LBNE: Physics and Status

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(on behalf of the LBNE Collaboration)

Northwestern University

Rencontre du Vietnam

"Windows on the Universe", ICISE, Quy Nhon

August 11–17, 2013

Outline

- Quick Introduction;
- Scientific Motivation;
- Oscillation Physics;
- Non-Oscillation Physics;
- Status and Near-Future Plans.

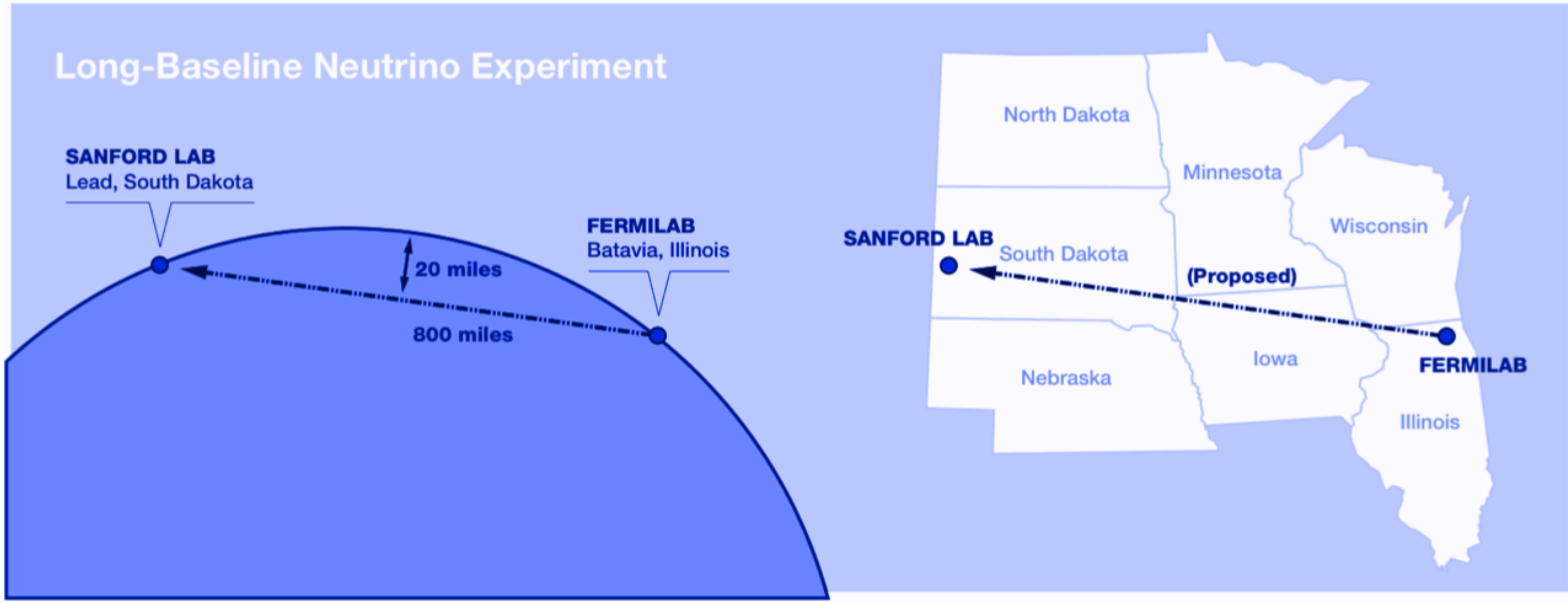
Further details:

"Science Opportunies with LBNE," arXiv:1307.7335

"Neutrinos" Plenary Session Tomorrow (AdG, Scholberg, Luk)

Long-Baseline Neutrino Experiment

- New **neutrino beam** (700 kW) from Fermilab
- **Near detector** at Fermilab (see previous talk)
- Optimal **1300 km baseline** from Fermilab to Sanford Lab
- **Large underground detector** (34 kt Liquid Argon TPC) at Sanford Lab



LBNE Staging

- DOE asked LBNE to plan for staged construction
- **LBNE10** (first stage, DOE CD-1 approval):
  - 10 kt (fiducial mass) LAr TPC
  - 700 kW, 120 GeV beam (6×10^{21} POT/year)
- **LBNE** (ultimate goal):
  - 34 kt (fiducial mass) LAr TPC, underground
  - 700-2300 kW beam (Project X)
  - Near detector

- **Sensitivity studies presented assume either LBNE10 or LBNE**

Detector mass	10 kt (**LBNE10**), or 34 kt (**LBNE**)
Beam	80 GeV, 700 kW
Systematics	1%, 5% normalization error on signal, background
Baseline	1300 km

Scientific Motivation

- CP Violation in neutrino sector?
  - Violation of a fundamental symmetry; viability of leptogenesis models
- Neutrino Mass Hierarchy
  - GUTs, Dirac vs. Majorana nature and feasibility of $0\nu\beta\beta$ decay
- Testing the Three-Flavor Paradigm
  - Precision measurements of known fundamental mixing parameters
  - New physics -> non-standard interactions, sterile neutrinos… (with beam + atmospheric ν sources)
  - Precision neutrino interactions studies (near detector)

Scientific Motivation

- Other fundamental physics enabled by massive detectors
  - Proton decay measurement
    - Grand Unification Theory
  - Astrophysics
    - Supernova ν burst flux

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

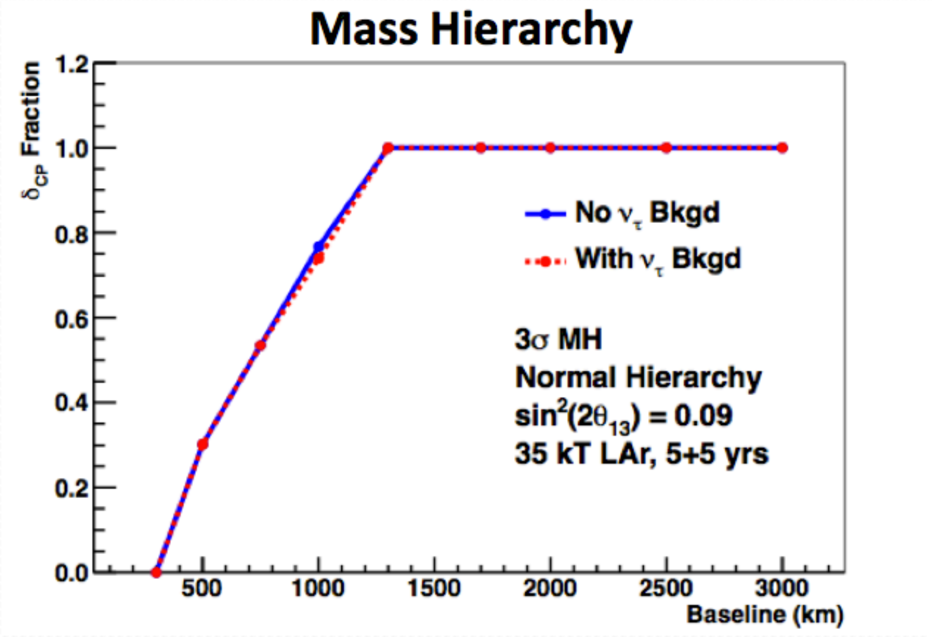
- 372 members, 61 institutions, 5 countries (April 2013)
- Applications from ~8 institutions/40 members being prepared
- Co-spokespersons Milind Diwan (BNL), Bob Wilson (CSU)

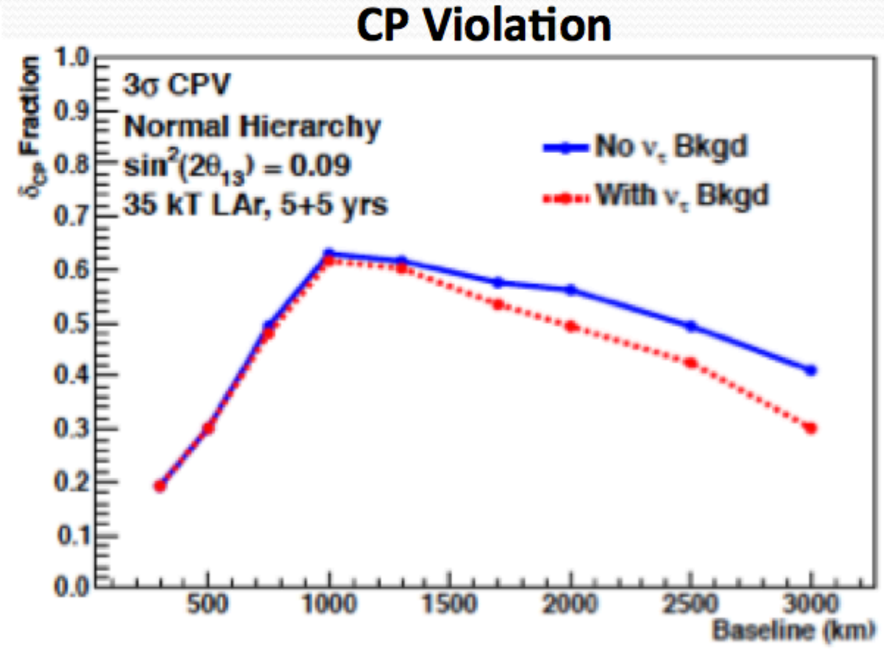
Fermilab, March 2013

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

Baseline Optimization

Detailed calculation with horn based realistic beam optimization at each baseline and assumption of liquid argon TPC of 35 kt. Assume 120 GeV protons at 700kW.





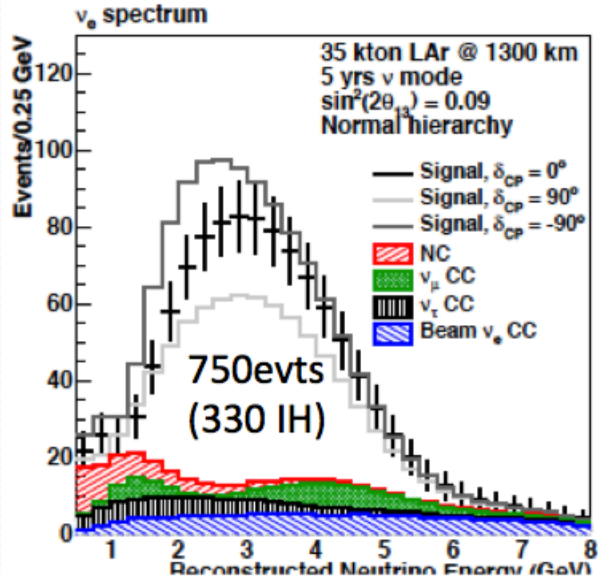
- The LBNE design with a 1300 km, 120 GeV proton beam, on-axis LArTPC far detector is economical for a comprehensive oscillation program
- Any other choice will necessitate larger detector or higher beam intensity

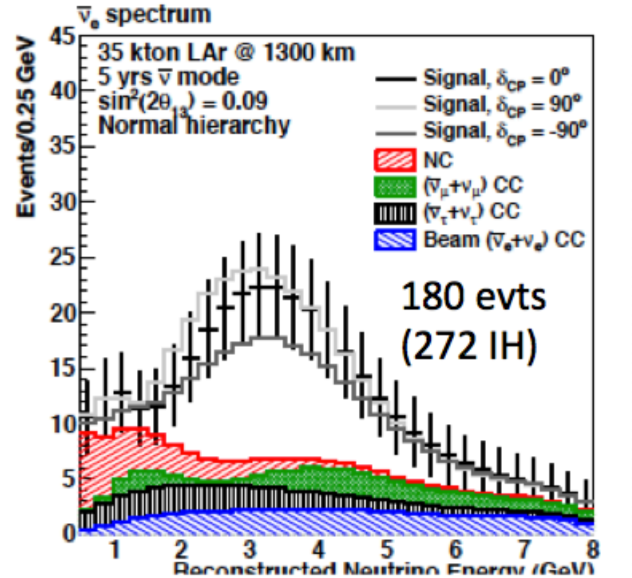
LBNE 34 kt Spectra

ν (5 yrs) | $\bar{\nu}$ (5 yrs)

Appearance

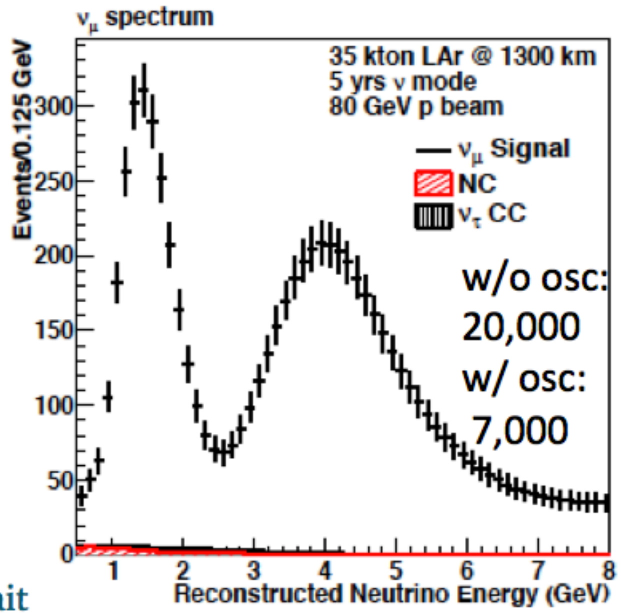
$\nu_\mu \rightarrow \nu_e$

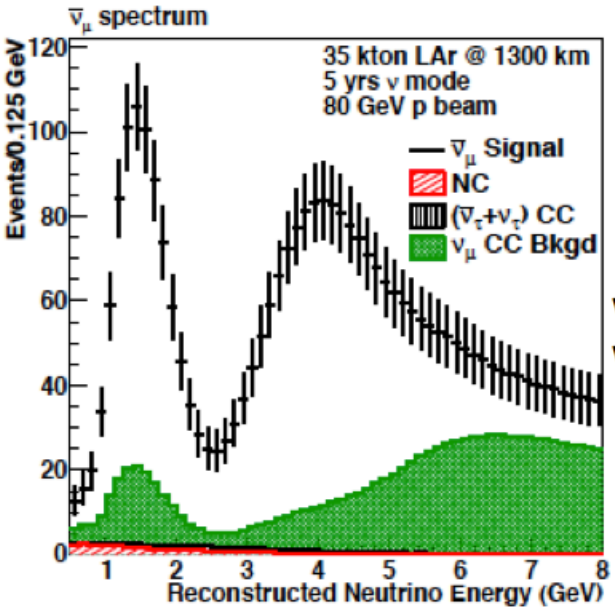




Disappearance

$\nu_\mu \rightarrow \nu_\mu$



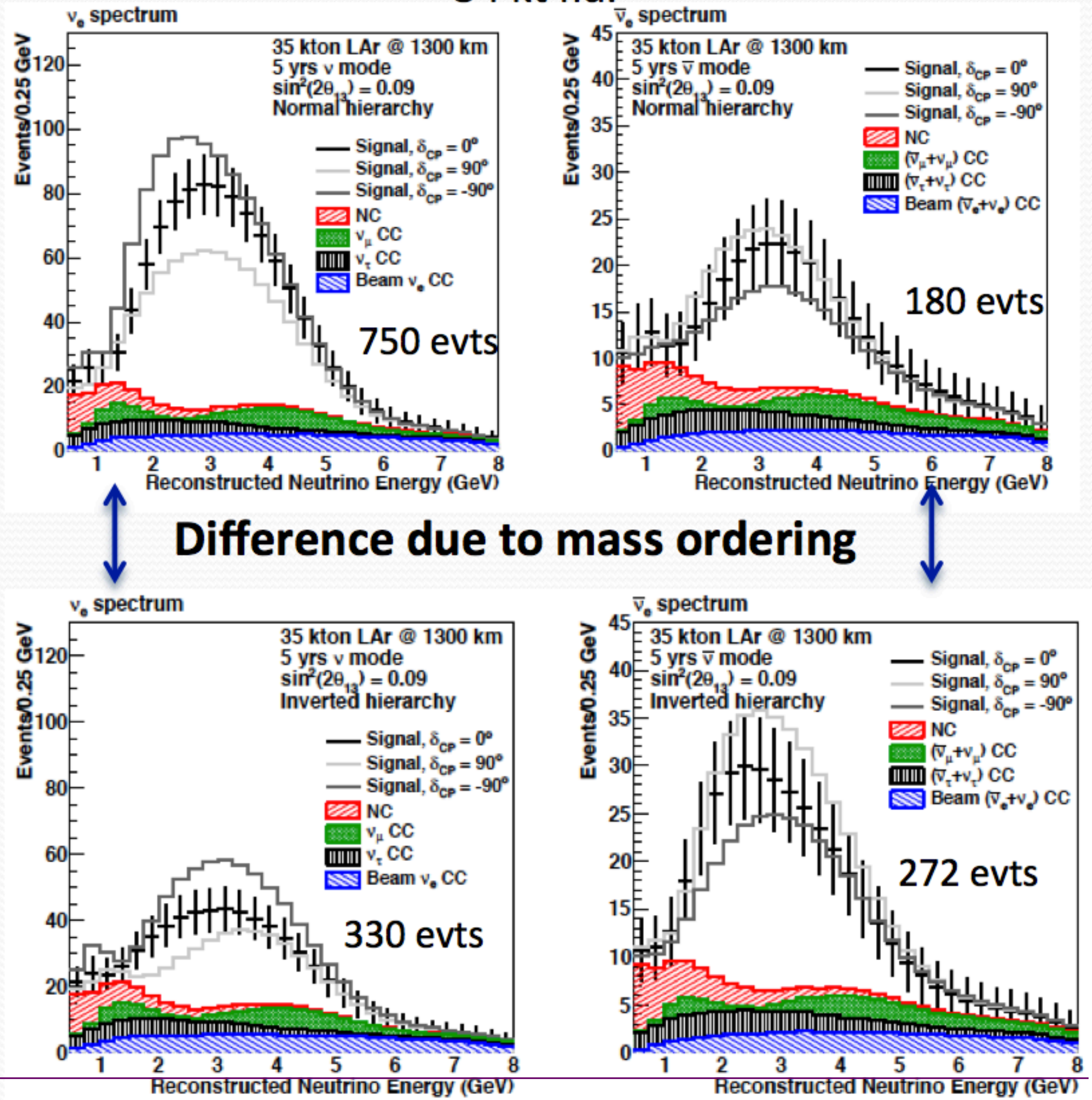


w/o osc: 6,700
w/ osc: 2,200

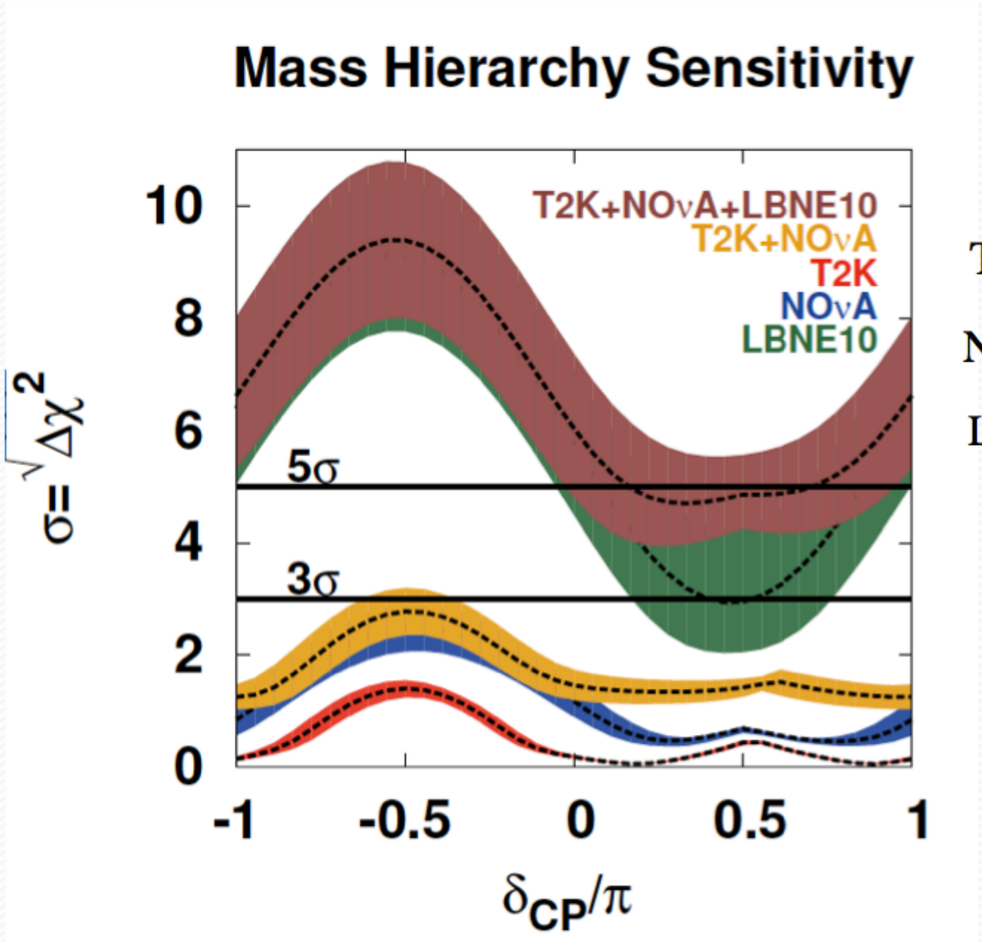
34 kt fid.

Normal

Inverted



Just 10 kt LArTPC Would be a Major Advance



T2K 750 kW x 5 yr (7.8×10^{21} pot) ν

NOνA 700 kW x (3 yr ν + 3 yr $\bar{\nu}$) (3.8×10^{21} pot)

LBNE10 (80 GeV*) 700 kW x (5 yr ν + 5 yr $\bar{\nu}$)

*Improved over CDR 2012 120 GeV MI proton beam

Bands: 1σ variations of θ_{13}, θ_{23}, Δm_{31}^2 (Fogli et al. arXiv:1205.5254v3)

- LBNE10 does much better than full program for existing experiments

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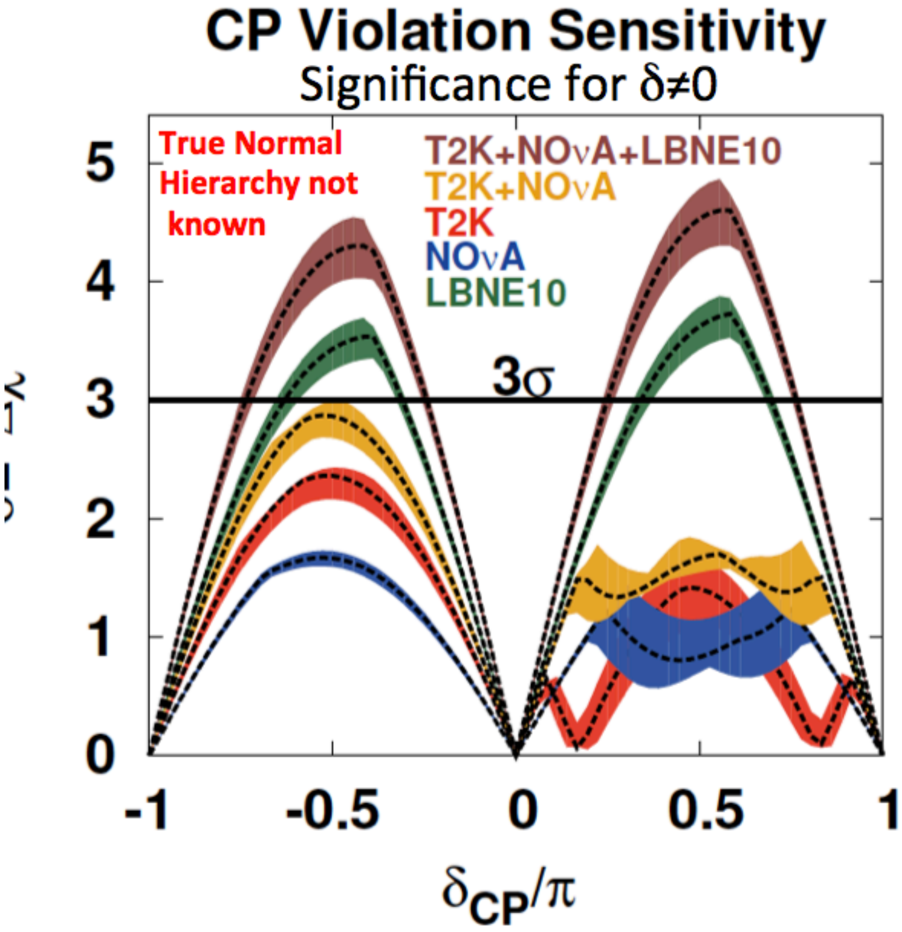

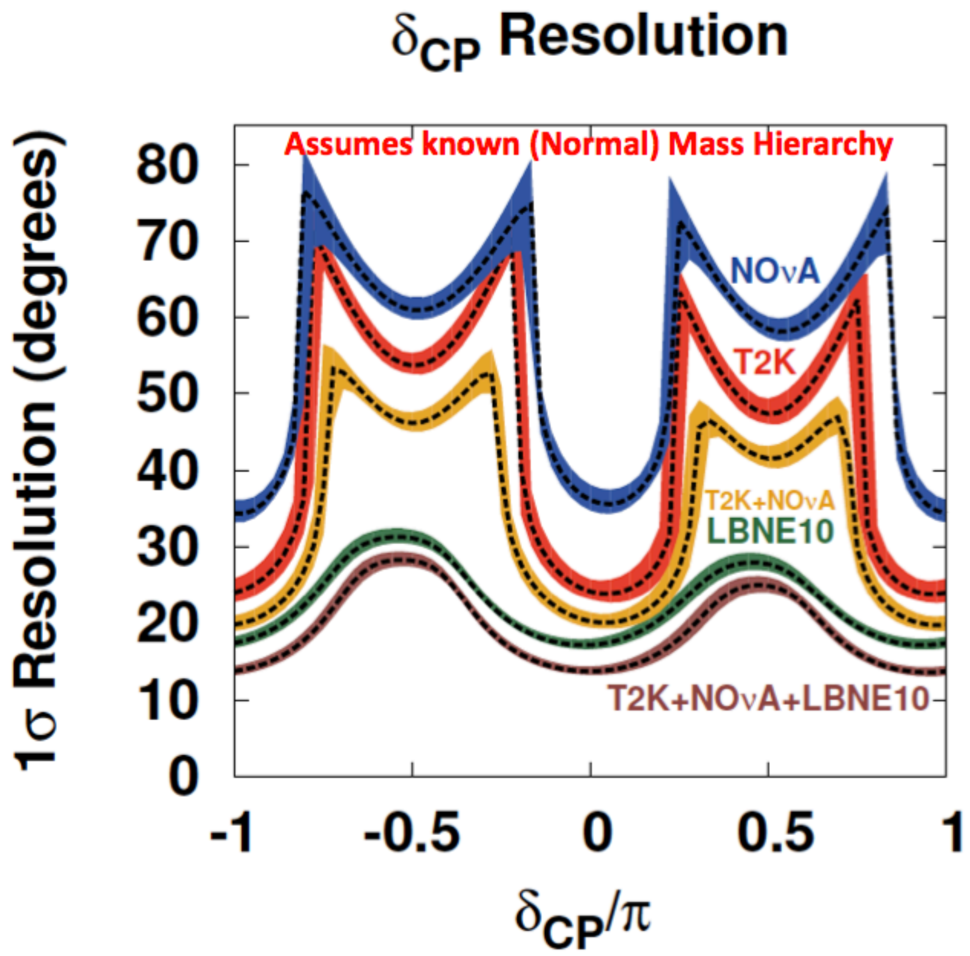

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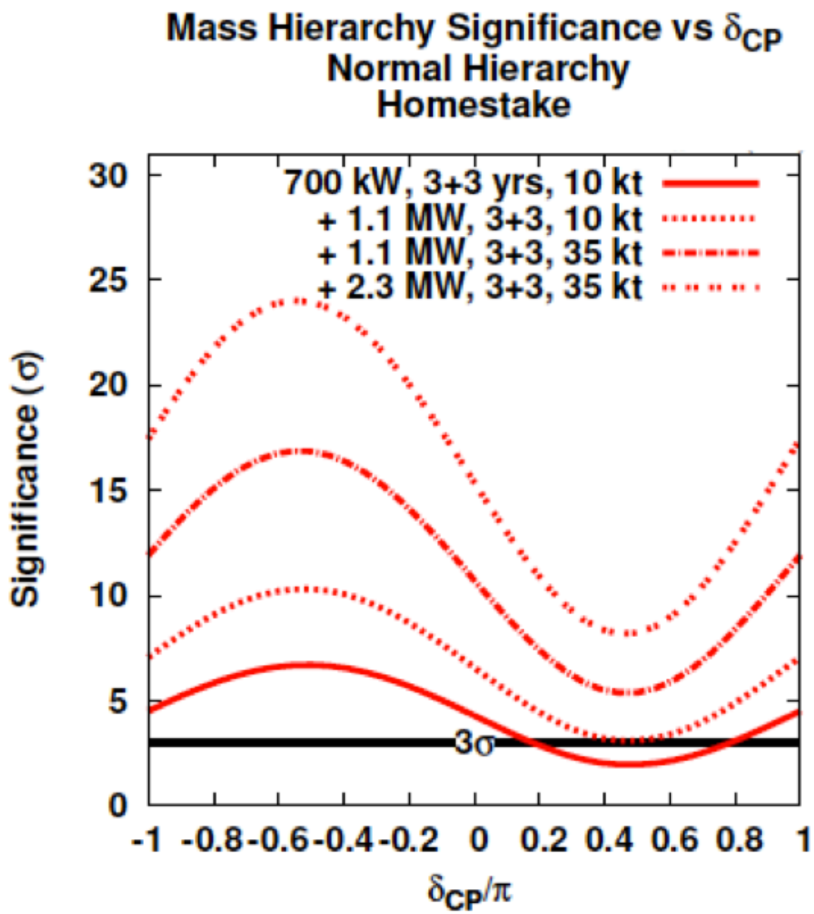
LBNE + Project X (1.1-2.3 MW) = Comprehensive Global Science Program

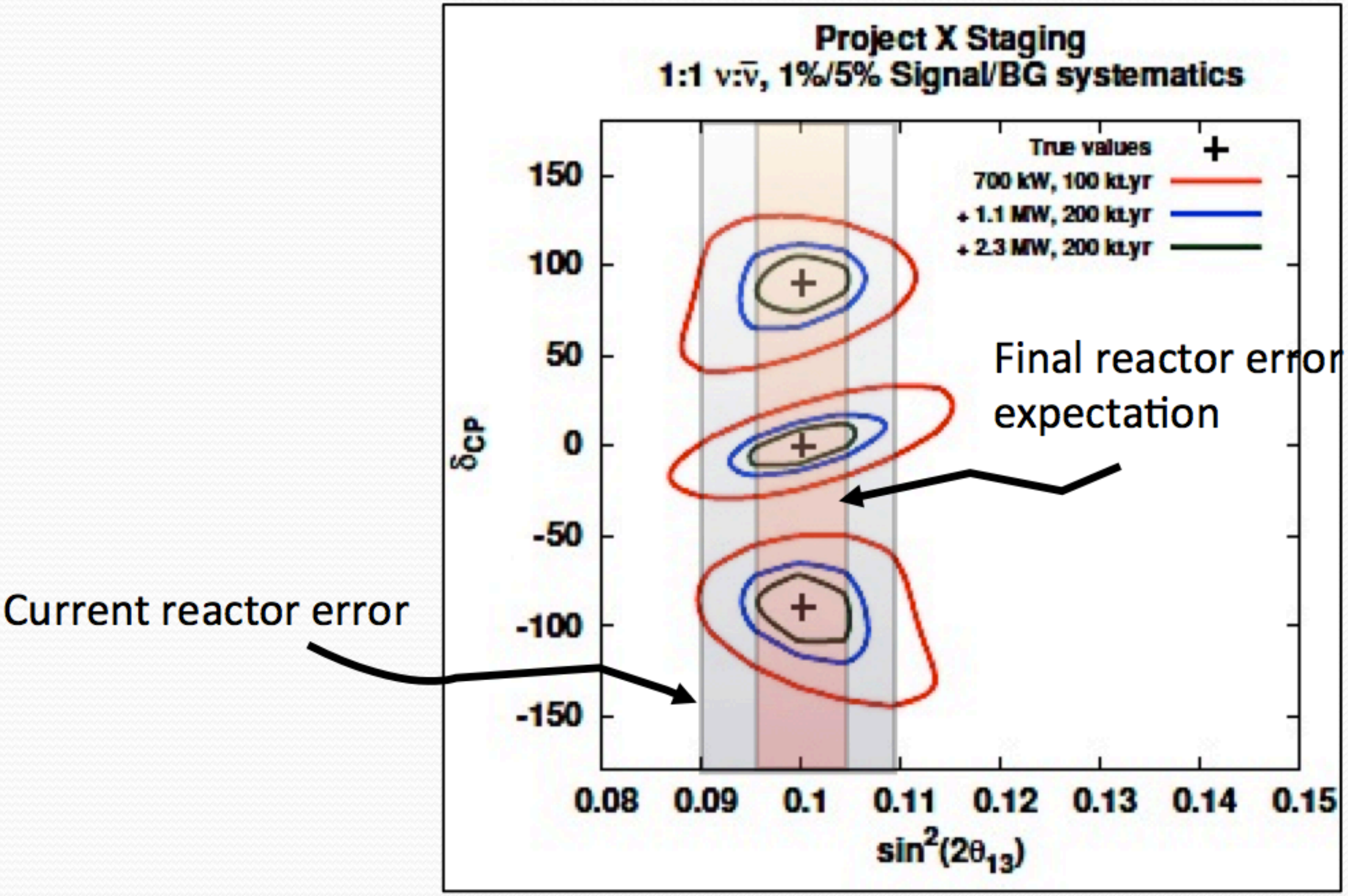
Run scenario:

- Operate w/ 700 kW w/ 10 kt LBNE
- Then 1.1 MW 1st phase Project X
- Add 25 kt LBNE FD
- Then 2.3 MW 2nd phase Project X



- With the Mass Hierarchy unambiguously determined in the same experiment more subtle matter effect features may be revealed

LBNE + Project X (1.1-2.3 MW) = Comprehensive Global Science Program



Non-Beam Physics

- Supernova Burst Neutrinos
- Proton Decay
- Atmospheric Neutrinos

Proton Decay

General Remarks

Discovery of proton decay would provide unambiguous evidence for Baryon Number (B) violation

B violation is essential for creation of matter in the Universe

Proton decay controls the ultimate fate of the Universe

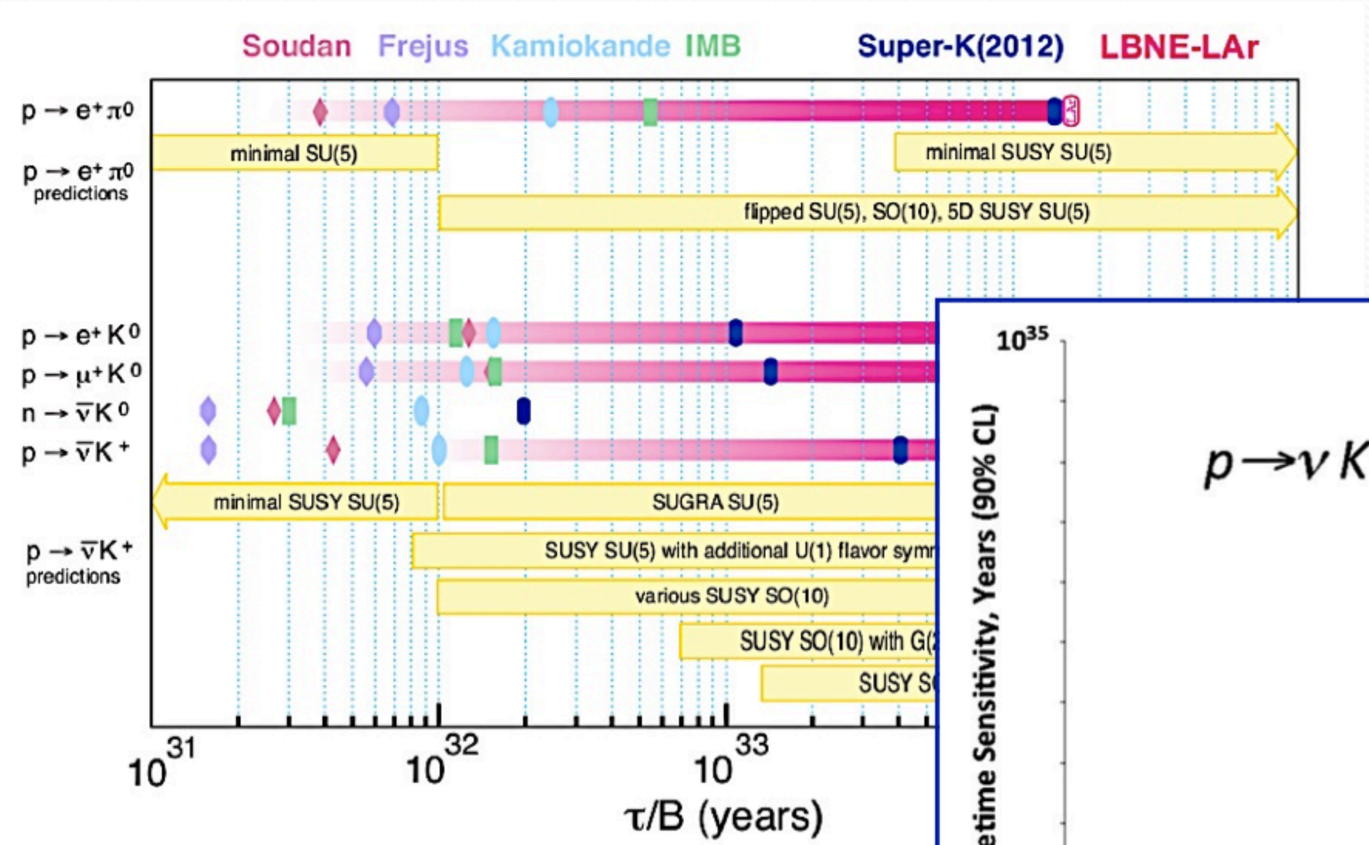
Proton decay is the missing link of Grand Unitied Theories for which strong circumstantial evidence exists

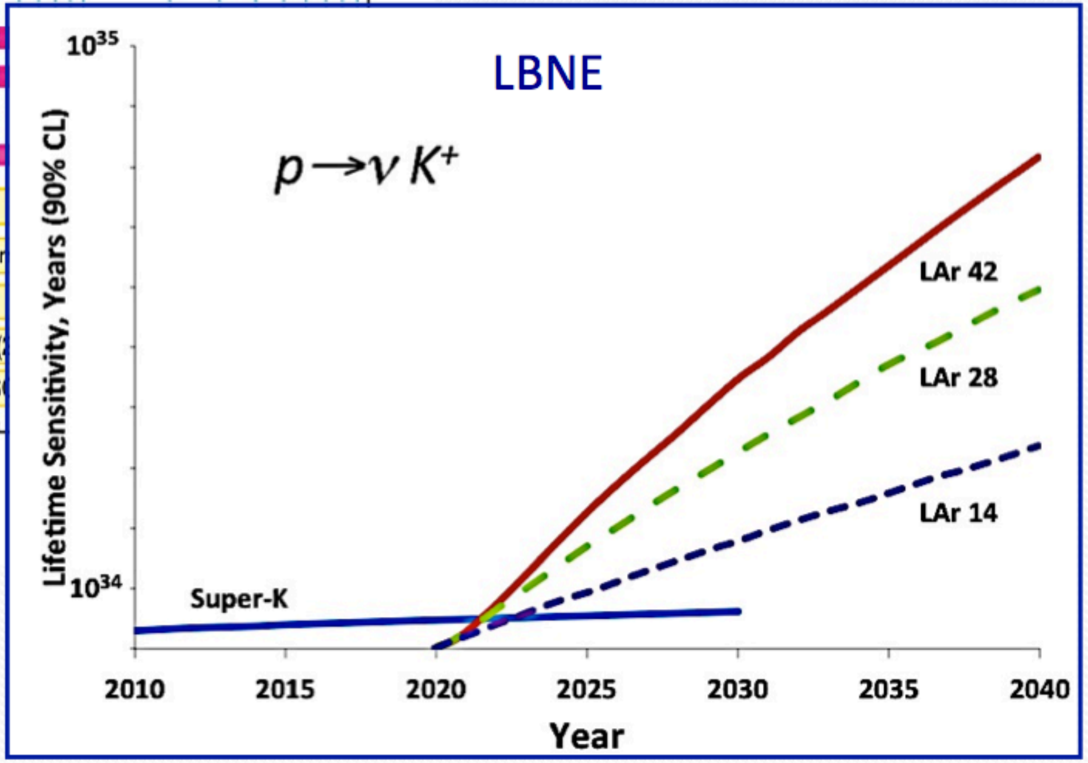
Discovery of proton decay would be a monumental scientific achievement for mankind

Large Underground Detectors are absolutely essential in acheiving this goal

K. Babu, ISOUPs, Asilomar June 2013

Proton Decay



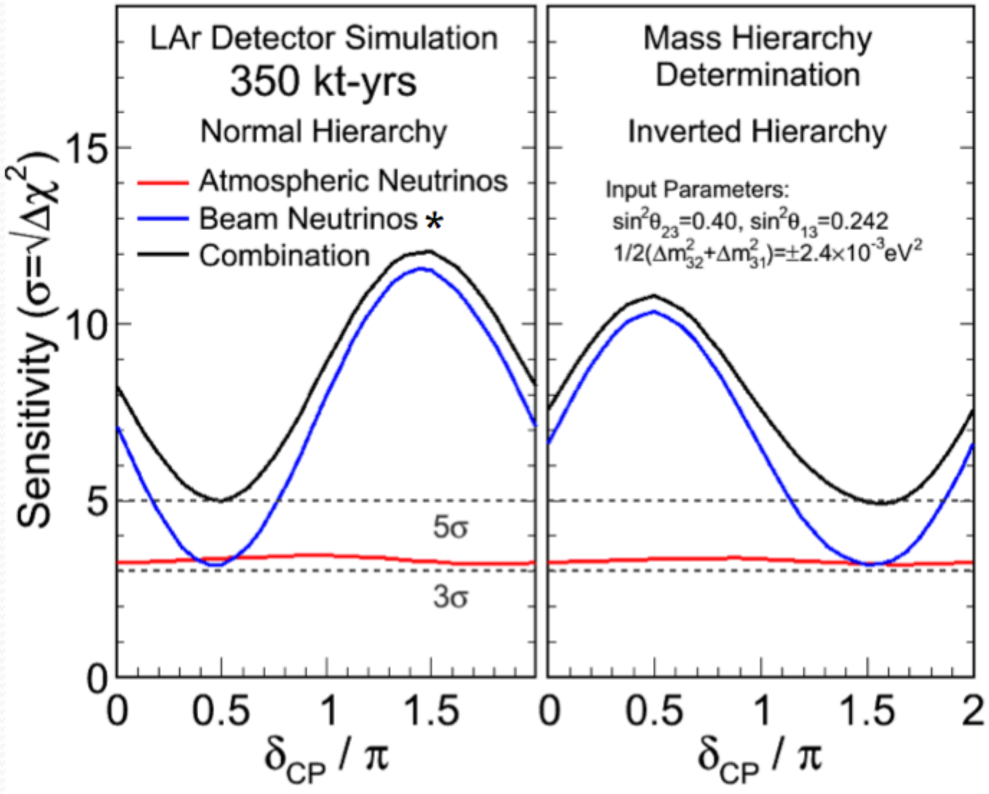


Adapted from a plot by E. Kearns

- LAr TPC high efficiency for kaon modes
- Especially interesting if SUSY discovered at LHC

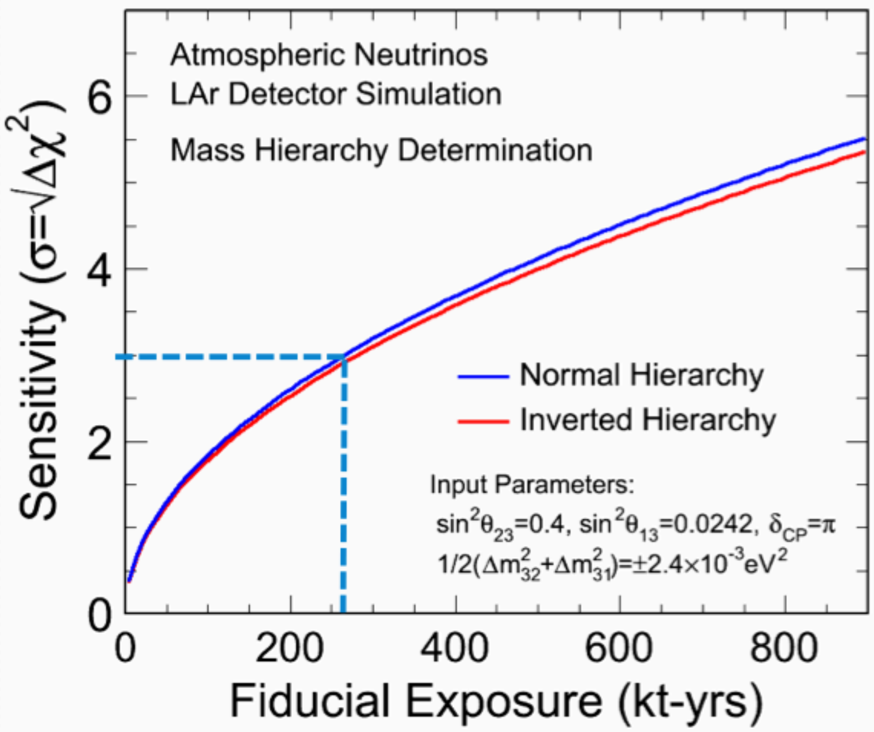
Atmospheric Neutrinos

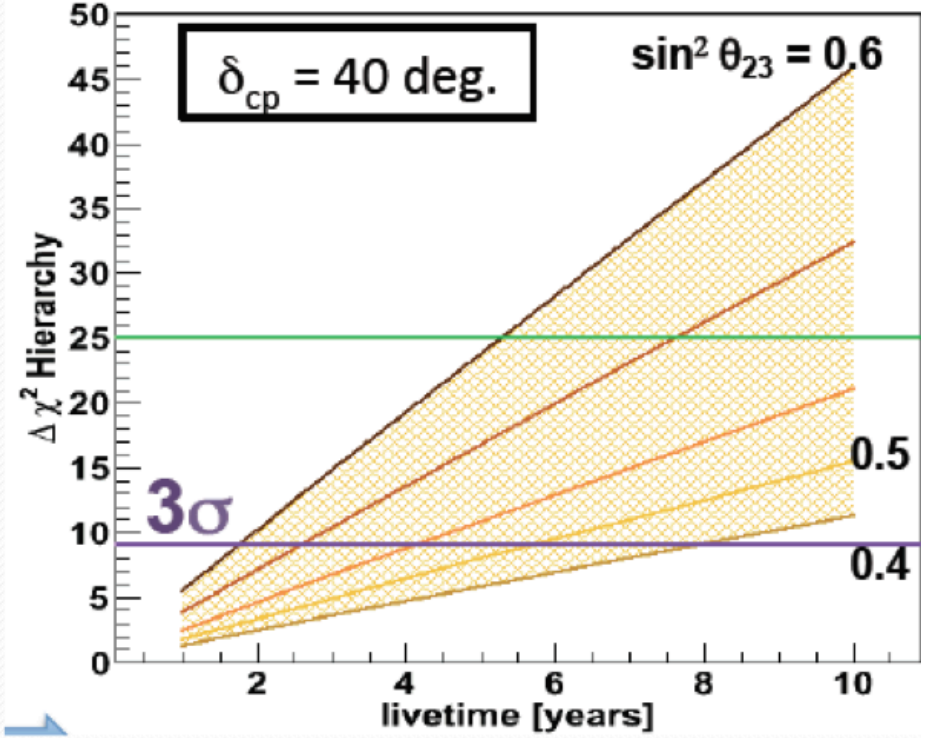
- **Large range of energy and baseline**
- In δ_{CP} range least favorable to the beam, atmospheric neutrinos have MH sensitivity comparable to the beam
- Help eliminate degeneracies in beam-only analyses
- MH from atmospheric neutrinos alone is >3σ for both hierarchies and all values of δ_{CP} in 350 kt-yrs
- **Combined sensitivity is >5σ for both hierarchies and all values of δ_{CP} in 350 kt-yrs.**
- Searches for new physics



- * Conceptual Design Report beam
- ~4000 e-like, 6000 μ-like fully-contained events
- Proton and decay-electron tagging for Atm. nus calculation

Atmospheric Neutrinos





LBNE MH Sensitivity

(H. Gallagher + A. Blake*)

HyperK MH Sensitivity

(C. Walter*)

- **HyperK and LBNE have comparable sensitivity to the MH with atmospheric neutrinos!**
- LBNE's higher resolution of event energy and direction makes up for smaller mass.

*ISOUPs, May 2013

LBNE Design Status

LBNE has a well-developed design for the complete project:

- Neutrino beam at Fermilab for 700 kW operation, upgradeable to 2.3 MW
- Highly-capable near neutrino detector on the Fermilab site
- 34 kt fiducial mass LAr far detector at
  - A baseline of 1300 km
  - A depth of 4300 m.w.e. at the Sanford Underground Research Facility (SURF)

However…

- Last year 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.
- 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.

Goal for LBNE Phase 1

- 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.

International Discussions

- 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 task force
- ICARUS/INFN groups in the process of joining LBNE
- We have also had preliminary discussions with:
  - CERN
  - Dubna
- We are hoping to initiate discussions with others:
  - Japan
  - China
  - Additional countries in the Americas, Asia and Europe
- Also exploring how to engage domestic funding agencies beyond the DOE

Summary

- CP violation parameter, mass hierarchy, non-standard interactions likely inaccessible to current generation experiments
  - **Need longer baseline and very large instrumented targets for a comprehensive program**
- Large detectors also probe physics not accessible any other way
  - Proton decay (Grand Unified Theories)
  - Supernova burst neutrinos from intra-galactic distances
- LBNE has received approval to begin this program
  - It will be the primary US HEP facility for the 2020's
  - With a budget of $867M we are proceeding with the most important aspects in the first phase and actively seeking partners to expand the scope
- LBNE will develop into a world center for neutrino physics to complement those for hadron/lepton colliders

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