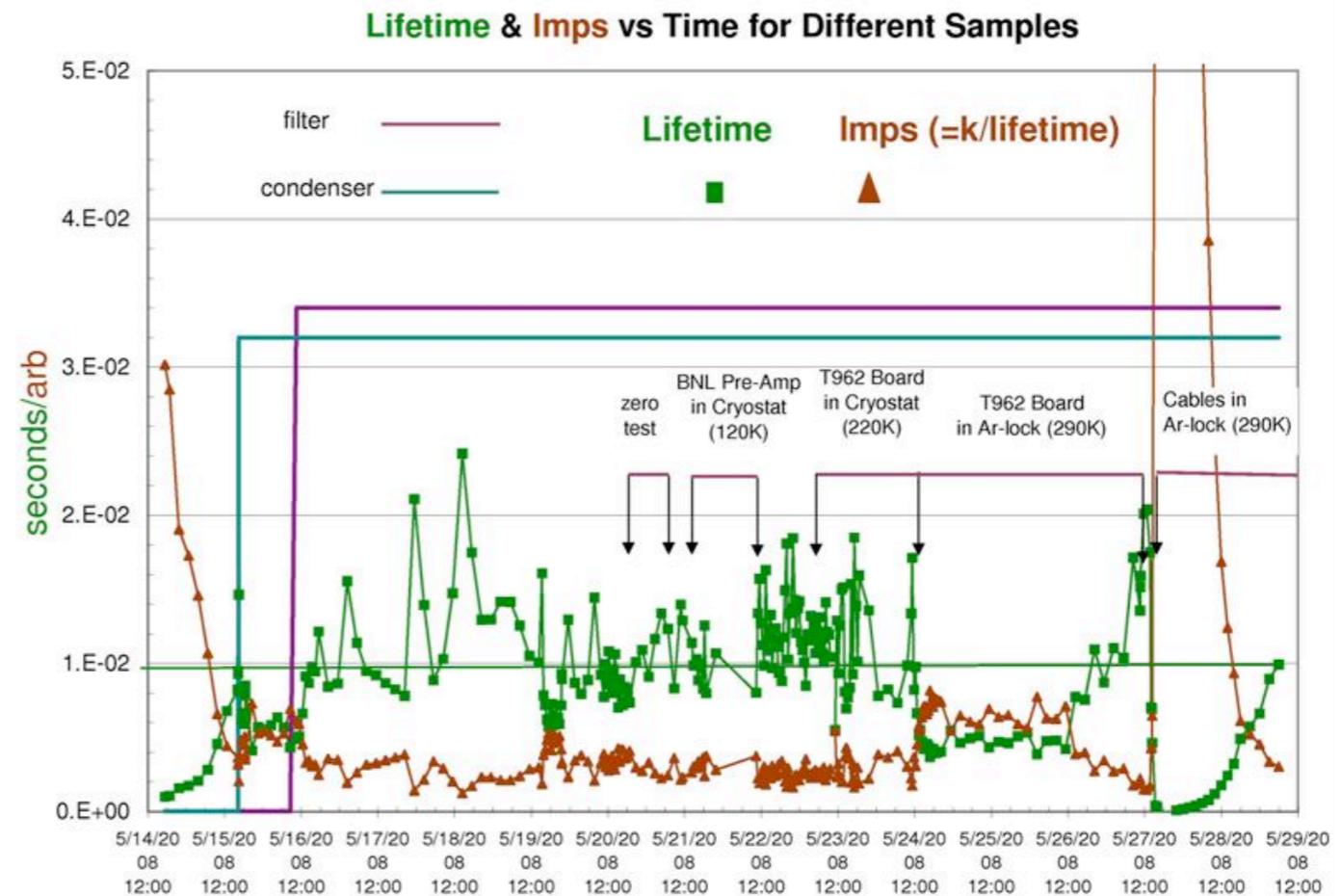
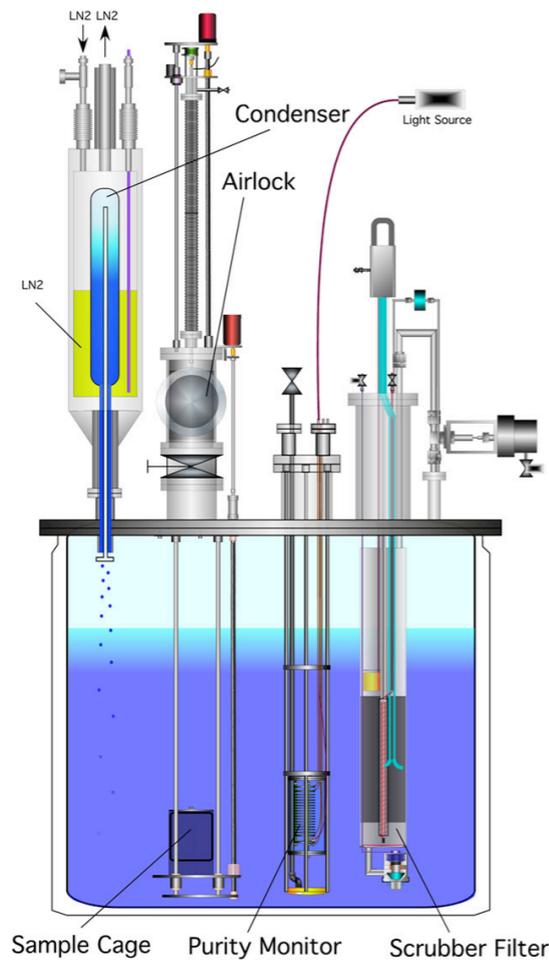


ArgoNeuT Bias Board



Cables/Cable-Tie Bundle

Measurements with the Materials Test System



ArgoNeuT: Electronics

- Bias voltage distribution & blocking capacitors on the TPC
- FET preamplifier similar to D0/ICARUS front-end
- Wide bandwidth filtering (10 - 159 kHz, now)
 - ▶ Full information on most hits/tracks
 - ▶ Employ DSP to extract hit/track parameters
- Digitization boards sample at 5 MHz (198ns), 2048 samples/channel
- Minimize noise sources
 - ▶ Double shielding of feed-through and preamplifiers
 - ▶ Remote ducted cooling
 - ▶ Extensive DC power filtering

