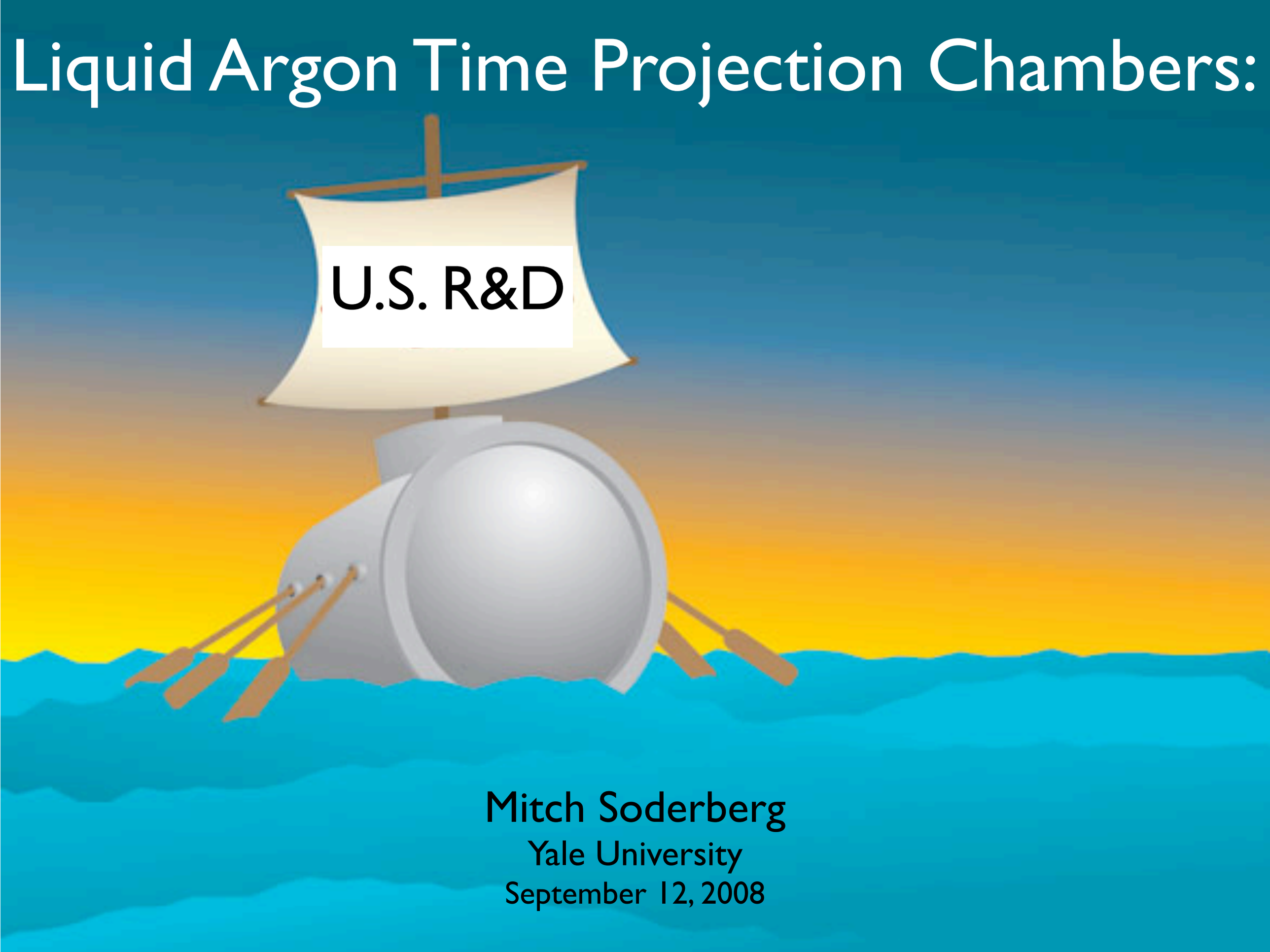
Liquid Argon Time Projection Chambers:



Mitch Soderberg
Yale University
September 12, 2008

Introduction

- Liquid Argon Time Projection Chambers (LArTPCs) continue to be an exciting option for future detectors.
  - ➡ combines excellent spatial resolution and calorimetry.
- Pioneering LArTPC work done in Italy by ICARUS collaboration.
- U.S. efforts to develop LArTPCs have expanded significantly in recent years.
- Several R&D efforts ongoing...will summarize in this talk.
- Ultimate goal is to build a massive (100 kiloton) detector capable of studying neutrino oscillations and searching for nucleon decay.

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."

Liquid Argon in the U.S.

Materials Test Stand

Bo

Rapid progress in LArTPC development

UCLA/Pisa
Long-Drift Test at
CERN

2007

100%
R&D

2007-

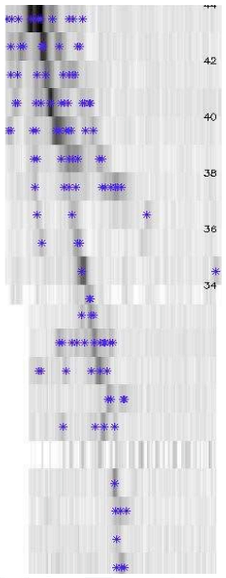
2008-

2011

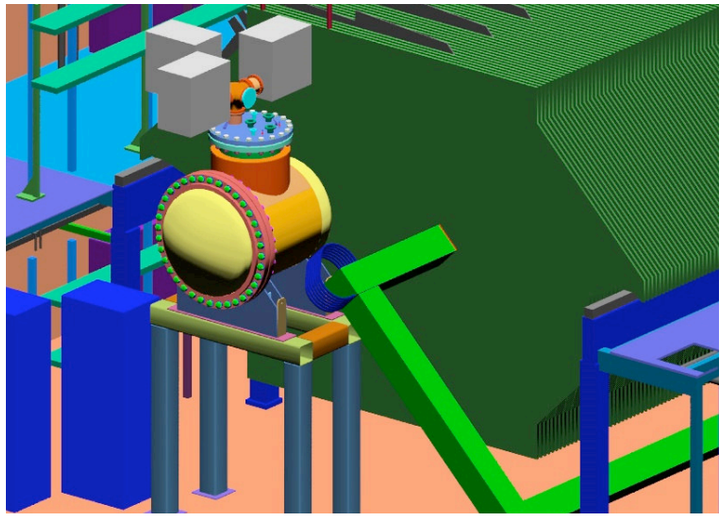
100%
Physics

201?

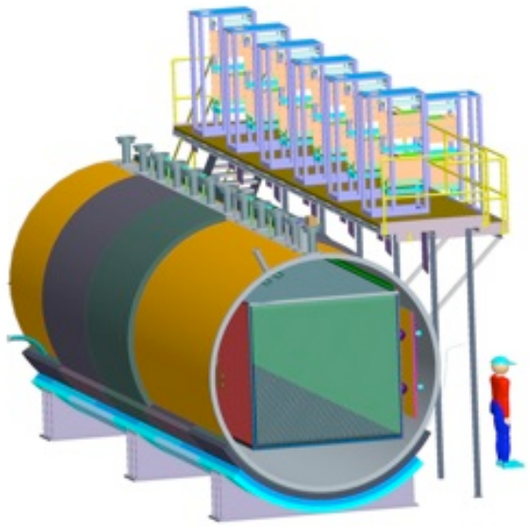
100 Kilotons



Yale Tracks

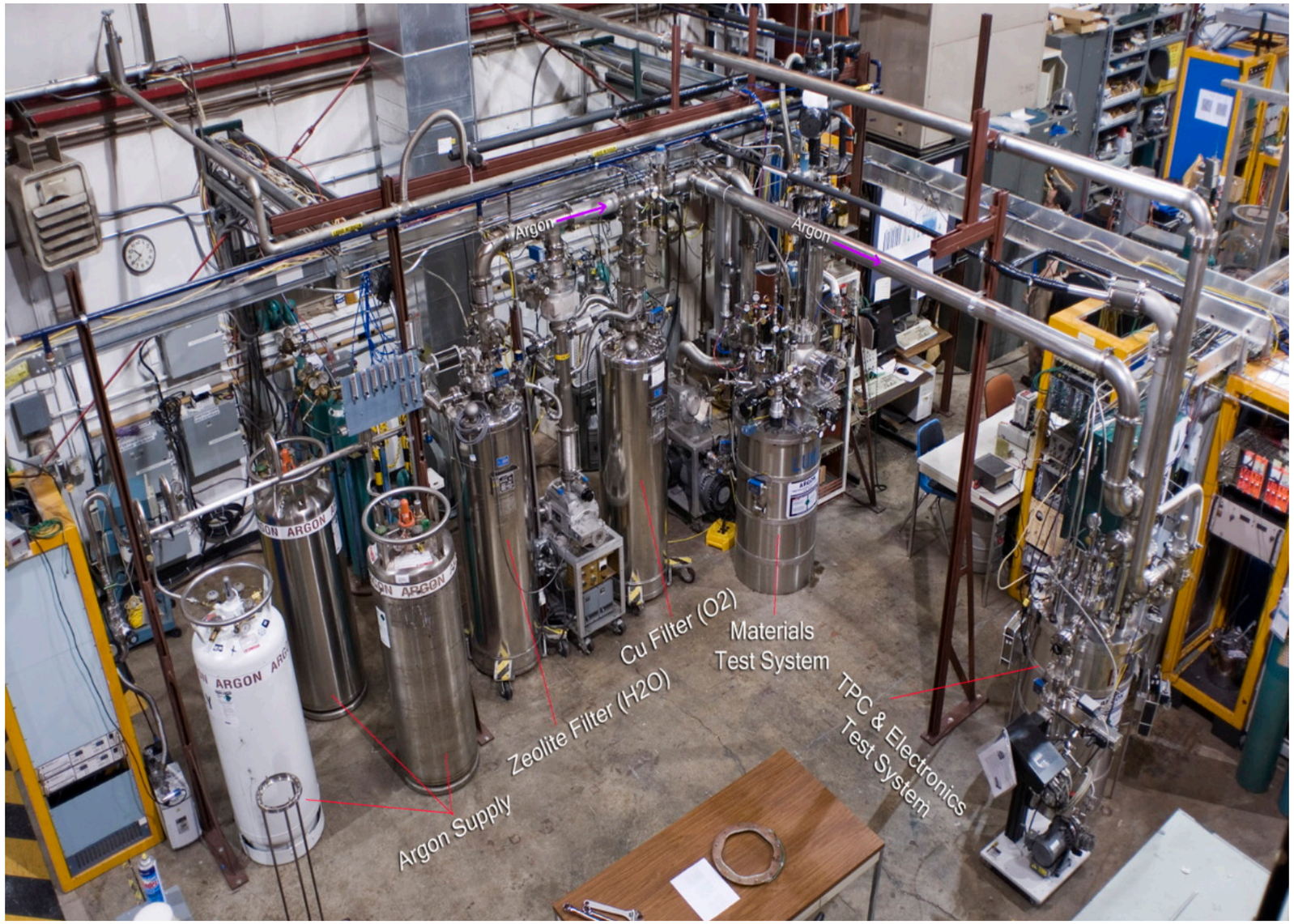


ArgoNeuT



MicroBooNE

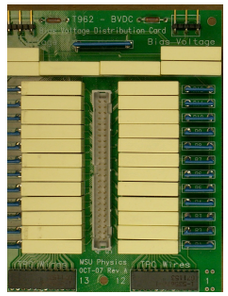
Materials Test System at Fermilab



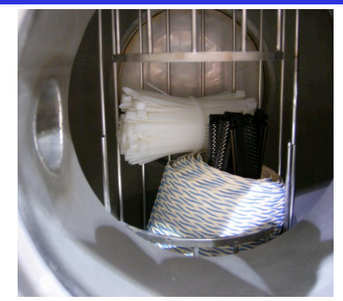
- A massive LArTPC will necessarily have large amounts of detector material, so controlling argon purity is vital.
- MTS is used to study the impact of different materials on argon purity.
- This facility also has a TPC test system for electronics.
- Fermilab group has designed new regenerable filters.

Materials Test System at Fermilab

BNL 4-ch Amp

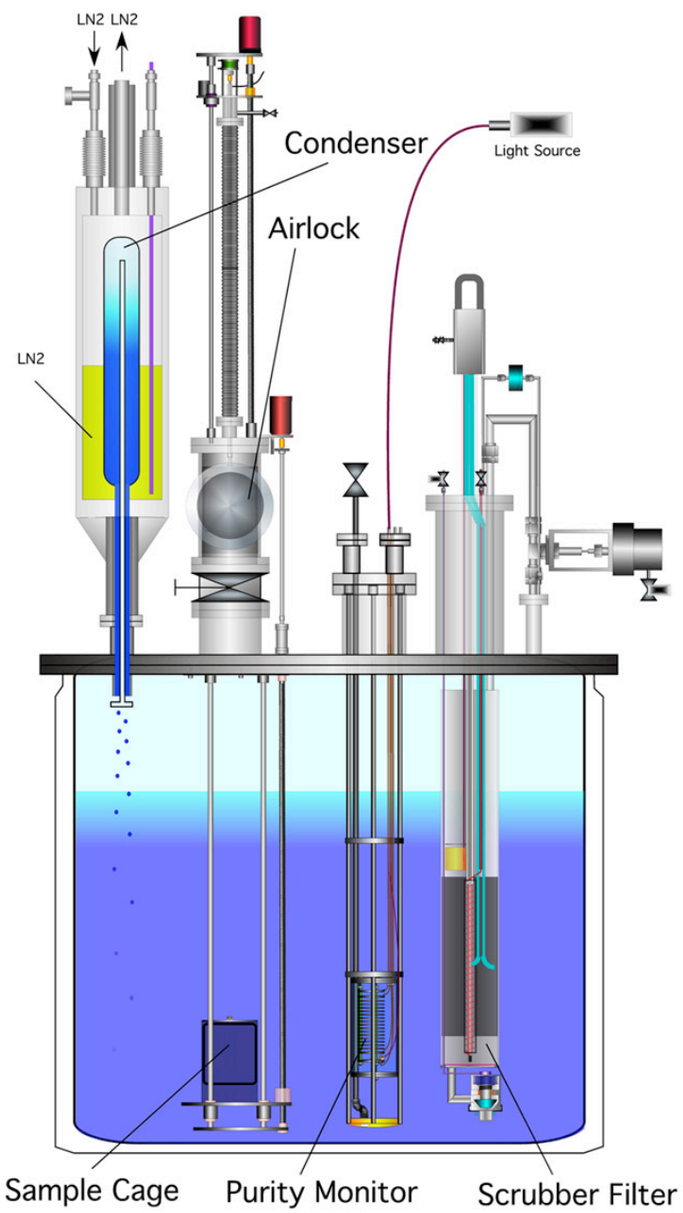


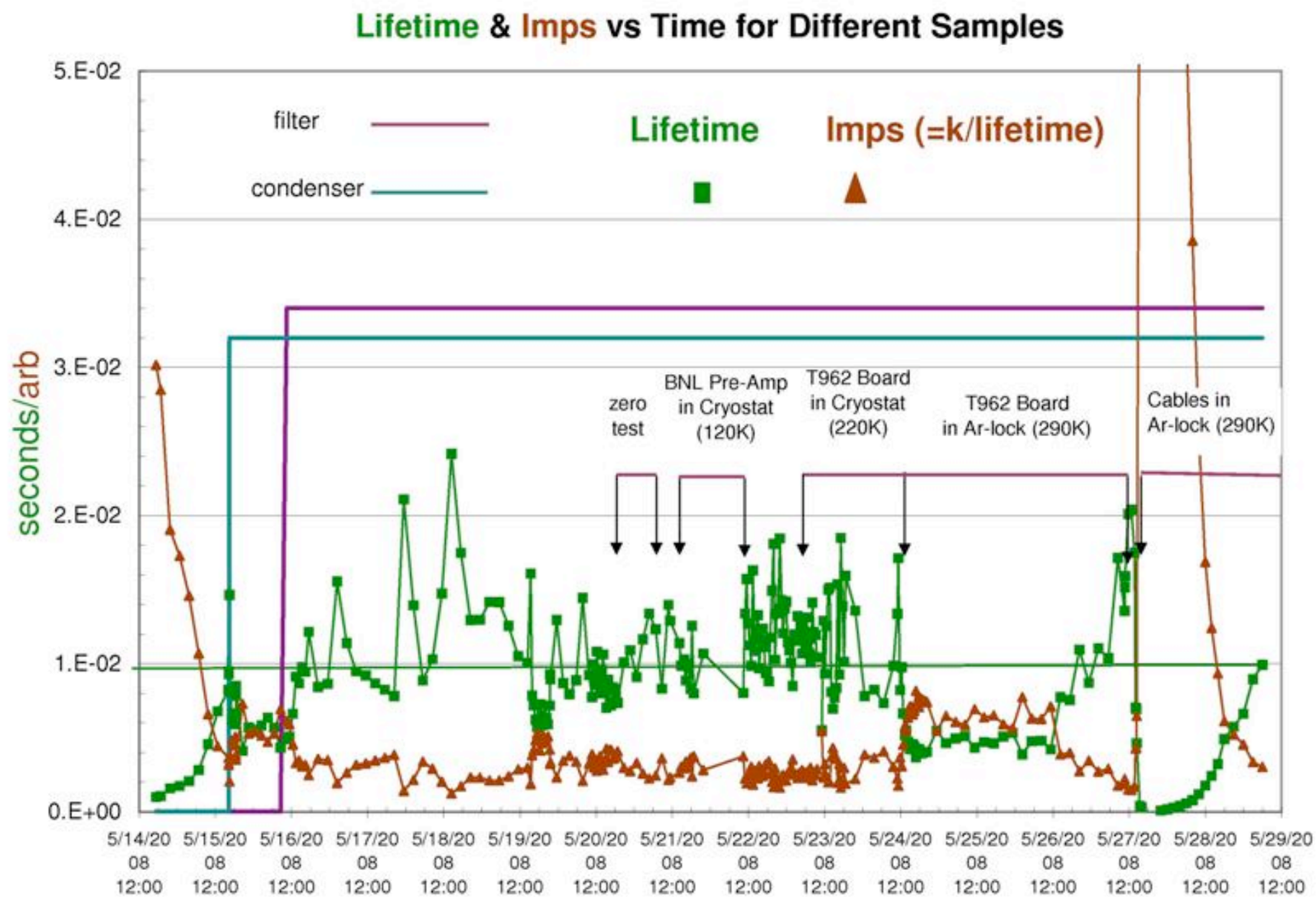
ArgoNeuT Bias Board



Cables/Cable-Tie Bundle

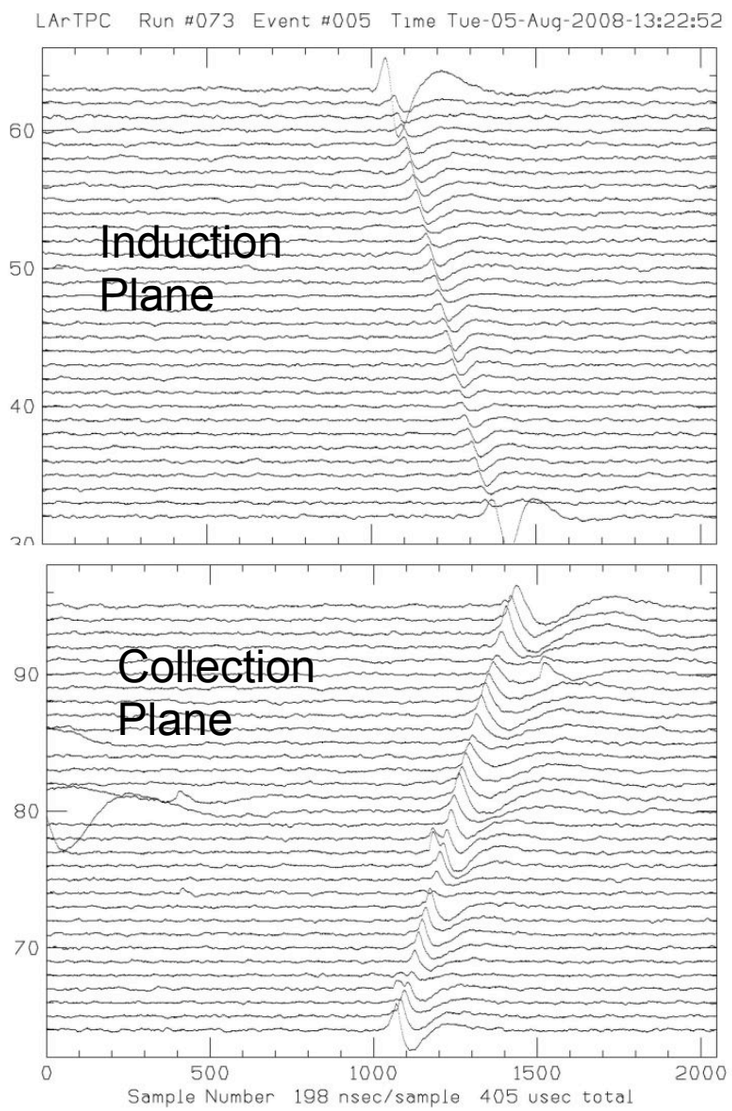
Measurements with the Materials Test System

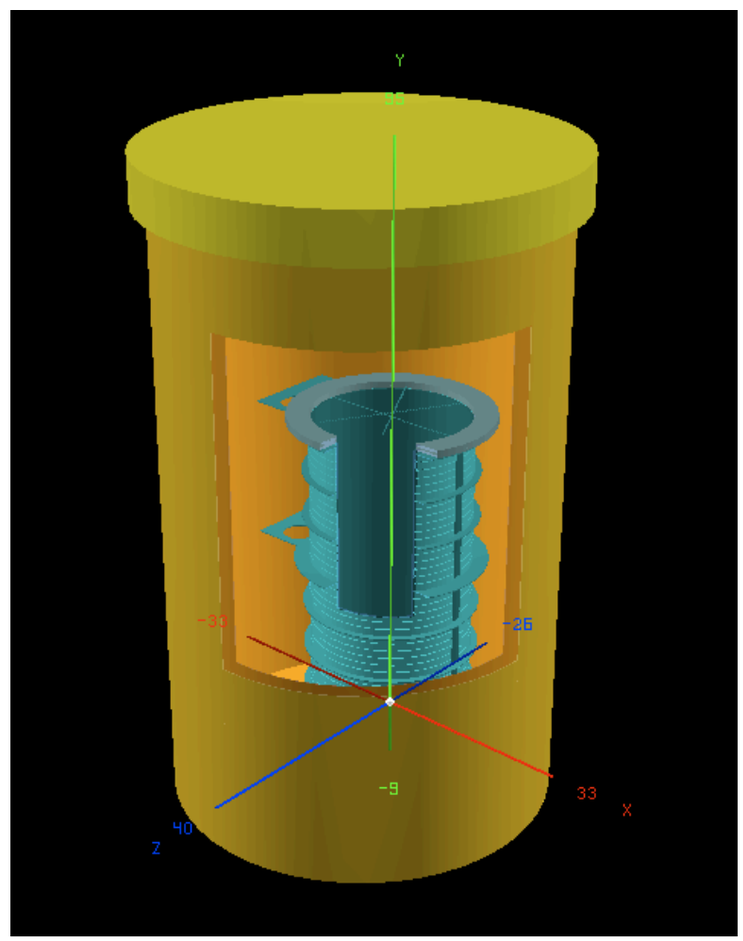




Electronics Test System

- TPC and cryostat for electronics development
- Cylindrical TPC:
  - 96 channels over 3 planes
  - 50 cm drift
  - 24 cm diameter
- Electronics designed and built at Michigan State University.
- Signal/Noise performance very good.



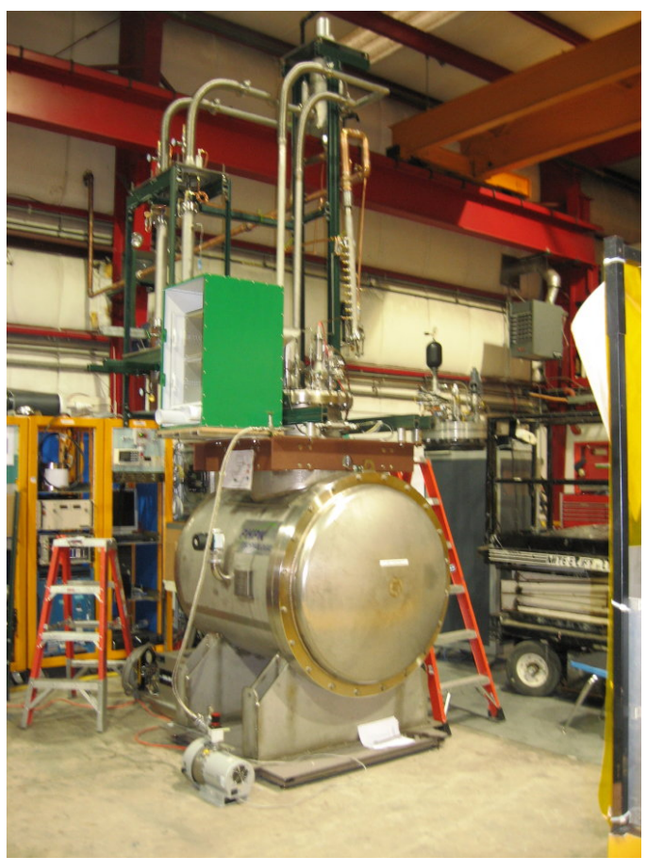


GDML Rendering of Bo, for use in GEANT4 Simulation

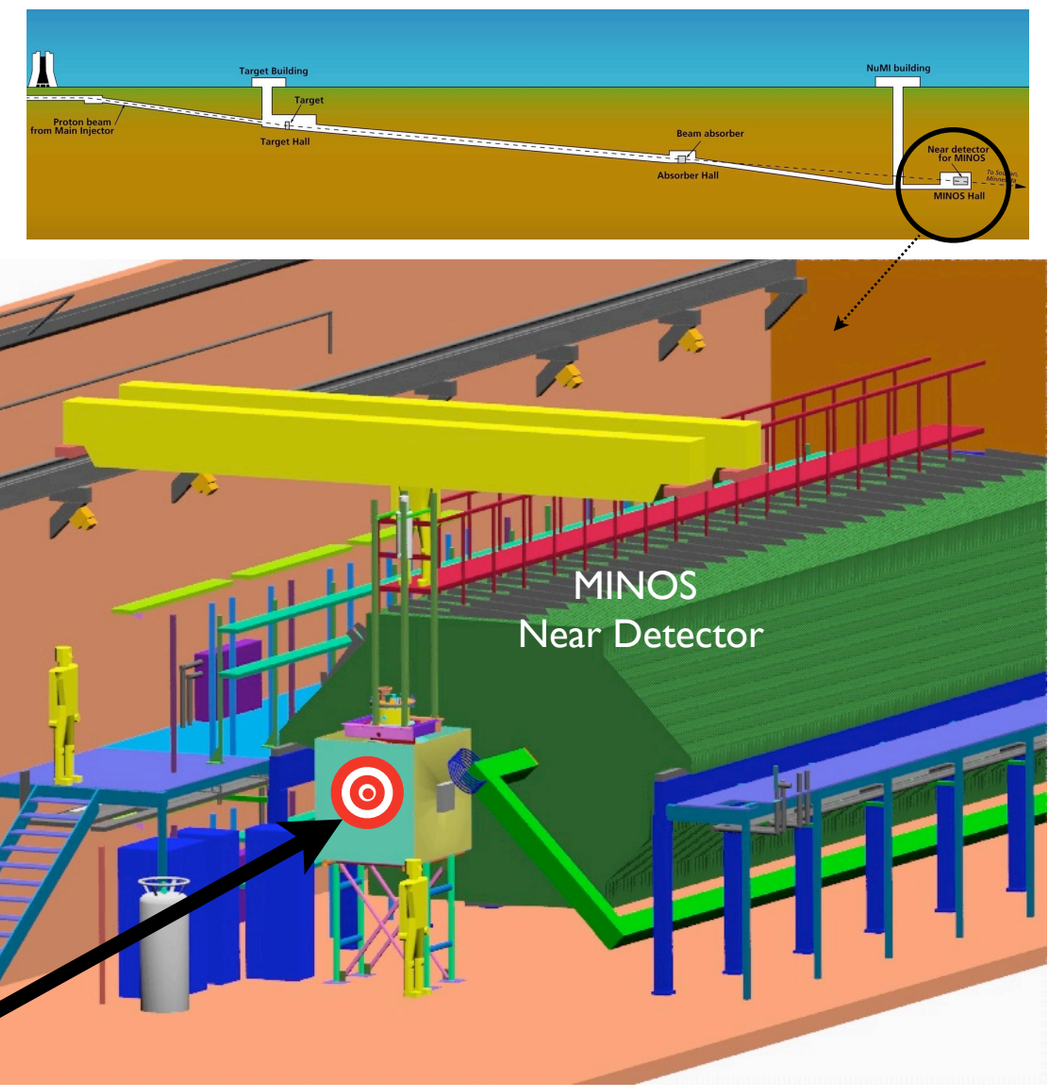
Bo TPC being installed at Fermilab

ArgoNeuT

- ArgoNeuT is a ~175 liter LArTPC (jointly funded by NSF/DOE)
  - ➡ Collaborating Institutions: L'Aquila, Fermilab, Gran Sasso, Michigan State, UT Austin, Yale
- Will sit in front of MINOS near detector in NuMI beamline. Use MINOS as a range stack.
- Goals:
  - Gain experience building/running LArTPCs.
  - Accumulate a sample of 10000's neutrino events.
  - Confront many aspects of underground running and safety.
  - Develop simulation of LArTPCs and compare with data.
  - Measure CCQE cross-section



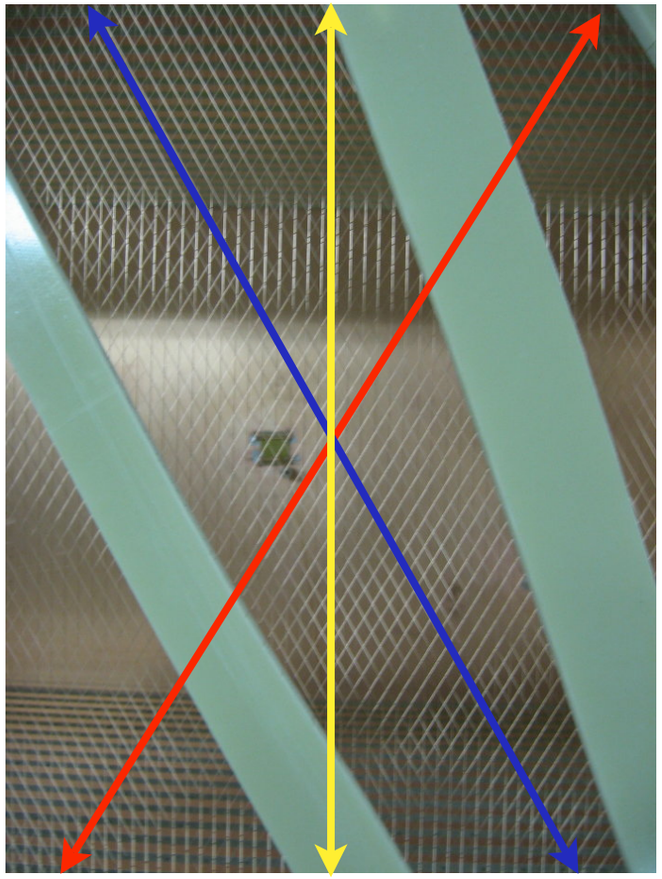
ArgoNeuT



NuMI Tunnel

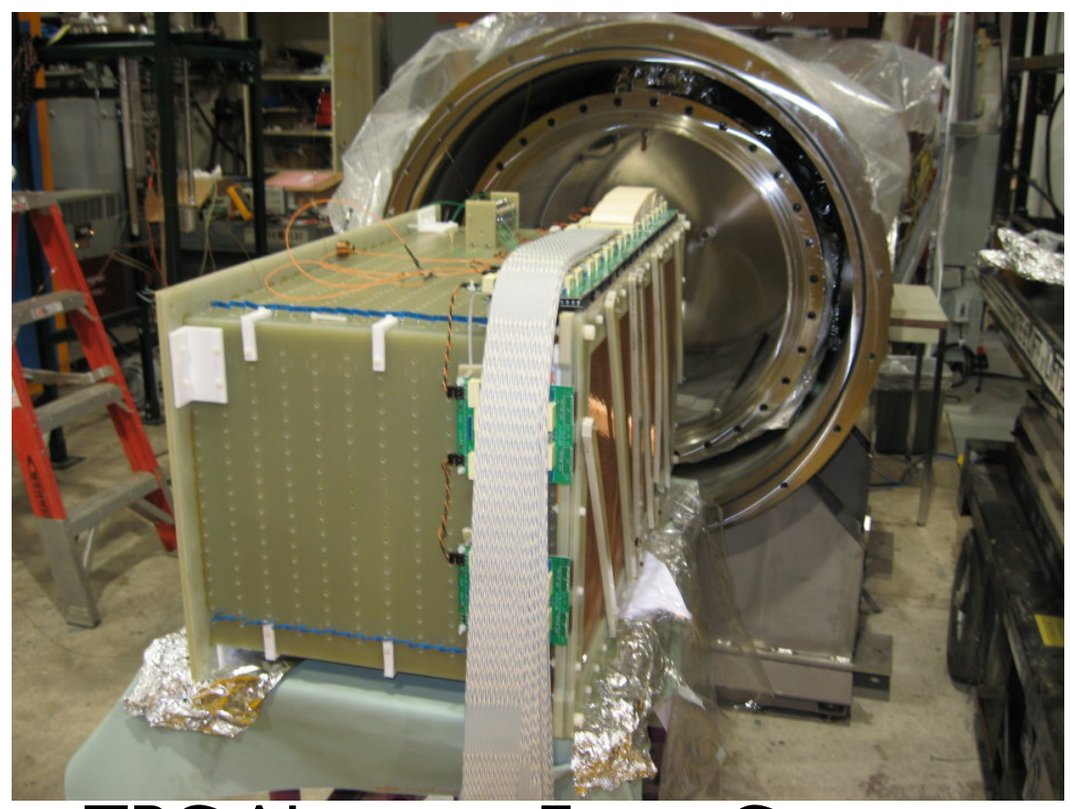
ArgoNeuT: TPC

- 175 liter active volume, 480 channels of signal.
- Collection, Induction2, Induction1 planes. Induction1 plane not read out.
- 4mm wire pitch, 4mm plane spacing.
- 500V/cm electric field.
- Max. drift of ~50cm.
- Bias voltage distribution boards located directly on TPC.
- 0.15mm diameter BeCu wire. Cu-clad G10 used for field cage.



±60° wires

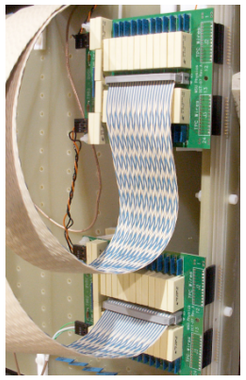
Wire Orientations



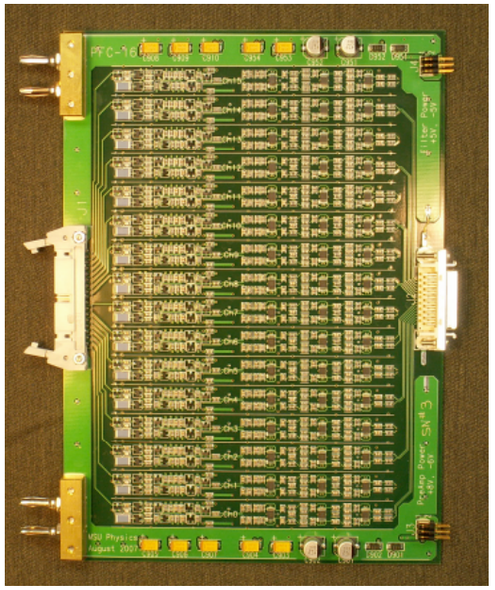
TPC About to Enter Cryostat

ArgoNeuT Electronics

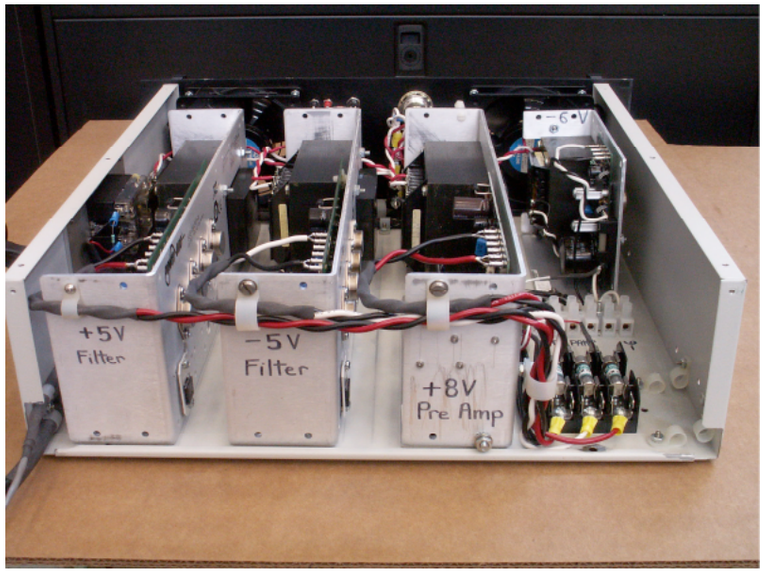
- Electronics for ArgoNeuT (480 channels)
  - Bias voltage distribution & blocking on the TPC
  - FET preamplifier similar to D0/ICARUS front-end
  - Wide bandwidth filtering (10 - 200 kHz, now)
    - Full information on most hits/tracks
    - Employ DSP to extract hit/track parameters
  - ADF2 card, sample at 5 MHz, 2048 samples/channel
  - Minimize noise sources
    - Double shielding of feed-through and preamplifiers
    - Remote ducted cooling
    - Extensive DC power filtering



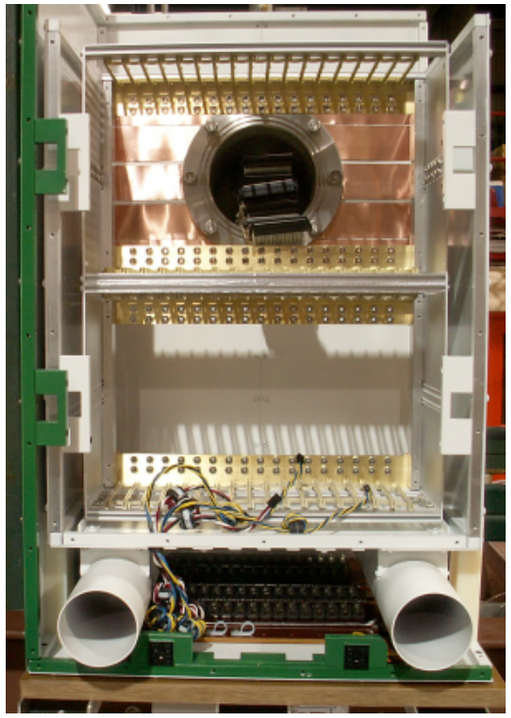
Bias Voltage R & C



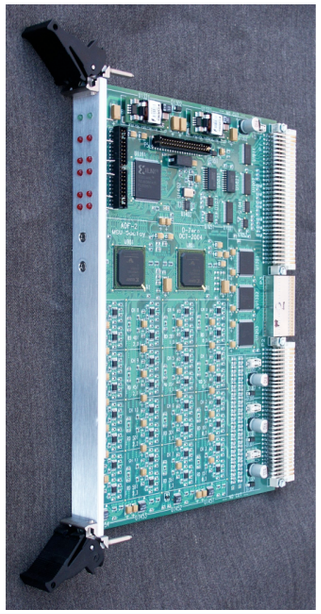
Preamp & filters



Custom power supply



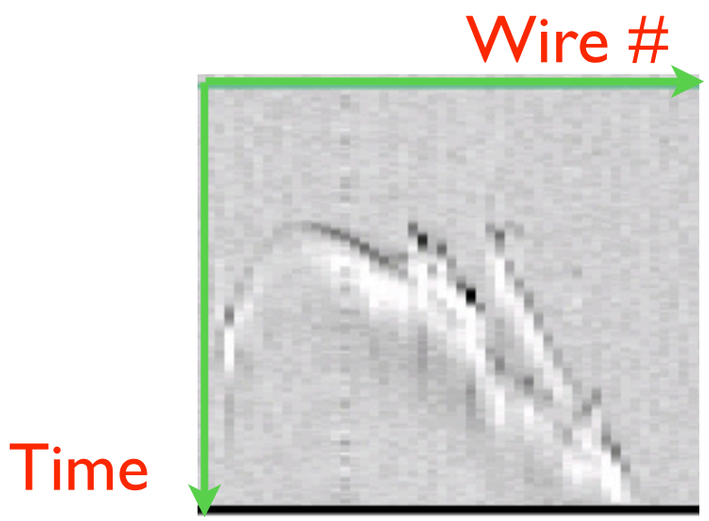
RF shielding & preamp cooling



ADF2

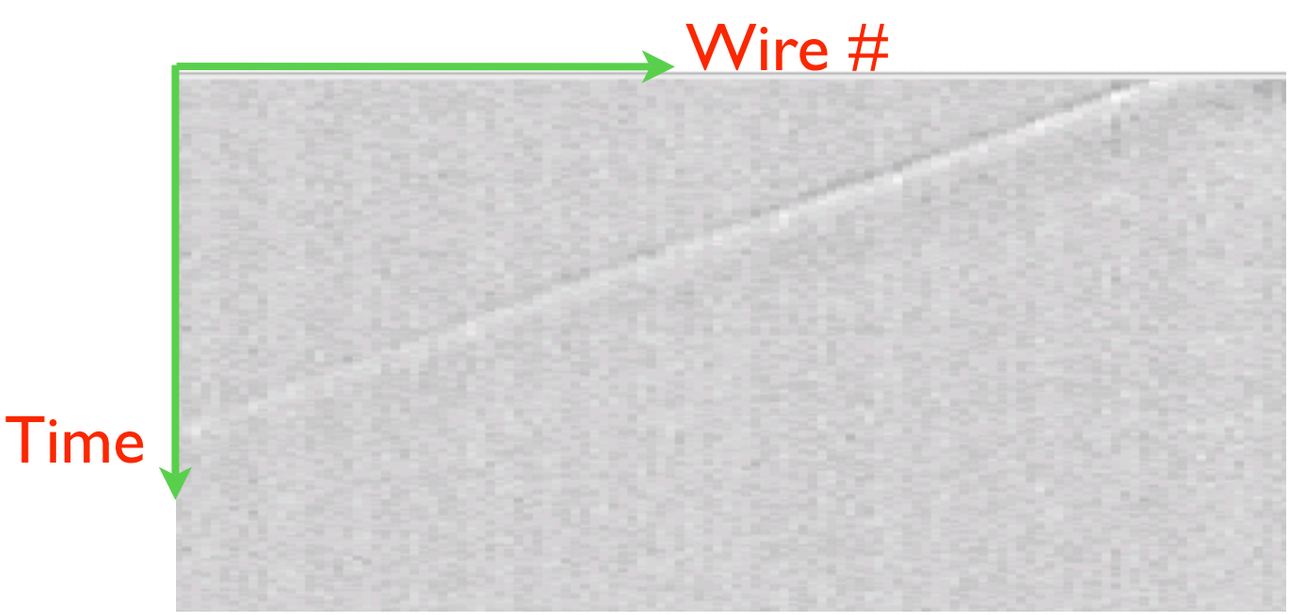
ArgoNeuT: Commissioning

- ArgoNeuT is just ending its commissioning run (~4 weeks above ground)
- We have collected many cosmic-ray events using a simple coincidence trigger.
- System has been very stable during this run!
- Plan to fix/upgrade a few items and begin move underground.

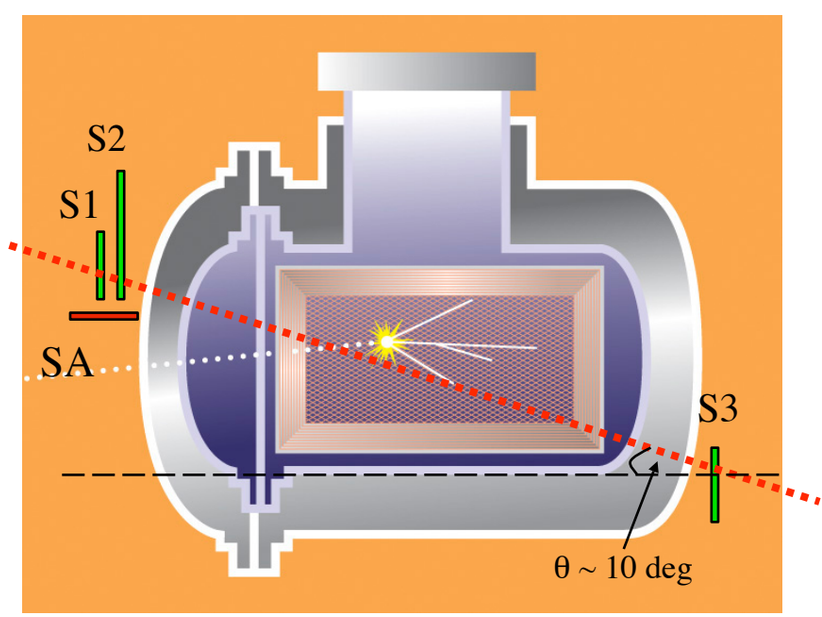


Collection View of 1st ArgoNeuT event

Event Type	# in 180 days (1.4×10^{19} PO)
ν_μ CC	28800
$\overline{\nu_\mu}$ CC	2520
ν_e CC	540
NC	9720



Induction View of Cosmic muon event

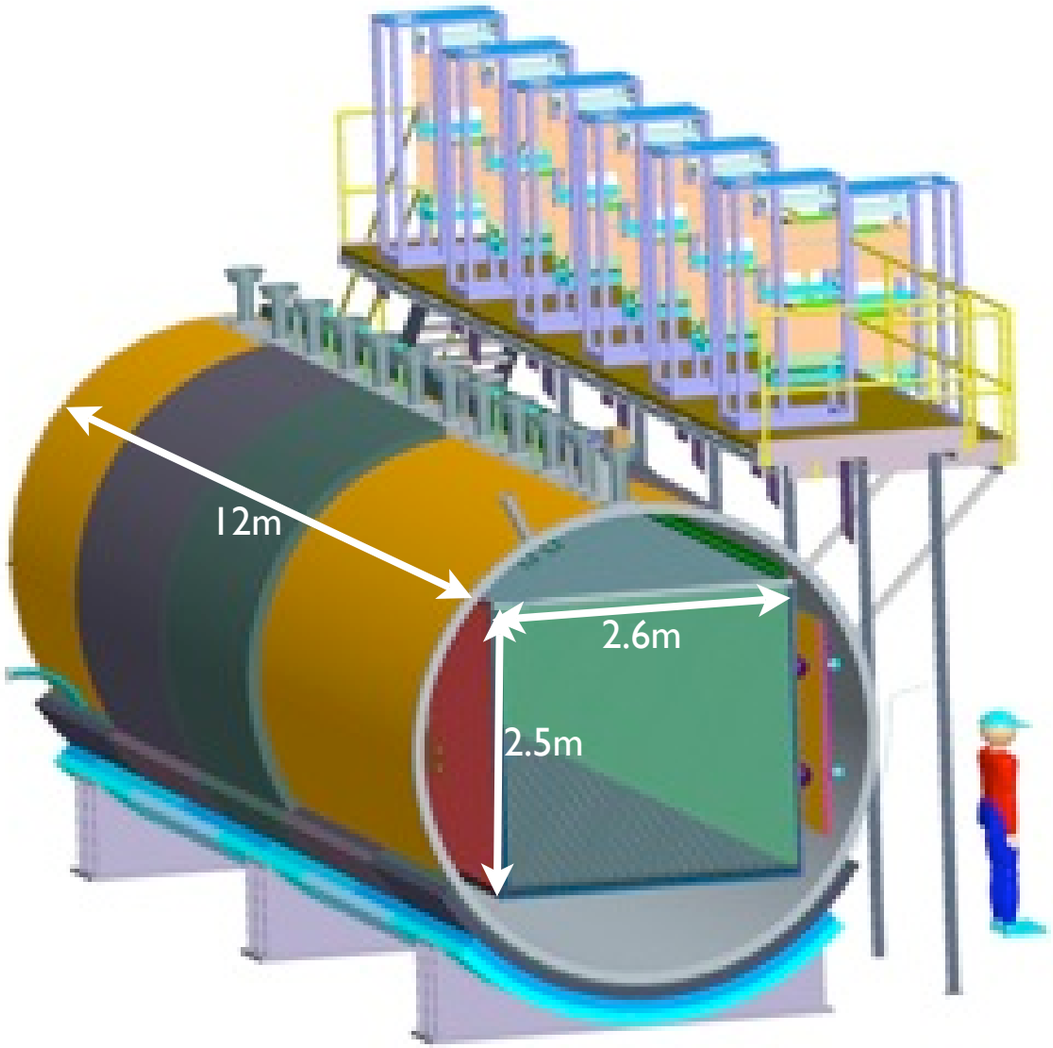


Cosmic Trigger for Commissioning

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
  - MiniBooNE excess
  - Low-Energy Cross-Sections
  - etc...

Stage 1 approval from Fermilab directorate in June!

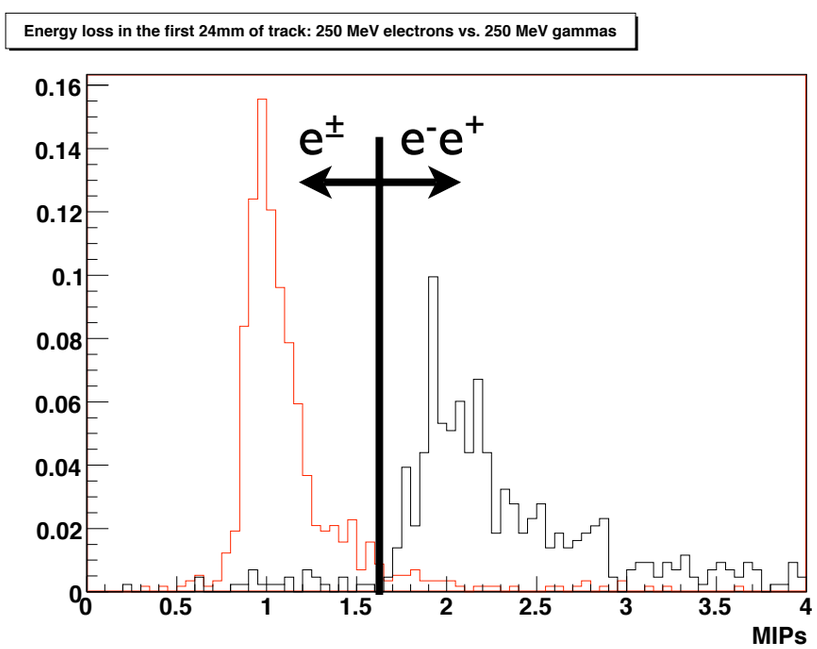


- ➡ Joint NSF/DOE Project
- ➡ NSF MRI for TPC and PMT systems

MicroBooNE: Physics Goals

- Address the MiniBooNE low energy excess
- Utilize electron/gamma tag (using dE/dX information).
- Low Energy Cross-Section Measurements (NC π^o, $\Delta \rightarrow N\gamma$,Kaon production, Photonuclear, ...)
- **Use small (~500) sample of Kaons to study proton-decay sensitivity.**
- Develop automated reconstruction.

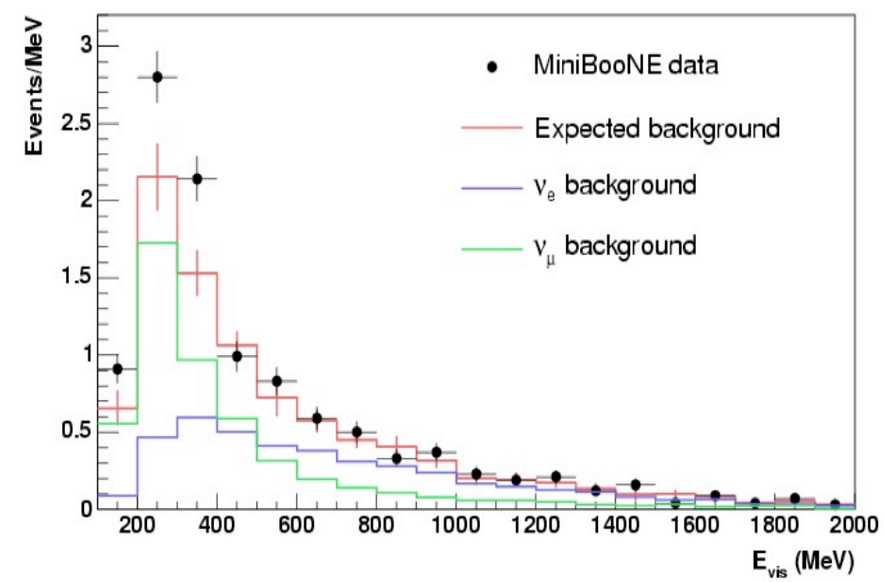
Discrimination via dE/dX



MiniBooNE Result Excess

200-300MeV: 45.2±26.0 events

300-475MeV: 83.7±24.5 events



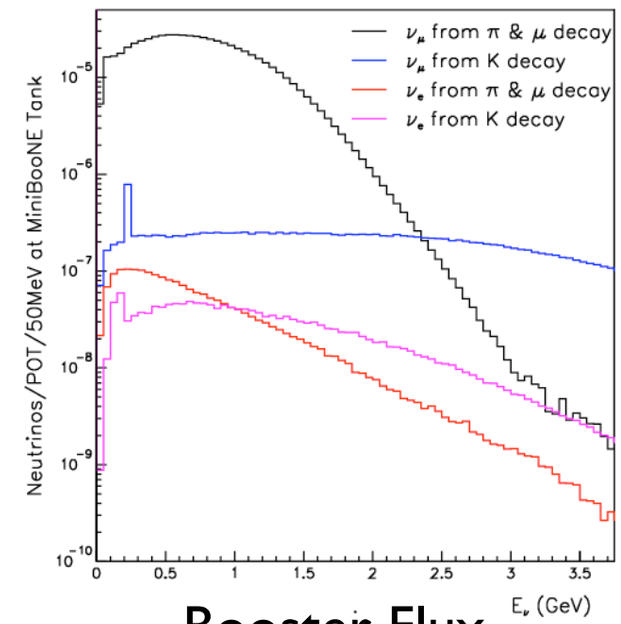
MicroBooNE will have 5σ significance for electrons, 3.3σ for photons

MicroBooNE: Location

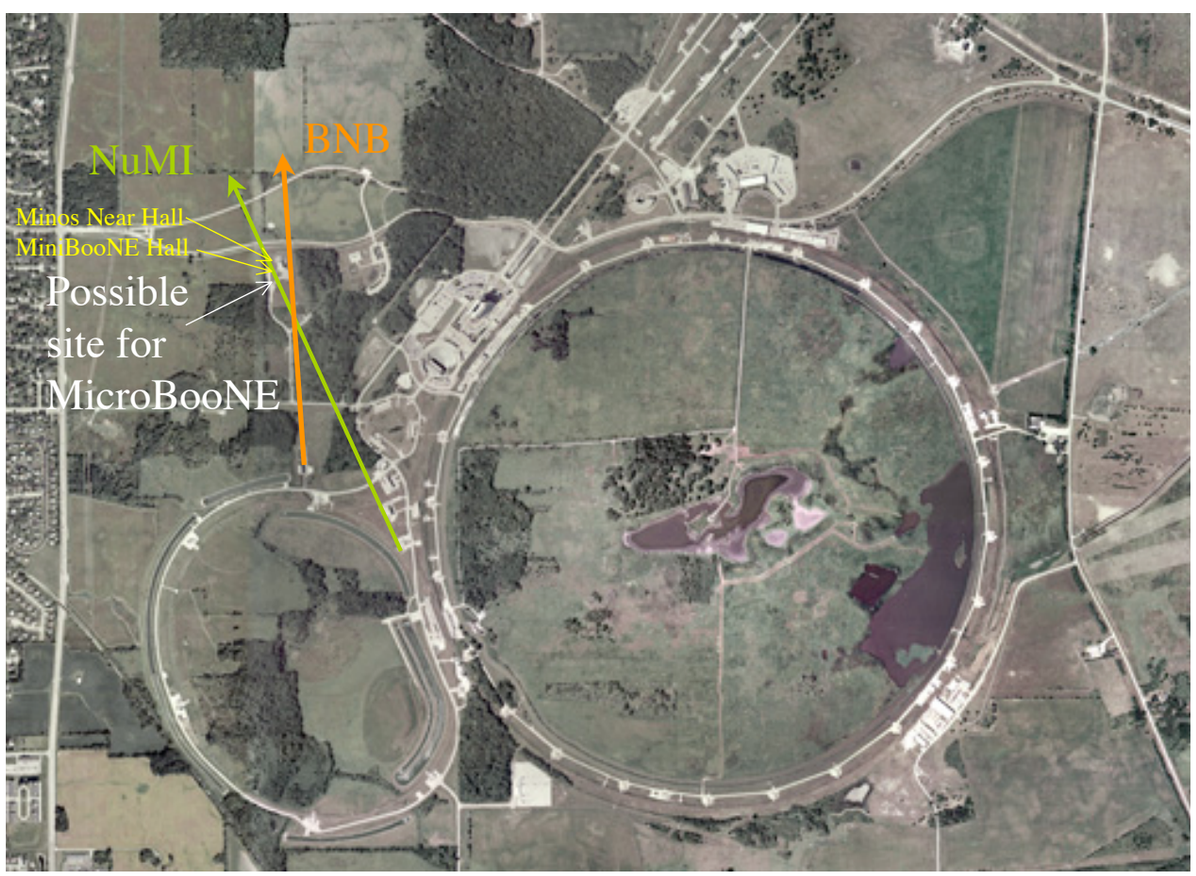
- MicroBooNE will sit on surface in on-axis Booster beam, and off-axis (LE) NuMI beam.

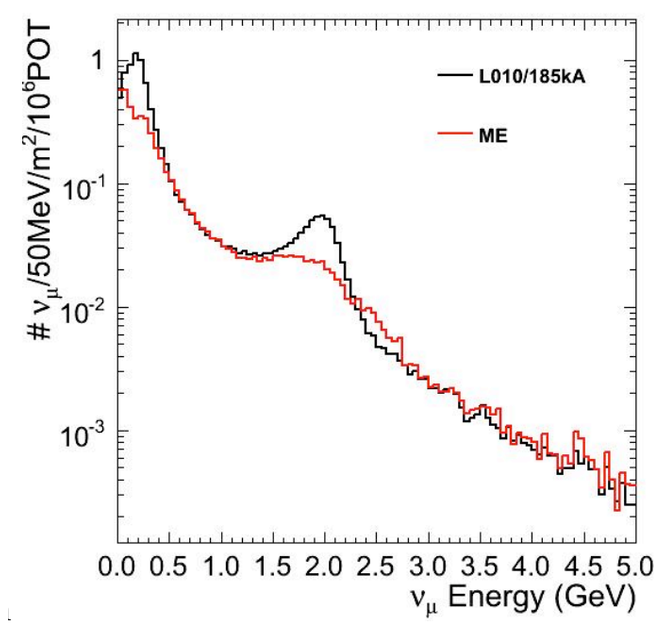
	BNB	NuMI
Total Events	100k	60k
ν_μ CCQE	39k	21k
NC π^o	8k	7k
ν_e CCQE	250	1.7k
POT/year	6×10^{20}	4×10^{20}

Expected Event Rates for 2-3 year run.



Booster Flux

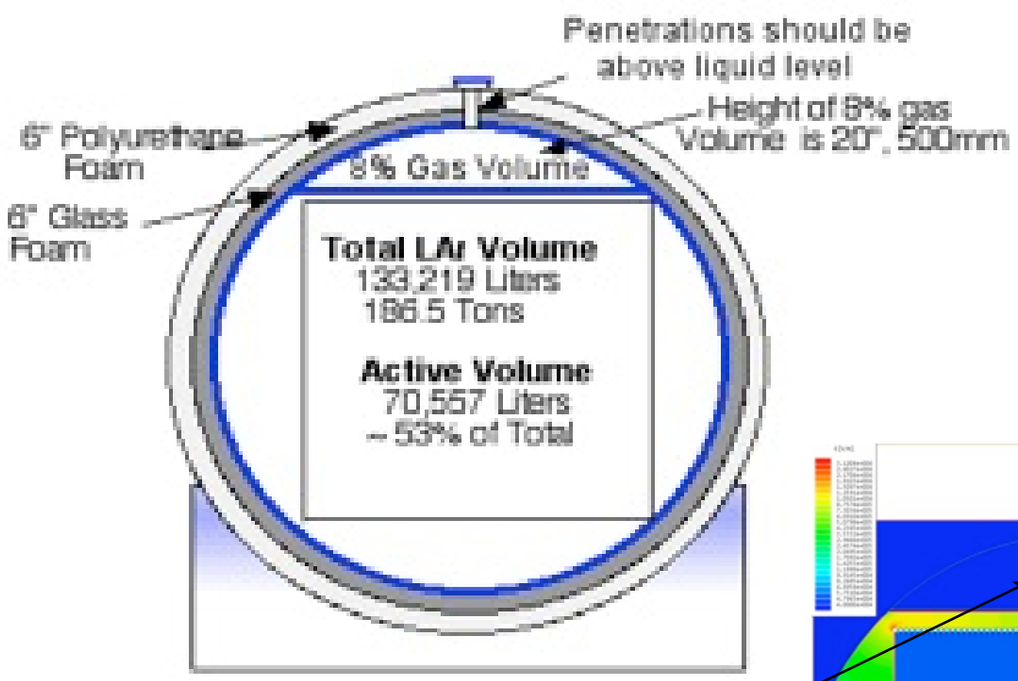


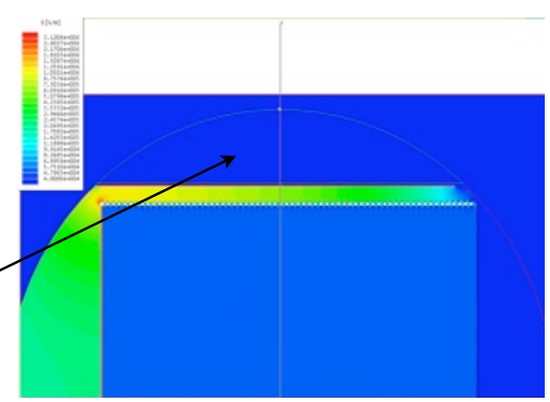


NuMI Flux

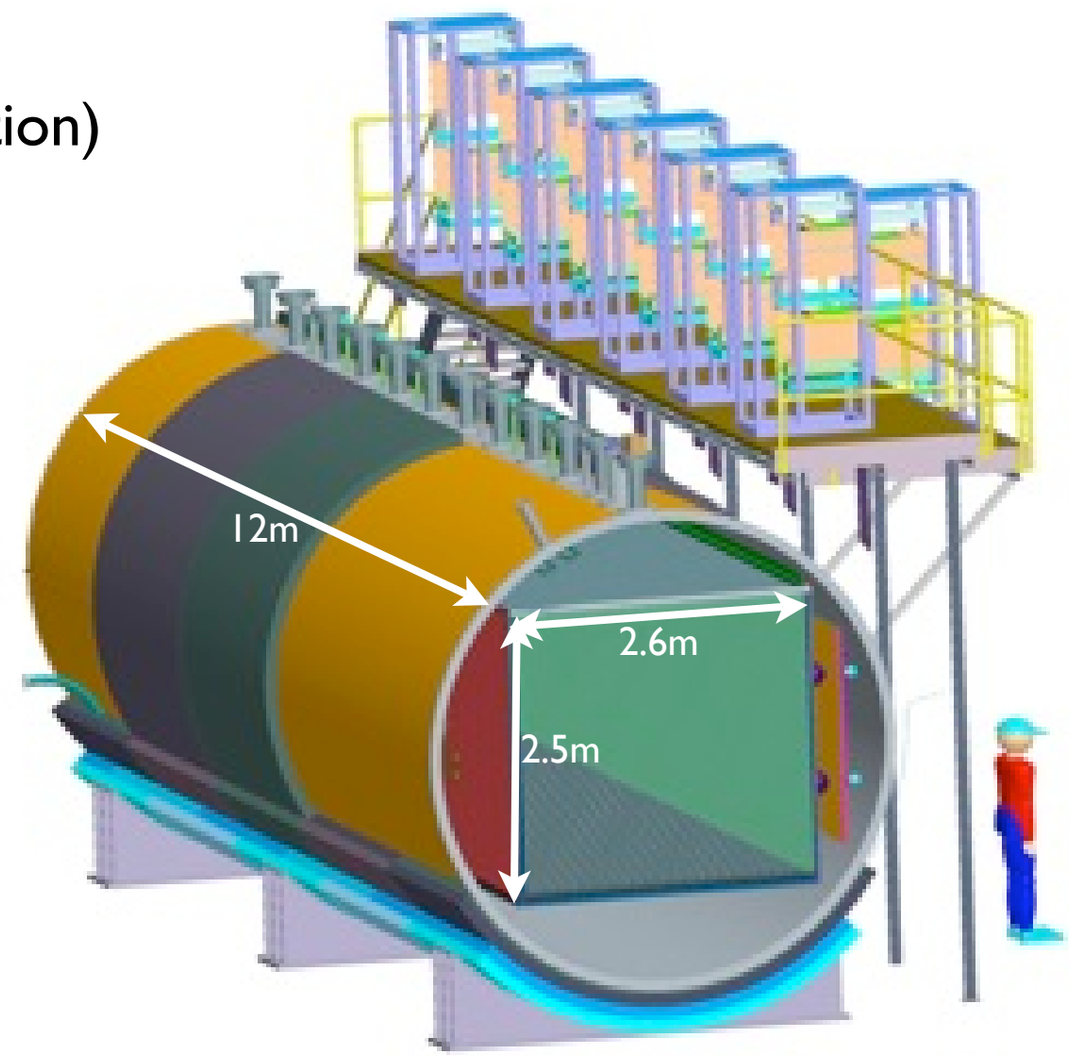
MicroBooNE: Design

- Cryostat (170 tons LAr) as large as can be commercially built offsite and delivered over the roads.
- Evacuable vessel with foam insulation.
- To sit on surface in on-axis Booster beam, off-axis NuMI beam.
- TPC parameters
  - 70 ton fiducial volume
  - ~2.5m drift (500V/cm)
  - 3 readout planes (±60° Induction, vertical Collection)
  - 10000 channels (using Cold Preamplifiers)
- 30 PMTs for triggering
- Purification/Recirculation system.



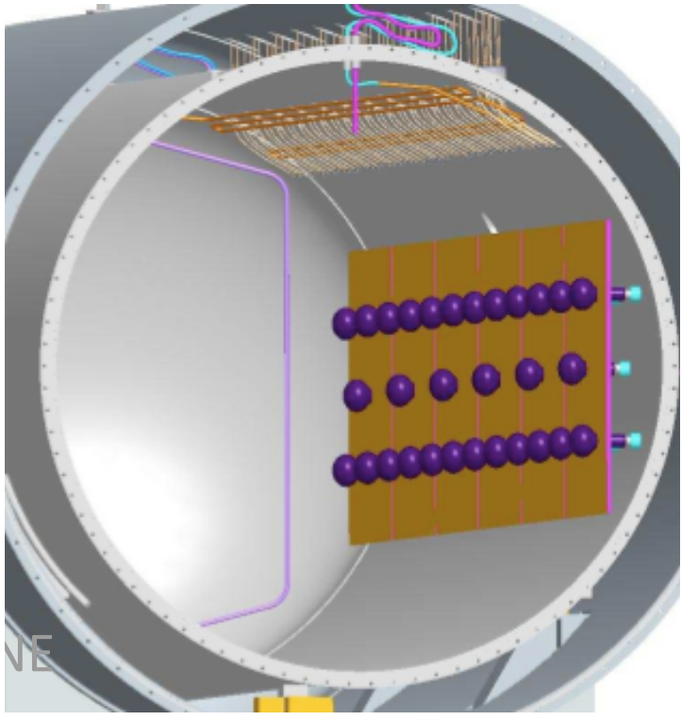


PreAmps in cold gas



MicroBooNE: Hardware R&D

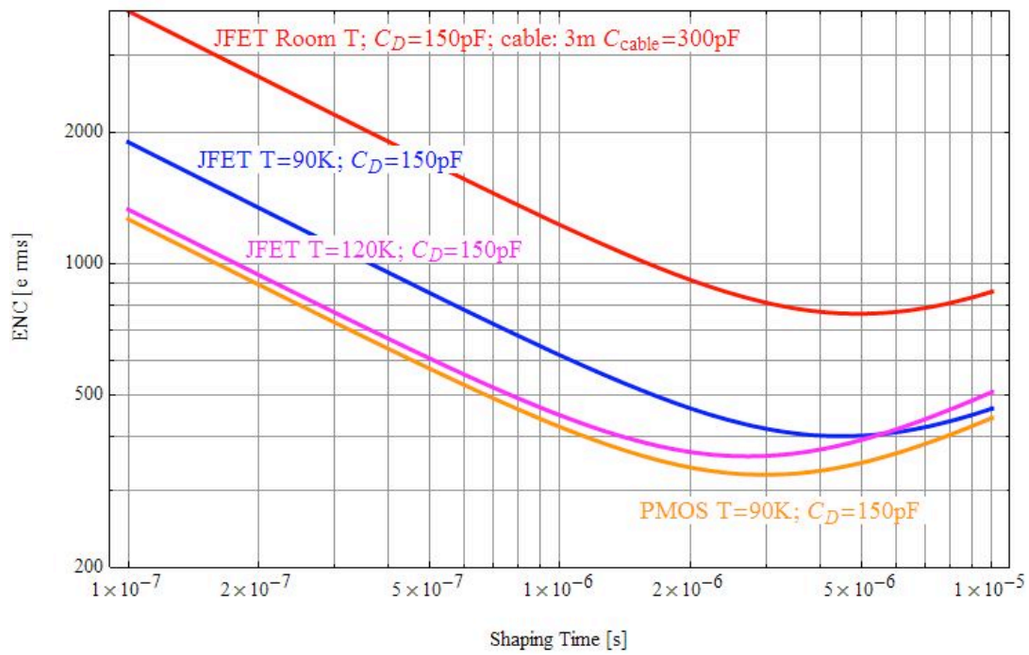
- Phase 1: Initial design relevant to MicroBooNE detector (previous slide).
- Phase 2: R&D for next generation LArTPCs
  - Cold Electronics: Next slide.
  - Purity Test: Purge vessel with argon gas, then fill with liquid, to see if high-purity liquid can be achieved without initial evacuation. Very massive LArTPCs will most likely not be evacuable, so purging will be necessary.
  - Long drift (2.5m): though not as long in massive LArTPCs, will test purity and reconstruction schemes.
- **Real data essential to understanding hardware performance!**



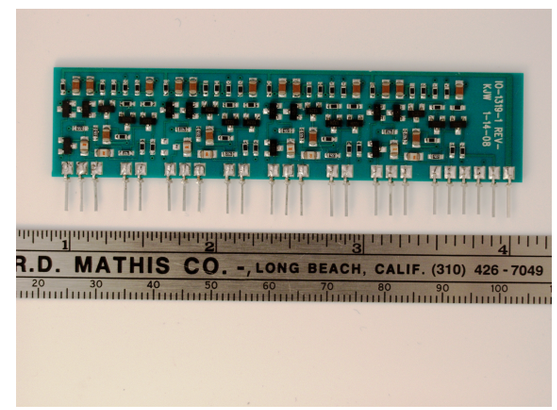
30 PMTs facing TPC

MicroBooNE: Cold Electronics

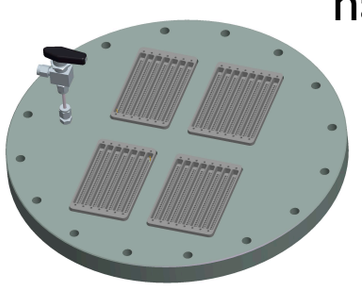
- Preamps will be placed inside of cryostat.
- Necessary step along the path to large detectors where signals must make long transits.
- Many future Hardware questions can be answered by MicroBooNE.
  - JFET/CMOS performance (~4 year development required for CMOS).
  - Maintaining purity with electronics inside tank.
  - Heat load due to power output of electronics in tank.
  - Multiplexing signals.



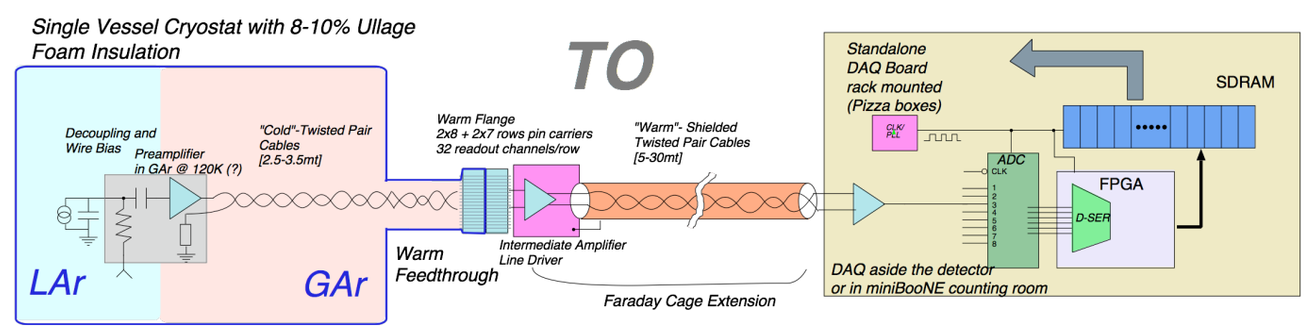
JFET (T=120 K)/pMOS (T=90K) have similar S/N performace



Quad-channel Pre-Amp prototype



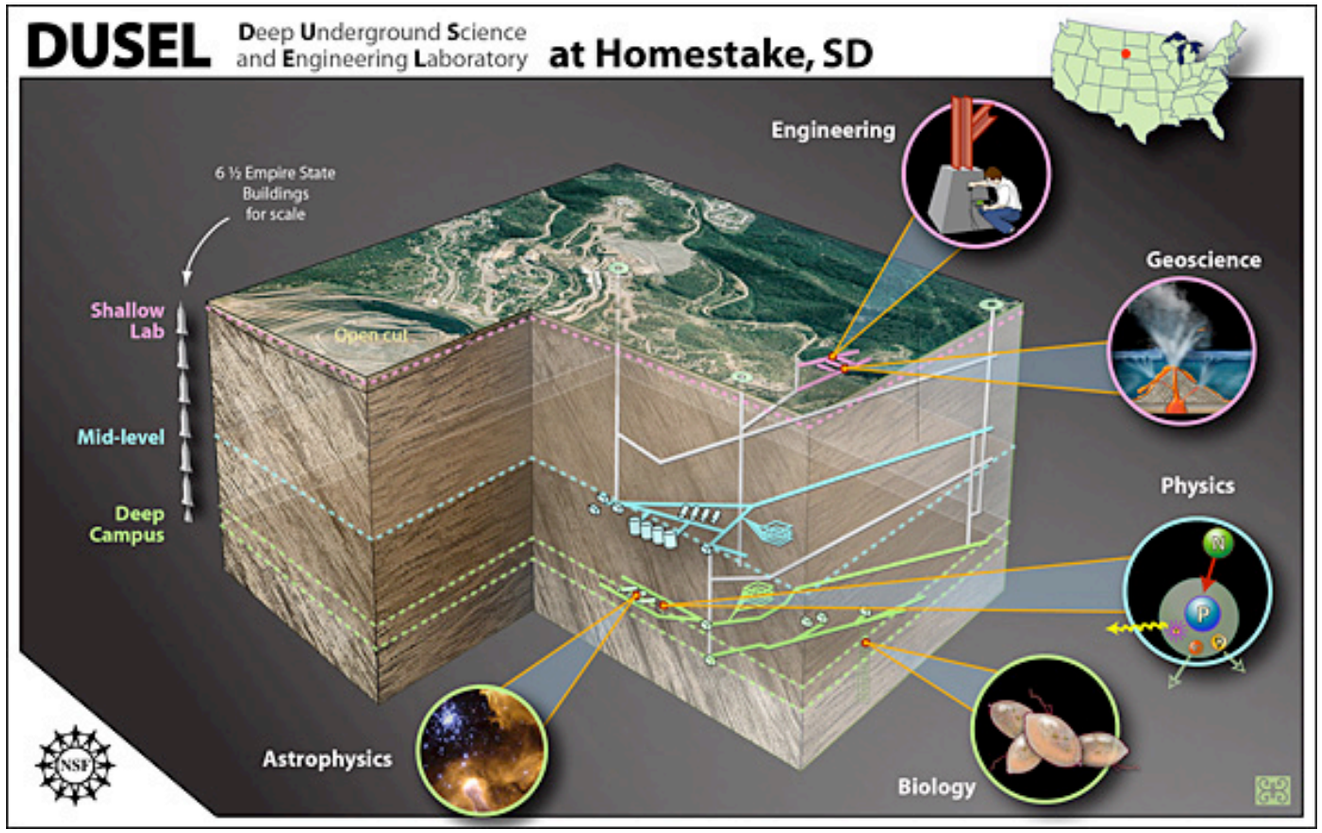
ATLAS style feedthrough

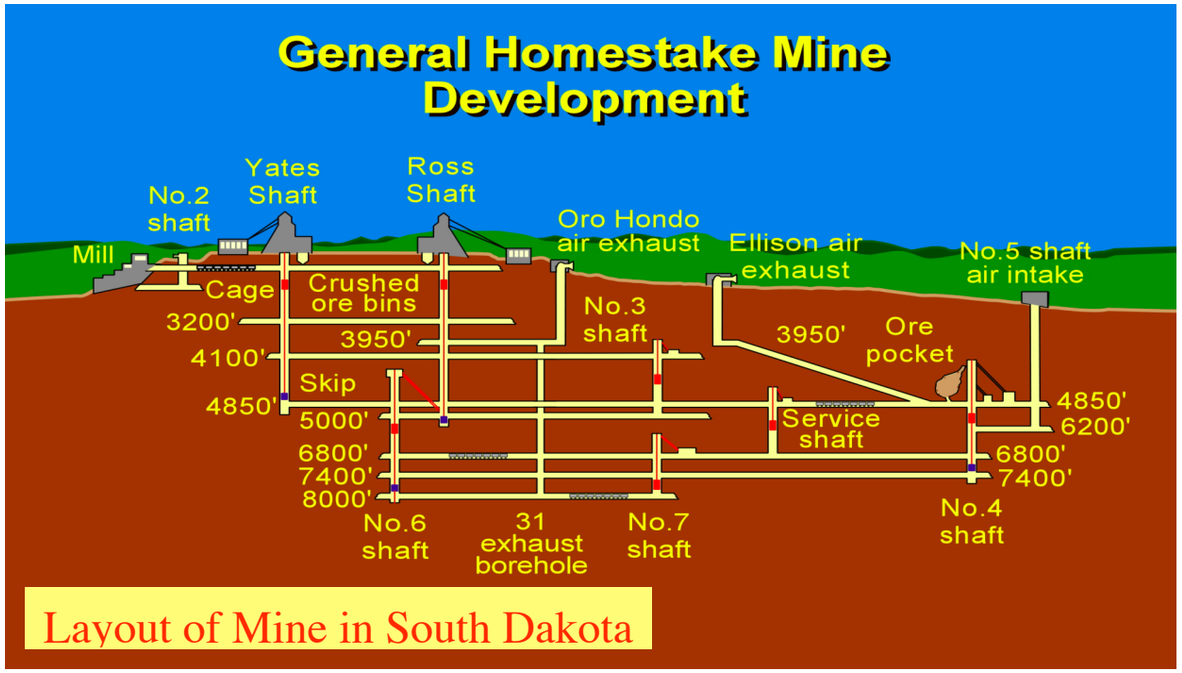


Readout Chain

Massive Detectors

- Ultimate goal of all this R&D is to build a large detector, preferably someplace very deep (e.g. - Homestake Mine in South Dakota, Soudan Mine in Minnesota).
- Proposed Project X at Fermilab could send intense neutrino beam to this far-site location.
- Working groups already forming in U.S. to explore possibility of massive detector at DUSEL.



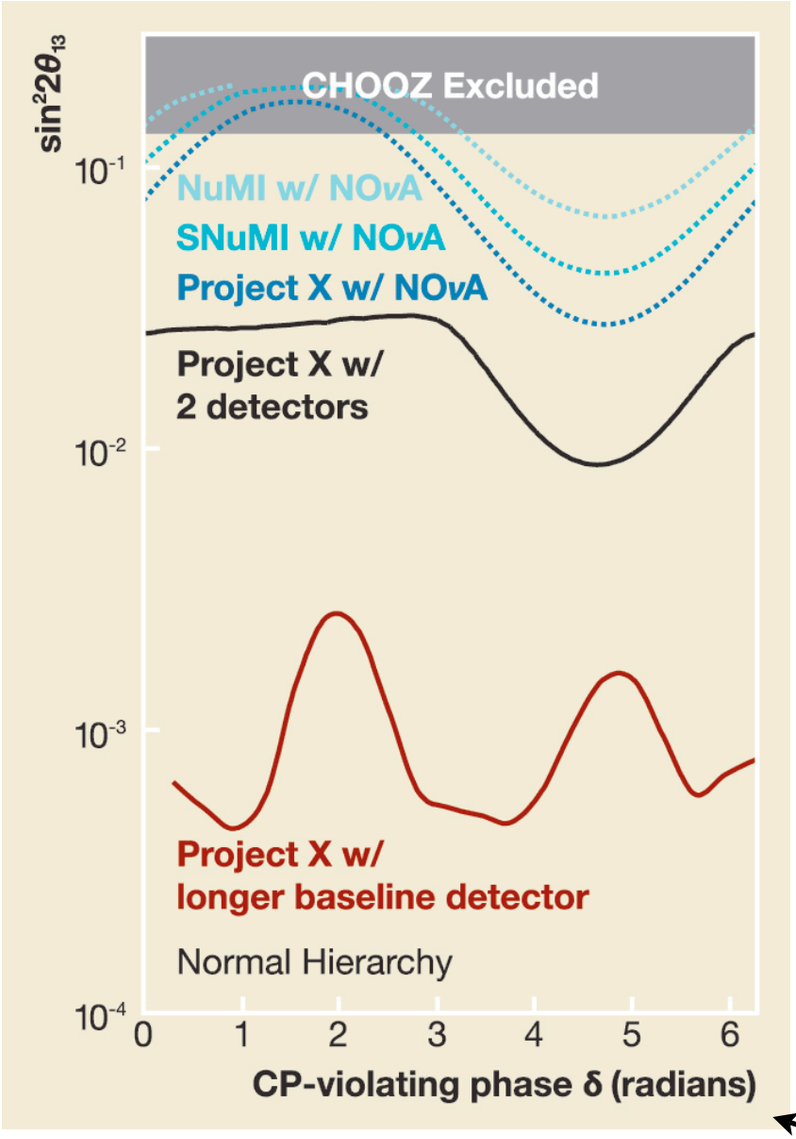


Recommendations from the Report of the P5 Panel to HEPAP, May 29, 2008:

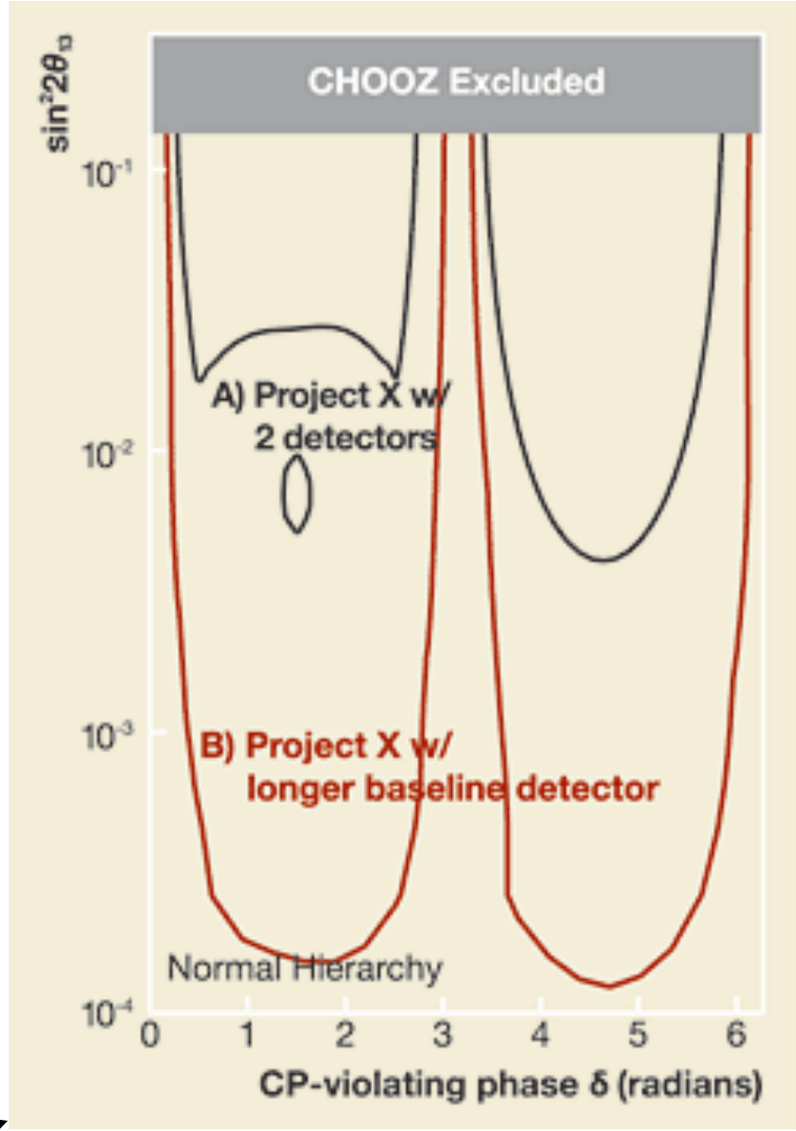
"The panel recommends proceeding now with an R&D program to design a multi-megawatt proton source at Fermilab and a neutrino beamline to DUSEL and recommends carrying out R&D in the technology for a large detector at DUSEL."

Massive Detector: Project X

- Tremendous sensitivity with large LArTPC and intense neutrino beam.
- Scenarios assume 3 years neutrino + 3 years antineutrino
- LArTPC Curves Assume:
  - 80% signal efficiency and 80% beam ν_e selection efficiency
  - no NC π^0 background and 5% systematic on background.



Mass Ordering



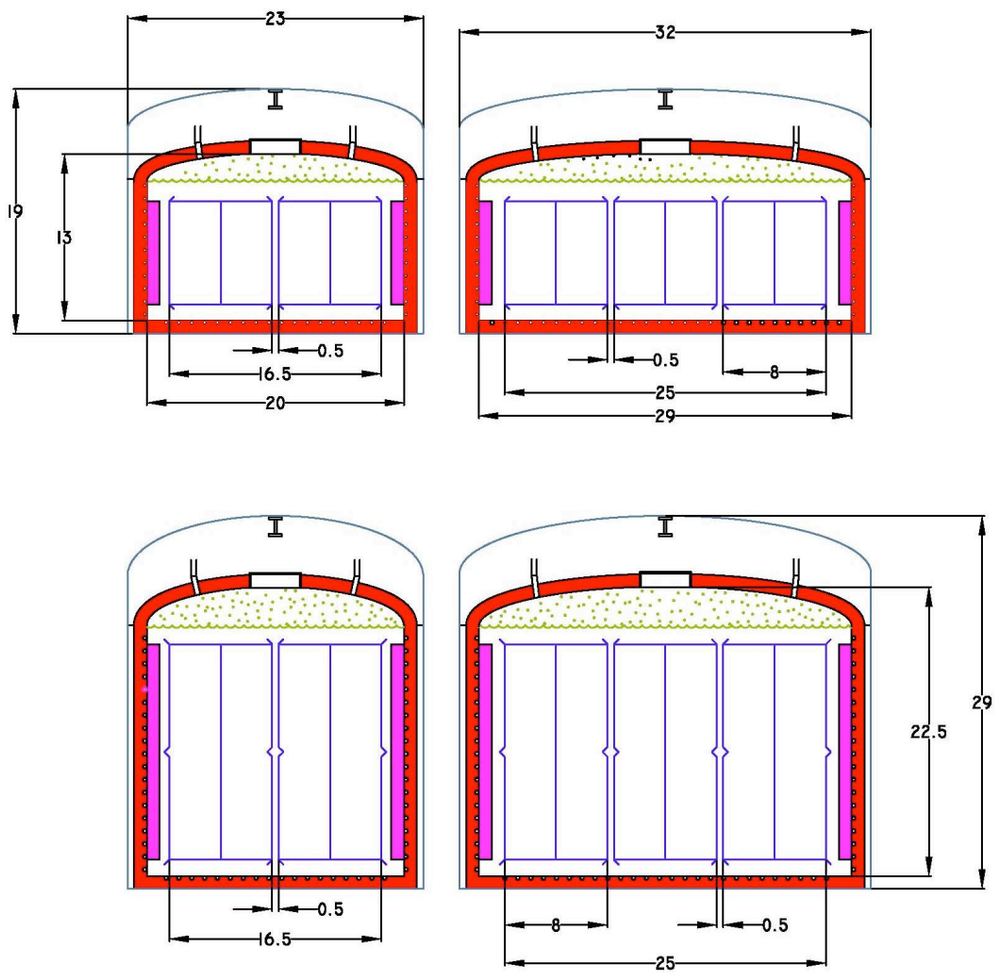
CP Violation

From Fermilab Steering Group Report
(Niki Saoulidou)

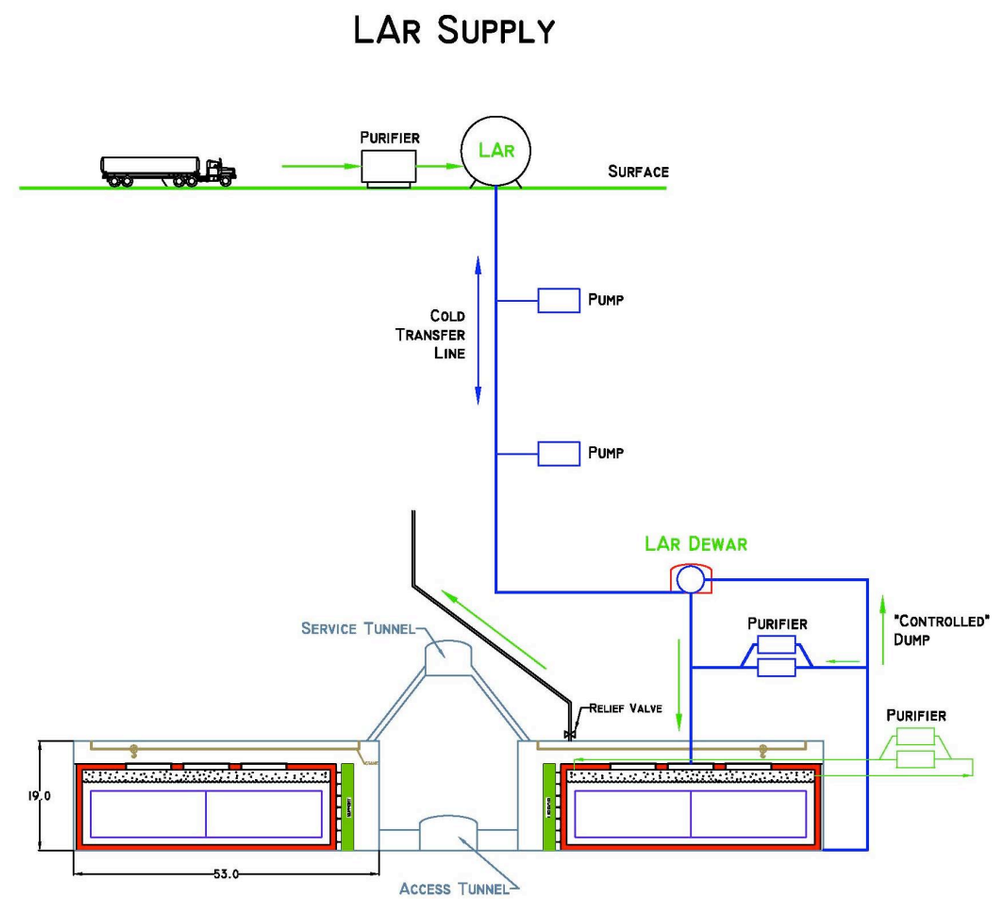
Massive Detectors: DUSEL

Some of the considerations and studies that are needed are:

- Depth? 300 ft. , 4850 ft., or in between?
- Proton Lifetime & Supernova Neutrinos : Can they be done at 300 feet? (Backgrounds?)
- Cost differential for different depths: Excavation cost, assembly cost differential , Safety issues, ...



Cavern/Cryostat designs are coupled



Example of cavern arrangement and liquid supply paths

Conclusions

- Much activity in U.S. to develop LArTPC technology.
- Materials Test Stand is an excellent resource for approving materials for use in future experiments.
- ArgoNeuT is current step for LArTPCs in U.S.; will collect 10000's of events!
- MicroBooNE is next major effort in U.S., and it will teach us many things we need to understand before attempting to build a massive detector that can be used to study neutrino oscillations and nucleon decay.
- Idea to build massive LArTPC detectors already generating lots of interest in the U.S.

Back-Up Slides

Noble Liquids: Properties

- Ionization and scintillation light used for detection (transparency to own scintillation).
- Ionization electrons can be drifted over long distances in these liquids.
- Very good dielectric properties allow high-voltages in detector.
- Argon is cheap and easy to obtain (1% of atmosphere).

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