The Long-Baseline Neutrino Experiment and the CAPTAIN program

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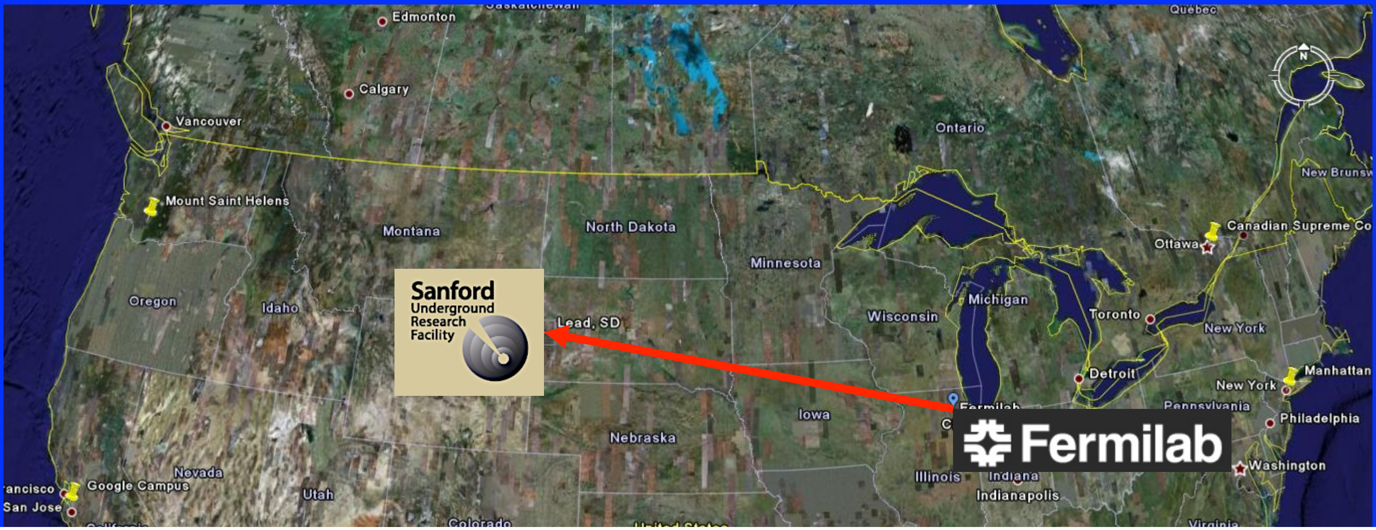
Outline

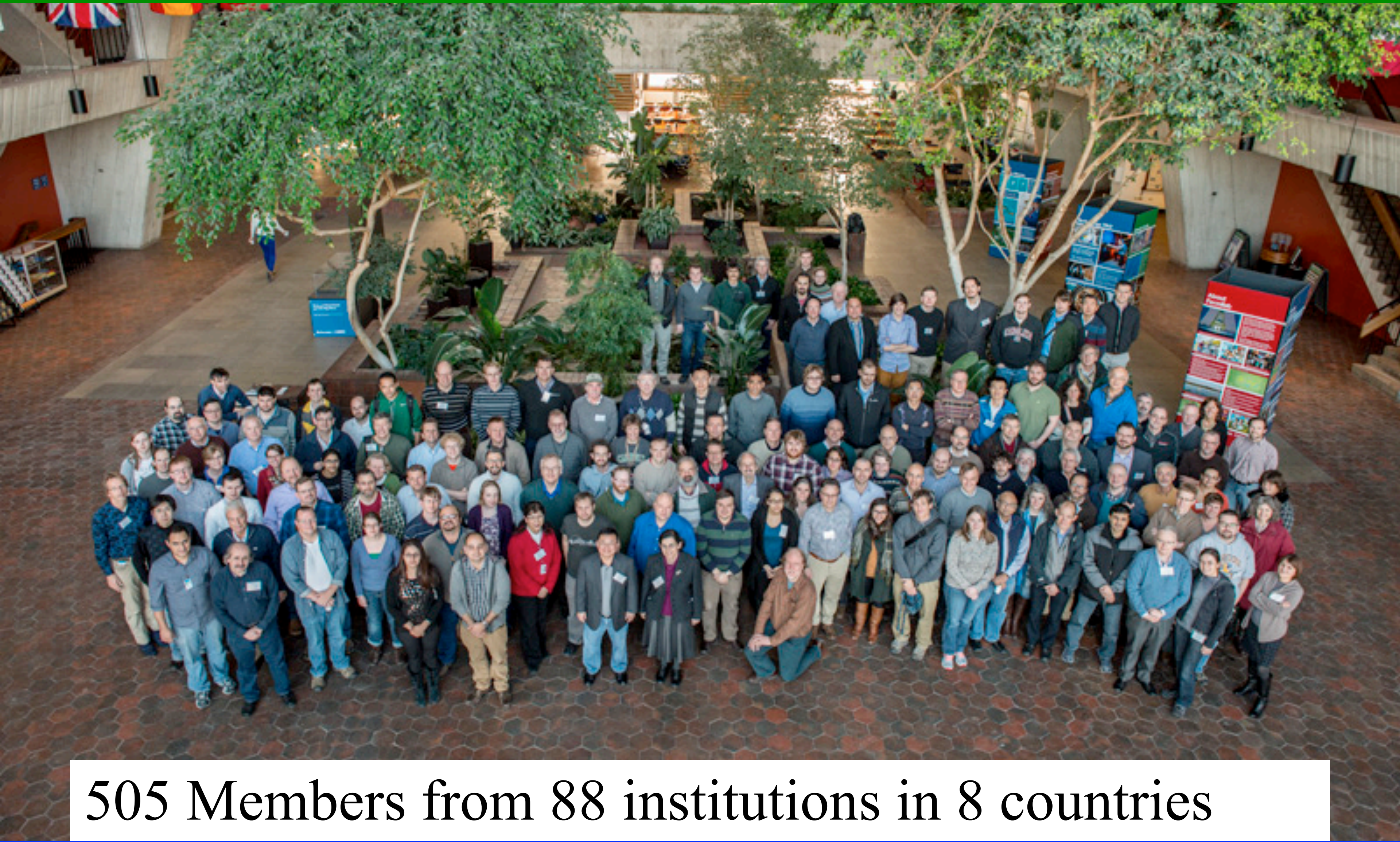
- The Long-Baseline Neutrino Experiment
  - Layout of LBNE
  - Neutrino Oscillation Studies with Beam Neutrinos
  - Underground Physics
  - Physics with the Near Neutrino Detector
  - Physics Challenges
- The CAPTAIN Program
  - Detector
  - Neutron Running
  - Neutrino Running
- Conclusions

The Long-Baseline Neutrino Experiment



- LBNE consists of
  - an intense neutrino beam at Fermilab
  - near detector systems at Fermilab
  - a 34 kt liquid argon time-projection chamber (TPC) at Sanford Laboratory at 4850 foot depth – 1300 km from Fermilab
- When constructed, LBNE will have the longest manmade baseline of any neutrino experiment

LBNE Collaboration



505 Members from 88 institutions in 8 countries

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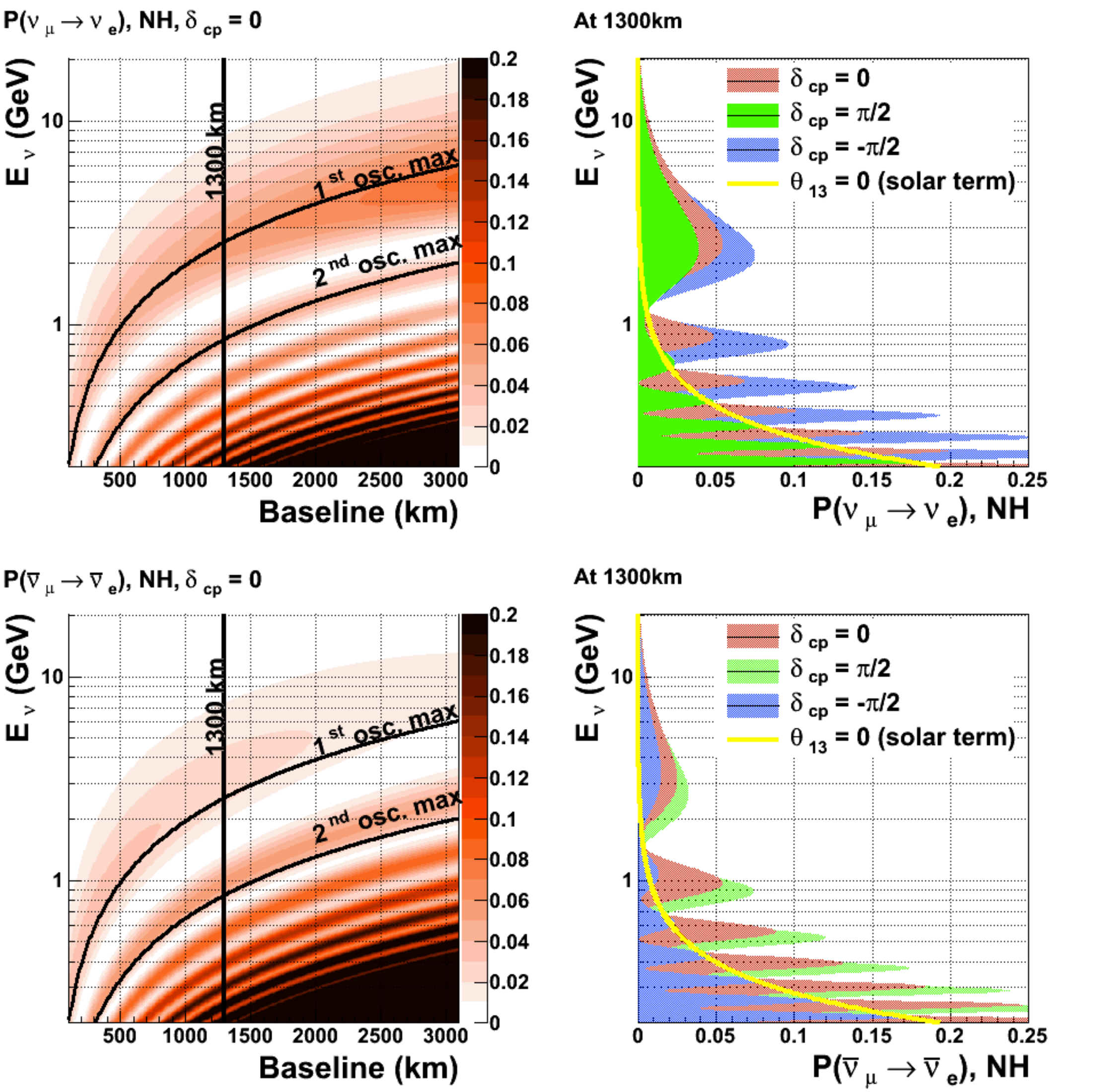
Scientific Motivation

- Neutrino oscillations require physics beyond the standard model
- Detailed studies of neutrino oscillations will allow us to answer important scientific questions:
  - What is the neutrino mass hierarchy?
  - Do neutrinos violate CP symmetry?
- High precision studies of neutrino oscillation phenomena allow us to test the three-flavor paradigm
  - Do sterile neutrinos exist?
  - Are there non-standard interactions (NSI)
- Building an experiment to address these issues with accelerator neutrinos enables much more science

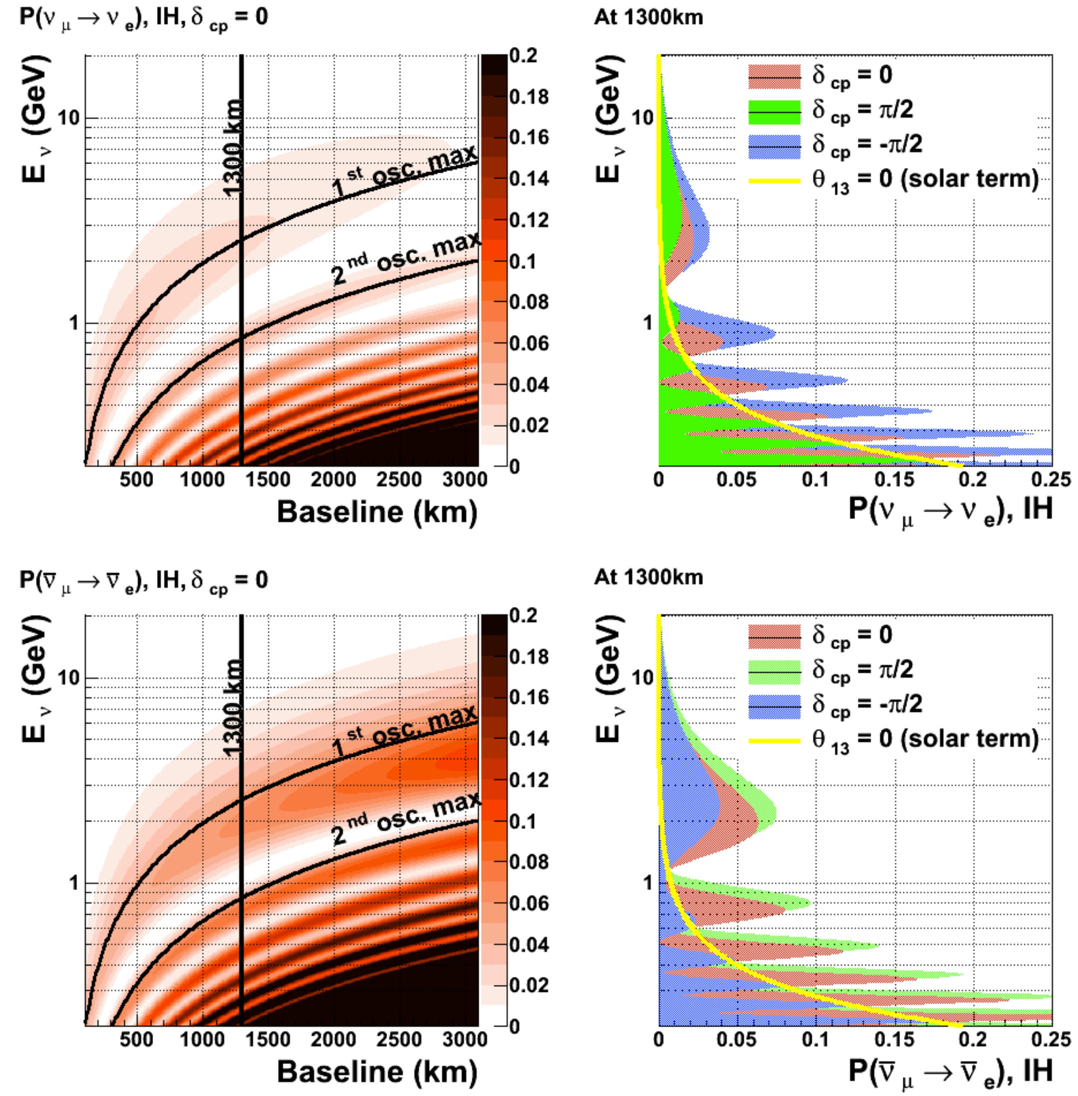
Appearance Oscillograms (Normal Hierarchy)

- Left plots: Neutrino oscillations vs energy and baseline for neutrinos (top) and antineutrinos (bottom) for $\delta_{CP} = 0$
- Right: Neutrino oscillations as a function of neutrino energy for different values of δ_{CP} for neutrinos (top) and antineutrinos (bottom) – solar term shown in yellow
- All plots assume Normal Hierarchy



Appearance Oscillograms (Inverted Hierarchy)

- Left plots: Neutrino oscillations vs energy and baseline for neutrinos (top) and antineutrinos (bottom) for $\delta_{CP} = 0$
- Right: Neutrino oscillations as a function of neutrino energy for different values of δ_{CP} for neutrinos (top) and antineutrinos (bottom) – solar term shown in yellow
- All plots assume Inverted Hierarchy



Scientific Motivation

- Physics enabled by intense neutrino source and high-precision near neutrino detector
  - Precision electroweak tests
  - Searches for high Δm^2 neutrino oscillation physics
  - Searches for ``dark photons''
- Physics enabled by a large, underground far detector
  - Atmospheric neutrino studies
    - complementary oscillation physics studies
    - indirect WIMP searches
    - astrophysical neutrino searches
  - Burst supernova neutrino studies
    - complementary oscillation physics studies
    - supernova physics
  - Baryon number violation
    - SUSY, Grand Unified Theories
- And many others, see arXiv:1307.7335 – LBNE Science Opportunities Document

LBNE Reconfiguration

Complete Design Independently Reviewed and Found to be Sound

Issued April 23, 2012

Fermilab

Final Rep

Director's Independe Design and CD-1 Rea of the LBNE I

March 26-30,

Director's Independent Conceptual Design and CD-1 Readi
March 26-30, 2012

Issued April 23, 2012

Executive Summary

This Director's review was designed to elicit the assembled committee's opinion on two primary questions. The first focus of the review was to perform an independent Conceptual Design review of the LBNE project to verify that the design is technically adequate, and should achieve the Project's scientific goals. The second focus was to perform a CD-1 Readiness review, with a focus on the project's cost, schedule, management, and ES&H.

The committee finds that the Conceptual Design for the LBNE project is sound, and should achieve the Project's scientific goals. Our determination is that the level of technical detail across the entire breadth of the LBNE project is sufficient to address the question of overall capability to achieve the scientific goals, as appropriate for this stage of the project. There are a number of components of the project that have advanced well beyond the conceptual stage.

The committee is confident that the LBNE project can be ready for a CD-1 review on the time scale given to the committee, the summer of 2012, if issues related to the funding profile and the resulting schedule are resolved. The management systems and documentation for the project are appropriate for a CD-1 review.

However …

- In 2012, US funding agency (DOE) asked us to stage LBNE construction and gave us a budget of $867M for the first phase
  - They also encouraged us to develop new partnerships to maximize the scope of the first stage.
- We chose to proceed with emphasis on the most important aspects of the experiment: 1300 km baseline and the full capability beam
  - With just the DOE budget, the far detector would be 10 kt LAr TPC at the surface and there would be no near neutrino measurements.
- An external review panel recommended this phase 1 configuration.
- DOE approved “CD-1” in December 2012 for this phase-1 scope.
- *Our plan continues to be to build the full scope originally planned, and are working with domestic and international partners to make the first phase as close as possible to the original goal.*
- *The P5 report concurs with the vision of a fully capable LBNE.*

DOE CD-1 Approval Document

lbne-doc-6681

Critical Decision 1
Approve Alternative Selection and Cost Range
of the
Long Baseline Neutrino Experiment (LBNE) Project
(Line Item Project 11-SC-40)
at the
Fermi National Accelerator Laboratory and
Sanford Underground Research Facility
Office of High Energy Physics
Office of Science

Purpose

The purpose of this paper is to document the review and approval by the DOE Office of Science Energy Systems Acquisition Advisory Board-equivalent for Critical Decision 1 (CD-1) "Approve Alternative Selection and Cost Range" for the Long Baseline Neutrino Experiment (LBNE) Project at the Fermi National Accelerator Laboratory (Fermilab) and Homestake Mine

Critical Decision 1, Approve Alternative Selection and Cost Range for the LBNE Project

Approval

Based on the information presente din this document and at the ESAAB review, I approve Critical Decision 1, Approve Alternative Selection and Cost Range for the Long Baseline Neutrino (LBNE) Project.

William Brinkman, Acquisition Executive
Director, Office of Science

12/10/12
Date

Tailoring of the scope definition prior to CD-2 to enhance scientific capabilities may also be considered. The physics opportunities offered by the beam from Fermilab and the long baseline may attract the support of other agencies both domestic and international. Contributions from such other agencies offer alternative funding scenarios that could enhance the science capabilities of the Project. If additional domestic or international funding commitments are secured sufficiently prior to CD-2, the DOE LBNE Project baseline scope could be refined before CD-2 to include scope opportunities such as a Near Neutrino Detector complex at Fermilab or an underground location at SURF for the far detector.

the neutrino mass states, would not be obtained, compromising the ability to understand the matter-antimatter asymmetry and resulting dominance of matter in the universe.

To meet the scientific and technical objectives for the LBNE experiment, the following draft key performance parameters have been developed.

http://lbne2-docdb.fnal.gov/cgi-bin/RetrieveFile?docid=6681;filename=LBNE%20CD-1%20appr.pdf

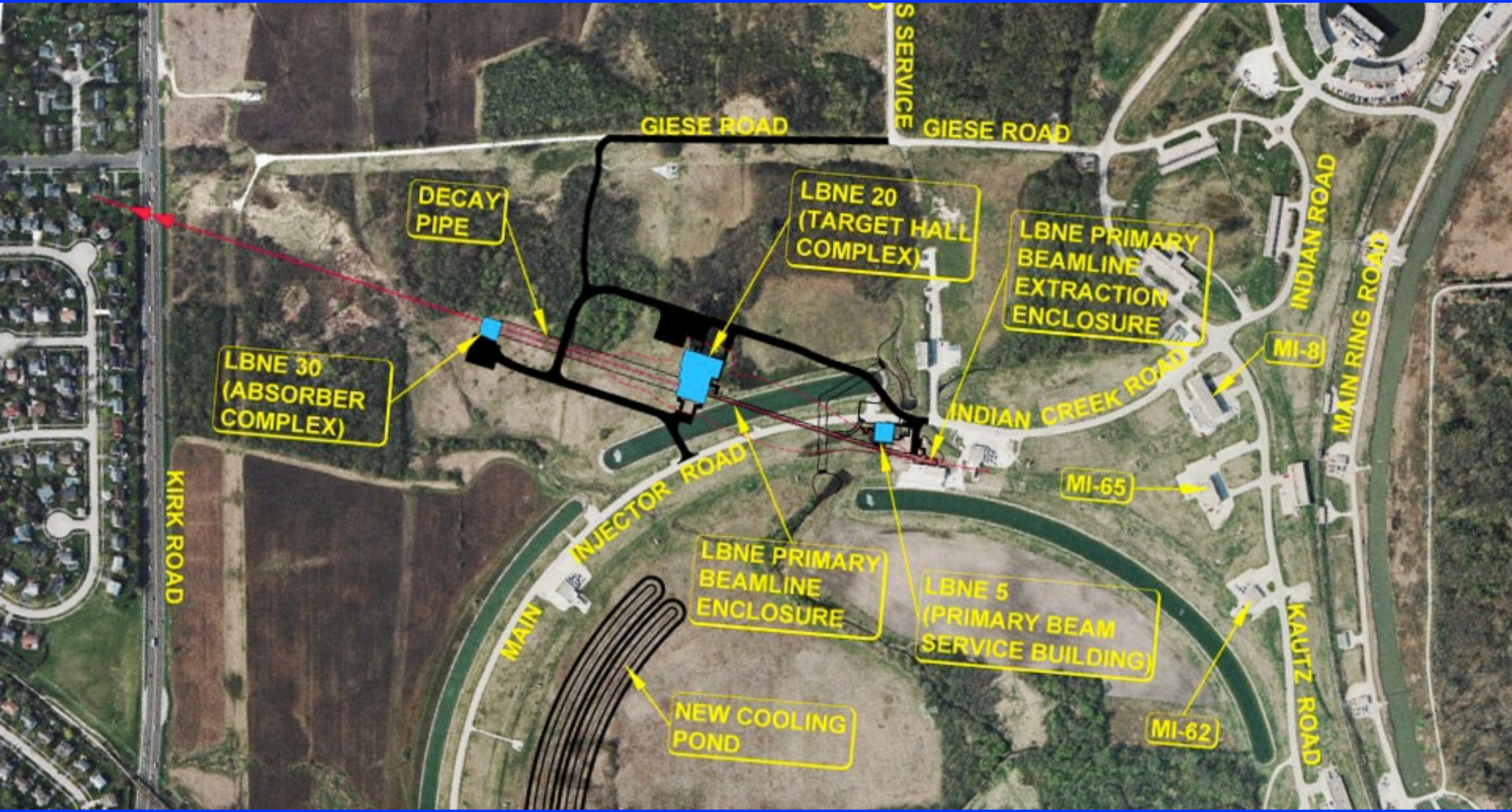
LBNE Phase I Goal

- Together with additional partners, build:
  - Neutrino beam for 700 kW, upgradeable to 2.3 MW
  - Highly-capable near neutrino detector
  - >10 kt fiducial mass LAr far detector at
    A baseline of 1300 km
    A depth of 4300 m.w.e.
- The world-wide community can build upon the substantial investment planned by the US to make LBNE a world facility for neutrino physics, astrophysics, and searches for non-conservation of baryon number.

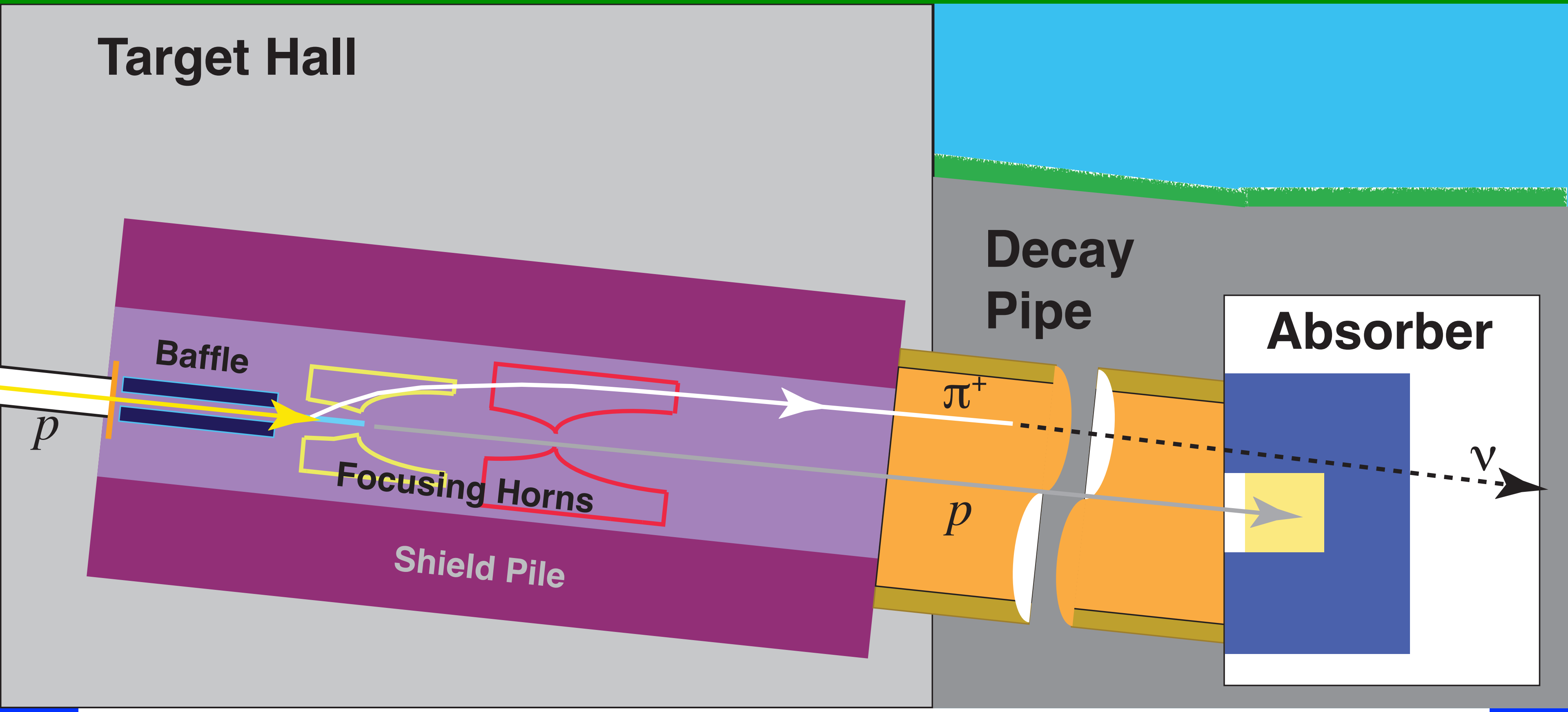
Engaging International Partners

- We are in discussion with a number of potential non-US partners, both physics groups and funding agencies, in:
  - Brazil
  - India
  - Italy
  - UK
- LBNE and LAGUNA-LBNO have established a working group to explore joining forces
- Italian ICARUS groups have joined LBNE
- We have initiated discussions with:
  - CERN
  - Dubna
- Engaging others potential partners:
  - Japan
  - China
  - Additional countries in the Americas, Asia and Europe
- Also engaging domestic US funding agencies beyond the DOE

Layout on the Fermilab site



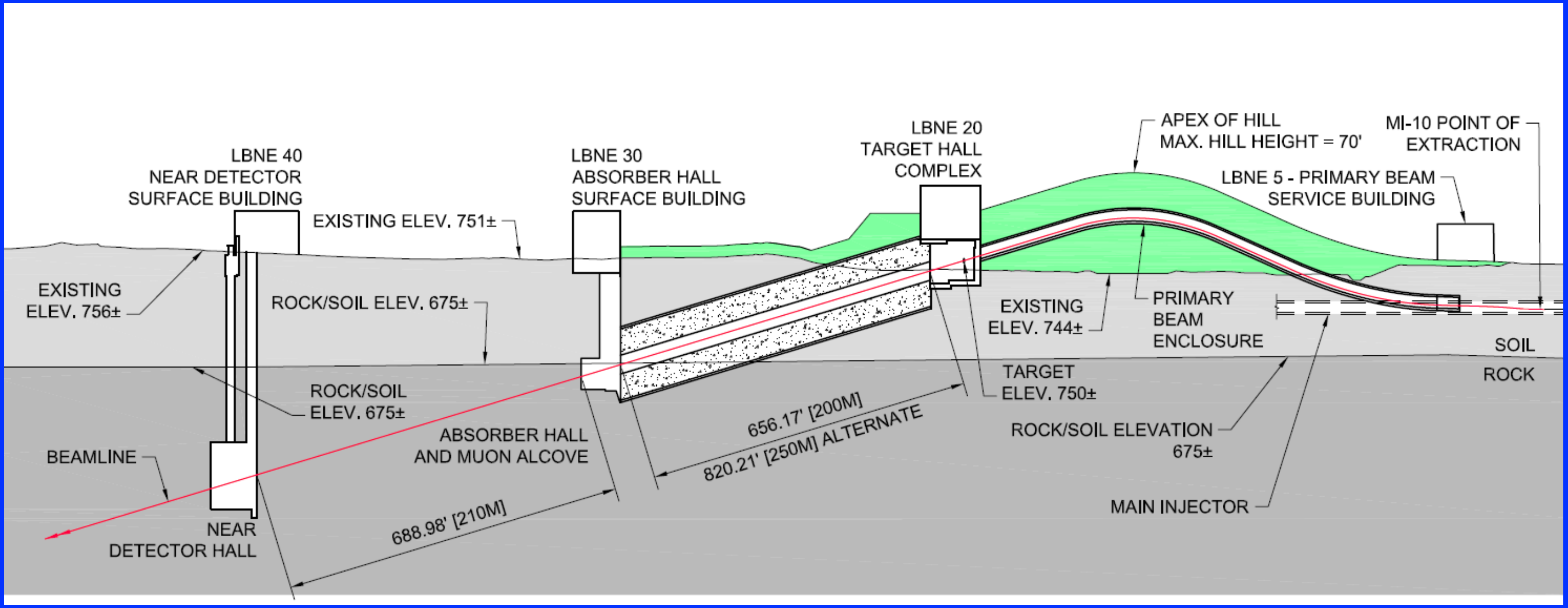
Layout of LBNE: Neutrino Beam



- Conventional neutrino beam from charged pion decay – beam power of 700 kW
- All permanent fixtures rated for 2.3 MW operation

Layout of LBNE: Near Detector Systems

Cross-section of NDS Layout



- Two sets of detector systems:
  - Measure muons after the absorber
  - Measure neutrinos
- NDS subproject led by LANL

Measurements of muons post-absorber

$\pi^+ \longrightarrow \mu^+ + \nu_\mu$

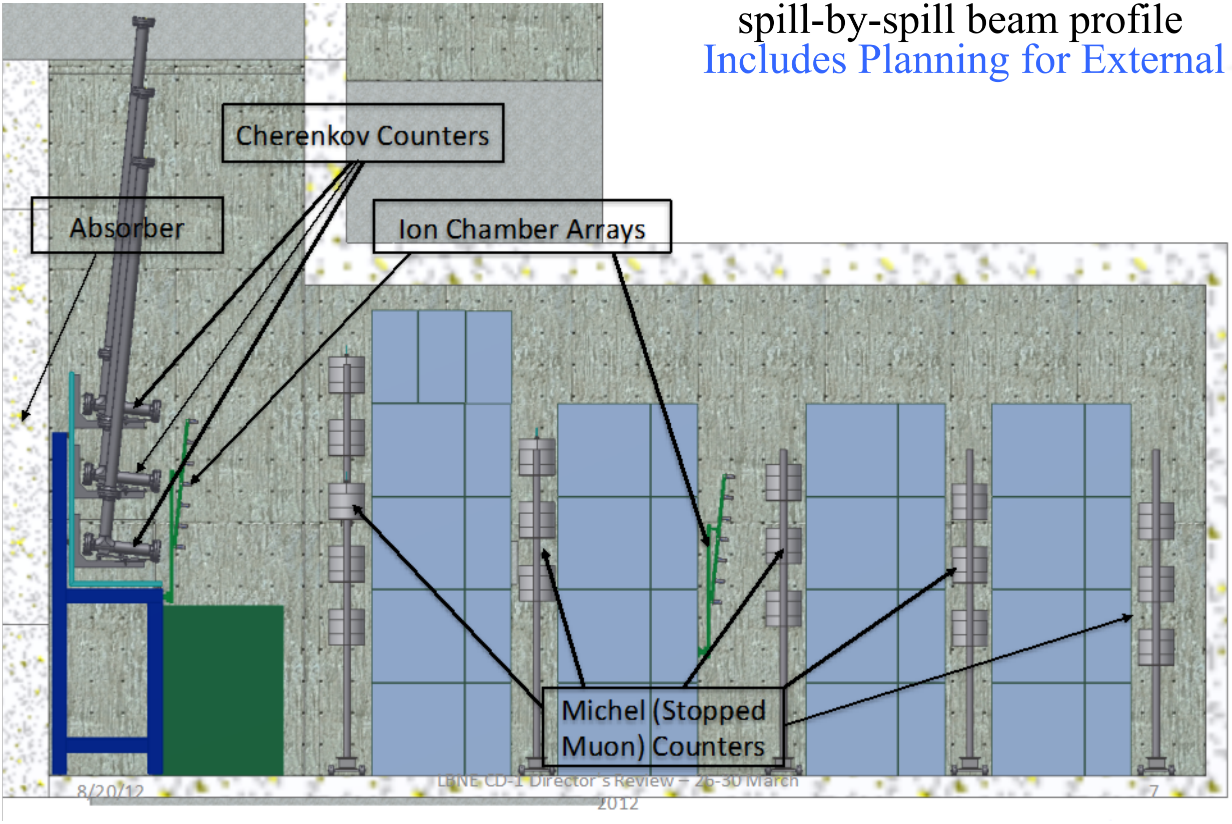
- $E_\nu = (0\text{-}0.43)E_\pi$
- $E_\mu = E_\pi - E_\nu = (0.57\text{-}1.0)E_\pi$

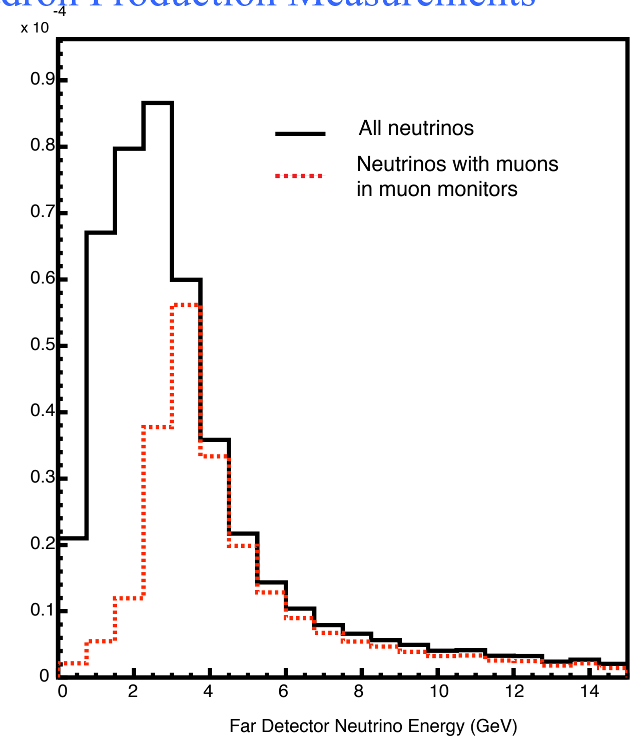
Cherenkov Detectors:
measure all muons above a variable threshold
constrains muon spectrum (correlated with E_ν)

Michel Decay Detectors:
measure muons that stop at a given depth in material
constrains muon spectrum

Ionization Chambers:
spill-by-spill beam profile

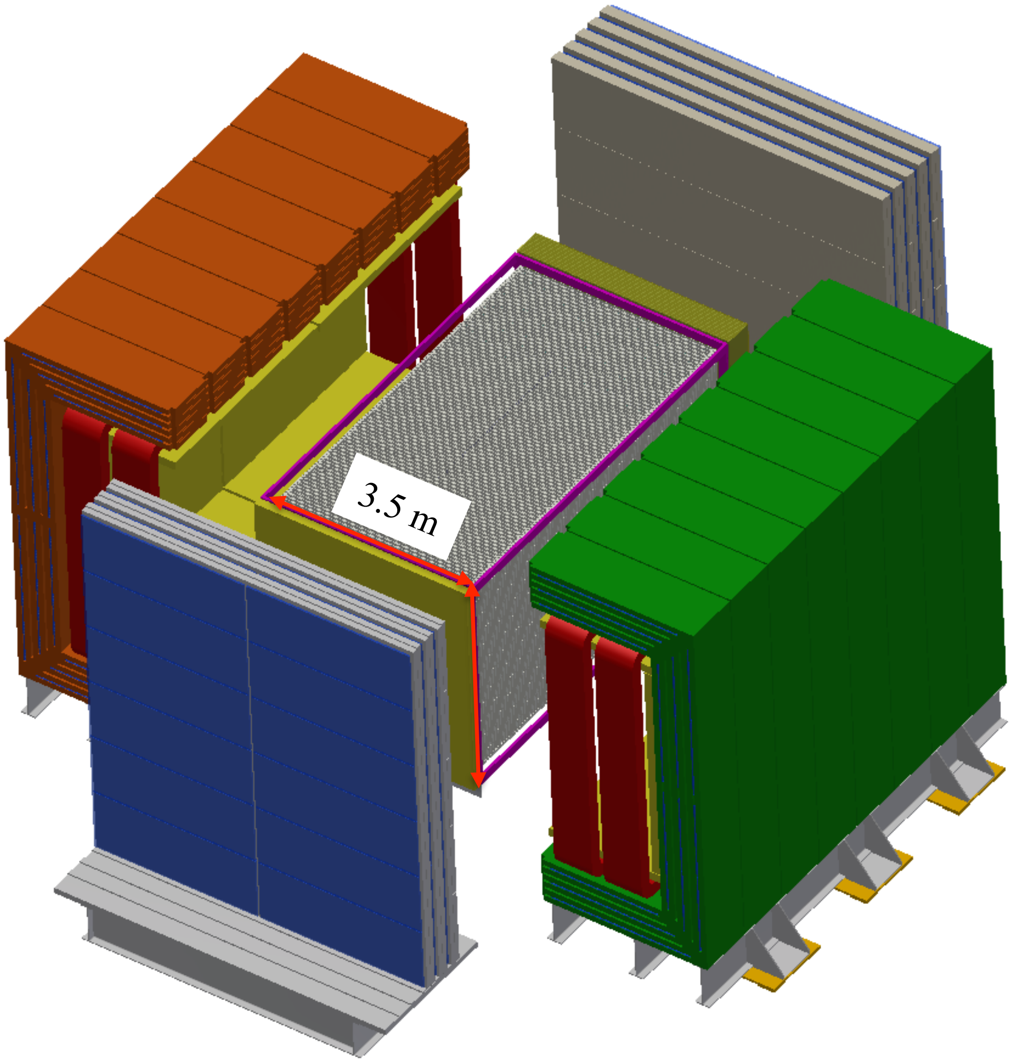
Includes Planning for External Hadron Production Measurements





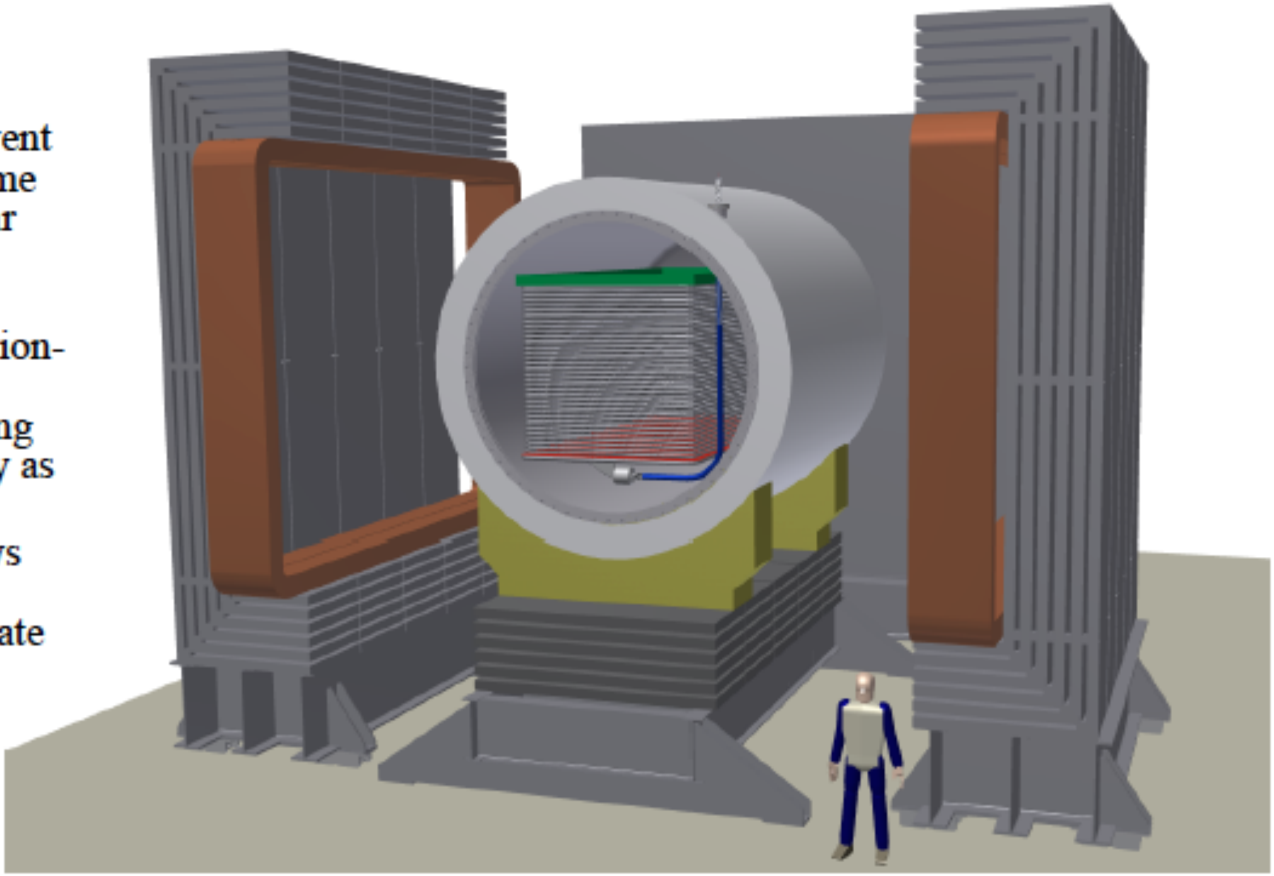
Near Neutrino Detector Reference Design

- High precision straw-tube tracker with embedded high-pressure argon gas targets
- 4π electromagnetic calorimeter and muon identification systems
- Large-aperture dipole magnet
- Philosophy
  - make high-precision, high-statistics measurements of neutrino interactions with argon (far detector nucleus)
  - measure inclusive and exclusive cross-sections to build and constrain models to predict the event signatures at the far site *and correlate them with the true neutrino energy*
  - make detailed studies of electron (and muon) neutrinos and anti-neutrinos separately



Alternate Design

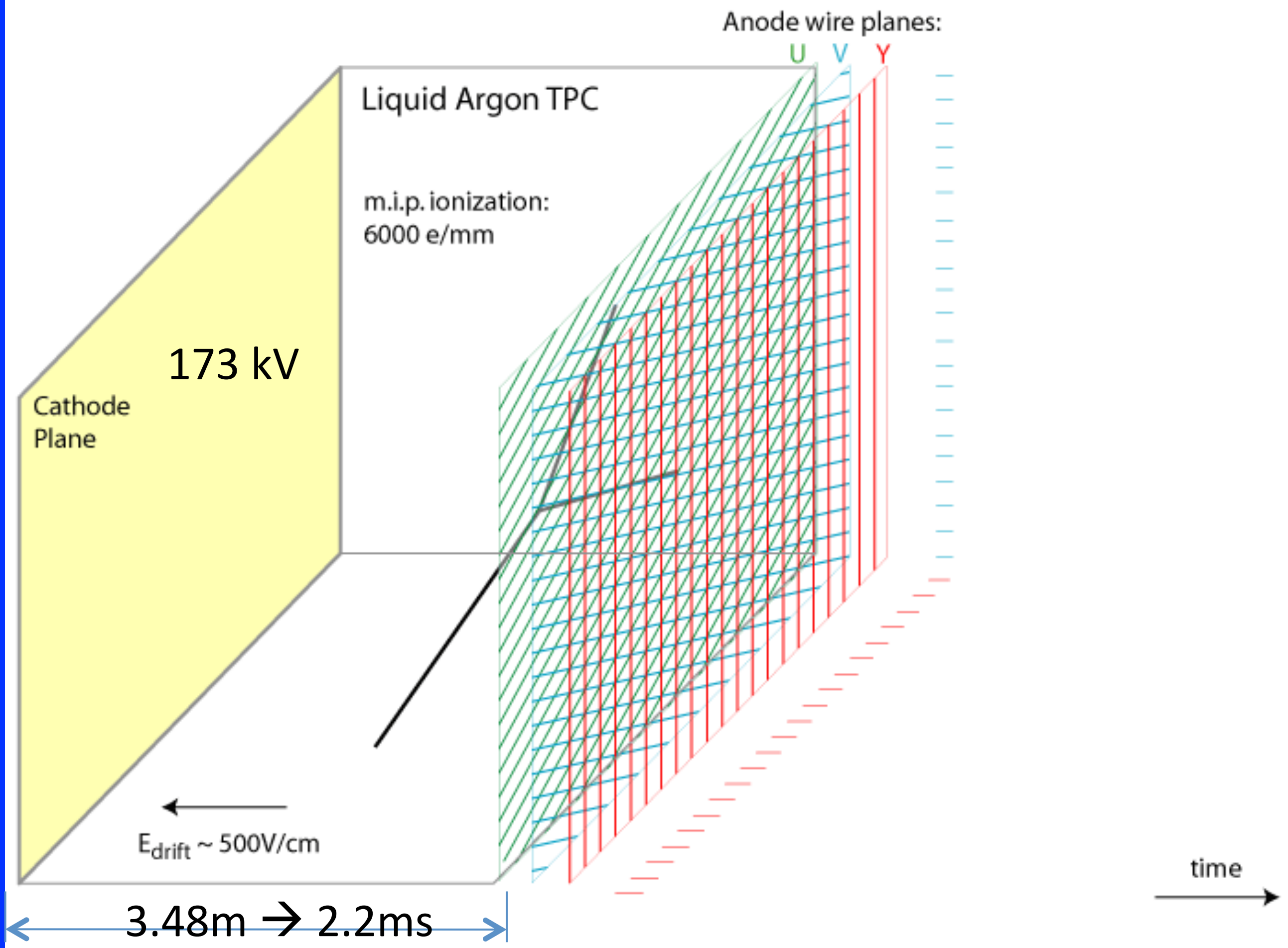
- Smaller (than the far detector) liquid argon TPC
- Philosophy
  - make high statistics measurements of event signatures in the same technology of the far site
  - try to minimize detector/reconstruction-related systematic uncertainties by using the same technology as the far site
  - magnetization allows for charged muon separation for separate neutrino and antineutrino studies



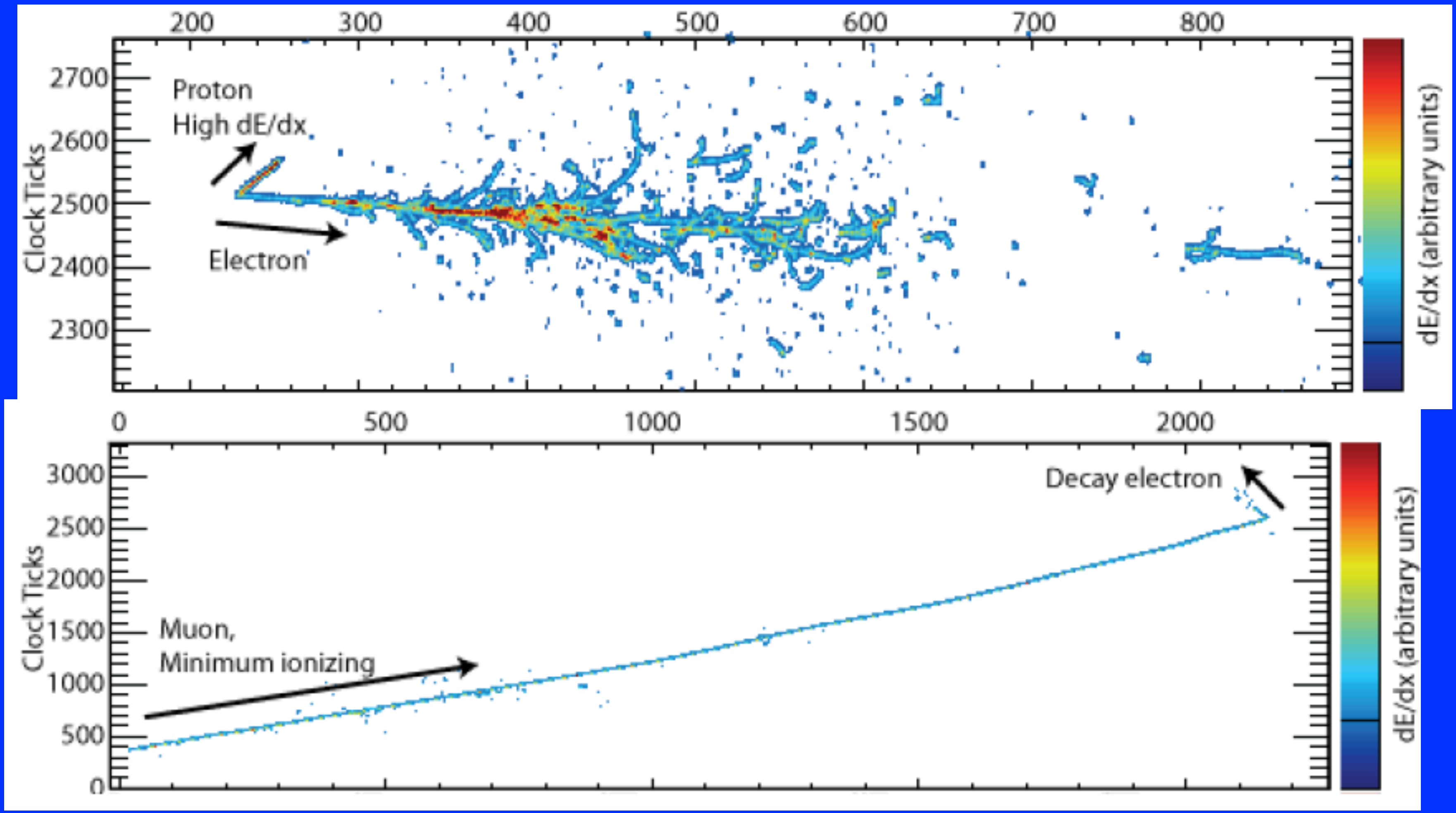
Layout of LBNE: Far Detector

Liquid Argon Time-Projection Chambers (TPCs)

MIP dE/dx = 2.2 MeV/cm
→ ~ 1fC/mm @ 500 V/cm
→ ~1 MeV/wire

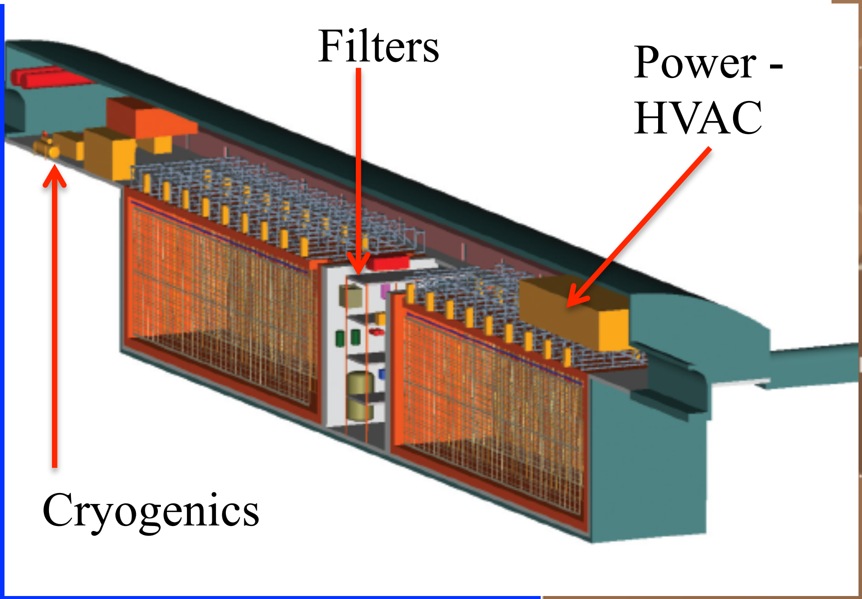


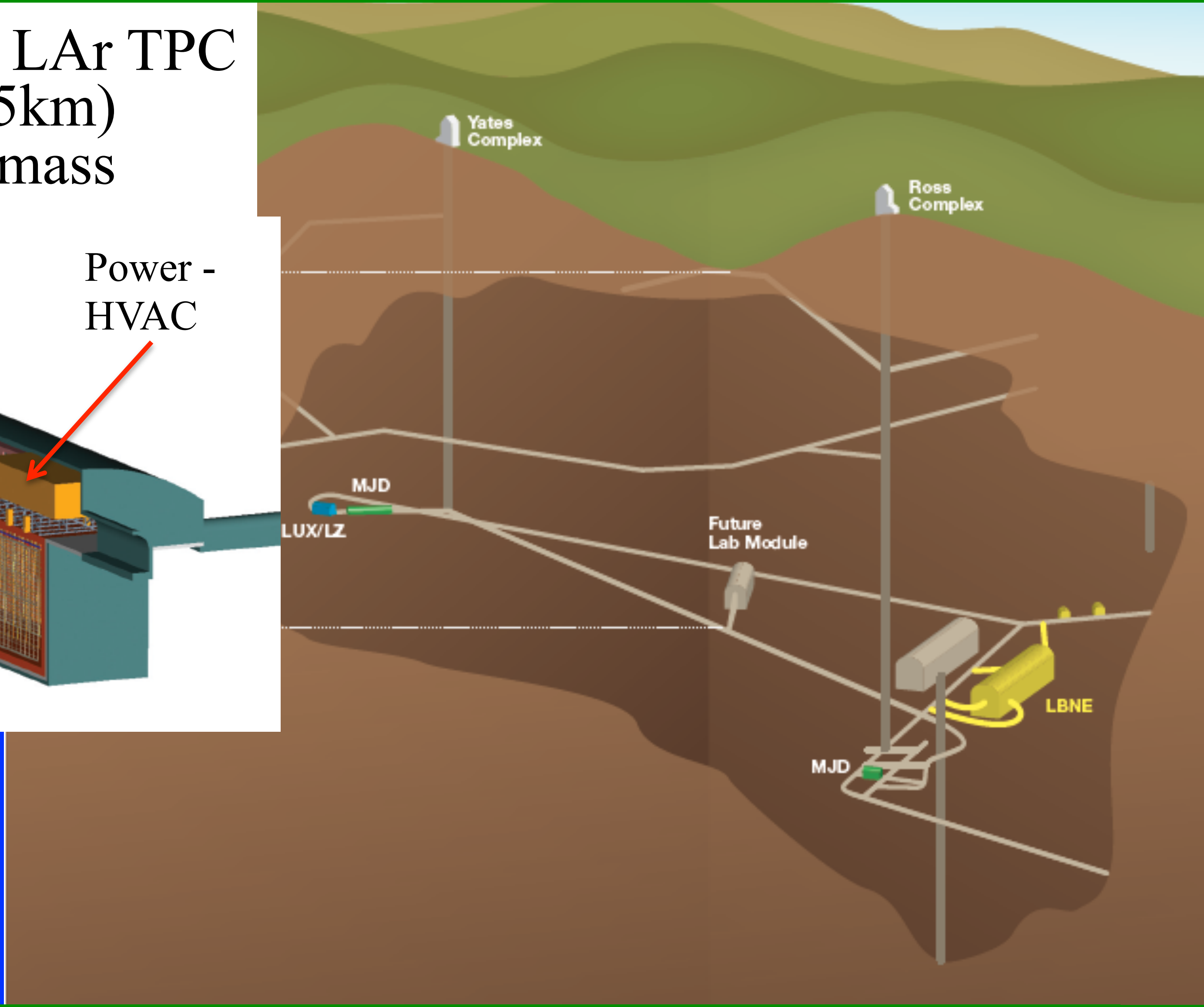
Liquid Argon TPC Performance



Far Detector Layout

34kt fiducial mass LAr TPC
at 4850'L (1.5km)
50kt total Ar mass





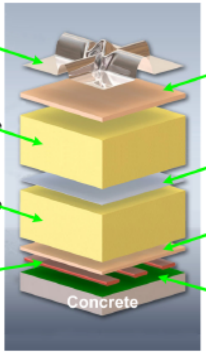
Cryostat Design

The LNGC "Tembek", one of the thirty-one 216,000 m³ LNG carriers ordered by Nakilat and delivered in 2008

LNG tanker with Membrane from GTT

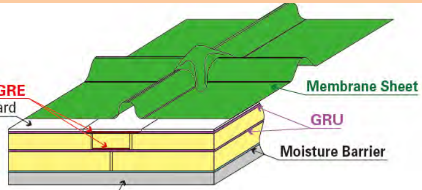
Vendors: Gaz Transport & Technigaz (GTT)
Ishikawajima-Harima Heavy Industries Co., Ltd. (IHI)

GTT Membrane Technology



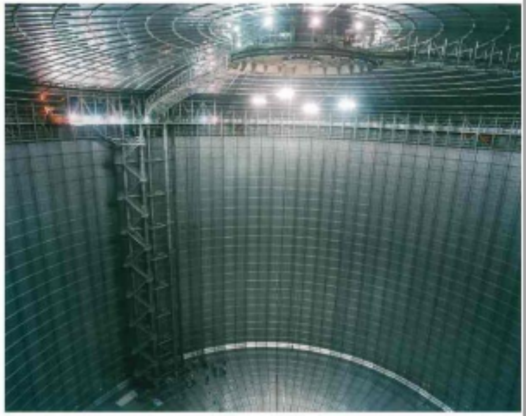
Nominal Panel Size
1m x 3m x 1.2 mm thickness

IHI Membrane Technology



GRE: Glass Cloth Reinforced Epoxy
GRU: Glass Cloth Reinforced urethane

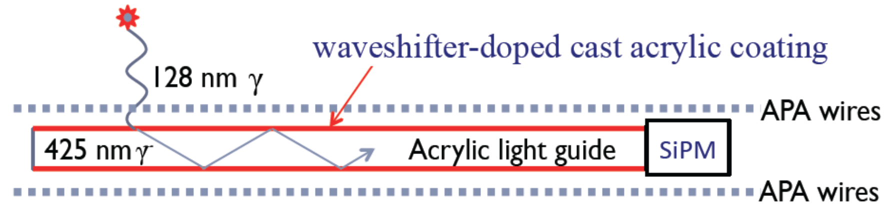
Nominal Panel Size
3m x 8m x 2 mm thickness



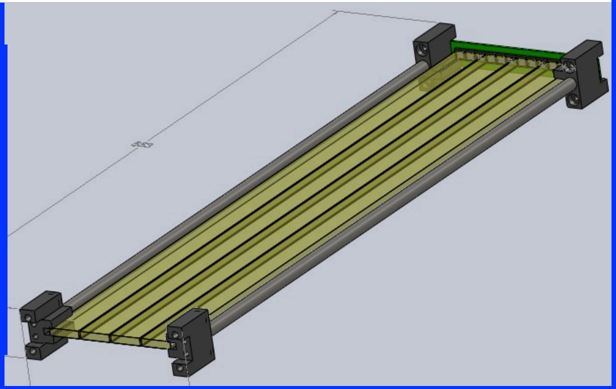
LNG Storage with Membrane from IHI

Photon Detection

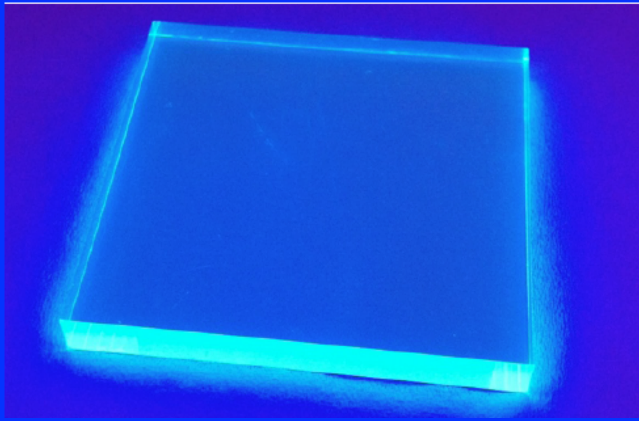
- The 2.2 ms drift time of the electrons is very slow.
  - The beam spill is 10 μs long – gives t0
  - For non-beam related physics the interaction time is unknown. Use the light to determine the event time.
- A lot of light, but complicated structure
  - Scintillation and Cherenkov radiation – 5 times more scintillation light
    - 23% of the scintillation light is prompt (~6ns)
    - 77% of the light is late (~1.6 μsec)
  - Scattering length is ~95 cm
  - Present coverage is 0.4%



Reference Design – wave-length shifter on surface

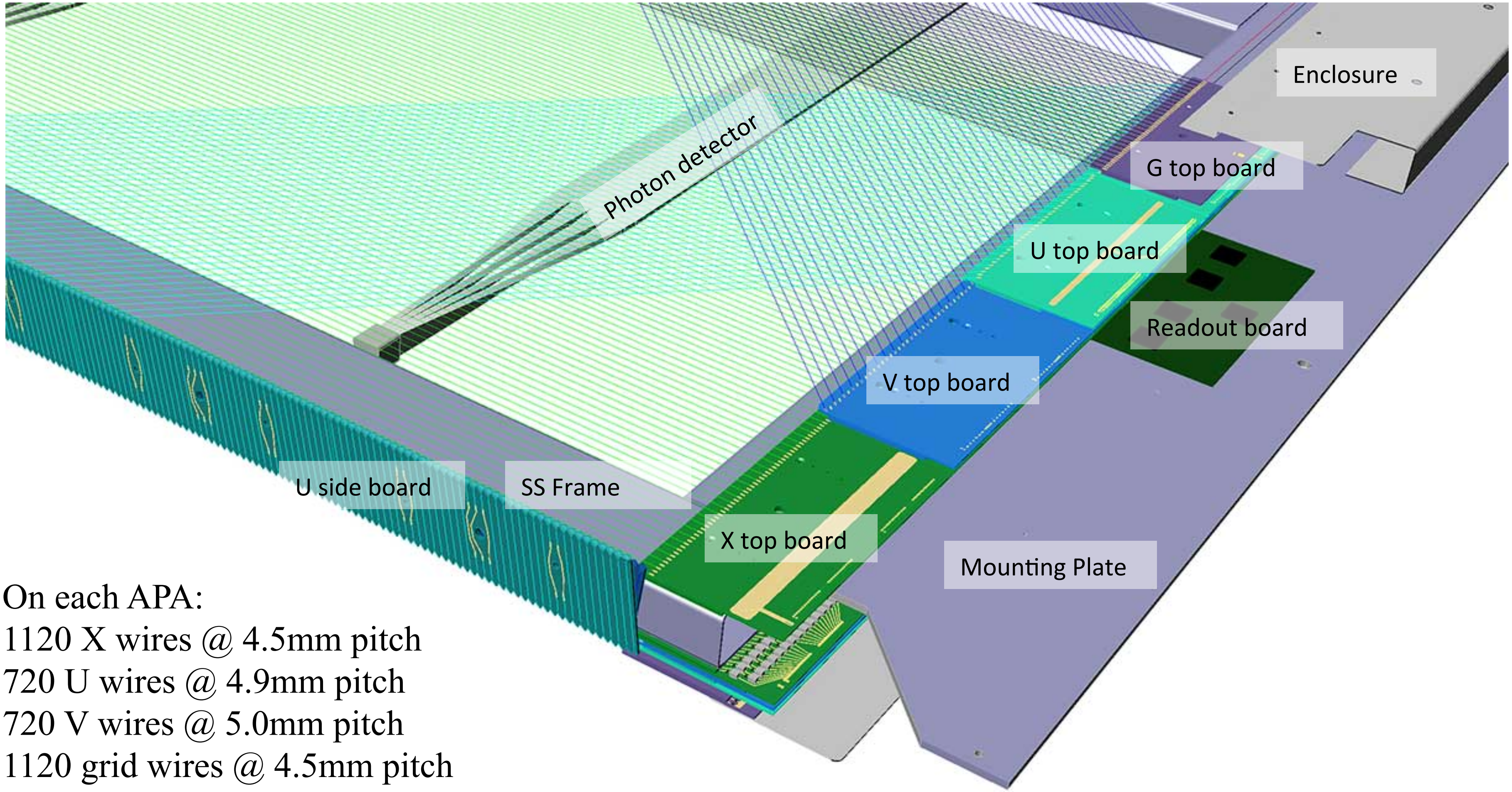


Alternate Design – doping of the bulk



Photon Detection System is critical for low energy events

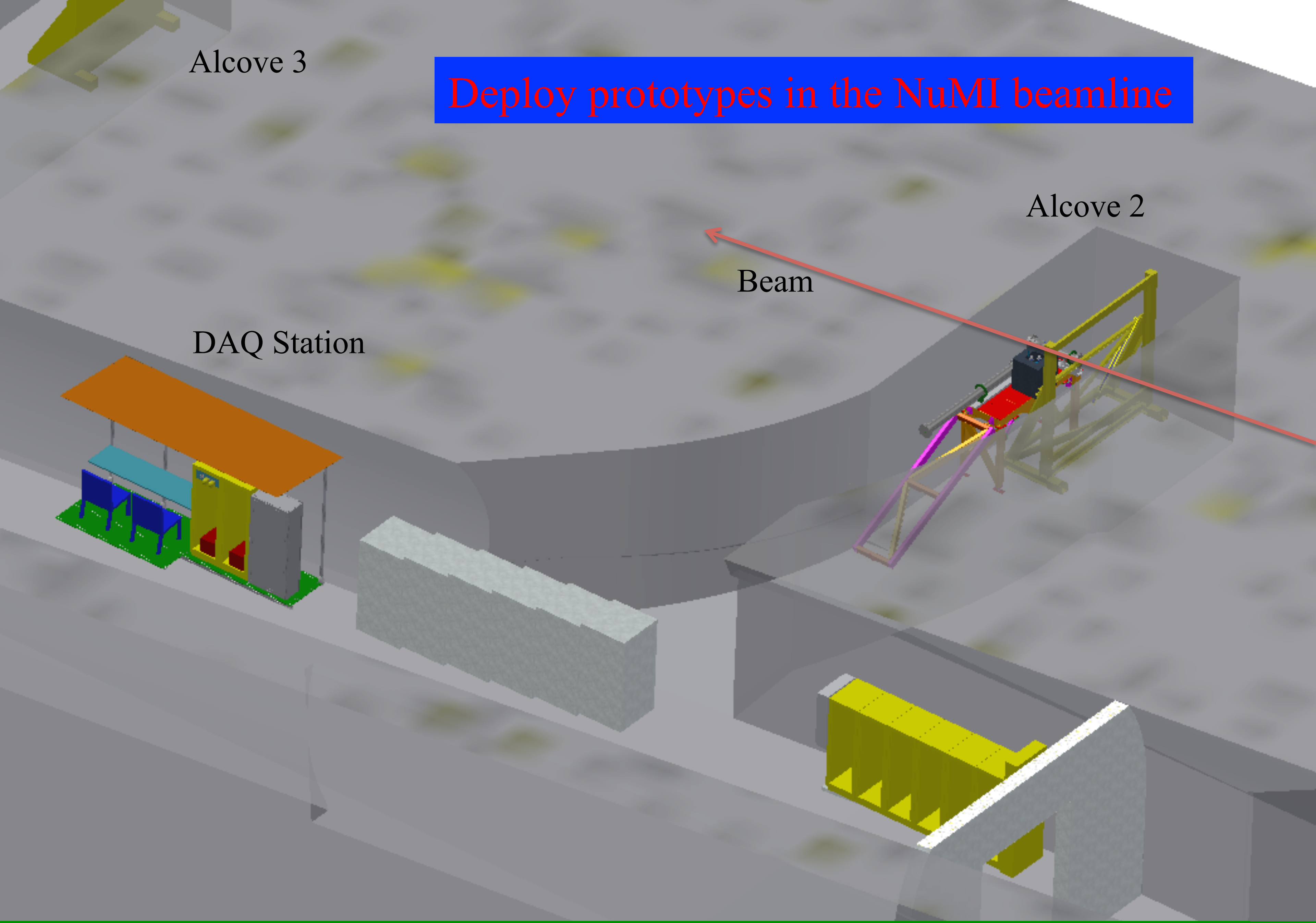
Anode Plane Assembly Close-up View



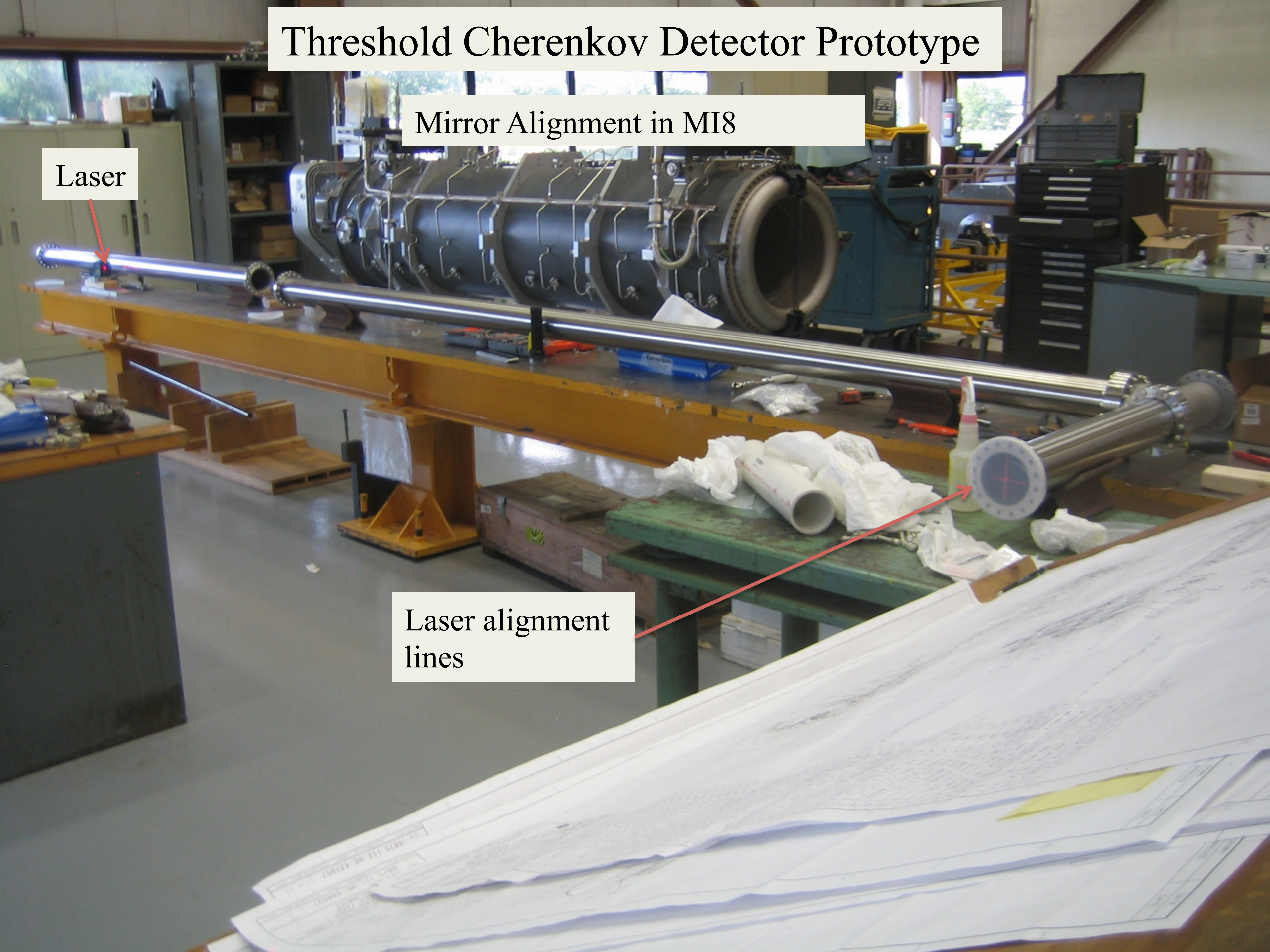
On each APA:
1120 X wires @ 4.5mm pitch
720 U wires @ 4.9mm pitch
720 V wires @ 5.0mm pitch
1120 grid wires @ 4.5mm pitch
150µm CuBe wires
10 photon detectors installed inside the APA frame

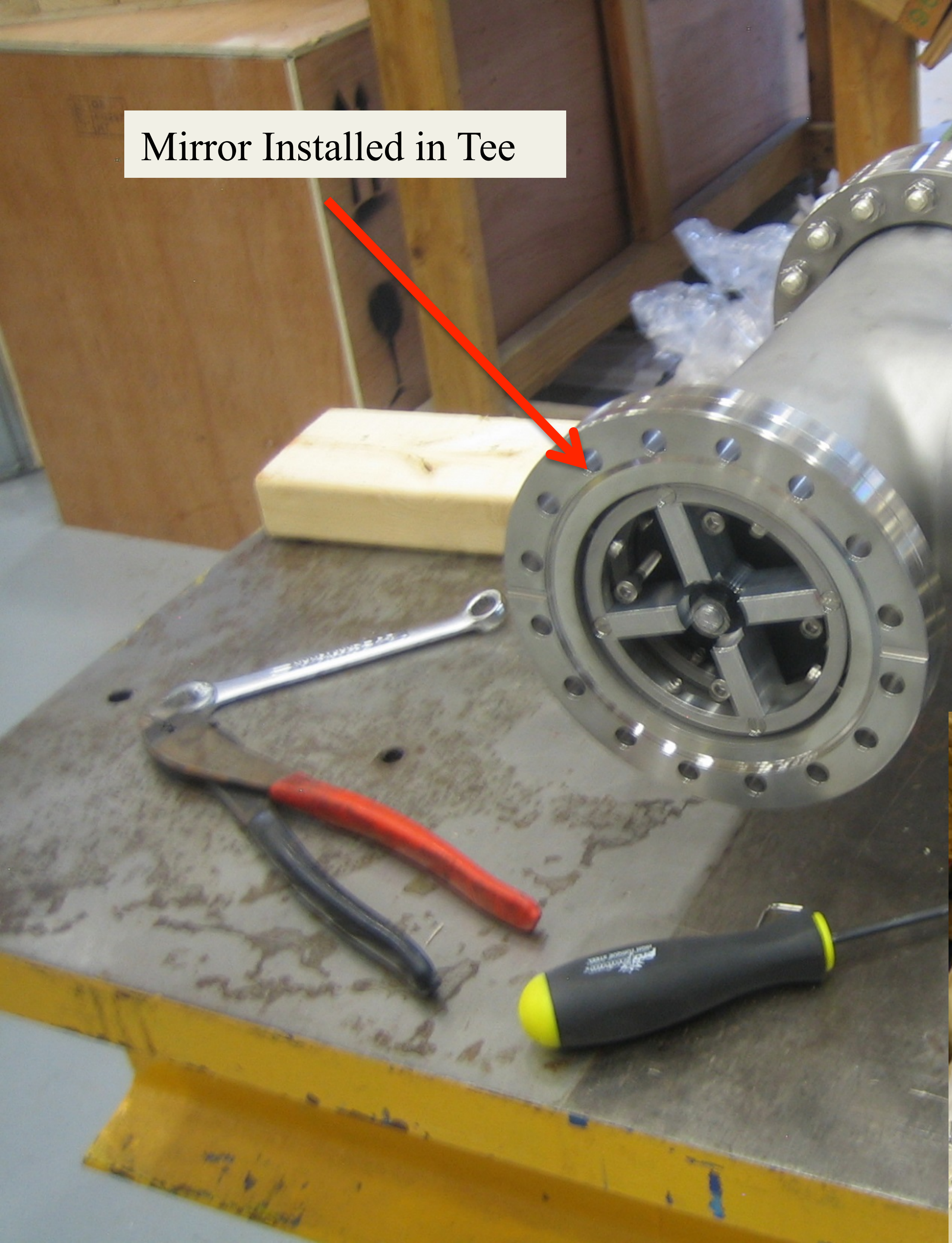
Prototyping Activities

Deploy prototypes in the NuMI beamline



Threshold Cherenkov Detector Prototype



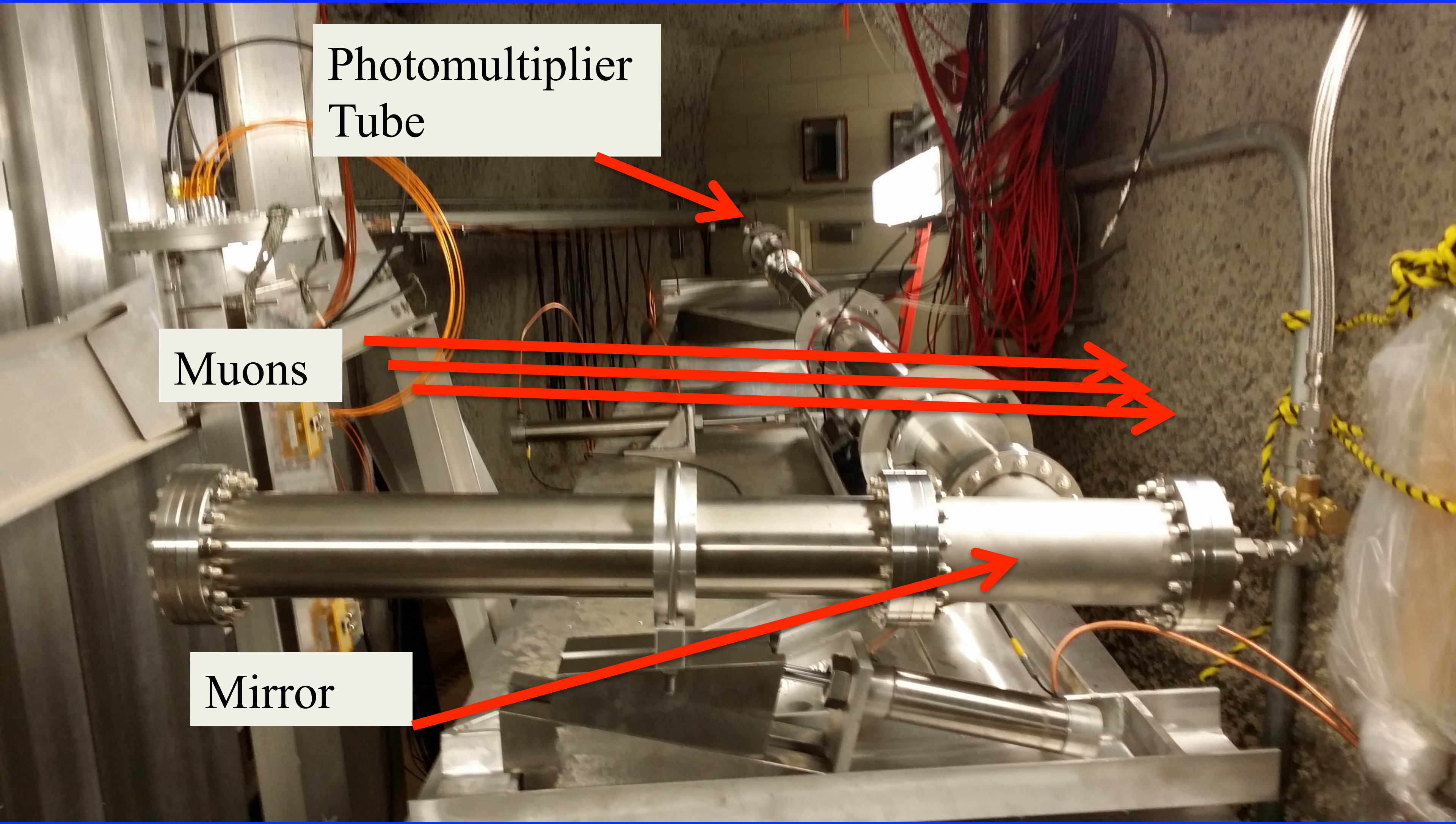

Mirror Installed in Tee


3.5 inch mirror

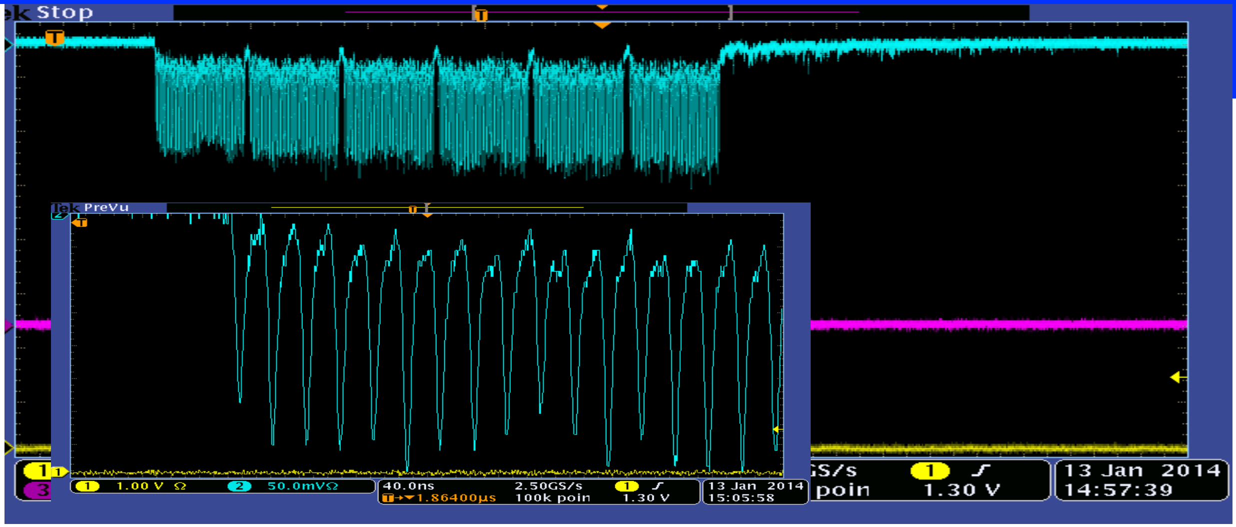
Sealed system being pumped down

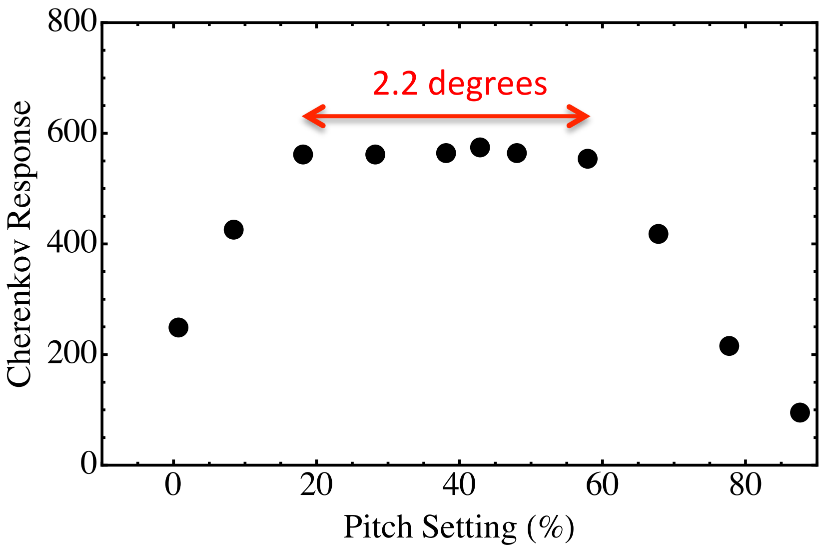

PFC Instructions

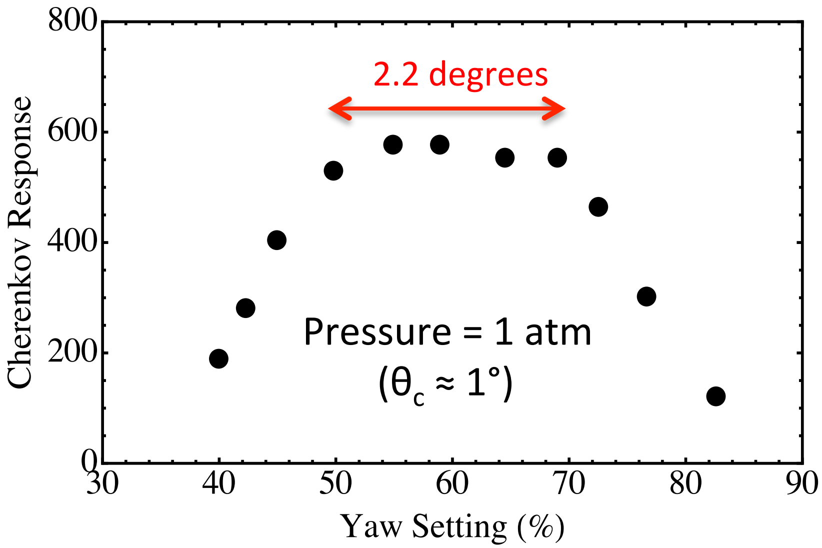
Threshold Cherenkov Detector Prototype



- Right figure: Full waveform showing the response for a NuMI spill; embedded figure: closeup of the 50 MHz booster RF structure
- Lower Left: Response (mV) versus pitch setting
- Lower Rightt: Response (mV) versus yaw setting

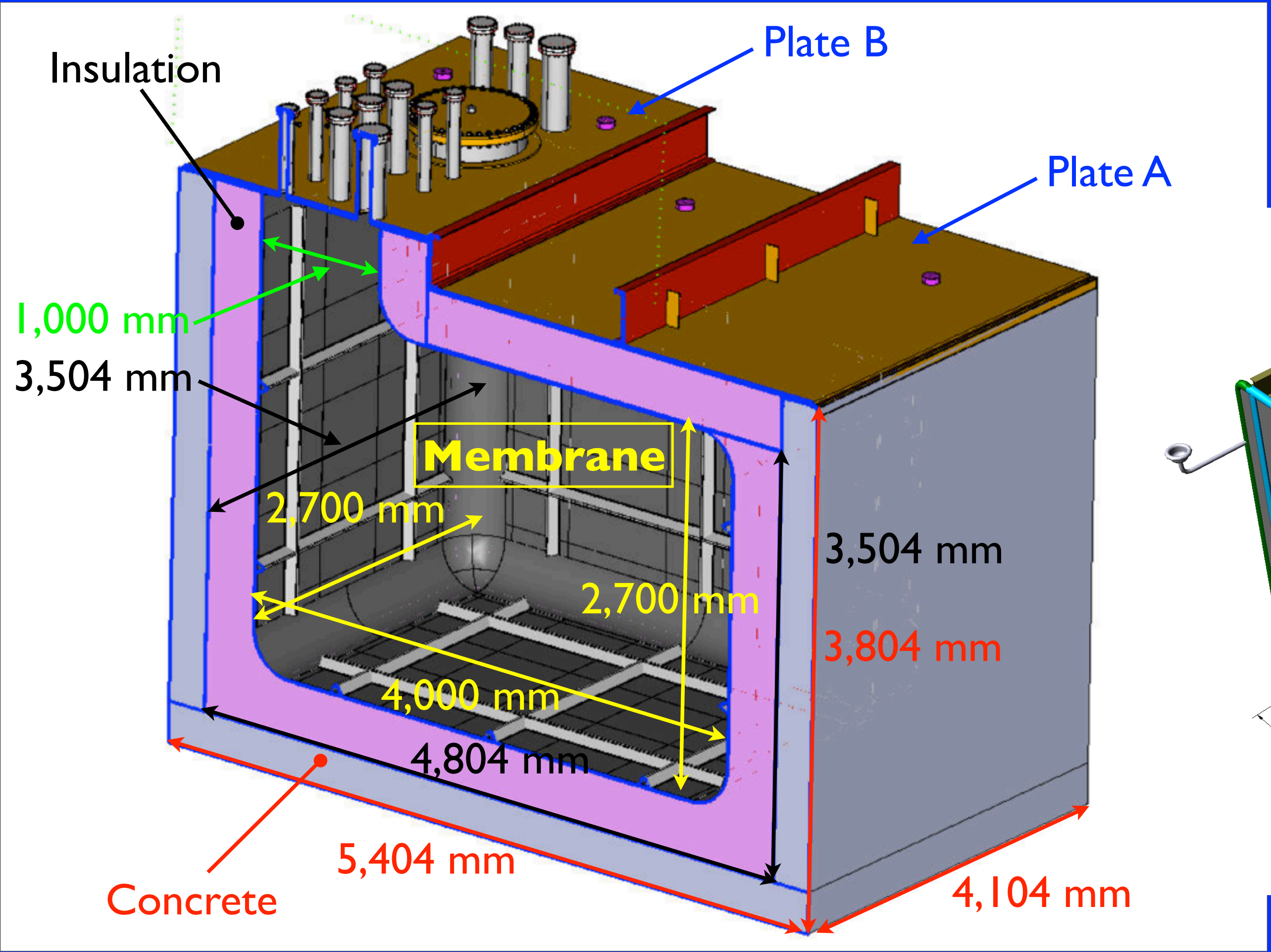




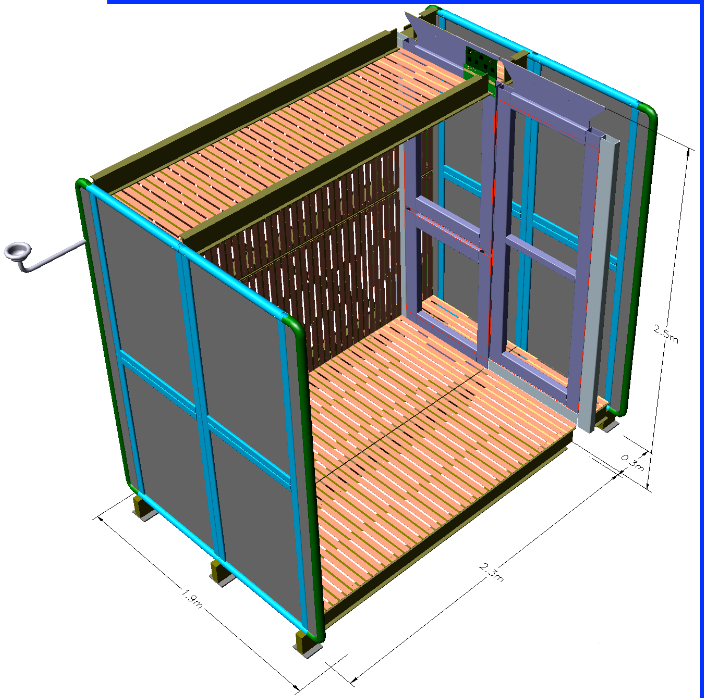


35 t Prototype Cryostat and TPC

IHI construction



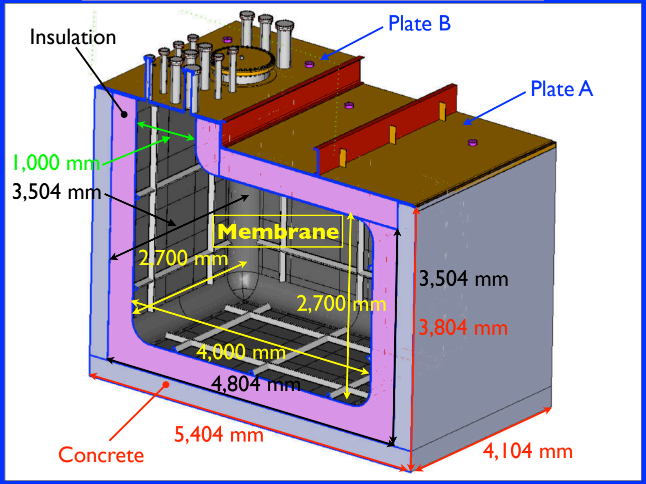
TPC



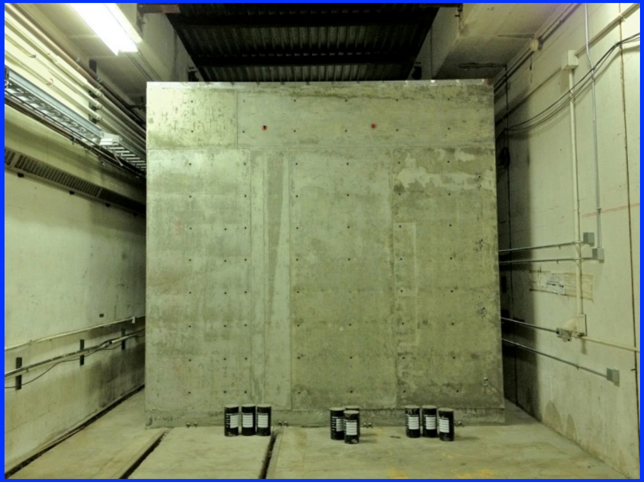
- Demonstrated required argon purity – install TPC next fiscal year

Prototype Construction

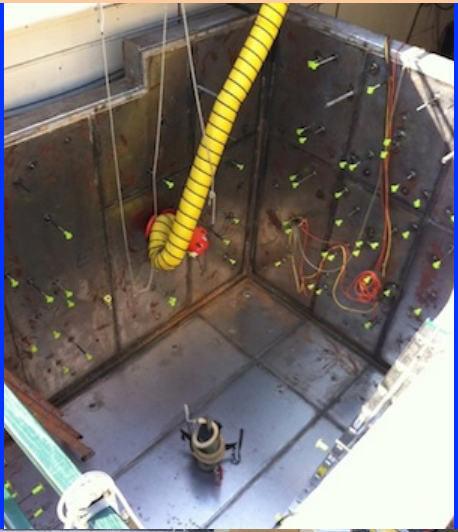
3 D Model of IHI Tank



Concrete Structure @ PC4



Carbon Steel Vapor Barrier



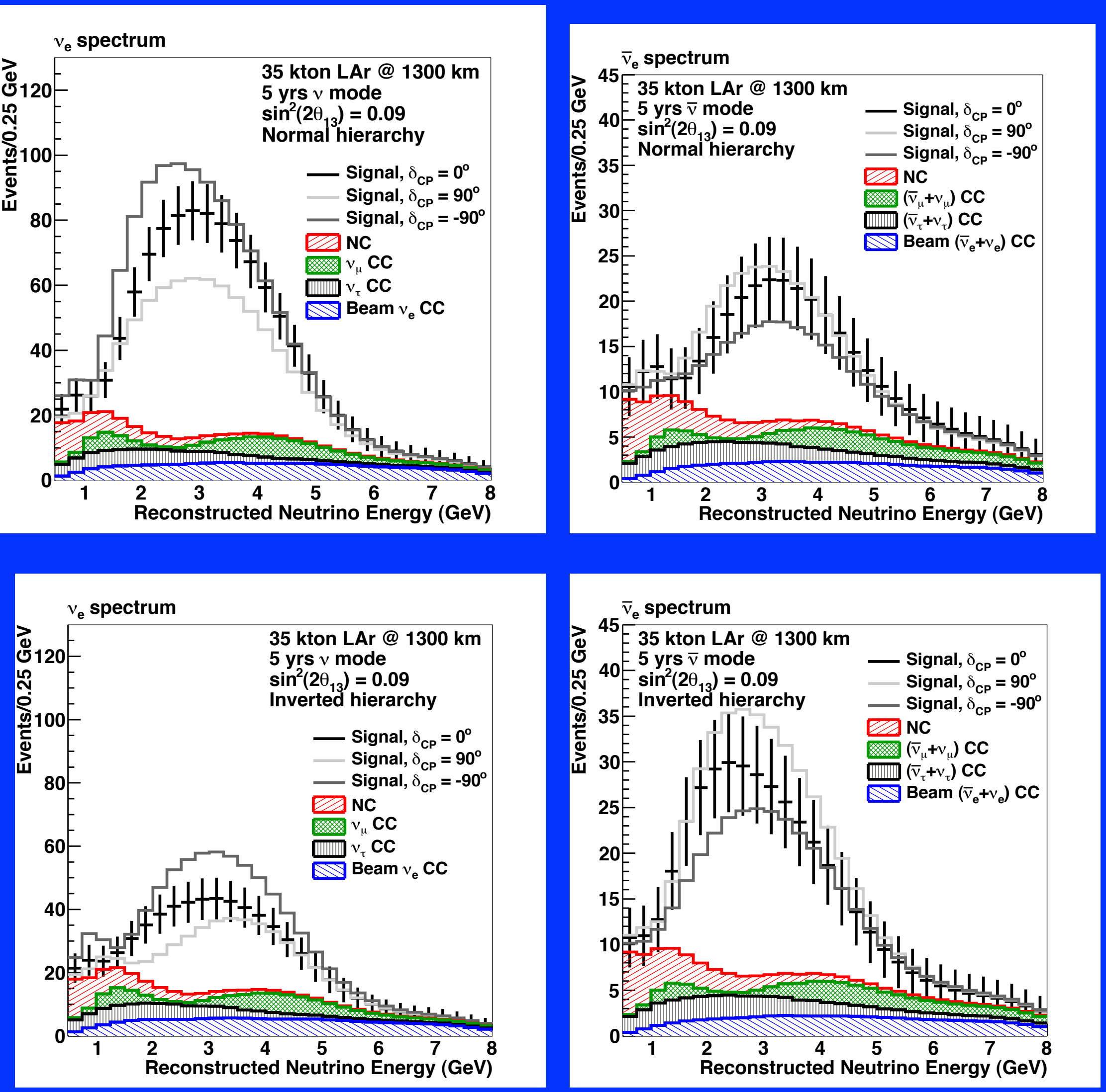
Two layers of foam (0.4 m)

Top View of Two Layers Foam

SS membrane Insert Begins

Anticipated Physics

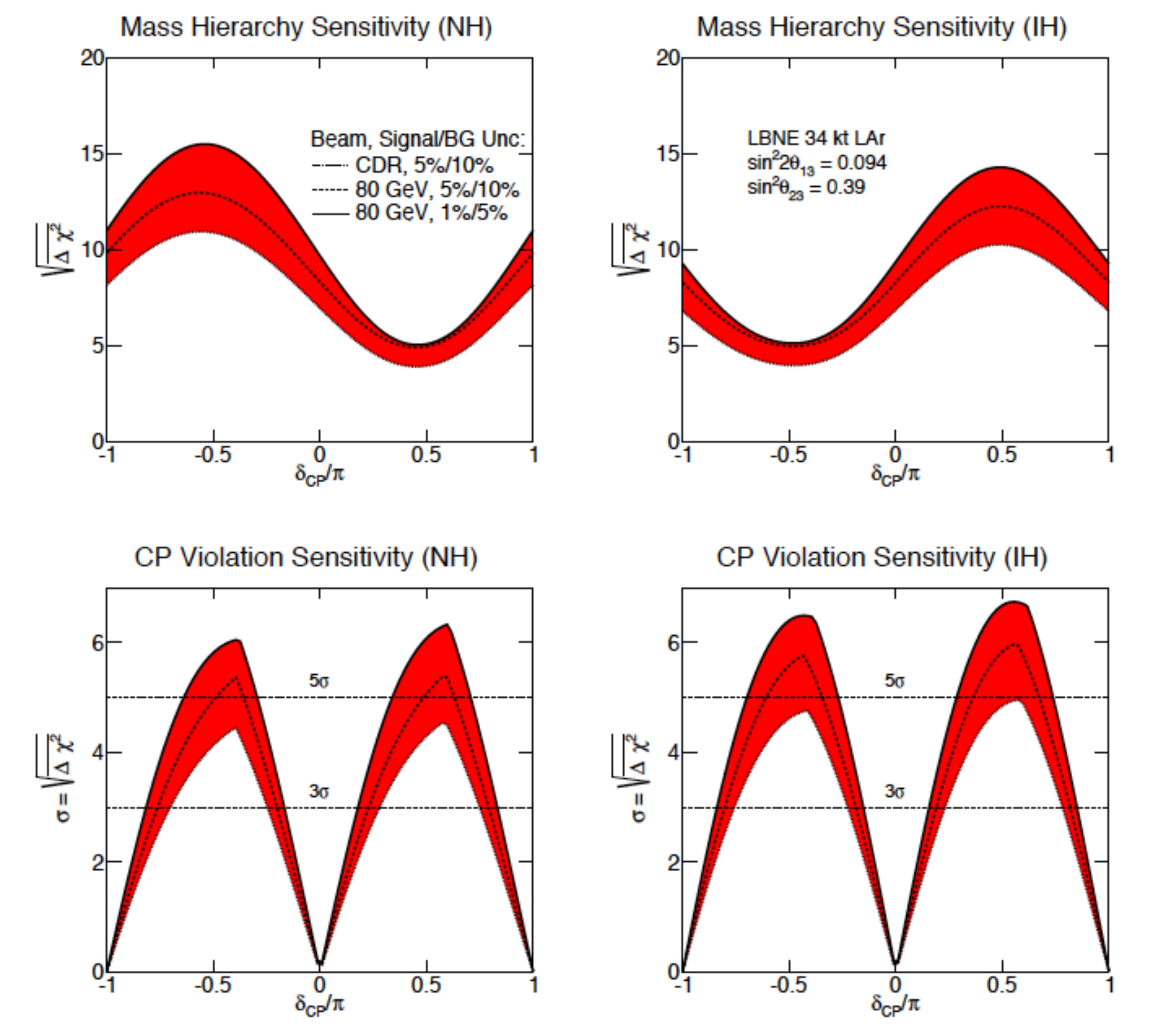
Electron (anti)neutrino appearance spectra



- Electron (anti)neutrino appearance spectra
- Tau neutrino background included
- Assume $\sin^2 2\theta_{13} = 0.09$, 80 GeV proton energy beam, 700 kW, 5 years running in each mode
- Left upper: neutrino, normal hierarchy
- Left lower: neutrino, inverted hierarchy
- Right upper: antineutrino, normal hierarchy
- Right lower: antineutrino, inverted hierarchy

Mass Hierarchy and CP sensitivities

- Ten years of running (5 + 5)
- Lower sensitivity: CDR beam with 5% signal and 10% background uncertainties
- Middle sensitivity: 80 GeV beam with 5% signal and 10% background uncertainties
- Best sensitivity: 80 GeV beam with 1% signal and 5% background uncertainty

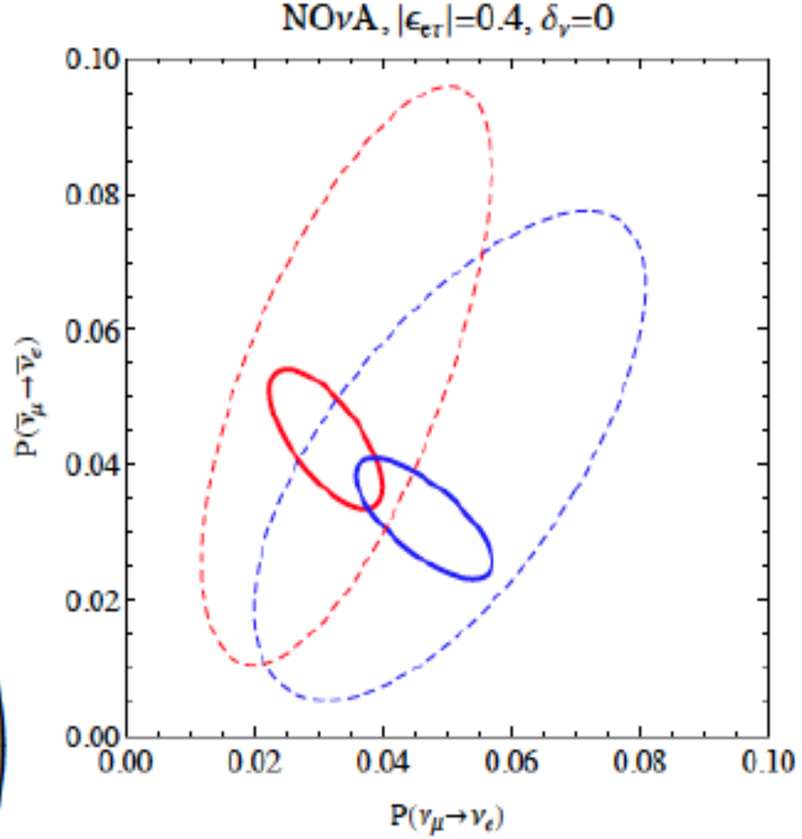


Non-Standard Interactions

New Physics in Neutrino-Matter Interactions

- Simplifying framework:
  - a single term: a flavor changing $qq\,\nu_e\nu_\tau$ interaction
  - subdominant to the SM weak interactions

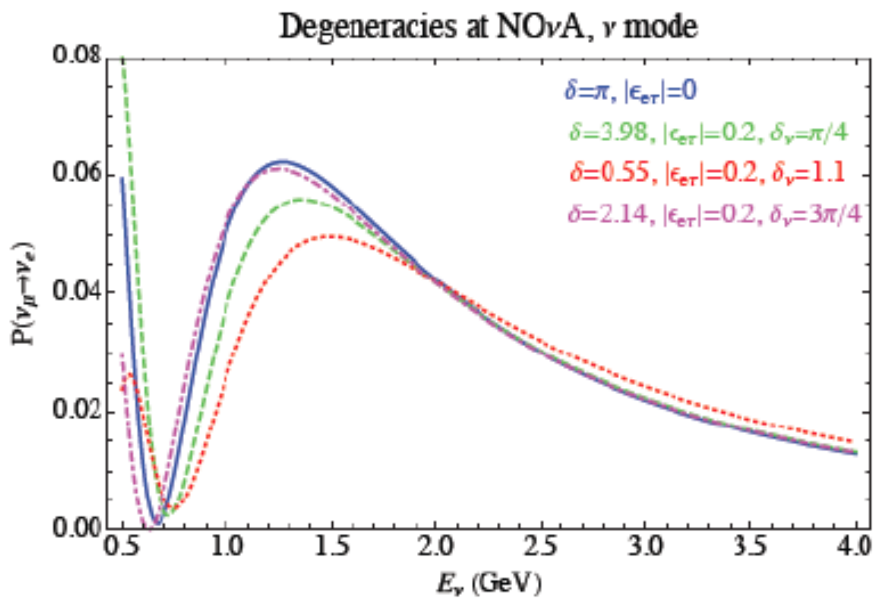
$$H_{mat}^{flav} = \sqrt{2} G_F n_e \begin{pmatrix} 1 & 0 & |\varepsilon_{e\tau}|\, e^{-i\delta_v} \\ 0 & 0 & 0 \\ |\varepsilon_{e\tau}|\, e^{i\delta_v} & 0 & 0 \end{pmatrix}$$

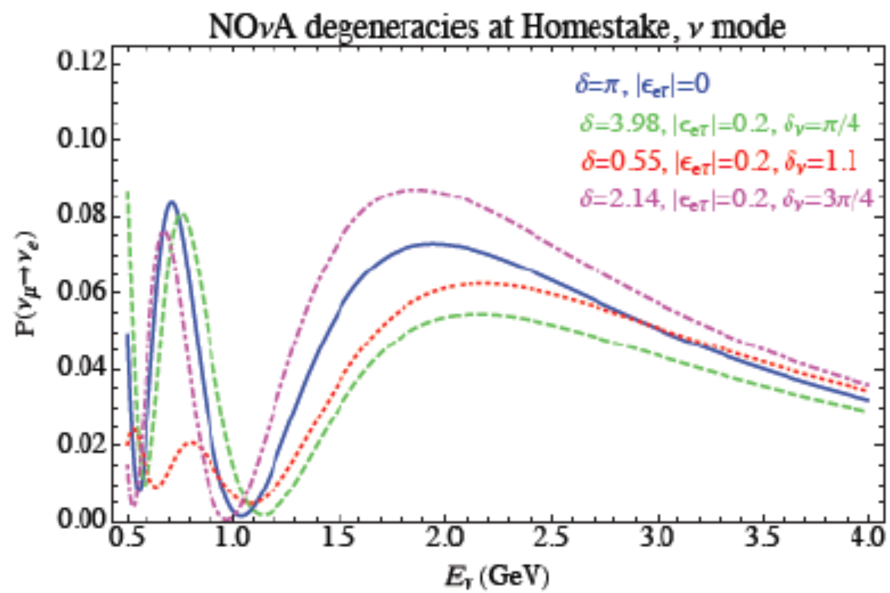


Alex Friedland

NSI

- LBNE spectral measurements can break the degeneracy

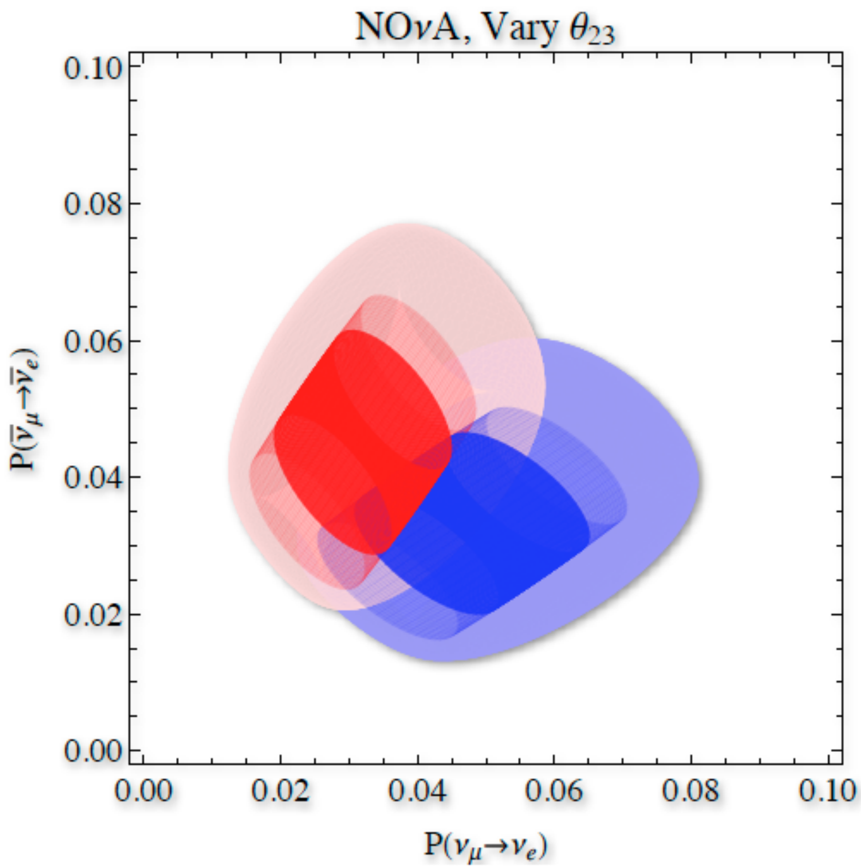


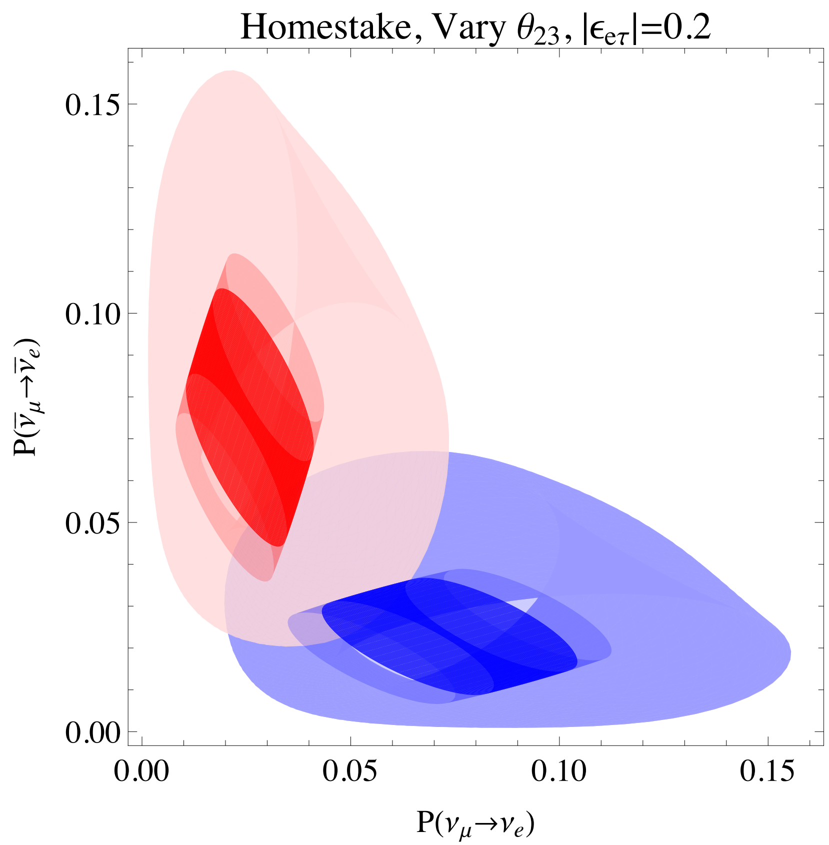


Requires a high precision near neutrino detector

From A. Friedland

LBNE can break NSI degeneracies



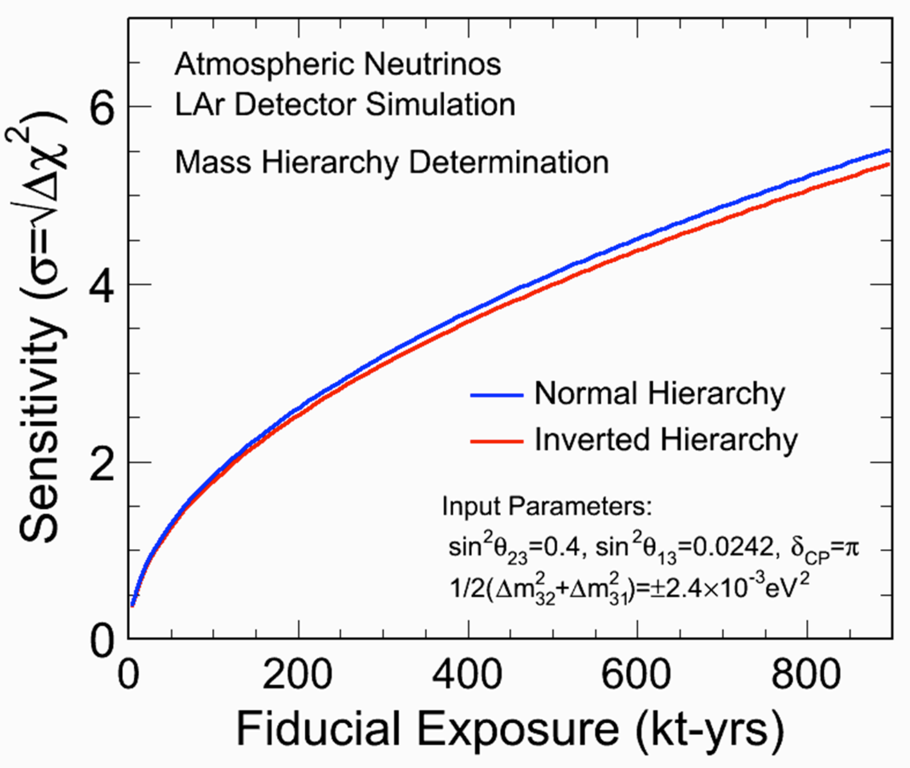


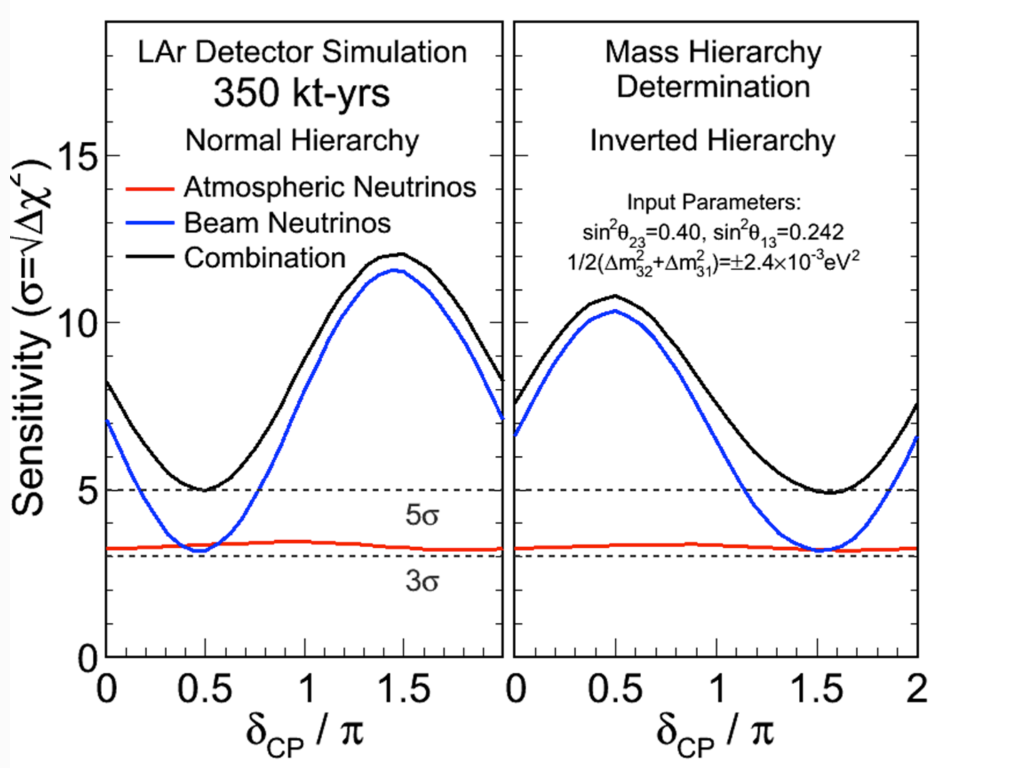
Larger distance and broad-band beam allow LBNE to break degeneracies – explore a broad range of new BSM physics

Atmospheric Neutrinos

- Largest L/E range of any neutrino source above muon production threshold
- Protons and low-energy charged pions are visible in liquid argon TPCs – better pointing resolution than water Cherenkov detectors at low-to-moderate neutrino energies
- Can separate muon neutrino and anti-neutrino events by searching for muon capture (75% probability for μ^-), final state proton vs. neutron for quasi-elastic neutrino interactions
- These features give the LBNE far detector sensitivity to the neutrino mass hierarchy

Atmospheric Neutrinos Neutrino Mass Hierarchy





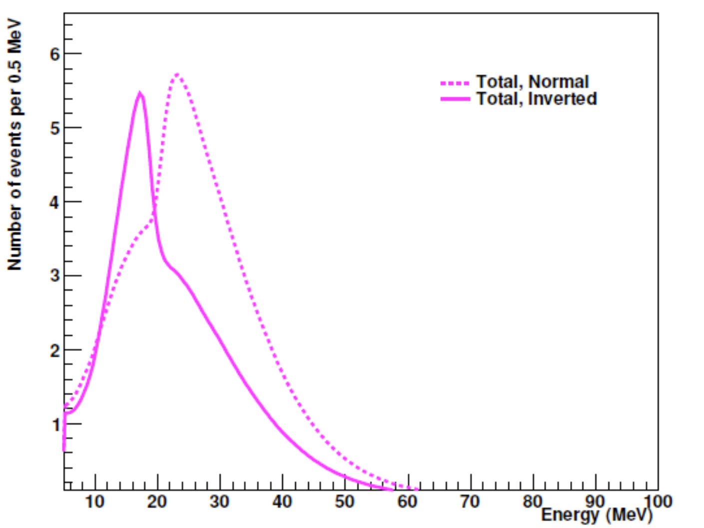
- Atmospheric neutrinos provide independent test in a different system with the same detector systematics
- Beam and atmospheric neutrinos combined give excellent sensitivity

Supernova Neutrinos

- Supernova bursts in our galaxy are a fantastic source of neutrinos
- Significant fluxes in < 10 seconds
- Matter effects unachievable from other sources
- Argon uniquely sensitive to CC electron neutrino interactions – complementary to water Cherenkov detectors sensitive to CC electron anti-neutrino interactions
- Expect several thousand events including 2000 CC electron neutrino interactions
- Spectral swap feature

$$(CC) \quad \nu_e + {}^{40}Ar \rightarrow e^- + {}^{40}K^*$$

- Expect electron signal and stubs of de-excitation gamma-rays



Baryon Number Violation

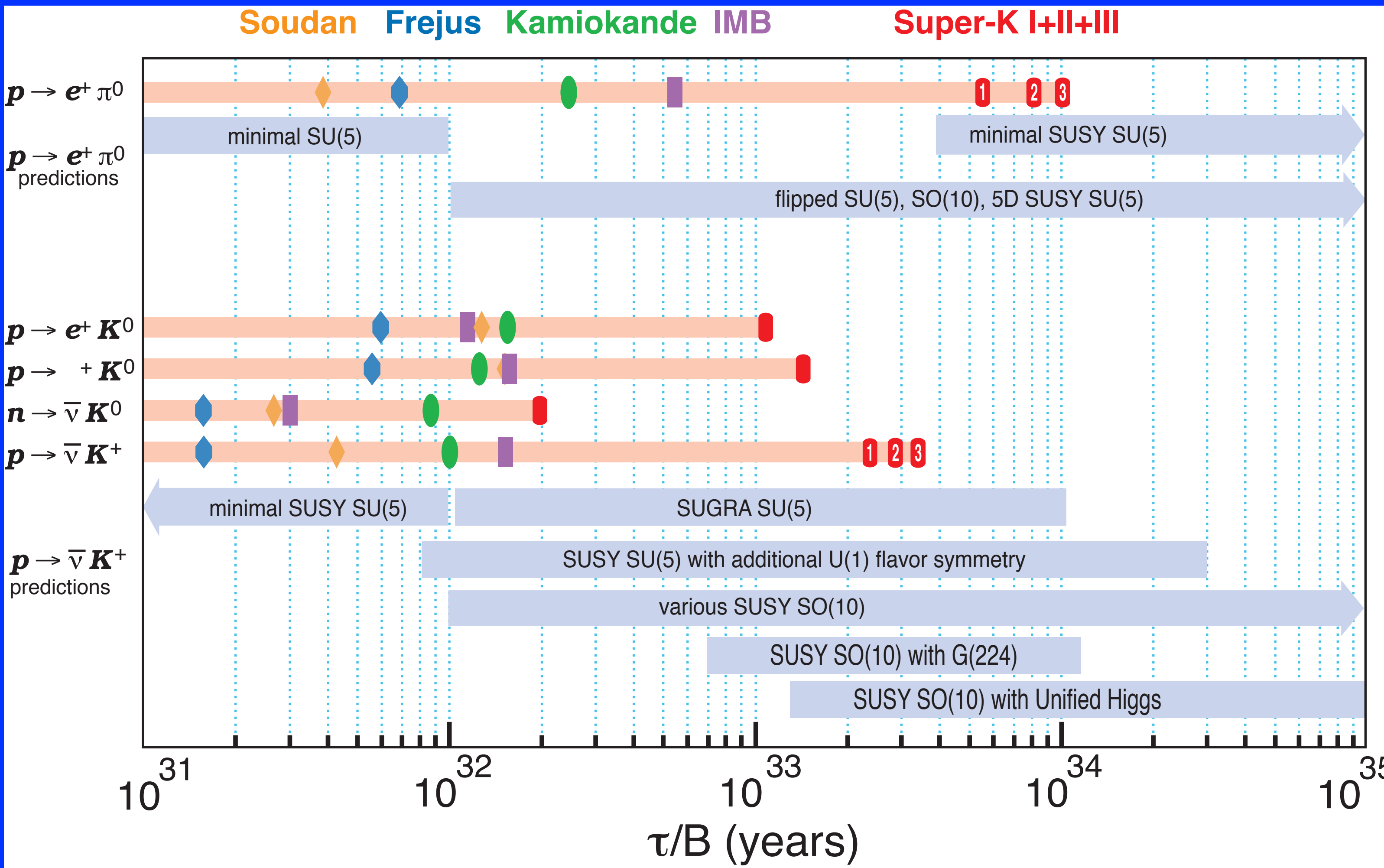
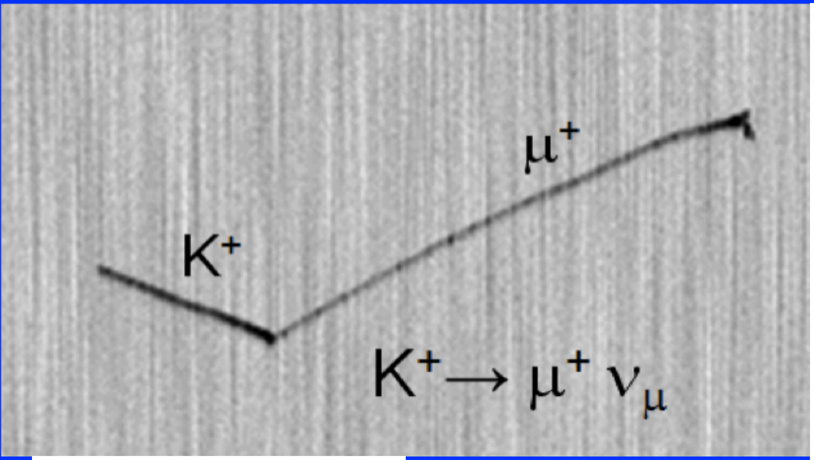


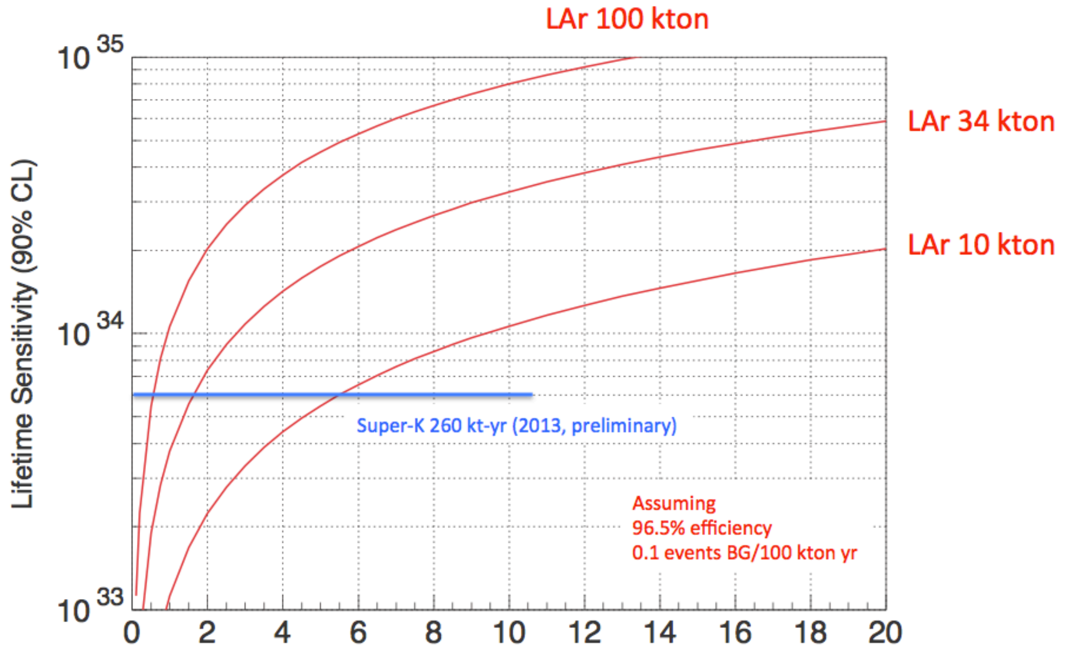
Figure from Kearns

Predicted by models beyond the Standard Model – Grand Unified Theories, Supersymmetry

Liquid Argon TPCs Complementary to Water Cherenkov Detectors



Icarus simulation

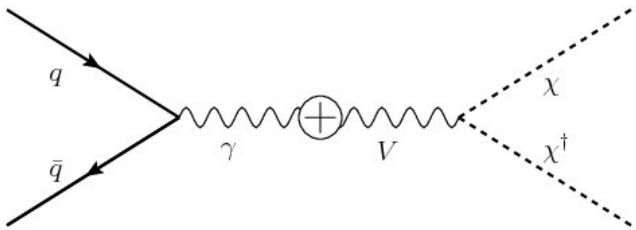


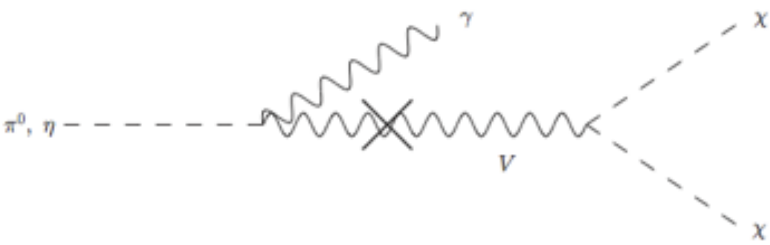
Decay Mode	Water Cherenkov		Liquid Argon TPC	
	Efficiency	Background	Efficiency	Background
$p \to \nu K^+$	19%	4	97%	1
$p \to \mu^+ K^0$	10%	8	47%	< 2
$p \to \mu^- \pi^+ K^+$			97%	1
$n \to e^- K^+$	10%	3	96%	< 2
$n \to e^+ \pi^-$	19%	2	44%	0.8

- Smaller exposure, so LAr shines with high efficiency modes

Physics with the Near Neutrino Detector

- Motivated by non-observation of SUSY, non-observation of direct detection experiments
- Simplest model, U(1) gauge field mixes with SM U(1) gauge field (dark photon)
- Can be produced when protons strike the LBNE target and decay into light (mass) dark-sector particles





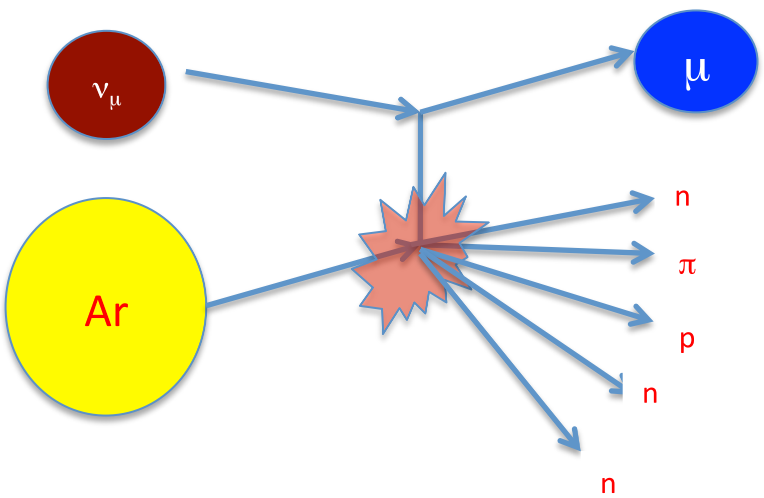
- Detectable in a neutrino detector – neutrino-like NC-like interactions
- Very forward electrons with late timing (mass much heavier than neutrinos)
- Special runs with no focussing would reduce the neutrino background

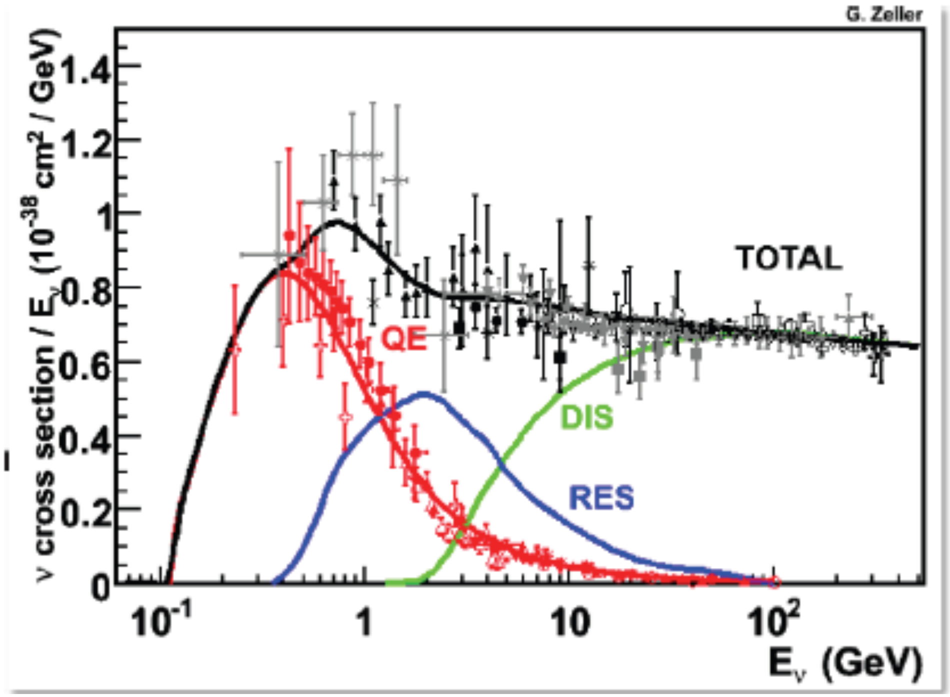
LBNE Physics Challenges – low-energy neutrinos

- Cosmogenic spallation backgrounds not well constrained
  - Spallation of argon from muon-argon photo-nuclear interactions
  - Muon-produced high energy neutrons – subsequent neutron spallation of argon
  - Muon-produced charged pions – subsequent spallation of argon
- Cross-sections have never been measured
  - Absolute cross-sections uncertain
  - Visible energy vs. neutrino energy
- Low energy is challenging for the TPC
  - Relatively poor energy resolution for the TPC at low energies
  - Trigger efficiency not well understood
- Use photon detection system to trigger and improve energy resolution
- A lot of light, but complicated structure
  - Scintillation and Cherenkov radiation
  - Prompt (~6ns) and late(~1.6 μsec) scintillation time constants
  - Scattering length 95 cm
- Anisotropic distribution of photon detectors in a TPC

LBNE Physics Challenges – medium-energy neutrinos

- LBNE does long-baseline physics in resonance regime (1st Oscillation Maximum at ~2.4 GeV) and resonance/DIS cross-over regime
- Atmospheric neutrinos are measured in the same neutrino energy regime
- Neutrino oscillation phenomena depend on mixing angles, masses, matter densities, distance from production to measurement point, neutrino flavor and neutrino energy
- Critical to understand the correlation between true and reconstructed neutrino energy

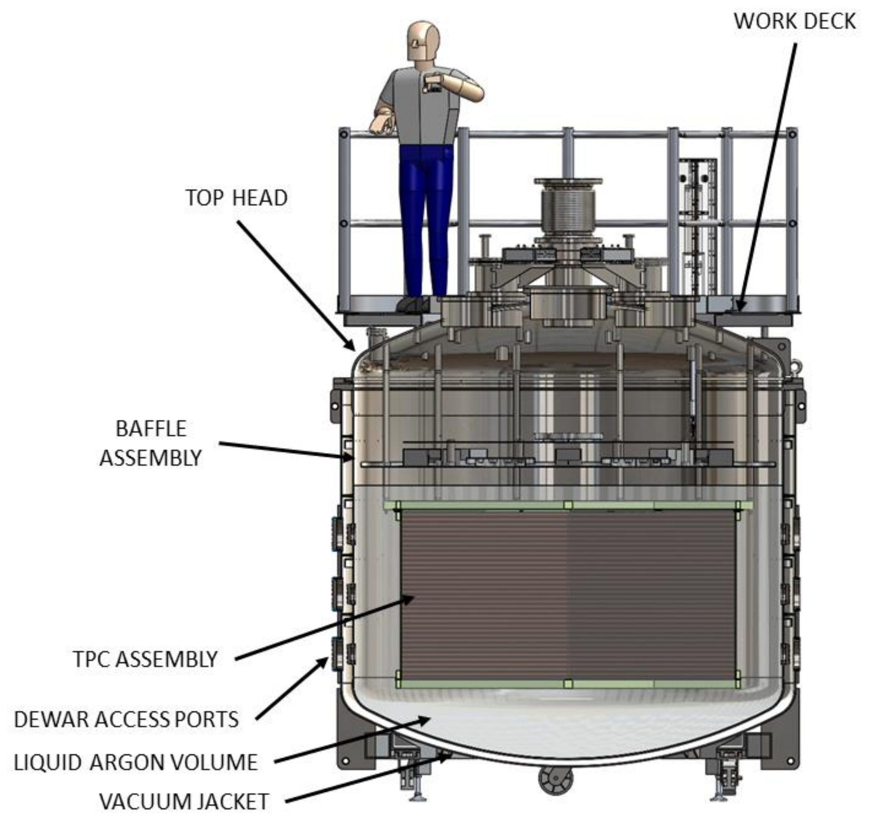




The CAPTAIN Program

CAPTAIN: Cryogenic Apparatus for Precision Tests of Argon Interactions with Neutrinos

- Liquid argon TPC
  - 5 instrumented tons
  - hexagonal TPC with vertical drift, apothem is 1 m
  - 2000 channels, 3mm pitch
  - cryostat 7700 liter capacity, evacuable, portable
  - all cryogenic connections made through top head
  - indium seal – can be opened and closed
  - photon detection system and laser calibration system
  - using same cold electronics and electronics chain as MicroBooNE (front end same as LBNE)
- Designed to operate safely at multiple facilities
  - compliant with standard pressure safety regulations
  - compliant with electrical safety practices
  - can be loaded and shipped by truck
- Being constructed with internal Los Alamos National Laboratory funds (Laboratory Directed Research and Development)
- CAPTAIN prototype, 1000 channels, 30cm drift, 400 instrumented kilograms
- Physics program focused on challenges to LBNE low-energy neutrino (supernova) and medium-energy neutrino (long-baseline and atmospheric) programs



CAPTAIN Collaboration

- Scientists from: Alabama, ANL, LBL, BNL, UC Davis, UC Irvine, UCLA, FNAL, Hawaii, Houston, Indiana, LANL, LSU, New Mexico, South Dakota, South Dakota State, Stony Brook
- Spokesperson: Mauger, Deputy Spokesperson: Clark McGrew (Stony Brook)[Sobel student]
- Michael Smy leads the development of the analysis for first data, in addition to intellectual leadership of the scientific program
- DOE supported groups have been permitted to redirect effort to CAPTAIN, in some cases new funds have been provided
- UC institutions supported through INPAC (funding via UC fee collected for managing LANL and other laboratories)

CAPTAIN collaboration

CAPTAIN Collaboration

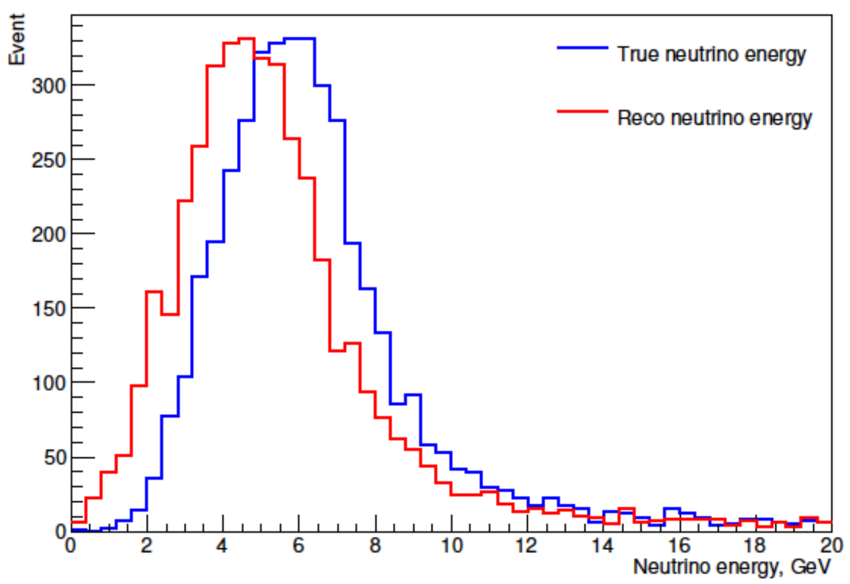
- Alabama: Ion Stancu
- ANL: Zelimir Djurcic
- LBL: Vic Gehman, Richard Kadel, Craig Tull
- BNL: Hucheng Chen, Veljko Radeka, Craig Thorn
- UC Davis: Hans Berns, Dan Danielson, Chris Grant, Aaron Manalaysay, Emilja Pantic, Robert Svoboda, Matthew Szydagis
- UC Irvine: Michael Smy
- UC Los Angeles: David Cline, Kevin Hickerson, Kevin Lee, Elwin Martin, Jasmin Shin, Artin Teymourian, Hanguo Wang, Lindley Winslow
- FNAL: Oleg Prokoviev, Jonghee Yoo
- Hawaii: Jelena Maricic
- Houston: Babu Bhandari, Lisa Whitehead
- Indiana: Stuart Mufson
- LANL: Jeremy Danielson, Steven Elliott, Gerald Garvey, Elena Guardincerri, Todd Haines, Wesley Ketchum, David Lee, Qiuguang Liu, William Louis, Christopher Mauger, Geoff Mills, Jacqueline Mirabal-Martinez, John Ramsey, Keith Rielage, Constantine Sinnis, Walter Sondheim, Charles Taylor, Richard Van de Water, Kevin Yarritu
- Louisiana State University: Flor de Maria Blaszczyk, Thomas Kutter, William Metcalf, Martin Tzanov
- New Mexico: Franco Giuliani, Michael Gold
- South Dakota: Chao Zhang
- South Dakota State: Robert McTaggart
- Stony Brook: Clark McGrew, Chiaki Yanagisawa

CAPTAIN Physics Program

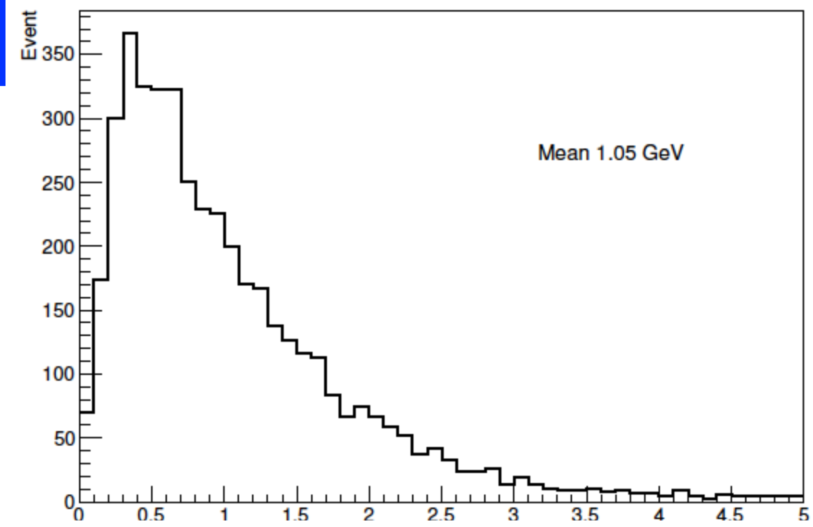
Neutron Beam
Low-Energy Neutrino Beam
Medium-Energy Neutrino Beam

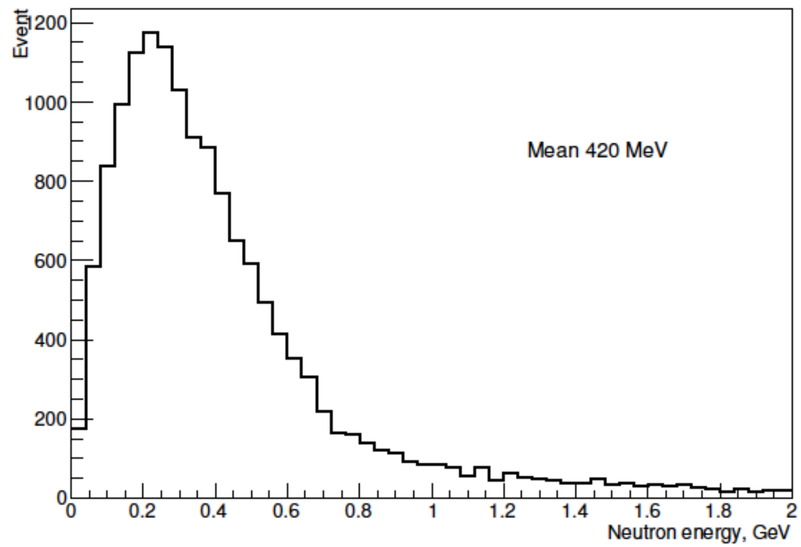
- Low-energy neutrino physics related
  - Measure neutron production of spallation products
  - Benchmark simulations of spallation production
  - Measure the neutrino CC and NC cross-sections on argon in the same energy regime as supernova neutrinos
  - Measure the correlation between true neutrino energy and visible energy for events of supernova-neutrino energies
- Medium-energy neutrino physics related
  - Measure neutron interactions and event signatures (e.g. pion production) to allow us to constrain number and energy of emitted neutrons in neutrino interactions
  - Measure higher-energy neutron-induced processes that could be backgrounds to ν_e appearance e.g. $^{40}Ar(n,\pi^0)^{40}Ar^{(*)}$
  - Measure inclusive and exclusive channels neutrino CC and NC cross-sections/ event rates in a neutrino beam of appropriate energy
  - Test methodologies of total neutrino energy reconstruction with neutron reconstruction

NuMI Medium Energy Tune

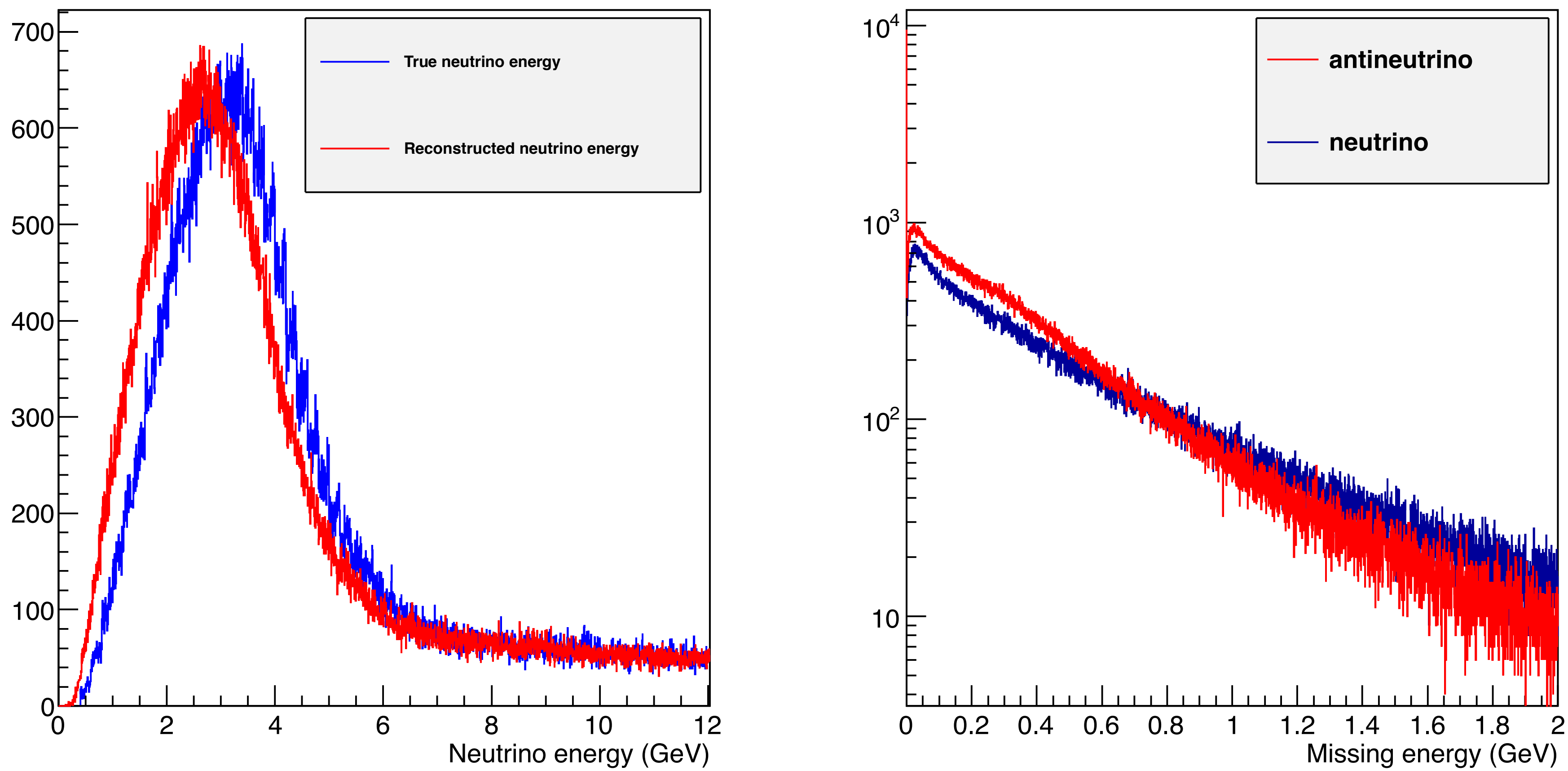


- Neutrons can carry away significant energy
- Uncertainties also large
- We would like to determine how to use these neutrons
- Deploy CAPTAIN in a neutron beam



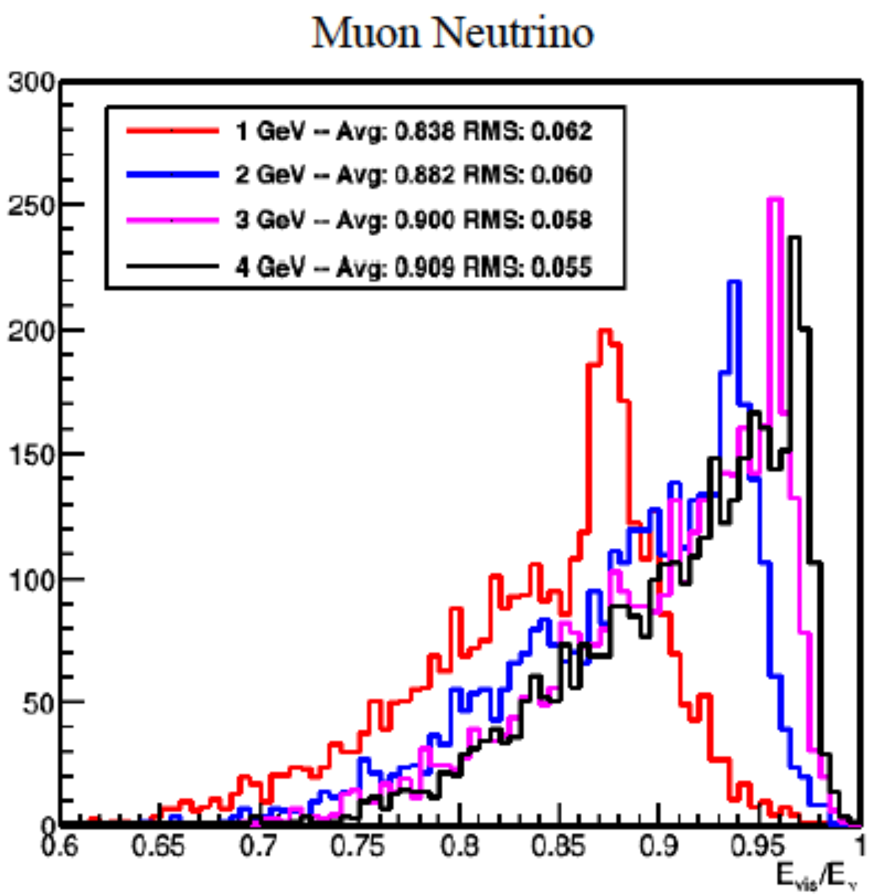


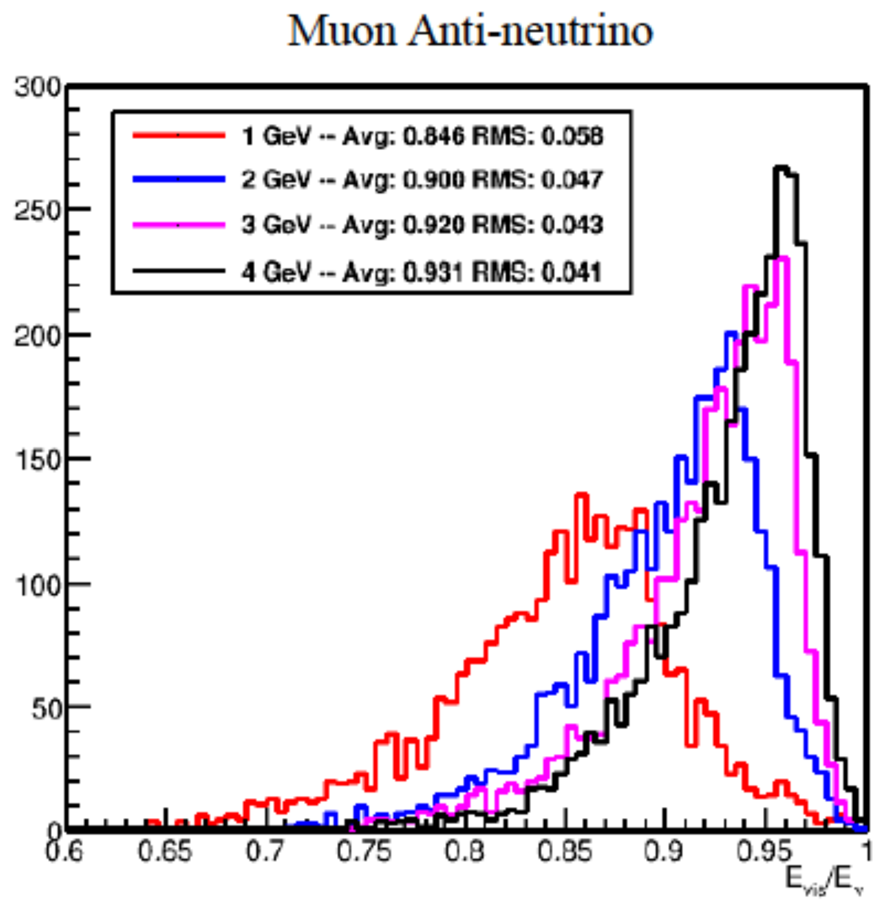
LBNE Beam



Missing neutrons for LBNE. Neutrino – Anti-neutrino differences. E. Guardincerri

Fraction of neutrino energy that is visible





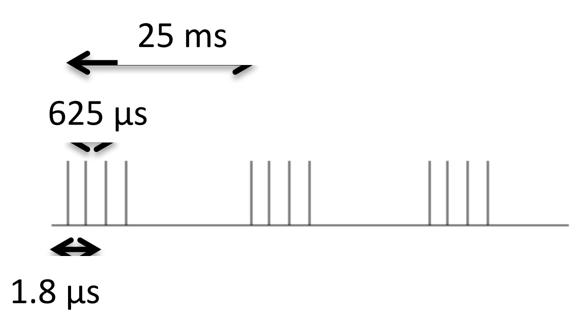
- Fraction is different for neutrinos and anti-neutrinos

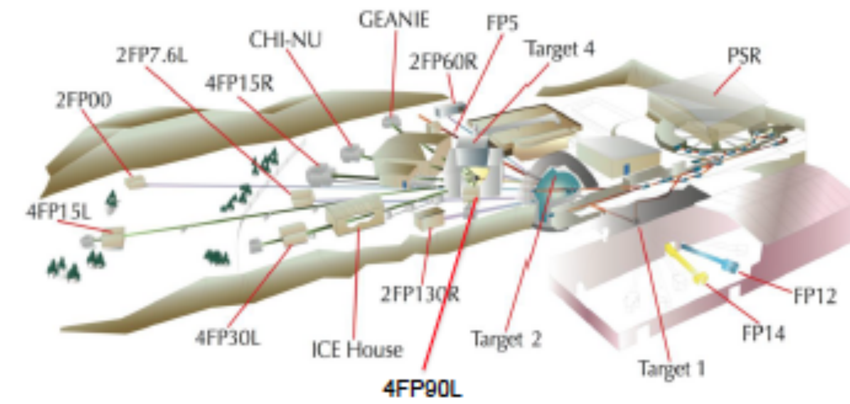
- Clark McGrew at the Santa Fe LBNE Scientific Workshop (http://public.lanl.gov/friedland/LBNEApril2014/)

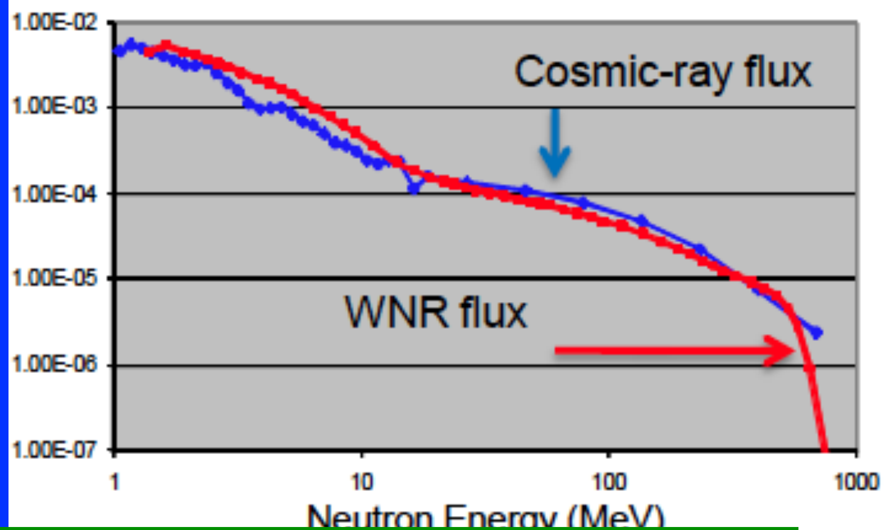
Neutron Beam at LANL

- Los Alamos Neutron Science Center WNR facility provides a high flux neutron beam with a broad energy spectrum similar to the cosmic-ray spectrum at high altitude

- Time structure of the beam
  - sub-nanosecond micro pulses 1.8 microseconds apart within a 625 µs long macro pulse
  - Repetition rate: 40 Hz

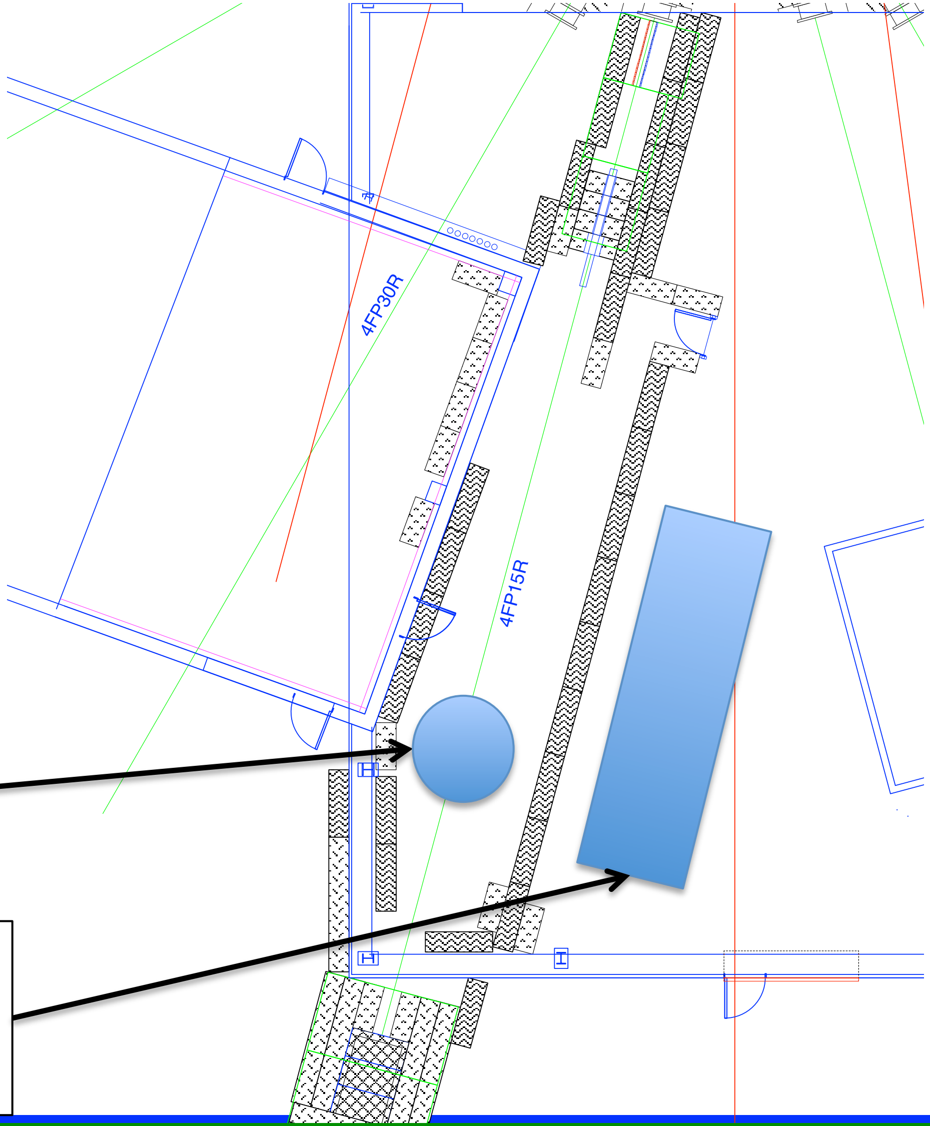






Neutron Beamline

- Anticipate two run conditions:
  - High-intensity (normal) where we expose our detector to a high flux, close the shutter, identify produced spallation events
  - Low-intensity where we get one neutron event per macropulse
- Granted two low-intensity runs last autumn for engineering studies
- Anticipate Mini-CAPTIAN run in autumn of this year



TPC

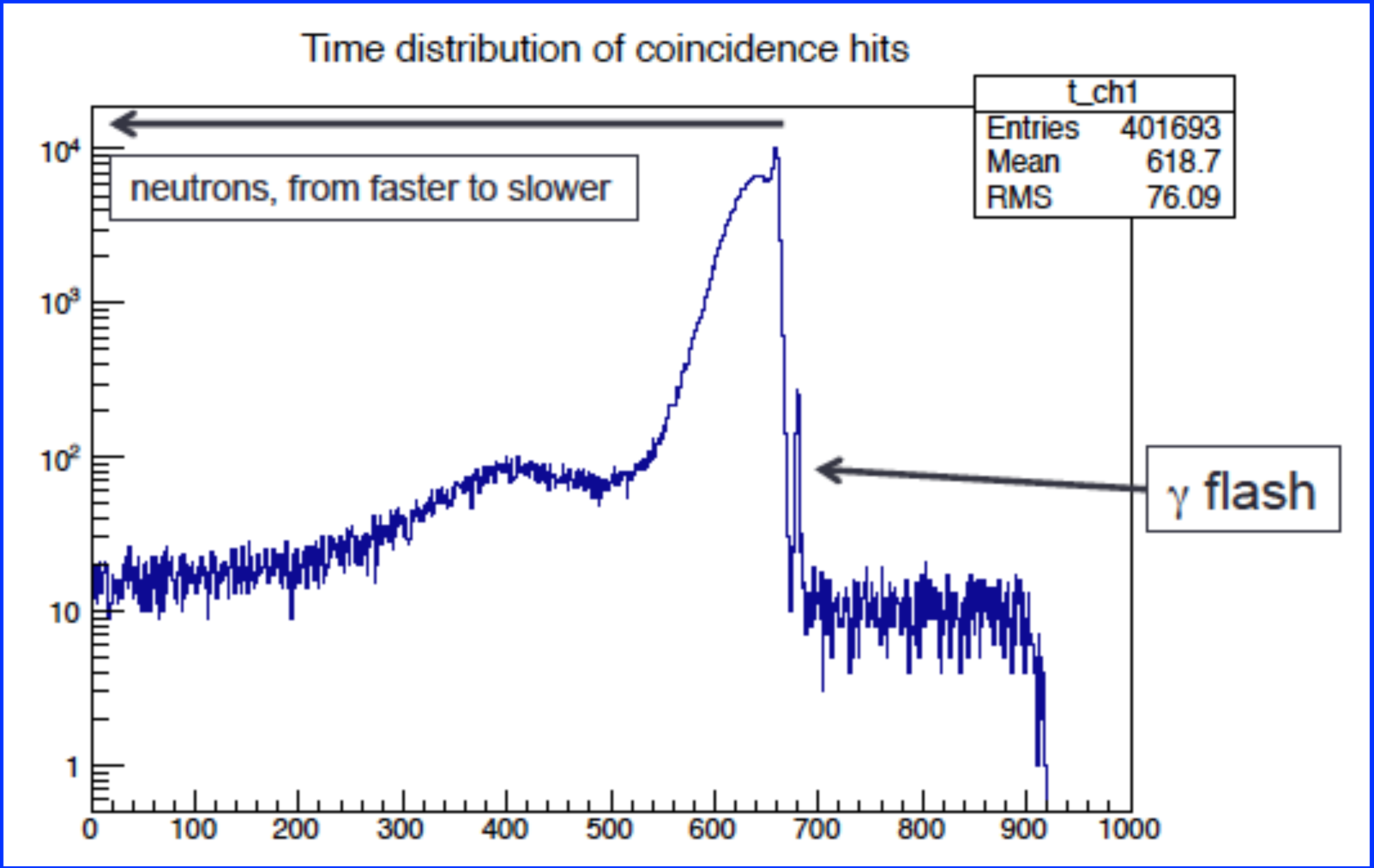
- Electronics and DAQ
- LAr purification system
- LAr cryogenic system

Low-intensity neutron running

48 in long plastic scintillator with 2 PMTs at 25 m from production target

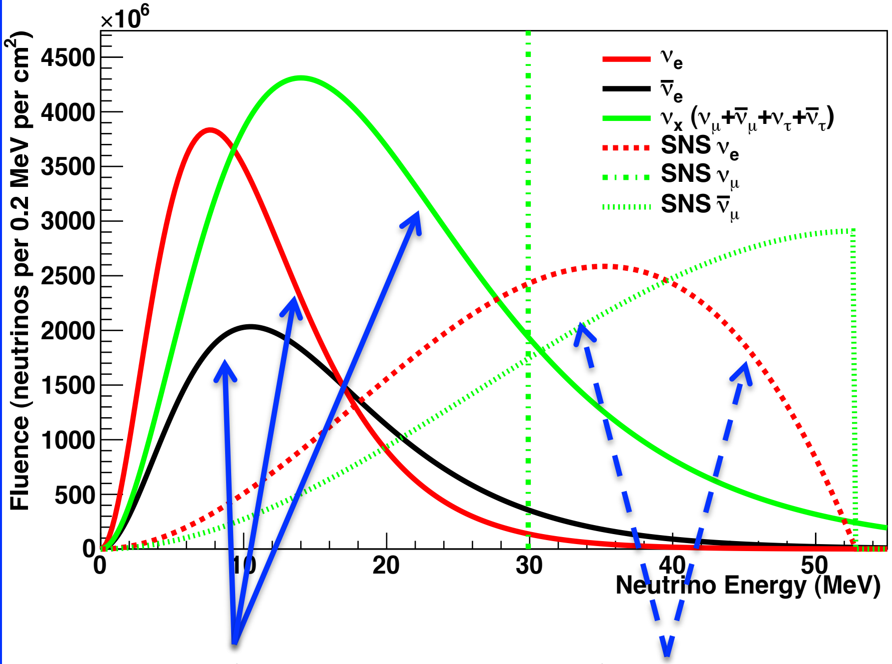
Effort led by Elena Guardincerri

Neutron Data



Neutron rate 0.63 Hz when beam set at 1 micropulse per macropulse

Running at a stopped pion source



Supernova neutrino spectra   Stopped π/μ spectra

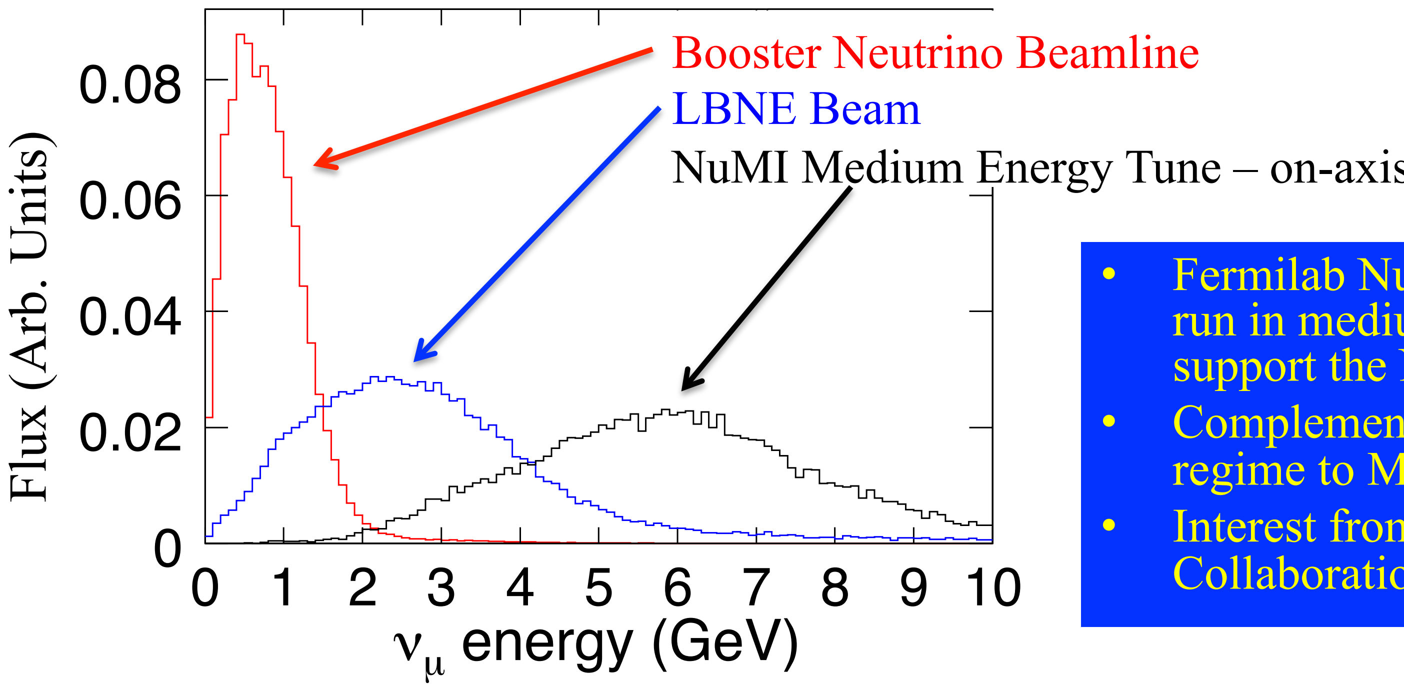
From:arXiv:1211.5199

Plot for SNS, but spectra are generic for a stopped π/μ source

- P5 report: ``The experiment (LBNE) should have demonstrated capability to search for supernova bursts"
- Neutrinos in the supernova energy regime have never been detected with a liquid argon TPC
- Cross-section uncertain
- Detection efficiencies unknown

- Exploring opportunities at FNAL using the BNB as a stopped pion source

Neutrino Spectra



- Fermilab NuMI beamline – will run in medium energy tune to support the Nova Experiment
- Complementary neutrino energy regime to MicroBooNE
- Interest from Minerva Collaboration

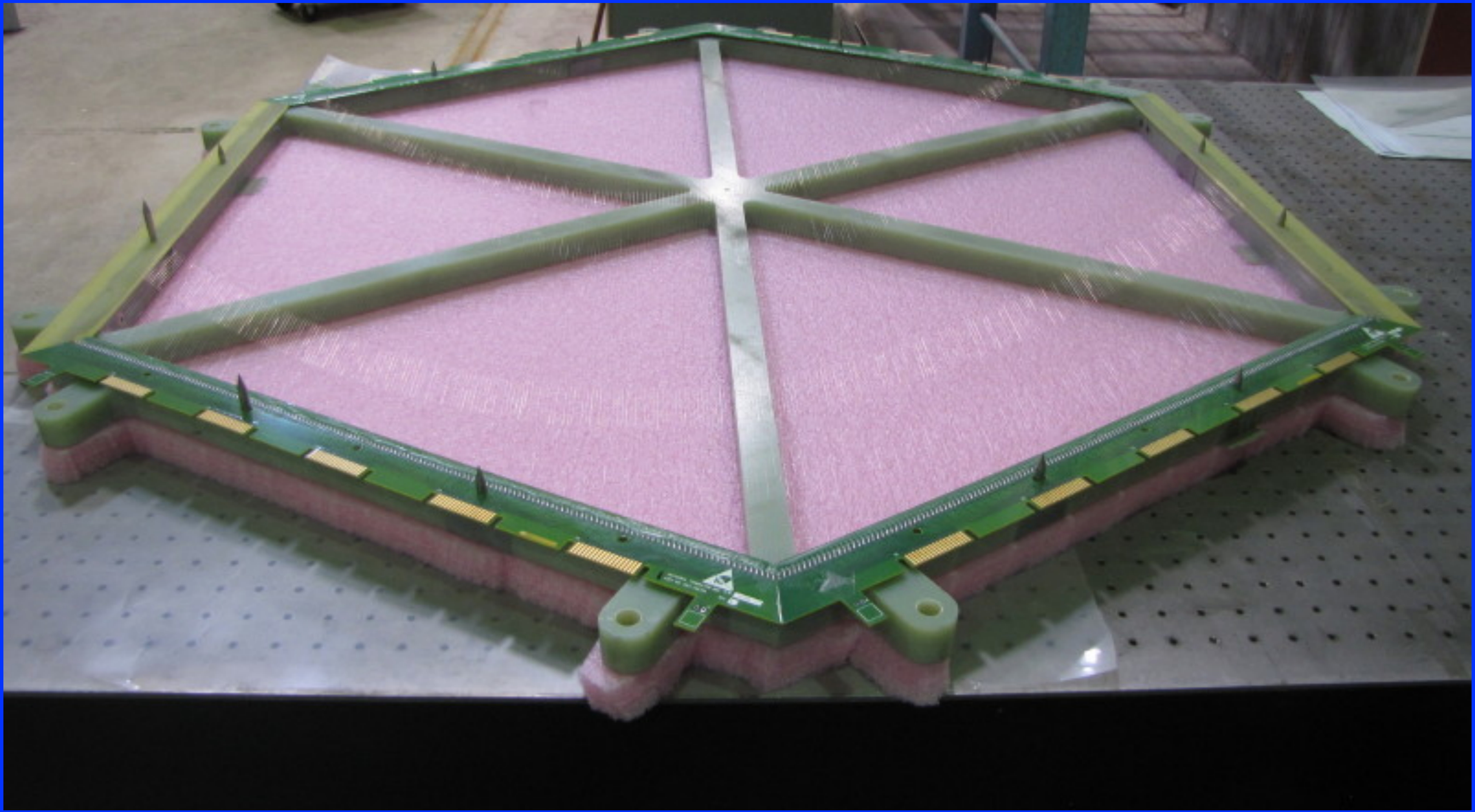
- Approximately 1 million contained events per year ($4x10^{20}$ POT) (containing all but lepton)
  - detailed exploration of threshold region for multi-pion production, kaon production
  - high-statistics data for algorithm development required for LBNE
  - employment of methods for neutron energy reconstruction
  - early development of multi-interaction challenge – must solve if wish to usefully employ a near liquid argon TPC

CAPTAIN Current Status

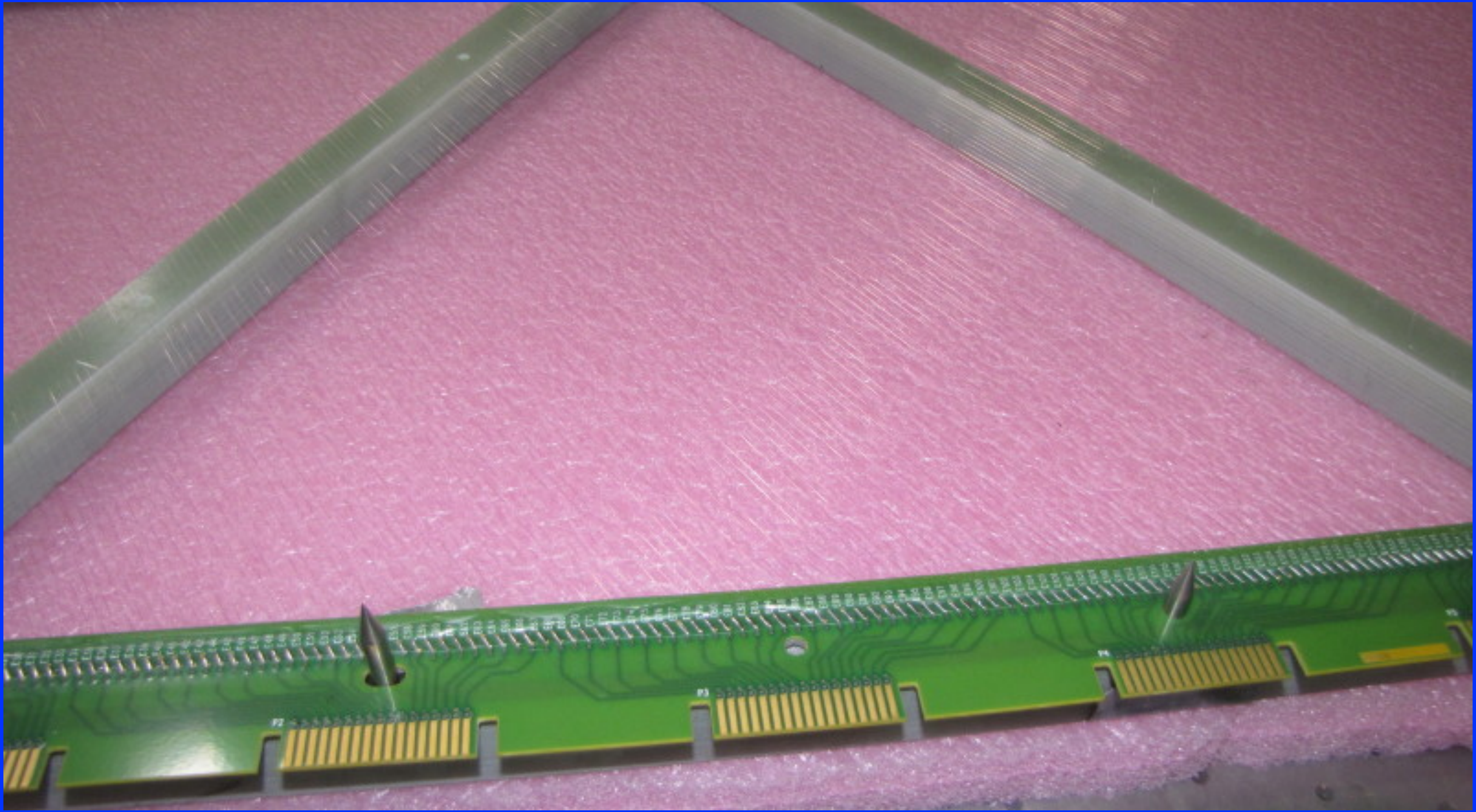
- Electronics end-to-end acquired and tested for the prototype and for CAPTAIN
- DAQ tested
- Prototype TPC completed
- Prototype TPC HV tested in air
- Cryogenic components assembled
- Nitrogen test of prototype TPC next week
- First argon fill in second half of June
- CAPTAIN cryostat delivery expected in June
- CAPTAIN purification skid expected in June
- CAPTAIN TPC assembled this summer at UCI

Mini-CAPTAIN field cage

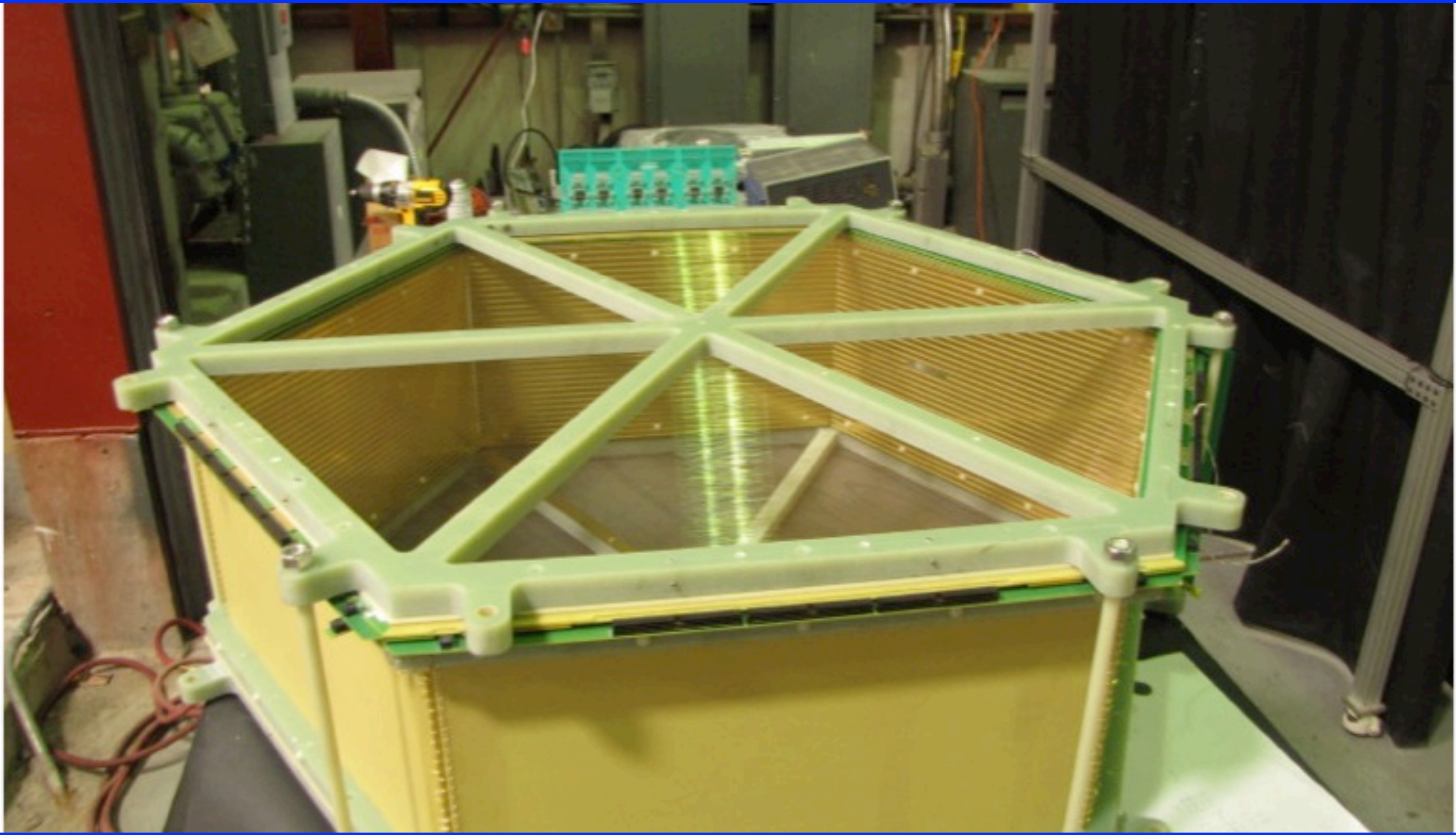
Mini-CAPTAIN wire frame



Wire-frame close-up

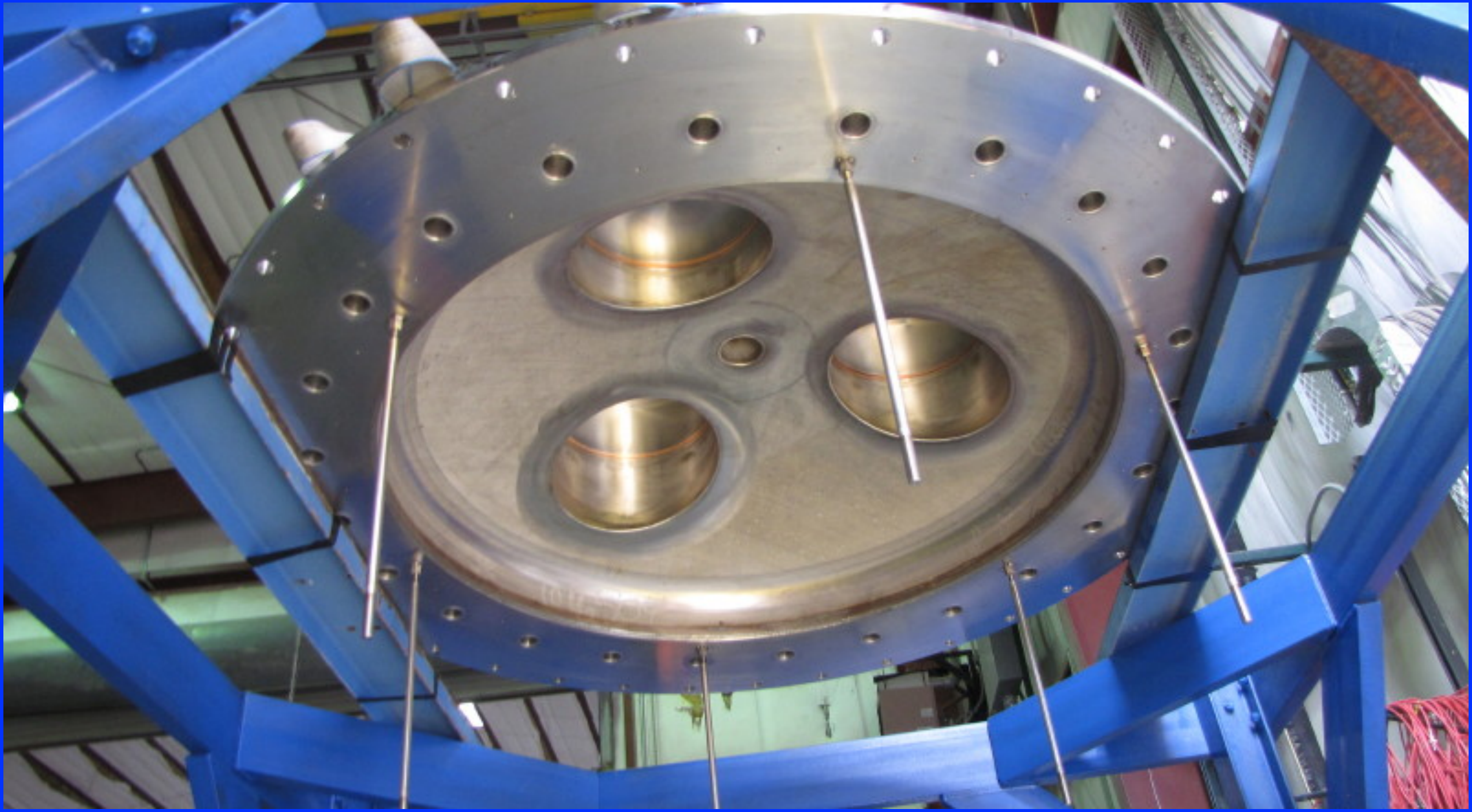


Mini-CAPTAIN TPC assembled



Mini-CAPTAIN cryostat

Mini-CAPTAIN lid and support stand



Prototype Detector

LANL postdoc Charles Taylor prepares the prototype

Cryostat at Vendor (April, 2014)

Cryostat last week

Conclusions

- The Long-Baseline Neutrino Experiment consists of an exciting and diverse physics program enabled by a strong and developing international partnership
- The beam neutrino physics probes the neutrino mass hierarchy, leptonic CP violation, non-standard neutrino interactions among others
- The highly capable near neutrino detector enables the long-baseline neutrino oscillation program as well as a significant high precision neutrino interaction program
- The far detector – besides its duties as a far detector for the beam physics program – enables searches for baryon number violation, measurements of neutrinos from supernova bursts, and measurements of atmospheric neutrinos
- The CAPTAIN Detector is a liquid argon time-projection chamber with 5 instrumented tons being constructed at Los Alamos National Laboratory
- CAPTAIN is designed to address scientific questions of importance to two major LBNE missions: low-energy (supernova) neutrinos and medium-energy (long-baseline, atmospheric) neutrinos and will do so with neutron beam running and neutrino running
- The CAPTAIN collaboration is a scientifically strong organization with significant leadership from UC institutions