The NOvA and LBNE long-baseline neutrino oscillation experiments.

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Introduction

This talk will discuss the present and future US based long-baseline neutrino oscillation experiments in the form of the near-completed NuMI Off-axis electron Neutrino Appearance (NOvA) experiment and the design stage Long-baseline Neutrino Experiment (LBNE).

Contents:

1. Introduction
2. A very brief introduction to long-baseline neutrino oscillation physics
3. NOvA
4. LBNE
5. Summary & conclusions

Long-baseline neutrino oscillations

NOvA & LBNE both measure neutrino flavour transition probabilities of a ν_μ beam over a long baseline.

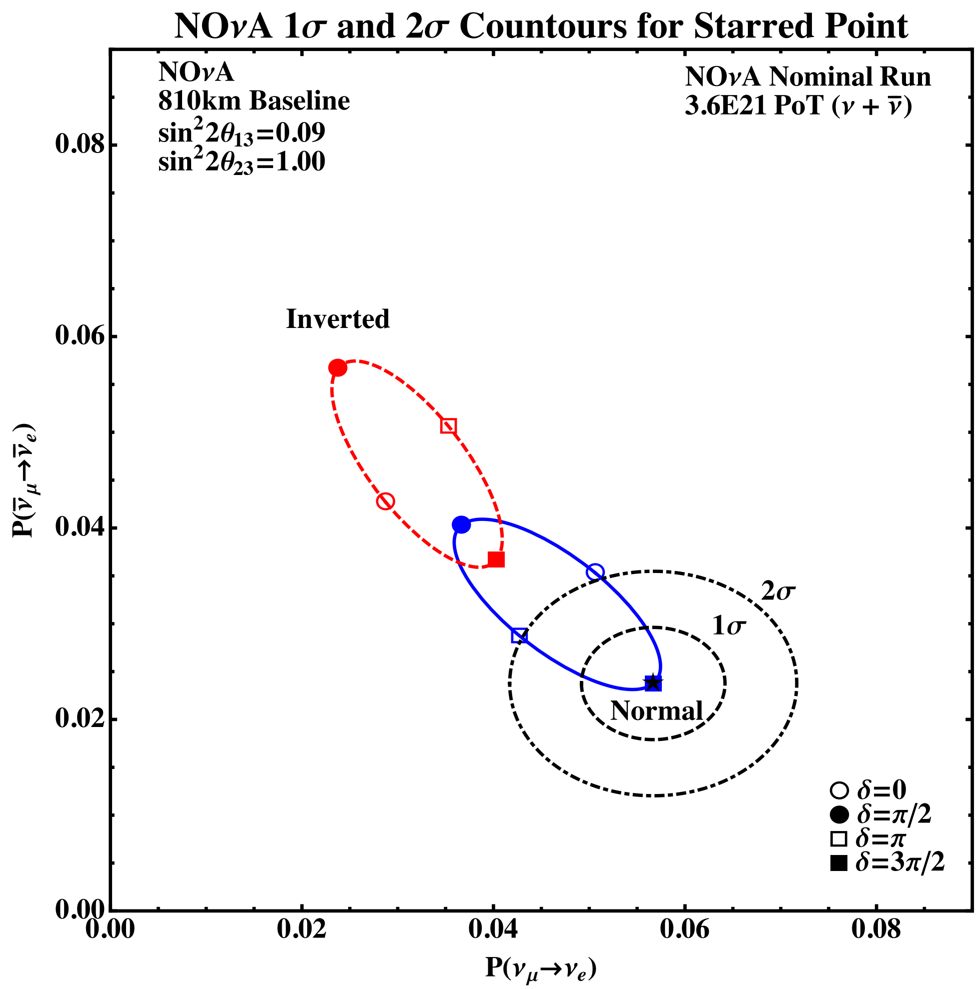
The key observables being the bi-probabilities of:

$P(\nu_\mu \rightarrow \nu_e)$ & $P(\text{anti-}\nu_\mu \rightarrow \text{anti-}\nu_e)$
appearance

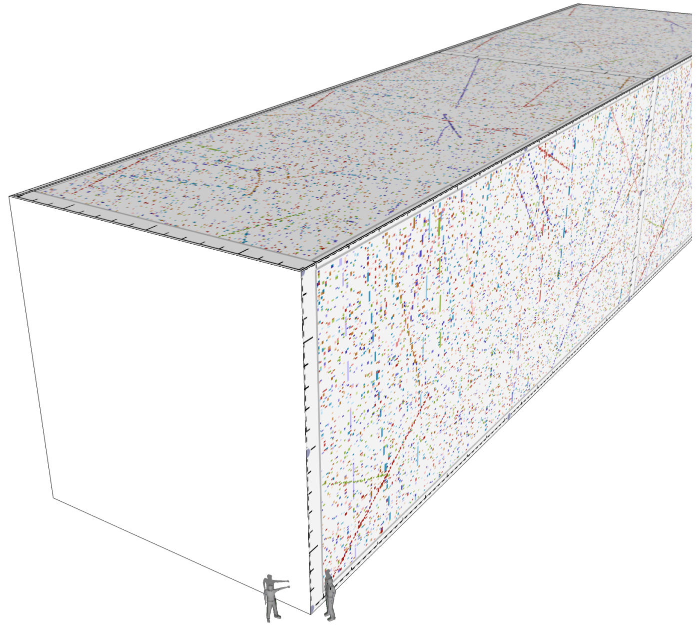
$P(\nu_\mu \rightarrow \nu_\mu)$ & $P(\text{anti-}\nu_\mu \rightarrow \text{anti-}\nu_\mu)$
disappearance

Notably the appearance transition probability is dependent on θ_{13}, θ_{23}, ∂_{CP} and Δm_{31}

Matter effects have a dependence on the relative sign of Δm_{31} → method for determining the mass hierarchy.



For the hypothetical NOvA example shown here. The measured value is shown in black. In this case (∂=3π/2, normal hierarchy) the normal hierarchy would be established at 95% CL.



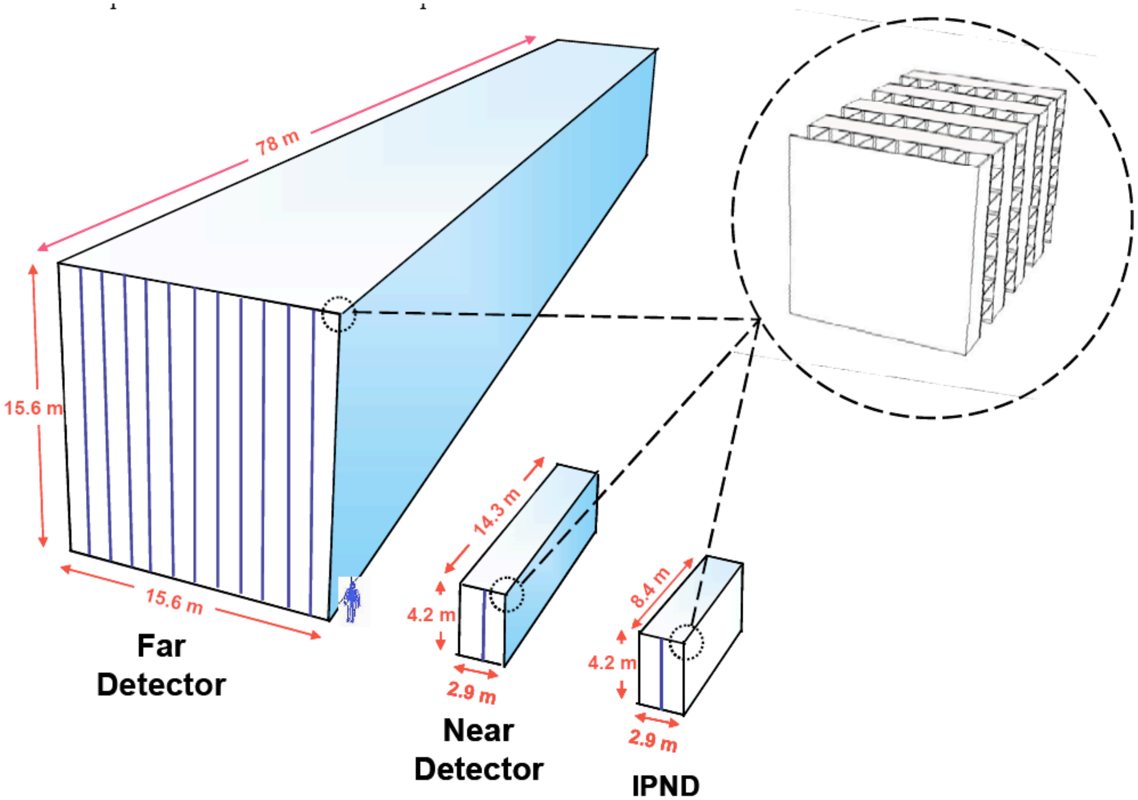

2014

NOνA

NOνA is a second generation long-baseline neutrino oscillation experiment situated in the Fermilab NuMI beam line.

300-ton near detector (ND) and a 14-kiloton far detector (FD) separated by 810 km.

Designed to measure the ν_e and ν_μ content of the NuMI beam before and after oscillation.



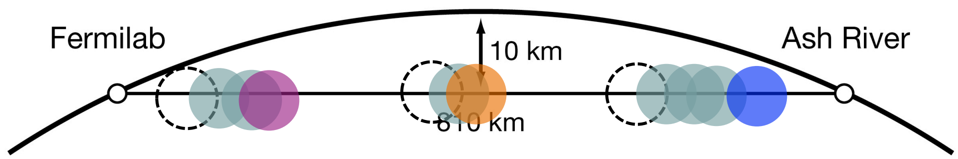
Make high precision measurements of the neutrino mixing parameters and determining the mass hierarchy.

- Precision θ_{23}
- Precision Δm^2_{32}
- θ_{13}
- Mass hierarchy
- Θ_{23} octant
- CPV

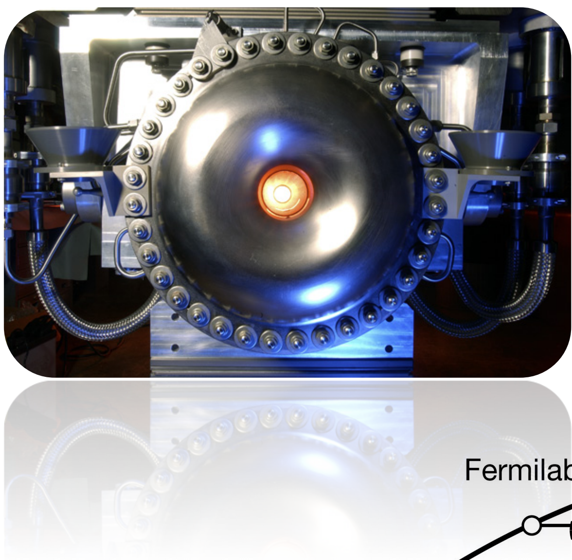
Nearing completion now!

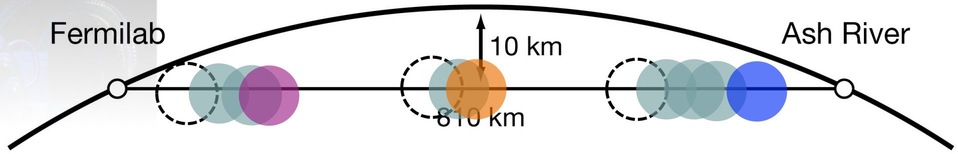
NOvA design


NOvA
Ash River
International Falls
Duluth
MN
Minneapolis
WI
Fermilab
IL


Fermilab
Ash River
10 km
810 km

NOvA design

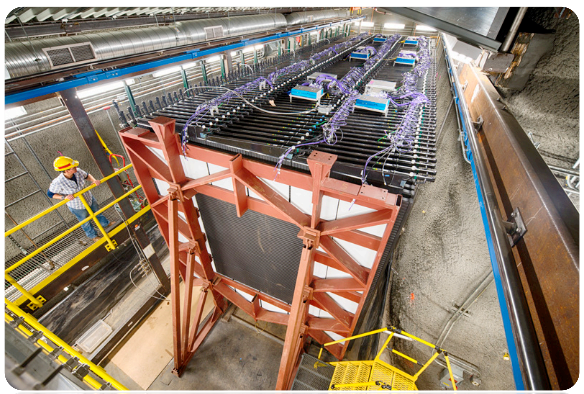


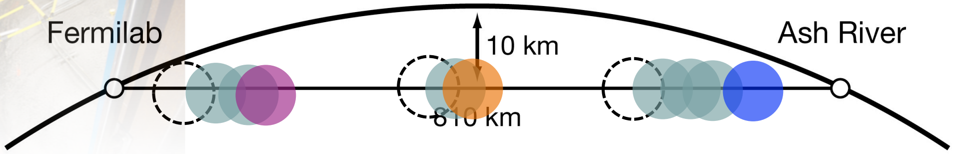


Upgraded "Neutrinos at the Main Injector" (NuMI) accelerator complex:

- 320 kW → 700 kW beam power.
- Nominal NOvA year is 6×10^{20} protons on target (PoT).
- 2.4×10^{20} PoT delivered since August 2013.

NOvA design

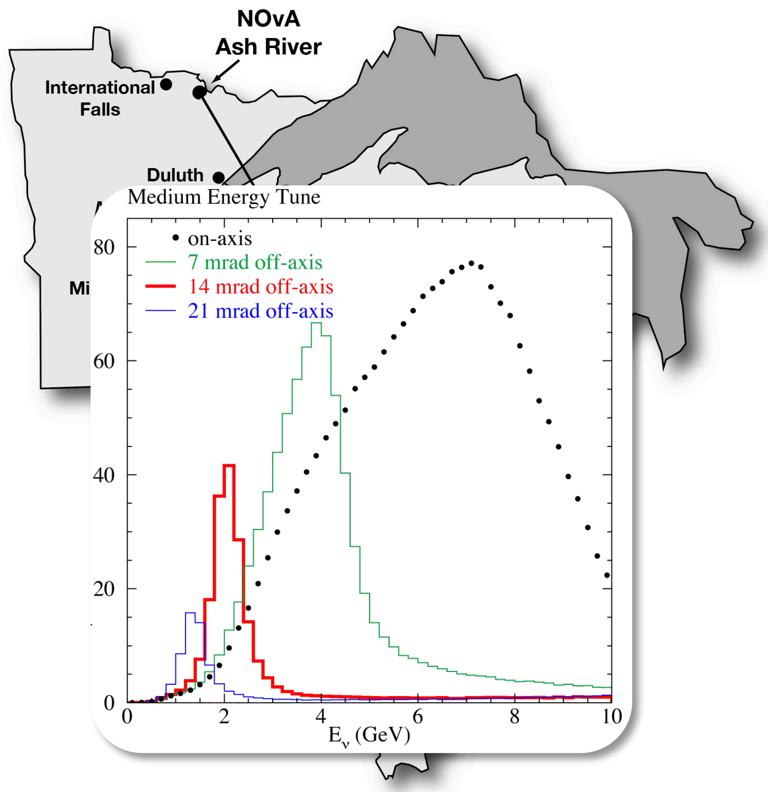


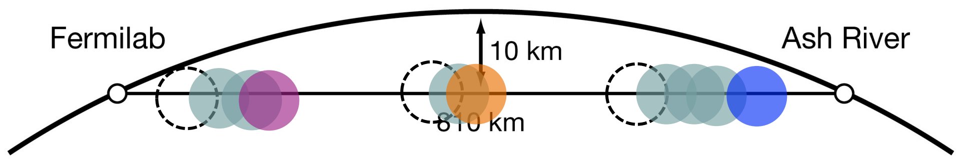


Underground 300-ton near detector.

- Functionally identical to far detector.
- Optimised for NuMI cavern rates: 4x sampling electronics.

NOvA design

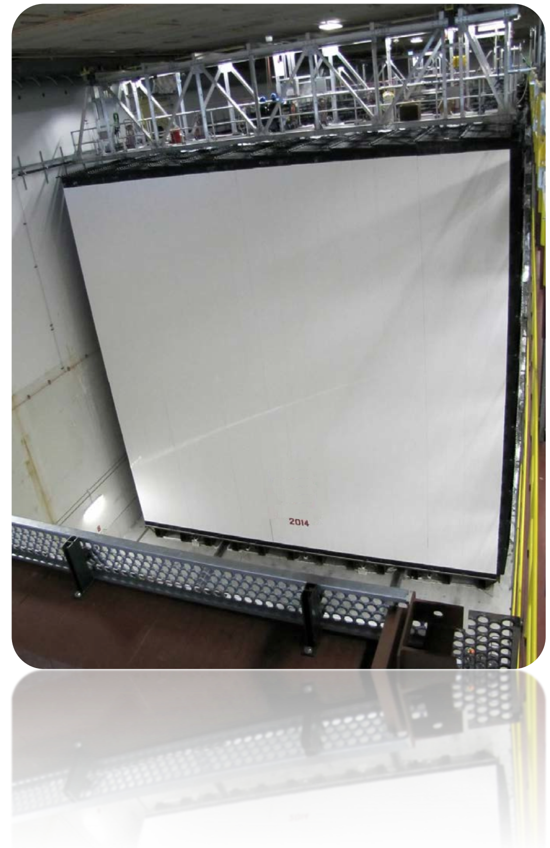


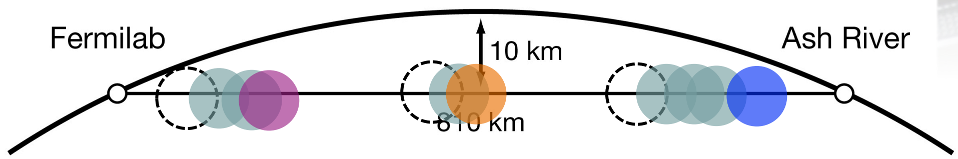


810 km 14 mrad off-axis baseline.

- Sharply peaked, narrow band beam centred at 2 GeV.

NOvA design

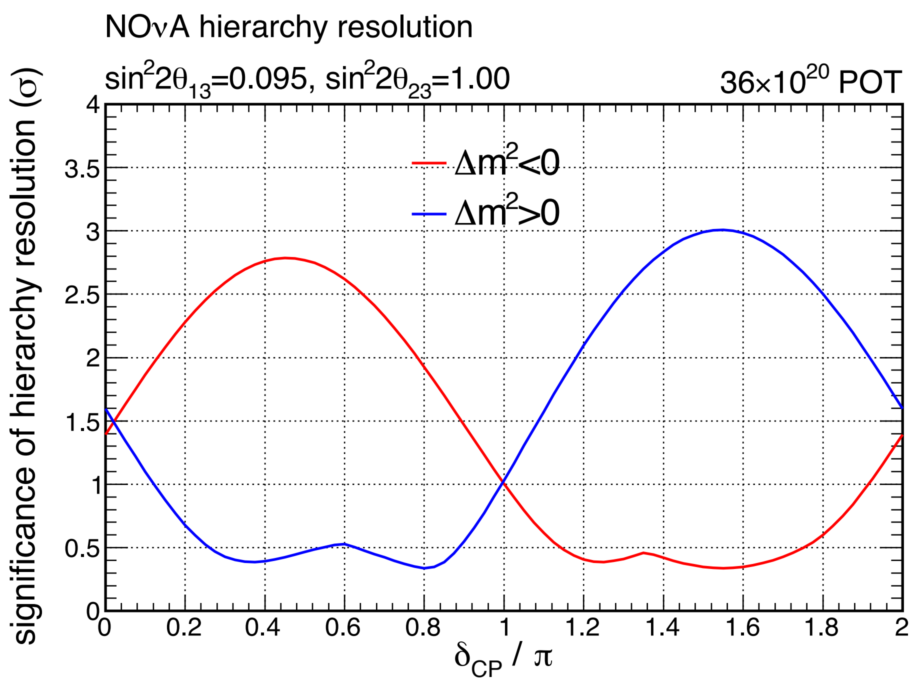


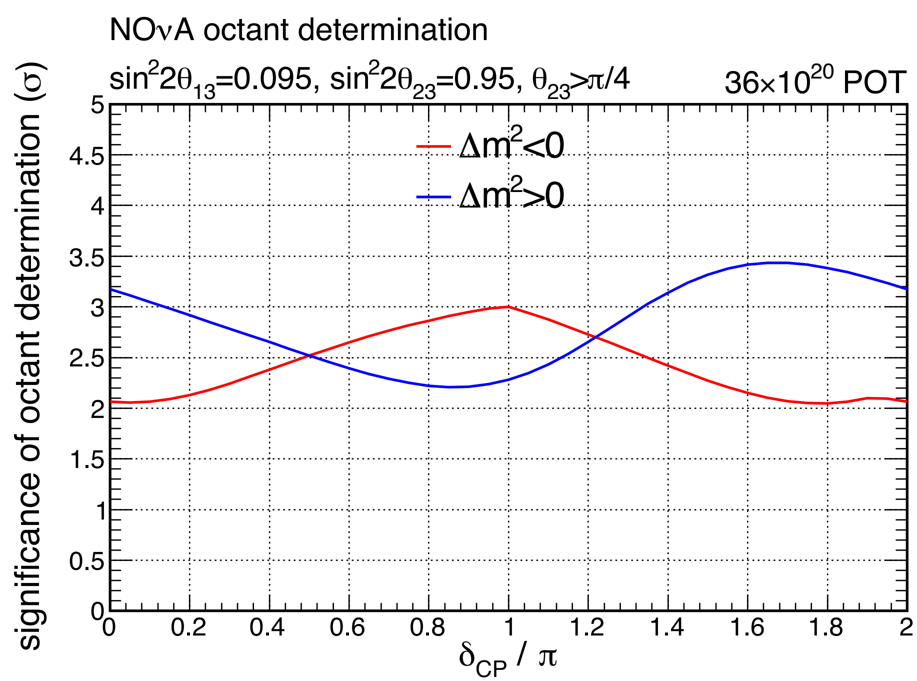


14,000-ton *surface* far detector cited at first oscillation maximum.

- Totally active, low Z, range stack/calorimeter.
- Liquid scintillator filled PVC.
- 896 alternative X-Y planes.
- “Largest plastic structure built by man”.

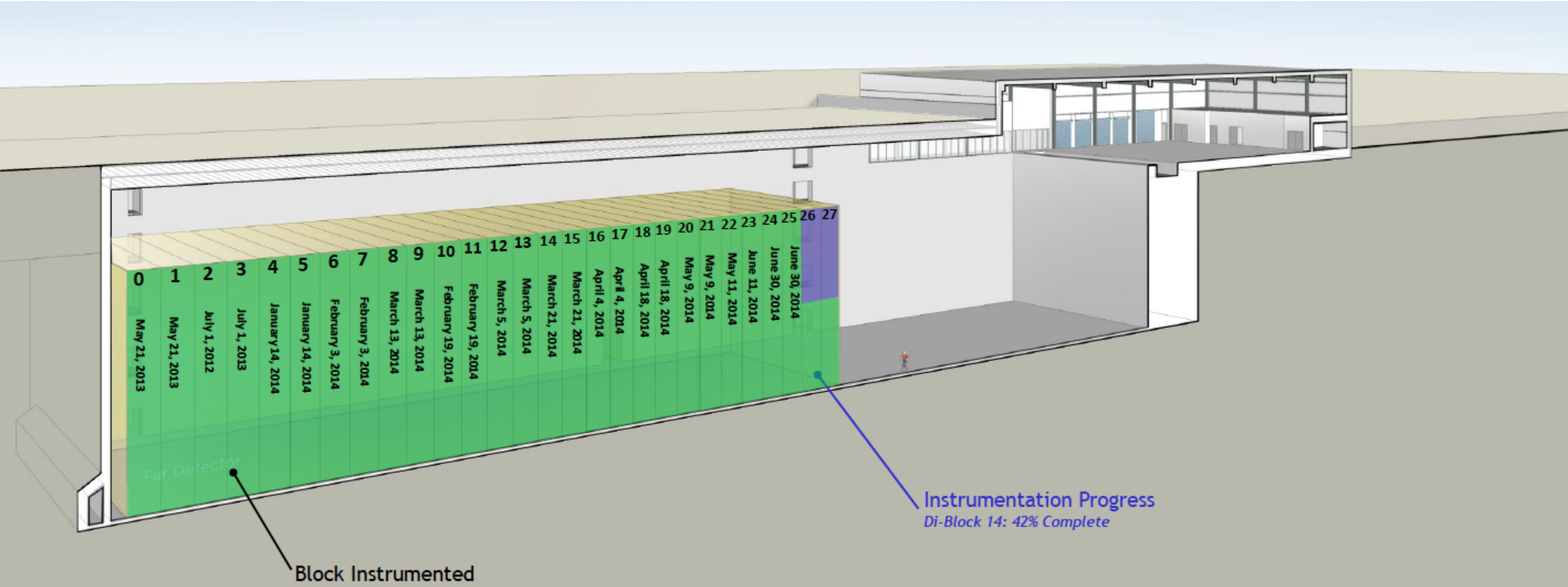
Sensitivities





- For maximal θ_{23}, NOvA's sensitivity to the resolution of the hierarchy reaches 95% CL over 1/3 of ∂_{CP}.
- For non-maximal θ_{23} NOvA can determine the θ_{23} octant at 95% CL over all ∂_{CP}.
- These sensitivities improve in combination with T2K and over longer running periods.
- Will also study: Precision θ_{23}, precision Δm^2_{32}, θ_{13}, CPV.

Far detector construction



14 kilotons = 28 NOvA Blocks

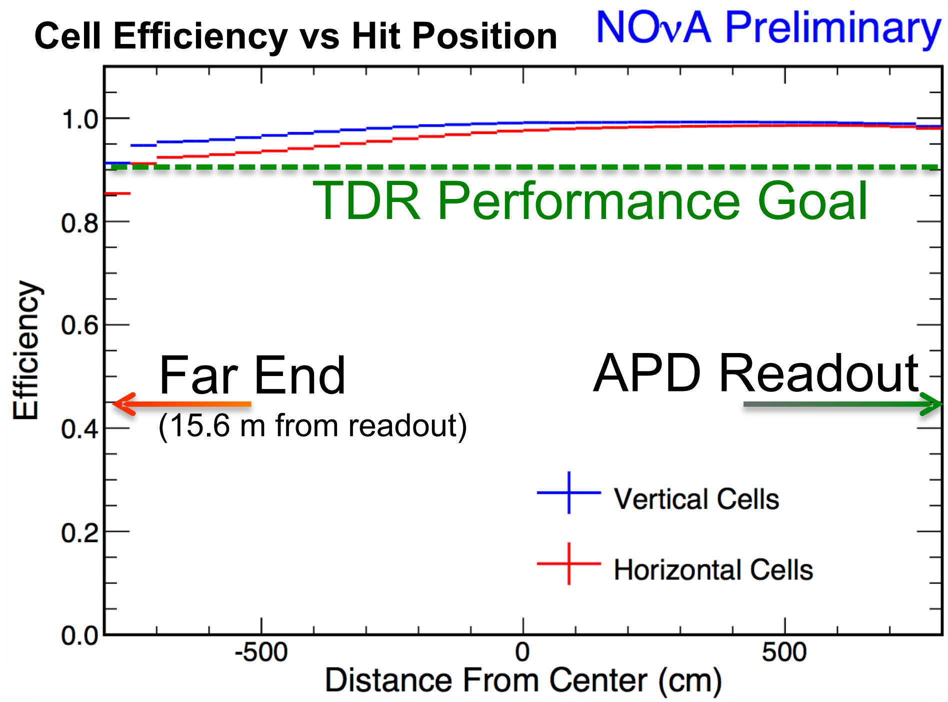
28 blocks of PVC modules are assembled and installed in place

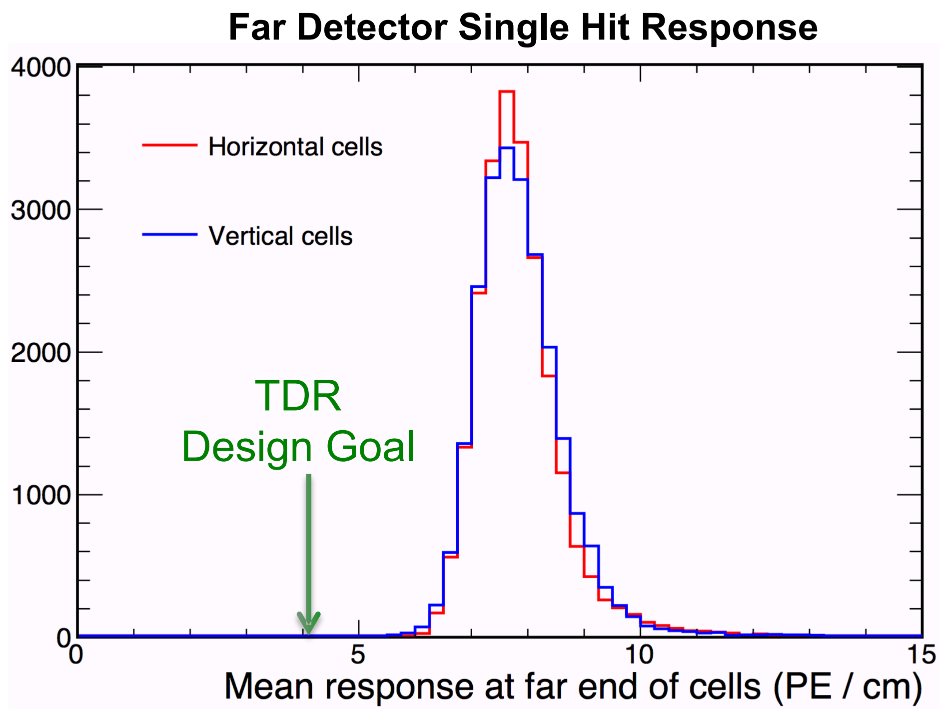
28 blocks are filled with liquid scintillator

26.84 blocks are outfitted with electronics

July 14th 2014

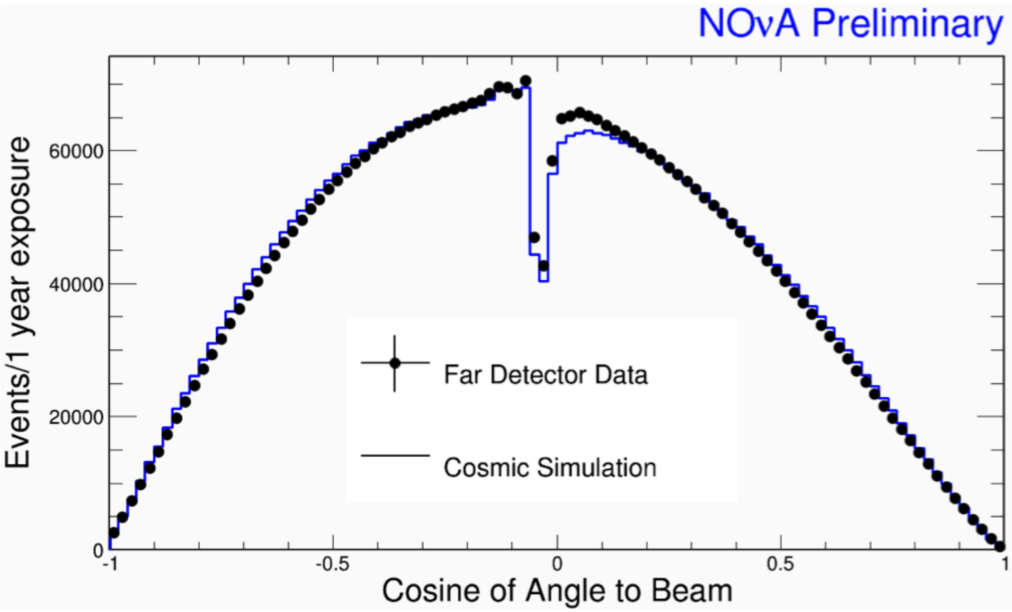
Far detector performance

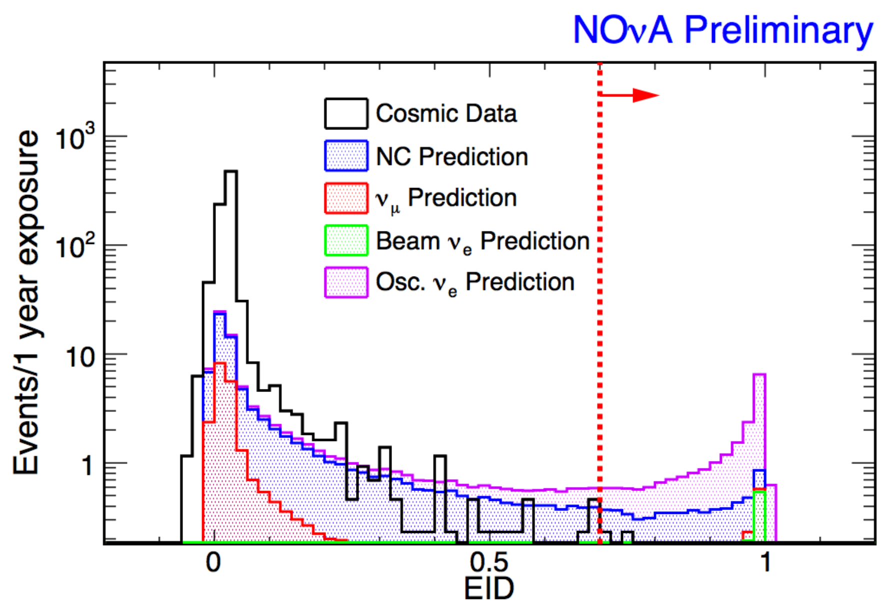




- Far detector response at the far end of the detection cell exceeds the technical design requirements.
- Detector exhibits >90% single cell efficiency in both view for hits on muon tracks
    - Full muon track reconstruction efficiency > 99%

Reconstruction and cosmic rejection

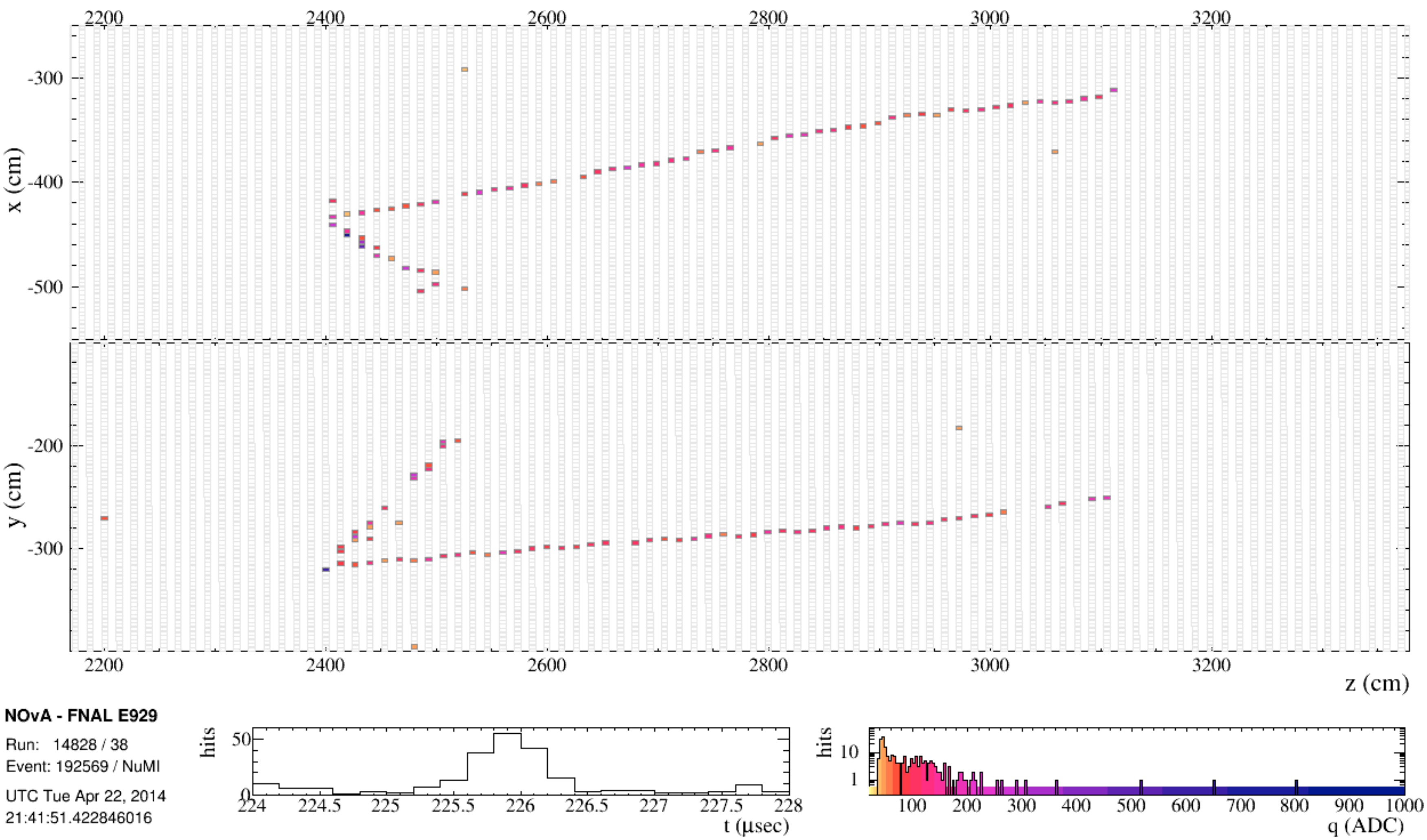




- Simulation and detector modeling has been extensively verified with cosmic ray data.
  - Excellent agreement over full detector volume.

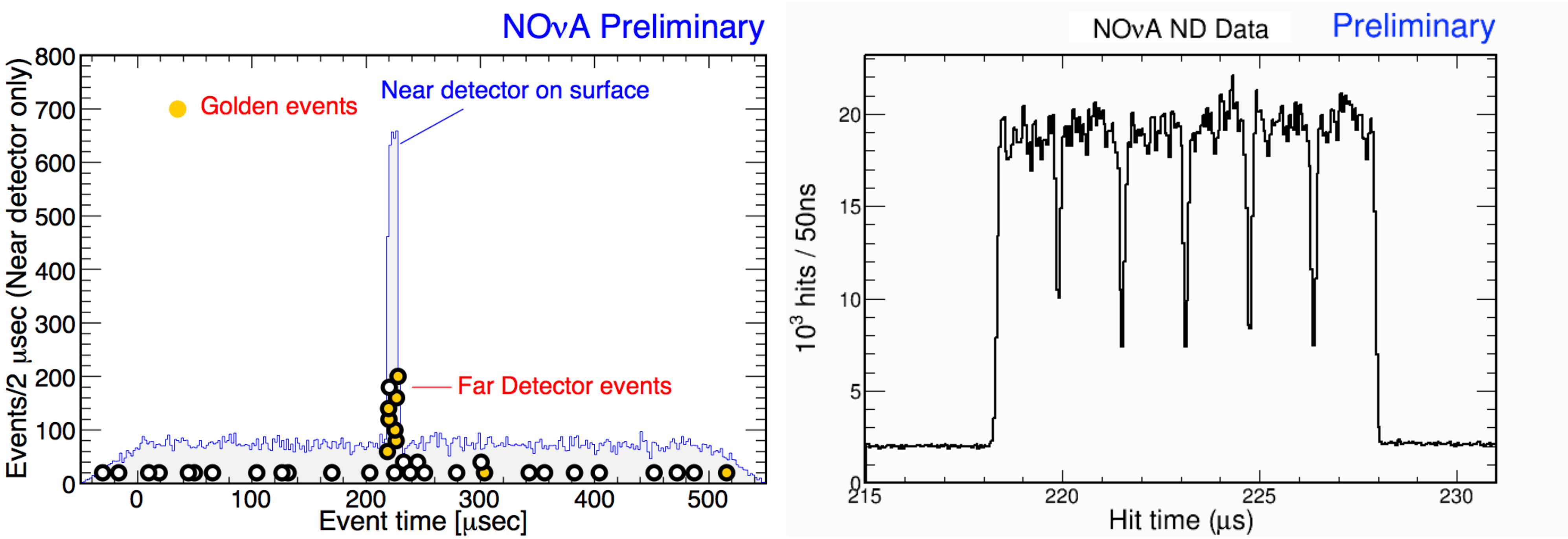
- Cosmic ray rejection efficiency of 20,000,000:1 demonstrated for ν_μ analysis & 40,000,000:1 for ν_e!
  - For ν_e that means we only expect ~7 background events per nominal year compared to ~14 signal events.

Beam candidate events



- Neutrino beam candidate events are being identified in the far detector!
  - Here: ν_μ CC candidate.

Beam timing

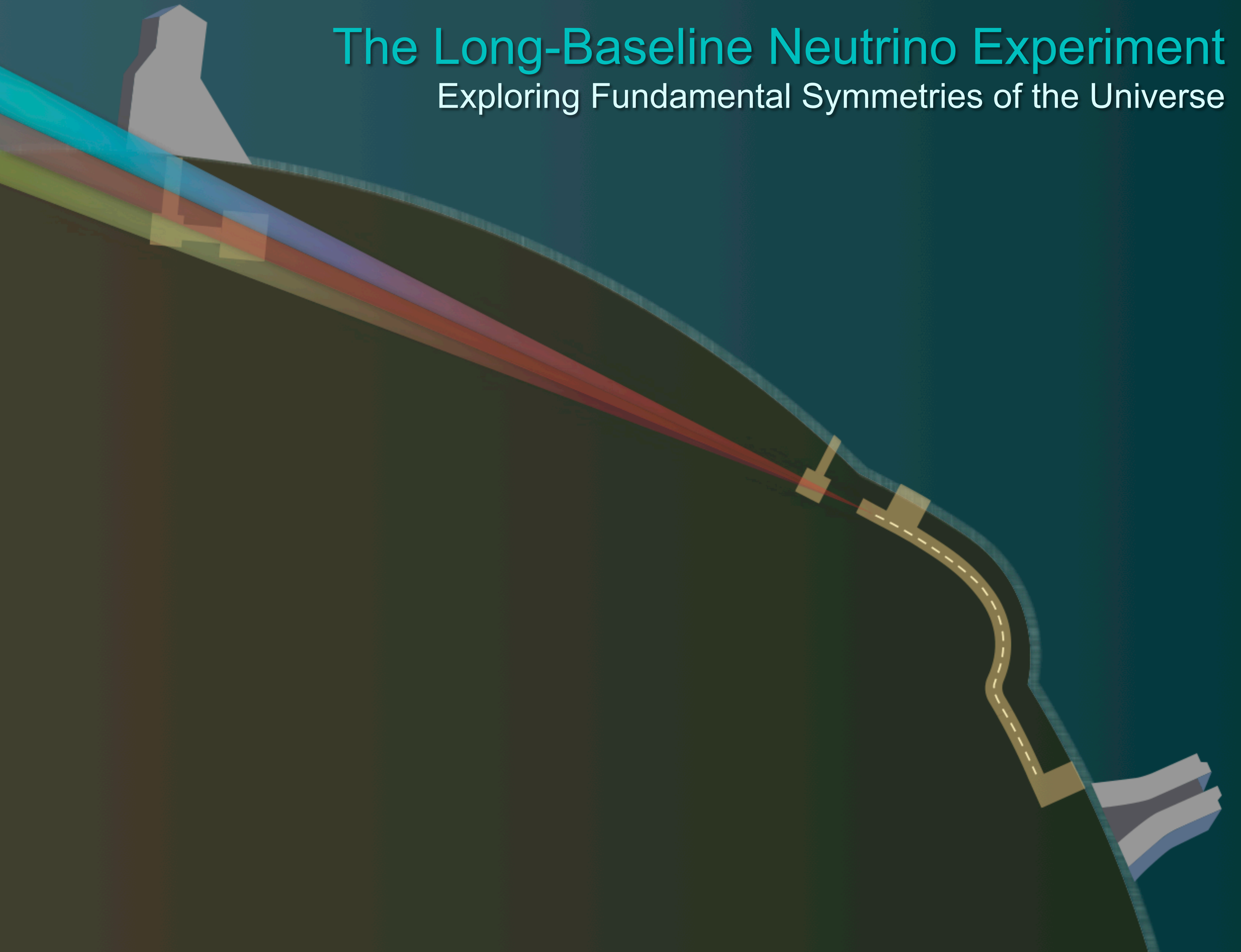


- Beam candidate events demonstrate clear beam timing peak.
- Beautifully clear in the ND!
  - Booster batch structure visible after only a few hours of running with a fraction of the detector!

Both FD & ND are nearly completed. NOvA is ready for physics!

The Long-Baseline Neutrino Experiment

Exploring Fundamental Symmetries of the Universe



LBNE

The Long Baseline Neutrino Experiment is detailed design stage future experiment based in the U.S.A.

The flagship HEP experiment of the US programme. DoE CD-1 approved in December 2012.

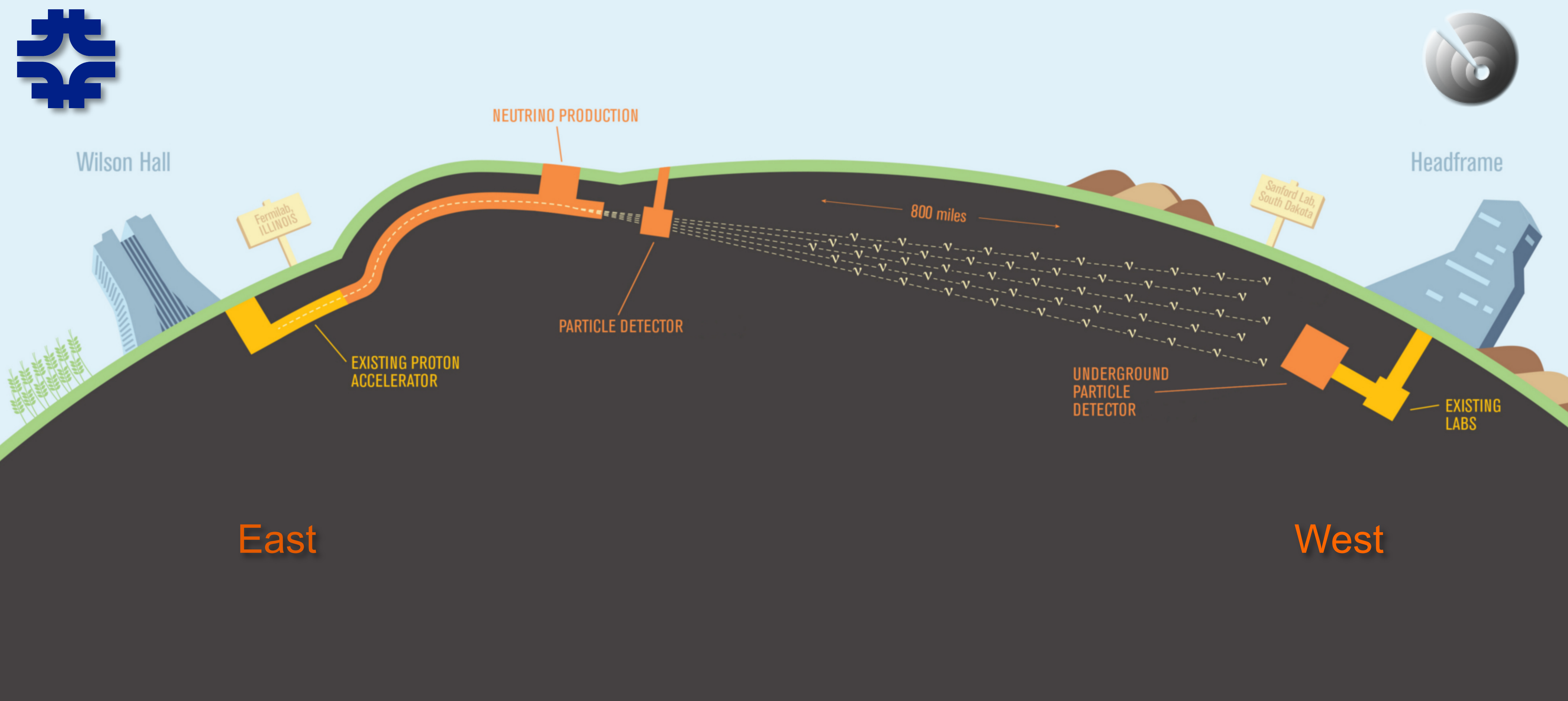
~500 collaborators from 88 institutes in 8 countries.

Should begin physics operation ~2025, to measure:

- CP violation in the neutrino sector & CP phase measurement
- Neutrino mass hierarchy determination
- Testing the three neutrino flavour paradigm
- Neutrino interaction measurements
- Supernova burst neutrinos & nucleon decay measurements

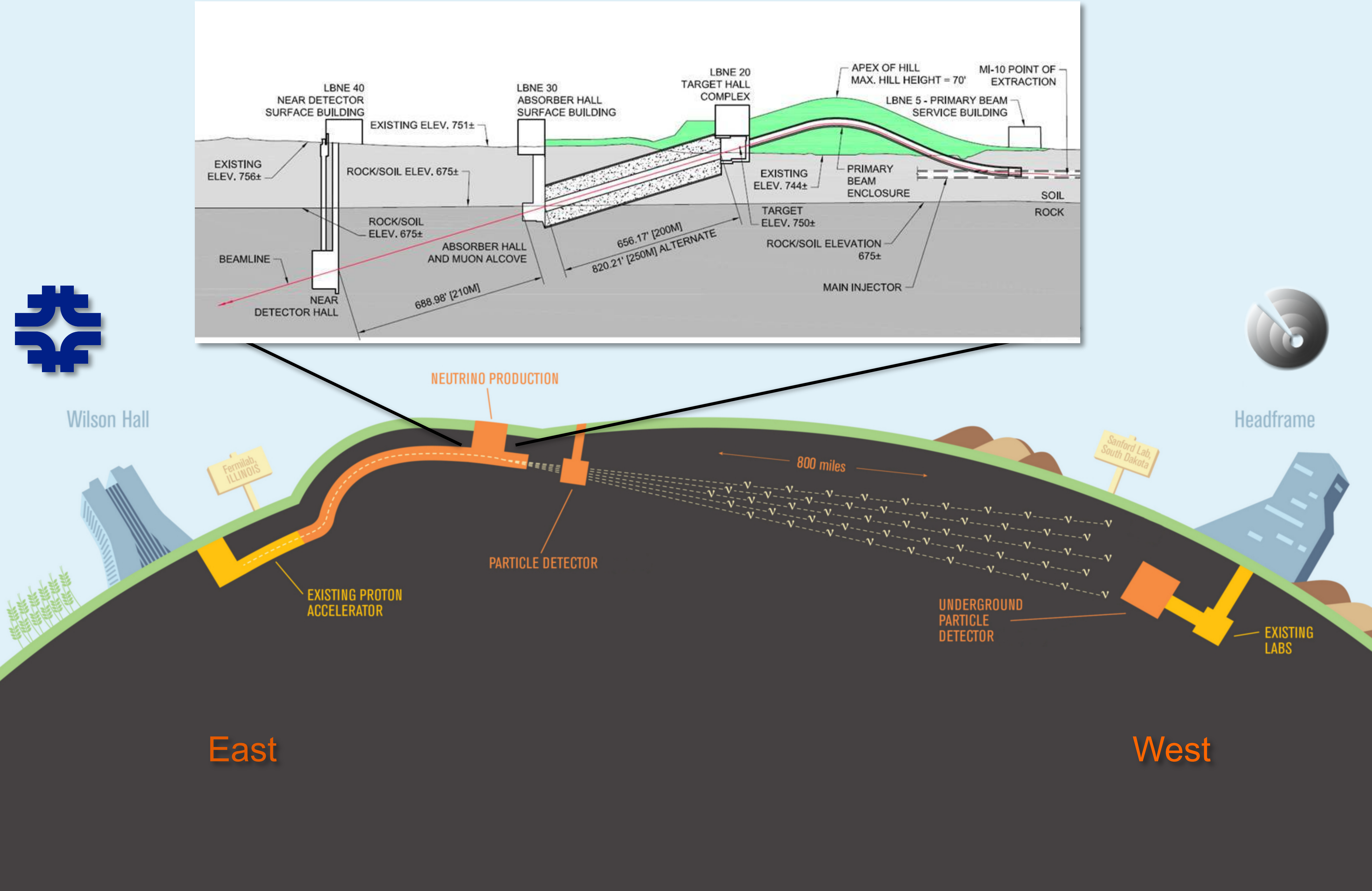
All in one experiment!

Experimental setup

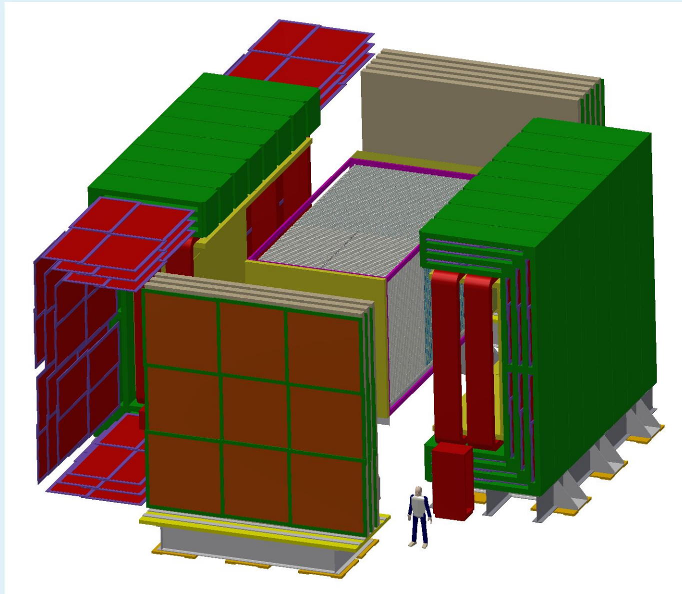


Experimental setup

Pure ν_μ >1 MW broadband beam courtesy of Proton Improvement Plan II

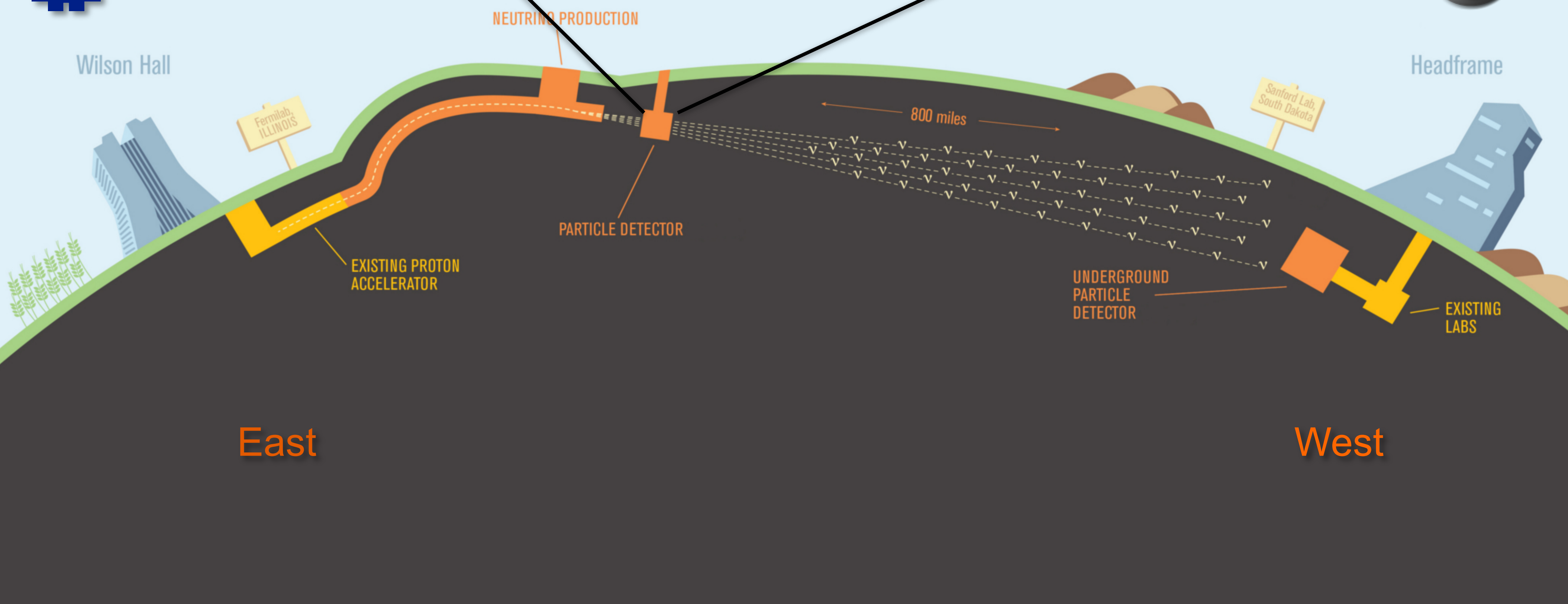


Experimental setup



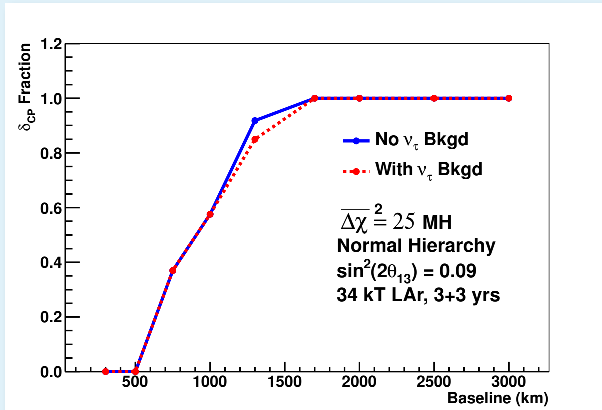
Highly-capable near detector system, 460 m from target.

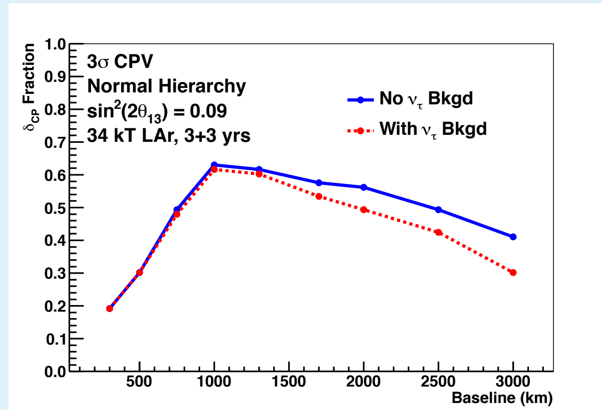
Proposal pending in India.

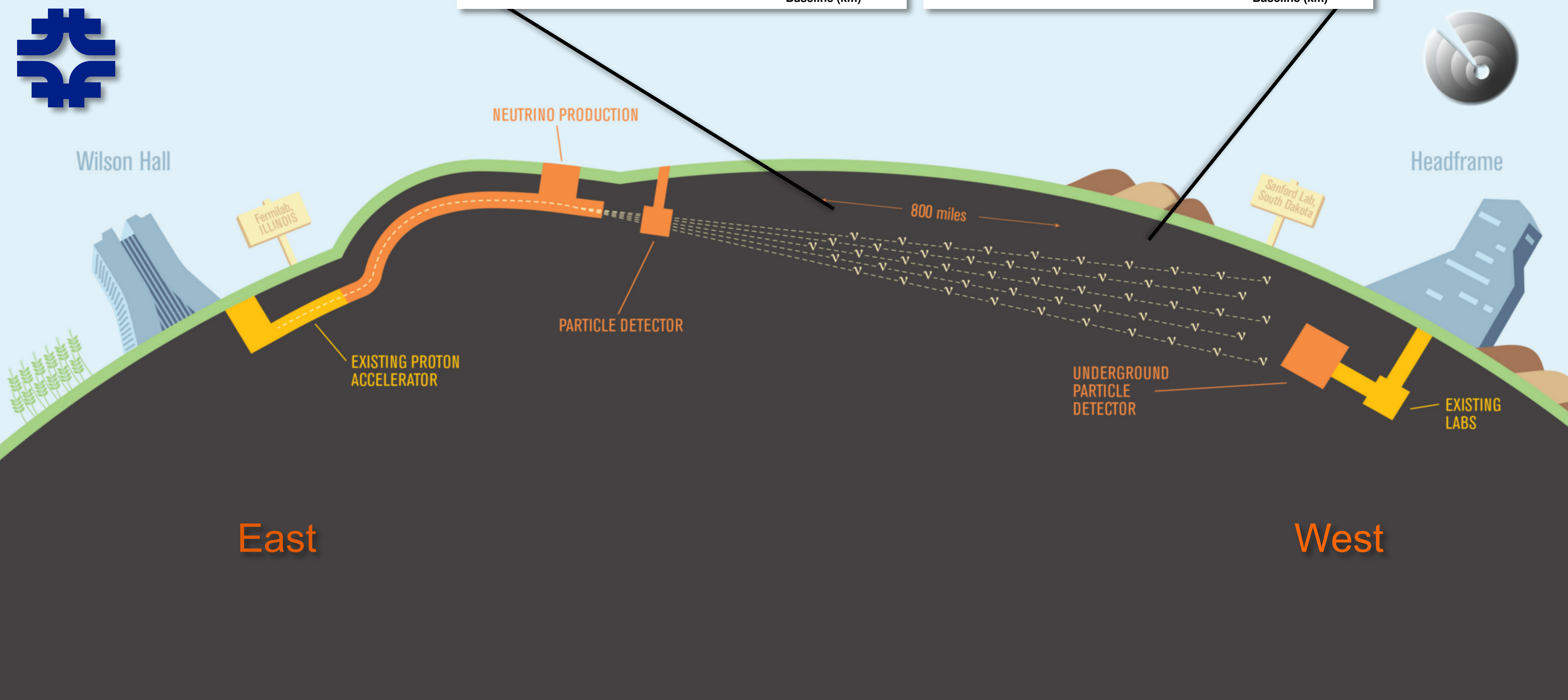


Experimental setup

1,300 km optimised baseline



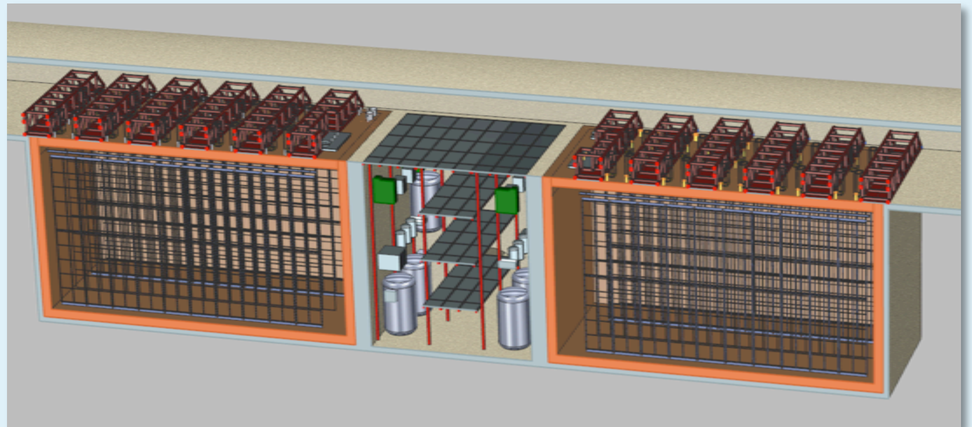


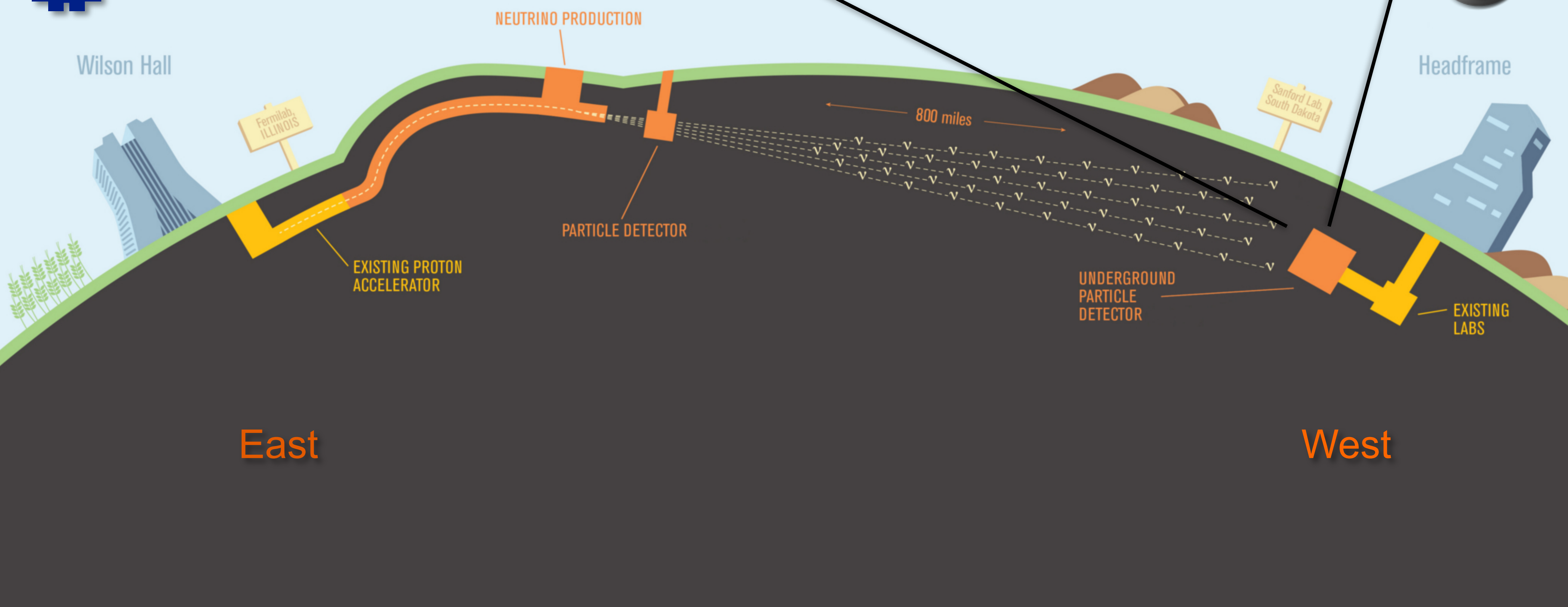


Experimental setup

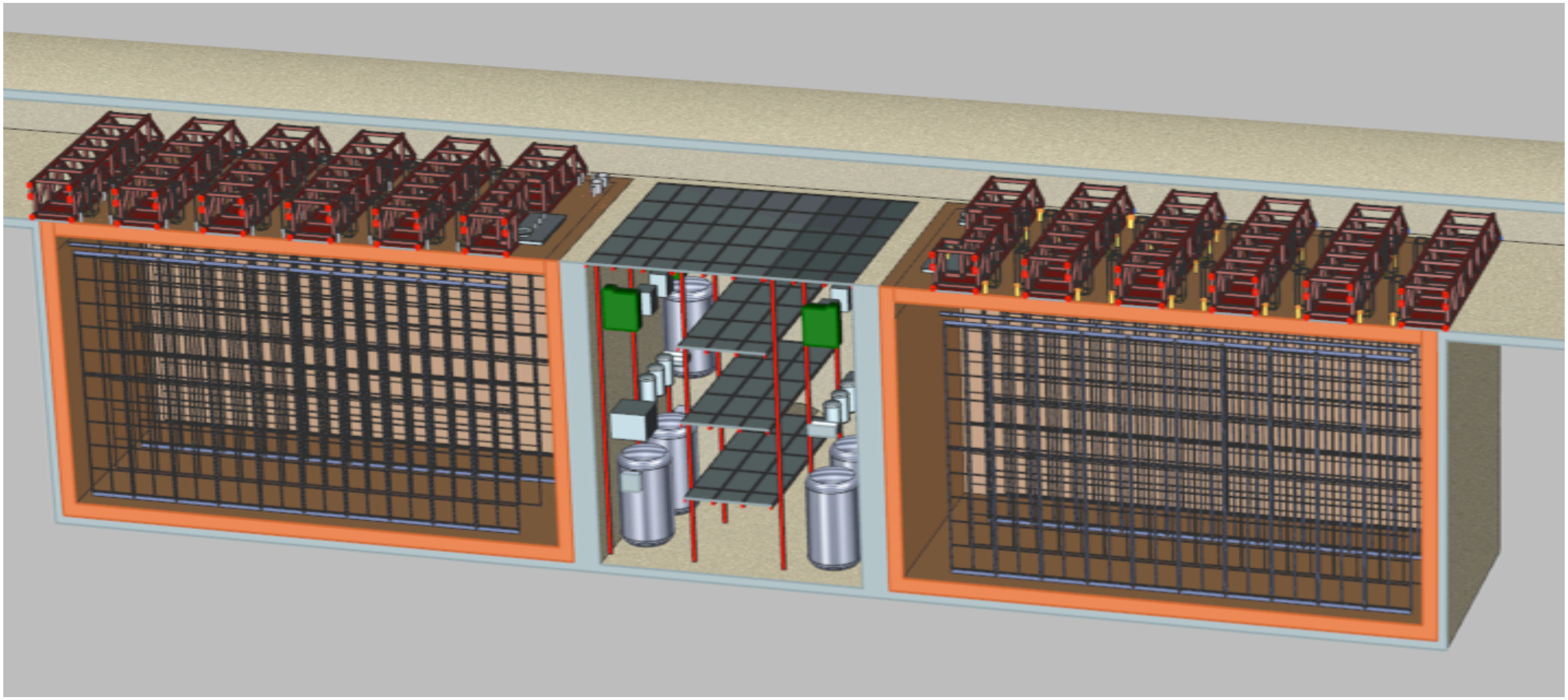
≥ 35 kiloton fiducial mass, underground (4,300 m.w.e.), liquid argon TPC far detector.

Total LAr mass ~50 kiloton. Design expect to evolve.





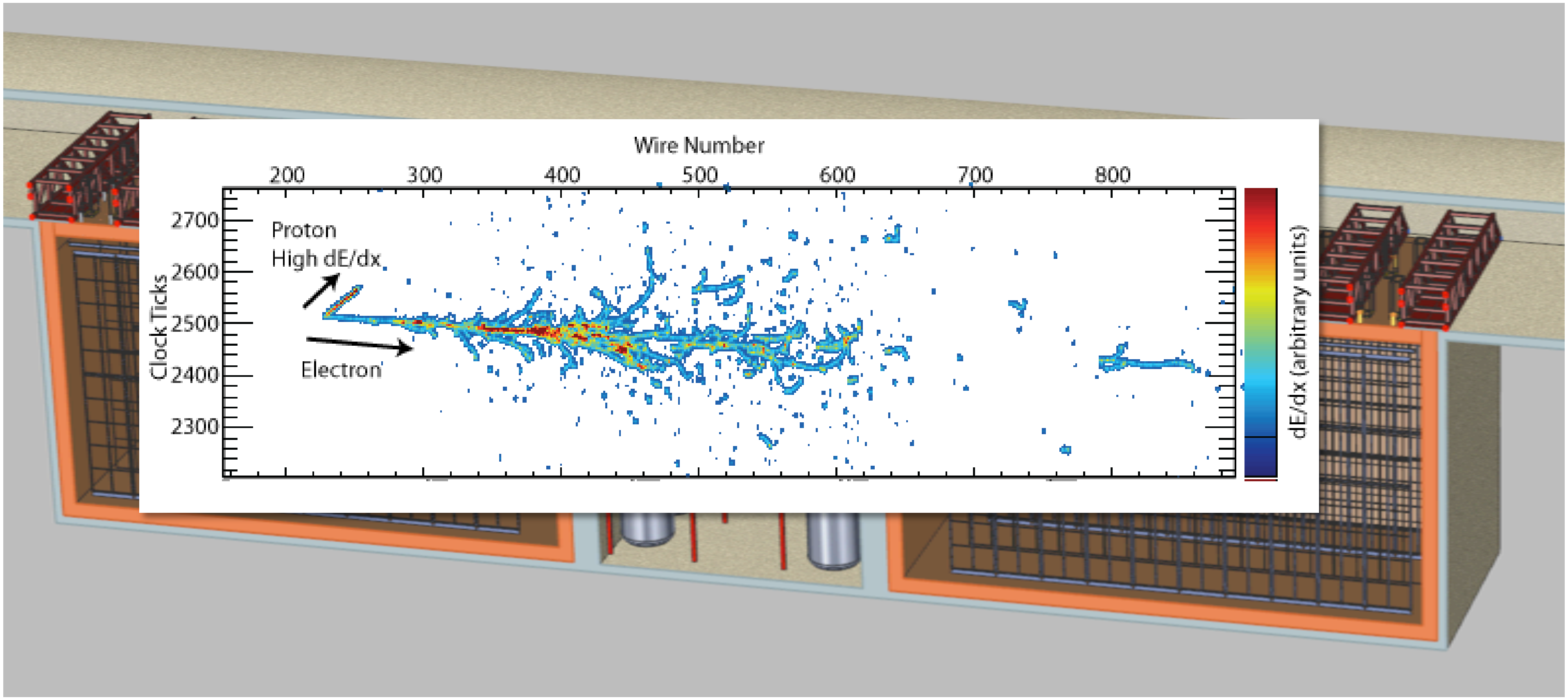
Detector design



LBNE Liquid Argon TPC based on ICARUS design.

- 15m x 23m x 62m x 2! Total liquid argon mass: ~50,000 tons! 120 wrapped APA planes w/ 10 photo paddles per plane.

Detector design



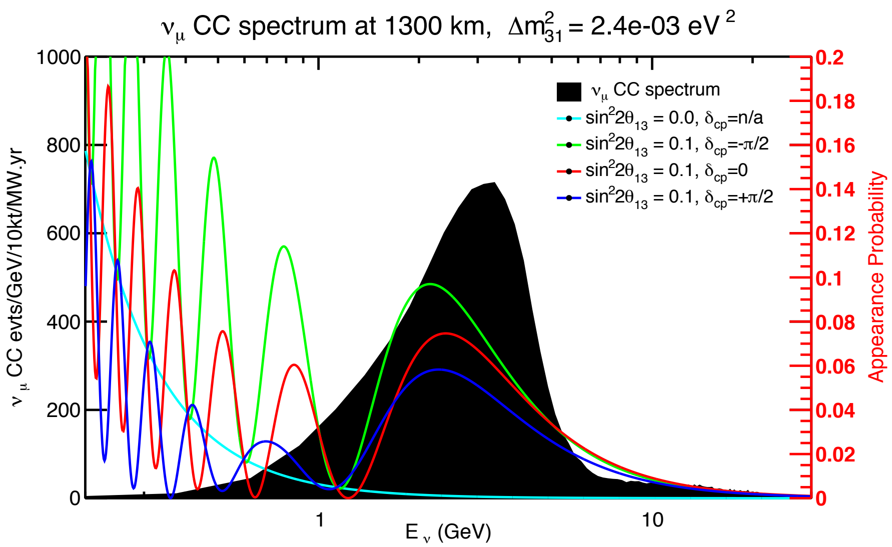
LBNE Liquid Argon TPC based on ICARUS design.

- 15m x 23m x 62m x 2! Total liquid argon mass: ~50,000 tons! 120 wrapped APA planes w/ 10 photo paddles per plane.

Liquid argon allows for “bubble chamber”-like reconstruction of neutrino interactions.

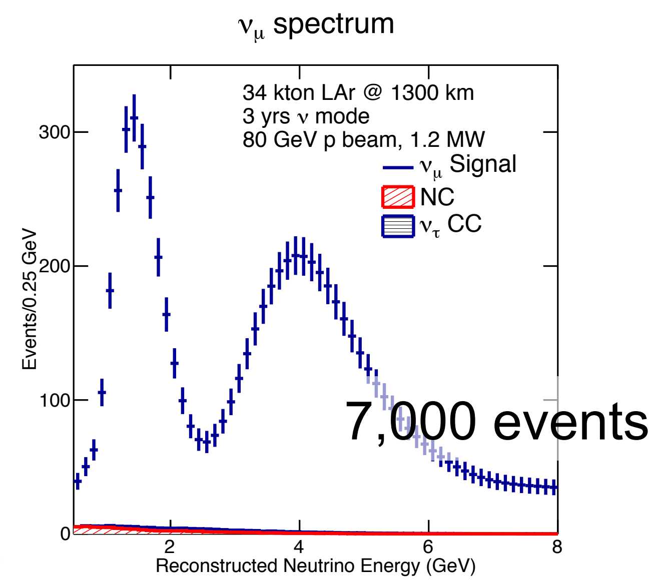
- 3D reconstruction, calorimetry, particle identification, excellent mm-scale position resolution.

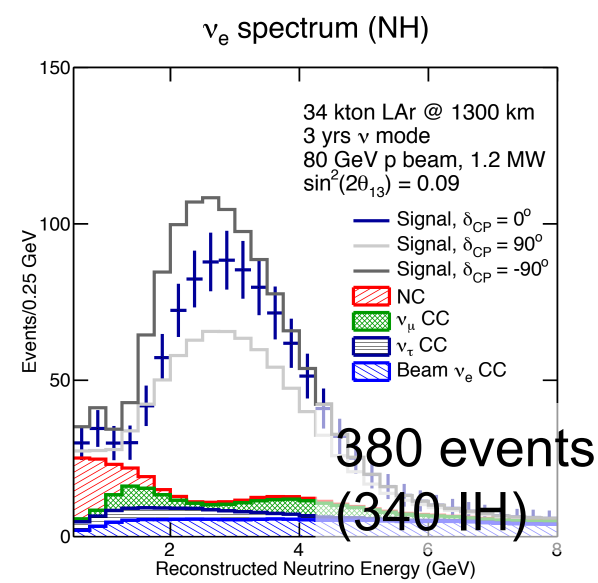
LBNE physics



disappearance

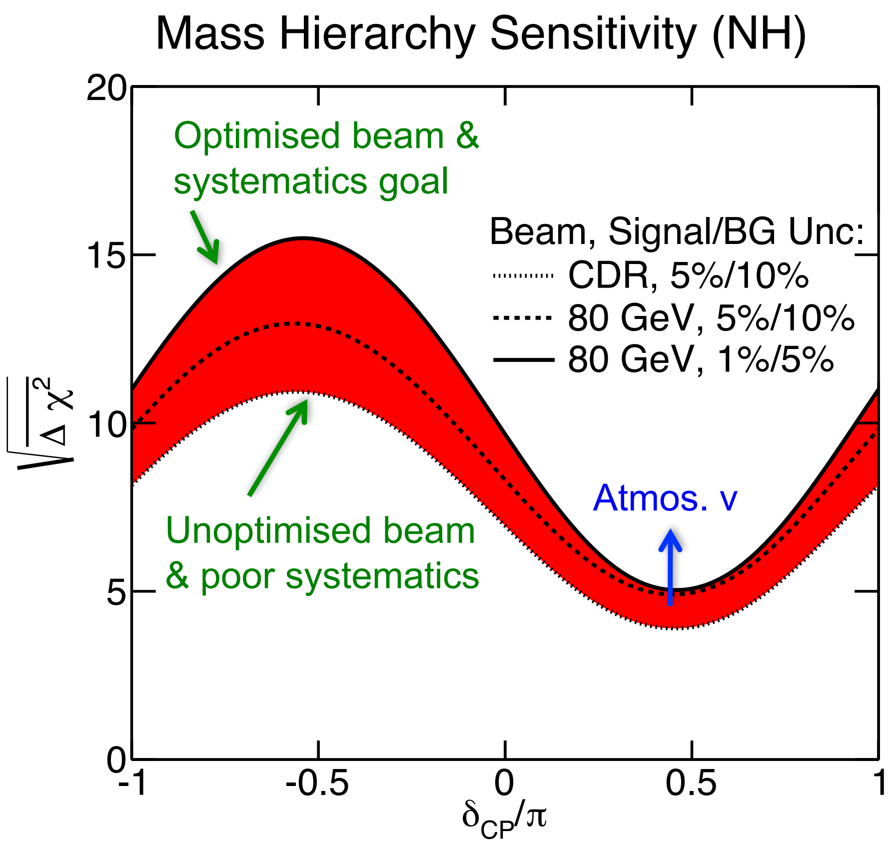
appearance

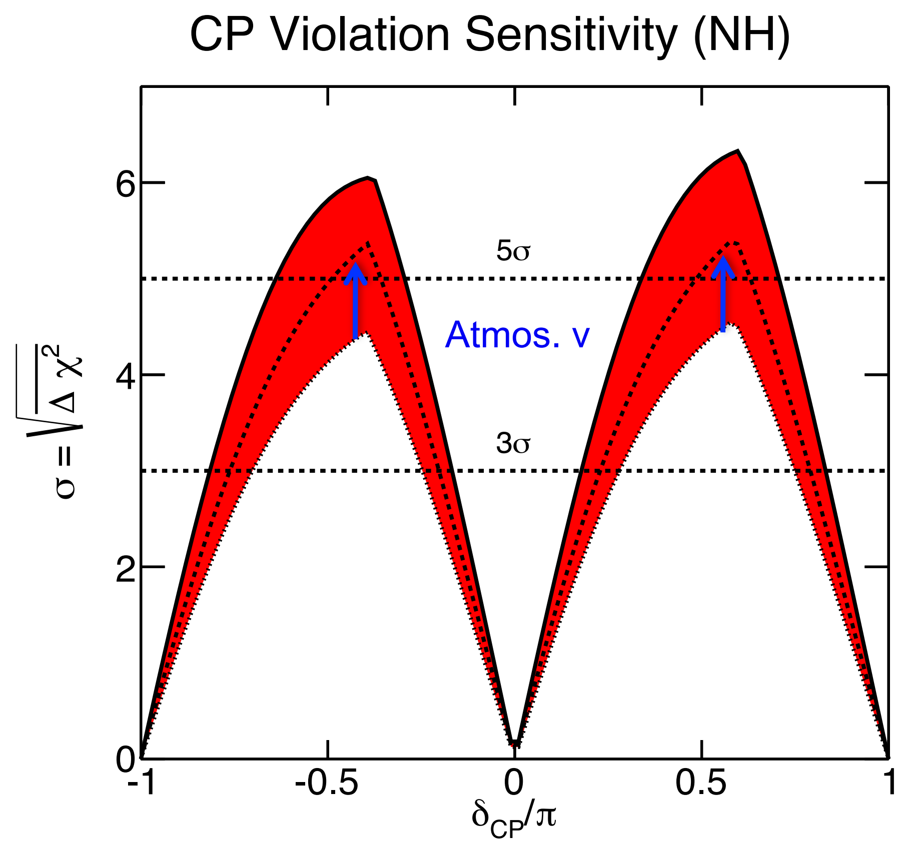




- The essential experimental technique is to produce a pure ν_μ beam with an energy spectrum matched to the oscillation pattern at the chosen baseline.
- Then measure the spectrum of ν_μ and ν_e at the near and far distant detectors.
- LBNE is a near optimal choice of beam and distance for sensitivity to CP violation, CP phase, neutrino mass hierarchy and other oscillation parameters in the same experiment.

Sensitivities

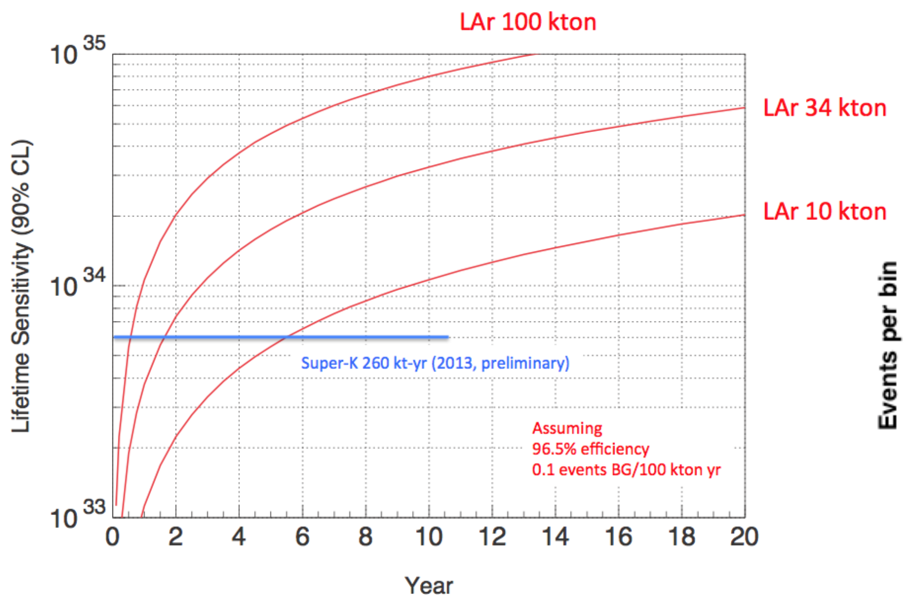


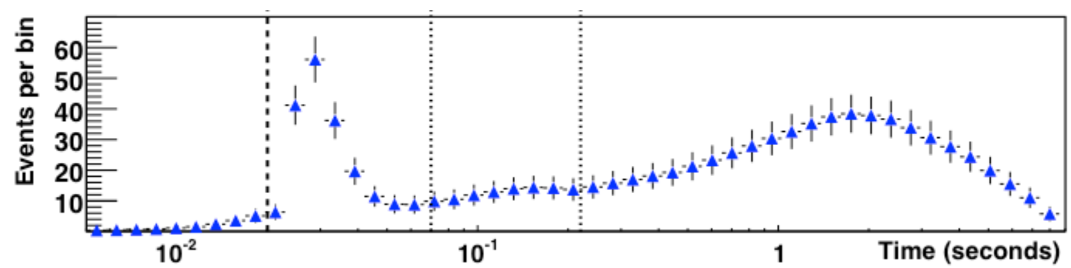


- Mass hierarchy is very well determined over most of the ∂_{cp} range
- CPV >3σ over most of the range & >5σ for maximal CPV
- Atmospheric neutrinos provide: independent $\sim\Delta X^2=4$ cross check on MH & ~1σ increased CPV sensitivity if combined with the beam.

Underground physics

- Being deep underground offers many other physics opportunities.
- E.g. supernova burst neutrinos.
    - 10 kpc → O(1,000) interactions.
- LAr TPC high efficiency/low background for kaon modes → excellent proton decay sensitivity.





LBNE in context

The flagship project for the US. PIP-II motivated by LBNE.

DOE funding commitment for $867M. LBNE are working with international partners to develop a fully international program hosted in the US.

- Have scope and schedule flexibility in the DoE approvals.
- Moving forward on long-lead conventional facility items.

P5: “Recommendation 13: Form a new international collaboration to design and execute a highly capable Long-Baseline Neutrino Facility (LBNF) hosted by the U.S…”

European strategy: “CERN should develop a neutrino programme to pave the way for a substantial European role in future long-baseline experiments. Europe should explore the possibility of major participation in leading long-baseline neutrino projects in the US and Japan.”

LBNF Summit 21st/22nd July at FNAL

- International collaboration with many opportunities for new collaborators

Summary & conclusions

- There is a vibrant programme on long-baseline neutrino physics based in the U.S.

- The NOvA detectors are very nearly complete.
- The NuMI accelerator complex continues ramp to full power.
- ν's observed in far detector.
- Demonstrated cosmic rejection 40 million to 1.
- Analysis methods awaiting near detector data for final tuning.
- **First oscillation results near end of year.**

- Building on substantial investments already made, an international partnership based on LBNE will deliver:
  - A high-power neutrino beam; A high-resolution near detector system; A far detector of ≥10 kt fiducial mass in a cavern that can accommodate a ≥ 35 kt detector.
- A series of meetings with government agencies, (inter)national laboratories, and researchers is being organized to fully internationalize the design, funding, construction and operation of the facility.
- **We hope many (more) of you will be part of this exciting program!**