Liquid Argon Neutrino Detector Development at Fermilab

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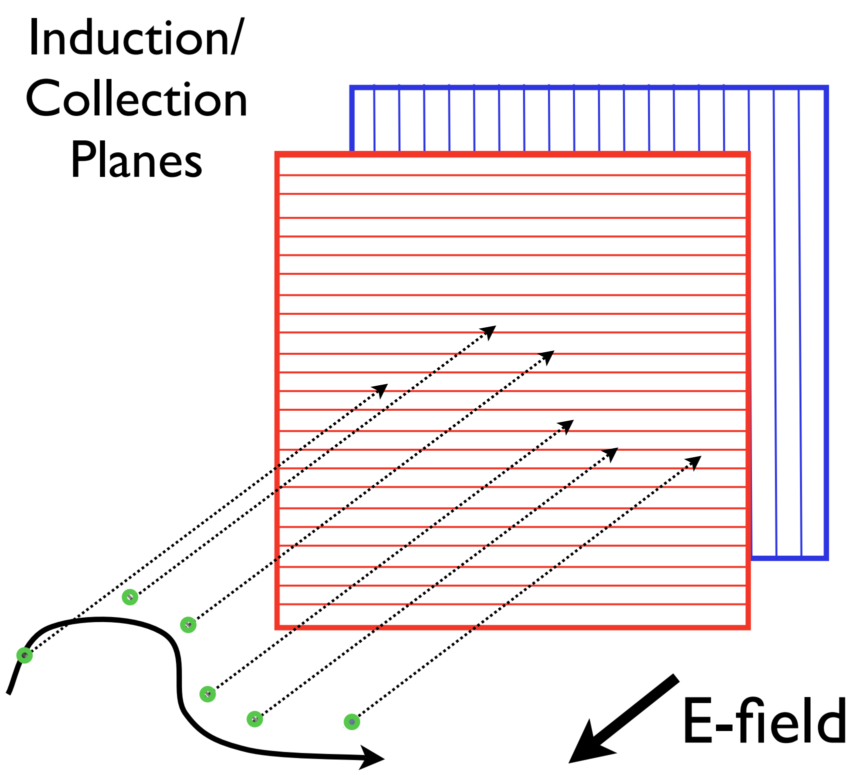
Neutrino 2010
Athens, Greece

Introduction

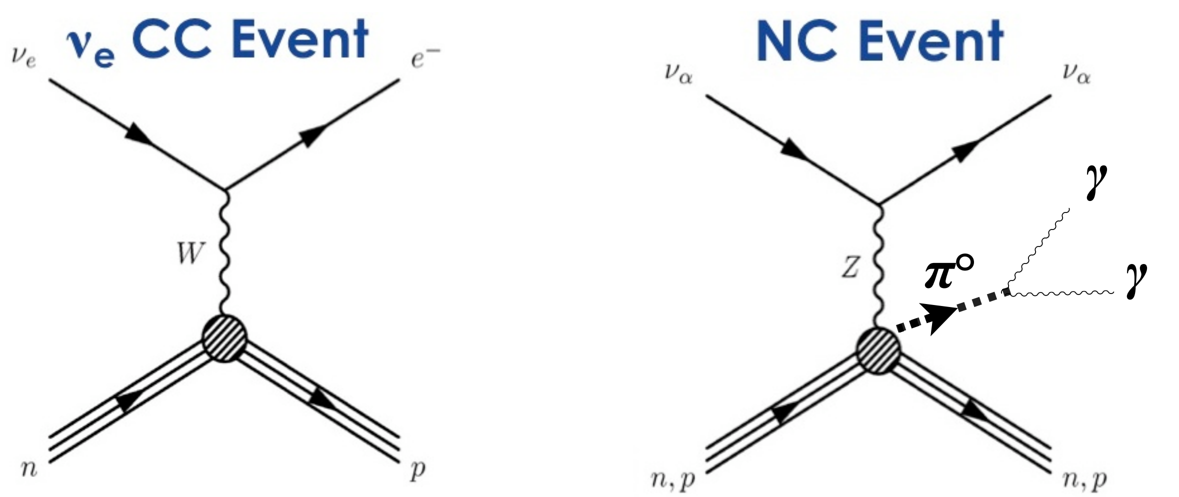
•Liquid Argon Time Projection Chambers (LArTPCs) are very attractive for neutrino physics.
•There is extensive experience with LArTPCs in Europe (see previous talk from ICARUS).
•In the U.S. there has recently been much activity in developing LArTPCs for future long-baseline neutrino experiments (LBNE).
•This talk will focus on LArTPCs of increasingly larger sizes that are being developed at Fermilab.



LArTPC idea: Ionization present in the aftermath of a neutrino interaction in liquid argon is drifted towards fine-grained readout wireplanes that are connected to low-noise electronics.

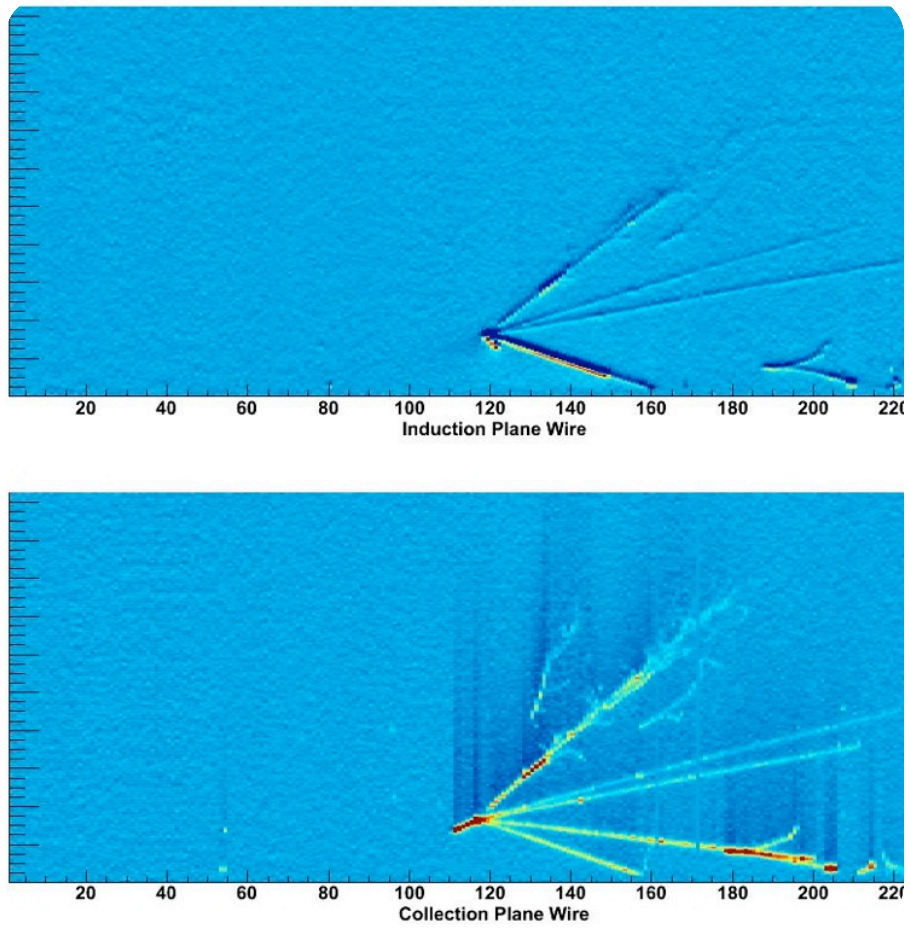
LArTPCs for Neutrinos

- Liquid argon provides a dense target for neutrino interactions, and ample ionization/scintillation for detection.
- Particle identification comes primarily from dE/dx (energy deposited) along track.
  - Wire spacing of a few millimeters combined with digital sampling provides fine-grained resolution
  - Photons (2x MIP dE/dx) and Electrons (1x MIP dE/dx) can be cleanly separated
  - Topological cuts can further improve photon/electron separation
- **Ideal for ν_e appearance experiment**
  - Excellent signal (CC ν_e) efficiency and background (NC π^0) rejection
- Beautiful, bubble-chamber like events!



"appearance" signal

"appearance" background



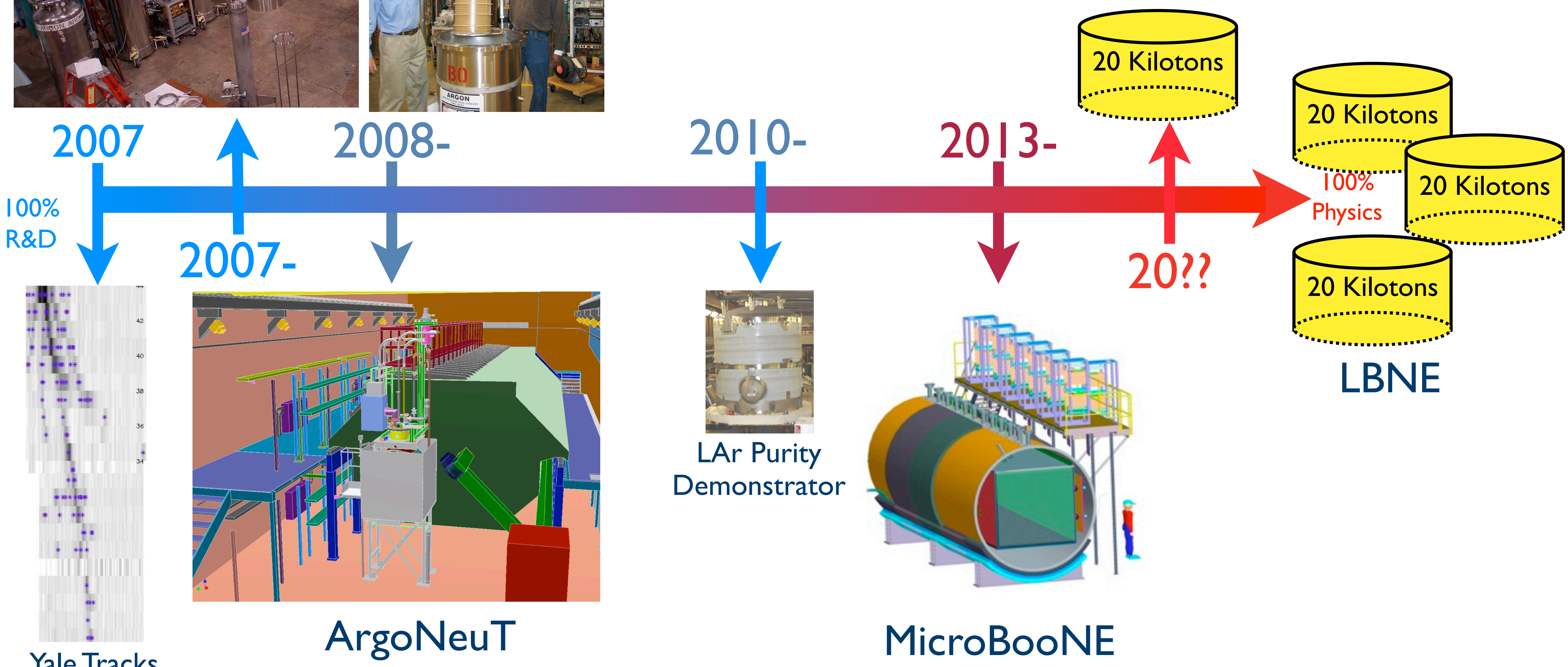
ArgoNeuT Event

Liquid Argon Activities at Fermilab

Materials Test Stand

Electronics Test Stand

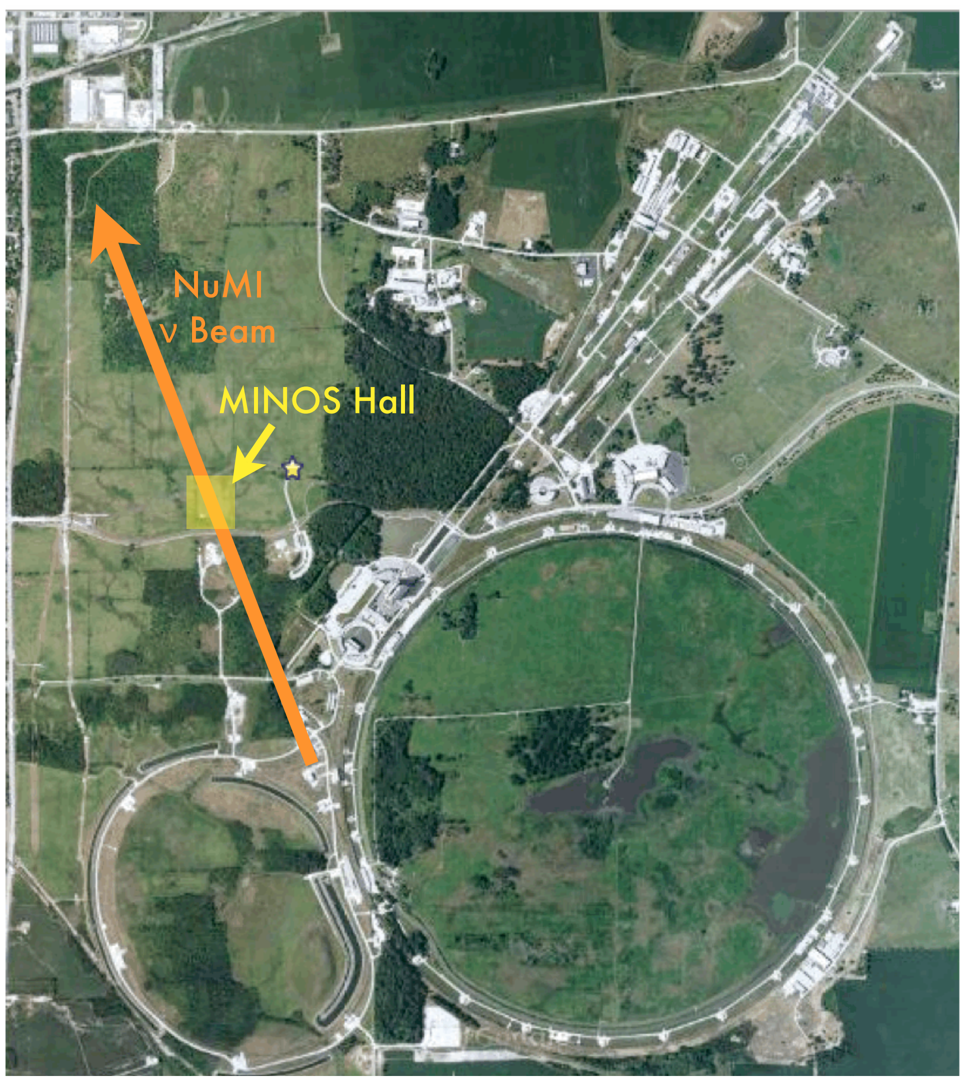
- Tremendous progress in LArTPC development in past few years at Fermilab.
- We are moving from pure R&D towards large detectors with great physics potential.



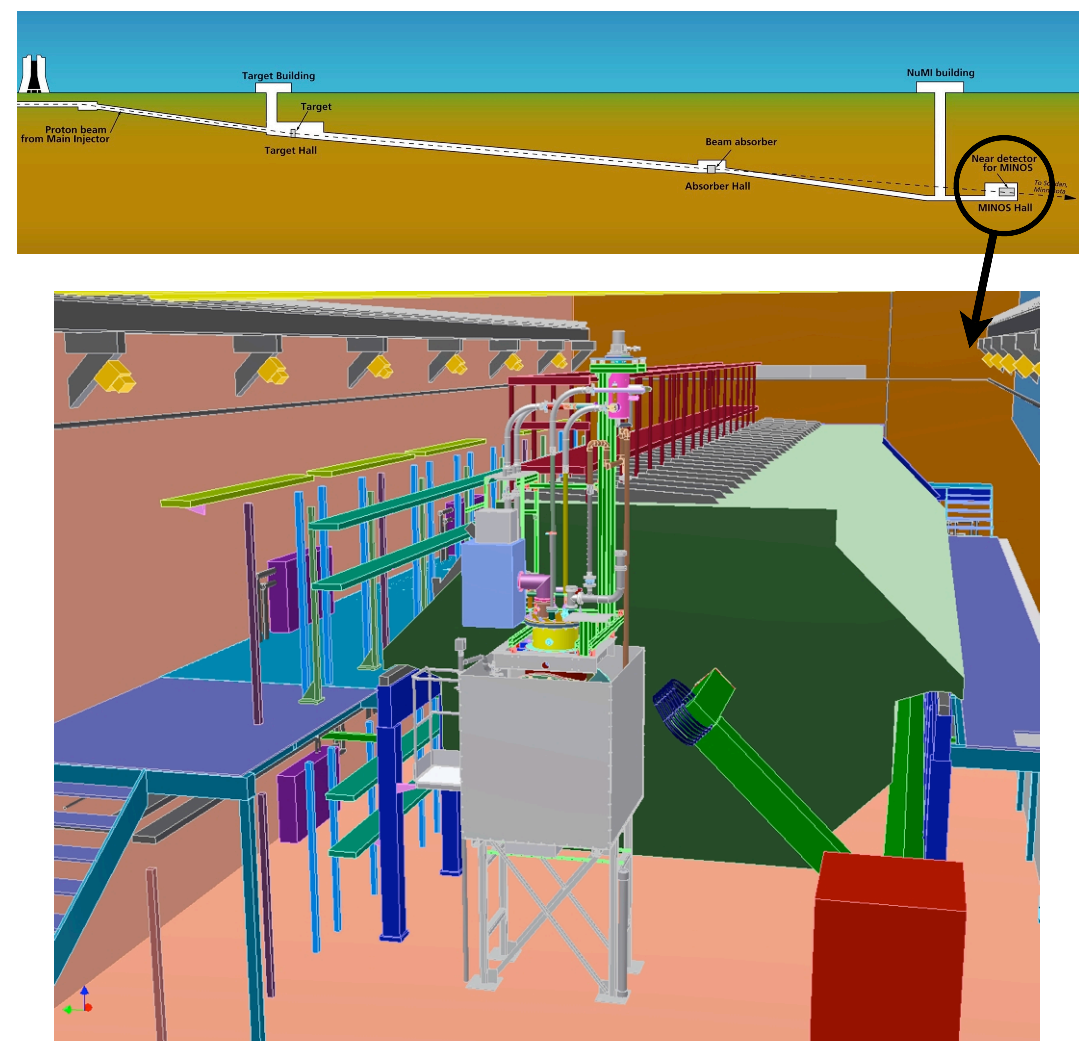
Refs:
1.) *A Regnerable Filter for Liquid Argon Purification* Curioni et al, NIM A605:306-311 (2009)
2.) *A system to test the effect of materials on electron drift lifetime in liquid argon and the effect of water* Andrews et al, NIM A608:251-258 (2009)

ArgoNeuT

- ArgoNeuT is a test project at Fermilab to operate a LArTPC in a neutrino beam.
- Operated in NuMI beam at Fermilab, in front of MINOS near detector (for muon reconstruction).
- Goals:
    - Gain experience building/running LArTPCs in an underground setting.
    - Accumulate neutrino/antineutrino events (1st time in the U.S., 1st time ever in a low-Energy beam).
    - Develop simulation and reconstruction for LArTPCs, and compare MC with data.



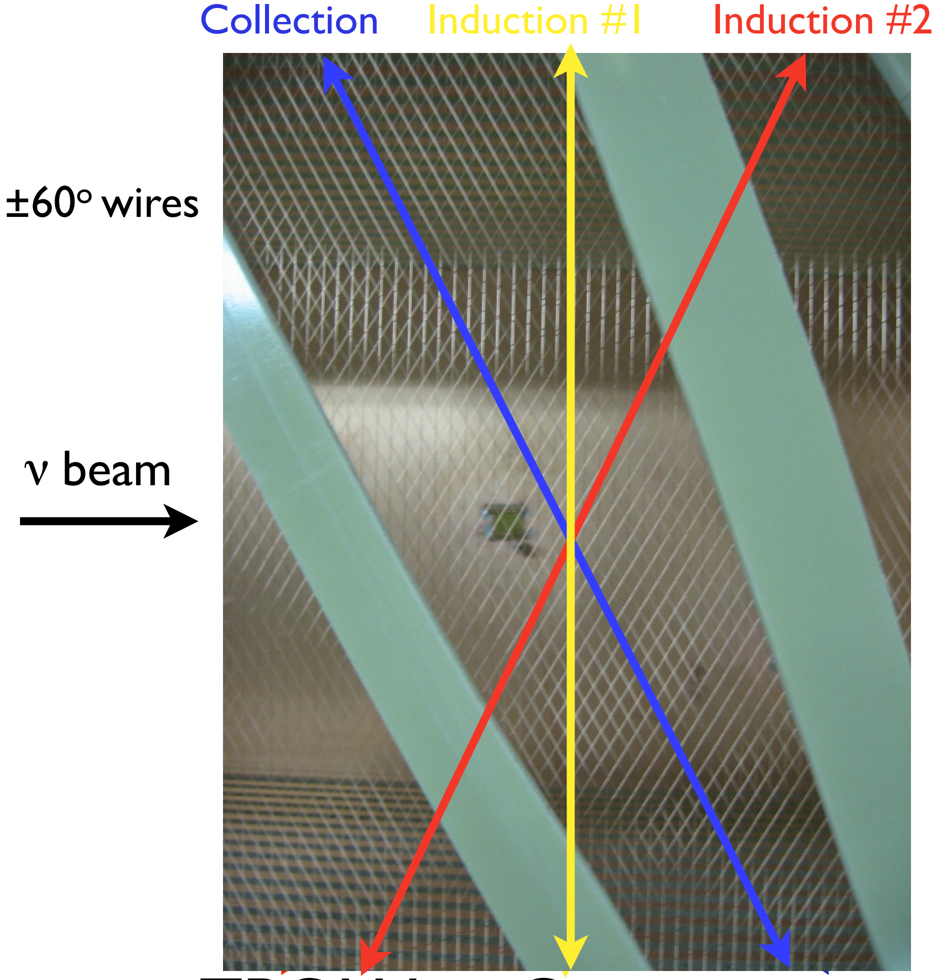
NuMI Beam at Fermilab



MINOS Hall at Fermilab

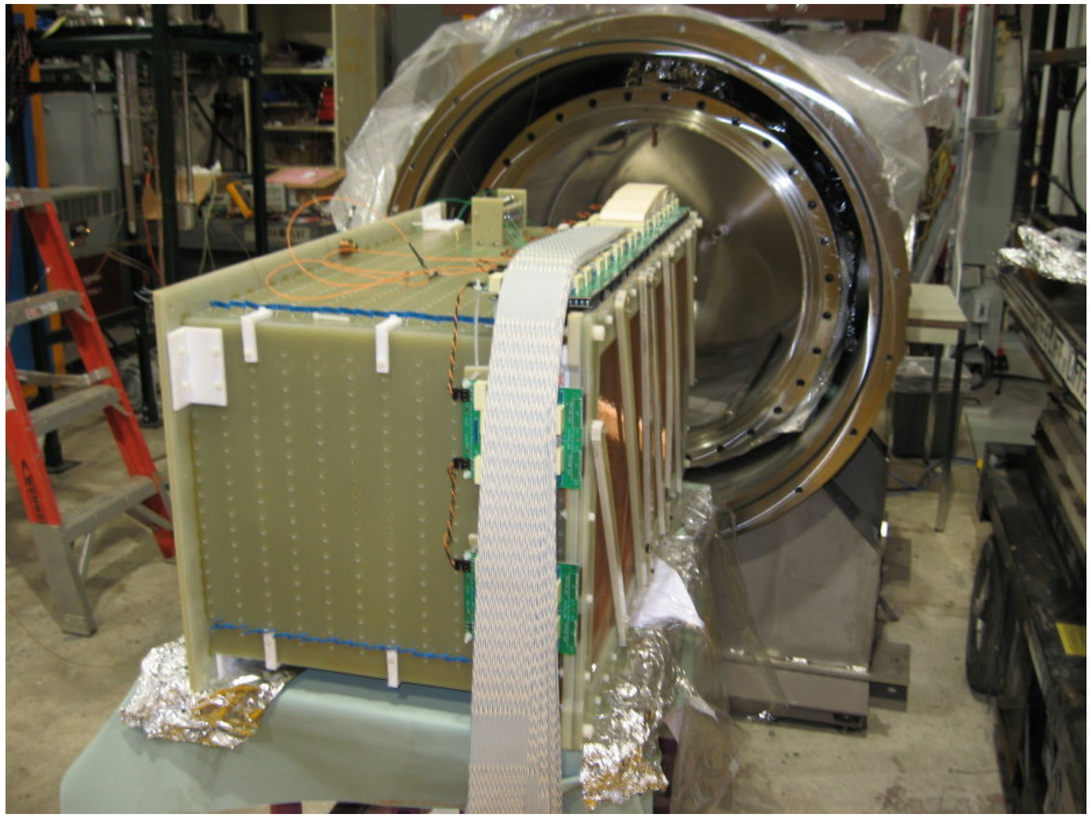
ArgoNeuT: Details

Cryostat Volume	500 Liters
TPC Volume	175 Liters
# Electronic Channels	480
Wire Pitch	4 mm
Electronics Style (Temperature)	JFET (293 K)
Max. Drift Length (Time)	0.5m (330μs)
Light Collection	None



TPC Wire Orientations

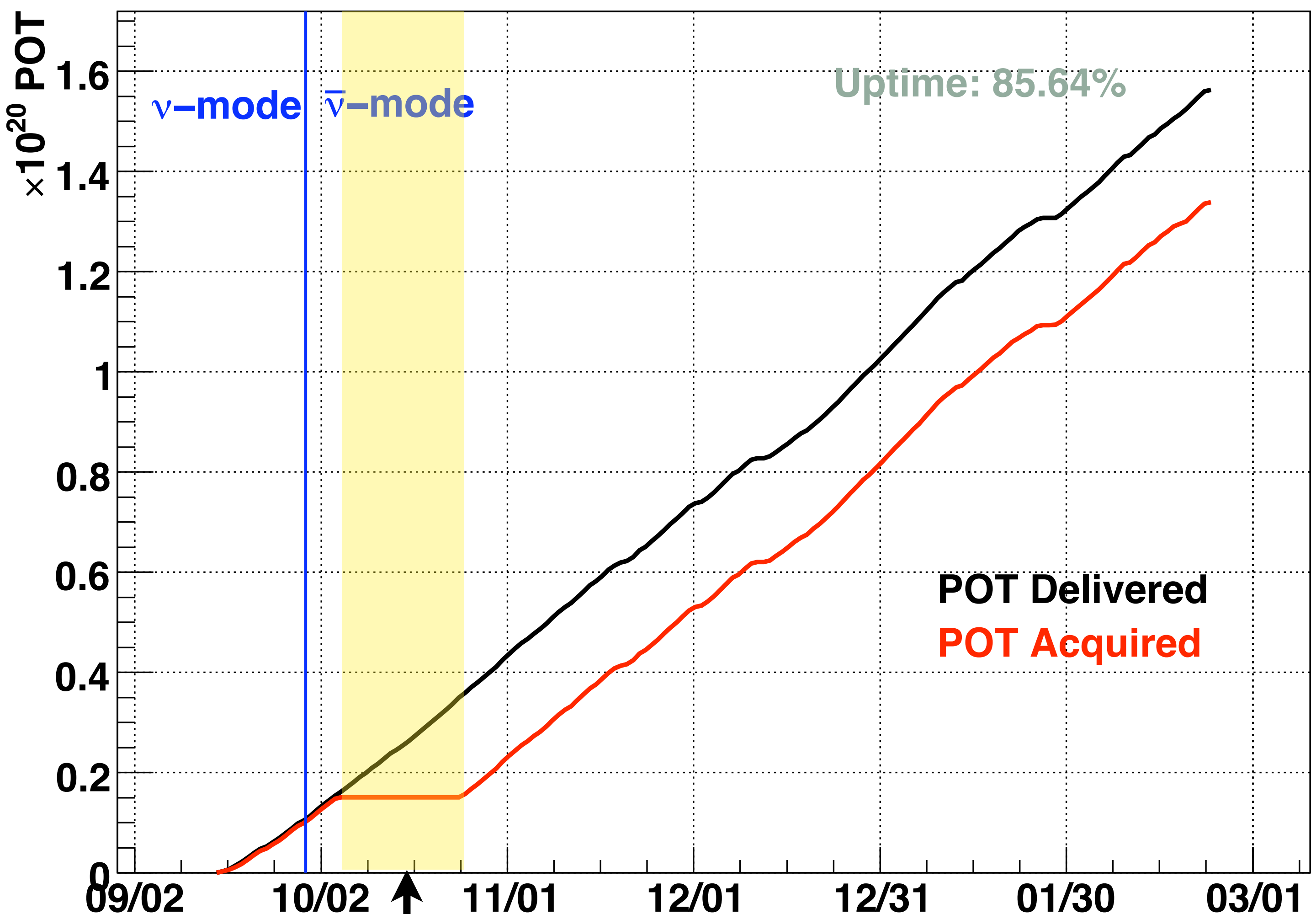

Moving underground (lowering down 350 ft. shaft)


TPC outside of vacuum-insulated cryostat

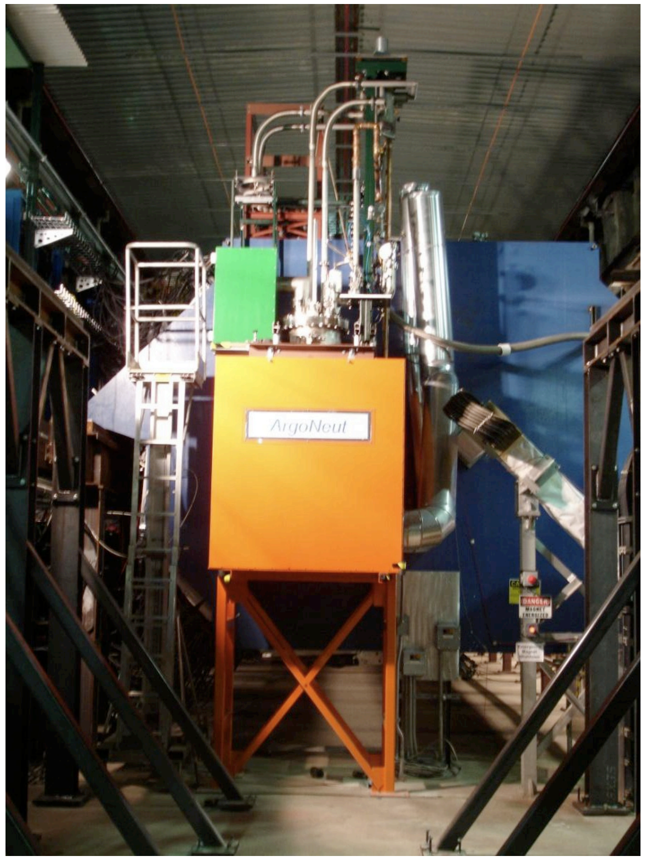
ArgoNeuT: NuMI Run

- ArgoNeuT acquired ~1.4E20 Protons On Target (P.O.T.), primarily in anti-neutrino mode
- Data is being used to develop techniques for reconstructing events in 3D
- Measuring dE/dx particle identification effectiveness using this data will be an important result
- We expect to obtain several cross-section measurements (e.g. CCQE)
- Essentially a “shift-free” detector once filled

ArgoNeuT POT delivered and accumulated



Failure and replacement of off-the-shelf cryocooler.



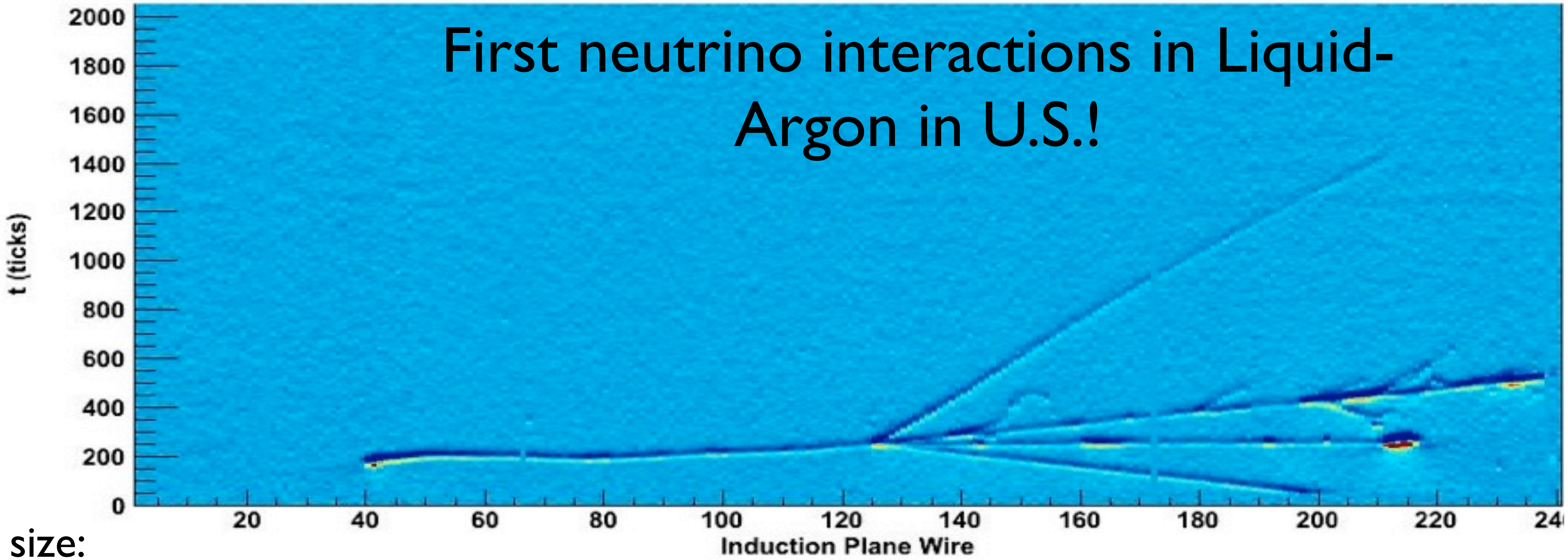
Installing Underground

Event Type	# in 1.4×10^{20} POT
ν_μ CC	5110
$\overline{\nu_\mu}$ CC	5490
ν_e CC	142
NC	4266

Total Sample

ArgoNeuT Neutrino Event

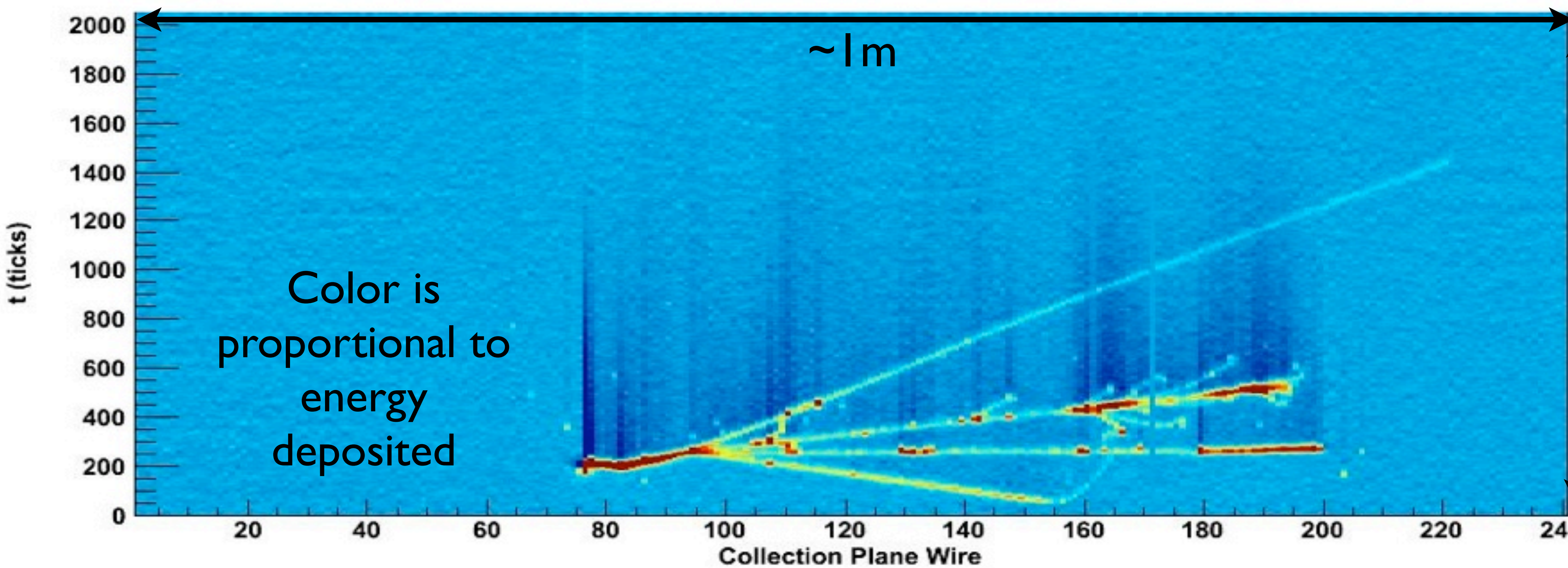
Drift Coordinate →



Pixel size:
4mm x 0.3mm

Raw Data

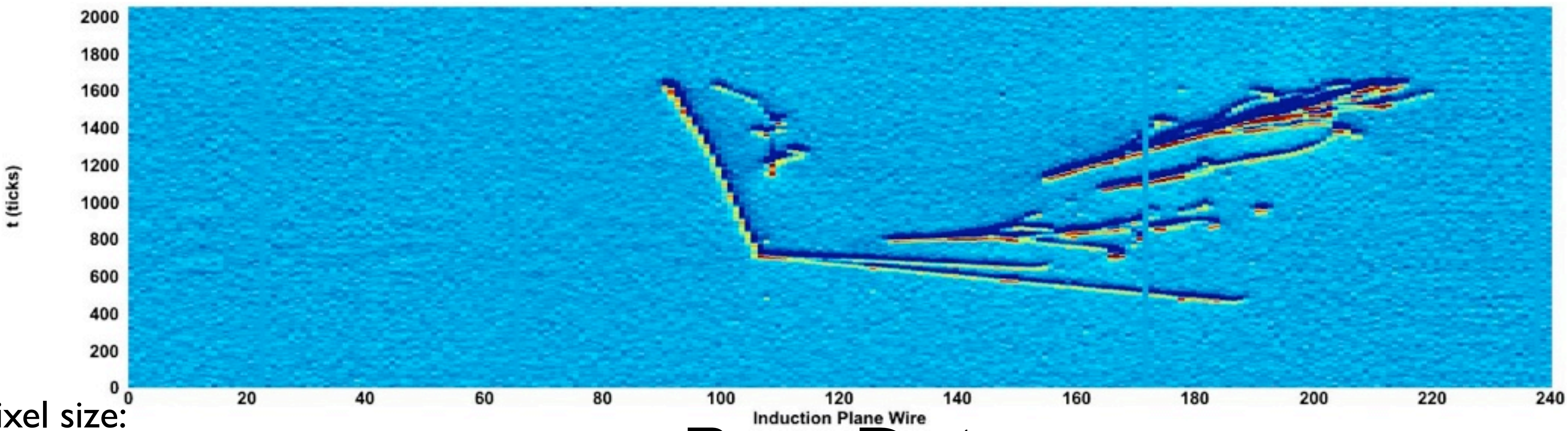
Drift Coordinate →



~0.5m

ArgoNeuT Neutrino Event

Drift Coordinate →



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Raw Data

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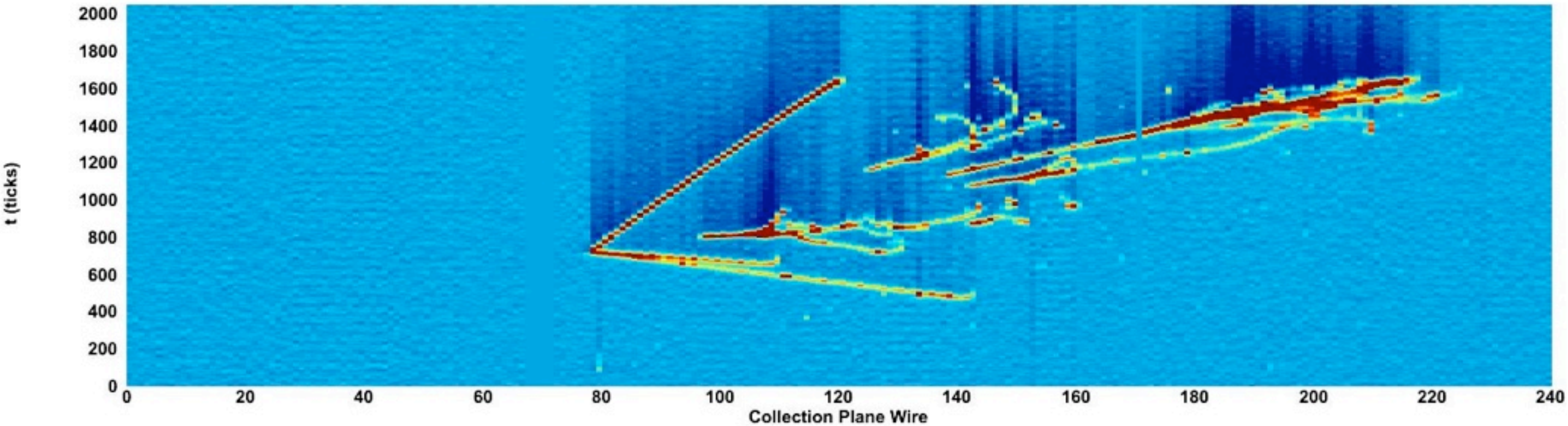
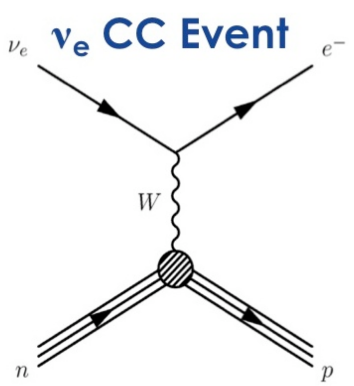
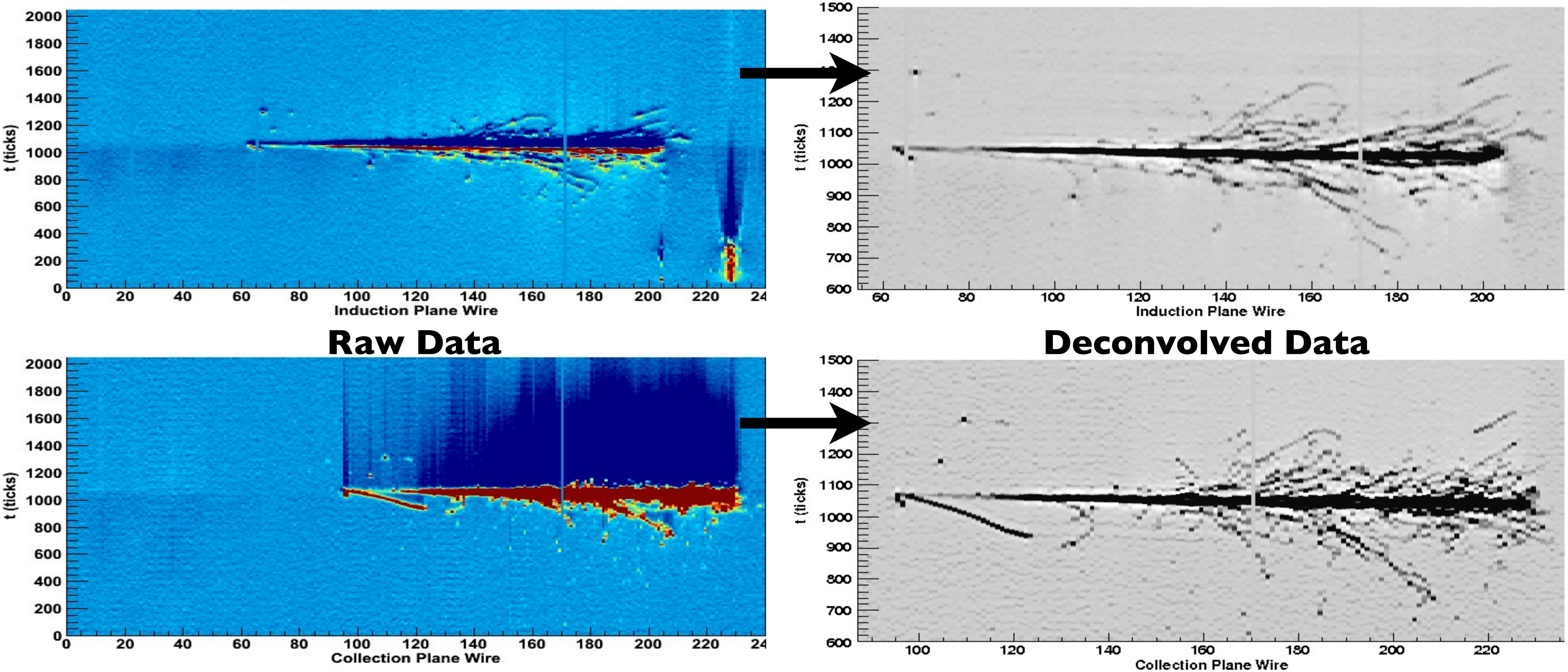


ArgoNeuT Neutrino Event



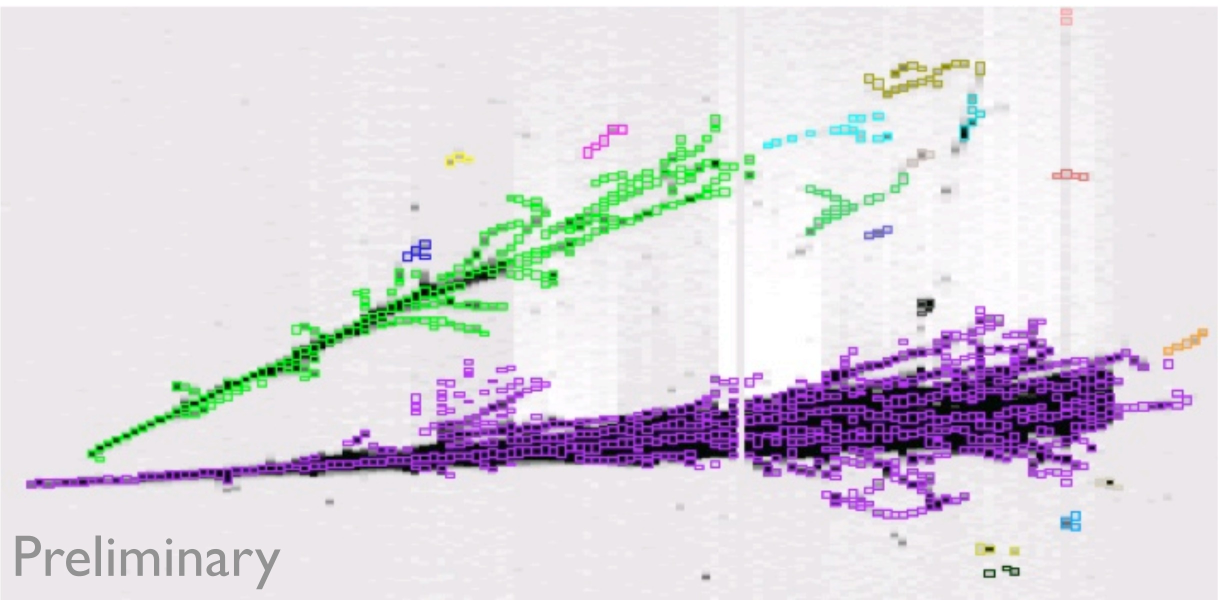
CCQE ν_e candidate



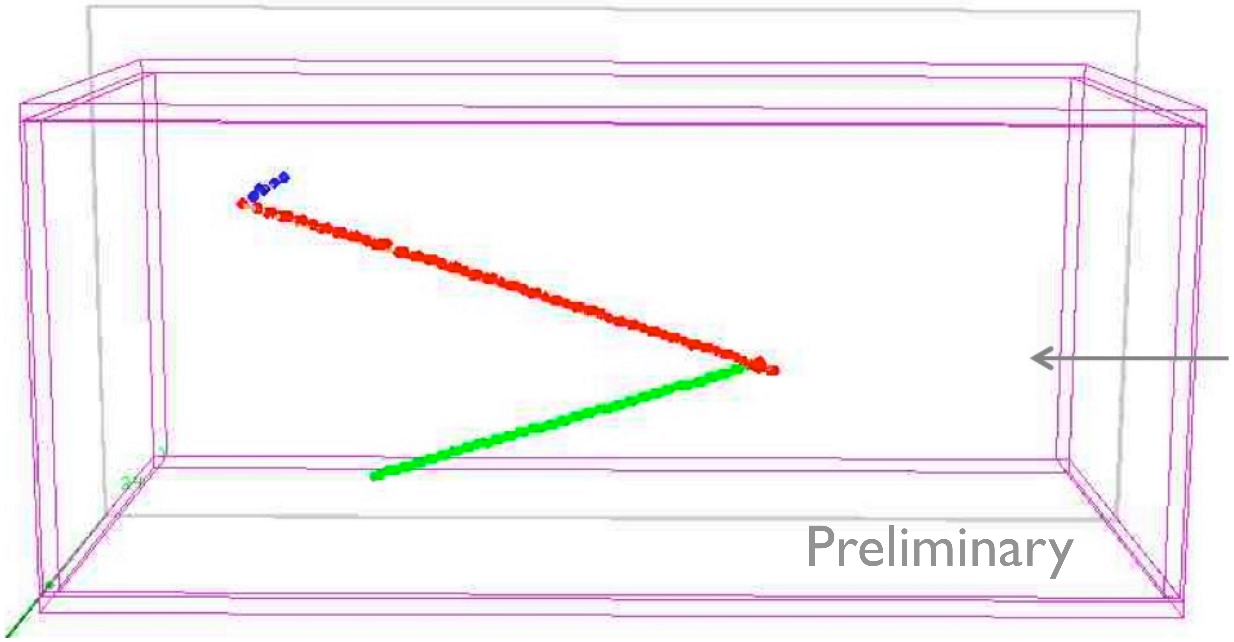
Electronics response is removed by Fourier Deconvolution

ArgoNeuT: Software

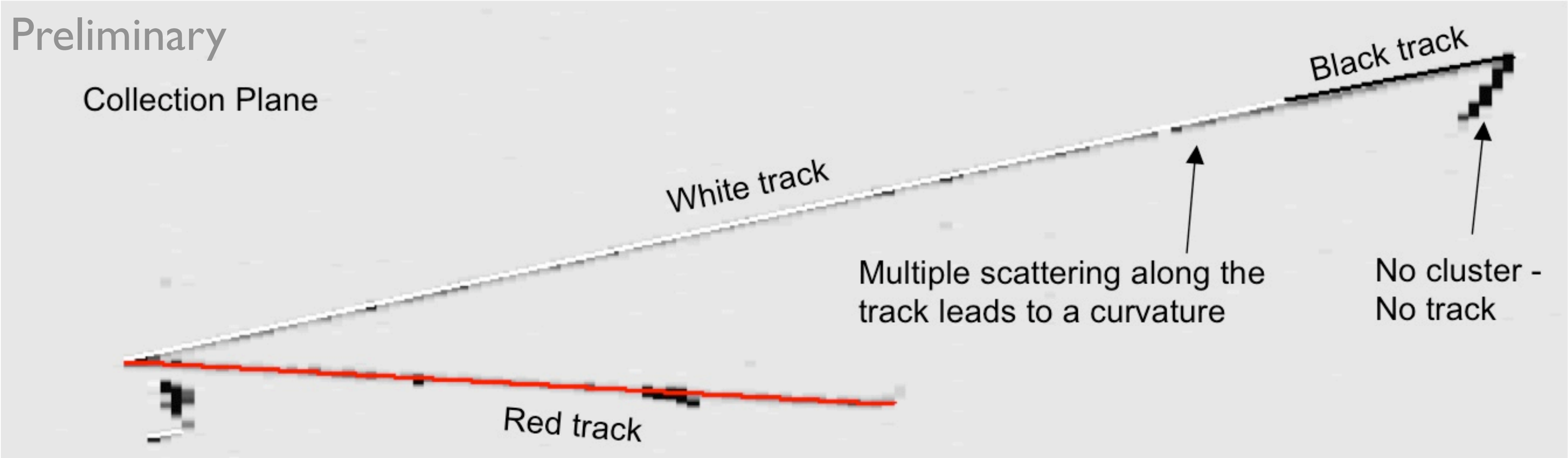
- Developing (automated) event reconstruction is critical.
- "LArSoft" is simulation/reconstruction/analysis code that can be used by future LAr experiments.
- Example: Different reconstruction techniques being developed...



Hit Finding + Density-based clustering.

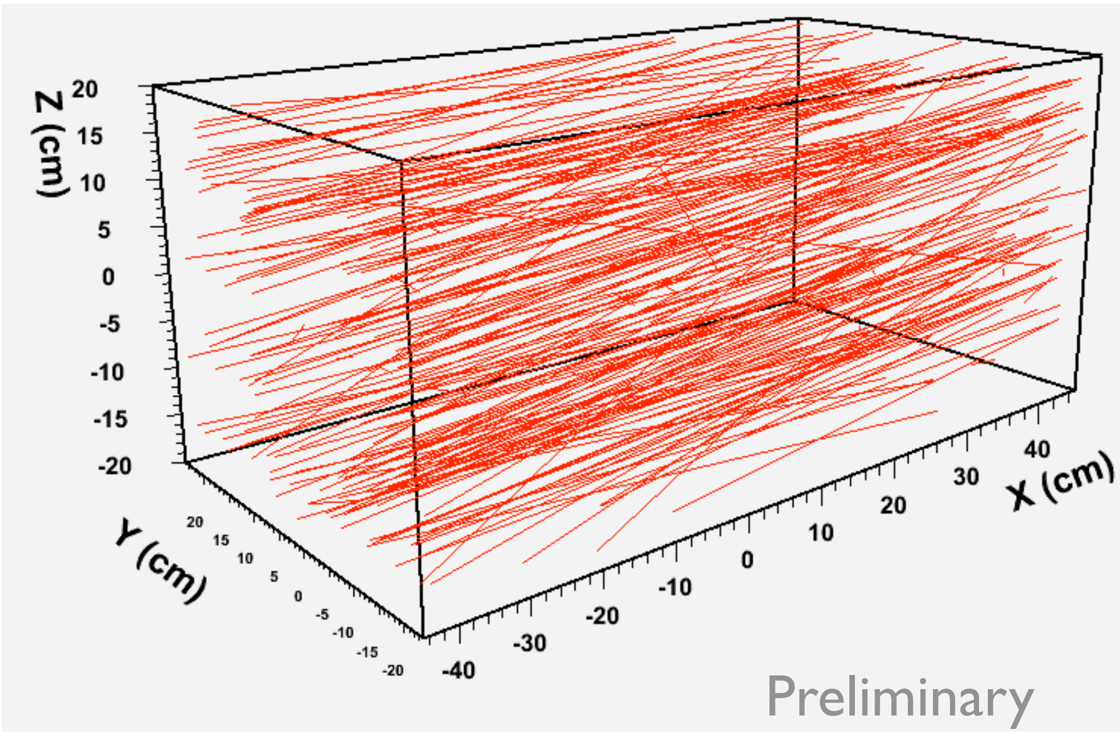


3D Reconstruction

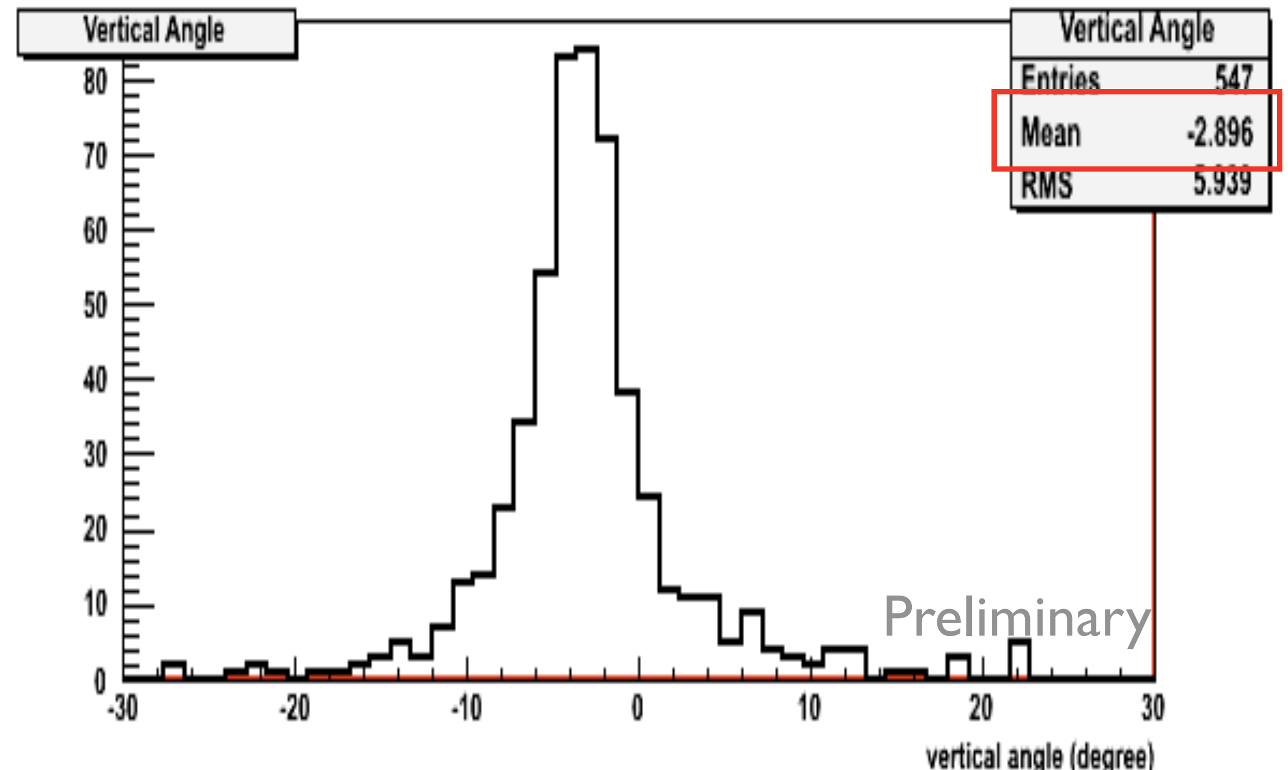


Straight-line reconstruction using Hough Transform.

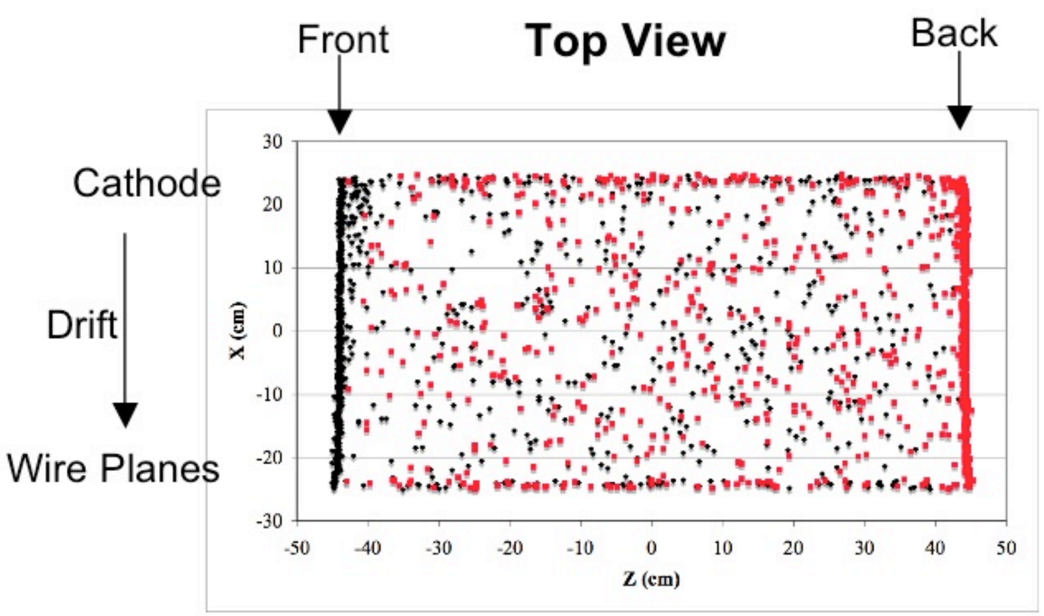
ArgoNeuT: Analyzing Muons



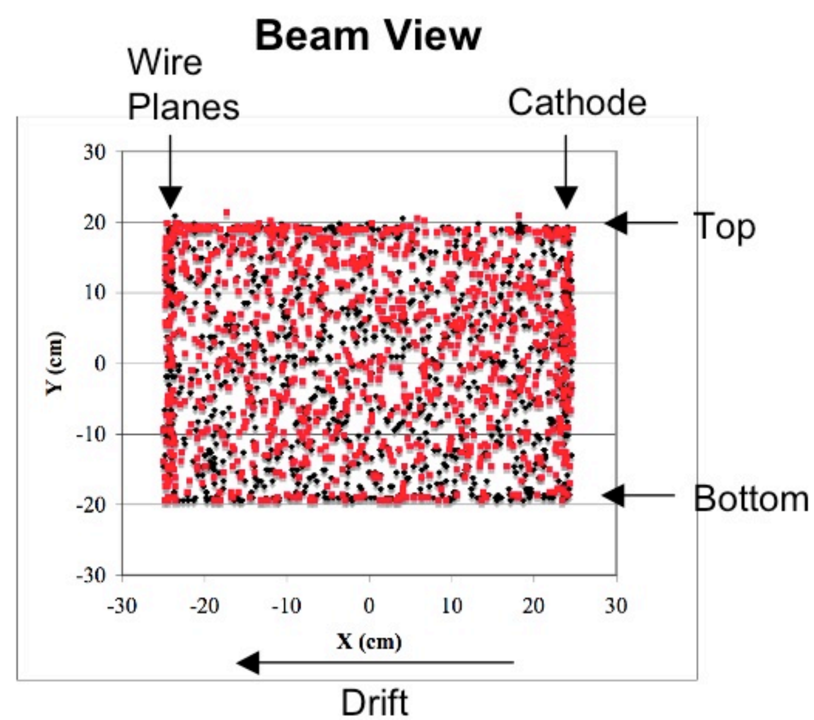
3D Reconstructed muons from few hours of running.



Angular distribution...NuMI Beam is at -3°



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



Working on publication to detail detector and analysis of large sample of muons in ArgoNeuT.

MicroBooNE

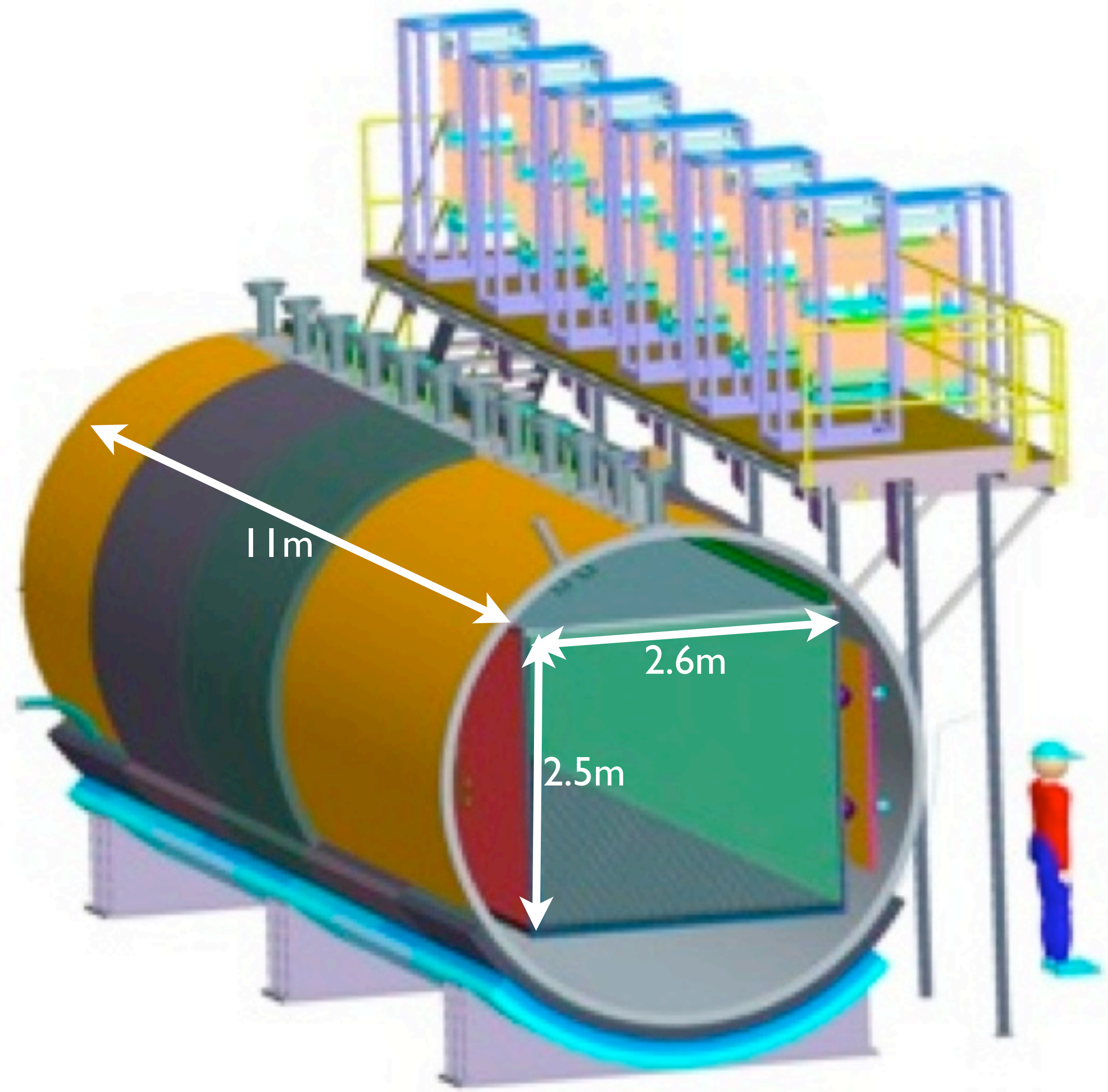
•MicroBooNE* is a LArTPC experiment that will operate in the on-axis Booster neutrino beam and off-axis NuMI neutrino beam on the surface at Fermilab.

•Combines timely physics with hardware R&D necessary for the evolution of LArTPCs.

- MiniBooNE low-energy excess
- Low-Energy Cross-Sections
- Cold Electronics
- Long-drift operation (strict demands on LAr purity)

Cryostat Volume	150 Tons
TPC Volume	90 Tons
# Electronic Channels	~9000
Wire Pitch	3 mm
Electronics Style (Temp.)	JFET (120 K)
Max. Drift Length (Time)	2.5m (1.5ms)
Light Collection	~30 8" Hamamatsu PMTs

★Stage 1 approval from Fermilab directorate in June 2008
★CD-0 (Mission Need) in October 2009
★CD-1 (reviewed early March)
★CD-2/CD-3a (Fall 2010)
★Turn On (2012-2013)



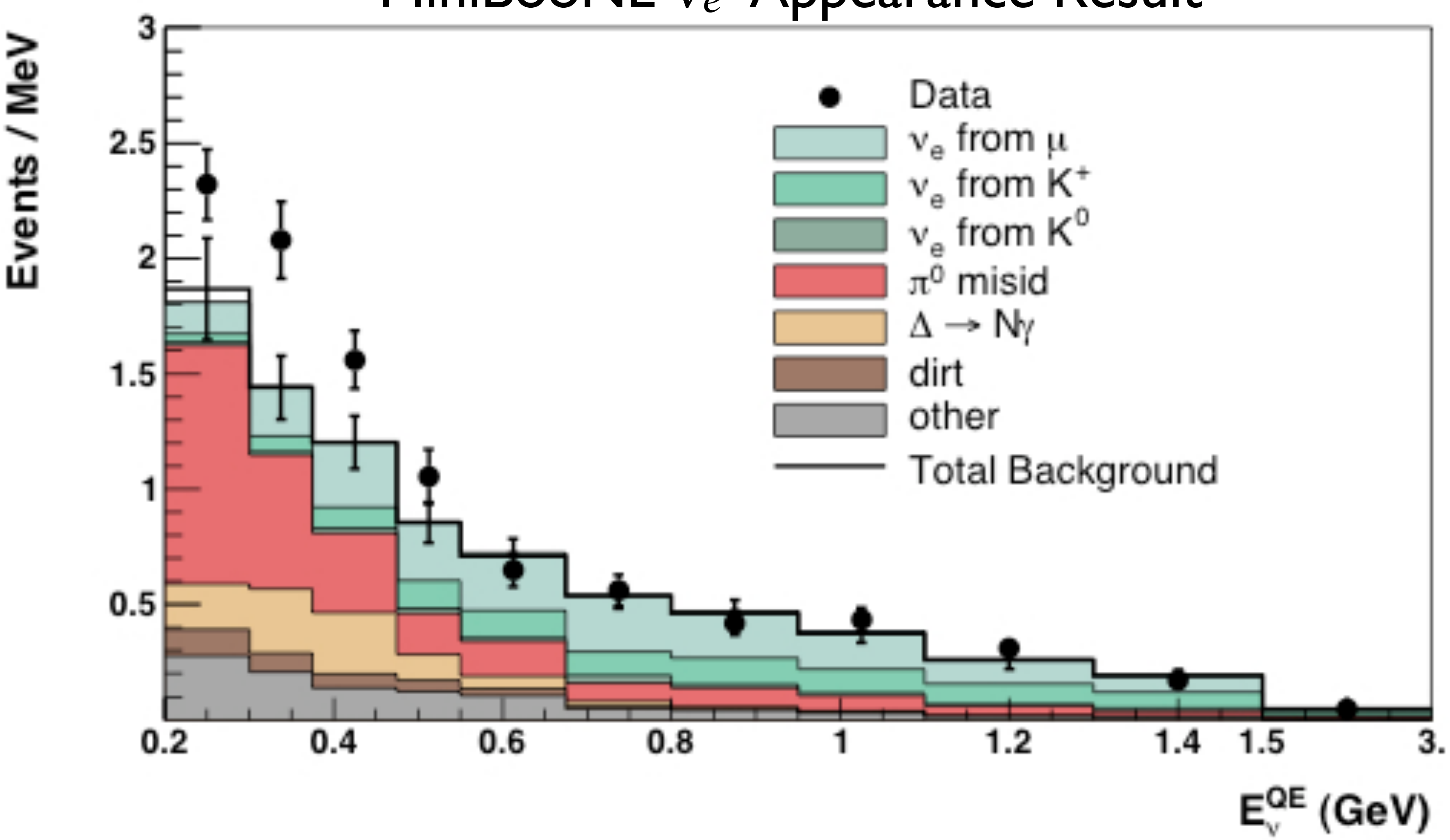
MicroBooNE Experiment
(DOE/NSF Supported)

*See poster from Vassili Papavassiliou

MicroBooNE: Physics Goals

- Address the MiniBooNE* low energy excess
  - Does MicroBooNE confirm the excess?
  - Utilize dE/dx + topology to determine if it is an electron-like or gamma-like process
- Low Energy Cross-Section Measurements (CCQE, NC π^o, $\Delta \rightarrow N\gamma$, Photonuclear, ...)
- Study processes relevant for proton-decay searches in a large LArTPC
- Fully implement automated reconstruction (building on ArgoNeuT's effort)

MiniBooNE ν_e Appearance Result



MiniBooNE Neutrino-Mode 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.

*See talks by:
Richard Van deWater
and
Georgia Karagiorgi
on Monday.

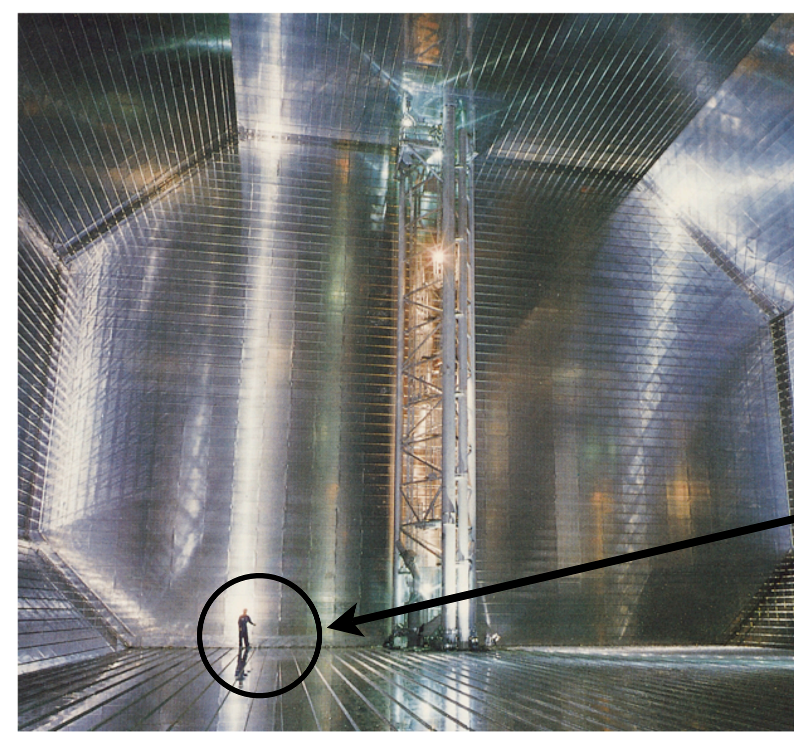
Refs:
1.) *Unexplained Excess of Electron-Like Events From a 1-GeV Neutrino Beam* MiniBooNE Collaboration, Phys. Rev. Lett. 102, 101802 (2009)

LBNE LArTPC

- Deep Underground Science and Engineering Laboratory (DUSEL) at the Homestake Mine in South Dakota is the proposed home of future long-baseline far detectors.
- Long Baseline Neutrino Experiment (LBNE*) collaboration is working on beam+near-detector(s)+far-detector(s) configuration.
- Conceptual design for a ~20 kiloton LBNE LArTPC detector:
  - "Membrane" style cryostat (used in Liquified Natural Gas shipping industry).
  - Alternative design with vacuum-insulated modular-style cryostat is also being considered.
  - Considering depths of 300, 800, and 4800 feet...(shallower depths allow possibility of drive-in access).

*LBNE Posters:
R. Bradford,
C. Mauger,
S. Ouedraogo,
M. Soderberg

Beam from Fermilab to DUSEL

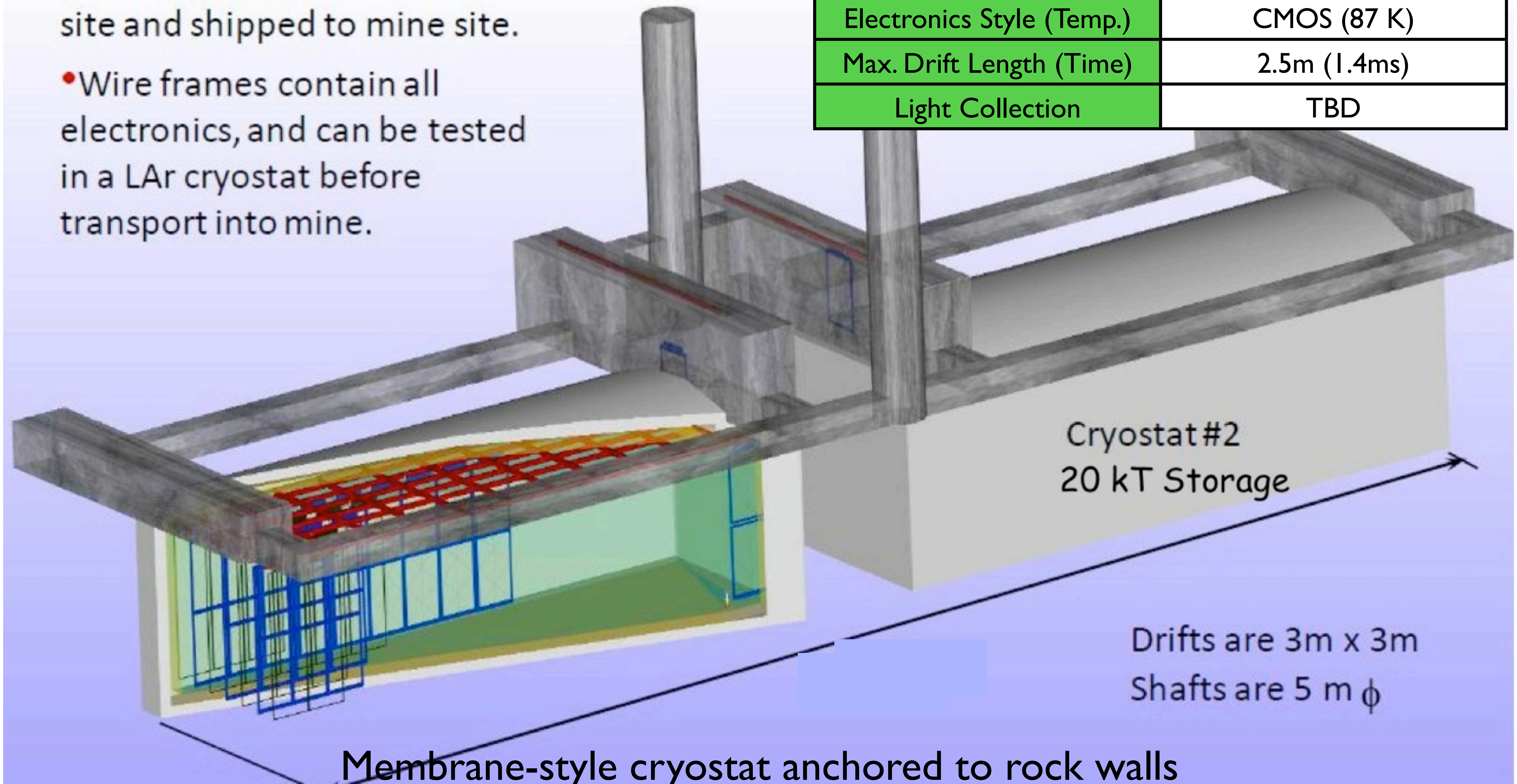


"Membrane" Cryostat

LBNE LArTPC: Conceptual Design

Cryostat Volume	25 kTons
TPC Fiducial Volume	16.8 kTons
# Readout Wires	~645000 (128:1 MUX)
Wire Pitch	3 mm
Electronics Style (Temp.)	CMOS (87 K)
Max. Drift Length (Time)	2.5m (1.4ms)
Light Collection	TBD

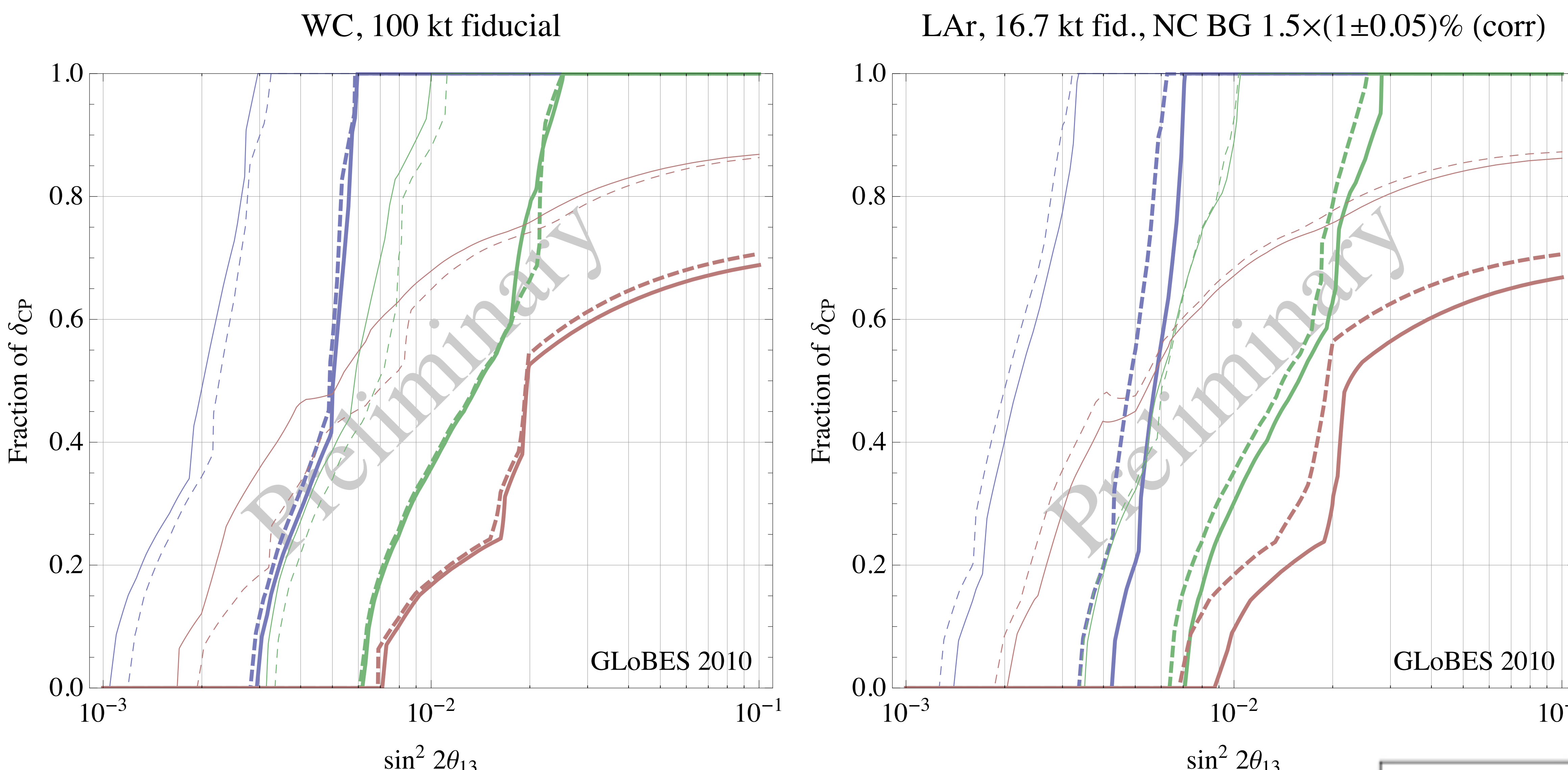
- Cathode and wire frames can be manufactured at a remote site and shipped to mine site.
- Wire frames contain all electronics, and can be tested in a LAr cryostat before transport into mine.

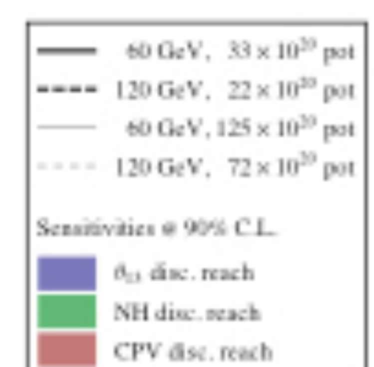


Membrane-style cryostat anchored to rock walls

LBNE LArTPC: Physics Reach

- Preliminary sensitivity calculations for 100 kTon Water Cherenkov and 16.7 kTon LArTPC.
- Indicates a ~6:1 equivalence between Water:LAr





Plots by J. Kopp

- LArTPC Plots Assume:
  - WBB design for LBNE
  - 85% ν_e efficiency
  - 5% background uncertainty

Conclusion

- Liquid Argon detectors provide exceptional capabilities for neutrino physics, and a significant amount of development is occurring in the U.S.
- **ArgoNeuT** project recently completed run in NuMI tunnel.
  - Data analysis underway
  - Proposing a new run in the SciBooNE location
- **MicroBooNE** is next major U.S. LArTPC, and it will probe MiniBooNE Low-E excess, and further develop technology.
- **LBNE** LArTPC at DUSEL offers extraordinary physics opportunities.

New Collaborators for "Phase II"!

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Michigan State University

K. Lang, R. Mehdiyev
The University of Texas at Austin

C. Anderson, B. Fleming, S. Linden, K. Partyka, M. Soderberg*, J. Spitz
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ArgoNeuT

Thanks to:

microboone

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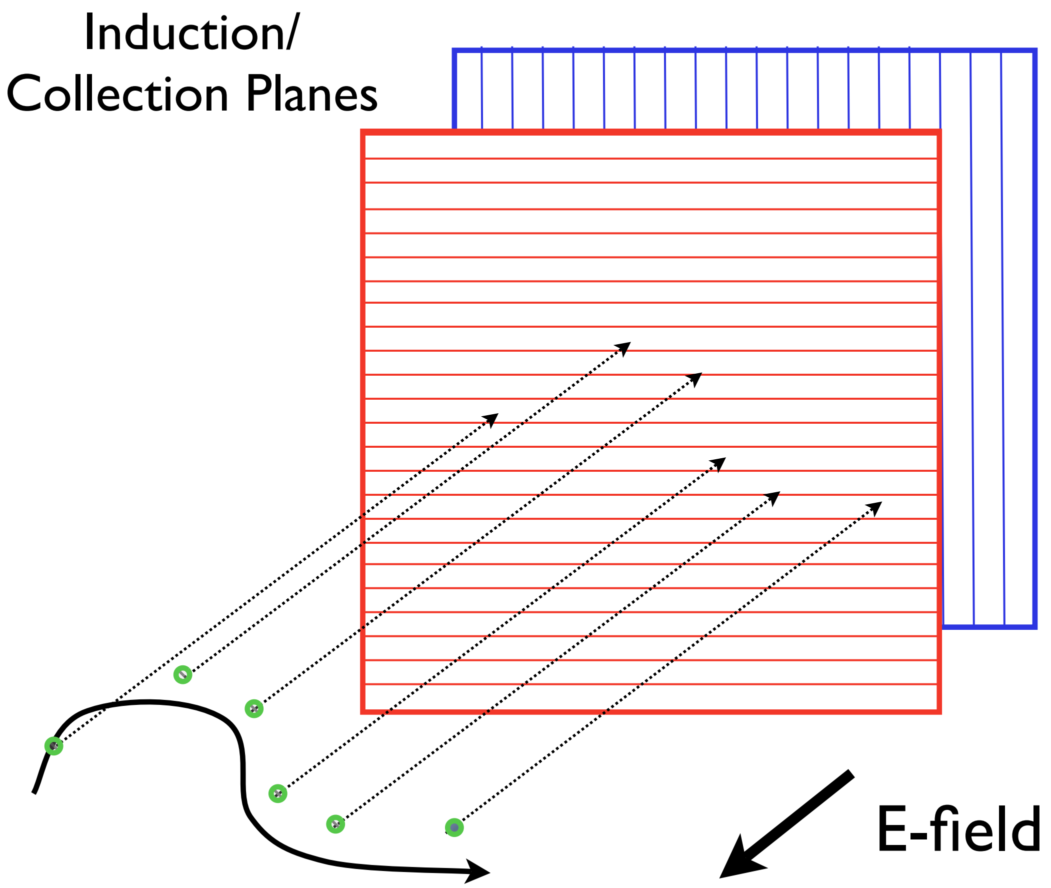
BACK-UP SLIDES

LArTPC Principle

TPC = Time Projection Chamber

- Neutrino interactions inside a TPC produce particles that ionize the argon as they travel (55k e^-/cm).
- Ionization is drifted along E-field to wireplanes, consisting of wires spaced a few mm 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)

Why Noble Liquids for Neutrinos?

- Abundant ionization electrons and scintillation light can both be used for detection.
- If liquids are highly purified (<0.1ppb), ionization can be drifted over long distances.
- Excellent dielectric properties accommodate very large voltages.
- Noble Liquids are dense, so they make a good target for neutrinos.
- **Argon** is relatively cheap and easy to obtain (1% of atmosphere).

	He	Ne	Ar	Kr	Xe	Water
Boiling Point [K] @ 1atm	4.2	27.1	87.3	120.0	165.0	373
Density [g/cm^3]	0.125	1.2	1.4	2.4	3.0	1
Radiation Length [cm]	755.2	24.0	14.0	4.9	2.8	36.1
dE/dx [MeV/cm]	0.24	1.4	2.1	3.0	3.8	1.9
Scintillation [γ /MeV]	19,000	30,000	40,000	25,000	42,000	
Scintillation λ [nm]	80	78	128	150	175	

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