

LBNE



Long-Baseline Neutrino Experiment

Jennifer Raaf, on behalf of the LBNE Collaboration
Fermilab Users Meeting
June 12-13, 2013



Introduction

- We have learned a lot about neutrino mixing
 - Measured 2 mass splittings and 3 mixing angles
- We have a viable & predictive model: 3x3 PMNS matrix
 - Question: *Is it a correct description of neutrinos?*
- Assuming it is... still many questions:
 - *What is the mass hierarchy?*

 normal? or  inverted?

- *Is $\theta_{23} = 45^\circ$?*
- *Is CP violated?* $P(\nu_\alpha \rightarrow \nu_\beta) \neq P(\bar{\nu}_\alpha \rightarrow \bar{\nu}_\beta)$?

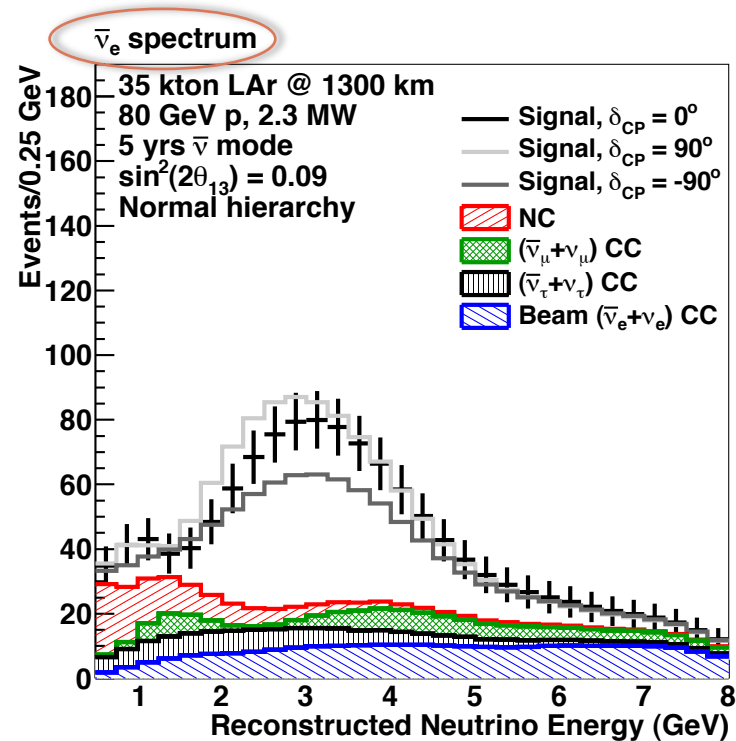
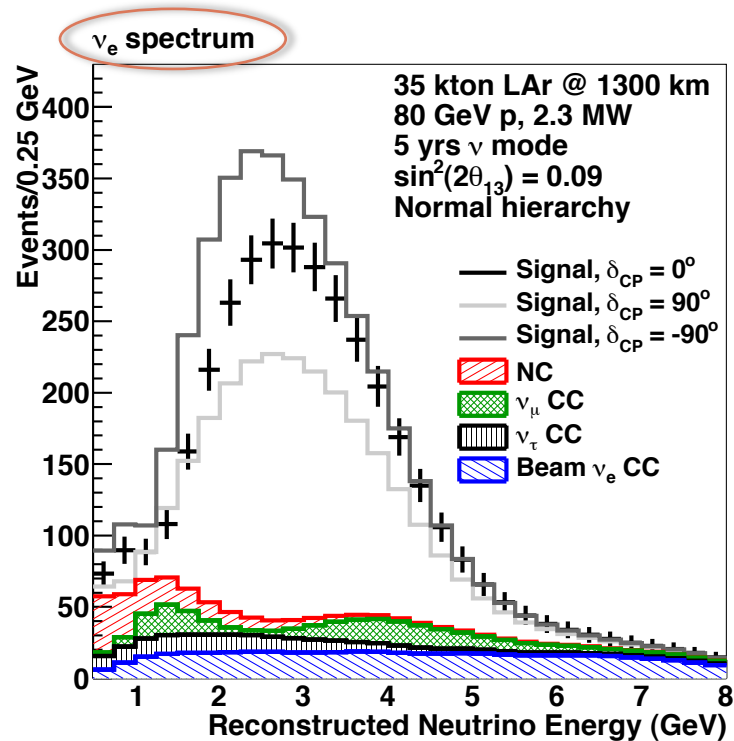
LBNE aims to address these questions (and more)

LBNE Scientific Motivations

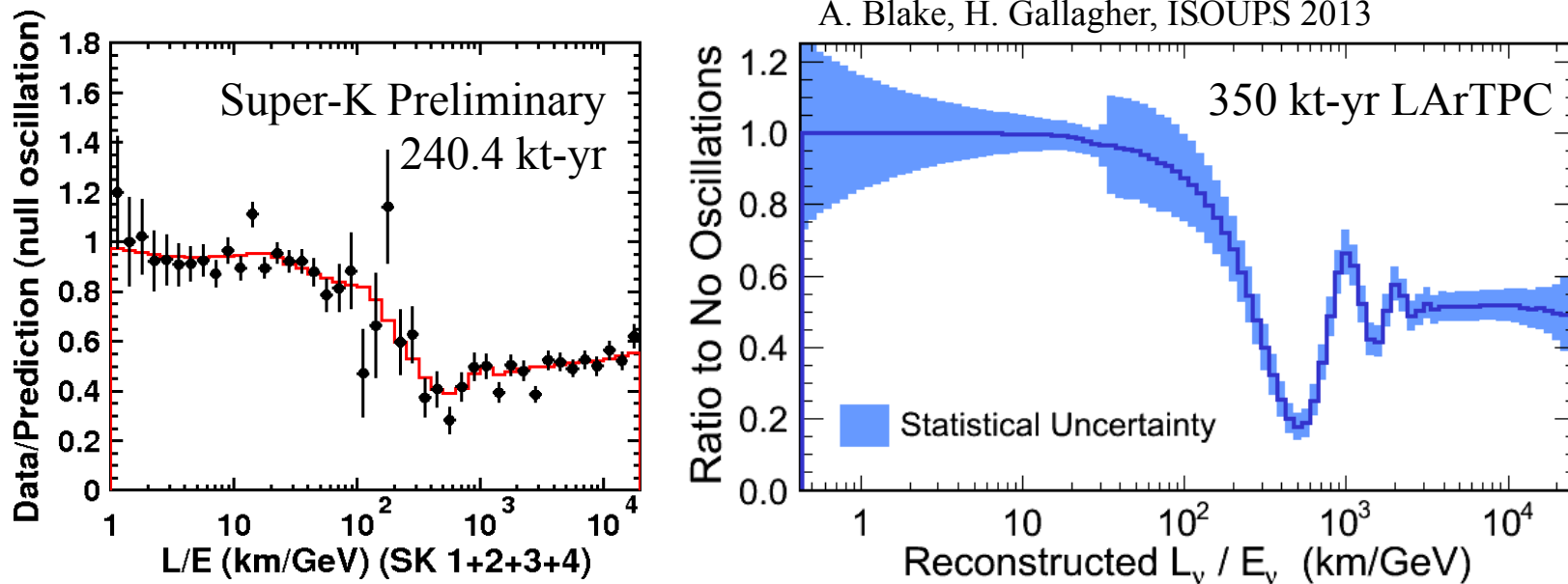
- **Explore 3x3 model of ν mixing**
 - Broad band beam and high resolution detector
 - CP violation and mass hierarchy
- **Atmospheric neutrinos**
 - Independent ν source, can determine mass hierarchy, and others
- **New ν physics**
 - Sterile ν , non-standard interactions, other
- **Proton Decay**
 - Test fundamental but unexplained conservation of baryon number
 - Grand Unified Theories predict specific decay modes, lifetimes, branching ratios
- **Astrophysics**
 - Supernova burst ν

CP Violation

- Signature of CP violation: difference in probabilities for $\nu_\mu \rightarrow \nu_e$ and $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ transitions



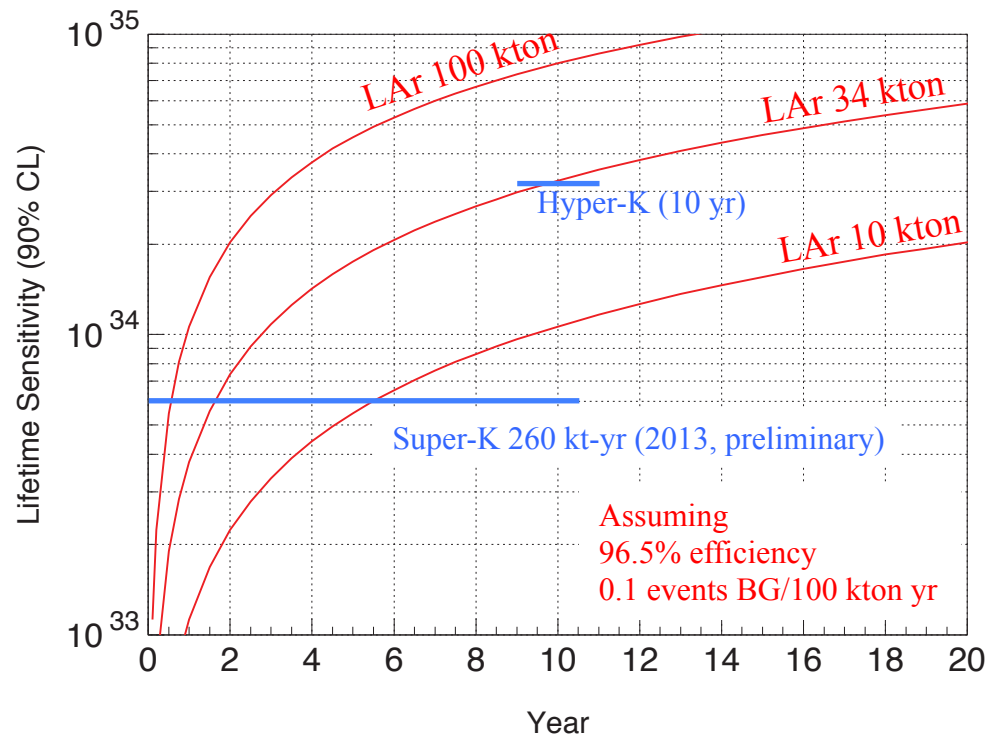
Atmospheric ν 's



- Excellent source of data for detailed exploration of oscillations
 - Free! Huge range of E and L, all flavors of ν and anti- ν in oscillated flux
 - Complementary dataset; help break degeneracies in beam-only analyses
- L/E: spectacular signature of oscillatory behavior in Super-K water Cherenkov detector, even more distinct in LAr (multiple osc dips visible!)
- Also good sensitivity to MH, θ_{23} octant, and more exotic physics

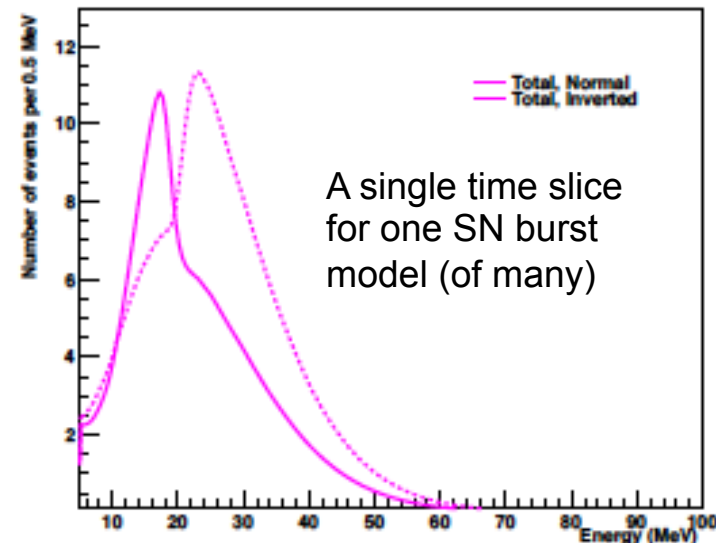
Proton Decay

- Searches for baryon-number-violating processes are highly motivated by Grand Unified Theories
 - In a massive underground detector, look for signatures of proton decay in a data sample of fully-contained events
 - Atmospheric ν 's = background to proton decay searches
- LAr has high efficiency for detecting SUSY-favored decay modes
 - Best for $p \rightarrow \bar{\nu} K^+$ but also good for many other modes
 - A *single* event could be evidence of beyond-SM physics
 - Even if no signal is seen, limits place strong constraints on theory



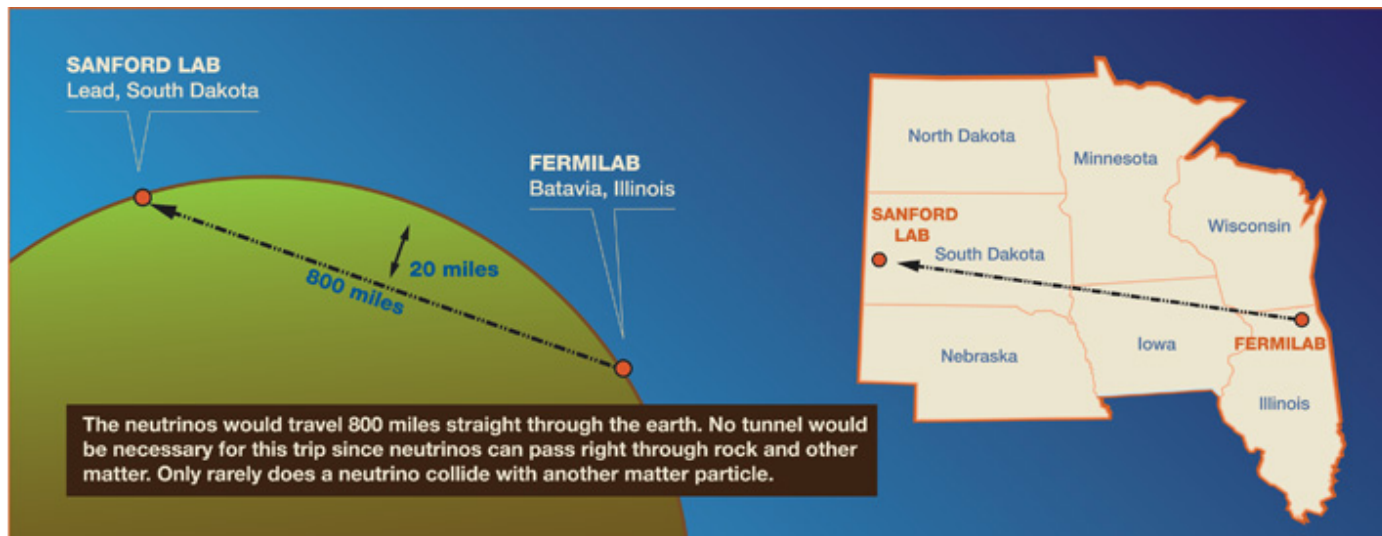
Supernova ν 's

- Nearby core collapse would provide a wealth of information via its ν signal
 - Thousands of ν interactions in 34 kt LAr detector in a very short time (10's of seconds)
 - Base model of core collapse was confirmed by observation of only 19 events in two detectors for SN1987A
 - Observation of high-statistics core collapse should allow us to watch time-evolution of neutrino flux, and more...
- Complementary measurements in LAr & WC
 - LAr sensitive to ν_e
 - WC sensitive to anti- ν_e
- A supernova *will* eventually happen (~few per century per galaxy)



LBNE is...

- New neutrino beam at FNAL
 - 700 kW, 60-120 GeV proton beam
 - 2.3 MW capable
- Near detector for neutrinos
- 34 kton far detector at 1300 km baseline (at Sanford Underground Research Facility, SURF) underground with 4850' overburden



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We were asked by DOE to make this a staged program.

We have initial approval for a 10 kton far detector on the surface, but that can be changed before the project baseline is finalized.

We are now actively seeking foreign partners to accomplish the goals listed above.

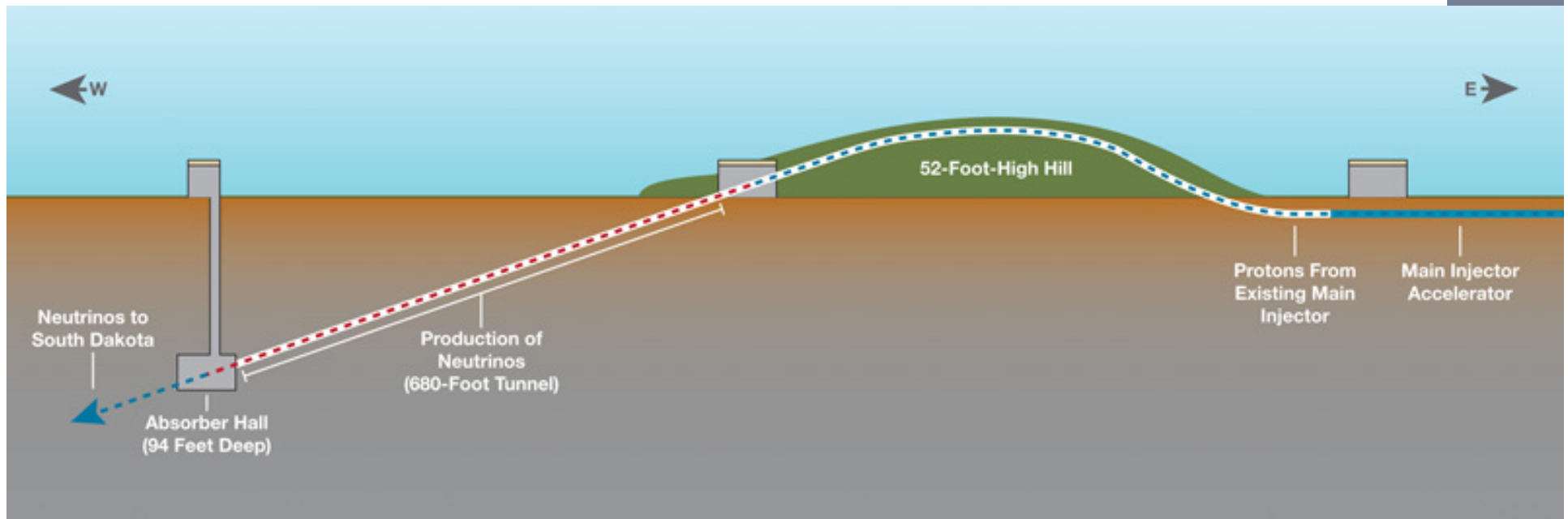
International Partnership

- Many discussions with potential non-US partners
 - In discussions: India, UK, Italy/ICARUS, Brazil, and LAGUNA-LBNO
 - Preliminary discussions: CERN, Dubna
 - Hoping to initiate discussions with: Japan, China, additional countries in the Americas, Asia, and Europe
- Last week, leadership of LAGUNA/LBNO and LBNE began exploring a combined collaboration... LBNx?
 - Wide support from both funding agencies and laboratories if a coherent consortium can be built
 - This is a very recent development which both collaborations are considering seriously

Extremely positive developments!
Stay tuned for more news in the near future.

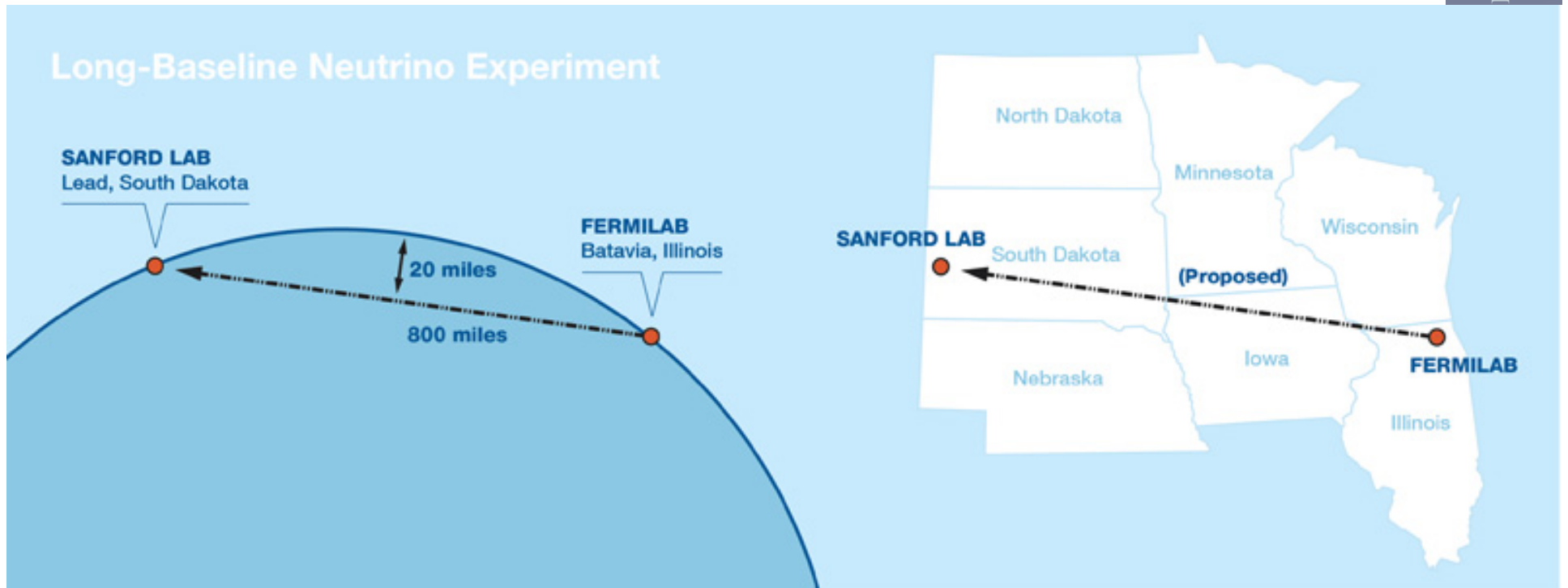
Ingredients For Success

- **Beam**
 - We know how to build this, based on past experience
 - Beamline also capable of handling higher power (2.3 MW)

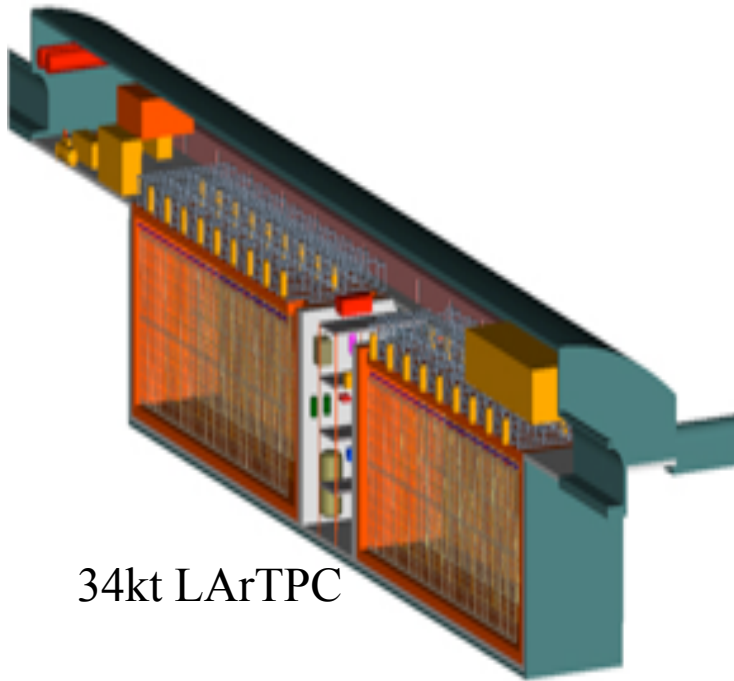


Ingredients For Success

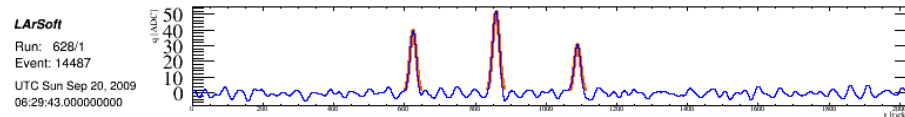
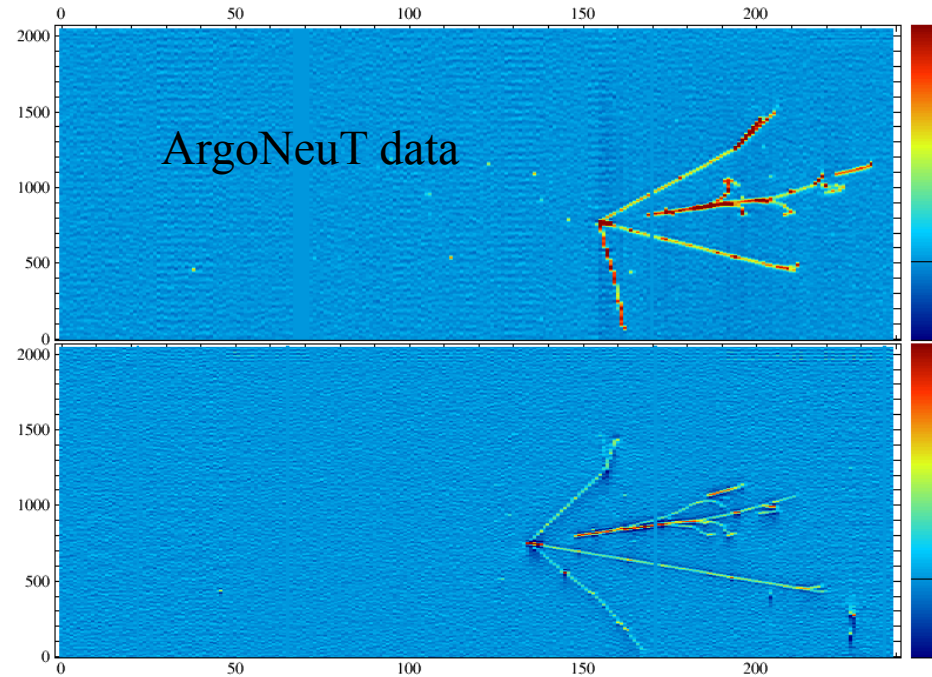
- **Beam**
 - We know how to build this, based on past experience
 - Beamline also capable of handling higher power (2.3 MW)
- **Baseline**
 - We know how to send neutrinos long distances (e.g., MINOS, NOvA)
 - Many detailed studies show that 1300 km (~800 miles) is optimal for this physics



Ingredients For Success



34kt LArTPC



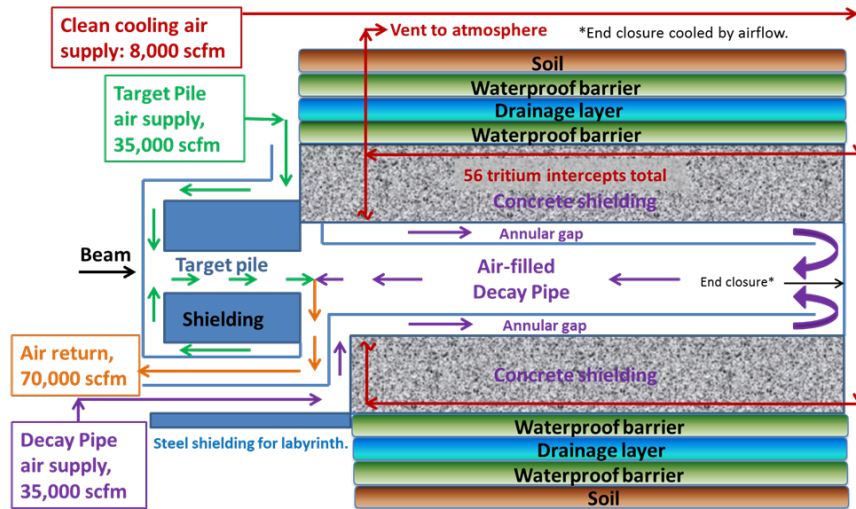
- **Detector**

- Liquid Argon time projection chamber (LArTPC)
 - High signal efficiency, low backgrounds, excellent resolution
- Successfully built and operated on small scales
- Now working to demonstrate that it can be done at the massive scale needed for LBNE

What is LBNE doing right now?

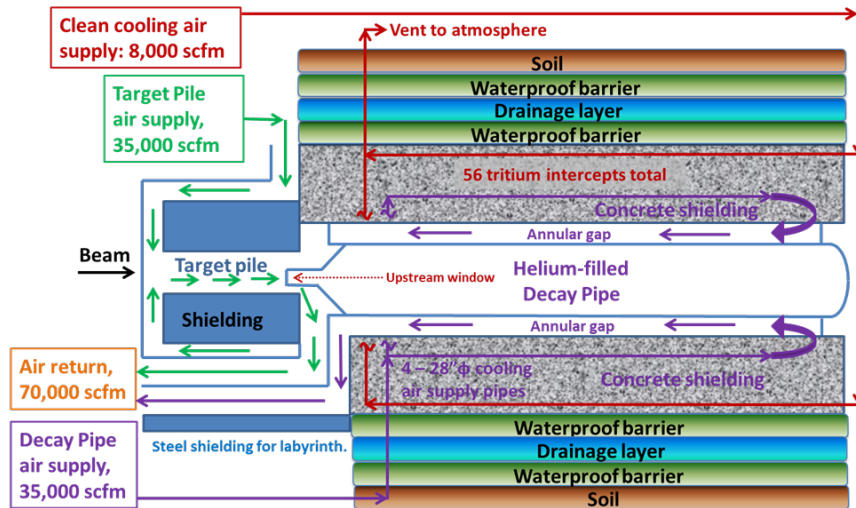
- **Near/Far Site development**
 - Preliminary geotechnical efforts for near and far site have started
- **Beamline development**
 - Advancing and improving beamline design
 - Decay pipe size, filling & cooling, target chase, target, horns, absorber...
- **Development of simulations & event reconstruction software**
 - Full Geant4-based simulation of LArTPC
 - LArSoft + PANDORA-based reconstruction efforts
- **Light collection system R&D**
 - Acrylic light guides, WLS-fiber-based system, wider acrylic panels with fibers...
- **35-ton Membrane Cryostat prototype**
 - Phase 1: Demonstrate membrane cryostat can achieve required purity for LBNE (This summer!)
 - Phase 2: Install and operate reduced-scale TPC and photon detectors (Install Summer 2014, Run Fall 2014)
- *Plus, many other efforts, some not strictly under LBNE auspices*

Beamline: Decay Pipe



Air-filled/
Air-cooled

Moving from air- to He-filled:
11% gain in ν_e appearance
signal in 2-5GeV region, and
better control of systematics

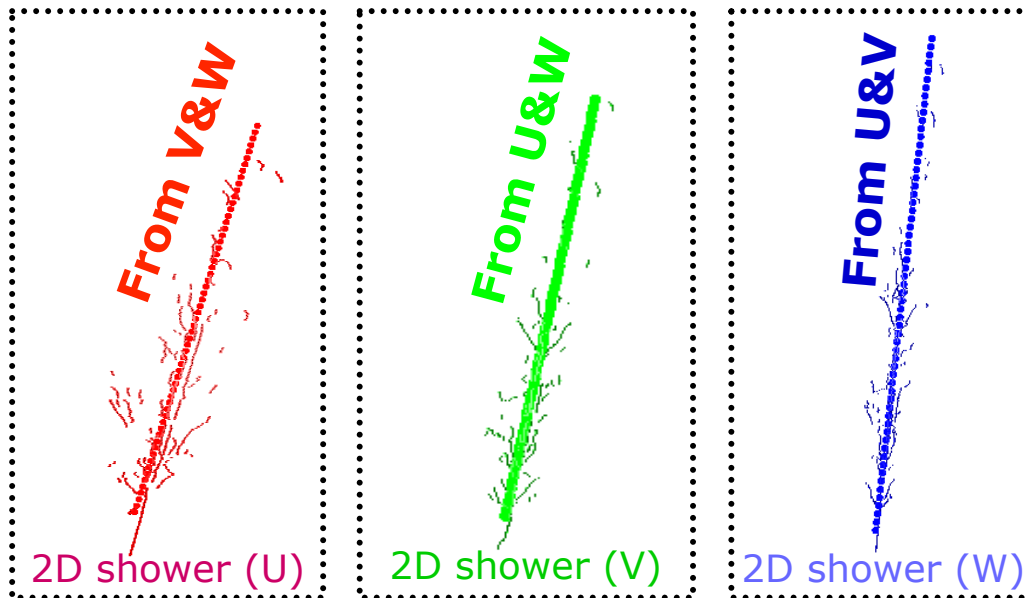


He-filled/
Air-cooled

Event Reconstruction

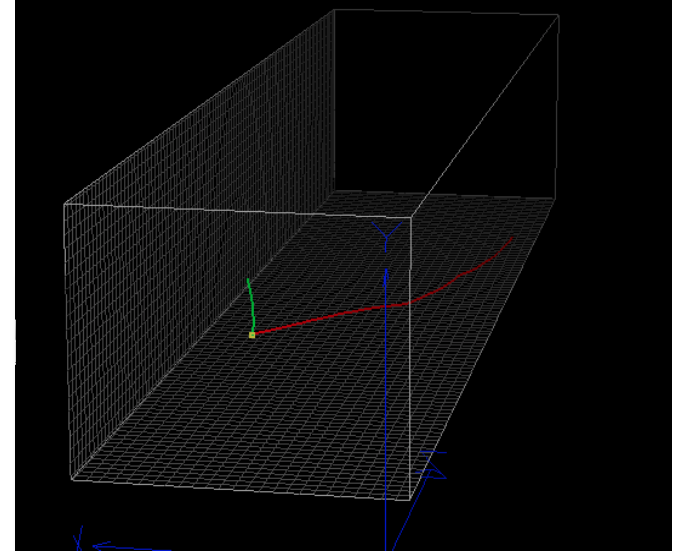
- Efforts on many fronts
 - LArSoft-based hit-finding, clustering, track and shower finding
 - 2D tracks and showers, some functional 3D reconstruction
 - Independent PANDORA-based development (2D, working on 3D)
- Good progress, but still working to move from 2D to full 3D reco

PANDORA-based 2D reconstruction

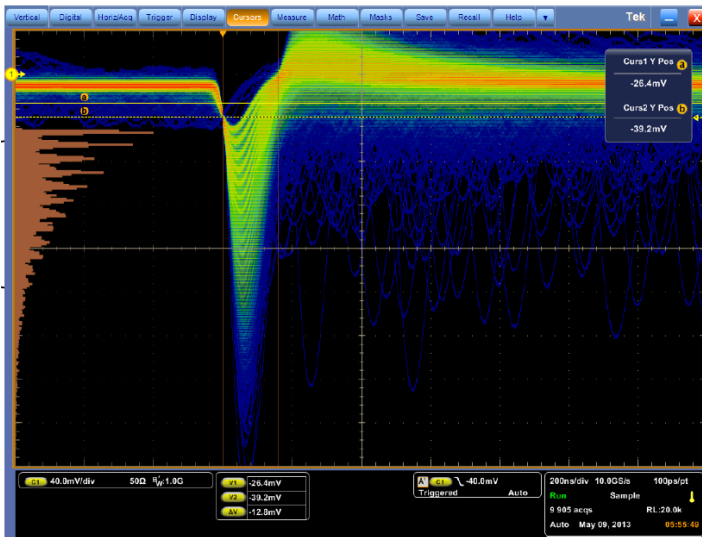
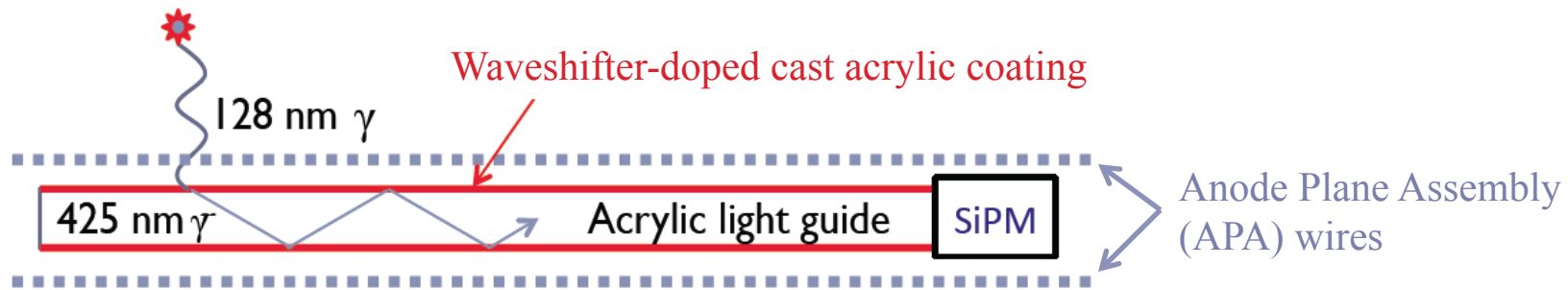


LArSoft-based 3D reconstruction

2 track CCQE-like event,
Both tracks identified and
vertex found



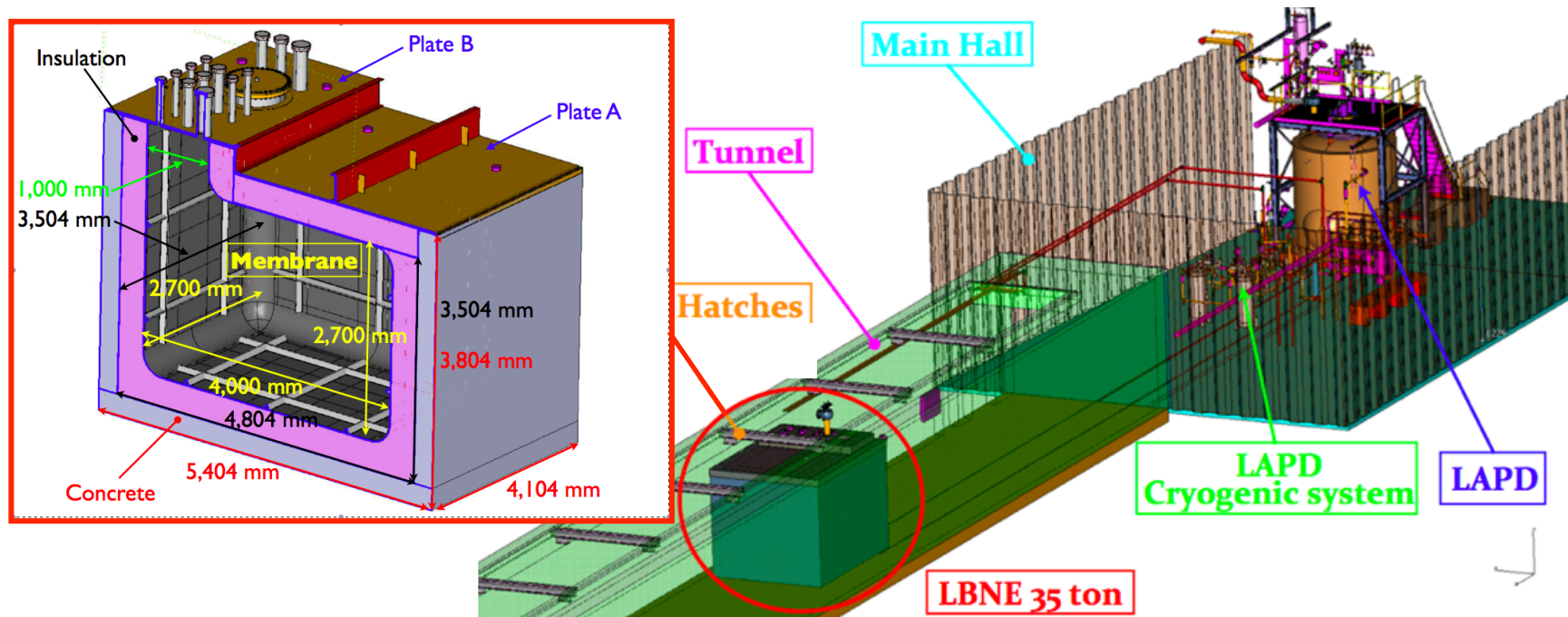
Light Collection R&D



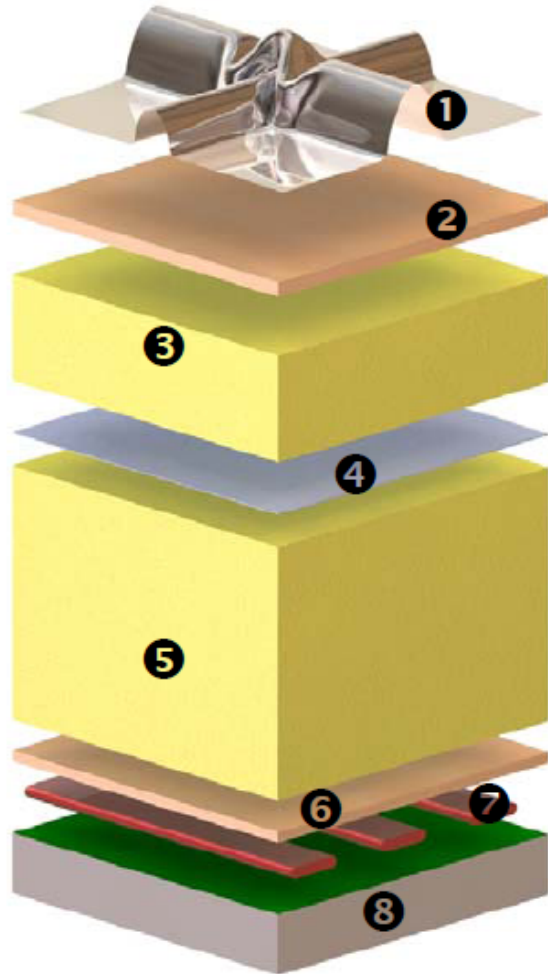
- Successfully exercised photon detection chain:
 - Acrylic waveguide w/Bis-MSB + SensL SiPM + Nevis shaper/amplifier + CAEN digitizer
- New facility to test full-length paddles coming online this summer
- R&D for other approaches
 - Cathode plane photon detector
 - Fiber in wider acrylic panels
 - WLS-fiber based system

35-ton Membrane Cryostat

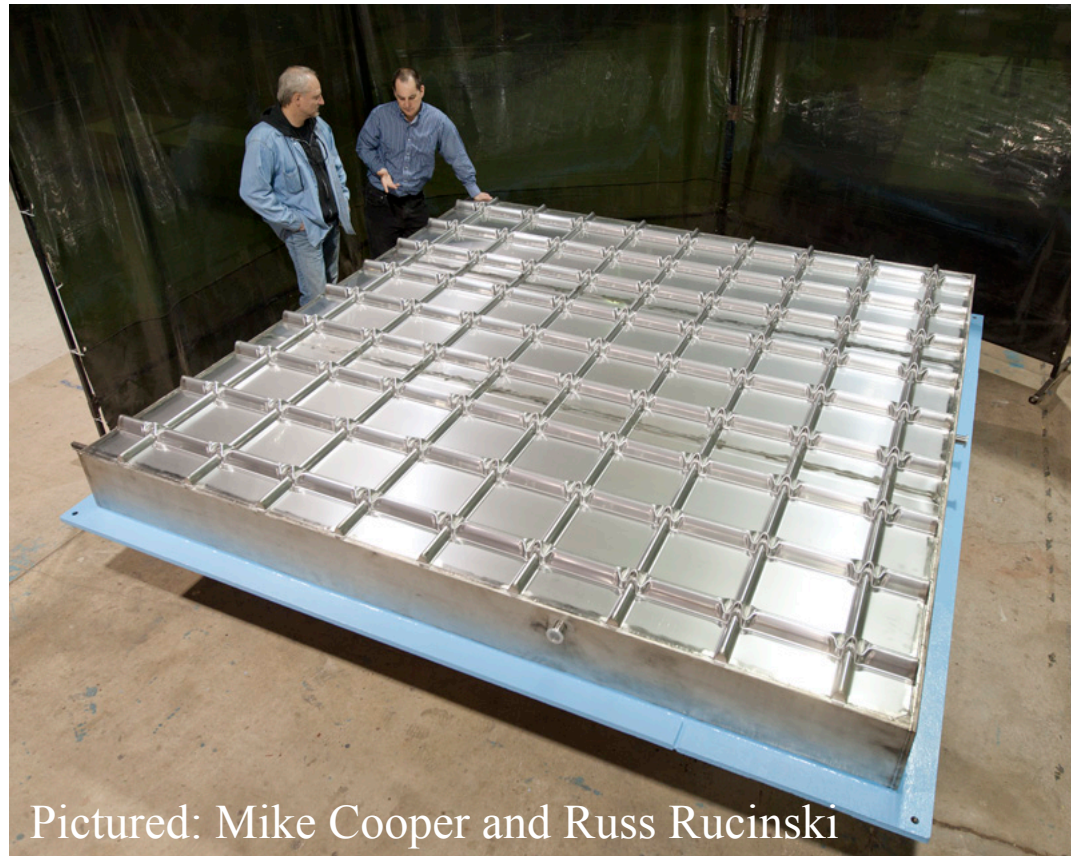
- Attractive option for extremely large LAr detectors
 - Well-understood technology from industry suppliers
 - Prototype will demonstrate thermal performance, feasibility for LAr, leak tightness
 - Also demonstrate that we can achieve and hold the purity requirements needed for the Far Detector



Membrane Cryostat

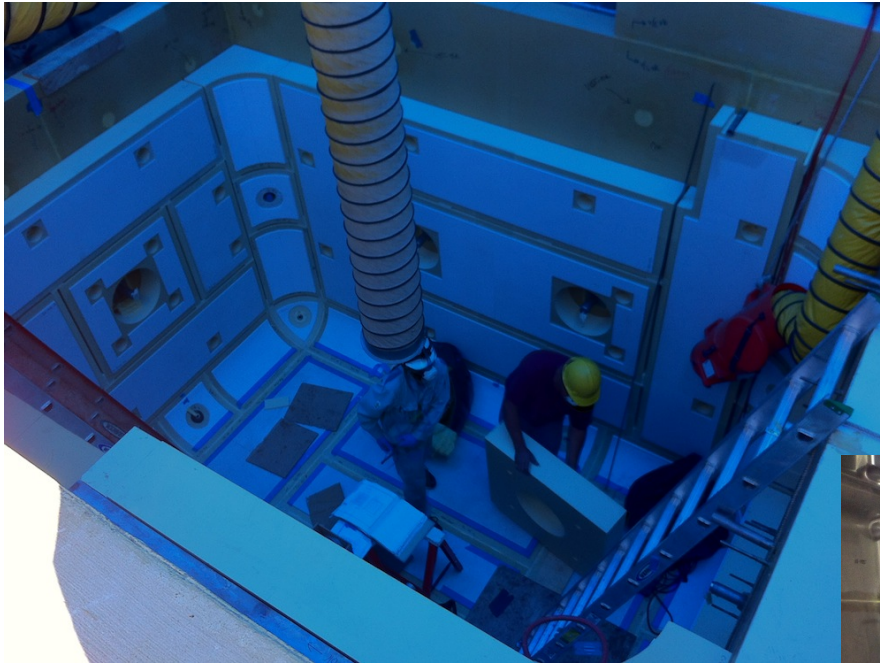


Membrane wall section



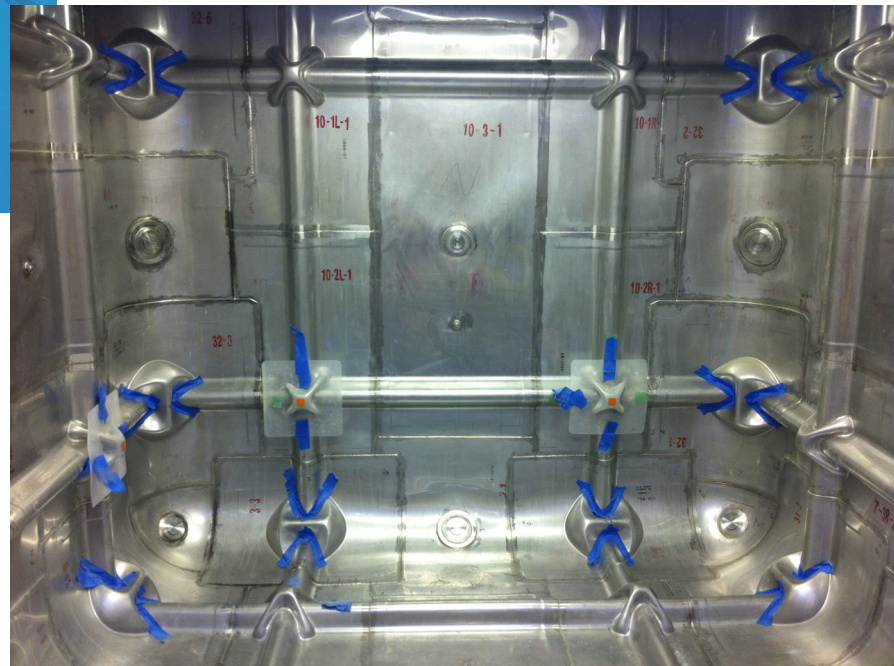
Pictured: Mike Cooper and Russ Rucinski

35-Ton Membrane Cryostat at PC4



Installing insulating foam
(working under a blue tarp in
mid-summer!)

Final layer: stainless steel membrane



Hard Workers

Thank you!

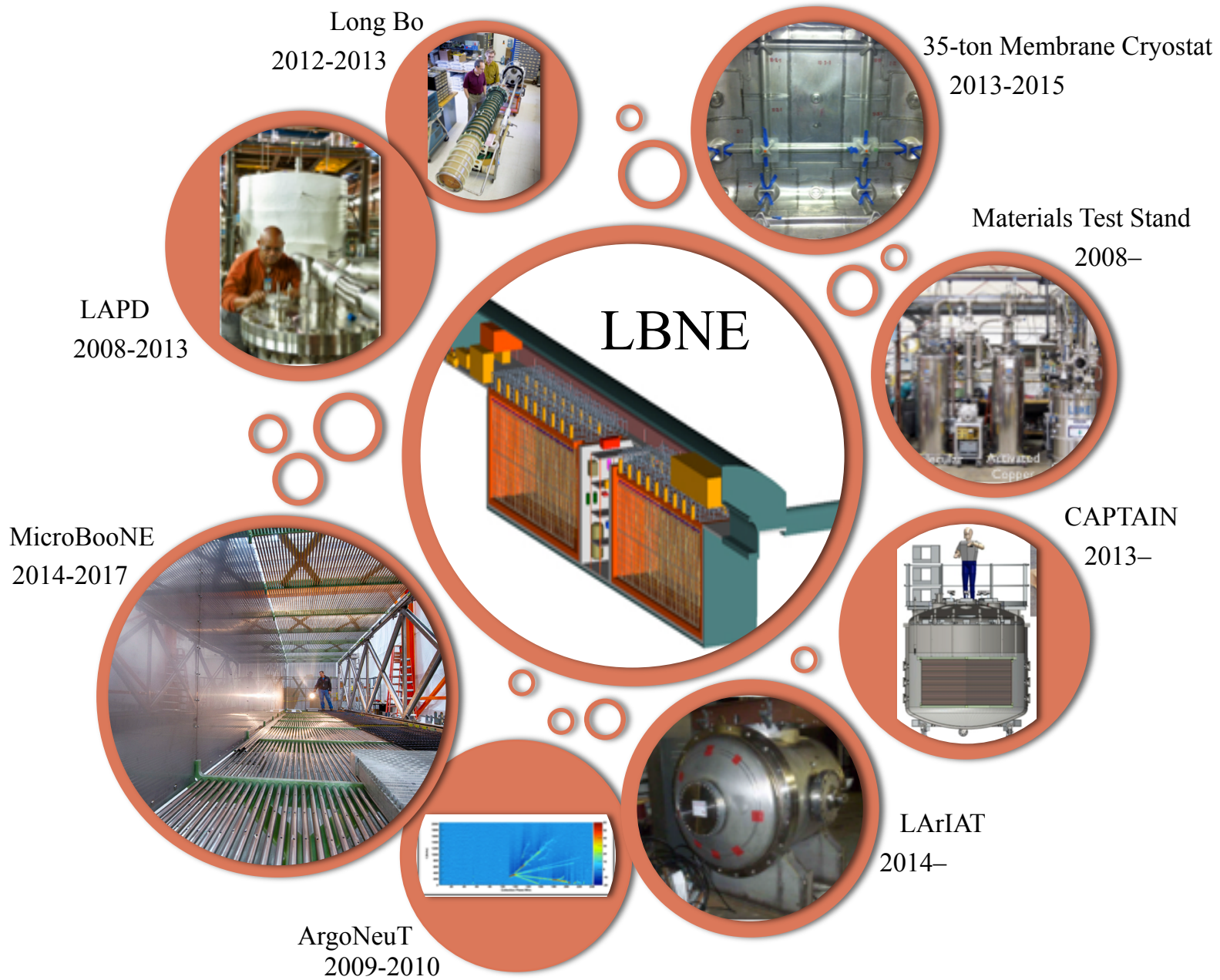


John Najdzion, Bob Kubinski, David Montanari, Ron Davis, Ryan Mahoney, Bryan Johnson, and workers from IHI (Japanese membrane cryostat company)

Not pictured: Terry Tope, Dan Markley, Michelle Stancari, Alan Hahn

Outlook

- LBNE will provide unparalleled measurements of mass hierarchy, CP violation in the lepton sector, precision tests of the 3ν mixing model, and the potential to reveal new physics
- In addition to accelerator-based physics, placing the detector underground will enable a rich program with proton decay, atmospheric ν 's and supernova ν detection
- We currently have a dedicated program (with many efforts) working toward the multi-kiloton scale experiment
 - Beamline optimization
 - Photon detection R&D
 - Software development
 - 35-ton membrane cryostat prototype
 - Other LAr R&D activities not discussed here
 - Will provide additional crucial input to LBNE (test beam calibrations)
 - Need (and have!) good coordination of efforts/goals among groups



Extras

LBNE Collaboration

Alabama
Argonne
Boston
Brookhaven
Cambridge
Catania
Columbia
Chicago
Colorado
Colorado State
Columbia
Dakota State
Davis
Drexel
Duke
Duluth
Fermilab
Hawaii
Indian Group
Indiana
Iowa State
Irvine
Kansas State
Kavli/IPMU-Tokyo
Lawrence Berkeley NL
Livermore NL
London UCL
Los Alamos NL
Louisiana State
Maryland
Michigan State
Minnesota
MIT



372 collaborators, 62 institutions, 5 countries (April 2013)

NGA
New Mexico
Northwestern
Notre Dame
Oxford
Pennsylvania
Pittsburgh
Princeton
Rensselaer
Rochester
Sanford Lab
Sheffield
SLAC
South Carolina
South Dakota
South Dakota State
SDSMT
Southern Methodist
Sussex
Syracuse
Tennessee
Texas, Arlington
Texas, Austin
Tufts
UCLA
Virginia Tech
Washington
William and Mary
Wisconsin
Yale

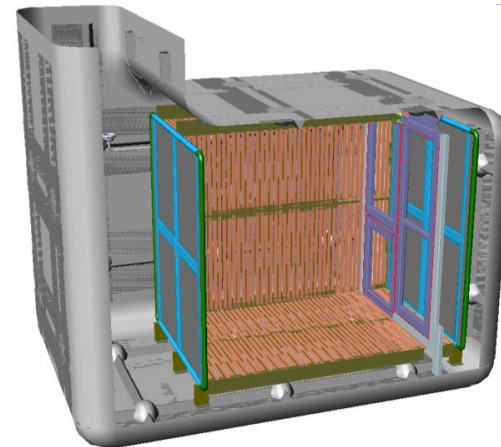
A Strawman Plan

DOE initial investment of \$867M

Additional Investment (TPC)	Capability Added	Science Gained	Science Priority
+ \$140M	Underground placement	ATM nus, p-decay, SNB nus	Very High
+ \$130-190M	Near Detector	Enhanced LB physics, near detector physics	Very High
+ \$200-350M	Add FD mass underground (10 kt -> 34 kt)	Precision CP and other 3-flavor paradigm measurements; p-decay	Very High

35-Ton: Schedule

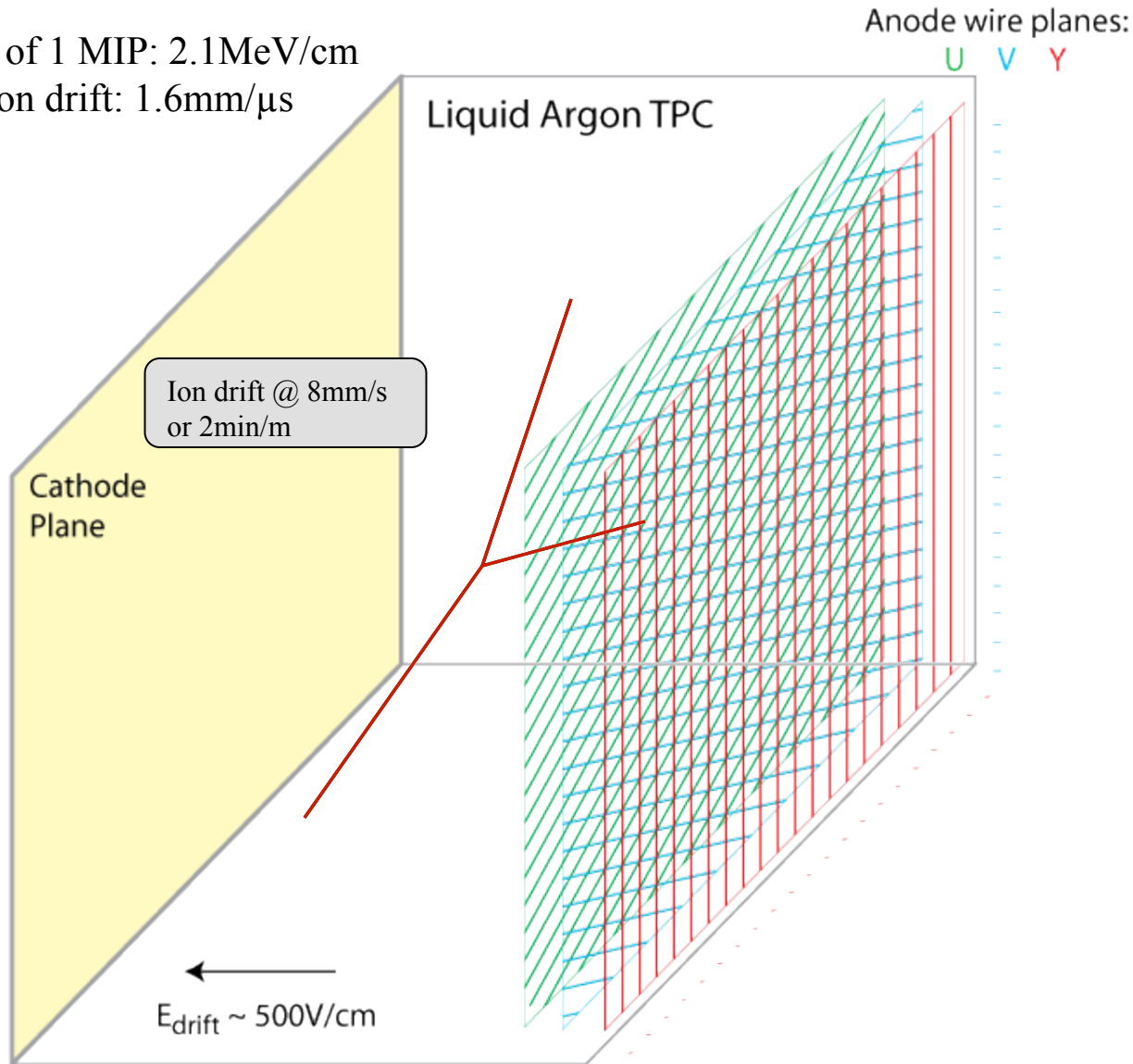
- Phase 1: Demonstrate membrane cryostat can achieve LBNE purity requirements
 - Now working on hookups to LAPD purification facility
 - Expect cooldown and purity run (~2 months) by the end of this summer
- Phase 2: Install and operate reduced-scale LBNE TPC with photon detectors
 - Install in Summer 2014, run in Fall 2014
 - Use prototype versions of LBNE far detector systems



LArTPC Principle of Operation

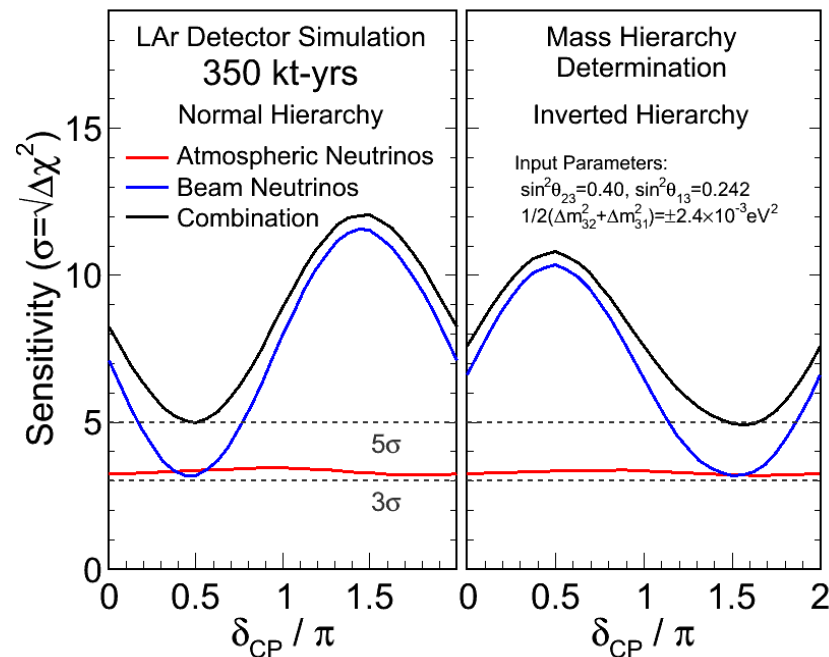
dE/dx of 1 MIP: 2.1 MeV/cm

Electron drift: 1.6 mm/ μ s



Mass Hierarchy

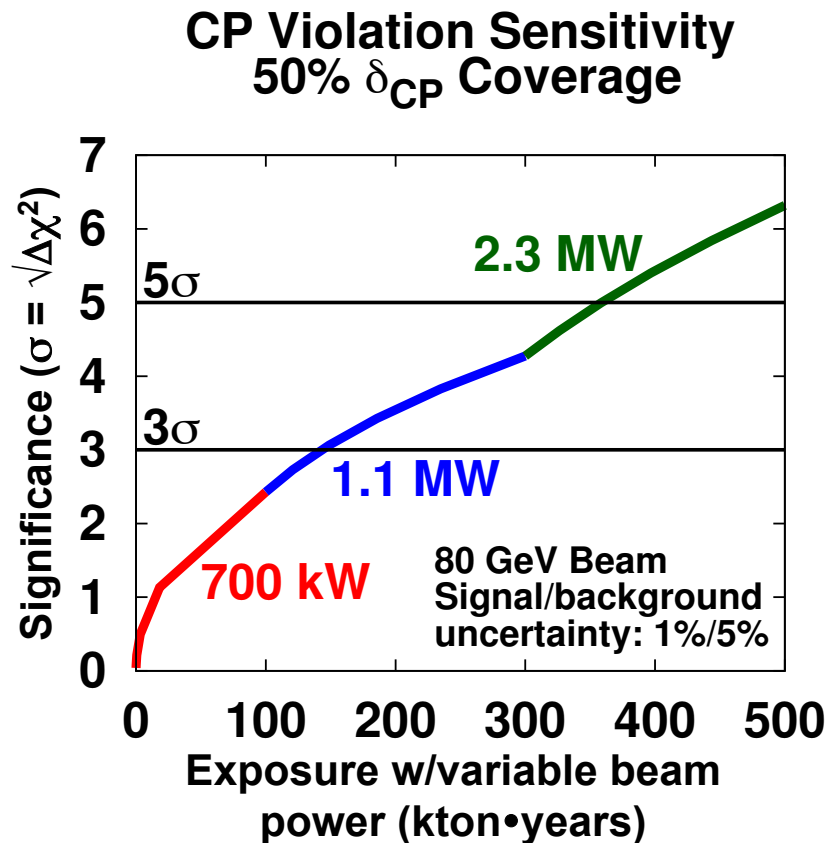
- Combined sensitivity to MH (atmospheric + beam) $>5\sigma$ for all values of δ_{CP} in both hierarchies, with 350 kt-yrs exposure
 - In δ_{CP} range least favorable for beam neutrinos, atmospherics have comparable sensitivity
 - $>3\sigma$ sensitivity to MH with atmospherics alone for all values of δ_{CP}



- Atmospheric neutrinos also improve sensitivity to determination of θ_{23} octant, and CP violation (but to a lesser extent).

LBNE Physics: CP Violation

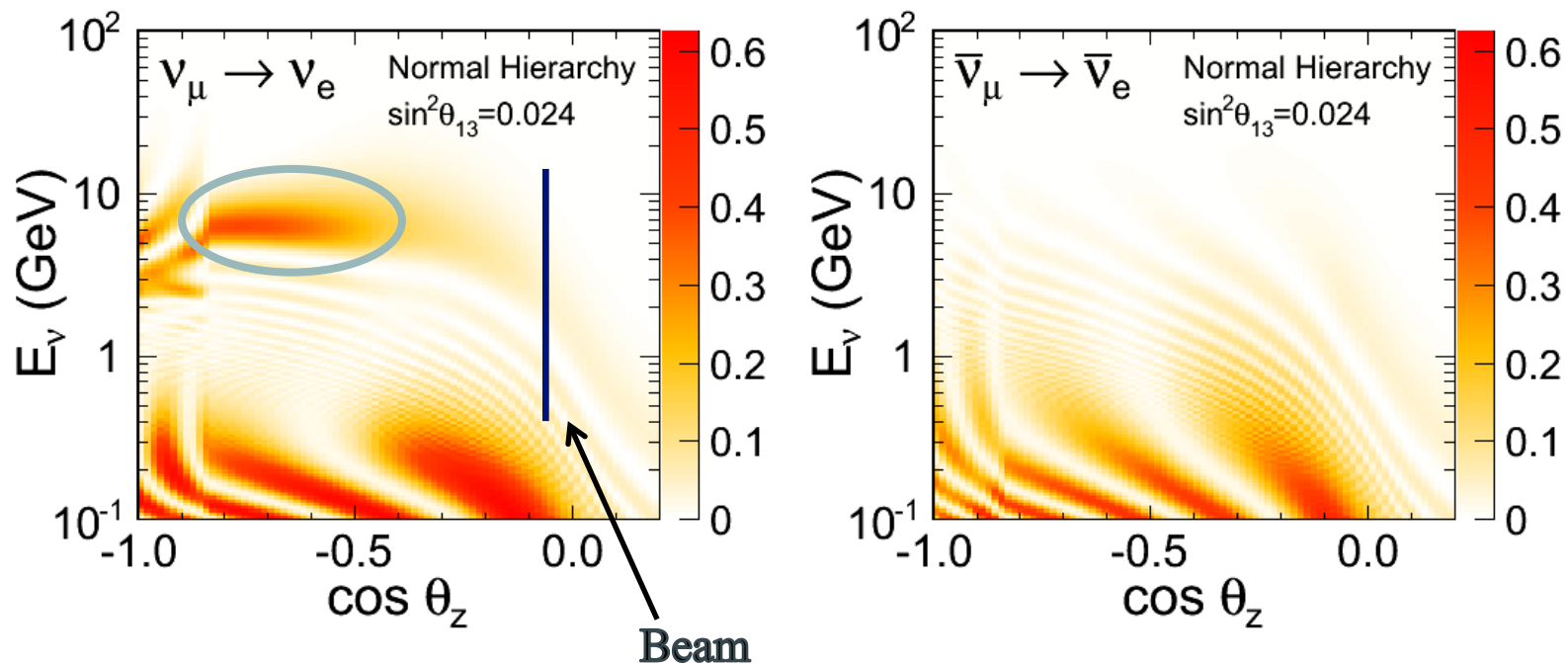
- Well-defined path to get to 5σ measurement of CP violation (w/50% coverage of δ_{CP} space)



- Start with 700 kW beam
- Move to Phase-1 Project X beam (1.1 MW)
- Then full Project X beam (2.3 MW)

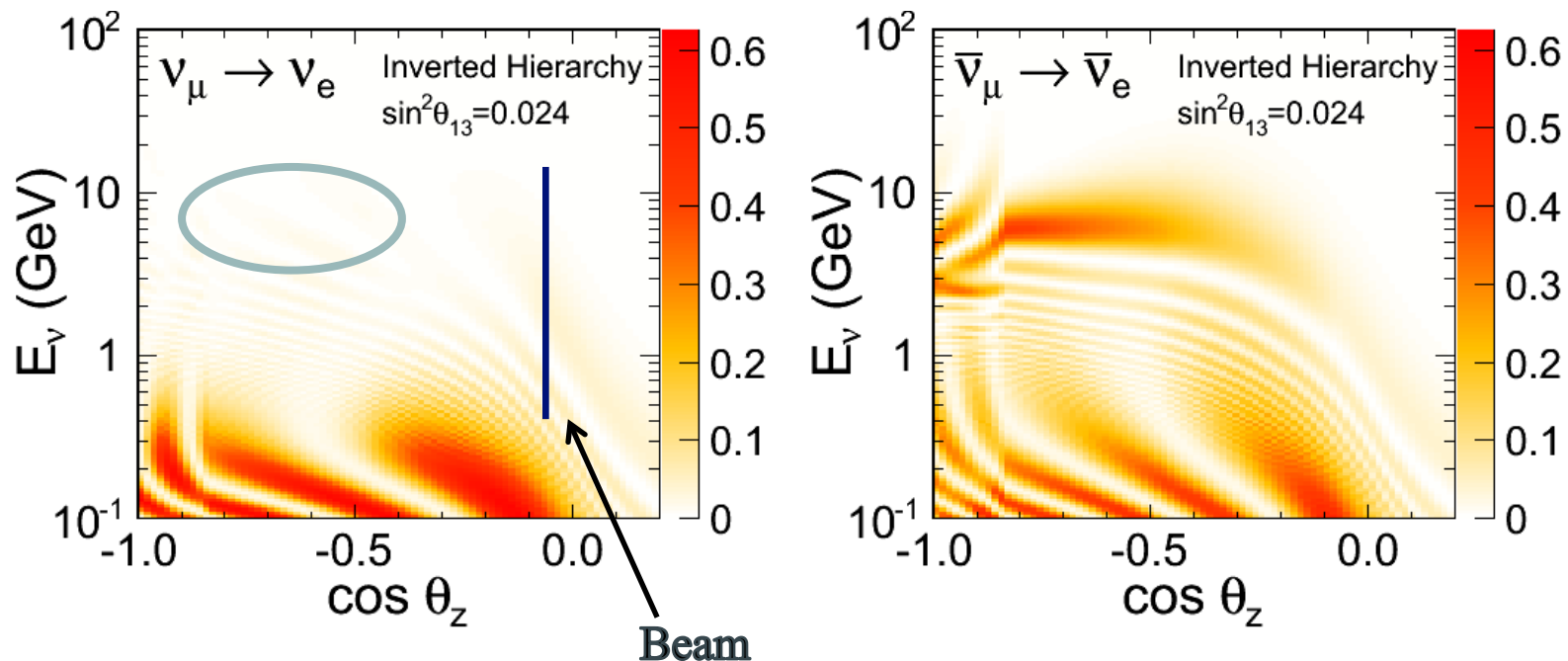
Atmospheric Neutrinos

- Excellent source of data for detailed exploration of ν oscillations
 - Free! Huge range of energies and baselines, all flavors, ν and anti- ν
 - Complementary dataset; help break degeneracies in beam-only analyses
- Mass hierarchy
 - Enhancement in 2-10 GeV upward-going ν for normal hierarchy (anti- ν for inverted hierarchy)

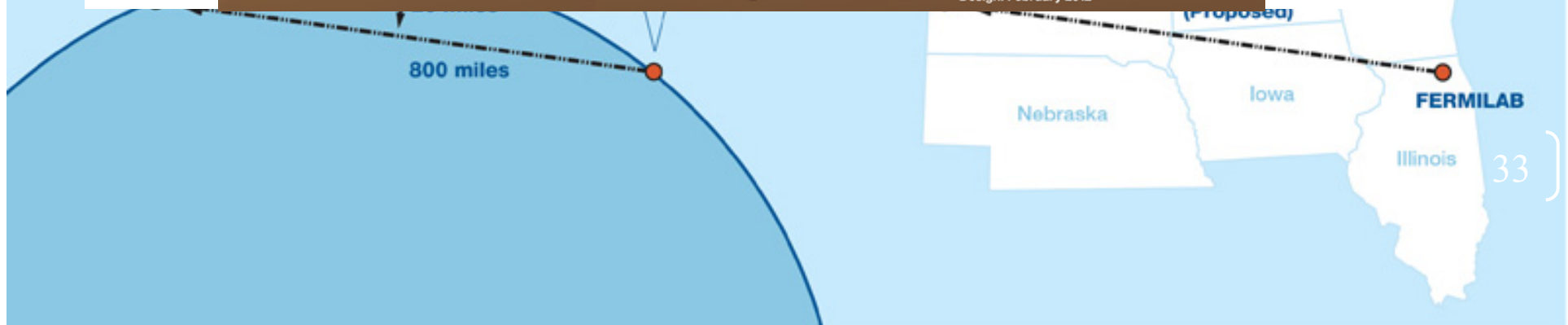
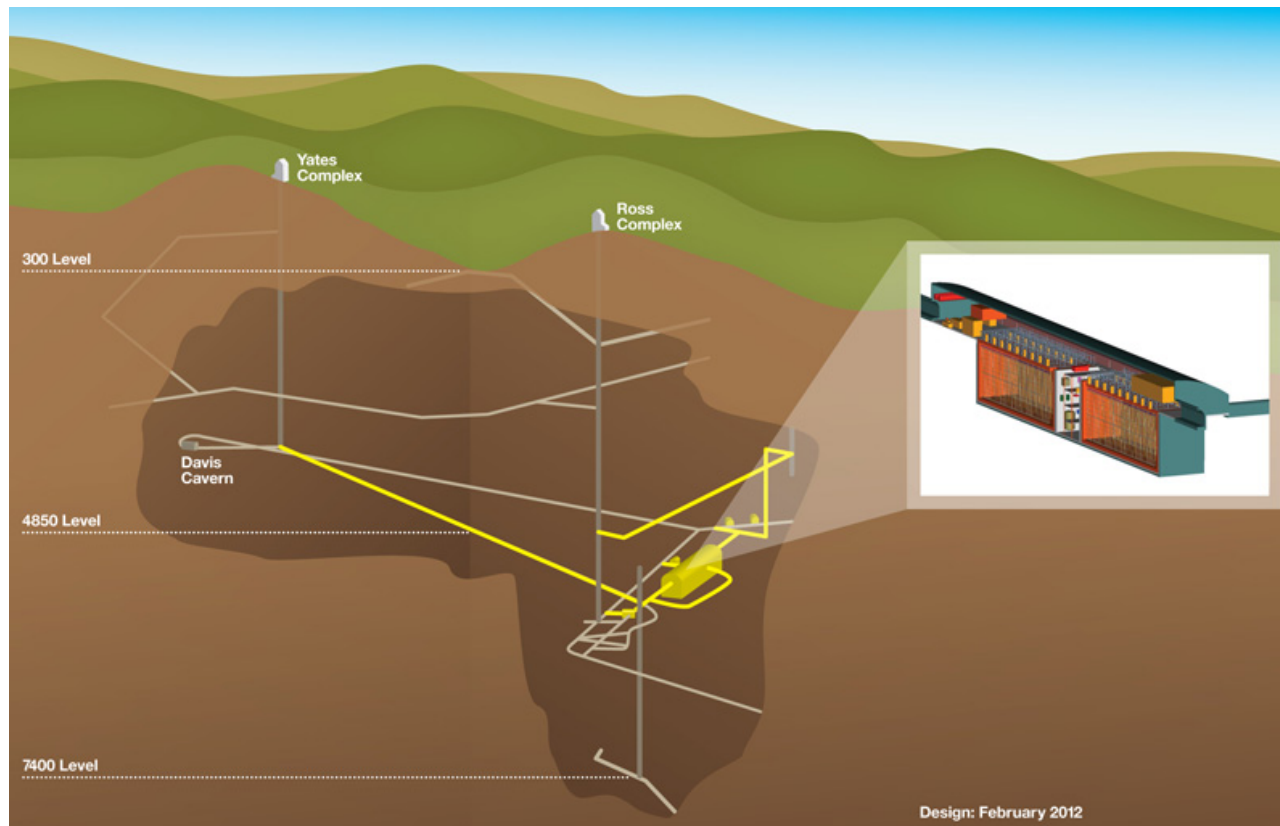


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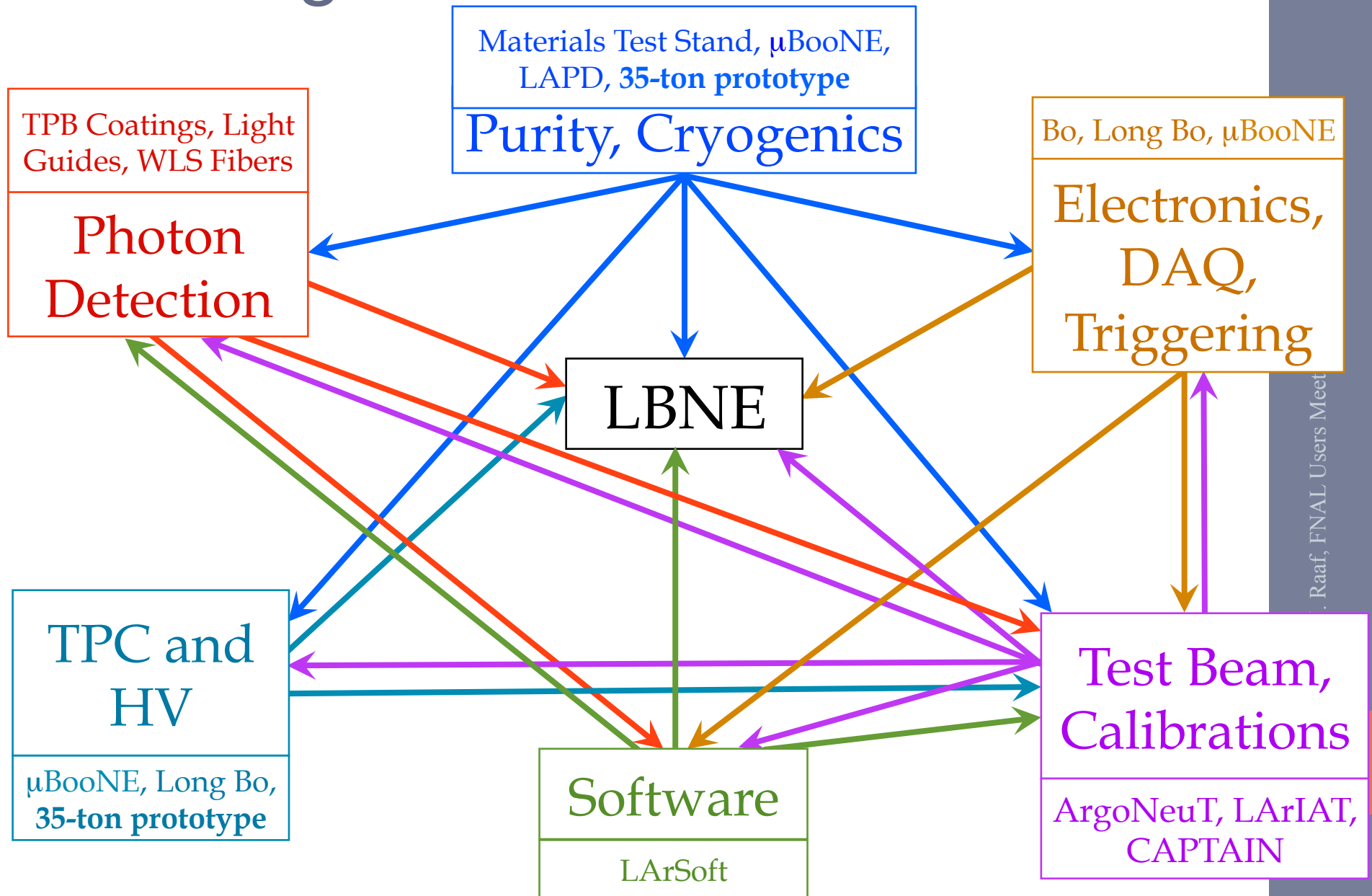
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Ingredients For Success



Working Toward a Common Goal



LArSoft



- LArSoft is a simulation, reconstruction and analysis framework for any LArTPC
- Goal is to have a fully automated simulation and reconstruction for any LArTPC
- LArSoft leverages the efforts of a variety of experiments into a single product
- Accreting a lot of new effort thanks to the LBNE technology decision and μ BooNE construction
- Now managed by Fermilab Scientific Computing

LArSoft Documentation at
<https://cdcv.s.fnal.gov/redmine/projects/larsoftsvn/wiki>

