MicroBooNE:
A New Liquid Argon Time Projection Chamber Experiment

Mitch Soderberg
Yale University
NuINT09
May 20, 2009

Introduction

- Liquid Argon Time Projection Chambers (LArTPCs) are well suited to study neutrino physics and beyond.
  - Combine excellent spatial resolution, calorimetry, and triggering capability.
  - In principle they are scalable to very large sizes (i.e. - channel count doesn't grow linearly with detector volume).
- Pioneering LArTPC work done by ICARUS collaboration.
- U.S. effort to develop LArTPCs has expanded significantly in recent years.
  - See next talk about ArgoNeuT!

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."

Department of Energy (DOE)

↑

HEPAP (High Energy Physics Advisory Panel)

↑

P5 (Particle Physics Project Prioritization Panel)

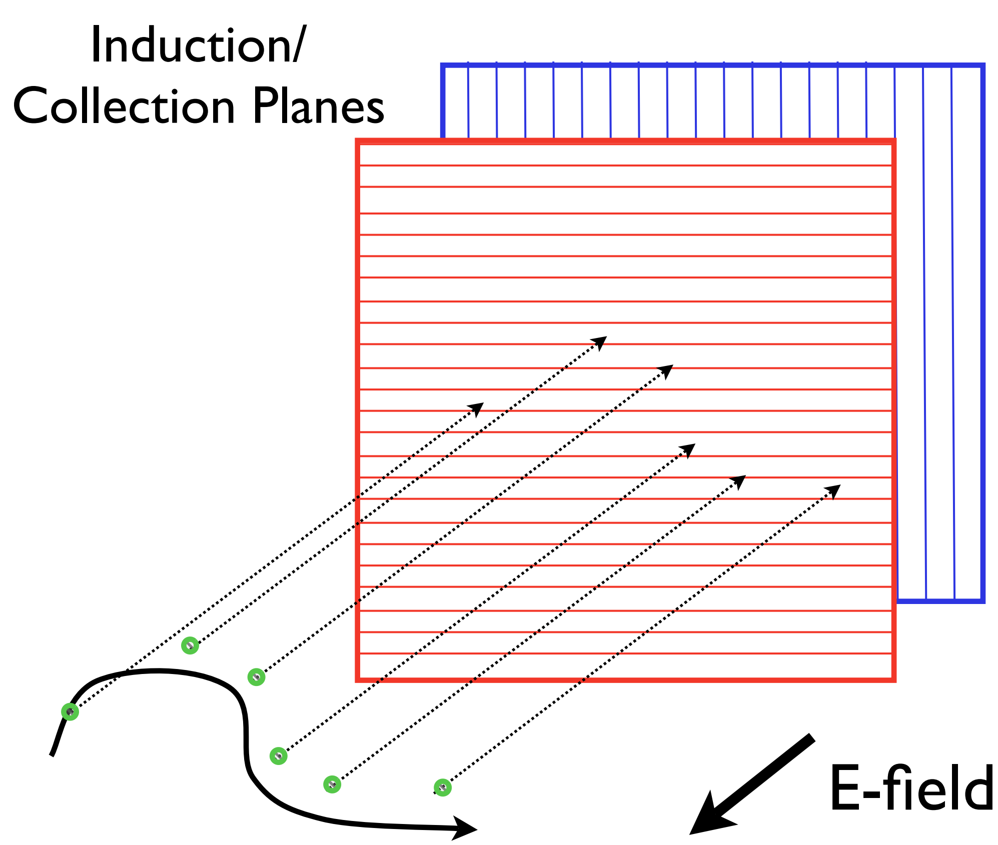
Talk Outline

- LArTPC Basics
- The MicroBooNE Experiment
- MicroBooNE Physics Prospects
- Conclusions

LArTPC Principal

TPC = Time Projection Chamber

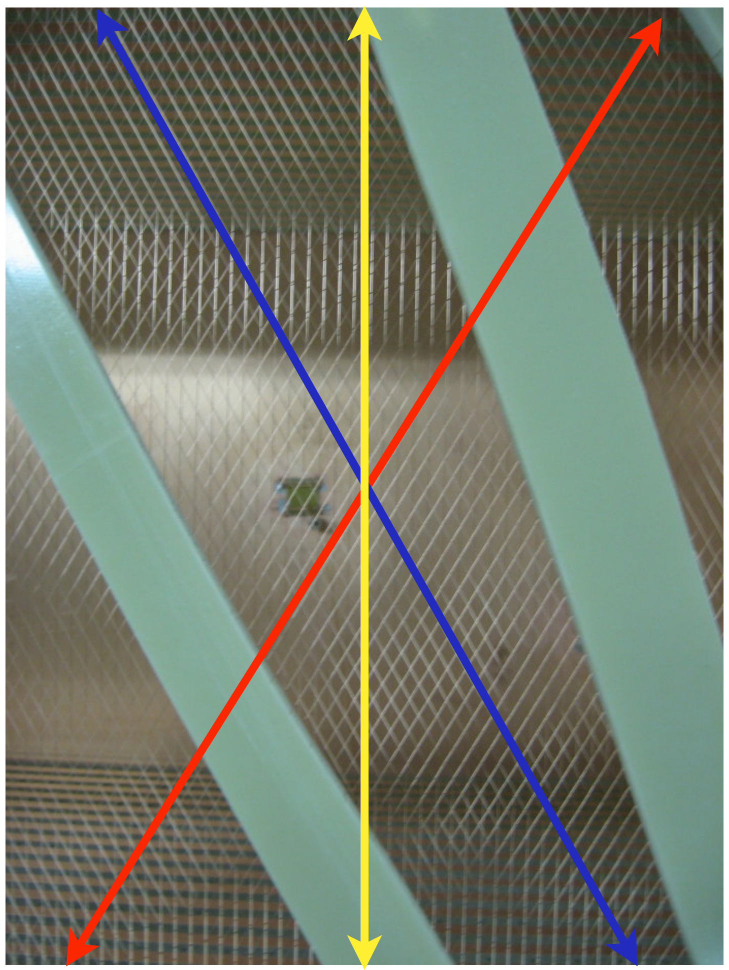
- Interactions inside TPC produce ionization particles
- Ionization drifts along electric field lines in TPC to readout planes.
- Location of wires within a plane give position measurements.
- Knowledge of drift speed, and T_0 of events, used to project back along drift direction to particle's origin.
- Scintillation light also present, can be collected by Photomultiplier Tubes and used in triggering.



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

Wireplanes

- TPC wireplanes act as an electrostatic grid.
- Biasing planes properly allows them to be transparent to drifting electrons.
- Transparency is a function of wire geometry and fields around each plane.
  - **Transparency + Multiple planes allow complimentary position measurements of same particle.**
- Optimize wire/plane pitch to increase resolution, but keep S/N high.



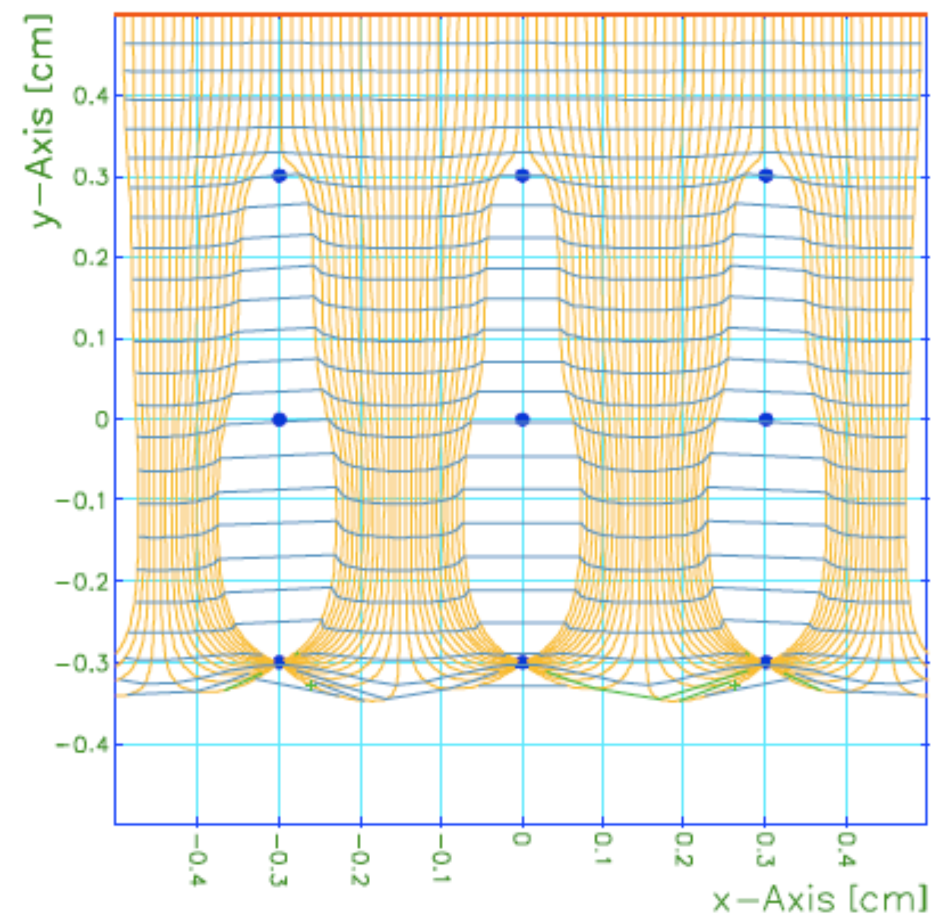
Wire Orientations

$$\frac{E_2}{E_1} \geq \frac{1+\rho}{1-\rho}$$

100% Transparency Condition:

$$\rho = \frac{2\pi r}{d}$$

r = wire radius
d = wire pitch



Garfield Simulation

Refs:
1.) *Design of Grid Ionization Chambers*, O. Bunemann, T.E. Cranshaw, and J.A. Harvey; *Canadian Journal of Research*, 27, 191-206, (1949)

Noble Liquids: Properties

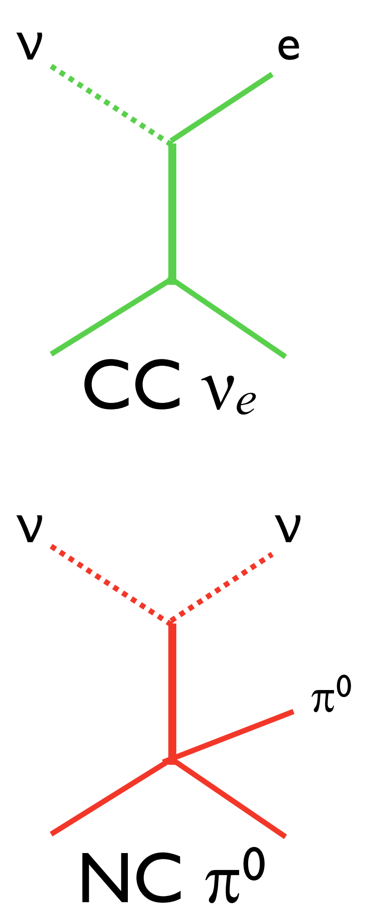
- Ionization and scintillation light can be used for detection.
- Ionization electrons can be drifted over long (*i.e.* - meters) distances in these liquids.
- Excellent dielectric properties allow these liquids to accommodate very high-voltages.
    - Operating voltages in LArTPCs can be high (~100s of kV) if drift length is long.
- Argon is relatively cheap and easy to obtain (1% of atmosphere).

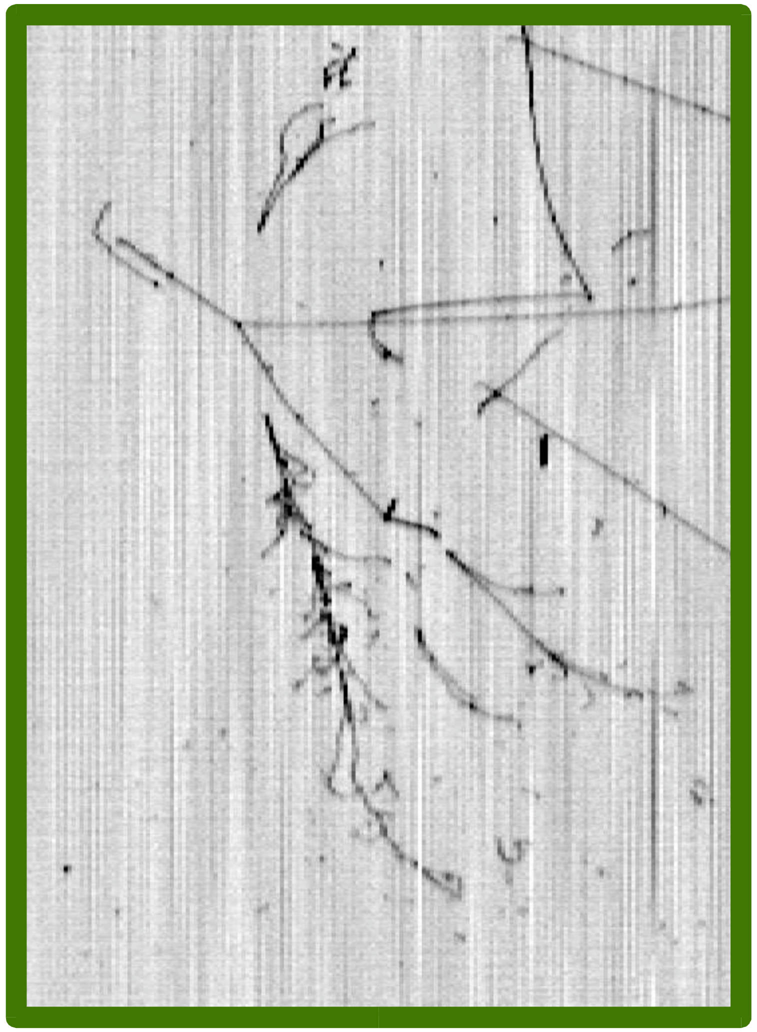
	He	Ne	Ar	Kr	Xe	Water
Boiling Point [K] @ 1atm	4.2	27.1	87.3	120.0	165.0	373
Density [g/cm^3]	0.125	1.2	1.4	2.4	3.0	1
Radiation Length [cm]	755.2	24.0	14.0	4.9	2.8	36.1
dE/dx [MeV/cm]	0.24	1.4	2.1	3.0	3.8	1.9
Scintillation [γ /MeV]	19,000	30,000	40,000	25,000	42,000	
Scintillation λ [nm]	80	78	128	150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

LAr TPC Advantages

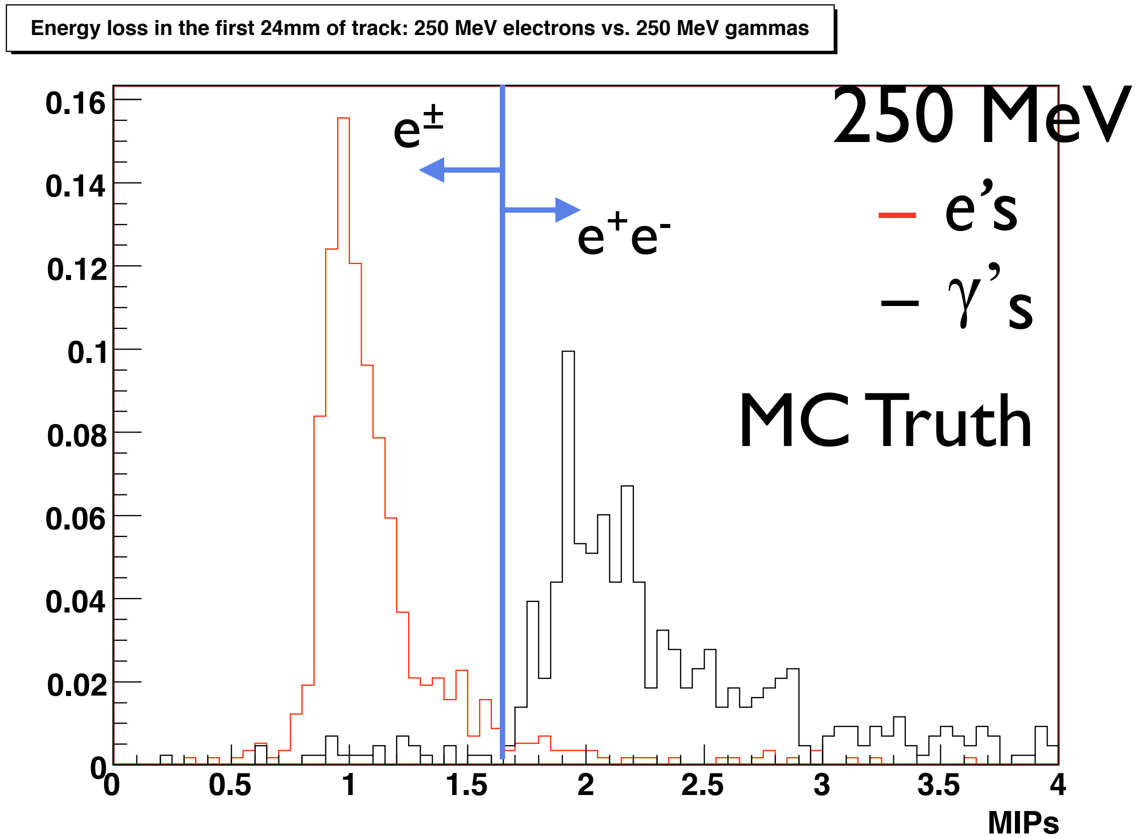
e/γ separation → superior background rejection

- Particle identification comes from dE/dx measured along track.
- Small wire pitch and fast sampling allow for very fine-grained imaging.
- ν_e appearance: Excellent signal (CC ν_e) efficiency and background (NC π^0) rejection
- Topological cuts will also improve signal/background separation





ICARUS Event



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

LArTPC Challenges

- Safety issues.
  - Oxygen Deficiency Hazard (ODH) if argon spills in a confined space.
  - Pressurized vessel needs to have adequate relief capability.
- Strict argon purity level required (parts per trillion).
  - High purity necessary for long-drifts (~5m) characteristic of a very large detector.
  - Detector materials' impact on purity must be understood.
- Electronics.
  - Wire signals are small, so sources of electronic noise must be strictly controlled.
  - High sampling rate + many wires = Flood of raw data.
- Vacuum/Cryogenic Environments
  - Every penetration into the cryostat must be vacuum tight, and pressure rated.
  - Every penetration into the cryostat increases the heat load on the system.

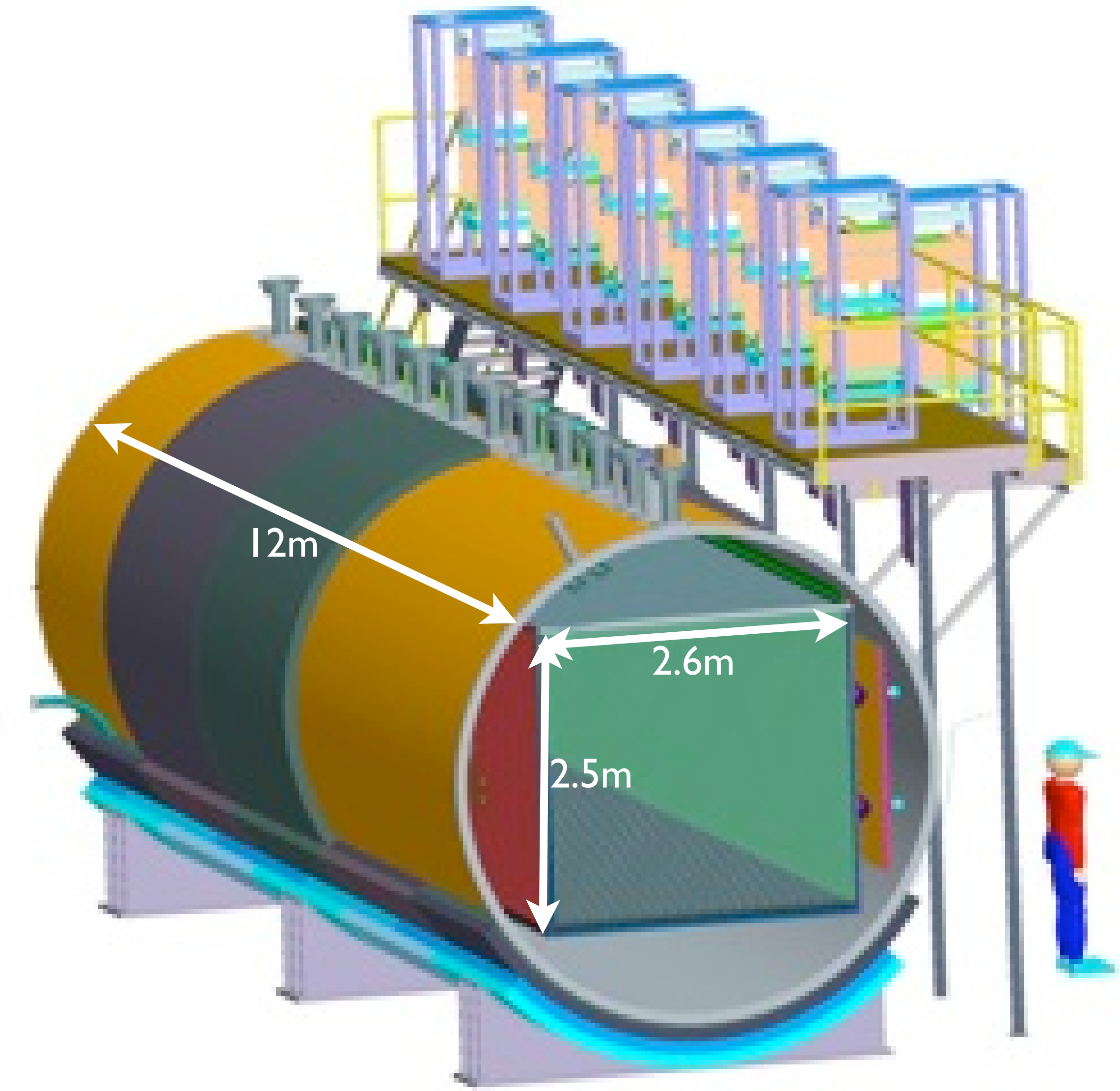
Current program of LArTPC development will address many of these challenges.

MicroBooNE

•MicroBooNE is a proposed Liquid Argon Time Projection Chamber (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
- Long Drift
- Purity test (purge with gas before beginning run)
- MiniBooNE low-energy excess
- 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 and PMT systems

MicroBooNE Collaboration

H. Chen, J. Farrell, F. Lanni, D. Lissauer, D. Makowiecki, J. Mead,
V. Radeka, S. Rescia, J. Sondericker, C. Thorn, B. Yu
Brookhaven National Laboratory, Upton, NY

R. Johnson
University of Cincinnati, Cincinnati, OH

L. Camilleri, C. Mariani, M. Shaevitz, W. Willis[‡]
Columbia University, New York, NY

B. Baller, C. James, S. Pordes, G. Rameika, B. Rebel, D. Schmitz, J. Wu
Fermi National Accelerator Laboratory, Batavia, IL

G. Garvey, J. Gonzales, B. Louis, C. Mauger, G. Mills, Z. Pavlovic,
R. Van de Water, H. White, S. Zeller
Los Alamos National Laboratory, Los Alamos, NM

B. Barletta, L. Bugel, J. Conrad, G. Karagiorgi, T. Katori, V. Nguyen
Massachusetts Institute of Technology, Cambridge, MA

C. Bromberg, D. Edmunds
Michigan State University, Lansing, MI

K. McDonald, C. Lu, Q. He
Princeton University, Princeton, NJ

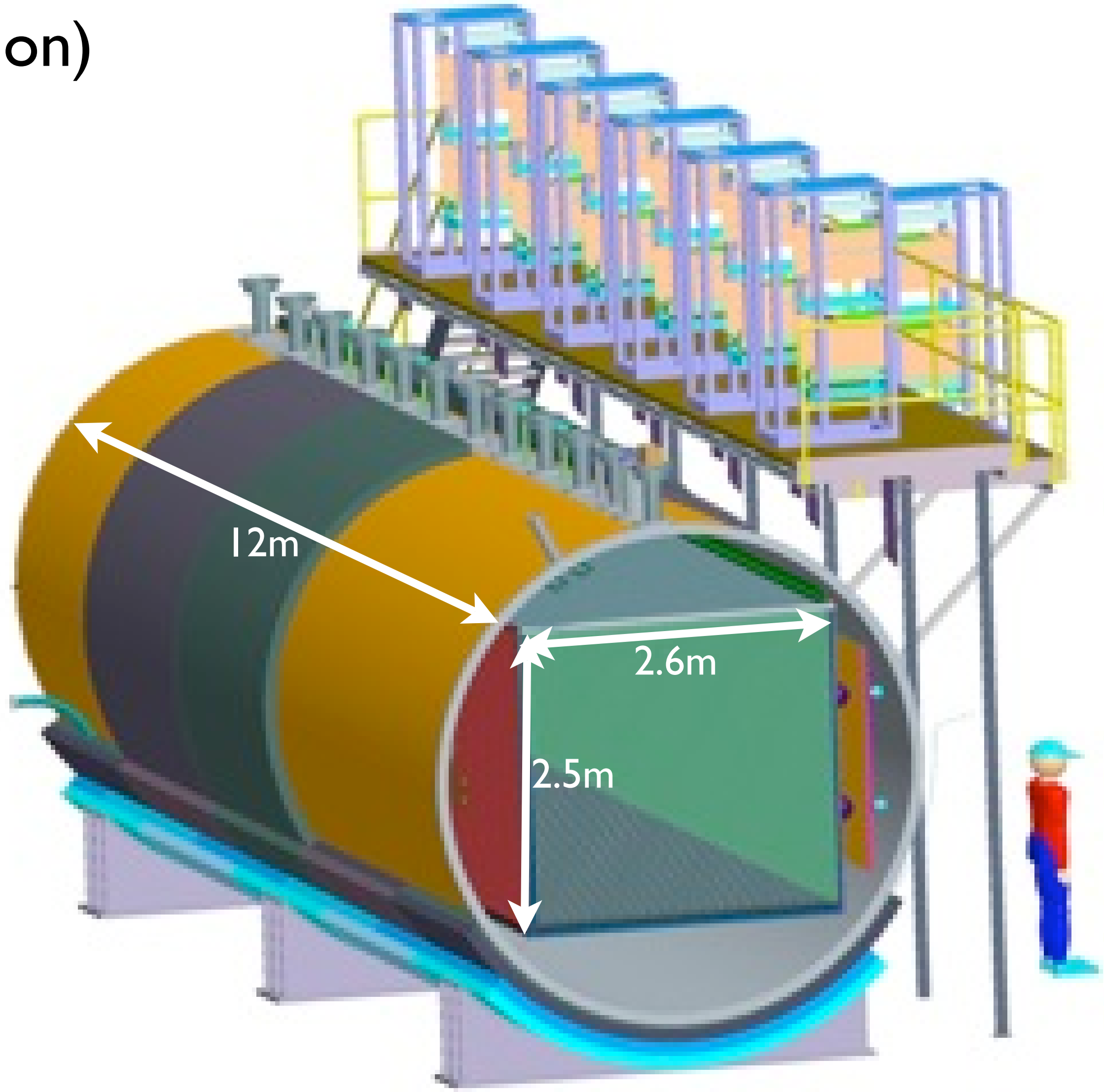
P. Nienaber
St. Mary's University of Minnesota, Winona, MN

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

C. Anderson, B. Fleming[†], S. Linden, M. Soderberg, J. Spitz
Yale University, New Haven, CT

MicroBooNE: Design

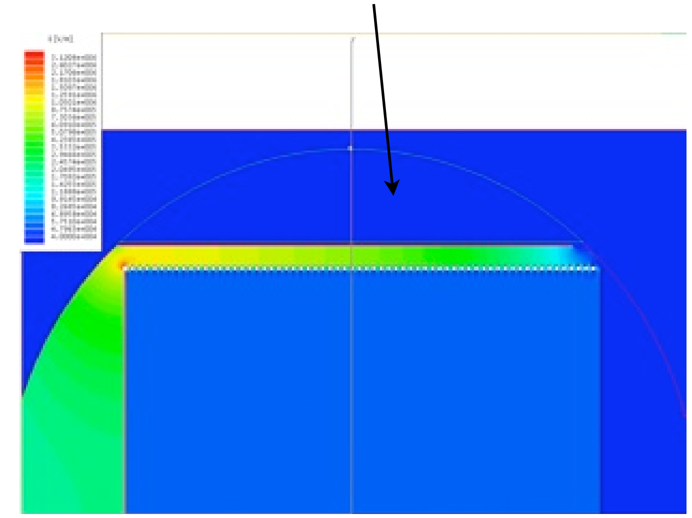
- Cryostat (170 Tons LAr) as large as can be commercially built offsite and delivered over the roads.
- TPC parameters
  - 70 Ton fiducial volume (depends on analysis definition)
  - 2.6m drift (500V/cm) ⇒1.6ms drift time
  - 3 readout planes (±30° Induction, vertical Collection)
  - ~10000 channels (**using Cold Preamplifiers**)
- ~30 PMTs for triggering
- Purification/Recirculation system.

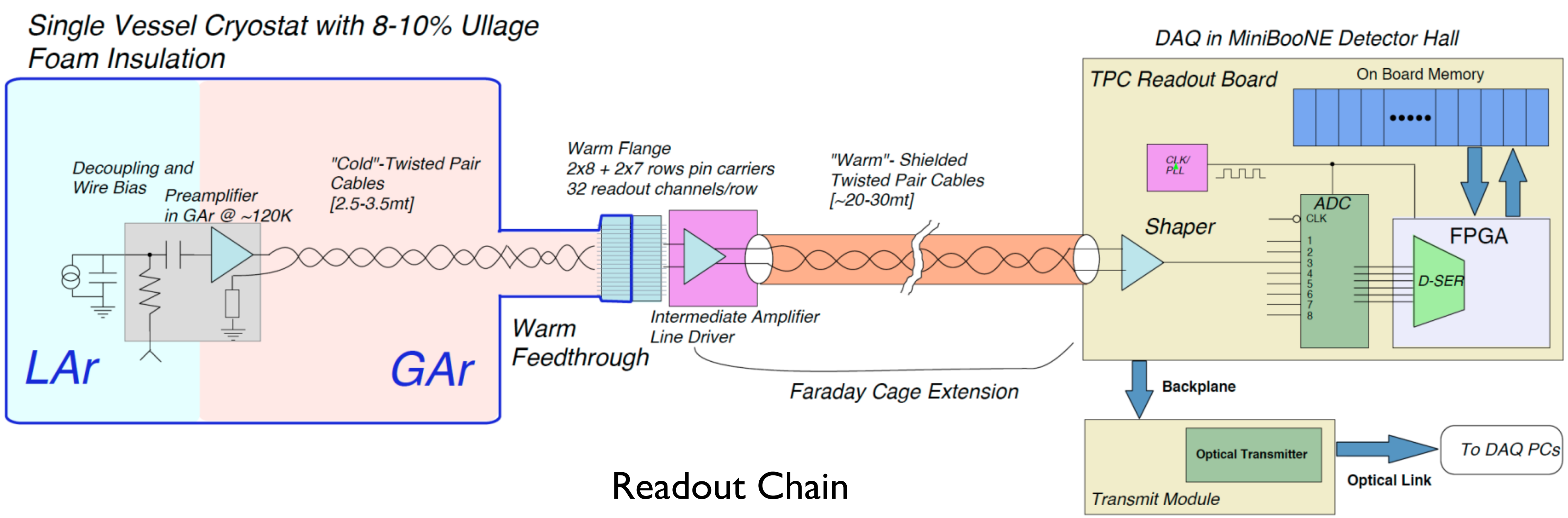


MicroBooNE: Cold Electronics

- 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 Hardware 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.

PreAmps in cold gas

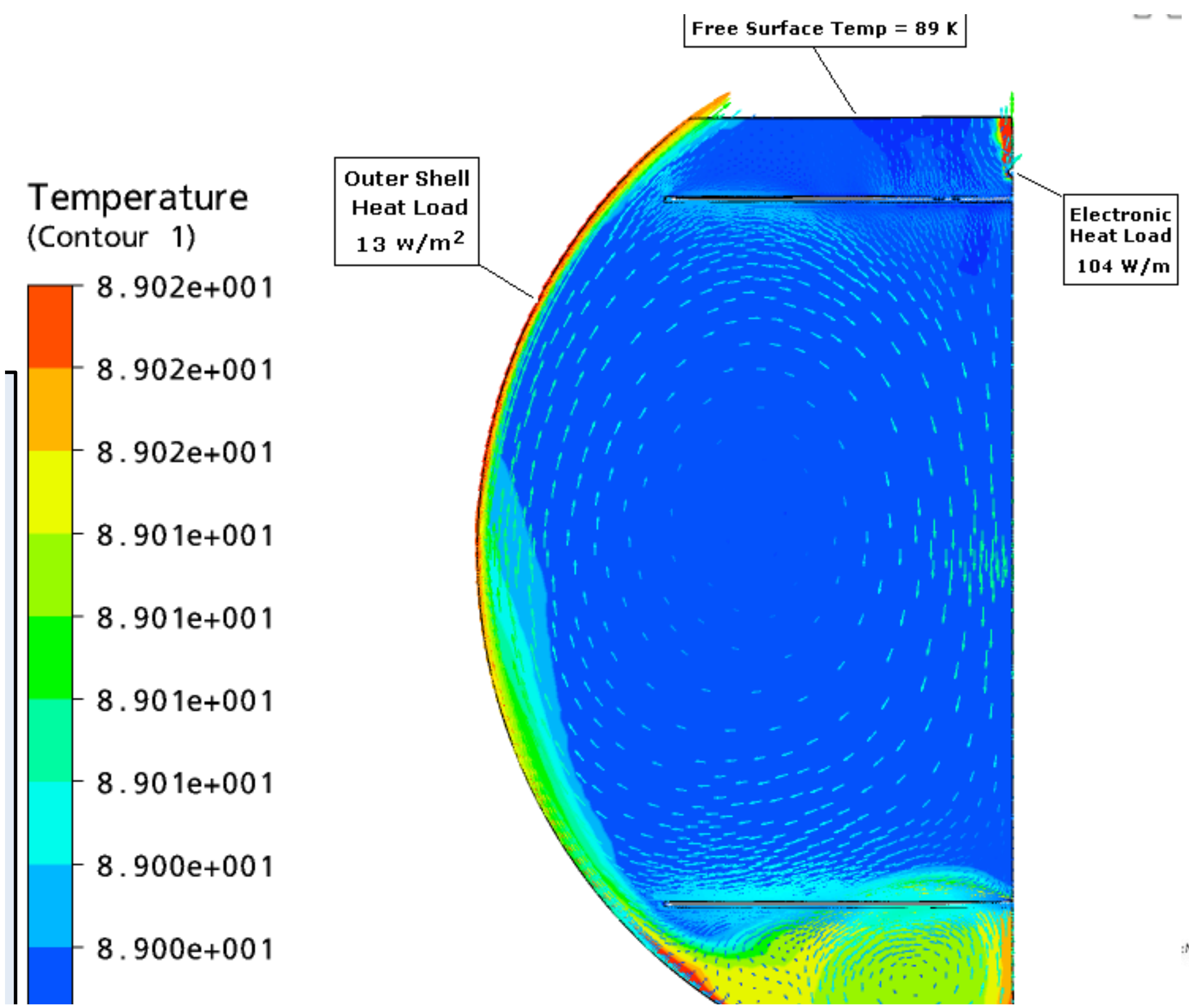




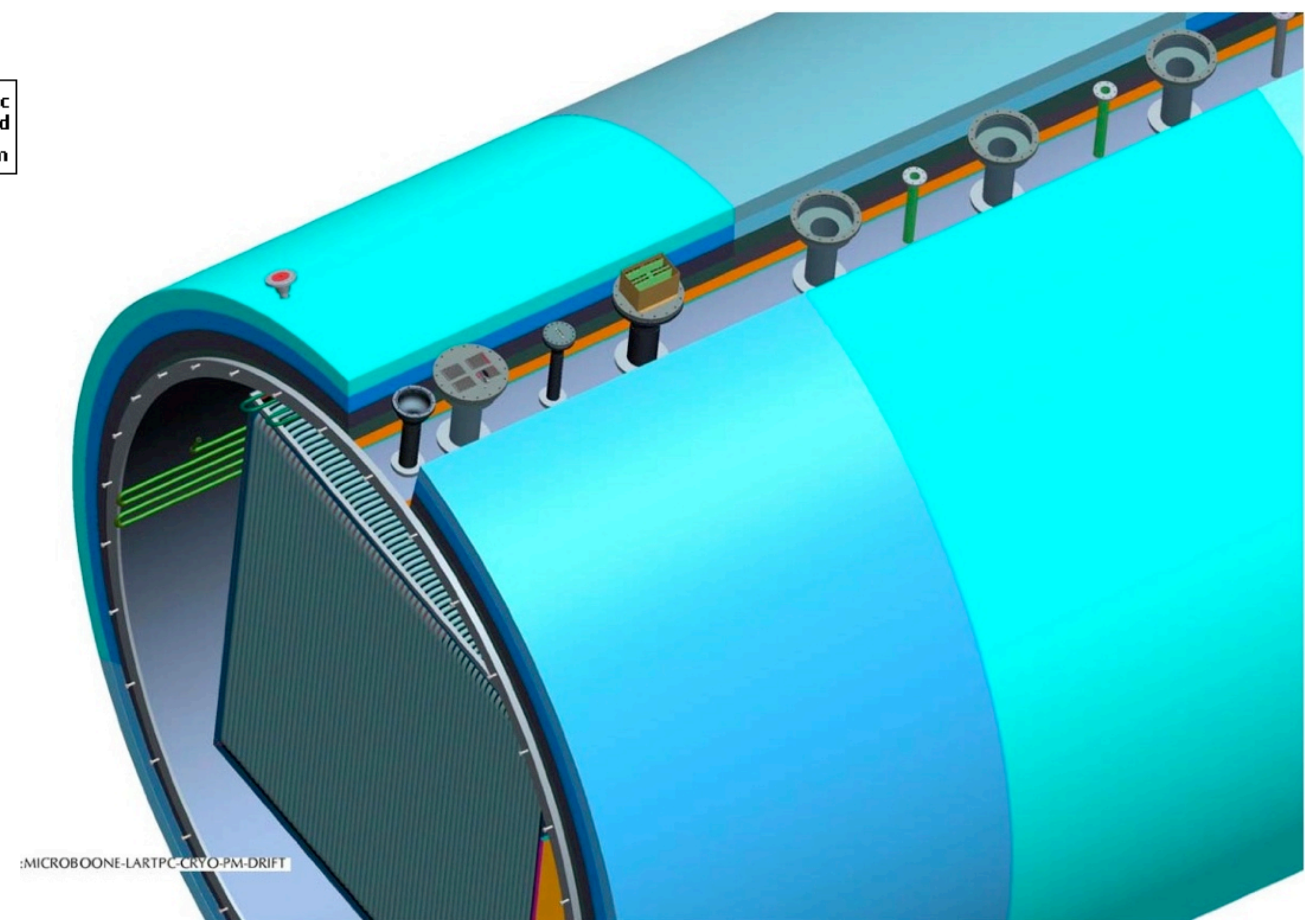
Readout Chain

MicroBooNE Cryogenics

- Preliminary studies have been performed to understand thermal load of system.
- ~16 inches (~40 cm) glass foam insulation
- 3.4kW total load (13W/m^2)
- Temp. gradient <<0.1K - crucial to reducing track distortions (drift velocity ~ T).
- Services and detector integration are being designed.



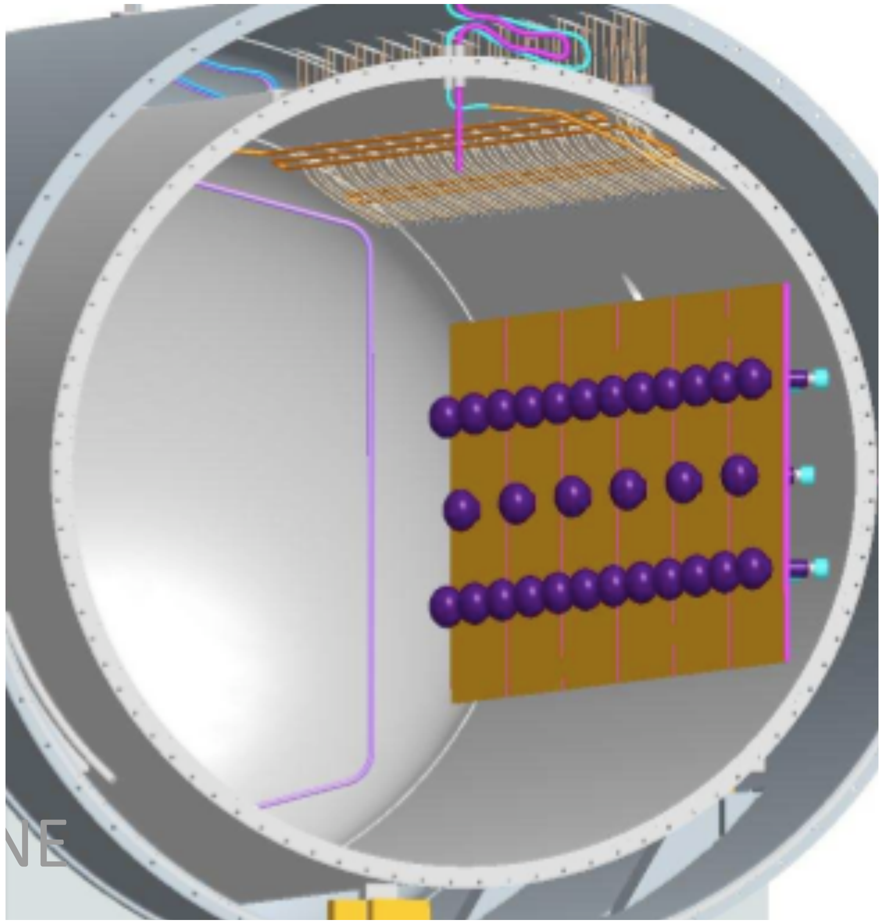
Temperature distribution



Detailed view of insulation/feedthroughs

MicroBooNE: Light Collection

- ~30 PMTs to aid in t_0 determination and help reduce data load
  - *i.e.* - require coincidence of beam spill and light signal in PMTs
- Most likely will use tubes from Hamamatsu
- Coat tubes with wavelength shifter (TPB = tetraphenyl-butadiene) to allow collection of VUV light.
- Design work on all PMT details ongoing.



30 PMTs facing TPC

8” PMT

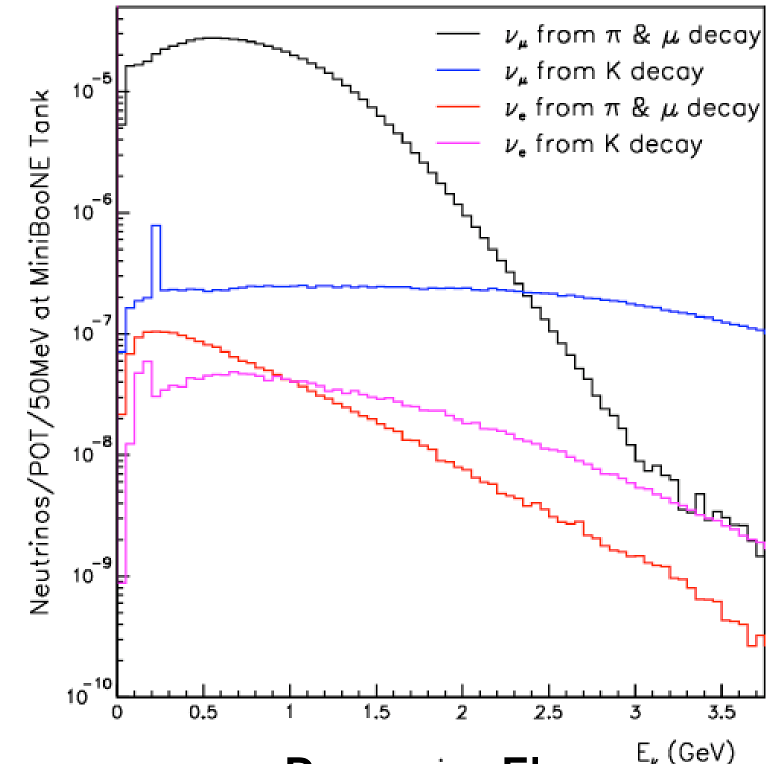
MicroBooNE: Location

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

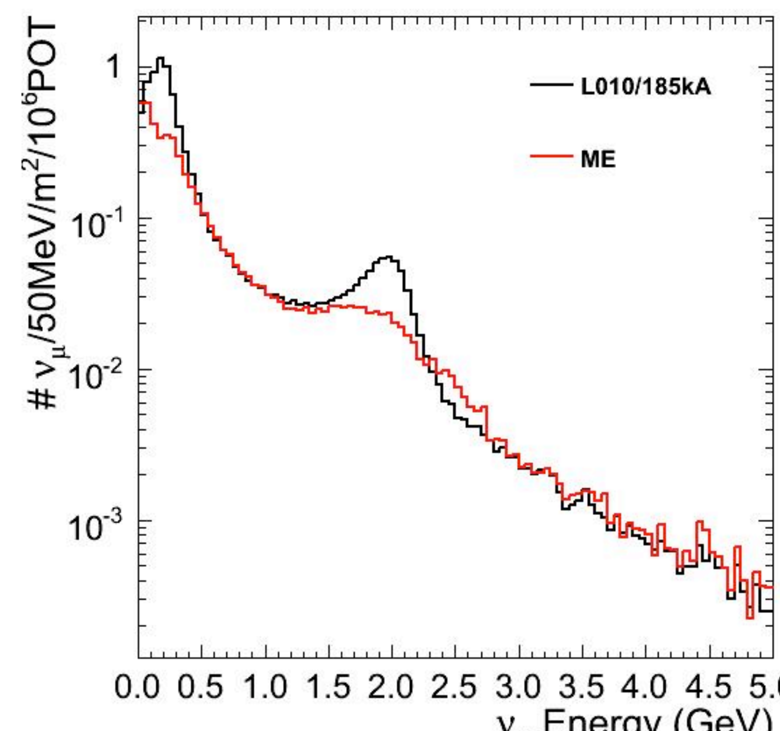
	BNB	NuMI
Total Events	145k	60k
ν_μ CCQE	68k	25k
NC π^o	8k	3k
ν_e CCQE	0.4k	1.2k
POT	$6x10^{20}$	$8x10^{20}$

Expected Event Rates for MicroBooNE.

Neutrino Beams at Fermilab



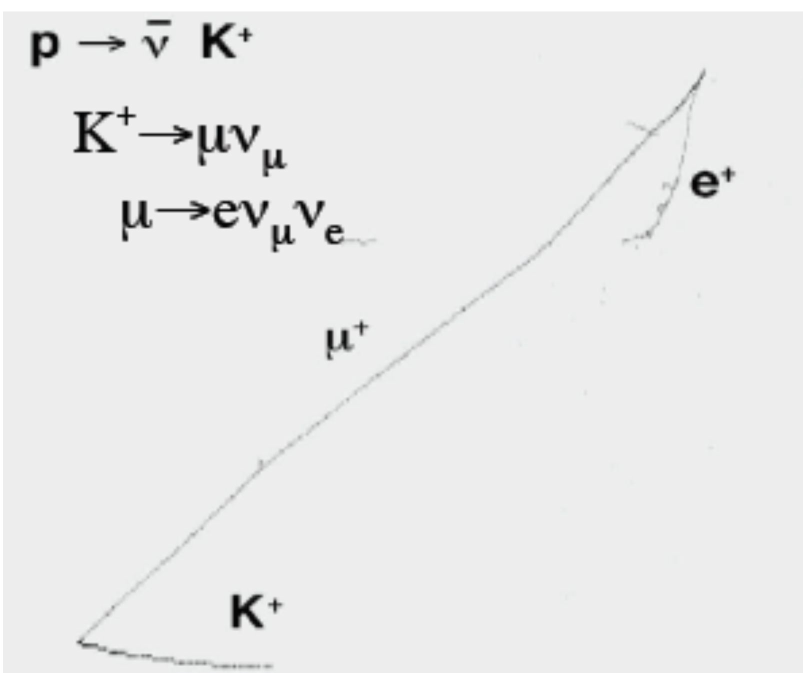
Booster Flux



NuMI Off-Axis Flux

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.

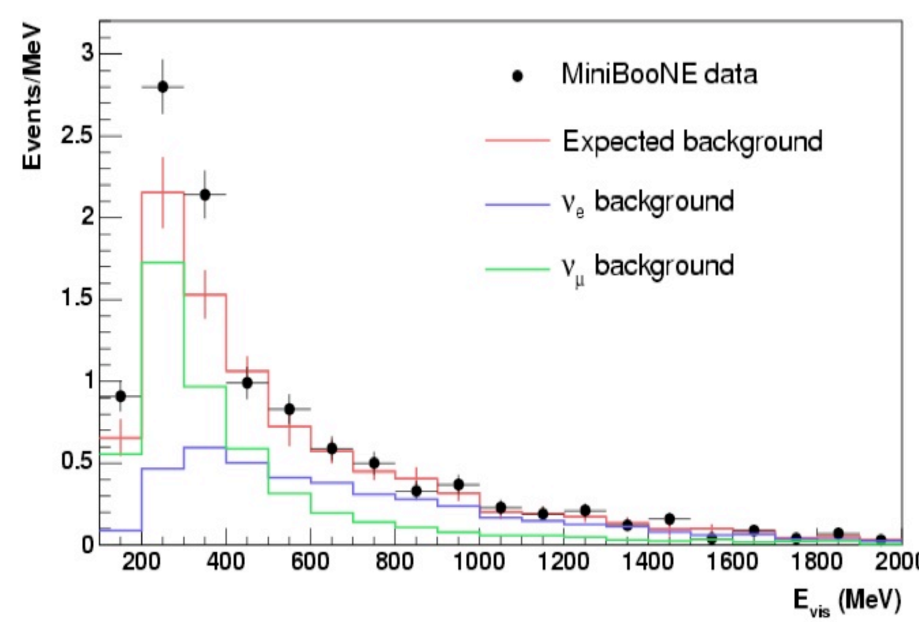


ICARUS Simulation

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)

MicroBooNE: Exotic Topics

- Supernova capability
  - Data will be buffered for ~1 hour...in case there is a supernova notification received.
  - Several modes of detection:
    - Elastic Scattering: $\nu + e^- \rightarrow \nu + e^-$
      - Sensitive to all neutrino species
    - Absorption (CC): $\nu_e + {}^{40}Ar \rightarrow e^- + {}^{40}K^*$, $\nu_e + {}^{40}Ar \rightarrow e^+ + {}^{40}Cl^*$
      - Search for charged particle in final-state.
      - Also identified via photon from de-excitation of K/Cl atom.
    - NC: $\nu + {}^{40}Ar \rightarrow \nu + {}^{40}Ar^*$
      - Sensitive to all neutrino species
      - Identified via photon from de-excitation of argon atom.
  - Studies of low-E threshold for PMTs are getting started.
- Sensitivity to Δ_s through $R_{NC/CC} = \frac{\sigma(\nu p \rightarrow \nu p)}{\sigma(\nu n \rightarrow \mu^- p)}$

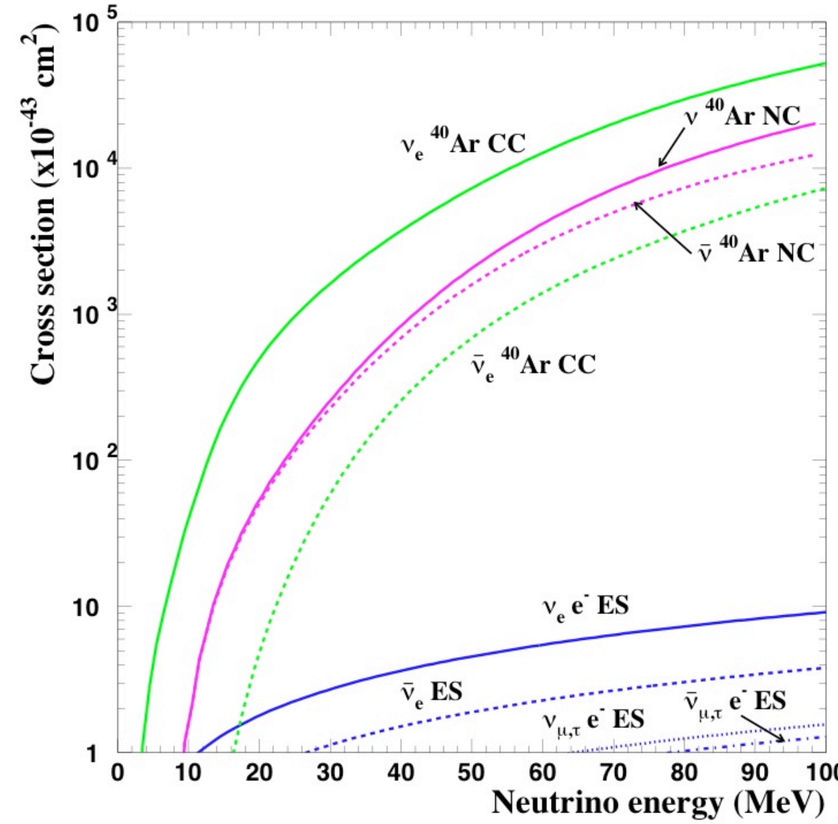


Figure 3: Neutrino cross sections relevant to the supernovae detection with a liquid Argon TPC detector.

Refs:

1.) *Supernova Neutrino Detection in a liquid Argon TPC*, A. Bueno, I. Gil-Botella, A. Rubbia, hep-ph/0307222

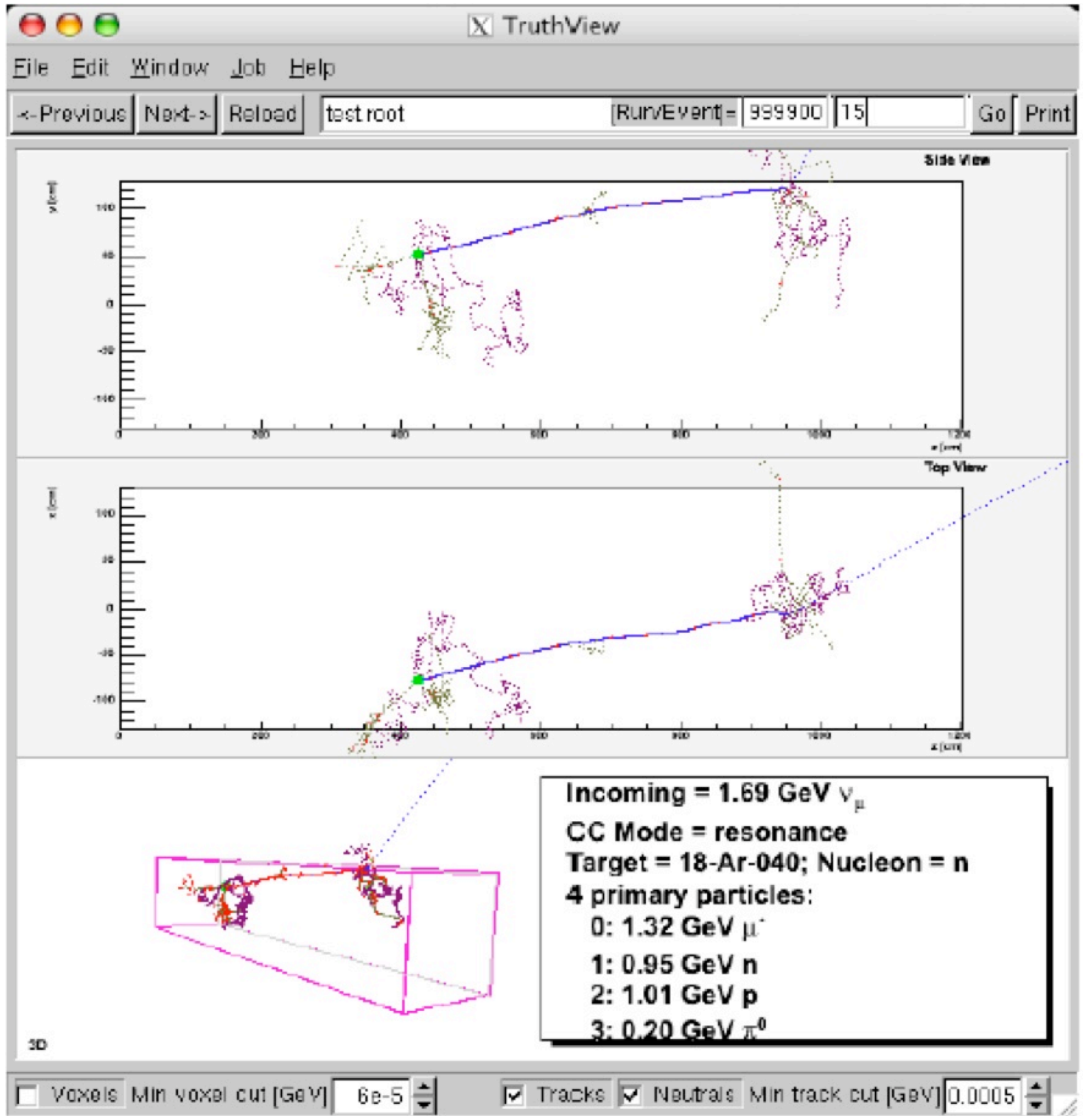
2.) *Oscillation effects on supernova neutrino rates and spectra and detection of the shock breakout in a liquid Argon TPC*, I. Gil-Botella, A. Rubbia, hep-ph/0307244

3.) *Decoupling supernova and neutrino oscillation physics with LAr TPC detectors*, I. Gil-Botella, A. Rubbia, hep-ph/0404151

4.) *Supernova relic neutrinos in liquid argon detectors*, A G Cocco *et. al*, JCAP12(2004)002

MicroBooNE: Simulation

- Joint effort among ArgoNeuT/MicroBooNE/LAr5 proponents to develop simulation/ reconstruction software.
  - Common tools, with different detector geometry plugged in.
- Utilizing FMWK code environment for this work.
- Creating a brand new GEANT4 simulation for LArTPCs
- Already have interfaced generators (GENIE/Nuance/etc...) with simulation.
- Computing needs of LArTPCs (data and MC) will be vast, so we're thinking of this as well.



Conclusions

- LArTPCs are wonderful neutrino detectors.
  - R&D in progress in the U.S. to address many of the technical challenges of these detectors.
- MicroBooNE is next major LArTPC effort in U.S.
  - will perform many physics measurements, such as studying the MiniBooNE low-E excess.
  - will investigate important hardware questions relevant for future massive detectors.
- Collaboration is currently making preparations for "CD" process...hope to have CD0/1 this year.

Back-Up Slides

Optical Properties

- Argon in an excellent scintillator.
- 128nm light (need to wavelength shift to collect....)
- De-excitation and recombination processes following the passage of ionizing particles in liquid Argon produce prompt scintillation radiation.