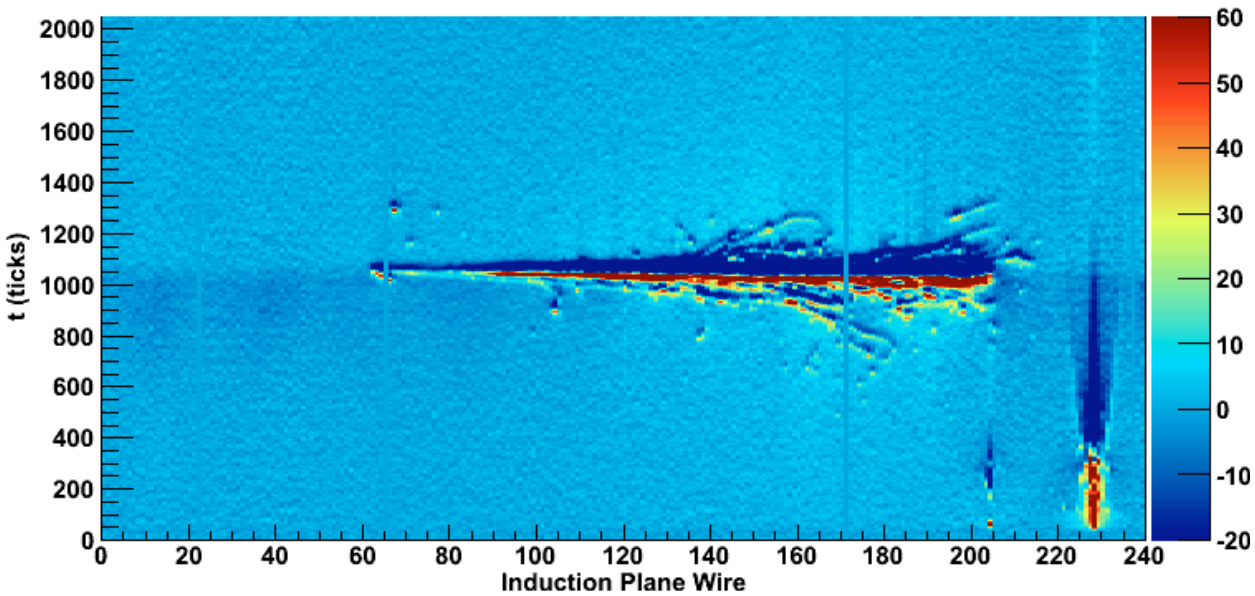
B.T.Fleming
March 29, 2010
GLA2010

From ArgoNeuT to MicroBooNE

- US-based LArTPC development program towards LAr20s
- MicroBooNE Physics and Development goals
- MicroBooNE Conceptual design

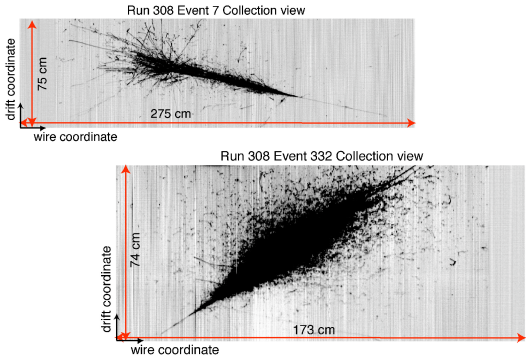


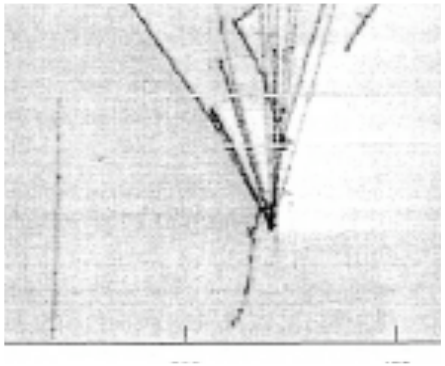
History of LArTPC development in the US

Early work US in the late 70s including small test stand in operation at LANL, building on LArTPC concept (Rubbia, 1977)

More recent: work began in the US ~2003 with FLARE and LArTPC efforts which
have grown to the existing program

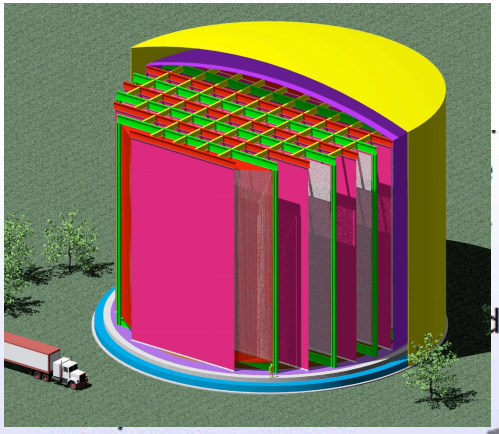
Success in the US greatly benefitted from building off all that has been learned by European LArTPC program!



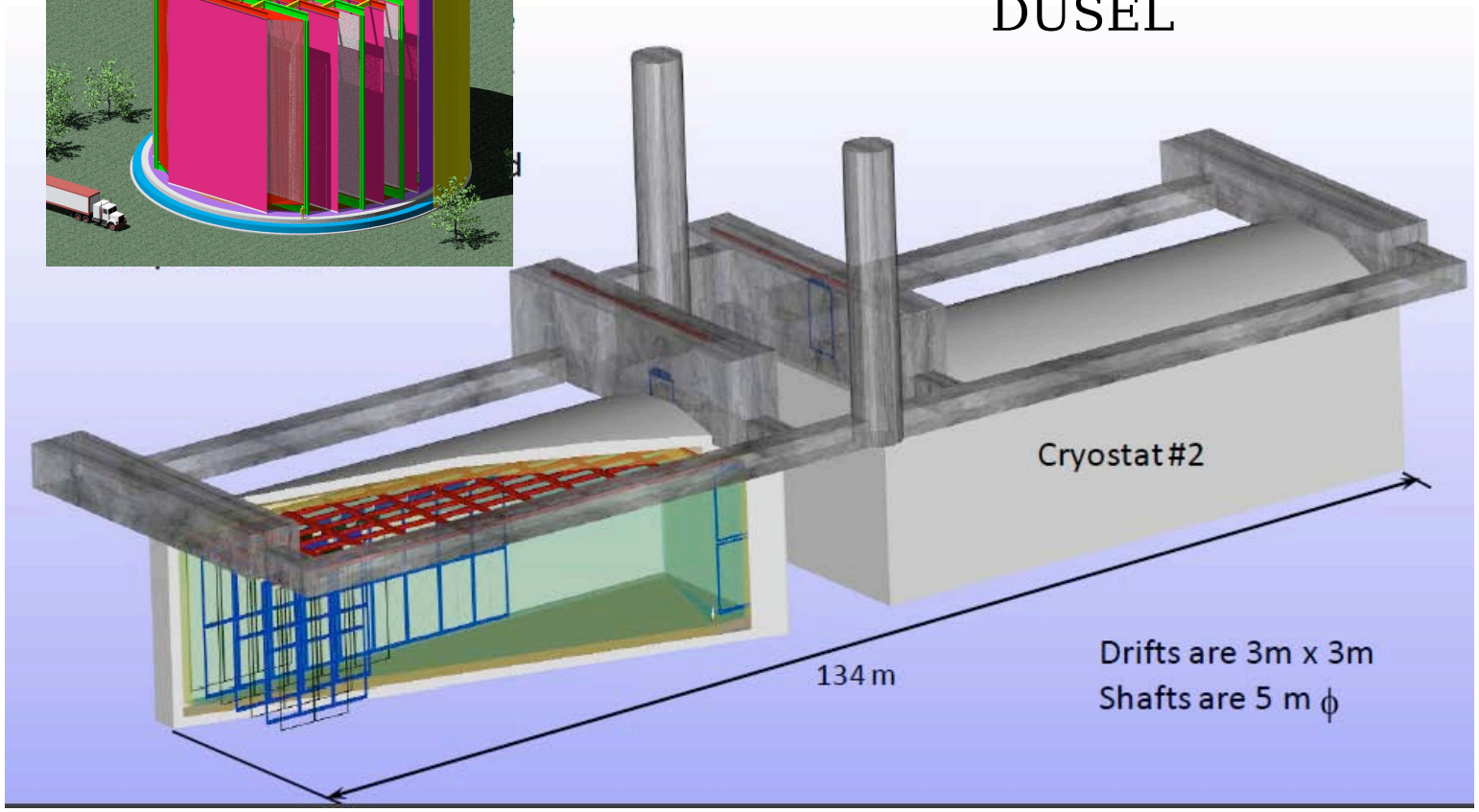


From the beginning of the recent effort, the focus has been on very massive detectors for oscillation physics and nucleon decay

FLARE detector (2005)

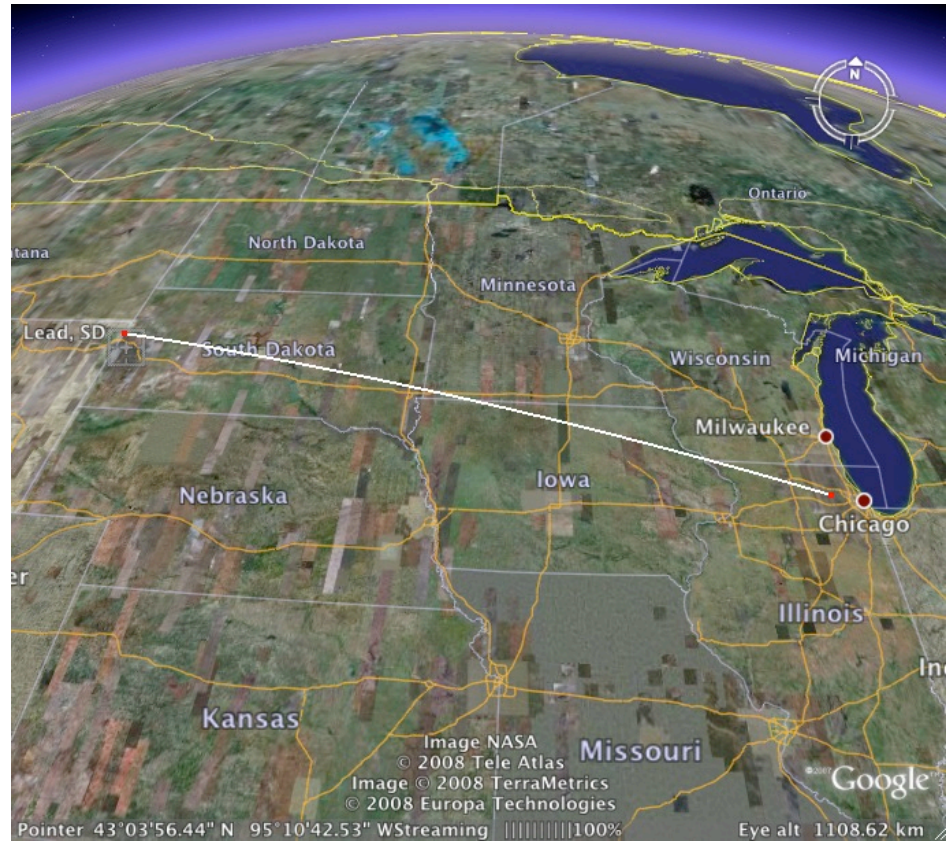


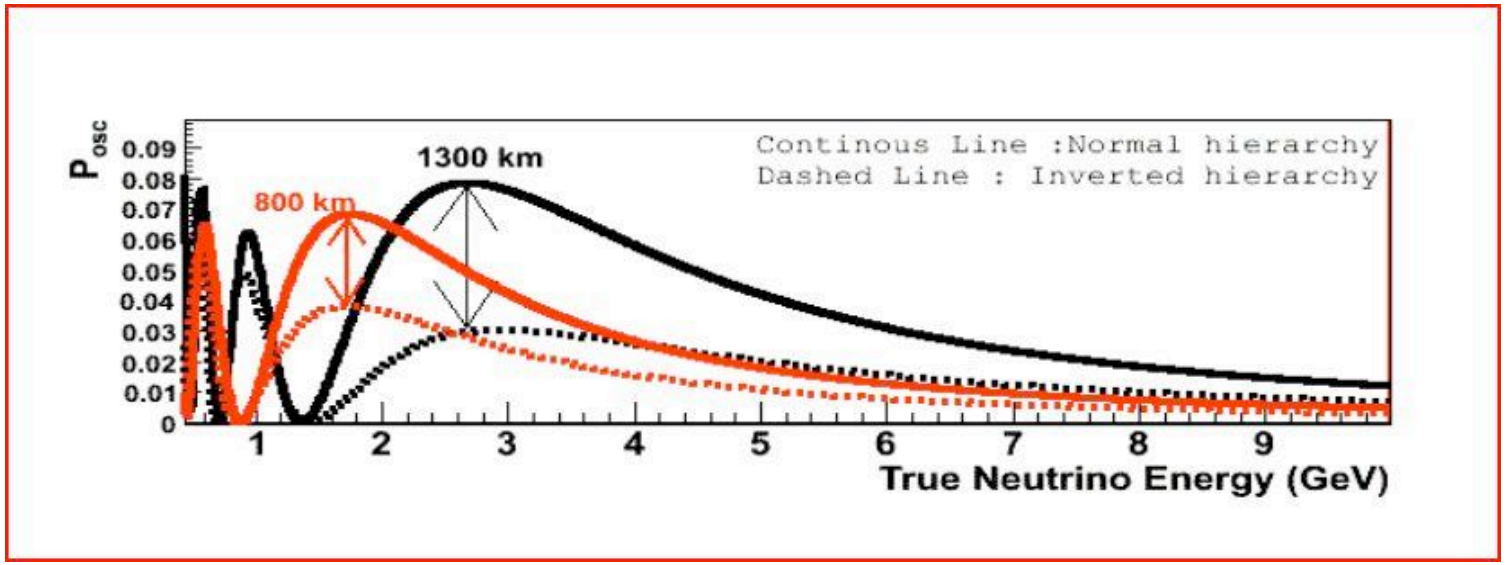
20kton modules for LBNE program at DUSEL



LBNE program:

- Intense neutrino and anti-neutrino beams from Fermilab
  - Start with 700 kW beam
  - Upgrade with high intensity proton machine (Project X) to 2MW
- Baseline of > 1000 km
- Very massive detectors in Homestake/DUSEL

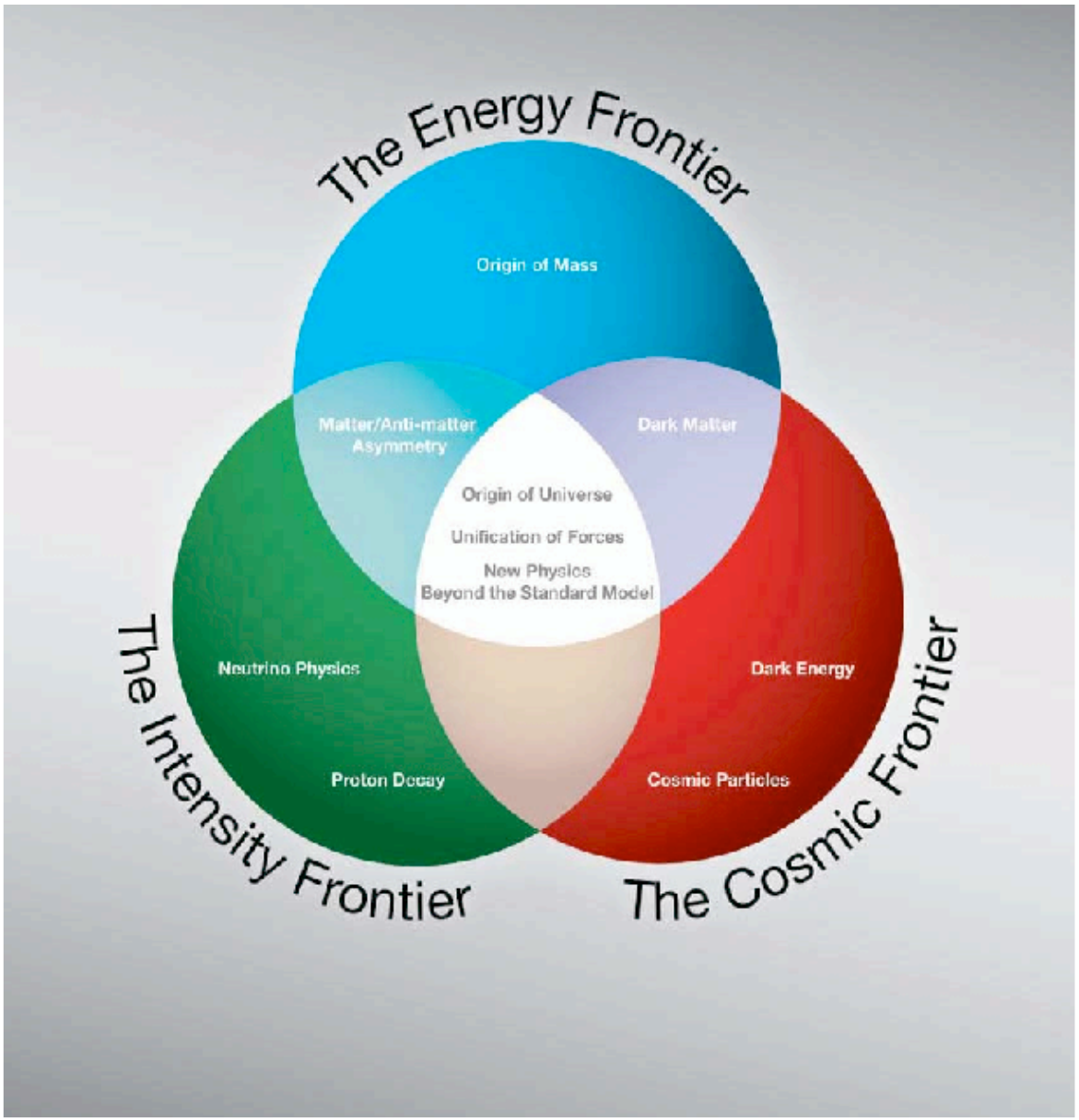




L = 1300 km (more matter effect in the oscillations

Broad band beam can cover 1st and 2nd maximum

Recommendations from the Report of the P5 Panel for particle physics, May 29, 2008



Recommendations from the Report of the P5 Panel for particle physics, May 29, 2008

At the Intensity Frontier:

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

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.

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.

Long Baseline Neutrino Experiment (LBNE Project) received DOE CD-0 in January: Mission-Need
Working towards CD-1 by end of 2010

Liquid-Argon Time Projection Chambers

Outlook of R&D Program in the US

Active Volume

Yale TPC & Bo

Yale TPC: Dismantled
Bo: Operational

0.00002 kton

15 x

ArgoNeuT

Operational
Physics: Measure neutrino-argon cross sections

0.0003 kton

330 x

MicroBooNE

Construction begins 2010
Physics: Investigate low-energy neutrino interactions

0.1 kton

4 x 50 x

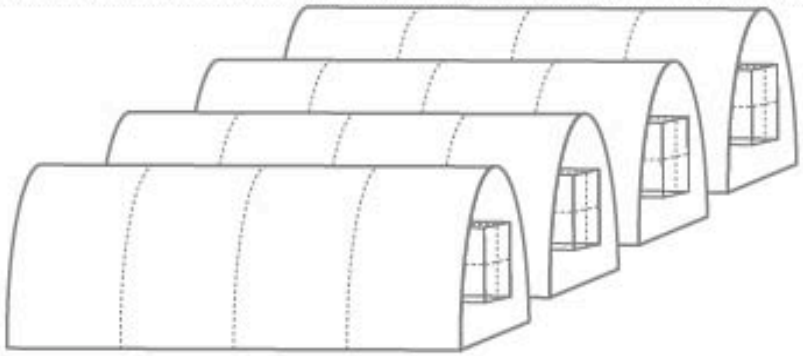
LAr TPC for LBNE

R&D in progress
Physics: Measure neutrino oscillations at 1,000+ km

20 kton

Final goal

Replicate proven technology
Physics: Search for CP violation in neutrino sector



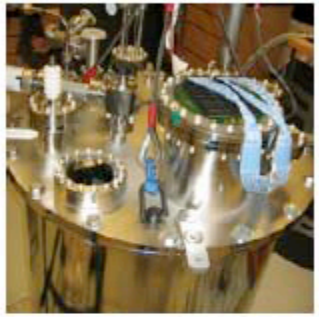
N x 20 kton

Liquid-Argon Time Projection Chambers

Status of R&D Program in the US

The first TPCs in the United States:

Yale TPC



Location: Yale University
Active volume: 0.00002 kton
Year of first tracks: 2007

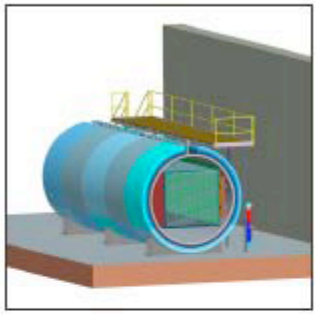
Bo

Location: Fermilab
Active volume: 0.00002 kton
Year of first tracks: 2008

ArgoNeuT

Location: Fermilab
Active volume: 0.0003 kton
Year of first tracks: 2008
First neutrinos: June 2009

MicroBooNE



Location: Fermilab
Active volume: 0.1 kton
Start of construction: 2010

Test stands to improve liquid-argon technology:

Luke

Location: Fermilab
Purpose: materials test station
Operational: since 2008

LAPD

Location: Fermilab
Purpose: LAr purity demo
Operational: 2010

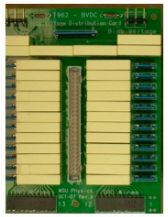
Under Development

- LAr20 cryostat prototype
- 5% electronics test
- TPC integration prototype
- Calibration prototype

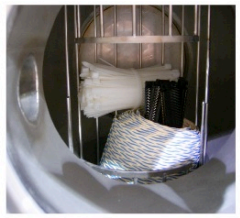
"Integrated Plan" for US-based program reviewed at FNAL, Nov. 2009
Submitted to DOE

Luke: Materials Test Stand at FNAL
Test materials in Argon and purification techniques for clean LAr

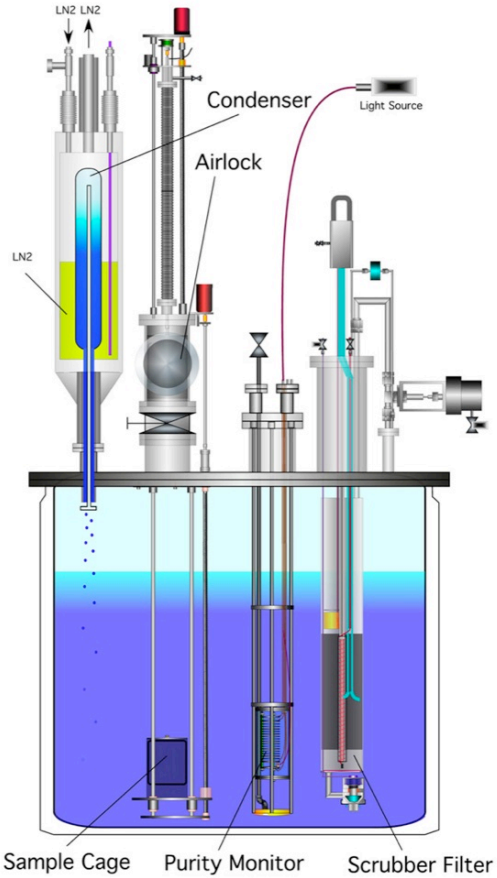
BNL 4-ch Amp

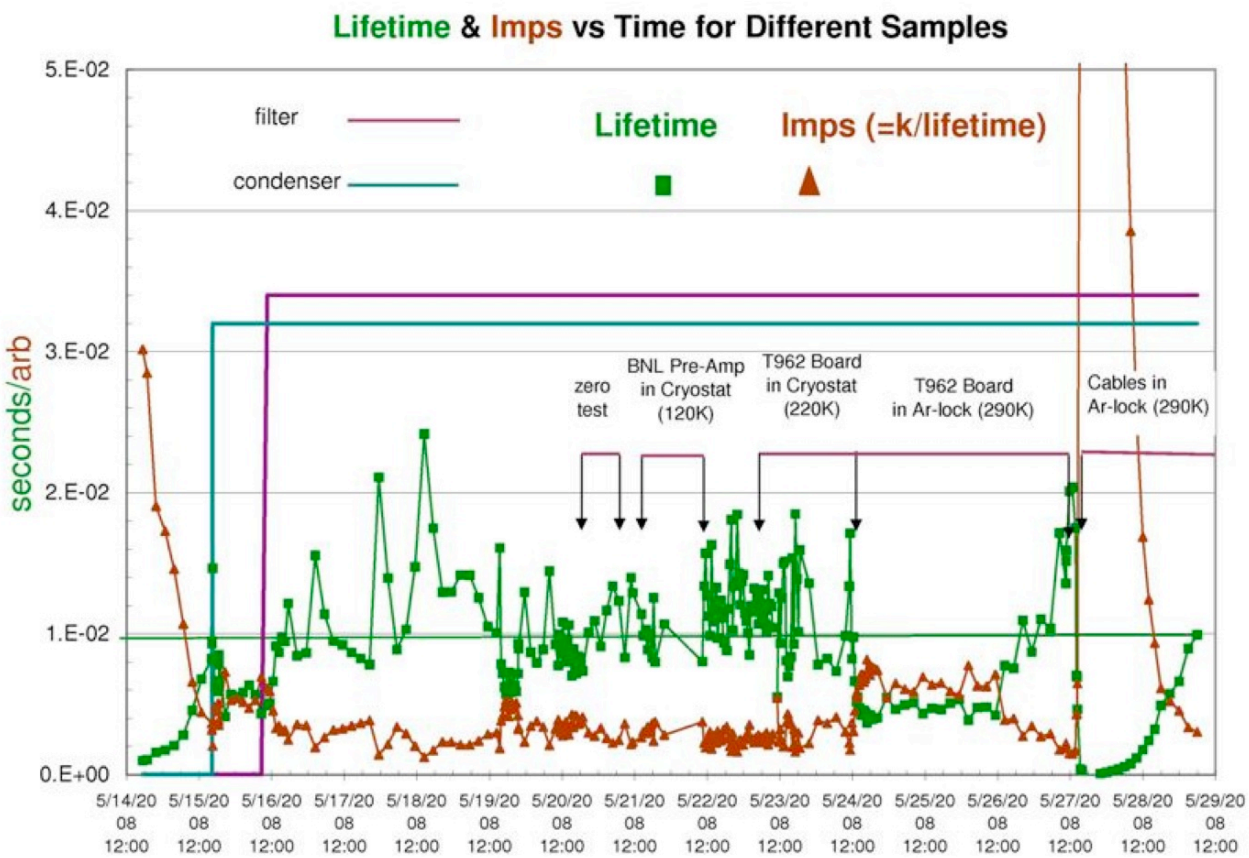


ArgoNeuT Bias Board



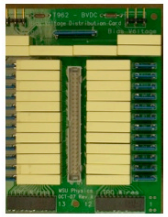
Cables/Cable-Tie Bundle



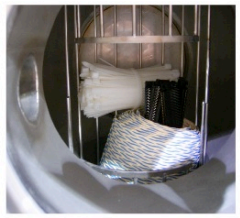


Luke: Materials Test Stand at FNAL
Test materials in Argon and purification techniques for clean LAr

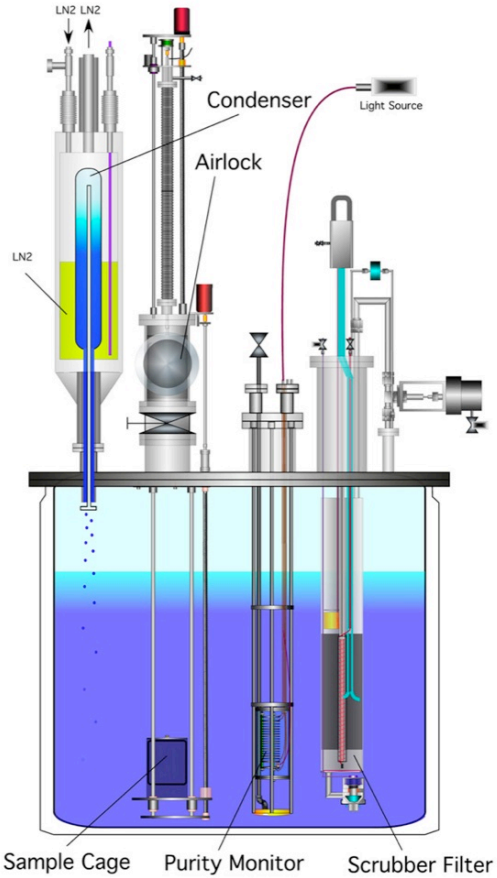
BNL 4-ch Amp



ArgoNeuT Bias Board



Cables/Cable-Tie Bundle

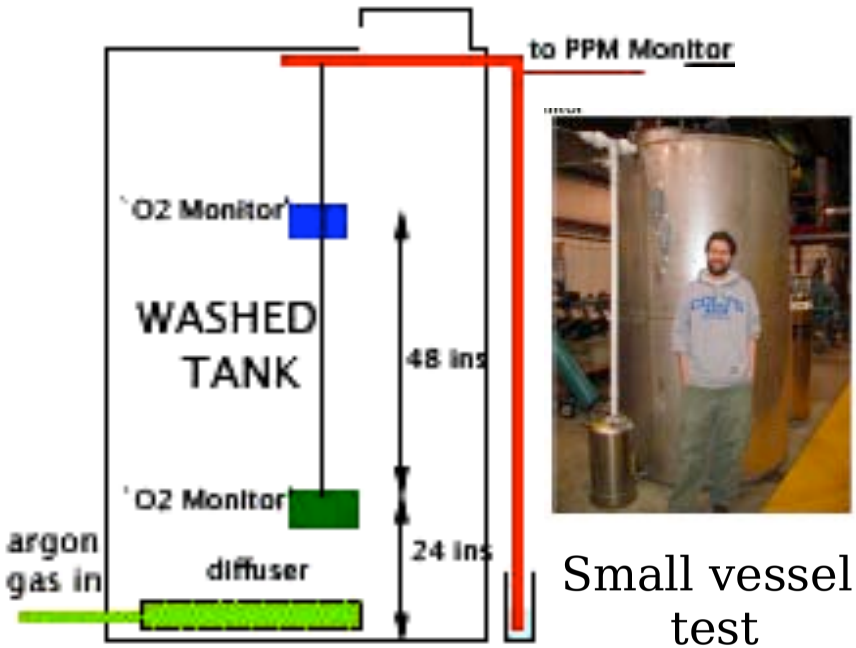


Material	Sample Surface Area (cm^2)	Effect of Material on Electron Drift Lifetime (LT)			Comments
		94 K liquid	≈120 K vapor	≈225 K Vapor	
Red-X Corona Dope[a]	100	None	None	LT Reduced from 8 to 1 ms; recovery observed.	H_2O concentration not monitored.
Deactivated Rosin Flux[b]	200	None	Not Tested	LT reduced from 8 to 1.5 ms recovery observed	H_2O concentration not monitored.
FR4	1000	None	Not Tested	LT reduced from 8 to <1 ms	Outgassed enough H_2O at 225 K to saturate sintered metal return.
Taconic[c]	600	None	Not Tested	LT reduced.	Sample outgases water at 225 K.
Hitachi BE 67G[d]	300	None	Not Tested	LT reduced; recovery observed	Sample outgases water at 225K; outgassing reduced over time.
TacPreg[e]	200	None	None	LT reduced; recovery observed	Sample outgases water at 225 K; outgassing reduced over time.
FR4, y-plane wire endpoint for uBooNE	225	None	None	LT reduced from 8 to 3 ms	Sample outgases water at 225 K.
FR4, y-plane wire cover for uBooNE	225	None	None	None	Sample was evacuated in airlock prior to testing
Devcon 5-min epoxy	100	None	None	LT reduced from 10 to 6 ms; some recovery observed	Sample outgases water at 225 K.

seconds/arb

Purity tests at FNAL: LAPD

- Small test stands at FNAL
- 20 ton purity demonstrator: LAPD
- MicroBooNE R&D program



Small vessel test

- Flush tank with clean Argon gas
- Monitor level of O_2 in tank as it is flushed
- 2.6 volume changes to reach 100ppm O_2

See Brian Rebel's talk

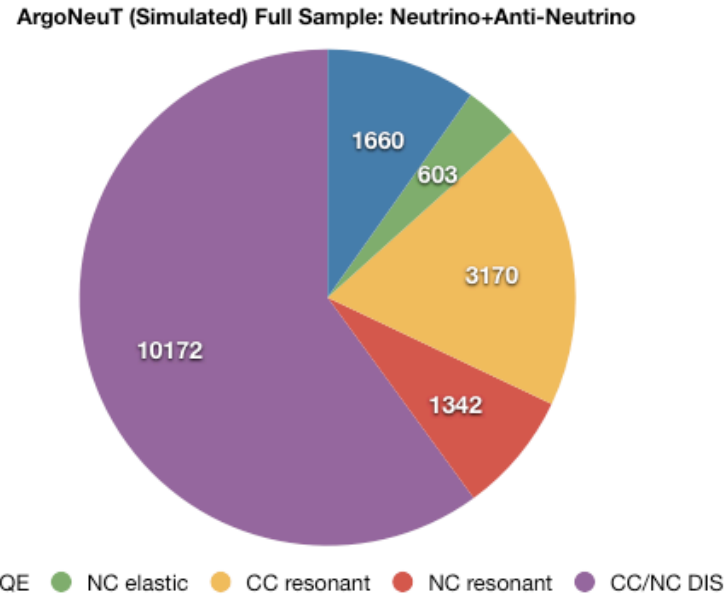
LAPD

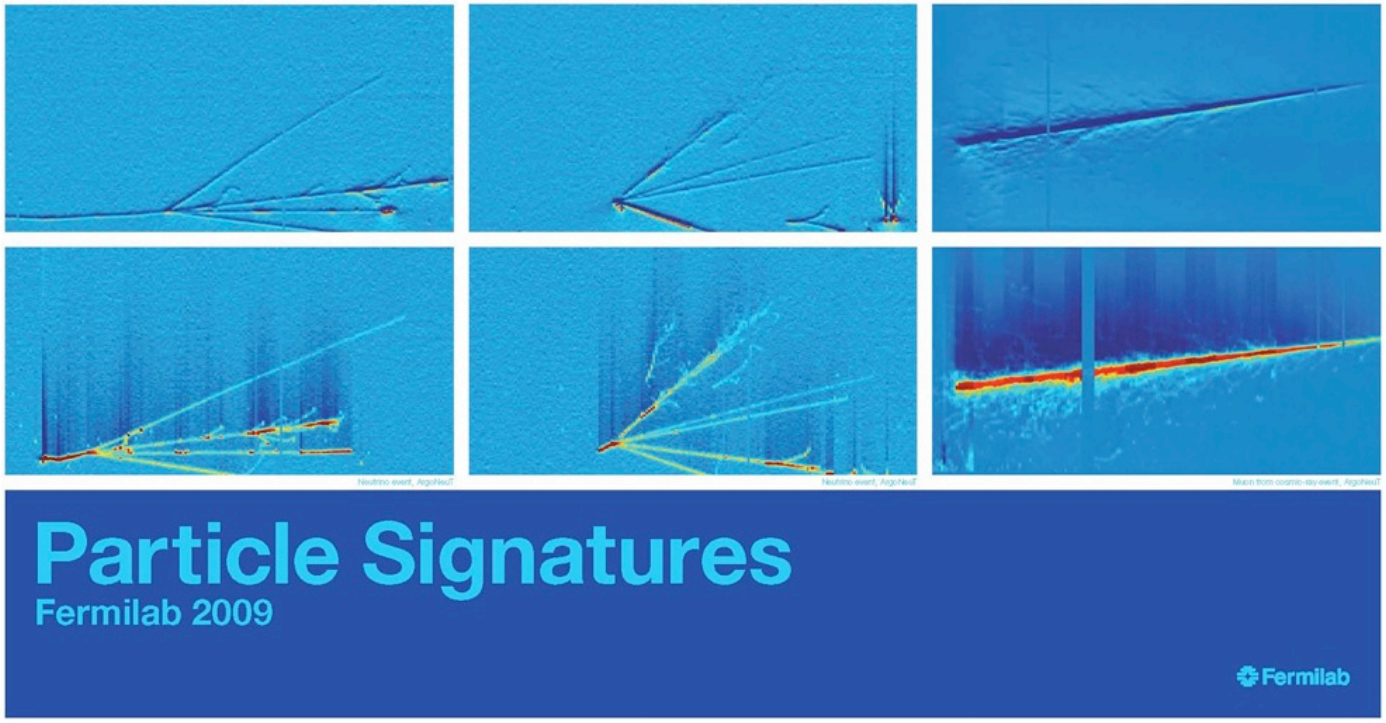
Location: Fermilab
Purpose: LAr purity demo
Operational: 2010

The LAPD Tank

ArgoNeuT

- 175 liter TPC
- In NuMI beam from May09-Feb10
- Collected ~17,000 ~3 GeV neutrino interactions
- Physics and development goals





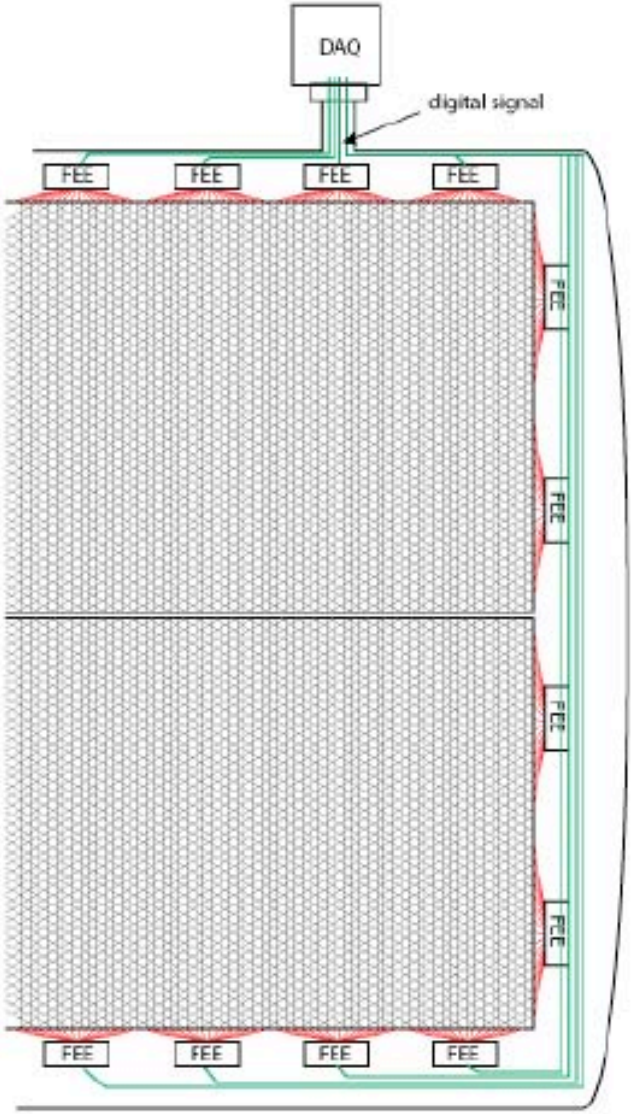
See Carl Bromberg's talk

Cold (87K) Electronics Concept

- Cosmic Ray Test Stand CMOS tests
  - Edwards (Michigan State)
- ASIC Development & testing
  - Radeka, Rescia (BNL)
  - Yarema (FNAL)
- Integration, grounding
  - Marvin Johnson (FNAL)

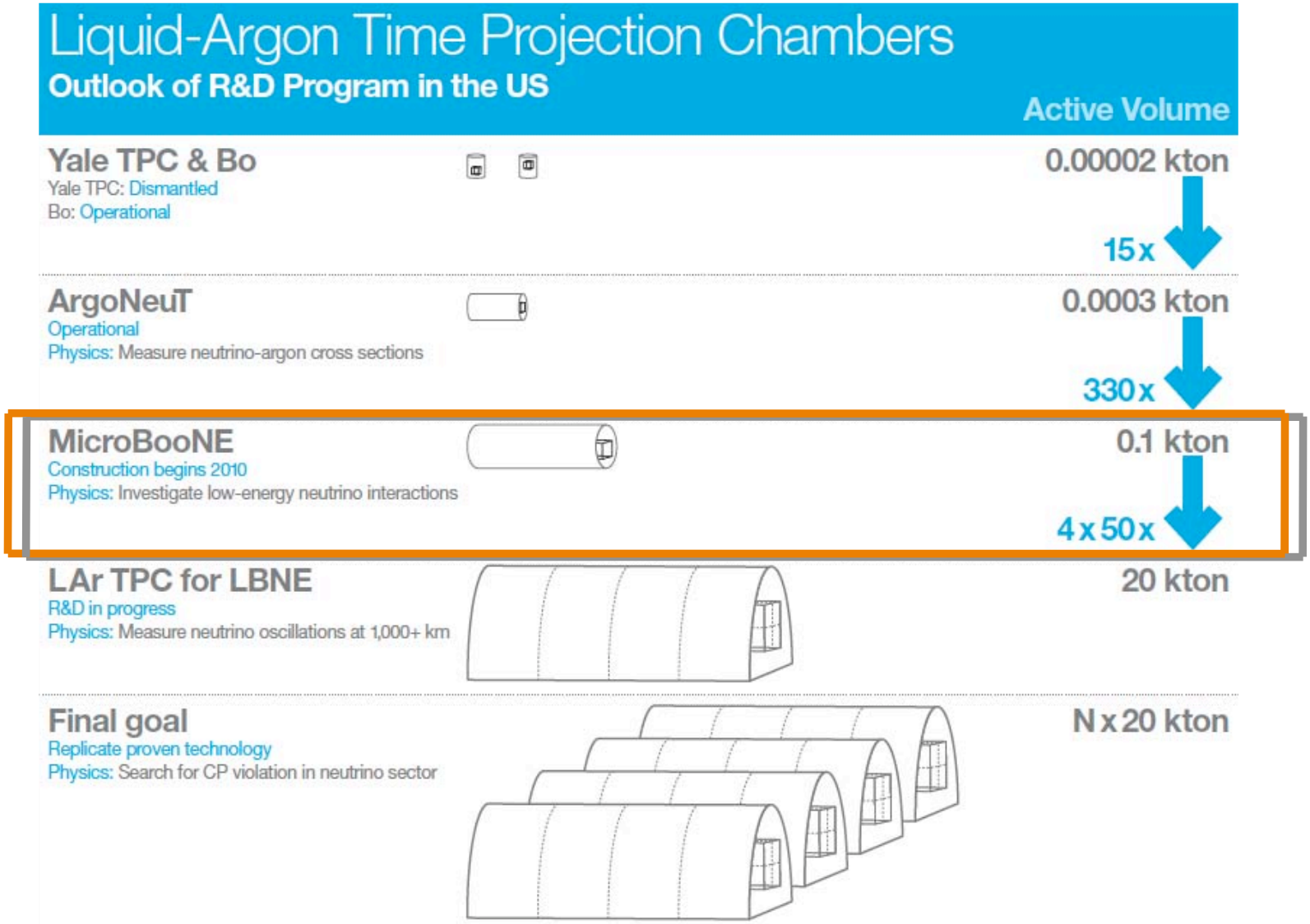
Bo

Location: Fermilab
Active volume: 0.00002 kton
Year of first tracks: 2008



see V. Radeka's talk

MicroBooNE within the Integrated Plan for LAr



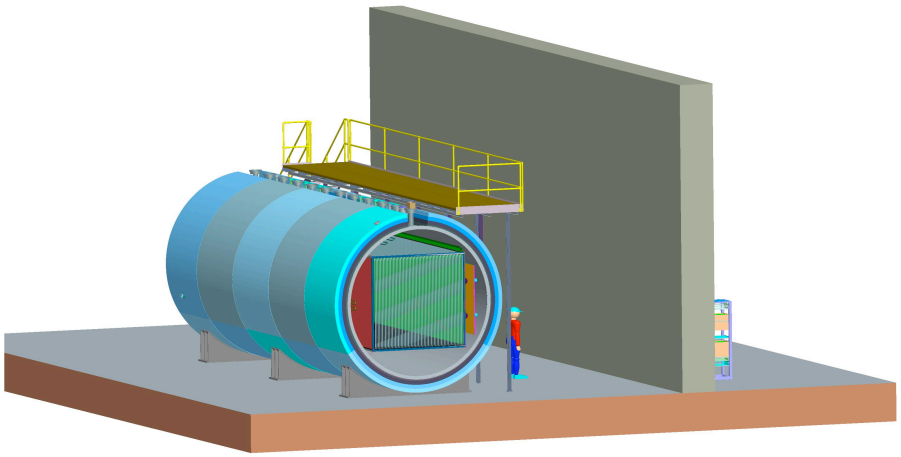
Collaboration

- *Brookhaven Lab*: H. Chen, J. Farrell, F. Lanni, D. Lissauer, D. Makowiecji, J. Mead, V. Radeka, S. Rescia, J. Sondericker, C. Thorn, B. Yu
- *Columbia University*: L. Camilleri, C. Mariani, M. Shaevitz, B. Willis**
- *FermiLab*: B. Baller, C. James, S. Pordes, G. Rameika, B. Rebel, D. Schmitz, J. Wu
- *Kansas State University*: T. Bolton, G. Horton-Smith, D. McKee
- *Los Alamos Lab*: G. Garvey, J. Gonzales, B. Louis, C. Mauger, G. Mills, Z. Pavlovic, R. Van de Water, H. White, S. Zeller
- *Massachusetts Institute of Technology*: W. Barletta, L. Bugel, J. Conrad, C. Ignarra, B. Jones, G. Karagiorgi, T. Katori, H. Tanaka
- *Michigan State University*: C. Bromberg, D. Edmunds
- *Princeton University*: K. McDonald, C. Lu, Q. He
- *St. Marys*: P. Nienaber
- *University of California, Los Angelas*: H. Wang
- *University of Cincinnati*: R. Johnson, A. Wickremasinghe
- *University of Texas at Austin*: S. Kopp, K. Lang
- *Yale University*: C. Anderson, B. T. Fleming*, S. Linden, K. Partyka, M. Soderberg, J. Spitz

13 institutions
58 collaborators
NSF funded/DOE funded

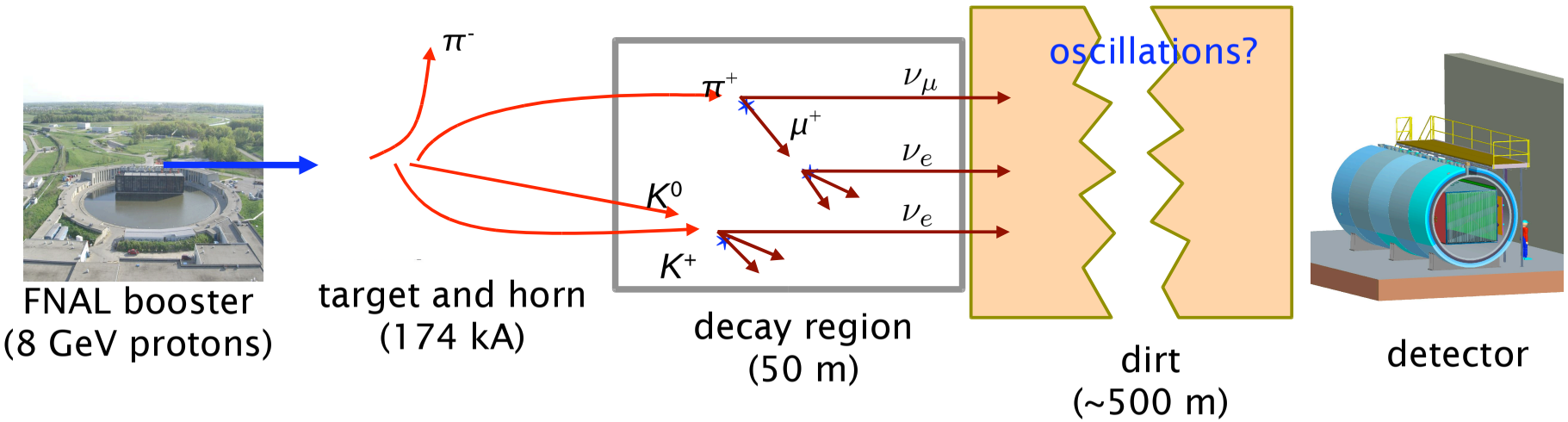
*=Spokesperson, **=Deputy Spokesperson

The MicroBooNE Experiment



MicroBooNE detector:

- 150 tons total Liquid Argon
- 89 tons active volume
- TPC: ~2.5 x 2.5 x 10.4m long
- Ionization electrons drift to beam right
- 30 PMTs peek through the wire chambers on beam right
- Will use BNB and NuMI beams at FNAL for physics program

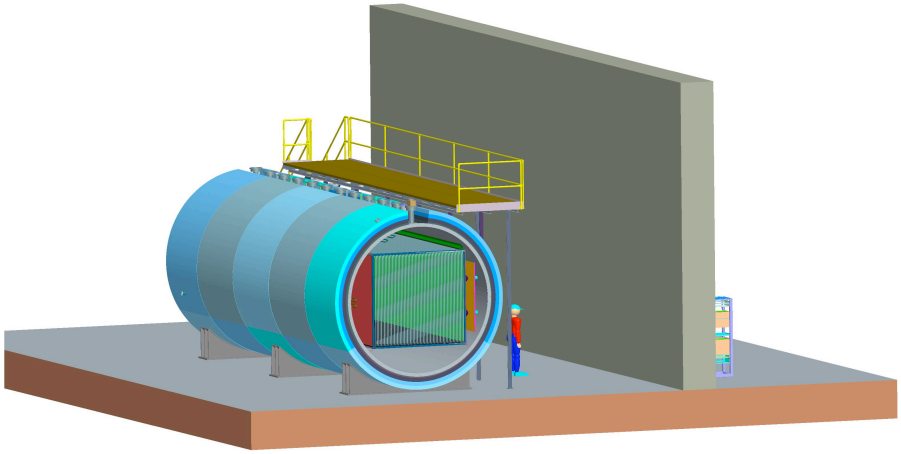


- Stage 1 approval from FNAL in 2008
- Partially funded through NSF in 2008-2009
- DOE CD-0: Mission Need received in September 2009
- DOE CD-1: Conceptual design complete: March 2010

MicroBooNE Physics and Development Goals

MicroBooNE Physics

- MiniBooNE low energy excess
- Suite of low energy cross section measurements

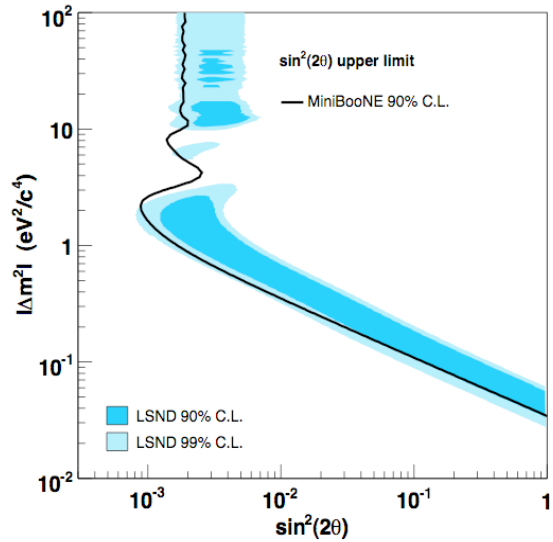


MicroBooNE LAr TPC Development Goals

- Demonstrate photon – electron identification
- Develop cold electronics
  - Implementation of cold electronics in Gaseous Argon (GAr)
- Purity: Test of GAr purge in large, fully instrumented vessel
- Refine sensitivity estimates for next generation detectors
- Test ability to run on surface
- Develop tools for analysis
- Develop cost scaling model for larger detectors

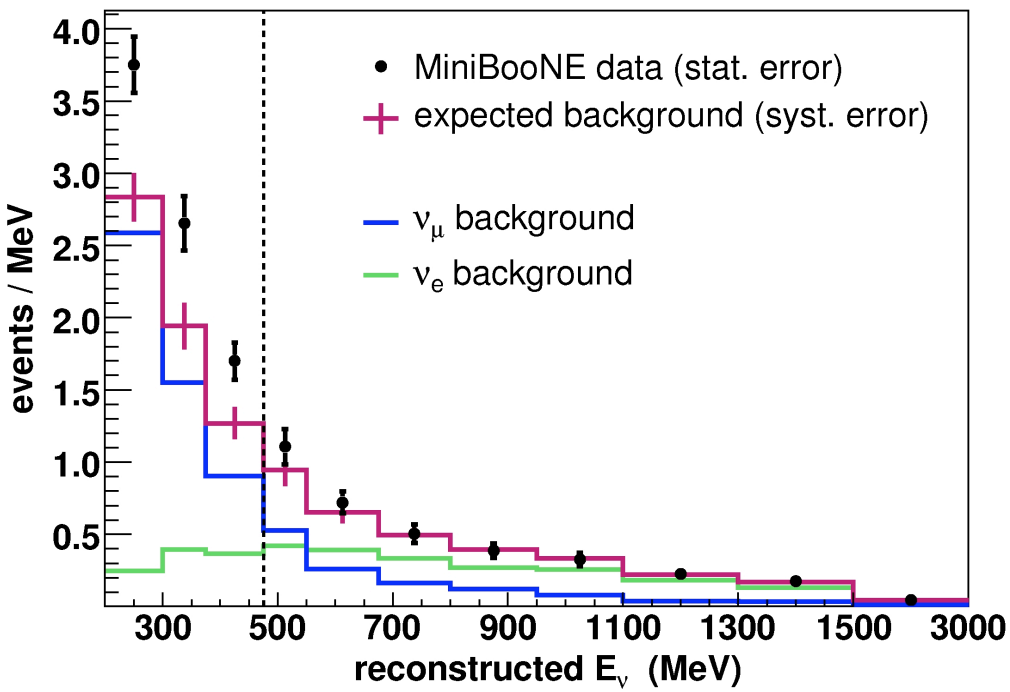
MiniBooNE oscillation search

Data consistent with background in $475<E_\nu^{QE}<3000$ MeV analysis region



Incompatible with the LSND experiment at 98% CL.

Excess below this not well understood



reconstructed neutrino energy bin (MeV)	200-300	300-475
total bkgnd	284±25	274±21
ν_e intrinsic	26	67
ν_μ induced	258	207
NC π^0	115	76
NC $\Delta\rightarrow N\gamma$	20	51
Dirt	99	50
other	24	30
data	375±19	369±19
	2.5σ	3.7σ

MiniBooNE spent ~1 year to understand the low energy region and continues to see a >3 sigma excess.....

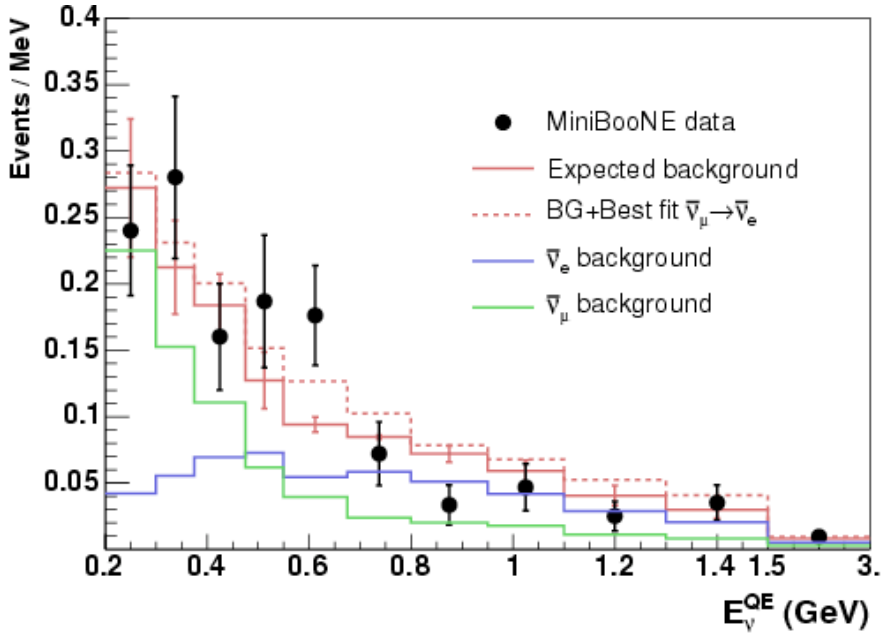
Some effects added to excess, some removed excess...

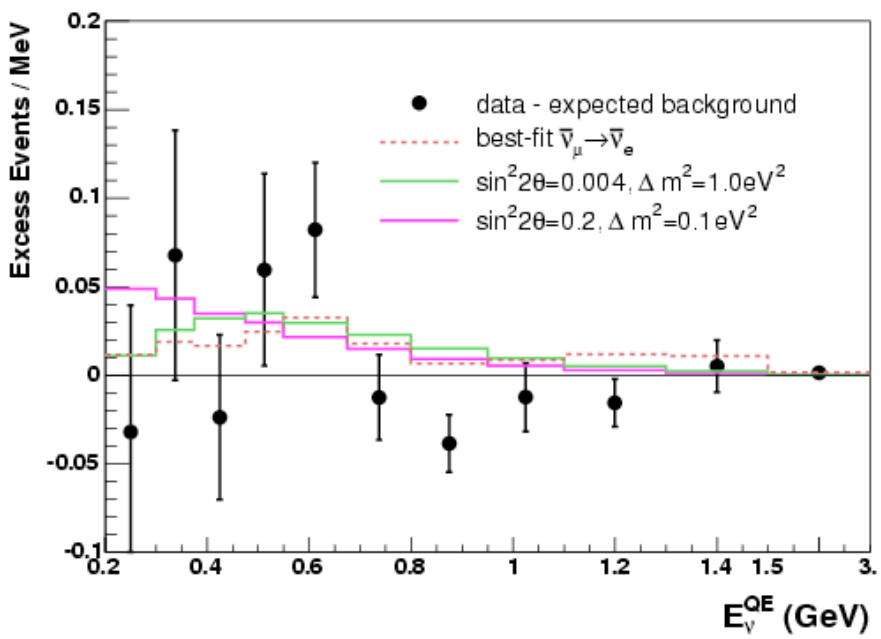
- Improved treatment of π flux errors
- Improved π^0/radiative Δ analysis
- Additional hadronic processes in cross section model
- Additional cuts to remove dirt events
- New data (0.83E20 pot in neutrino mode during SciBooNE run)

Final Results

	reconstructed neutrino energy bin (MeV)	
	200-300	300-475
total bkgnd	186.8±26.0	228.3±24.5
ν_e intrinsic	18.8	61.7
ν_μ induced	168	166.6
NC π^0	103.5	77.8
NC $\Delta \rightarrow N\gamma$	19.5	47.5
Dirt	11.5	12.3
other	33.5	29
data	232	312
	1.7 σ	3.4 σ

Low energy excess results in anti-neutrino mode





Data above 475 MeV
is consistent with
background
0.3σ excess

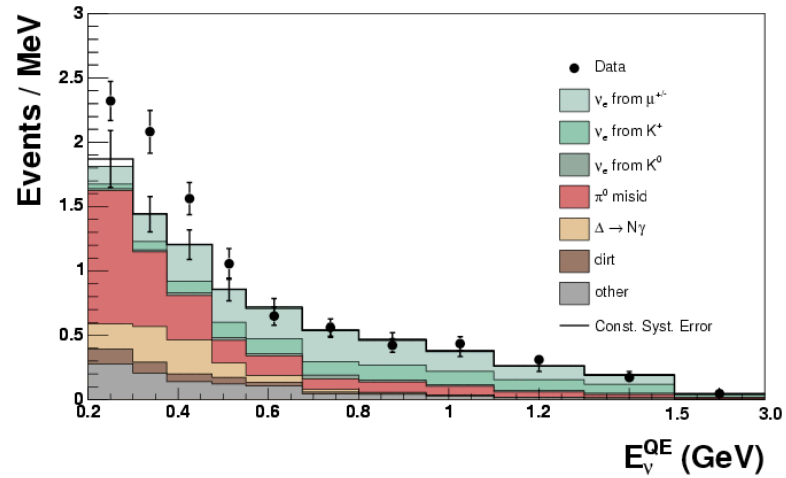
Data below 475 MeV
No low energy excess
observed.....
-0.04σ excess

Background subtracted

Sensitivity to the low energy excess

MicroBooNE's LArTPC detection technique extremely powerful

- e/γ separation capability removes ν_μ induced single γ backgrounds
- electron neutrino efficiency: ~x2 better than MiniBooNE
- sensitivity at low energies (down to tens of MeV compared to 200 MeV on MiniBooNE)



Translates to 5σ sensitivity if excess is ν_es

4σ if excess is γs

(Micro = detector ~x5 smaller than MiniBooNE can address low energy excess)

Inability to identify excess as ν_es or γs illustrates the need for the best detectors for ν_e appearance physics

→ the strength of the LAr detection technique

Important for MicroBooNE and for LAr program beyond!

Neutrino Cross Section Measurements

	Nuance channel	Reaction	#interactions/6E20 POT 70 ton FV	% of total ν_μ
CCQE	1 (CC)	$\nu_\mu n \longrightarrow \mu^- p$	52524	45.0
NCelastic	2 (NC)	$\nu_\mu N \longrightarrow \nu_\mu N$	16945	14.5
Single pion resonant	3 (CC)	$\nu_\mu p \longrightarrow \mu^- p\pi^+$	16124	13.8
	4 (CC)	$\nu_\mu n \longrightarrow \mu^- p\pi^0$	6106	5.2
	5 (CC)	$\nu_\mu n \longrightarrow \mu^- n\pi^+$	5833	5.0
	6 (NC)	$\nu_\mu p \longrightarrow \nu_\mu p\pi^0$	2878	2.5
	7 (NC)	$\nu_\mu p \longrightarrow \nu_\mu n\pi^+$	1819	1.6
	8 (NC)	$\nu_\mu n \longrightarrow \nu_\mu n\pi^0$	3572	3.1
	9 (NC)	$\nu_\mu n \longrightarrow \nu_\mu p\pi^-$	2368	2.0
DIS	91 (CC)	$\nu_\mu N \longrightarrow \mu^- X$	1123	1.0
	92 (NC)	$\nu_\mu N \longrightarrow \nu_\mu X$	410	0.4
Coherent/diffractive	96 (NC)	$\nu_\mu A \longrightarrow \nu_\mu A\pi^0$	1479	1.3
	97 (CC)	$\nu_\mu A \longrightarrow \mu^- A\pi^+$	2293	2.0
Subtotal			113474	97.3

	Nuance channel	Reaction	#interactions/6E20 POT 70 ton FV	% of total ν_e
CCQE	1 (CC)	$\nu_e n \longrightarrow e^- p$	285	37.2
NCelastic	2 (NC)	$\nu_e N \longrightarrow \nu_e N$	89	11.7
Single pion resonant	3 (CC)	$\nu_e p \longrightarrow e^- p\pi^+$	110	14.4
	4 (CC)	$\nu_e n \longrightarrow e^- p\pi^0$	48	6.3
	5 (CC)	$\nu_e n \longrightarrow e^- n\pi^+$	53	6.9
	6 (NC)	$\nu_e p \longrightarrow \nu_e p\pi^0$	19	2.5
	7 (NC)	$\nu_e p \longrightarrow \nu_e n\pi^+$	13	1.7
	8 (NC)	$\nu_e n \longrightarrow \nu_e n\pi^0$	24	3.1
	9 (NC)	$\nu_e n \longrightarrow \nu_e p\pi^-$	17	2.2
DIS	91 (CC)	$\nu_e N \longrightarrow e^- X$	26	3.4
	92 (NC)	$\nu_e N \longrightarrow \nu_e X$	9	1.1
Coherent/diffractive	96 (NC)	$\nu_e A \longrightarrow \nu_e A\pi^0$	9	1.1
	97 (CC)	$\nu_e A \longrightarrow e^- A\pi^+$	17	2.2
Subtotal			719	93.9

Suite of low energy cross section measurements

- Measurement of Δs
- Coherent vs. resonant pion production
- K production: cross sections and proton lecay studies
- Electron neutrino cross sections

These drive MicroBooNE detector requirements

- Rare channels require good statistics
- Low energy channels require low trigger hreshold
- Resolution of activity at the interaction ertex needed to observe nuclear effects

Expected event rates for 6.6 x 10^{20} pot on the BNB neutrino target

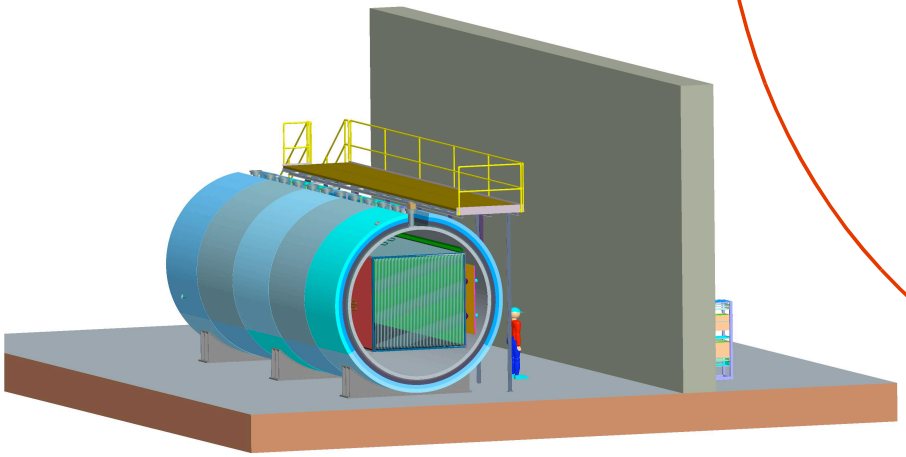
MicroBooNE Physics and Development Goals

MicroBooNE Physics

- MiniBooNE low energy excess
- Suite of low energy cross section measurements

MicroBooNE LAr TPC Development Goals

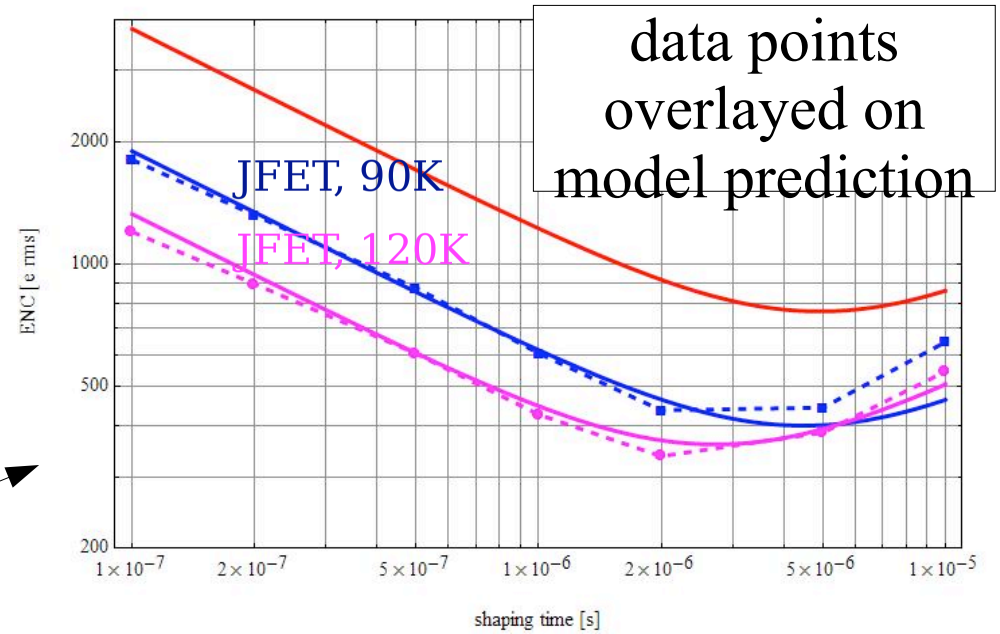
- Demonstrate photon – electron identification
- Develop cold electronics
  - Implementation of cold electronics in Gaseous Argon (GAr)
- Purity: Test of GAr purge in large, fully instrumented vessel
- Refine sensitivity estimates for next generation detectors
- Test ability to run on surface
- Develop tools for analysis
- Develop cost scaling model for larger detectors



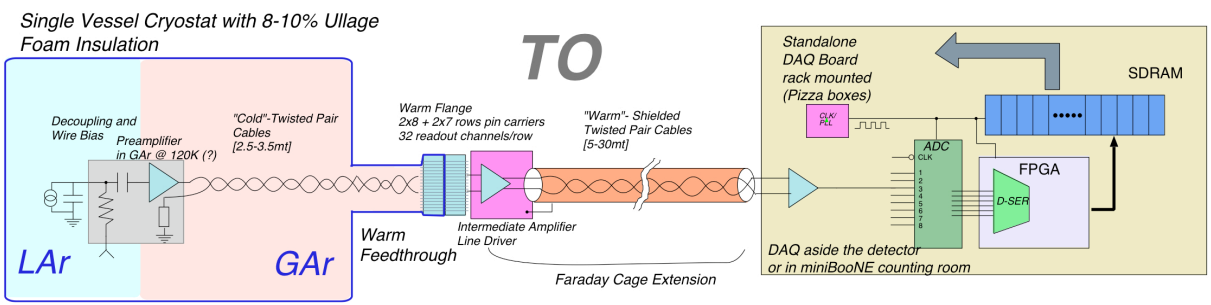
MicroBooNE readout electronics design

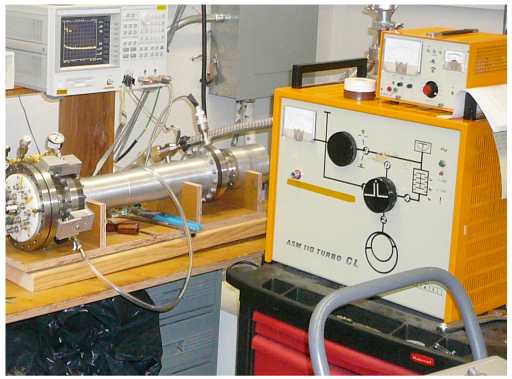
One step towards fully cold electronics....

JFET in GAr ullage:
- low noise at 1-2 μs shaping
- Study S/N levels expected in next generation LArTPCs

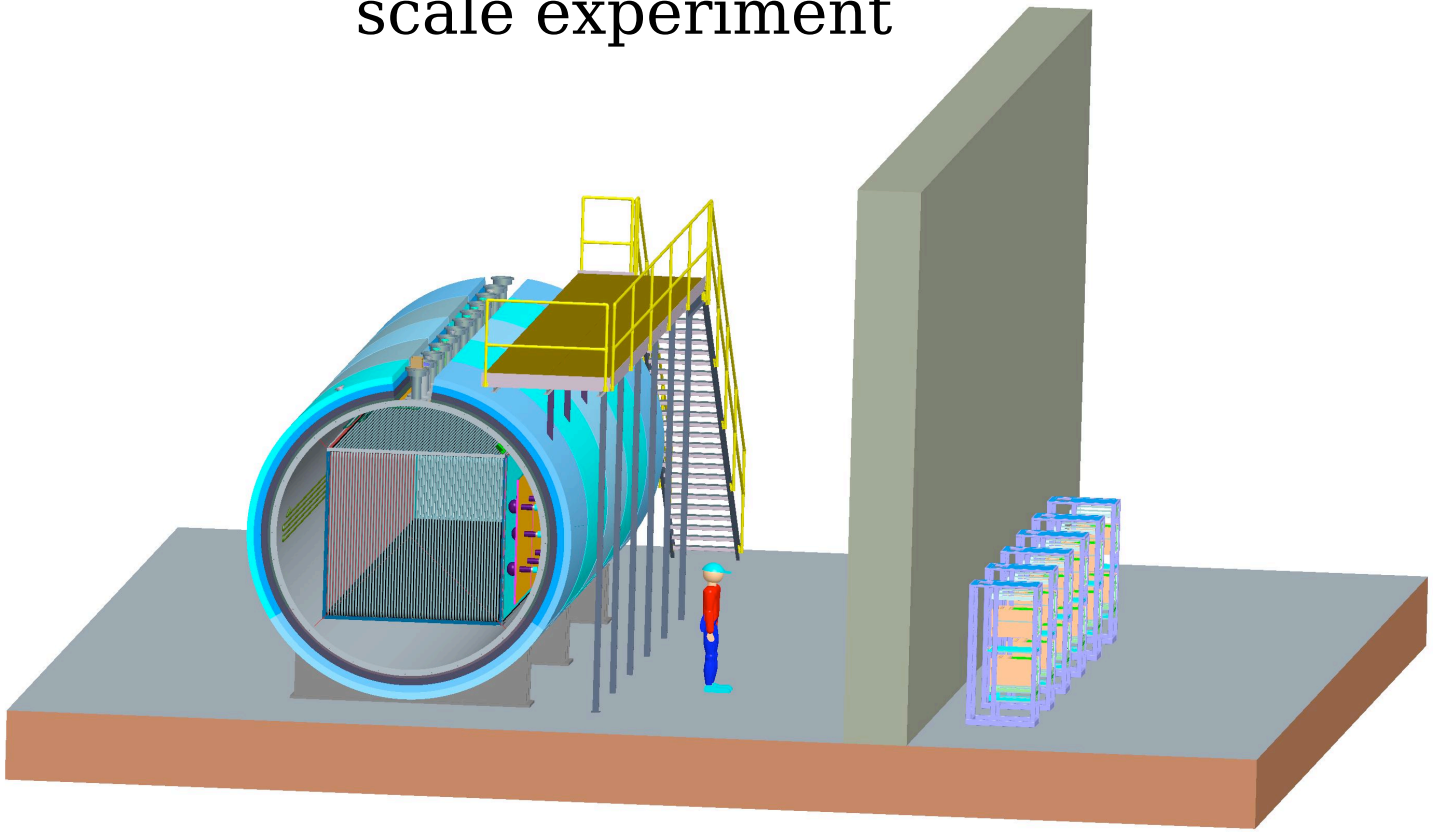


Bench tests of JFET hybrid at Brookhaven: room temp, 90K, 120K





MicroBooNE purification program: Achieve purity without evacuation in full physics scale experiment



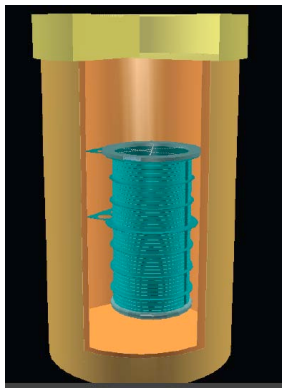
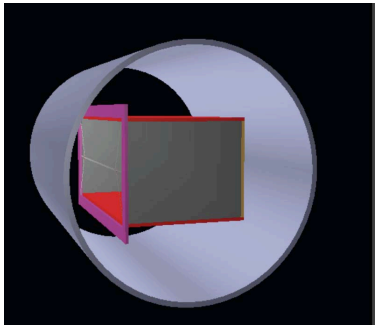
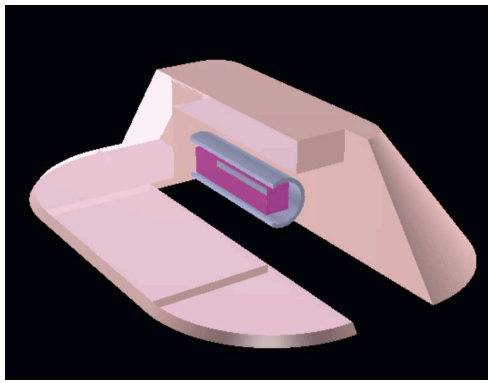
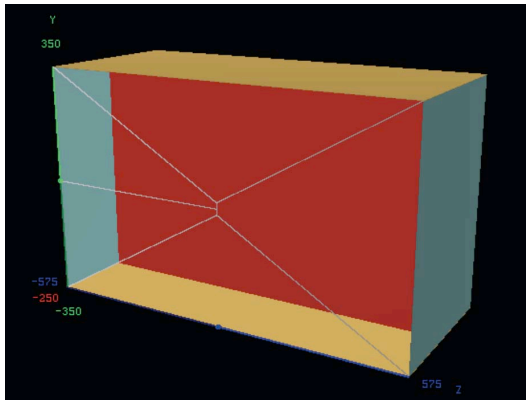
<u>MicroBooNE Purge test: 6 week program to precede physics run</u>

- 10 volume changes of GAr to reduce O_2 concentrations to 10 ppm
- Recirculate filtered gas or introduce small amount of LAr as getter and continue purification for ~1 month
- Introduce filtered LAr and test for purity

Physics Development

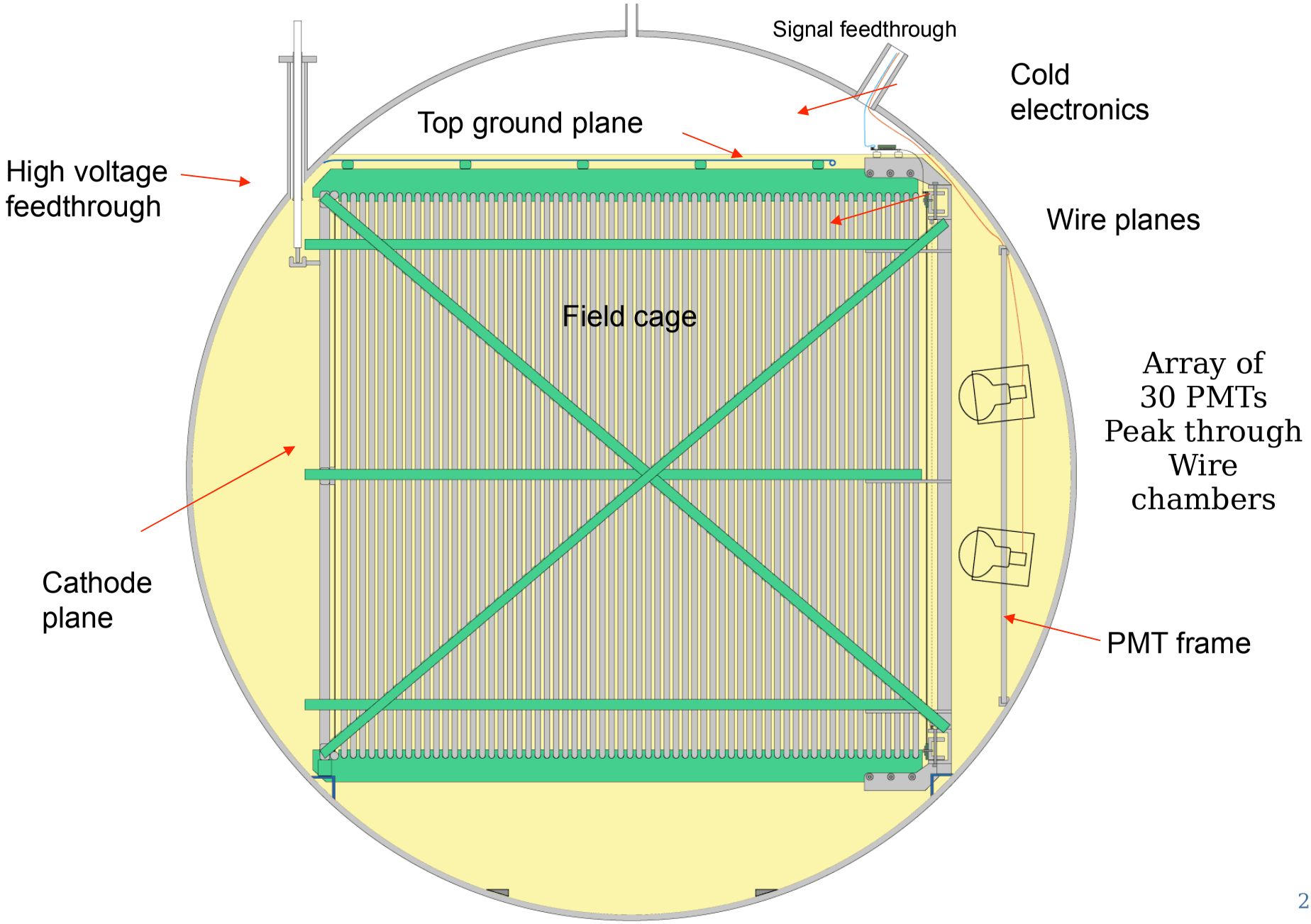
- Collect and analyze data!
  - Publish results with long term running of LArTPC
- Measure cross sections: Important for next generation LArTPCs
- Fine-tune sensitivity estimates for oscillation physics
- Fine-tune sensitivity estimates for proton decay
- Test capability of surface operation -> 24 cosmics per MicroBooNE 4.8ms readout
- Test and develop capability of self-triggered SN detection
- Develop Analysis tools -> LArSoft effort spans ArgoNeuT/MicroBooNE/LBNE

LArSoft Simulation and Reconstruction package under development for a number of different LarTPC projects.

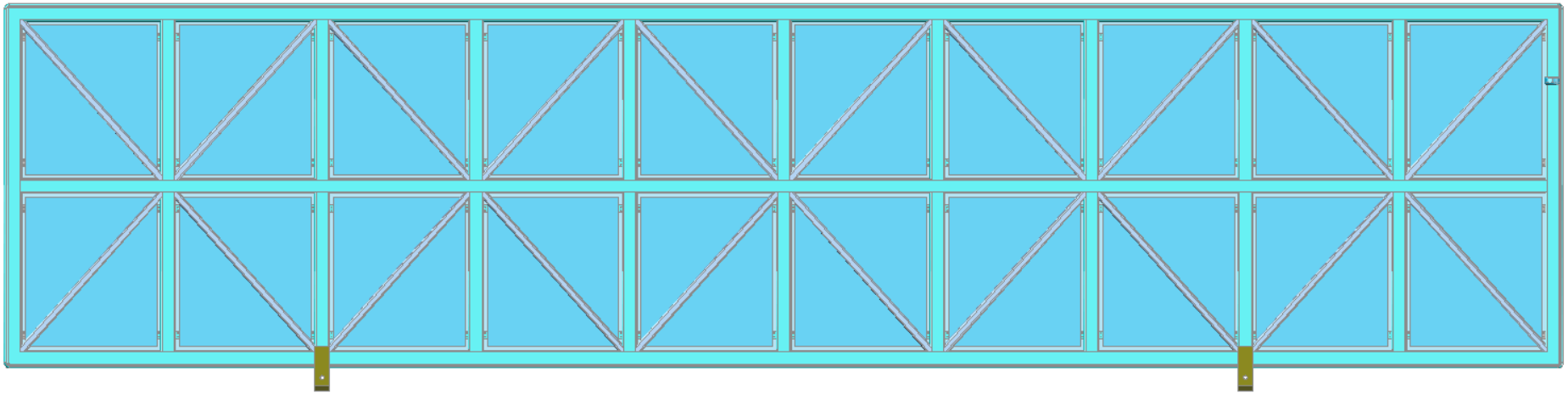





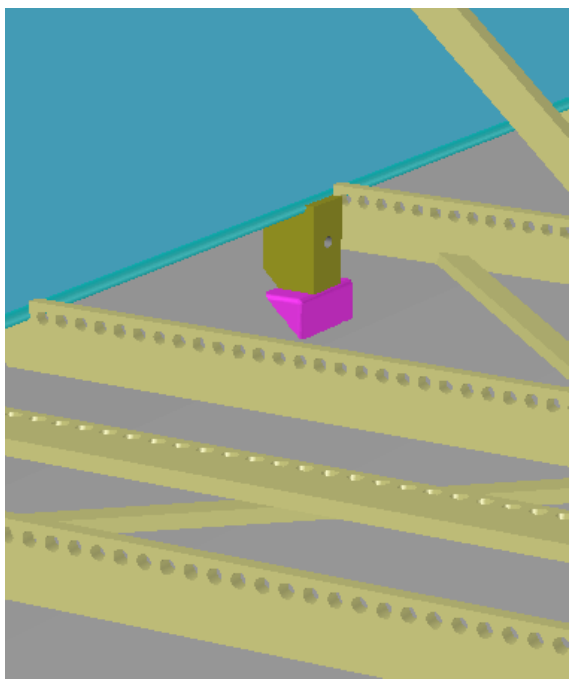
The same software, but different geometry file for each

Conceptual Design of MicroBooNE TPC



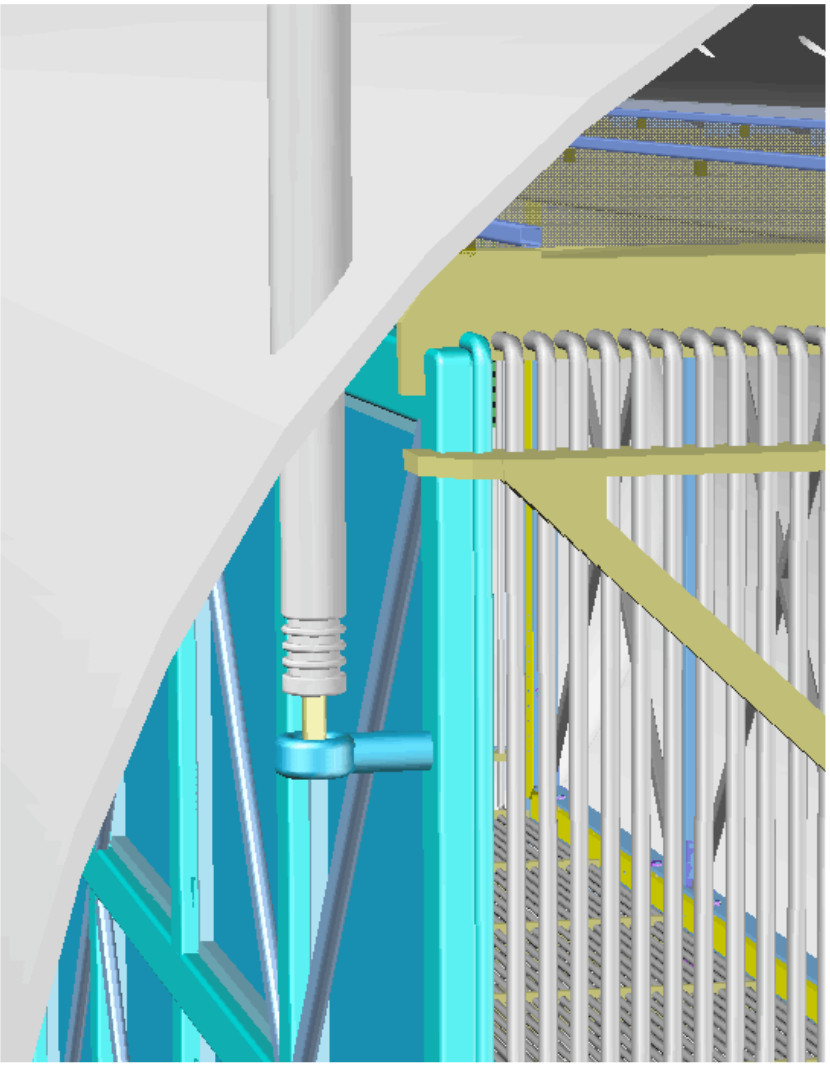
TPC Cathode Plane

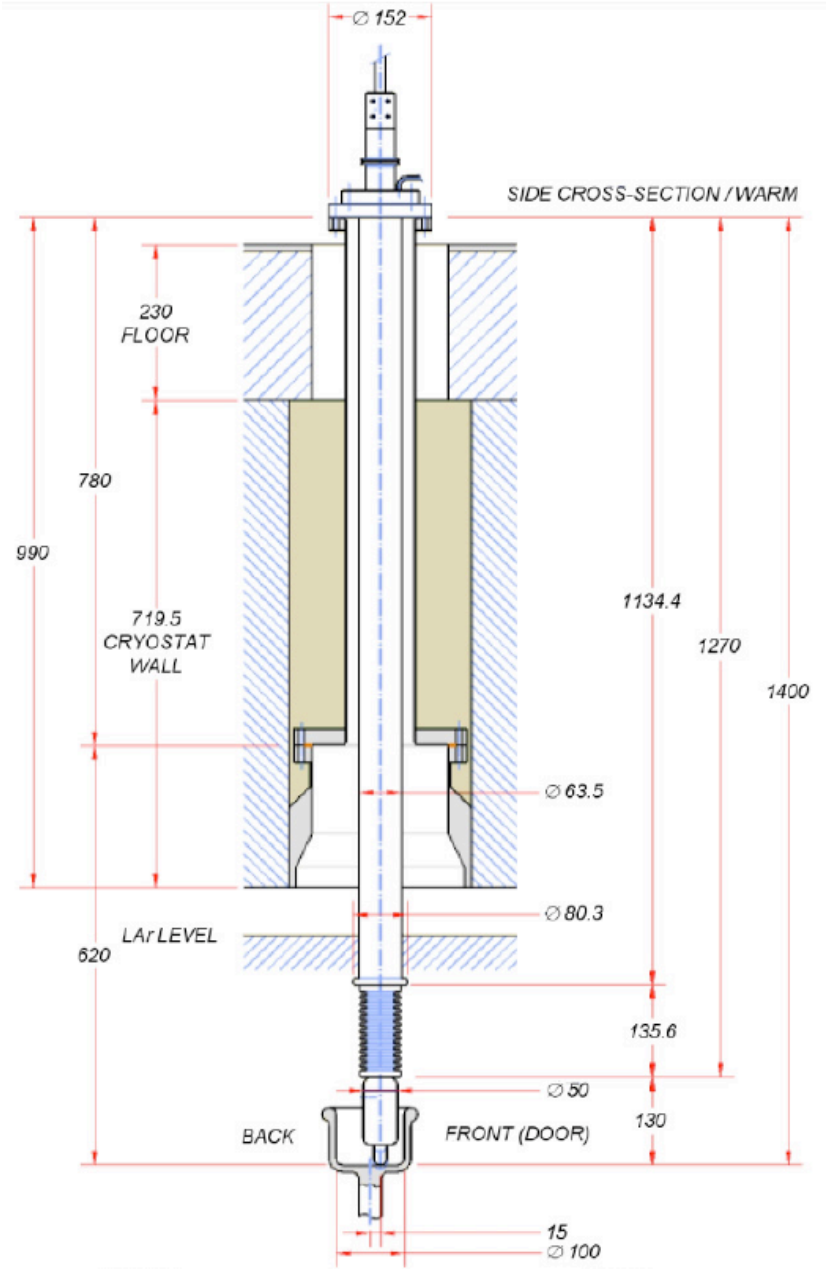


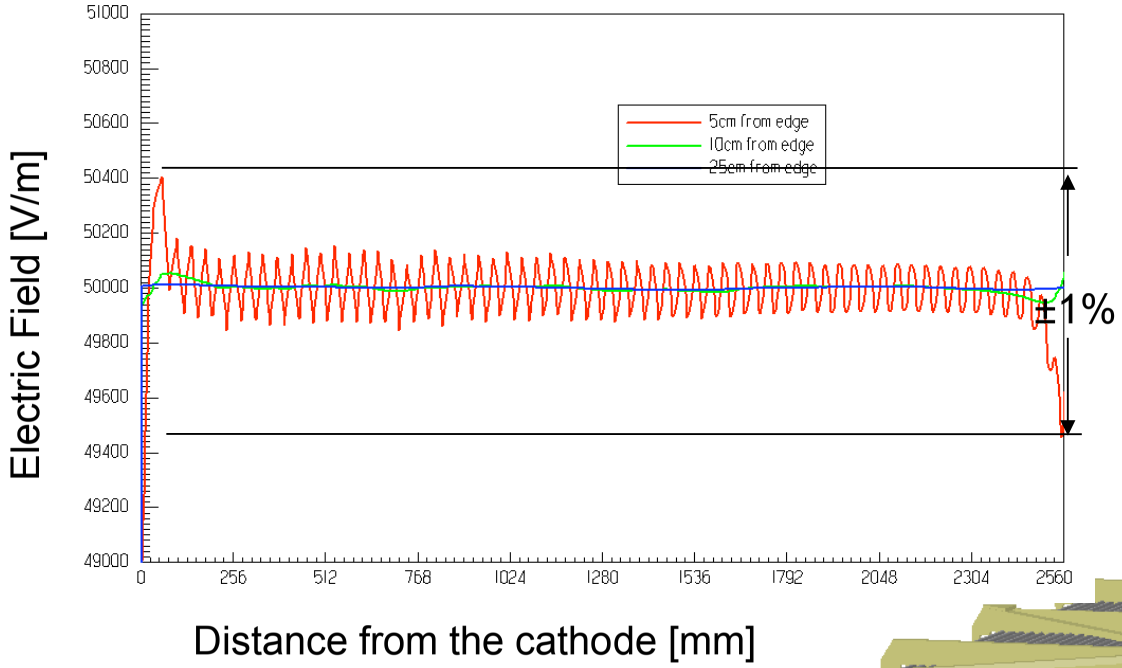


20 (~4'x4') adjustable panels form the cathode surface

HV Feedthrough design similar to the ICARUS design



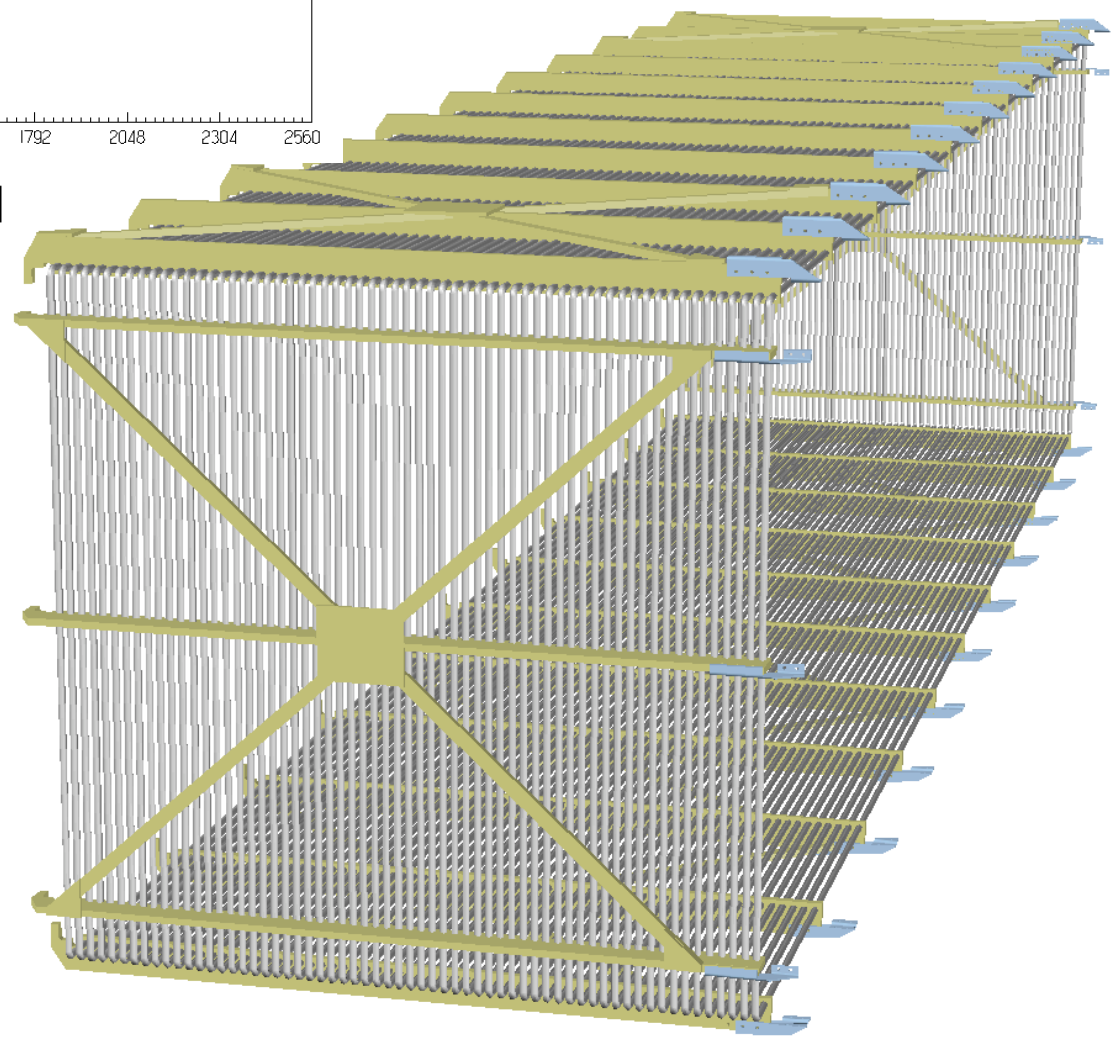




Field cage tubing steps voltage down from -128k

Field is nearly uniform out to 5cm from tubing

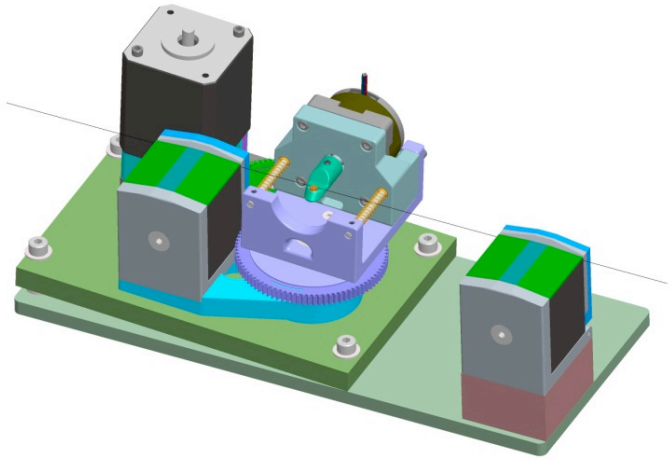
"NanoBooNE" mechanical prototype constructed

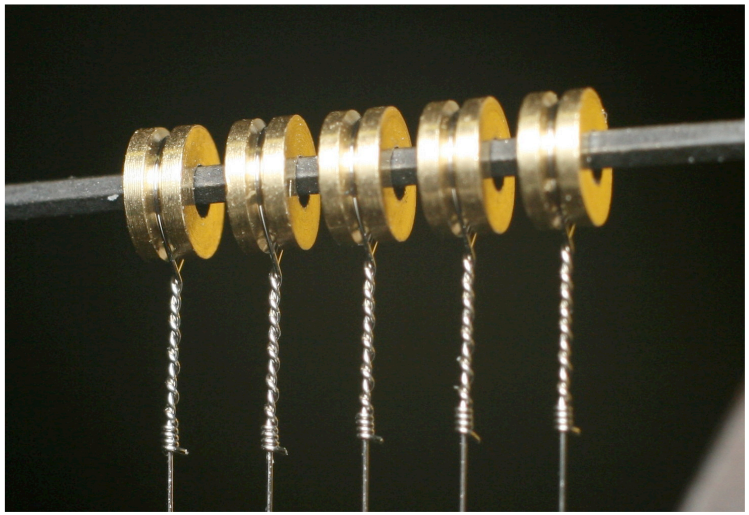


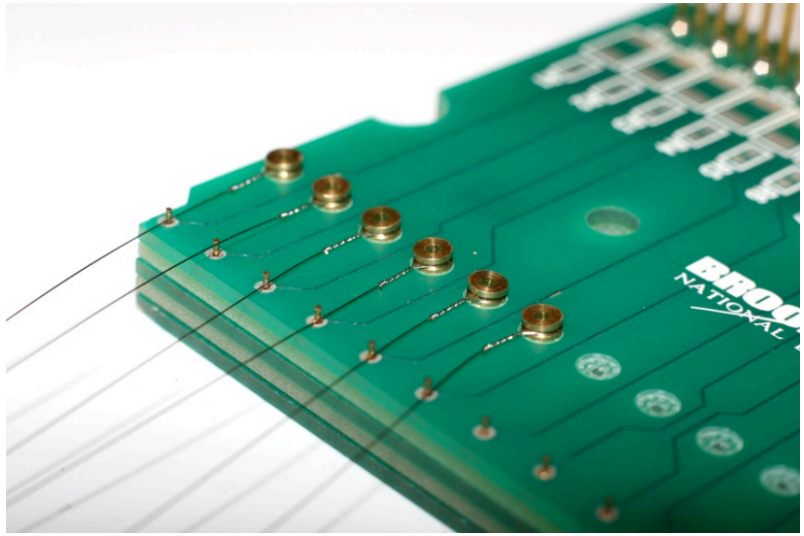
Three wire planes (U,V,Y) readout ionization electrons

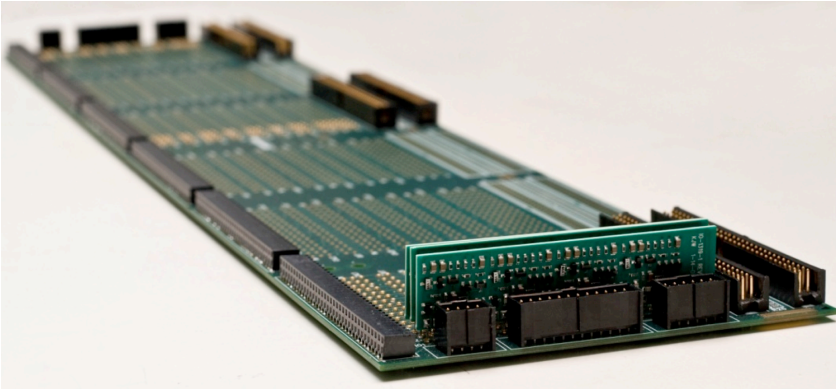
- 3mm wire pitch
- Y: vertical, U,V: +/- 60 degrees to Y
- Nominal wire length: Y: 2.5m, U,V: 5m
- 3456 Y wires, 2400 each U,V wires
- Wire material is stainless steel coated with copper and a gold flash: high breakload, low resistance.
- Wire attachment via ferrule attached to wire carrier boards
- Fully automated wire winding machine

Rotating head of the winding machine

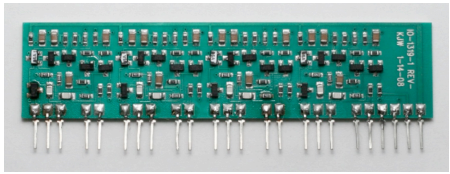




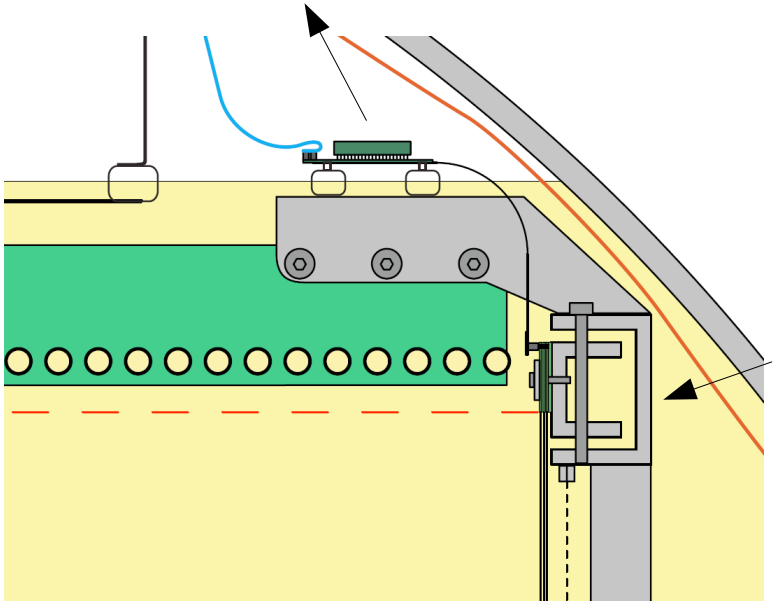


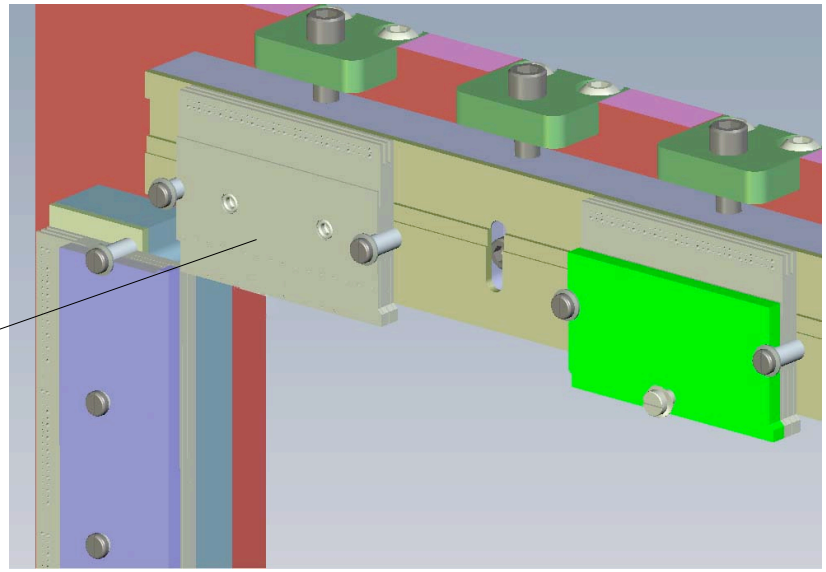


Wire carriers are mounted to wire frame and route cables to the on-detector electronics in the gas ullage at the top of the detector

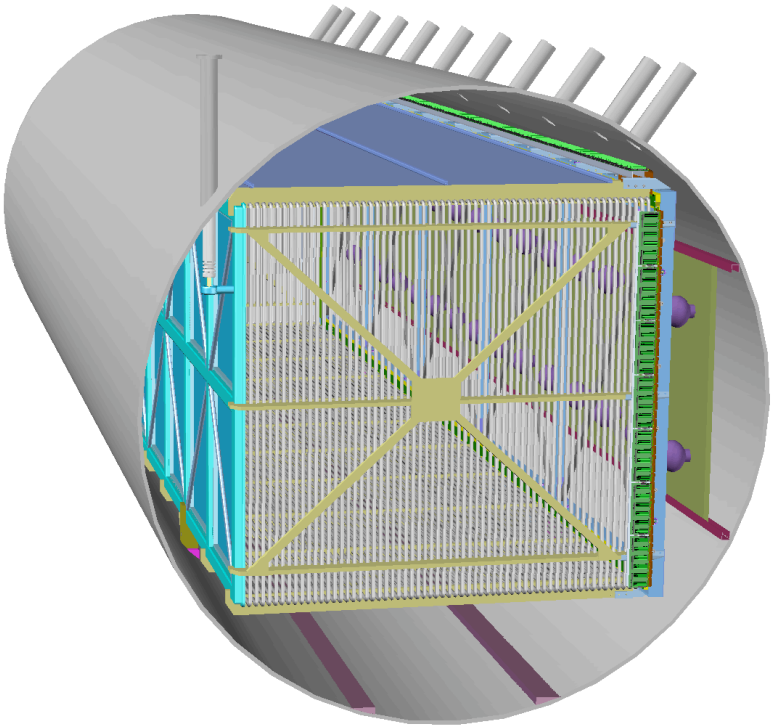


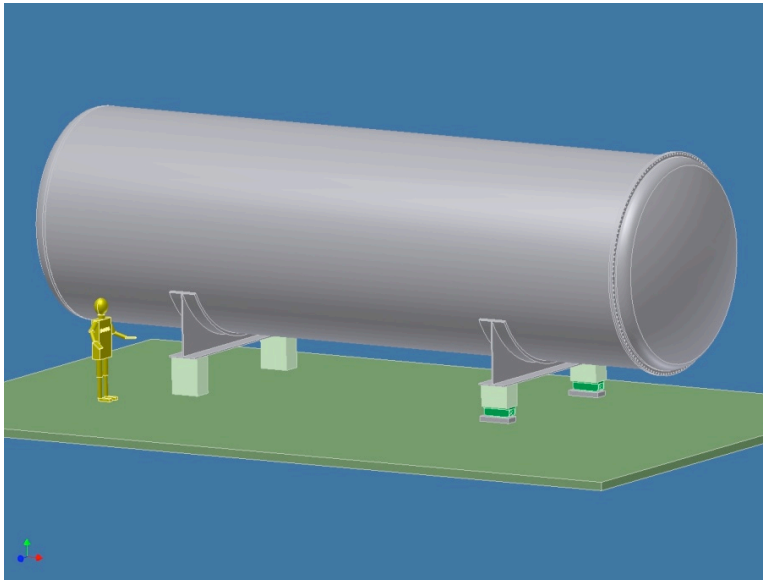
Prototype amplifiers and motherboards

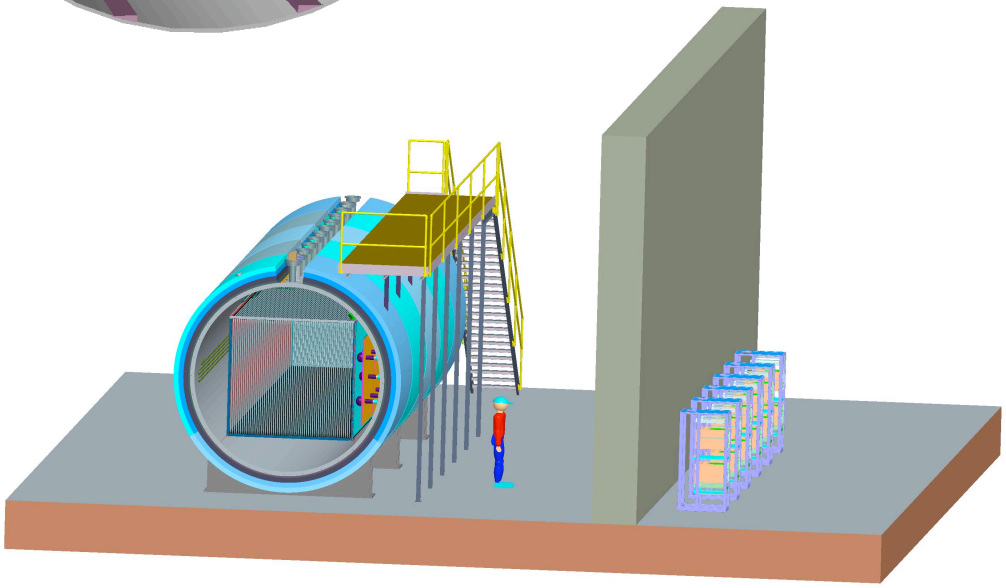




TPC and PMT array is housed in a Stainless steel cryostat covered with foam insulation

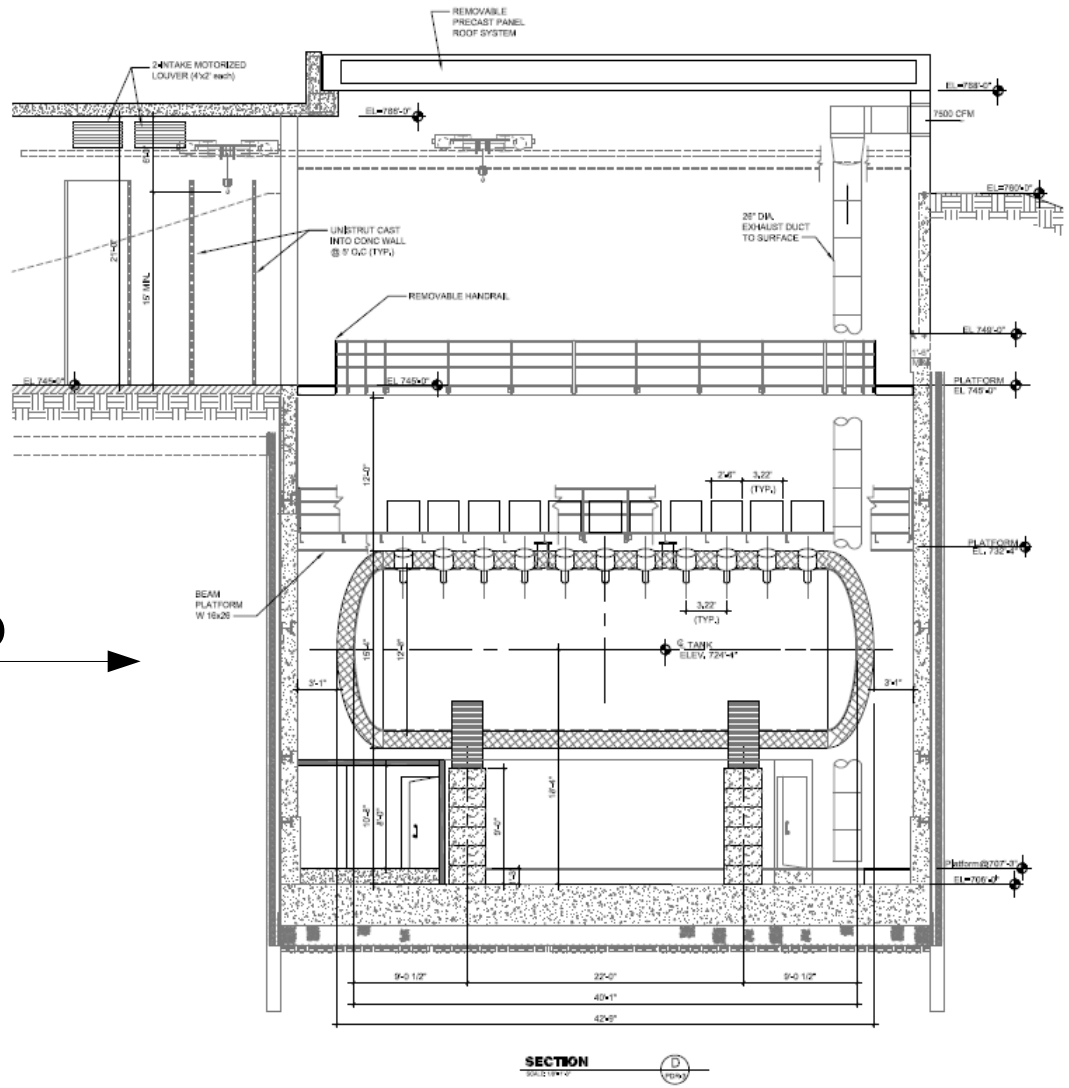






Detector will be located in the MiniBooNE detector enclosure, on beam axis of the Booster Neutrino Beam, 500m from the neutrino production target

Neutrino Beam



Summary
Integrated Plan towards development of LBNE scale detectors

MicroBooNE is in the design and construction phase with first beam expected in early 2013

Final goal: 20kton modules of LArTPC detectors for the LBNE program: