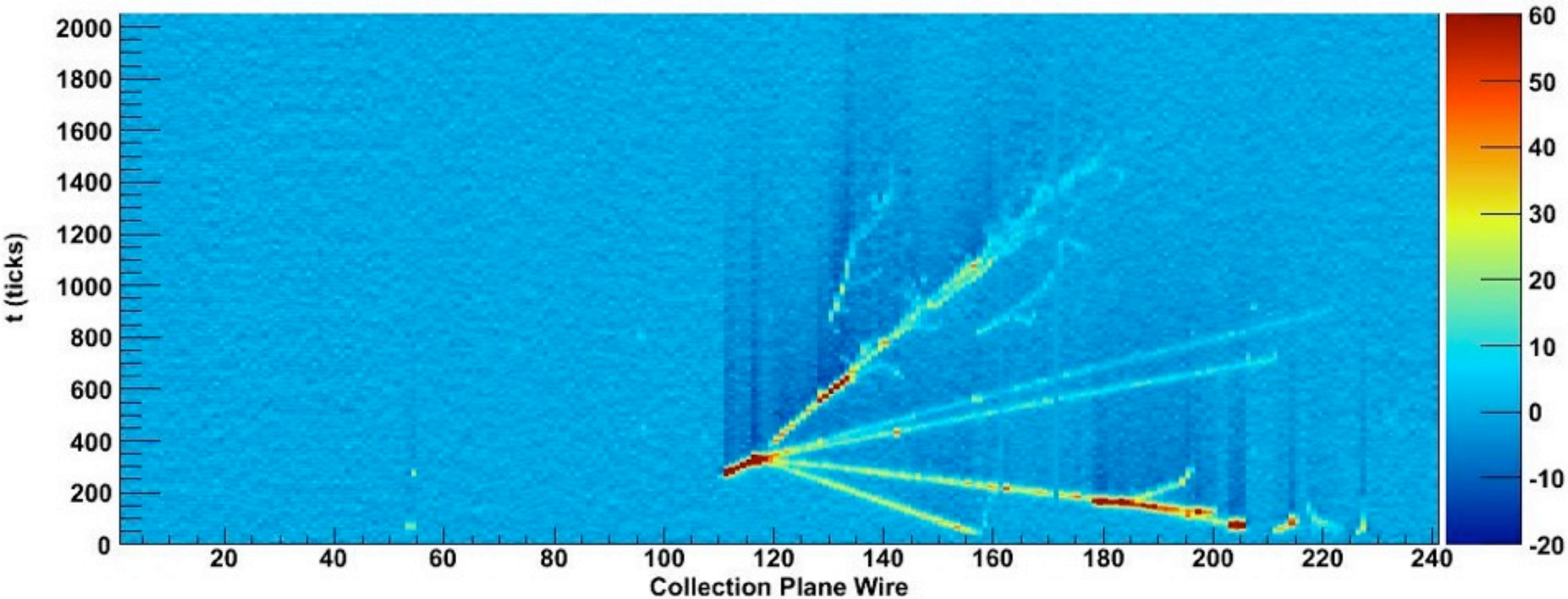
Future Long Baseline Experiments:

options for U.S.



Mitch Soderberg

Yale University

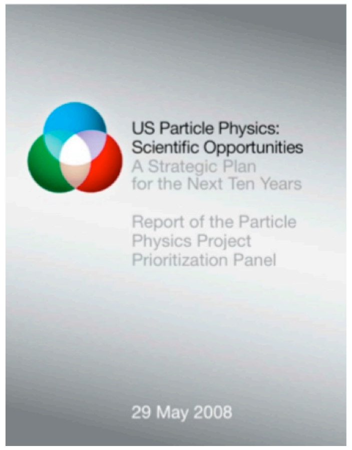
WIN ’09, Perugia, Italy

September 16, 2009

U.S. Long Baseline Introduction

- NOvA construction is beginning (see talk by M. Sanchez)
- Long-Baseline Neutrino Experiment (LBNE) group, sponsored by NSF and DOE, has formed to plan the next phase of U.S. based experiments after NOvA
- This next phase of experiments will more precisely measure θ_{13}, as well as going after CP-violation and the mass hierarchy

NOvA Location in Minnesota



US Particle Physics: Scientific Opportunities
A Strategic Plan for the Next Ten Years
Report of the Particle Physics Project Prioritization Panel
29 May 2008

Recommendations from the Report of the P5 Panel to HEPAP, May 29, 2008:

"The panel recommends a world-class neutrino program as a core component of the US program, with the long-term vision of a large detector in the proposed DUSEL laboratory and a high-intensity neutrino source at Fermilab"

Department of Energy (DOE)

↑

HEPAP (High Energy Physics Advisory Panel)

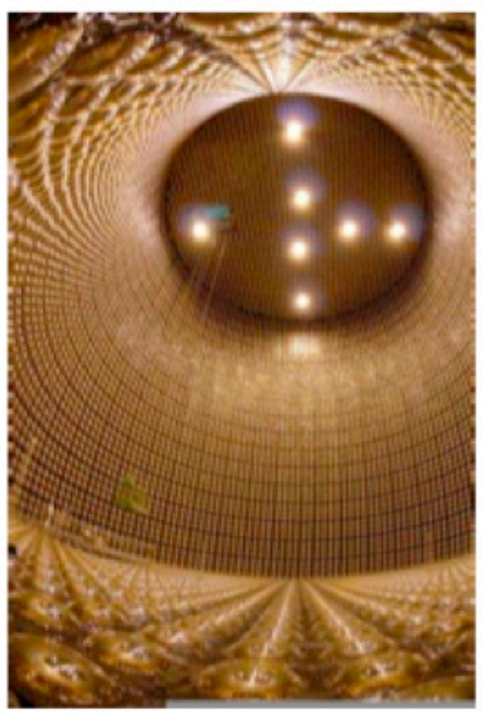
↑

P5 (Particle Physics Project Prioritization Panel)

Far Detectors

- Two far detector technologies considered for the future long-baseline neutrino program: Water Cerenkov and Liquid Argon (LAr)
- Water detector aiming for total fiducial mass of 300ktons, LAr aiming for 60 ktons.
- Both technologies can also potentially look for supernova neutrinos and proton decays.
- LBNE group also considering design of beams and near detectors.

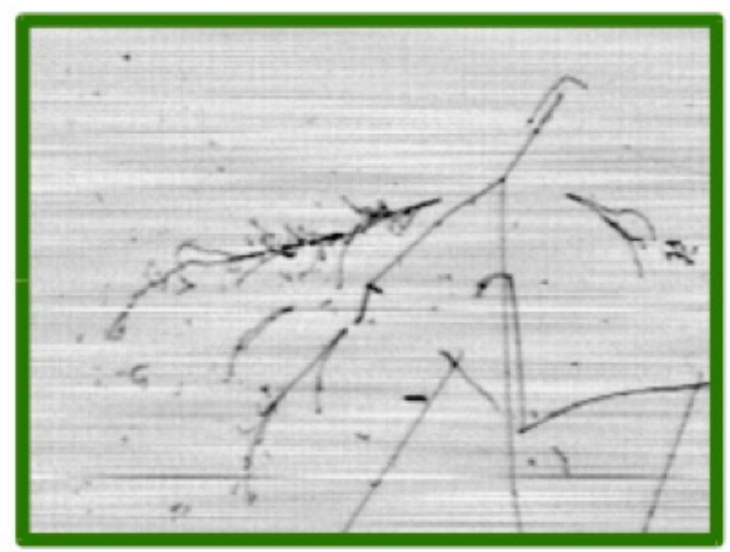
Water Cerenkov
imaging detector



(3 x 100 kton modules
total = 300 kton)

This talk

Liquid Argon TPC
very fine-grained tracking detector



ICARUS event

(20-60 kton)

LBNE Collaboration

- Many interested scientists!

Argonne National Laboratory
M. Goodman, M. Sanchez, M. Wetstein

Brookhaven National Laboratory
M. Bishai, R. Brown, H. Chen, G. de Geronimo, M. Diwan, R. Hackenberg, R. Hahn, S. Hans, D. Jaffe, S. Junnarkar, S. Kettell, F. Lanni, D. Makowiecki, B. Marciano, W. Morse, Z. Parsa, C. Pearson, V. Radeka, S. Rescia, J. Sondericker, J. Stewart, C. Thorn, B. Viren, M. Yeh, B. Yu

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University of California, Davis
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University of California, Irvine
B. Kropp, M. Smy, H. Sobel

University of California, Los Angeles
K. Arisaka, D. Cline, Y. Meng, F. Sergiampietri, H. Wang

Caltech
R. McKeown

University of Catania and INFN, Catania
V. Bellini, R. Potenza

University of Chicago
E. Blucher, M. Dierckxsens

Colorado State University
B. Berger, N. Buchanan, W. Toki, R. Wilson

Columbia University
L. Camilleri, C. Chi, C. Mariani, M. Shaevitz, W. Sippach, W. Willis

Drexel University
C. Lane, J. Maricic

Duke University
J. Fowler, K. Scholberg, C. Walter

Fermilab
D. Allspach, B. Baller, S. Childress, P. Hurh, J. Hylen, G. Koizumi, T. Lackowski, C. Laughton, P. Lucas, B. Lundberg, P. Mantsch, J. Morfin, V. Papadimitriou, R. Plunkett, S. Pordes, G. Rameika, B. Rebel, K. Riesselmann, R. Schmitt, D. Schmitz, P. Shanahan, R. Zwaska

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B. Fujikawa, R. Kadel

Lawrence Livermore National Laboratory
A. Bernstein, R. Bionta, S. Dazeley, S. Oeudraogo

Los Alamos National Laboratory
G. Garvey, T. Haines, W. Louis, C. Mauger, G. Mills, Z. Pavlovic, R. Van de Water, H. White, G. Zeller

Louisiana State University
T. Kutter, W. Metcalf, J. Nowak

University of Maryland
E. Blaufuss, G. Sullivan

Michigan State University
E. Arrieta-Diaz, C. Bromberg, D. Edmunds, J. Houston, B. Page

University of Minnesota
M. Marshak, W. Miller

(currently ~150 people from 33 institutions)

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R. Gran, A. Habig

MIT
W. Barletta, J. Conrad, P. Fisher

University of Pennsylvania
J. Klein, K. Lande, M. Newcomer, R. Van Berg

Rensselaer Polytechnic Institute
D. Kaminski, J. Napolitano, S. Salon, P. Stoler

Princeton University
K. McDonald, Q. He

South Carolina University
S. Mishra, R. Petti, C. Rosenfeld

Institute for Physics & Mathematics of the Universe, U. Tokyo
M. Vagins

Tufts University
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University of Wisconsin, Madison
B. Balantekin, F. Feyzi, L. Gladstone, K. Heeger, A. Karle, R. Maruyama, P. Sandstrom, C. Wendt

Yale University
B. Fleming, M. Soderberg

LAr Introduction

- Liquid Argon Time Projection Chambers (LArTPCs) are well suited to study neutrino physics and beyond.
  - Combine excellent spatial resolution and calorimetry.
  - In principle they are scalable to very large sizes.
- Pioneering work done by ICARUS collaboration
- U.S. effort to develop LArTPCs towards large detectors has expanded significantly in recent years.
- Rest of this talk will quickly survey current and planned LArTPC projects in the U.S.

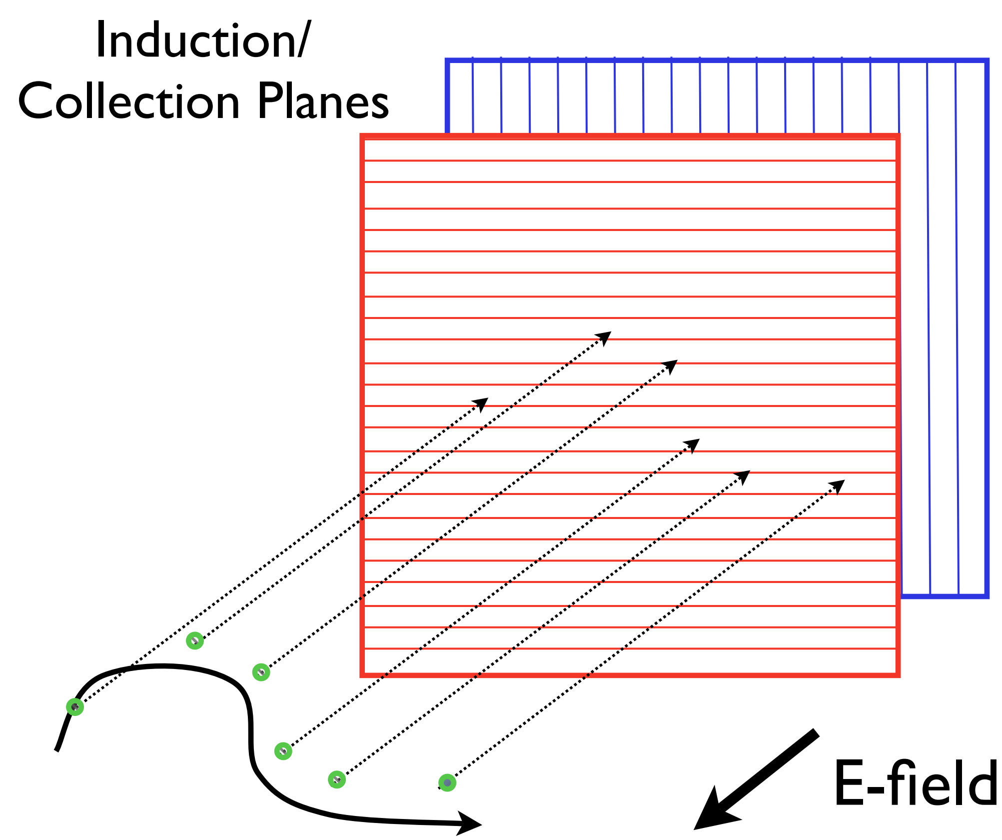
Recommendations from the Report of the P5 Panel to HEPAP, May 29, 2008:

"The panel recommends support for a vigorous R&D program on liquid argon detectors and water Cerenkov detectors in any funding scenario considered by the panel. The panel recommends designing the detector in a fashion that allows an evolving capability to measure neutrino oscillations and to search for proton decays and supernovae neutrinos."

LArTPC Principal

TPC = Time Projection Chamber

•Neutrino interactions inside a TPC* produce ionization particles
•Ionization drifts along electric field lines towards wireplanes, which are connected to low-noise charge amplifiers and fast ADCs.
•Location of wires within a plane provide position measurements...timing of pulse information needed to determine drift coordinate.
•Multiple non-destructive wireplanes can be utilized, providing independent position measurements needed for full 3-D reconstruction.
•Knowledge of drift speed, and T_0 of events, used to project back along drift direction to particle's origin.
•Scintillation light also present, can be collected by Photomultiplier Tubes and used in triggering.

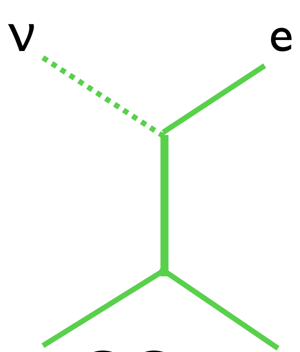


Refs:
*.) *The Liquid-argon time projection chamber: a new concept for Neutrino Detector*, C. Rubbia, CERN-EP/77-08 (1977)

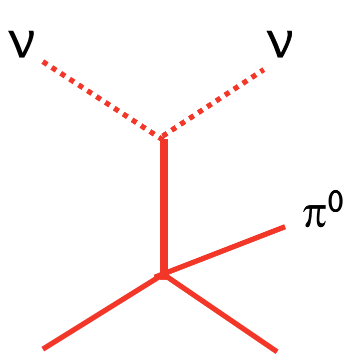
LAr TPC Advantages

e/γ separation → superior background rejection

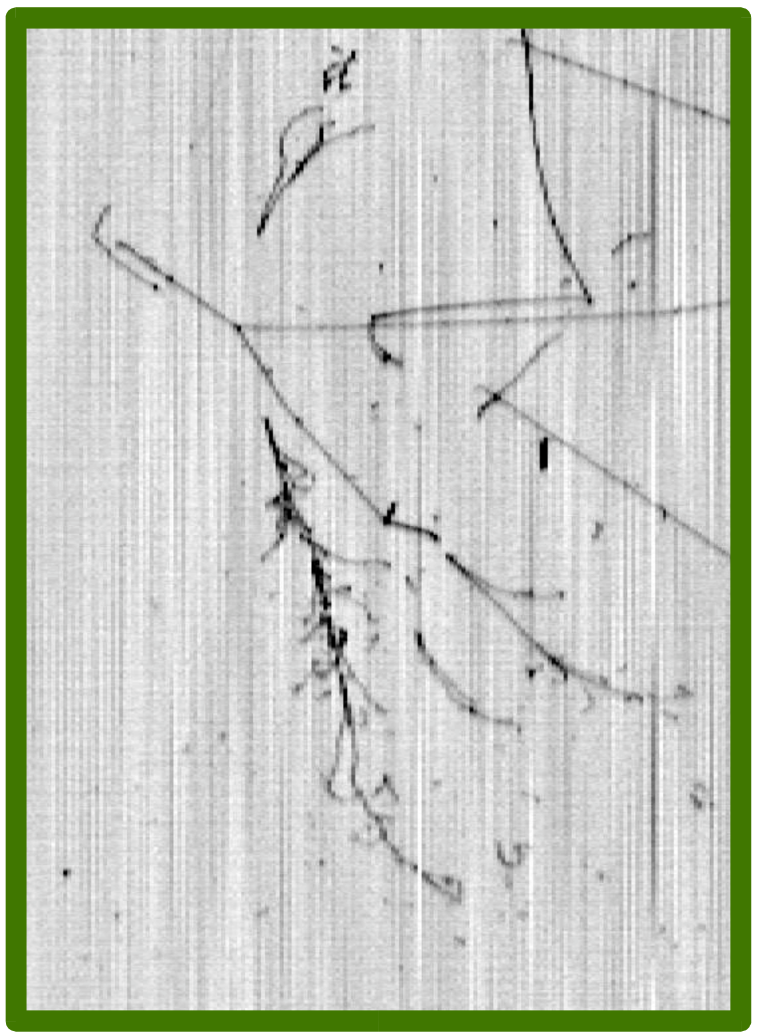
- Particle identification comes from dE/dx measured along track.
- ν_e appearance: Excellent signal (CC ν_e) efficiency and background (NC π^0) rejection
- Topological cuts will also improve signal/background separation

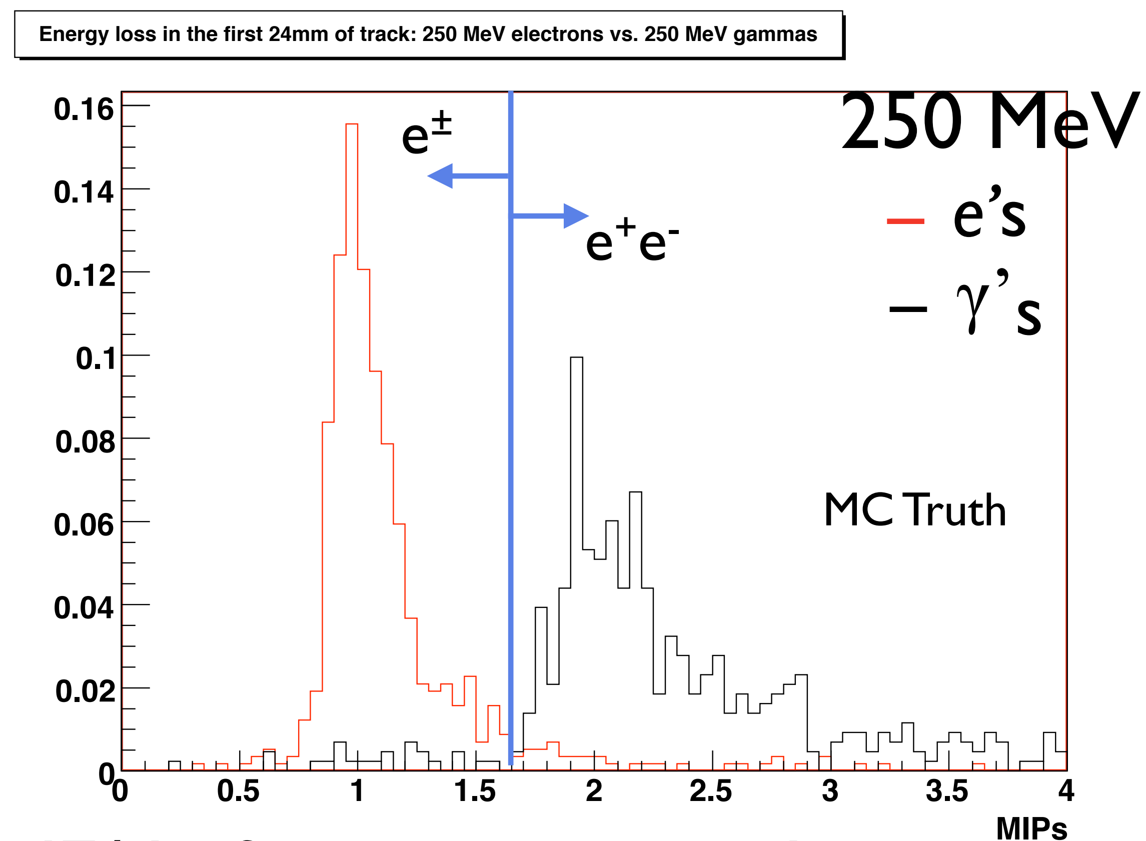


CC ν_e



NC π^0


ICARUS Event



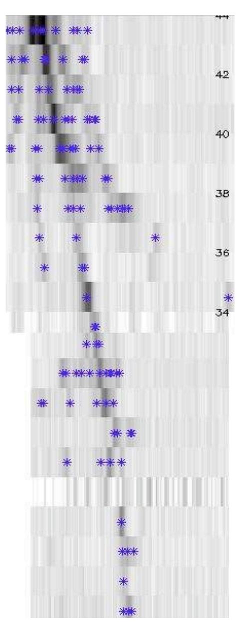
dE/dx for electrons and gammas in first 2.4 cm of track

Liquid Argon in the U.S.

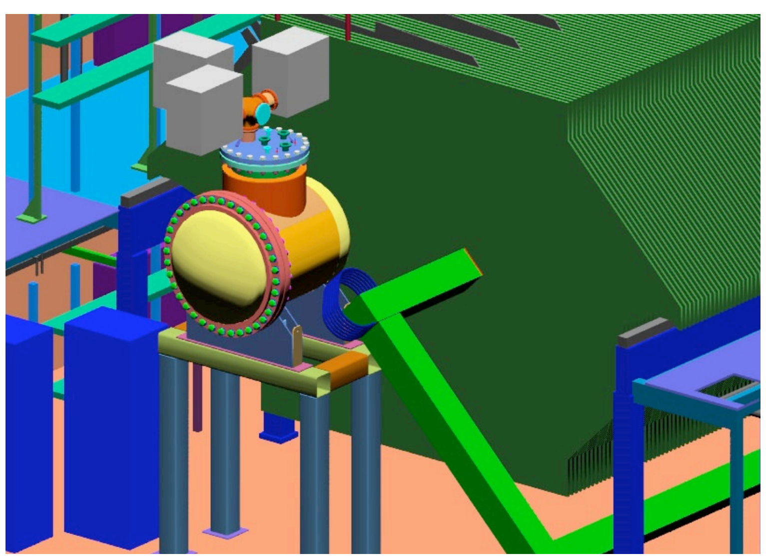
Materials Test Stand

Bo

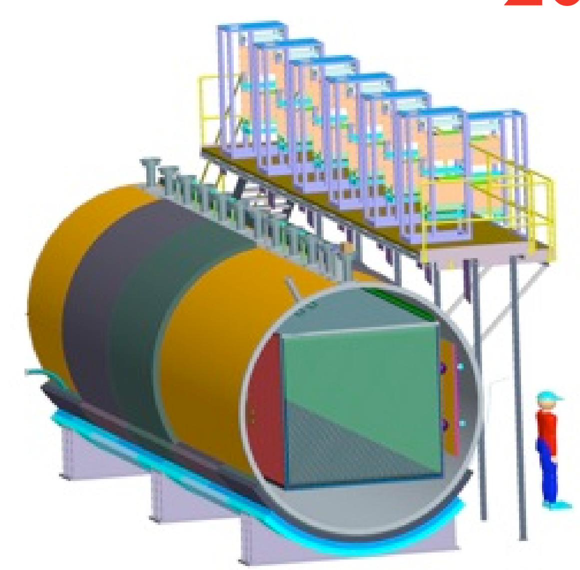
- Rapid progress in LArTPC development.
- Developing an integrated plan to get to final, massive detector(s).



Yale Tracks

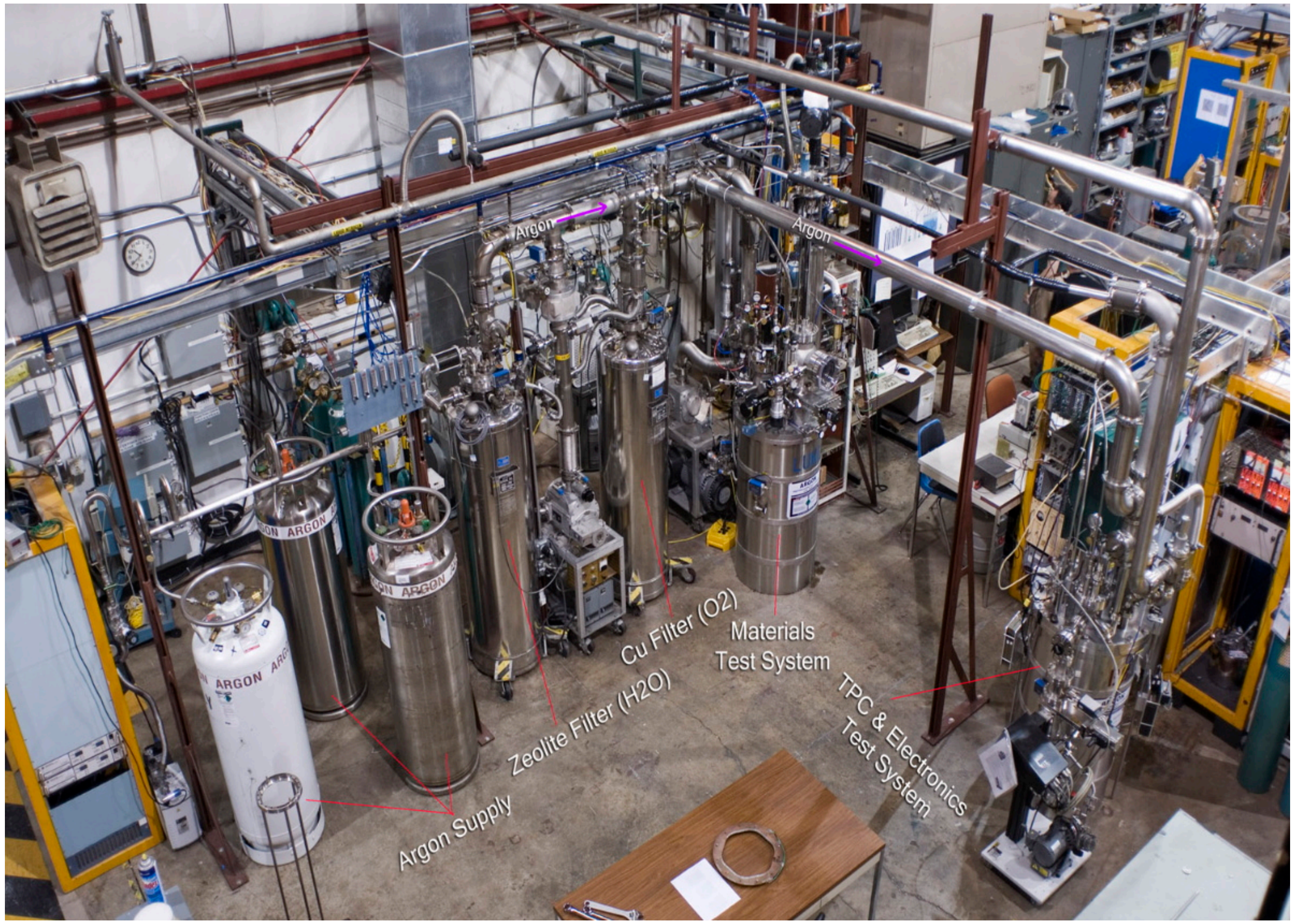


ArgoNeuT



MicroBooNE

Purity Systems at Fermilab



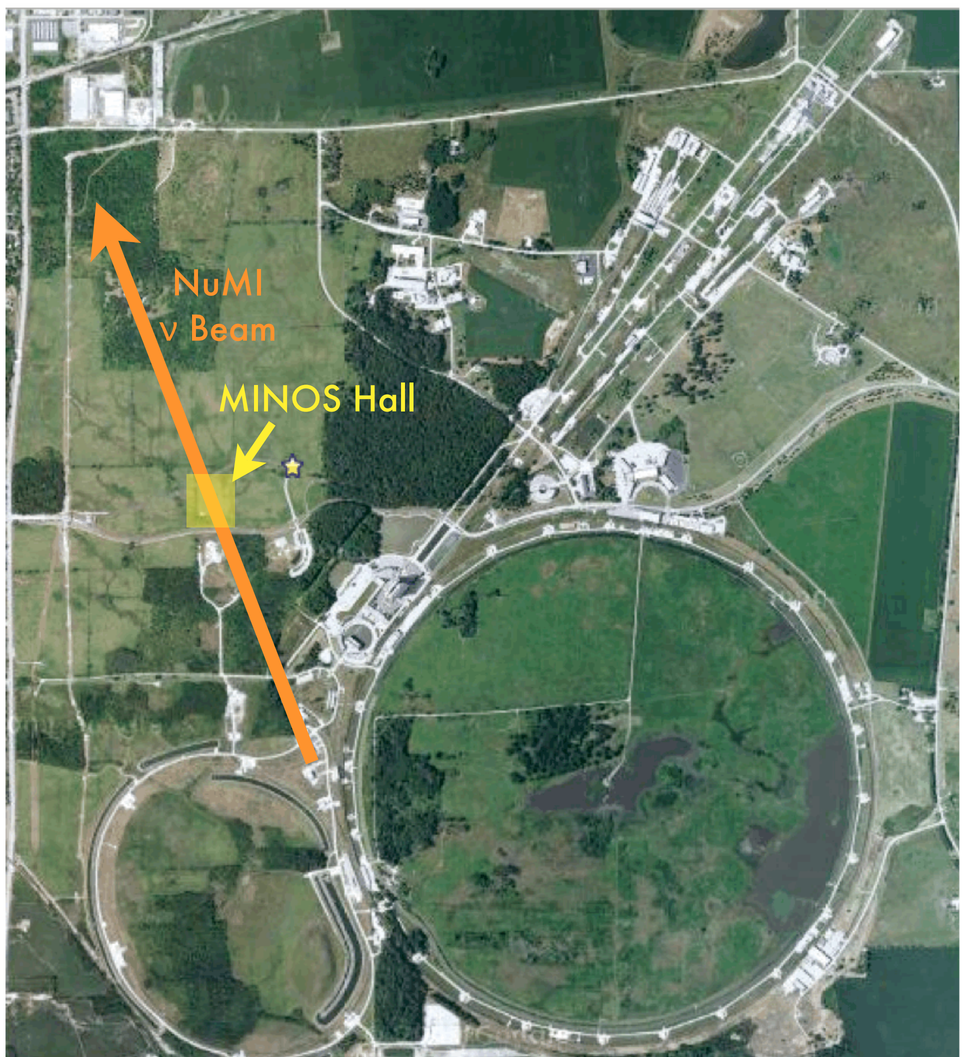
Materials Test Stand at Fermilab

Cryostat for 20-ton test

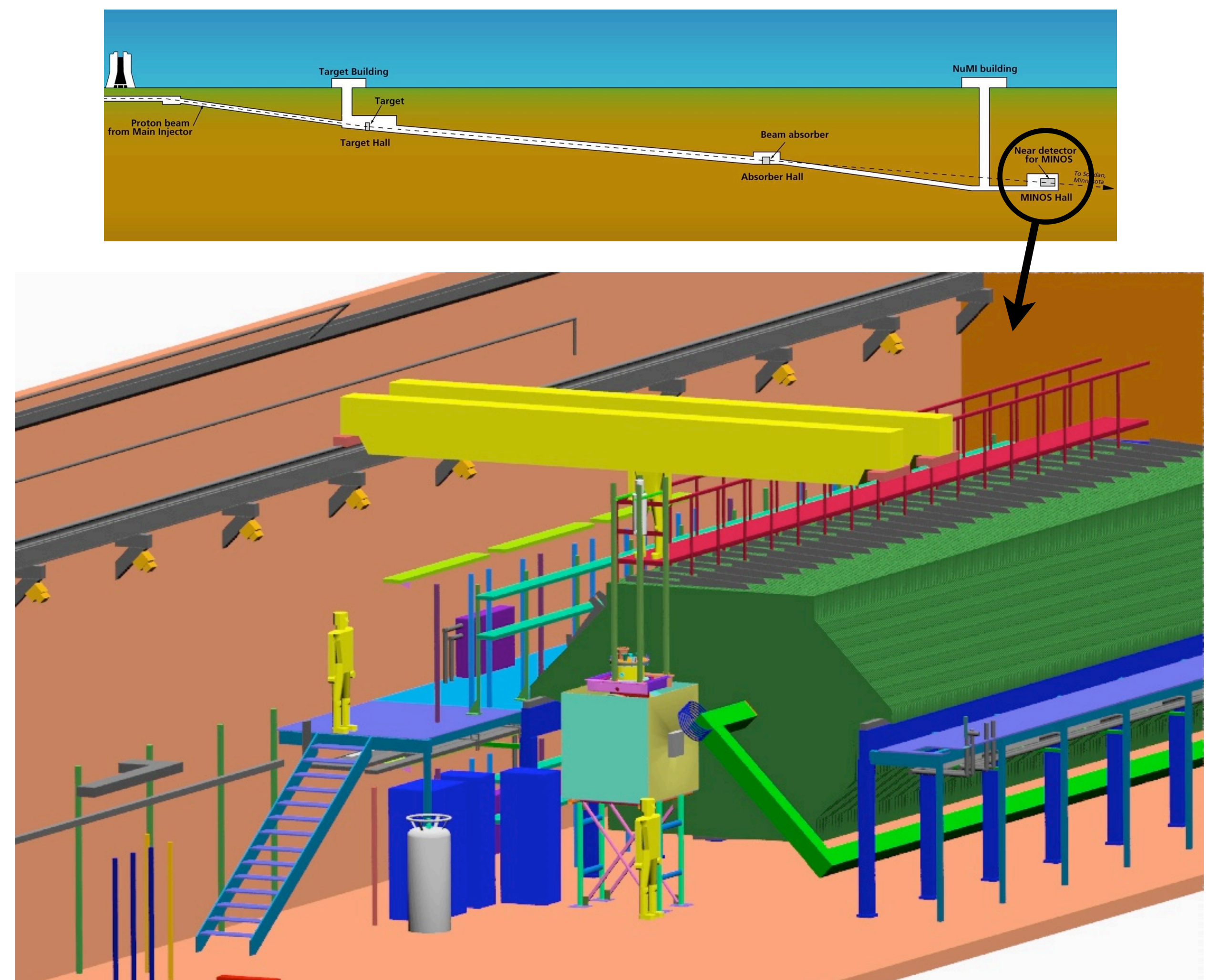
- Controlling argon purity is vital, but a massive LArTPC will necessarily have large amounts of detector material.
- Fermilab group has several projects focused on better understanding argon purity.
- Materials Test Stand is used to study the impact of different materials on argon purity.
- 20-ton purity demonstration (LAPD) will shed light on whether purity can be achieved starting from a non-evacuated environment.

ArgoNeuT

- ArgoNeuT is a ~175 liter LArTPC
- Jointly funded by DOE/NSF
- Sits 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).
    - Confront <u>some</u> aspects of underground running and safety.
    - Develop simulation of LArTPCs and compare with data.



Fermilab



MINOS Hall at Fermilab

ArgoNeuT Collaboration

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Michigan State University

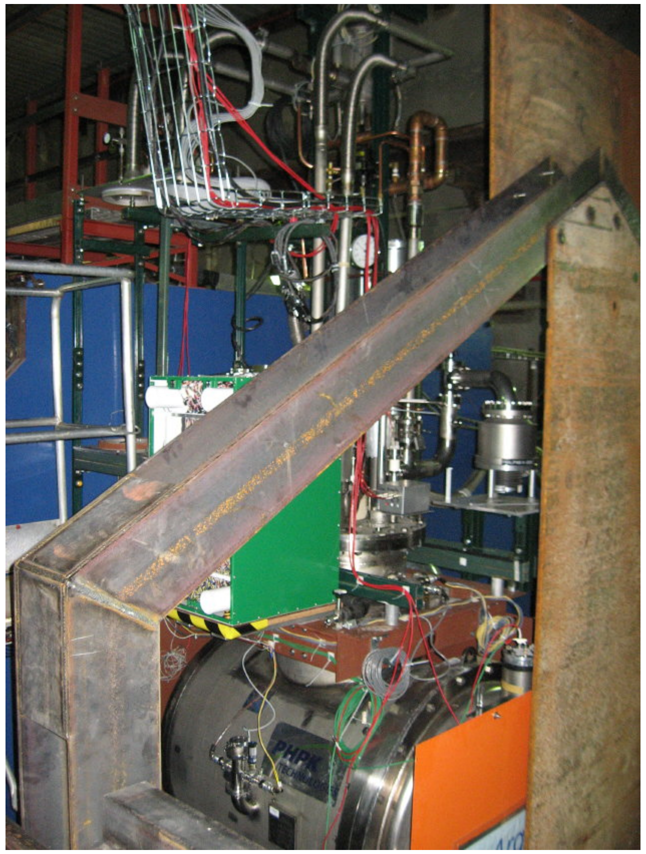
S. Kopp, K. Lang
The University of Texas at Austin

C. Anderson, B. Fleming*, S. Linden, M. Soderberg, J. Spitz
Yale University

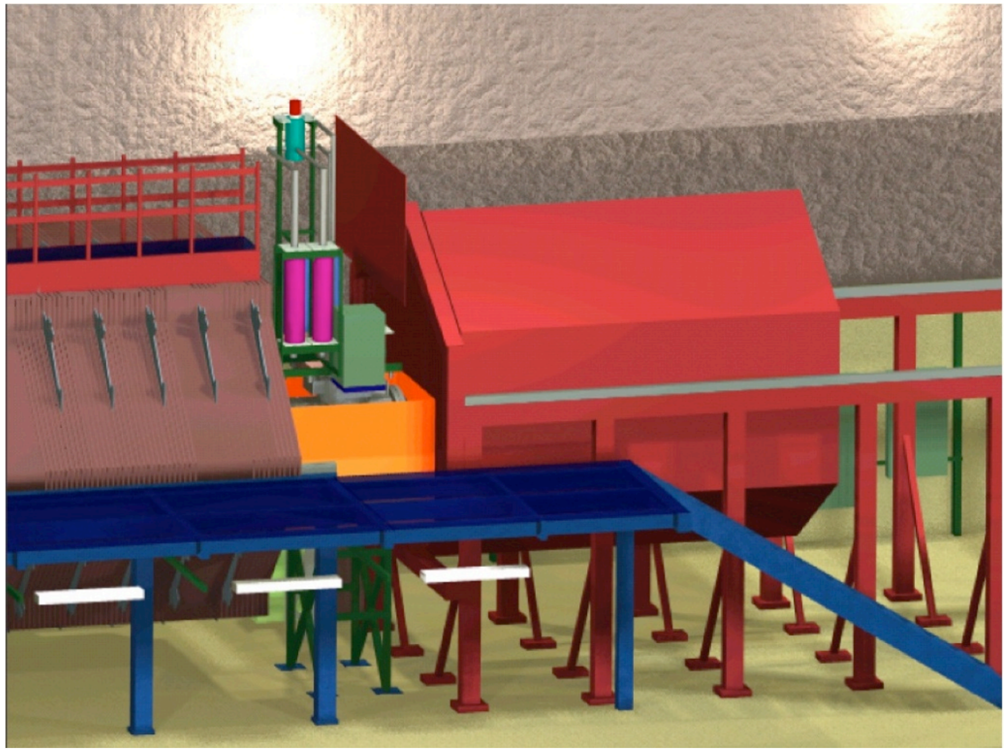
ArgoNeuT Status

•Filled the cryostat underground Friday, May 8.
•Initial argon purity was low....recirculating has cleaned things up...and should continue to do so.
•Took neutrino data for ~1 month before summer shutdown...continuing run in the Fall in antineutrino mode.
•Cryo. system has been continuously operating since our initial fill.
•Electronics (480 channels split between induction/collection planes) performing very well...low noise levels.

Moving underground

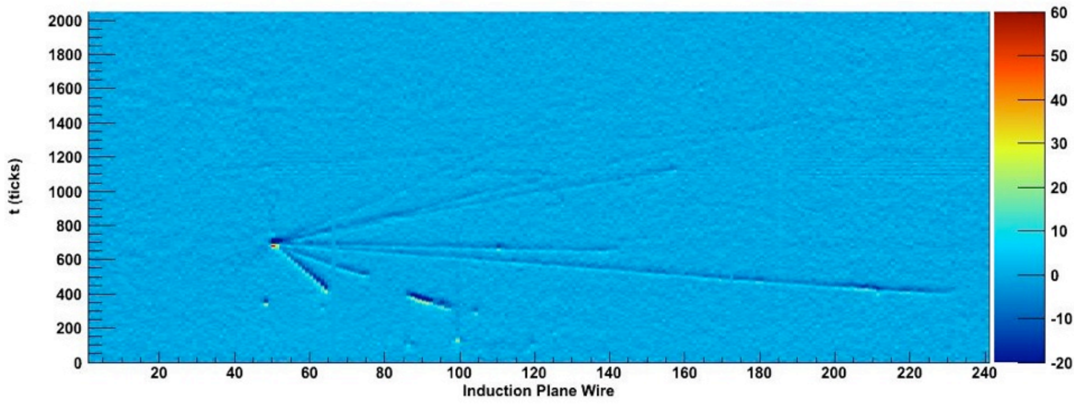


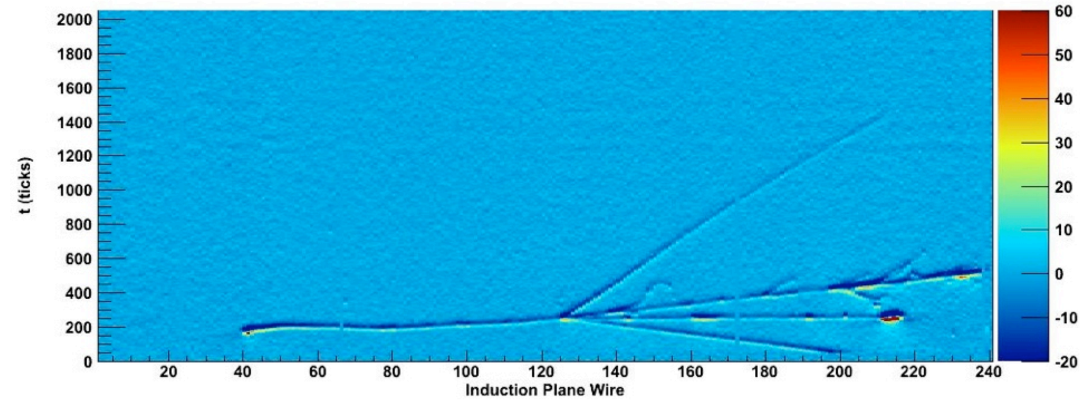
Looking through Minerva frame.

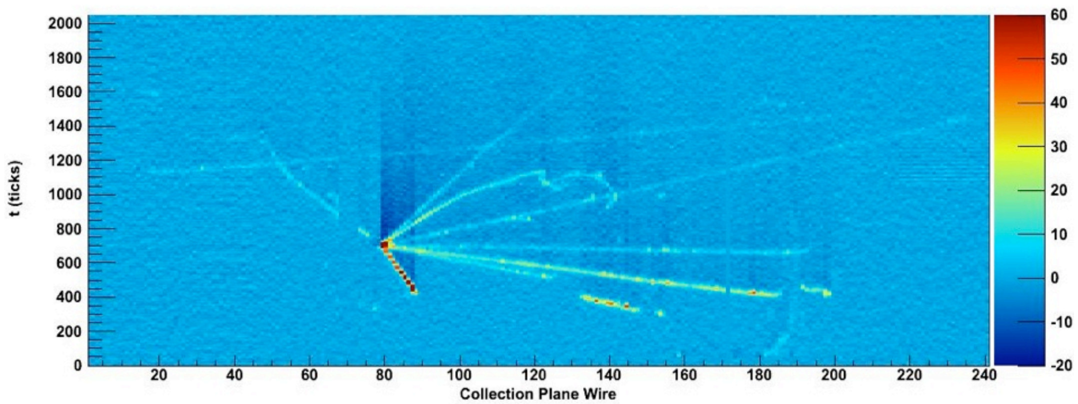


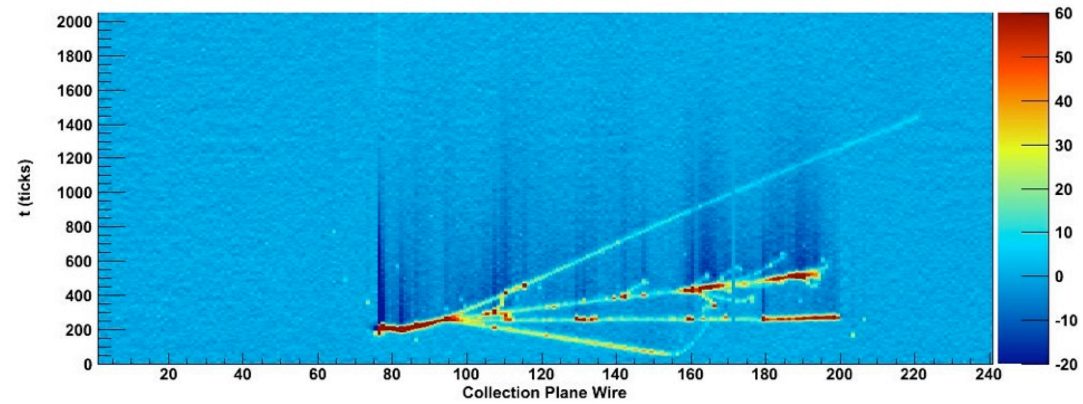
Schematic of NuMI experiments

ArgoNeuT Neutrino Events

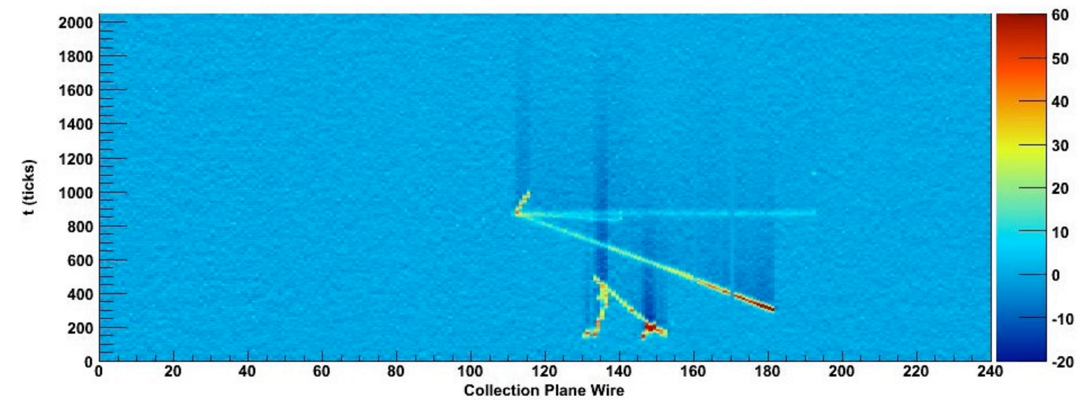


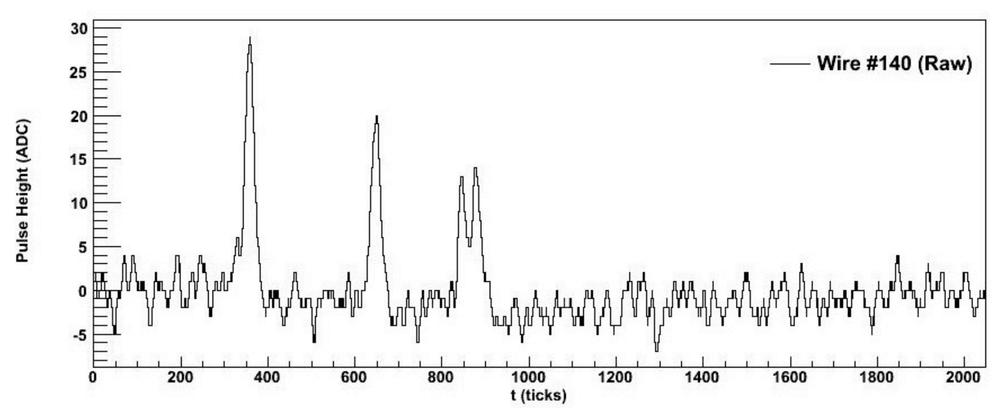






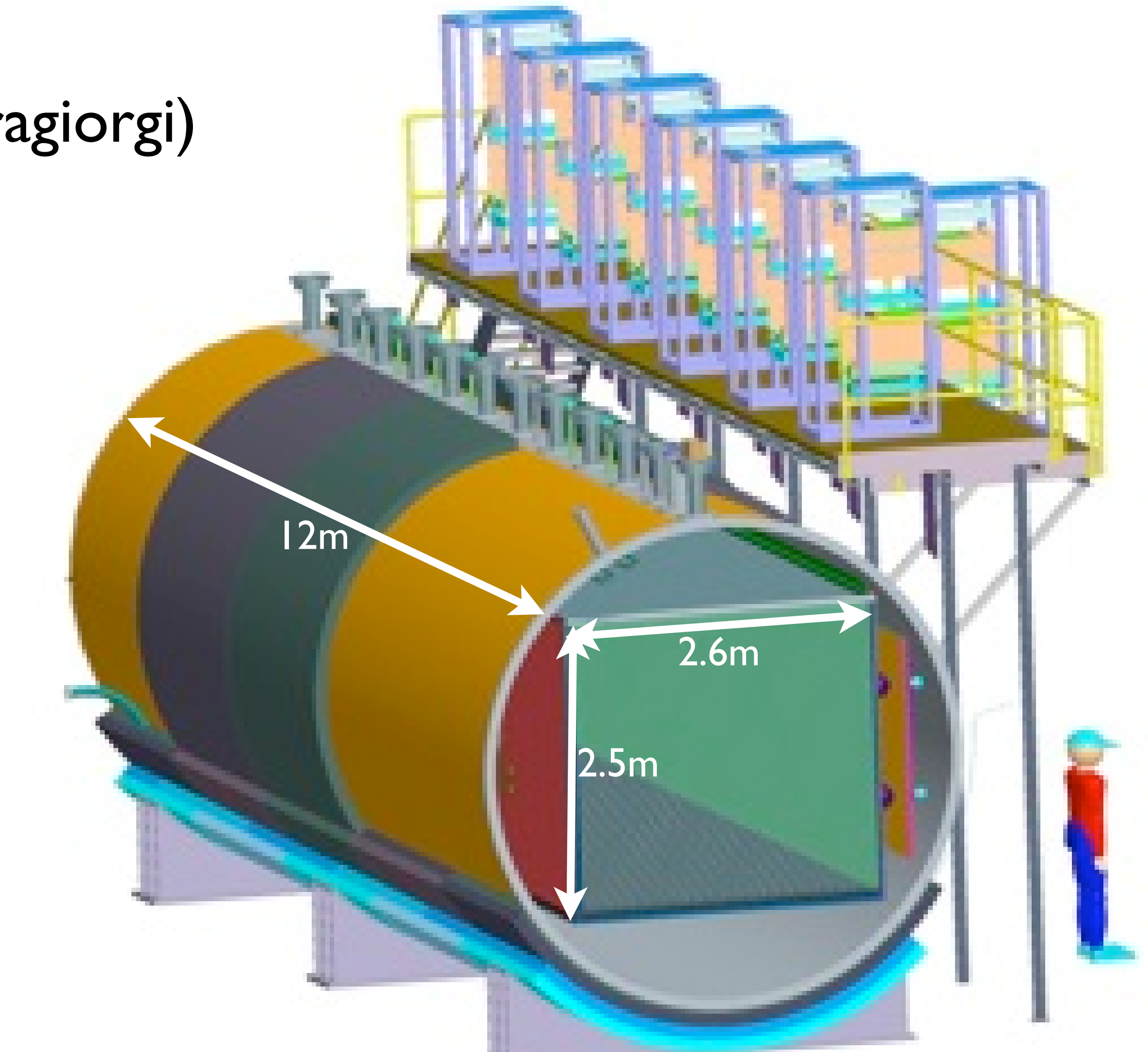
- •ArgoNeuT is taking data in the NuMI antineutrino beam now!
- •These are the <u>raw data</u> for a few events from neutrino mode.





MicroBooNE

- MicroBooNE is a proposed LArTPC detector to run in the on-axis Booster and off-axis NuMI beam on the surface at Fermilab.
- Combines timely physics with hardware R&D necessary for the evolution of LArTPCs.
    - Cold Electronics (10000 channels)
    - Long Drift
    - Purity test (purge with gas before beginning run)
    - MiniBooNE low-energy excess (see talk by G. Karagiorgi)
    - Low-Energy Cross-Sections
    - R&D Physics for larger LArTPC detectors.



Stage 1 approval from Fermilab directorate in June 2008

➡Joint NSF/DOE Project
➡NSF MRI for TPC, PMT, and readout electronics systems ($1.5M)

MicroBooNE Collaboration

H. Chen, J. Farrell, F. Lanni, D. Lissauer, D. Makowiecki, J. Mead,
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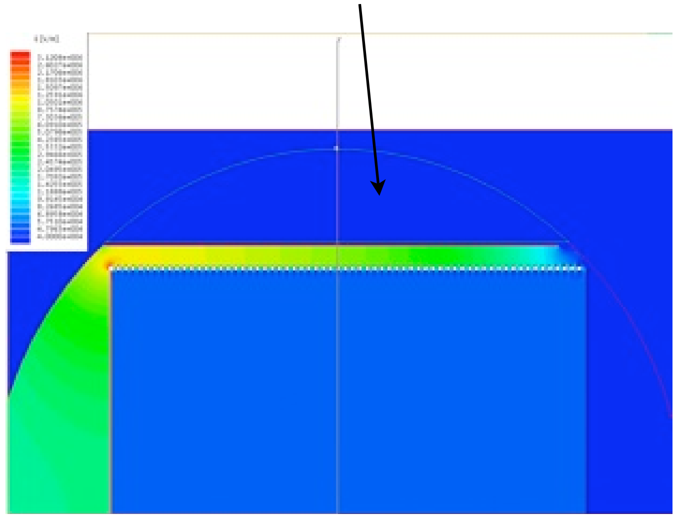
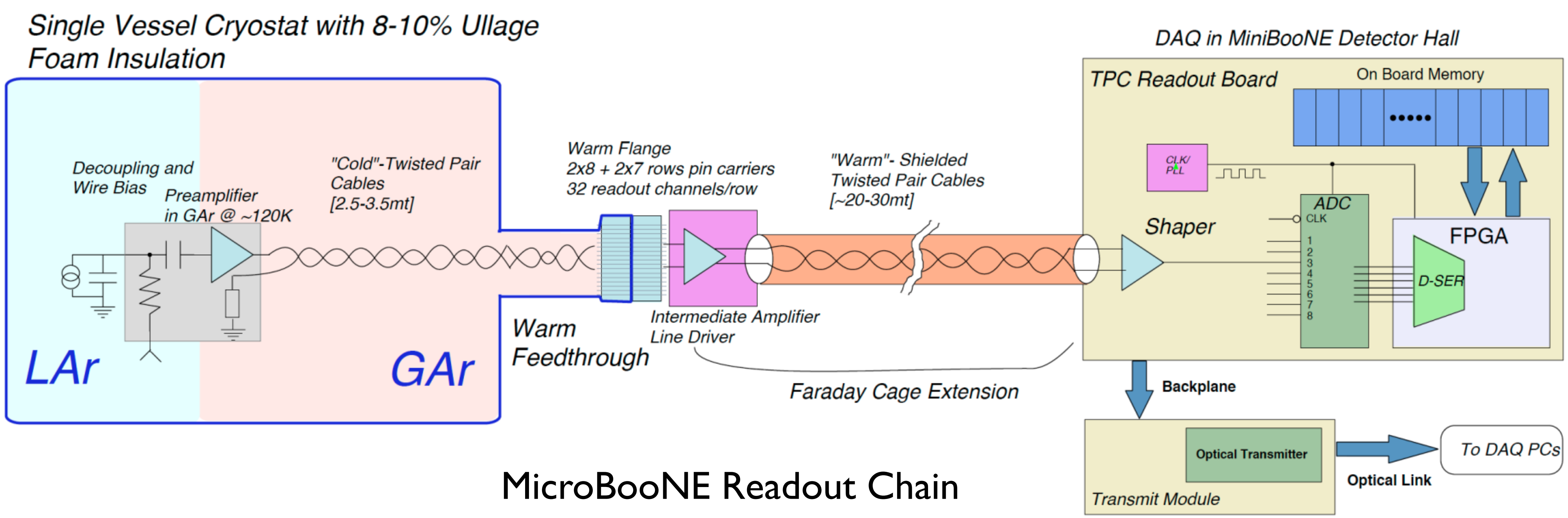
Yale University, New Haven, CT

MicroBooNE: Cold Electronics

- MicroBooNE has 10000 channels spread over 3 instrumented wireplanes.
- Preamps will be placed inside of cryostat.
  - x3 better S/N compared with room temperature performance.
  - Necessary step along the path to large detectors where signals must make long transits.
- Many future electronics questions can be answered by MicroBooNE.
  - JFET/CMOS performance (~4 year development required for CMOS).
  - Maintaining purity with electronics inside tank.
  - Heat load due to power output of electronics in tank.
  - Multiplexing signals inside tank (reduce required feedthroughs).

PreAmps in cold gas





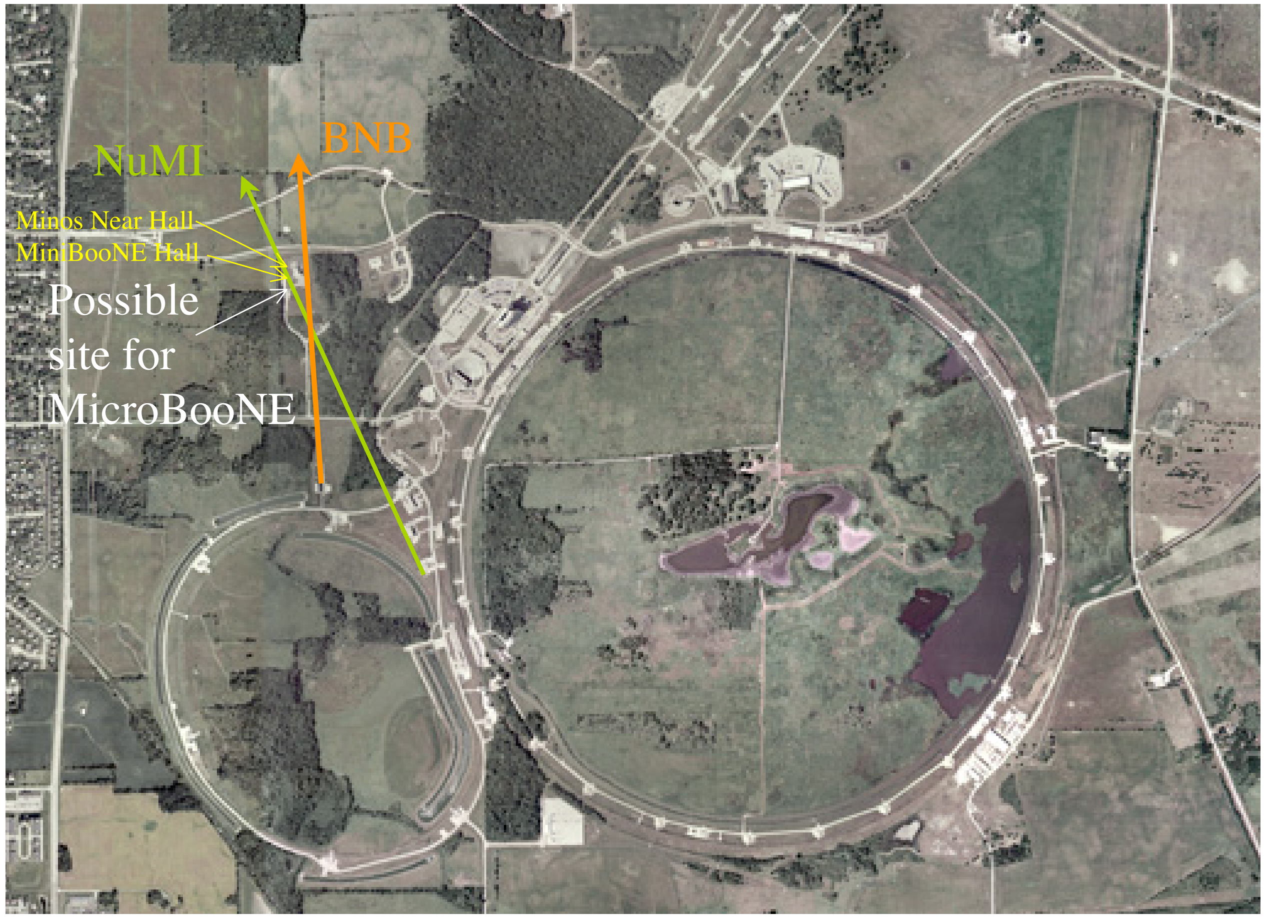
MicroBooNE Readout Chain

MicroBooNE: Location

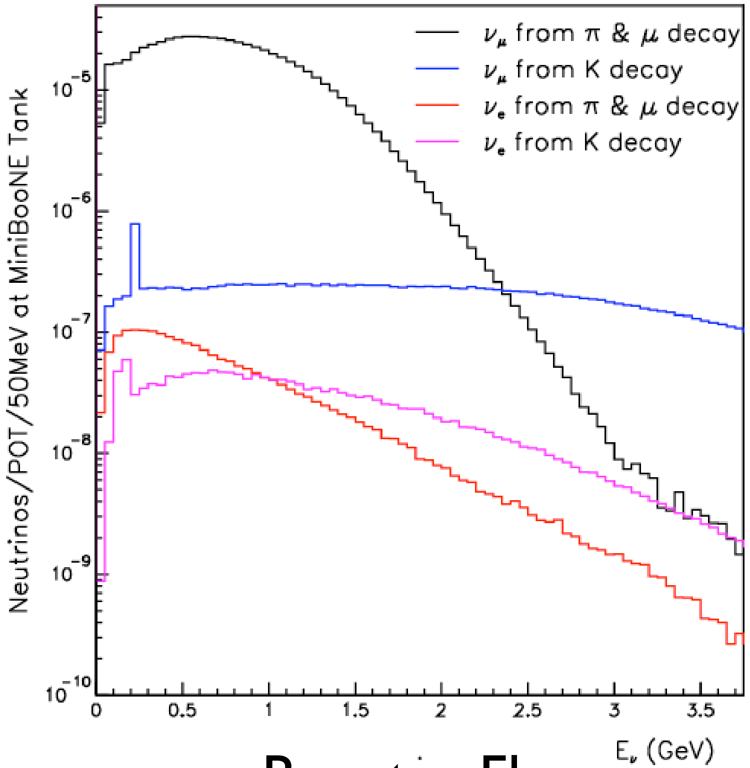
- MicroBooNE will sit on surface in on-axis Booster beam, and off-axis (LE) NuMI beam.

	BNB	NuMI
Total Events	145k	60k
ν_μ CCQE	68k	25k
NC π^o	8k	3k
ν_e CCQE	0.4k	1.2k
POT	$6\text{x}10^{20}$	$8\text{x}10^{20}$

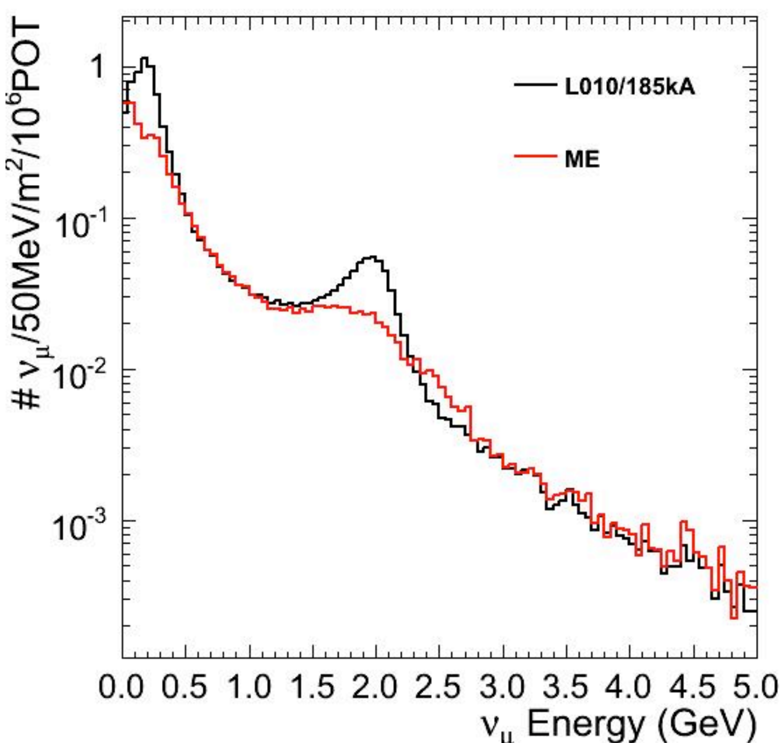
Expected Event Rates for MicroBooNE in 2-3 years.



Neutrino Beams at Fermilab



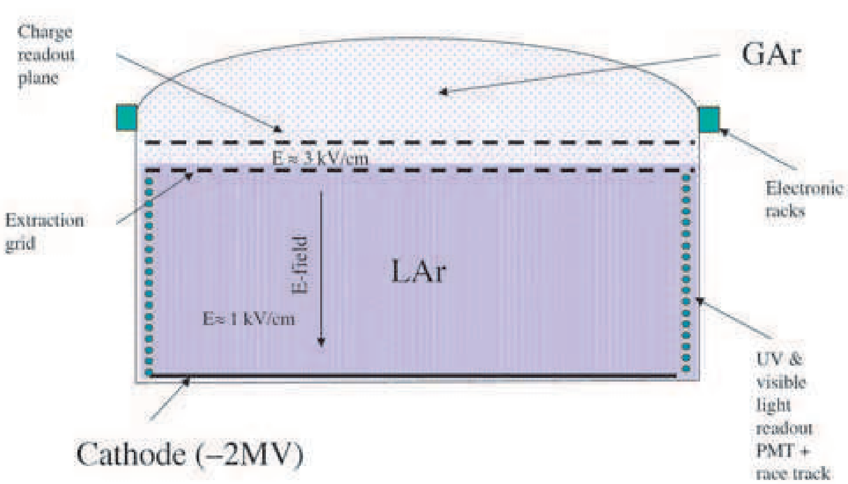
Booster Flux



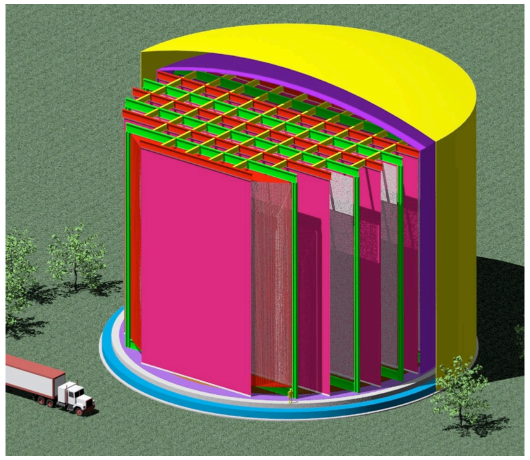
NuMI Off-Axis Flux

Massive LAr Detectors

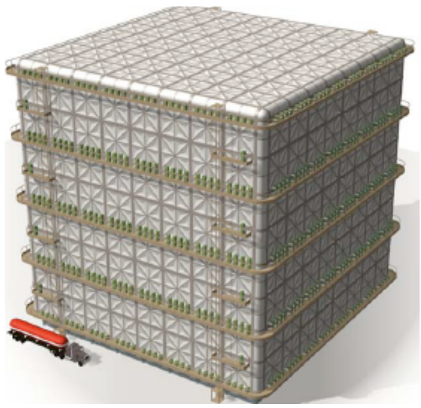
- Ultimate goal of this technology is a many kiloTon far-site LArTPC
- Several detector ideas have been thought of... (see below)
- Main technical challenges:
    - Safety
    - Purification of large quantity of argon (perhaps not from a vacuum environment)
    - Readout (long wires ⇒ increased capacitance ⇒ increased noise)
    - Long drift (need to compensate for diffusion, recombination, purity, etc..)
    - Underground construction technique
    - Huge quantities of data!



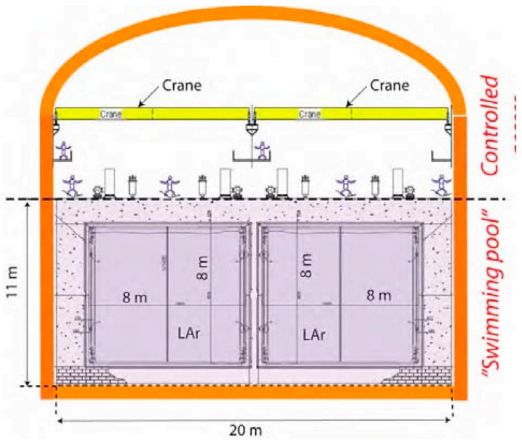
GLACIER



FLARE



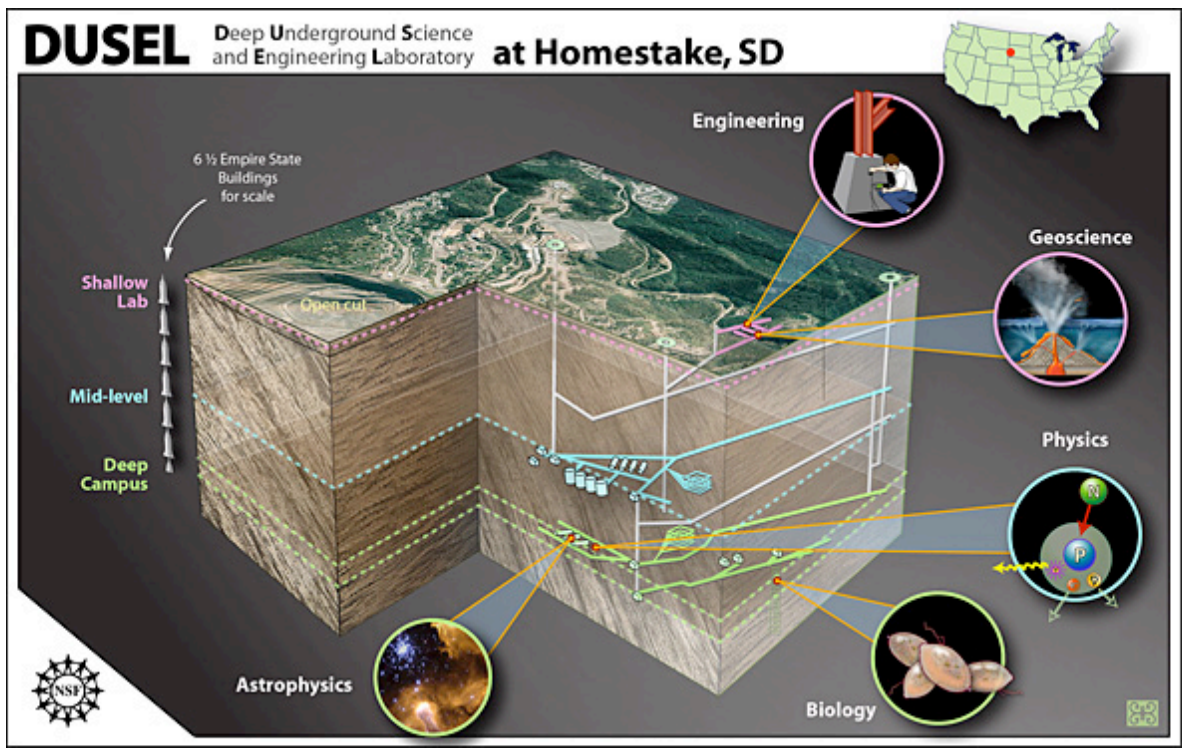
LANNDD

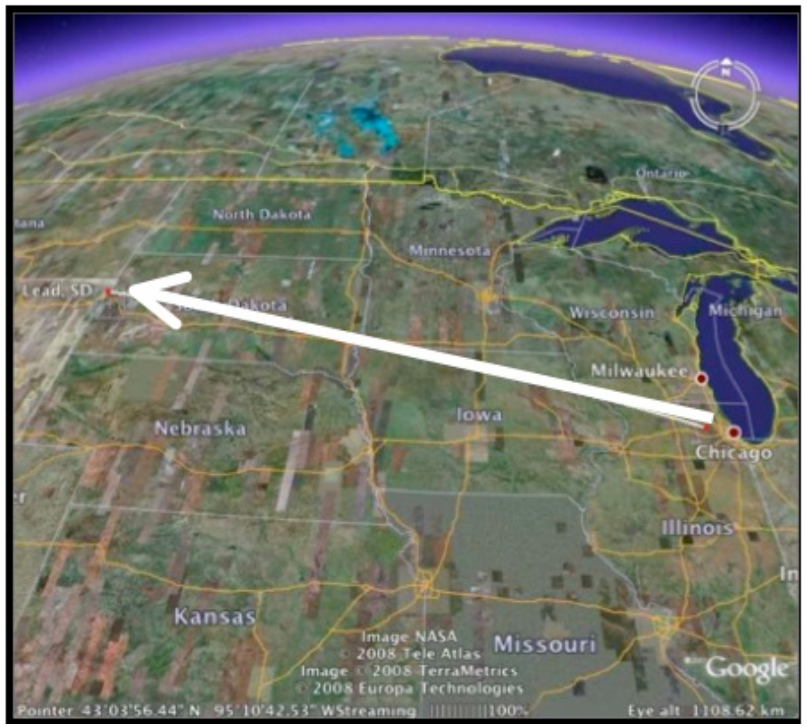


MODULAR

Massive Detector Location

- Prefer to put this huge detector someplace very deep (e.g. - Homestake Mine in South Dakota, Soudan Mine in Minnesota) to reduce cosmic background.
- Proposed Project X at Fermilab sends intense neutrino beam 1300km to this far-site location.
- LBNE group focused on possibility of massive detector at DUSEL:
  - 1st stage of LBNE plan does not include Project X (starts with 700kW beam, and a large far-site detector module)
  - upgrade to this is Project X (2.3MW) + more modules





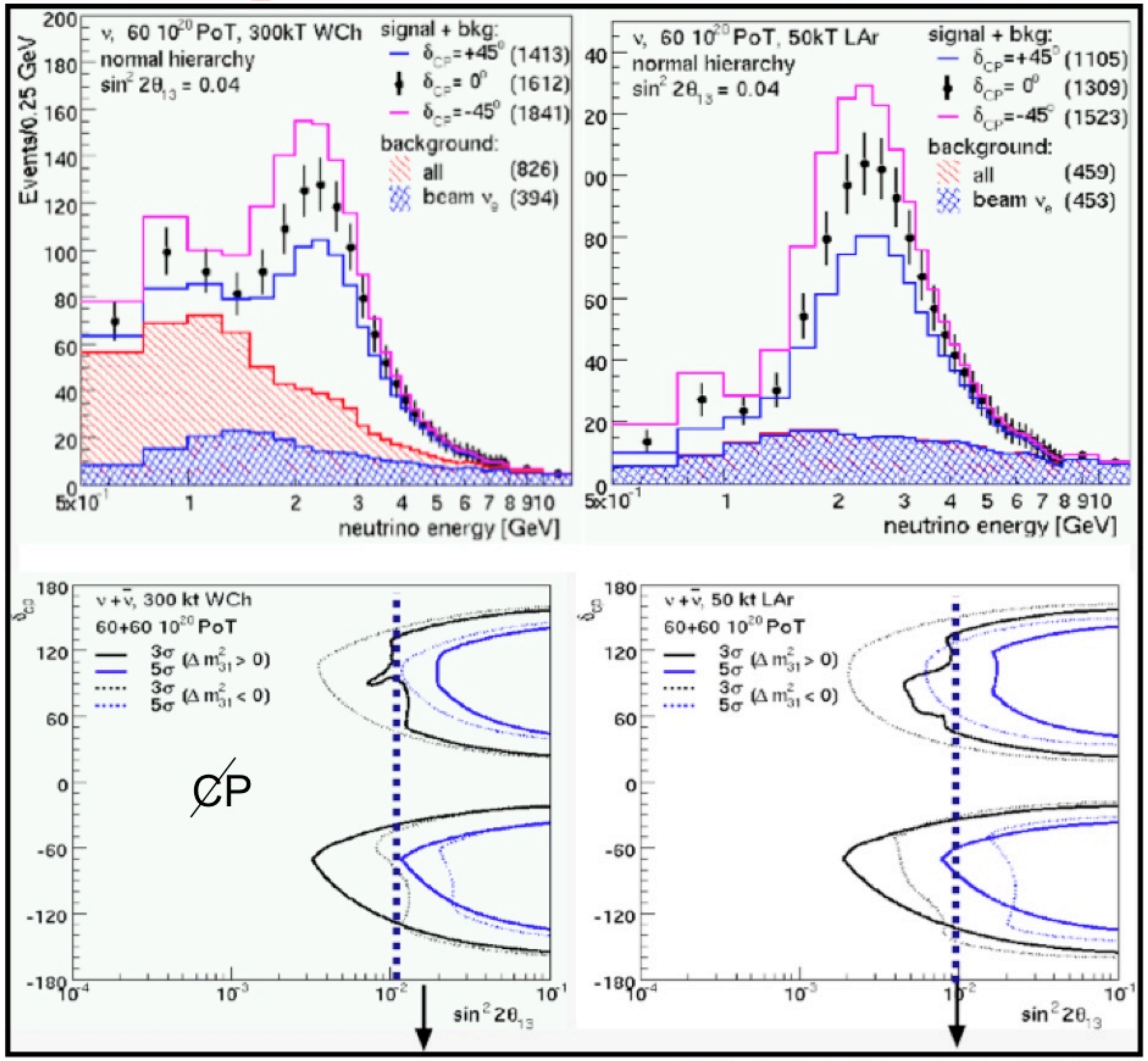
Recommendations from the Report of the P5 Panel to HEPAP, May 29, 2008:

"The panel recommends proceeding now with an R&D program to design a multi-megawatt proton source at Fermilab and a neutrino beamline to DUSEL and recommends carrying out R&D in the technology for a large detector at DUSEL."

Massive Detector: Physics Reach

- Tremendous sensitivity when large LArTPC and intense neutrino beam are combined.
- CP-violation sensitivities below show ~6:1 equivalence between Water Cerenkov and LAr.

300kT H_2O Cerenkov 50kT liquid argon



(M. Dierckxsens, 2008)

- Plots Assumes:
  - WBB design for LBNE
  - 120 GeV Protons
  - 5% background uncertainty
  - ν + anti-ν running for CP sensitivities

Conclusion

- Considerable activity in U.S. to develop LArTPC technology.
- The ultimate goal is to build a massive LArTPC that can be utilized in a future long-baseline experiment.
- ArgoNeuT is current step for LArTPCs in U.S.; will collect 10000's of events!
- MicroBooNE is next major effort in U.S.
  - Combines timely physics measurements with important hardware R&D necessary before attempting to build very massive detector.
- LBNE collaboration for a massive detector + intense beam to DUSEL has formed and is already holding regular meetings.

Back-Up Slides

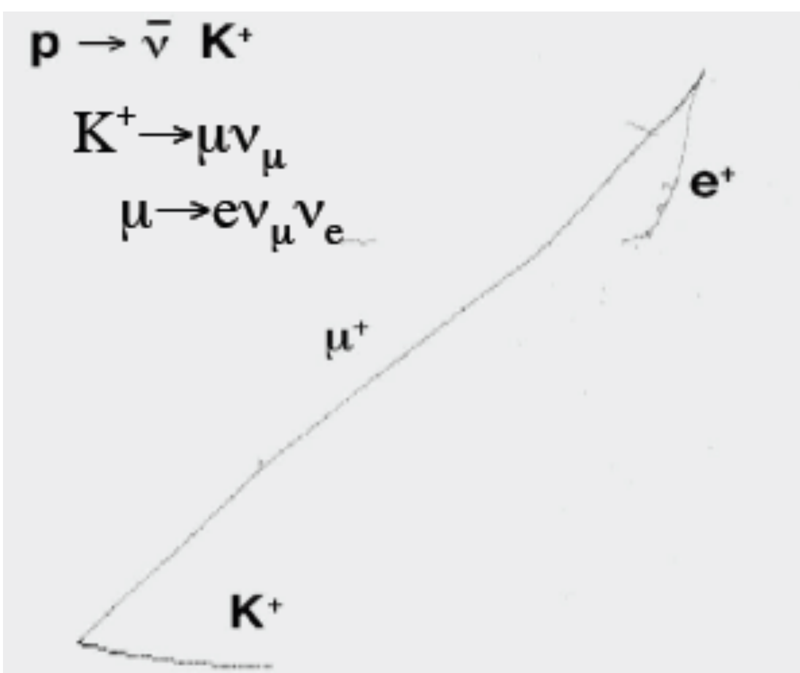
Noble Liquid Properties

- Abundant ionization and scintillation light can be used for detection.
- Ionization electrons can be drifted over long distances in these liquids if they are purified.
- Excellent dielectric properties allow these liquids to accommodate very high-voltages.
- 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	

MicroBooNE: Physics Goals

- Address the MiniBooNE low energy excess
- Utilize electron/gamma tag (using dE/dX information).
- Low Energy Cross-Section Measurements (CCQE, NC π^o, $\Delta \rightarrow N\gamma$, Photonuclear, ...)
- Use small (~500) sample of Kaons to develop PID for future proton-decay searches.
- Continue development of automated reconstruction.

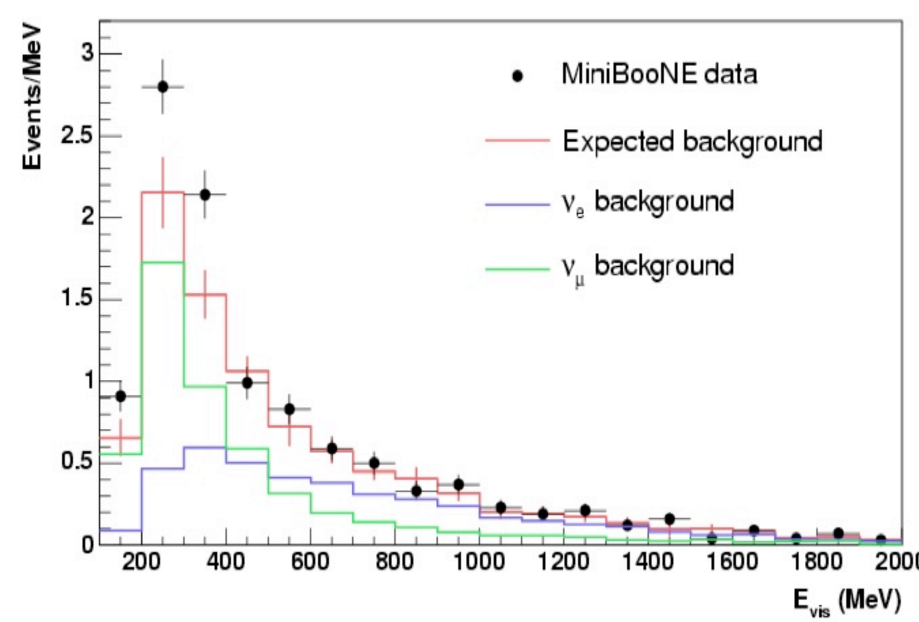


ICARUS Simulation

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)