Long-Baseline Neutrino Experiment in US

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CERN neutrino discussion (Nov. 26, 2013)

LBNE configuration is:

- **A horn-produced broad-band beam with 60-120 GeV protons at 700 kw (upgradable to 2.3 MW) from FNAL.**
- **Planning change: 700 kw → 1.2 MW at LBNE start.**
- **A baseline of 1300 km towards the Sanford Underground Research Facility in Lead, South Dakota.**
- **A 35 kt fiducial volume liquid argon time projection chamber located at the 4850 ft level.**
- **A high resolution near detector at FNAL.**
- **This configuration will be achieved in a phased manner according to financial constraints.**

Scientific Vision

- **Neutrino mass and mixing is the only laboratory based evidence for new physics beyond the standard model.**
- **All new information regarding neutrinos has come from neutrino oscillation measurements.**
- **Therefore a new high statistics, high resolution long-baseline neutrino oscillation experiment with appropriate scale is well motivated.**
- **The experimental scale is determined by the remaining unknowns: CP violation in neutrinos, mass ordering of neutrinos, and the apparent mu/tau symmetry (θ_{23} octant)**
- **We want to perform a comprehensive experiment with sufficient internal redundancy as well as scientific breadth.**
- **The full physics menu must include nucleon decay and SNB neutrinos (and other underground physics).**

Community support for LBNE – Snowmass

Planning the Future of U.S. Particle Physics

Report of the 2013 Community Summer Study

Conveners: M. Bardeen, W. Barletta, L. Bauerdick, R. Brock, D. Cronin-Hennessy, M. Demarteau, M. Dine, J. L. Feng, M. Gilchriese, S. Gottlieb, J. L. Hewett, R. Lipton, H. Nicholson, M. E. Peskin, S. Ritz, H. Weerts

Division of Particles and Fields Officers in 2013: J. L. Rosner (chair and corresponding author), I. Shipsey (chair-elect), N. Hadley (vice-chair), P. Ramond (past chair)

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The Long-Baseline Neutrino Experiment (LBNE) will measure the mass hierarchy and is uniquely positioned to determine whether leptons violate CP. Future multi-megawatt beams aimed at LBNE, such as those from Project X at Fermilab, would enable studies of CP violation in neutrino oscillations with conclusive accuracy. An underground LBNE detector would also permit the study of atmospheric neutrinos, proton decay, and precision measurement of any galactic supernova explosion. This represents a vibrant global program with the U.S. as host.

Neutrinos

arXiv:1310.4340

Conveners: A. de Gouvêa[50], K. Pitts[32], K. Scholberg[26], G.P. Zeller[27]

Subgroup Conveners: J. Alonso[46], A. Bernstein[41], M. Bishai[8], S. Elliott[42], K. Heeger[78], K. Hoffman[43], P. Huber[74], L.J. Kaufman[35], B. Kayser[27], J. Link[74], C. Lunardini[4], B. Monreal[15], J.G. Morfín[27], H. Robertson[75], R. Tayloe[35], N. Tolich[75]

LBNE plays a central role in the future U.S. program,

LBNE Science Collaboration

- **452 members, 78 institutions, 6 countries (Sept. 2013)**
- The collaboration has well-organized scientific and technical working groups.
- There is frequent communication with the funding agencies.

- 357 US + 95 non-US
  - 21% non-US; 26% of faculty/scientists
  - More than doubled non-US fraction since CD-1
  - First non-US member elected to Exec Comm. (Sept 13)
  - 30% growth in the past year

Fort Collins, September 2013

International Collaborators

- **UK(9 inst.): Well integrated into the collaboration; ongoing discussions with STFC for phased funding.**
- **Italy(7 inst.): Bringing crucial ICARUS expertise to the experiment; discussions with INFN on future funding.**
- **India(5 inst.): Proposal for a high resolution near detector prepared. Many FNAL/DOE interactions with Indian funding agencies.**
- **Brazil(5 inst.): Integrated into the far detector design. R&D proposal to FAPESP (Sao Paulo funding agency) for photon detectors. Federal government proposals planned.**

International Dialogues

- **LAGUNA/LBNO: We share the same scientific goals and experimental strategies and have a joint physics task force. Discussing joint R&D at CERN and in the US.**

- **Italy: Communication with senior members of NESSiE at the LBNE Sept. 2013 collaboration meeting. Near term interests in R&D and short-baseline discussed.**

- **Russia: LBNE added to FNAL/INR MOU. Preliminary discussion with Dubna. MOU in progress between JINR and Panjab U. for strawtube tracker development.**

- **Japan: Japan-US Committee for Cooperation in High Energy Physics - Neutrino Task Force for coordination of proposals in areas of joint interest in accelerator, detector and physics development**

Scientific Priorities

- **LBNE design follows these priorities**
  - ➡ **CP violation in the neutrino sector**
  - ➡ **CP phase measurement regardless of its value.**
  - ➡ **Neutrino mass hierarchy determination.**
  - ➡ **Determination of θ_{23} octant and precision parameter measurements.**
  - ➡ **Precision tests of 3-flavor neutrino model.**
  - ➡ **Atmospheric neutrino measurements (confirmation of mass ordering with independent data)**
  - ➡ **Nucleon decay**
  - ➡ **Supernova burst neutrinos**
  - ➡ **As a very capable near detector will be needed, it is recognized that it could have a synergistic scientific program of precision neutrino and weak interaction physics.**

Experimental Design

- Our experimental focus is on $\nu_\mu \rightarrow \nu_e$ and anti-$\nu_\mu \rightarrow$ anti-ν_e with superb particle identification and energy resolution, as this channel is most suitable for current neutrino beam and detector technologies.

- The measured neutrino mixing parameters in the 3-flavor framework suggest that the CP asymmetry will be <30% (first max) and therefore >1000 events are needed.

- World-wide studies have concluded that beams with 1-2 MW of power at high energies and unprecedented large far detector fiducial mass is needed regardless of baseline to achieve above statistics.

- A baseline of >1000 km and a broad-band beam are needed for a comprehensive experiment with sensitivity to mass ordering and spectral shape.

- Detector must have sufficient overburden to allow sensitivity to nucleon decay and supernova.

Event rate and spectra expectation.

Assumptions:

35 kt LArTPC

1.2 MW operation at 80 GeV.

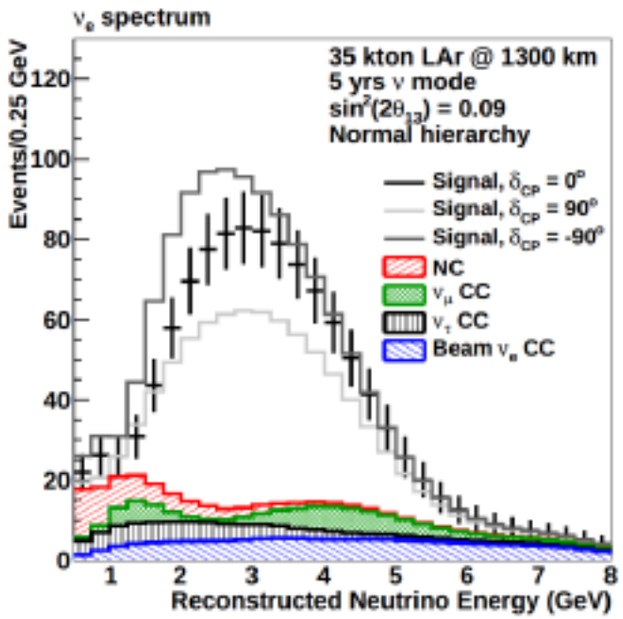
~3 yrs for each polarity.

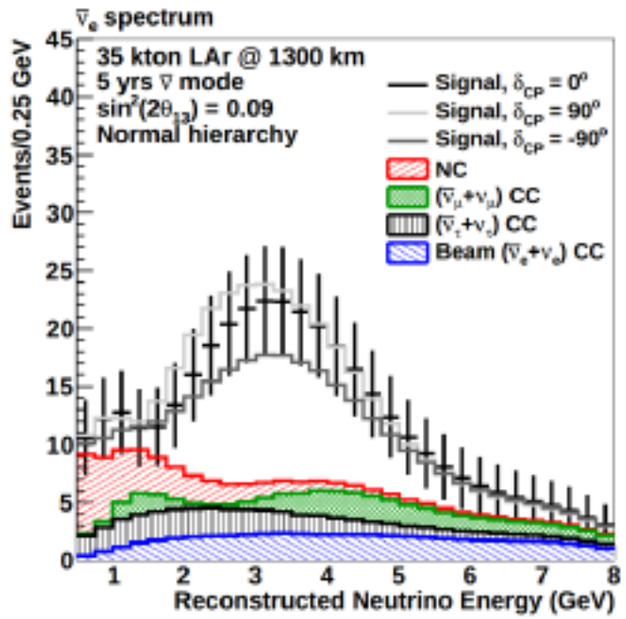
Normal Hierarchy

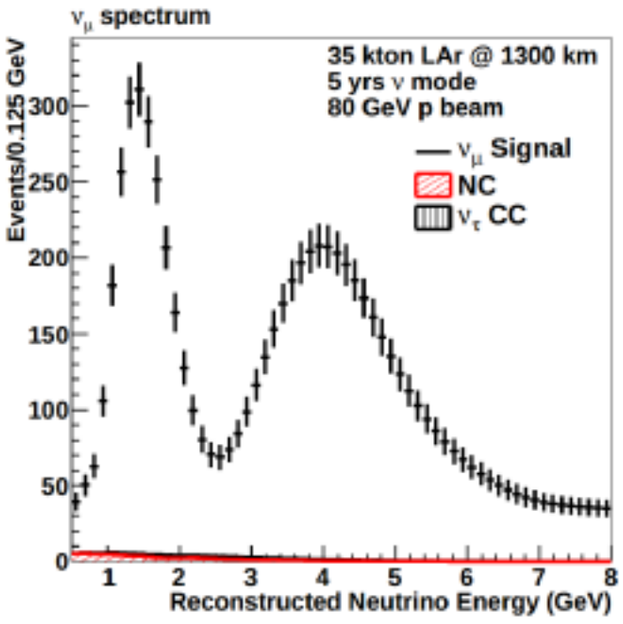
δ_{CP}= 0

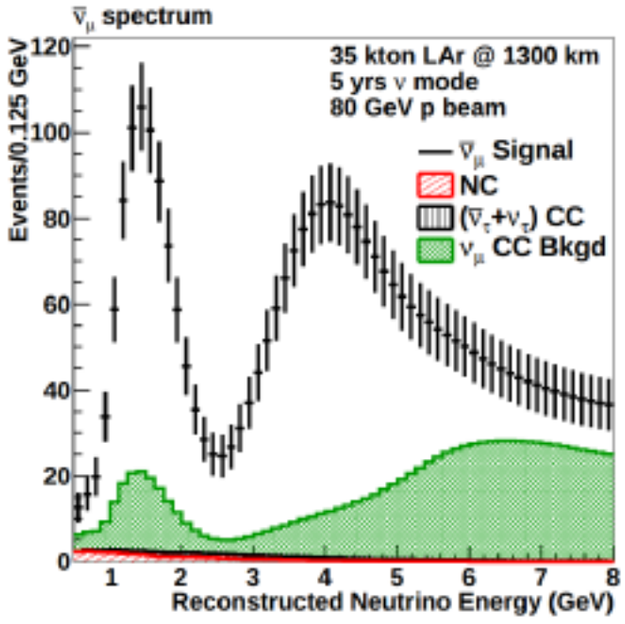
Rest of the parameters are at best fit from 2012

80 GeV Beam	ν mode	$\bar{\nu}$ mode
Signal: $\nu_e + \bar{\nu}_e$	777	189
BG: NC	67	39
BG: $\nu_\mu + \bar{\nu}_\mu$ CC	84	39
BG: Beam $\nu_e + \bar{\nu}_e$	147	81
BG: $\nu_\tau + \bar{\nu}_\tau$ CC	49	32



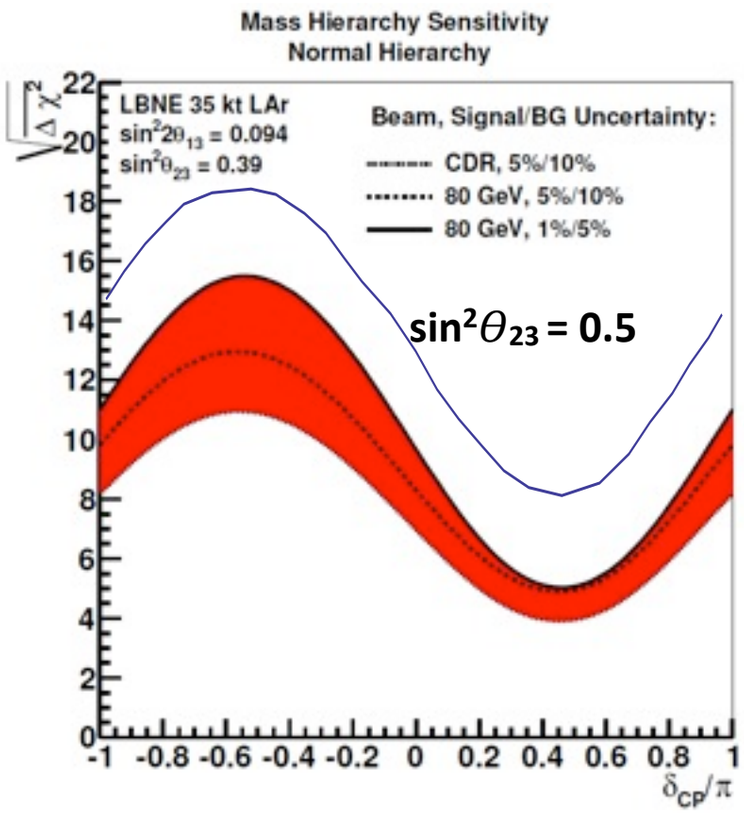


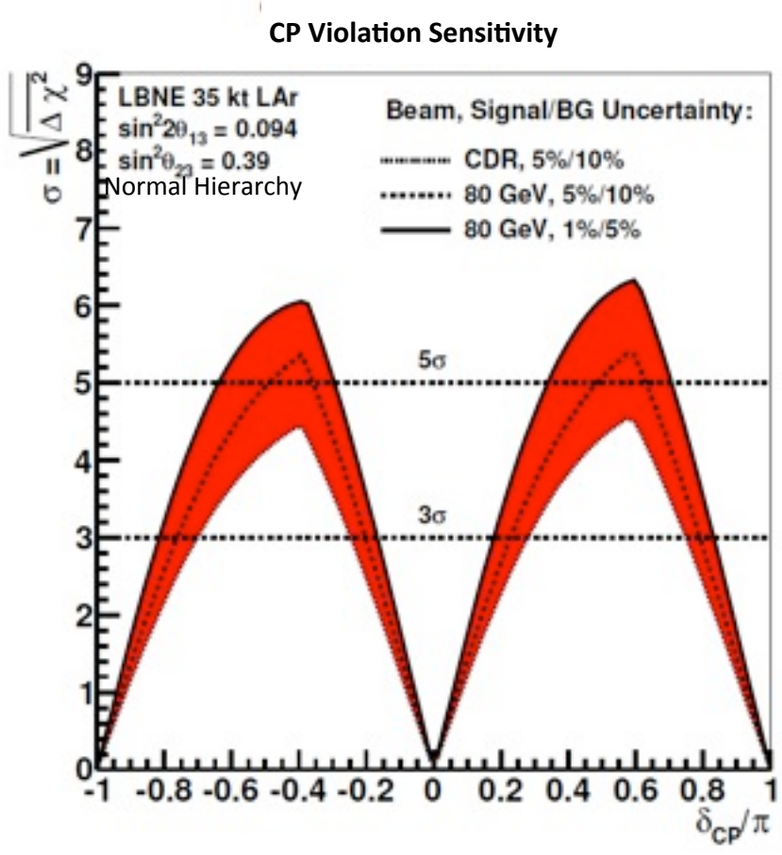


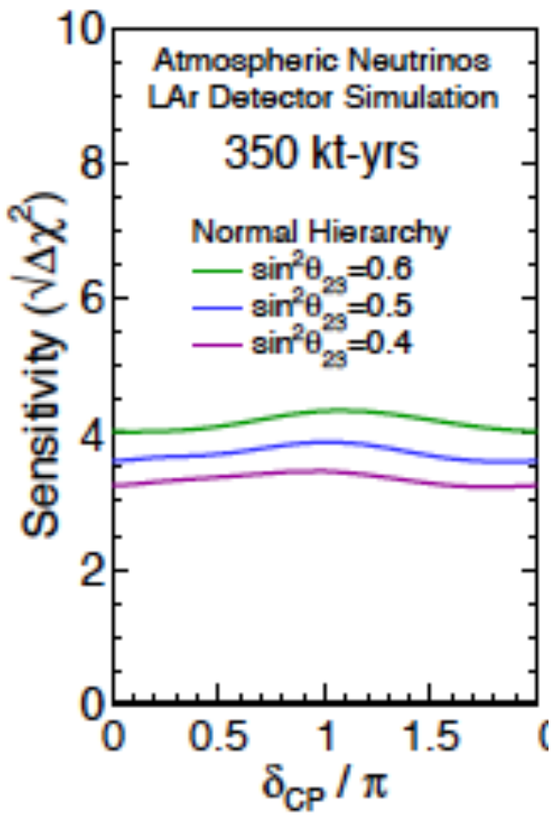


- **At 1300 km full oscillation structure is visible in the energy spectrum. A combined spectral fit provides unambiguous parameter sensitivity in a single experiment.**

Sensitivity





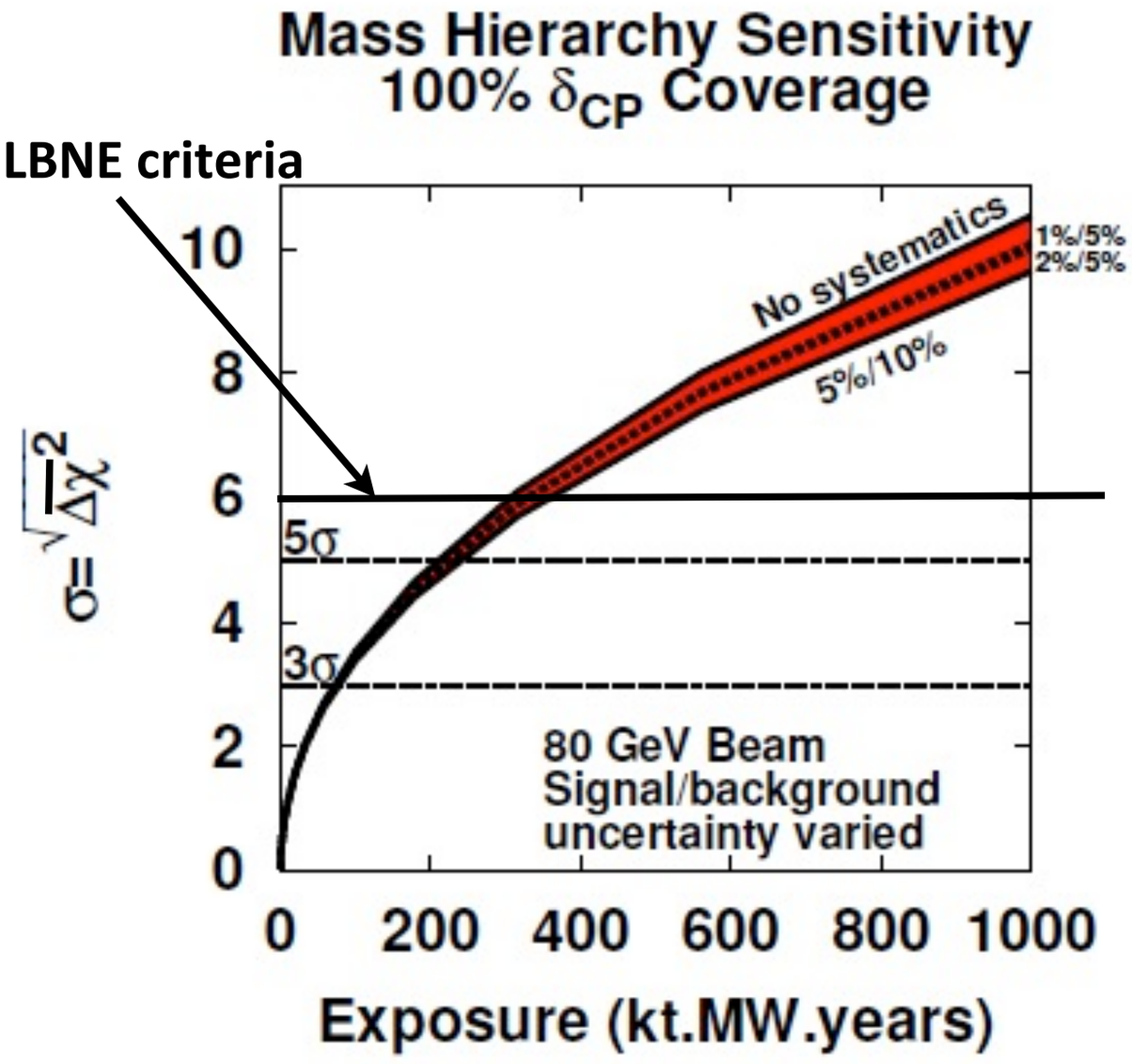


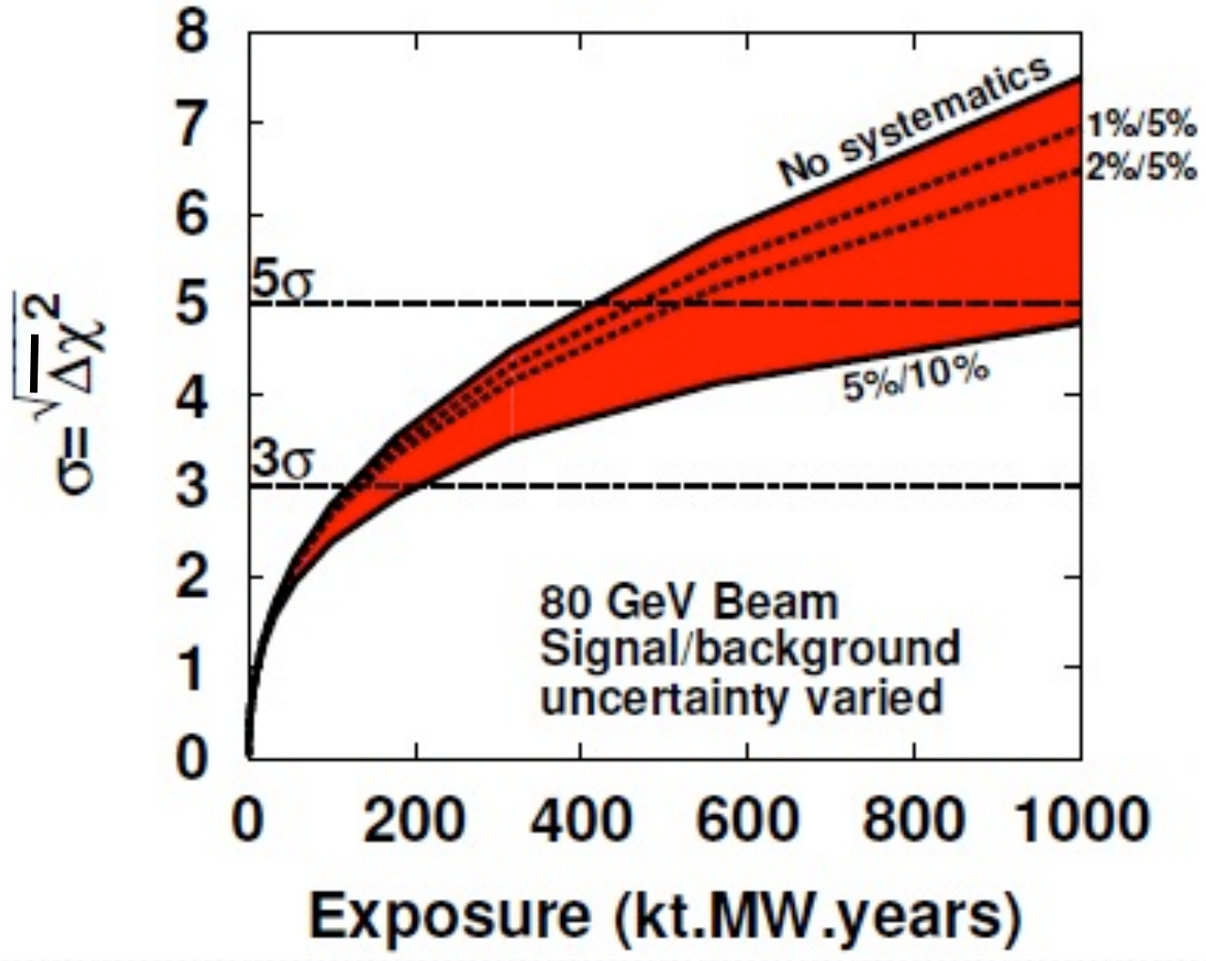
Exposure 245 kt.MW.yr
1.2 MW x 35 kt x(3ν+3$\bar{\nu}$) yr

Parameter sensitivity to $\sin^2\theta_{23}$ = 0.39 → 0.5

- **For NH versus IH hypothesis testing, following PDG (Neyman-Pearson) formalism, we find that α = β < 0.13% (two hypothesis testing) to be a sufficient criteria. These are probabilities of either rejecting the correct hierarchy or accepting the wrong one.**
- **LBNE will produce two independent checks on hierarchy (beam and ATM nus) with average $\Delta\chi^2$ > 36 (beam) or >9 (atmospheric).**

Impact of Normalization Uncertainties

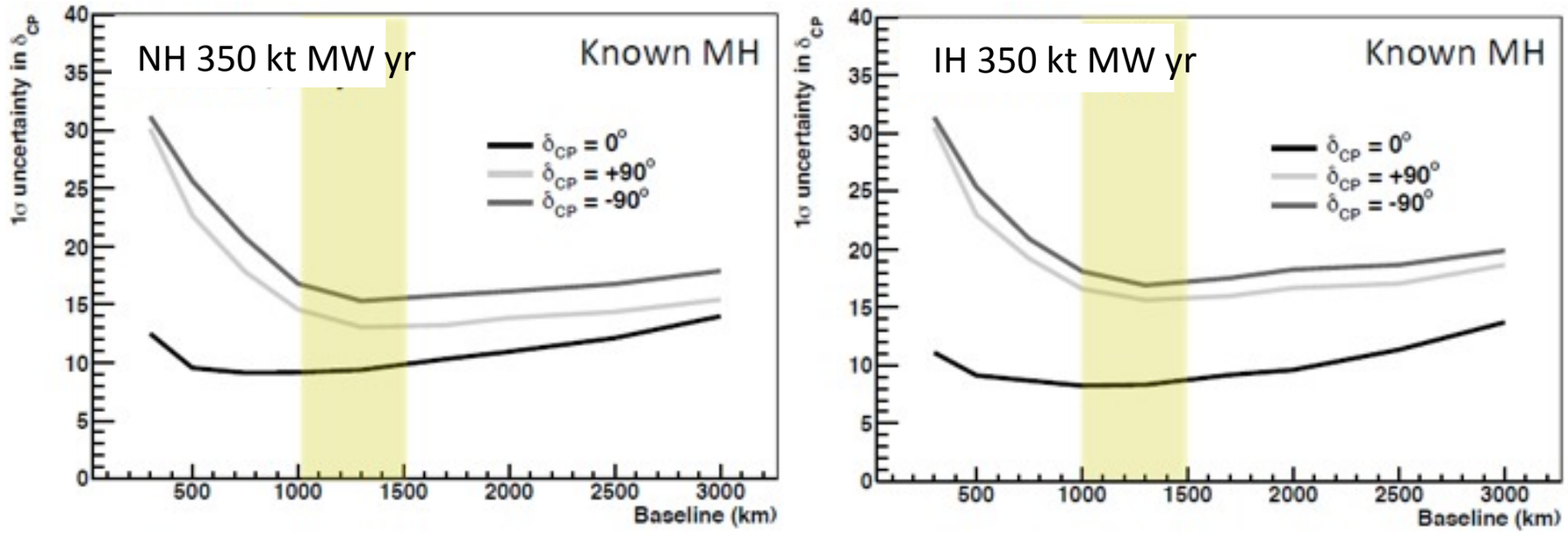




- **The systematic precision is required to be better than the expected statistics at each stage of the experiment. High precision is needed after 200kt*MW*yr.**
- **MH relatively insensitive to systematics; but further study needed.**
- **MINOS appearance result has achieved better than 5%/5% systematics.**

Baseline Optimization

- **A thorough study of optimization of a long-baseline experiment was performed recently by LBNE collaborators (arXiv: 1311.0212). For each baseline length, the beam spectrum was optimized in a realistic way using simulations of a horn-produced beam with 120 GeV protons.**



- **The resolutions were calculated as a function of exposure as well as baseline length. An optimum is obtained for phase resolution when there is sufficient shape information and statistics.**
- **The event rate at first and second maximum per unit exposure is largely independent of baseline due to kinematics.**

Further Scientific Issues

- **Since project start LBNE has addressed financial and schedule constraints. The CD1 conceptual design includes many compromises as well as opportunities.**
- **Phasing: Our intent remains to achieve the full LBNE configuration as soon as possible, but given the financial constraints we must examine intermediate steps for detector mass.**
- **Beam optimization: Possible enhancements by improvements to the decay pipe, horns, target, and lower energy running are under consideration.**
- **Possibility for Growth: The geotechnical studies at SURF will examine enough rock to accommodate >70 kt detector. The beam shielding will be designed to withstand >2.3 MW.**
- **FNAL is committed to increasing the beam power from the Main Injector in reasonable steps in parallel to LBNE.**

Detector Mass/Beam Power Scenario

- Plausible timeline for a phased international program

  - 2025-2030
    Detector mass: 15 kt (fid.)
    Proton beam power: 1.2 MW
    - Exposure: 90 kt.MW.yr

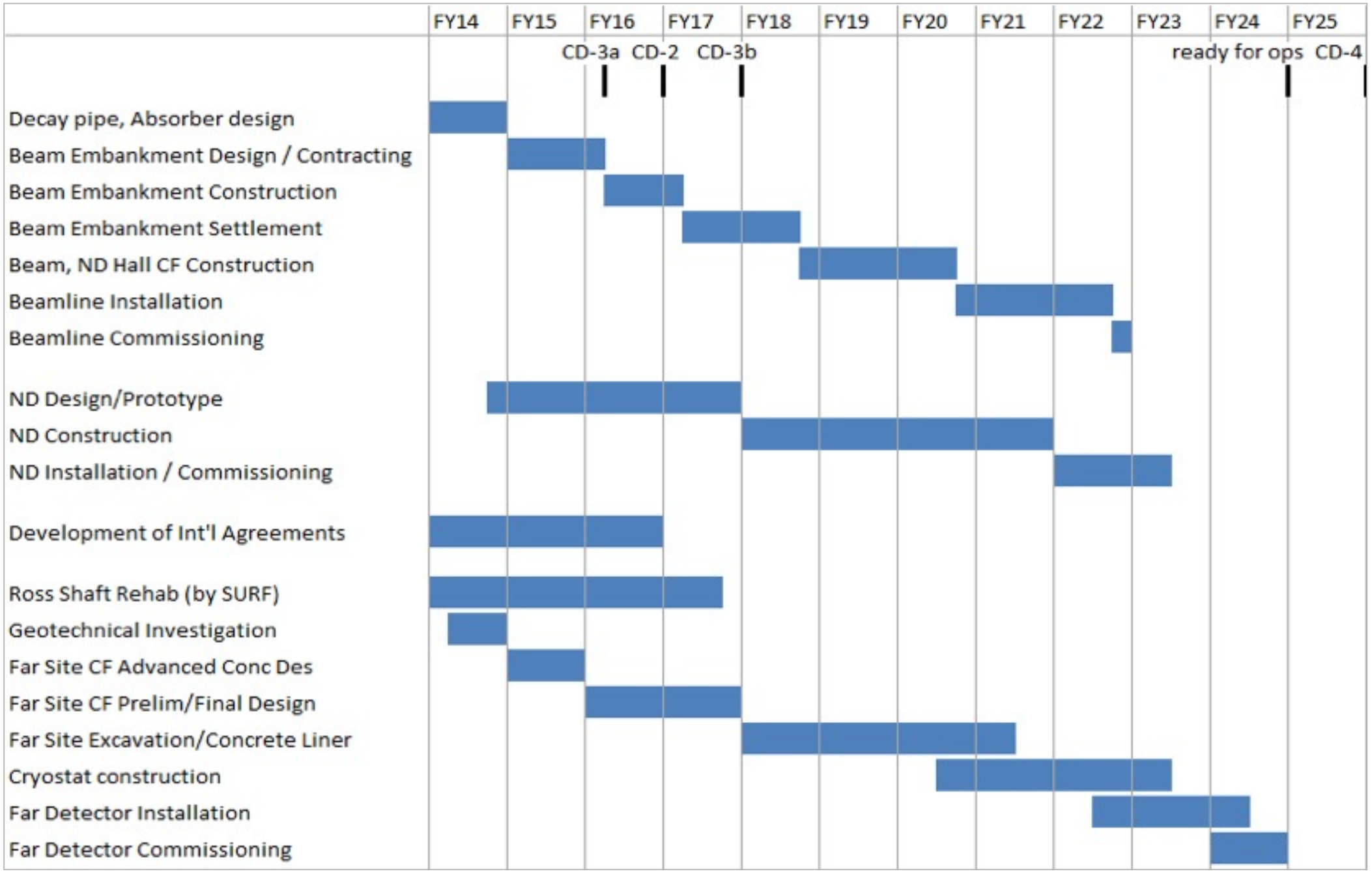
  - 2030-2035
    Add 20 kt = 35 kt
    Proton beam power: 2.3 MW
  - Total Exposure: 490 kt.MW.yr

Project Status and Schedule

- DOE has granted CD1 (critical decision on conceptual design with site decision) with $867M commitment with flexible scope in December of 2012.
- There is agreement that scope presented at CD1 (reduced surface FD, no ND) will be modified based on evolving partnerships.
- The project schedule and funding profile from the DOE can be adjusted to produce the best global experiment.
- We intend to form an International Advisory Group of scientists to advise on collaborative and financial mechanisms with our respective funding agencies.
- The project will proceed according to the current DOE Critical Decision (CD) process modified to include multiple international partnerships. We have many examples to guide us including CMS, ATLAS, LHC, Daya Bay, etc.

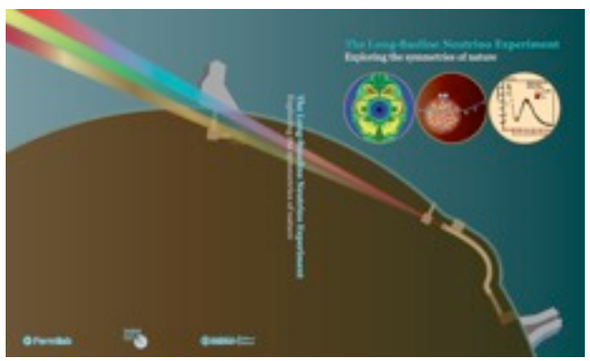
Project Status and Schedule (cont.)

Plausible Schedule for international LBNE



Conclusion

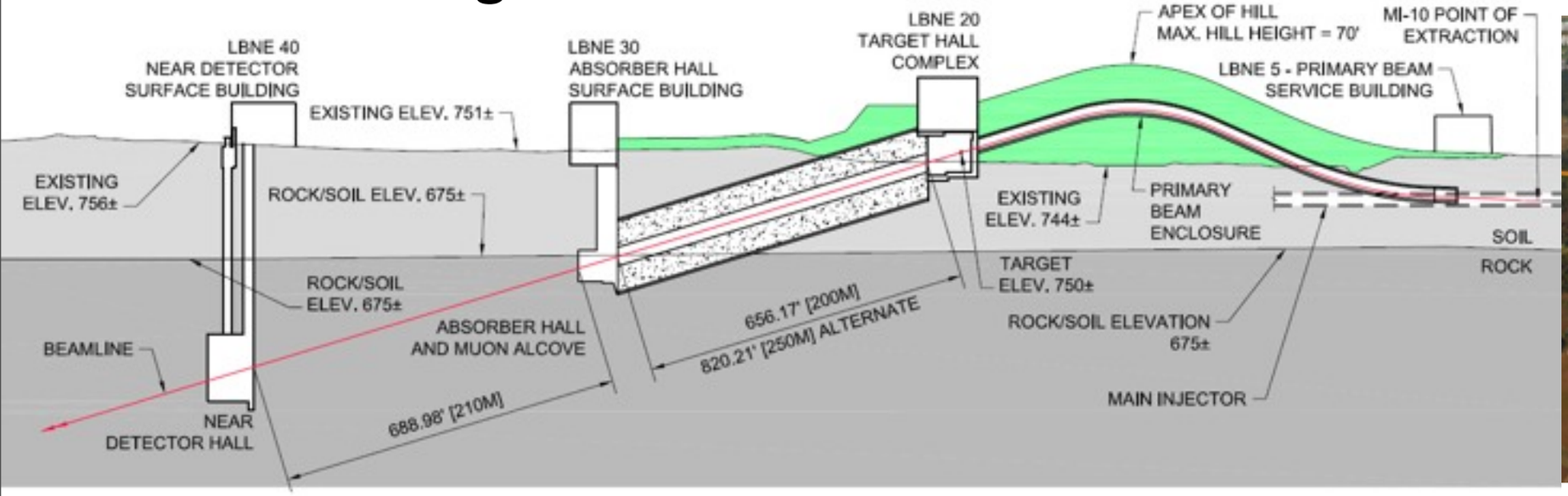
- **Scientific motivation and scale of the next generation long-baseline neutrino oscillation experiment is well-known. LBNE design in the US meets the requirements for a comprehensive experiment aimed towards CP violation in the neutrino sector.**
- **The US is in a unique position to execute this program given the availability of high intensity accelerator**
  - **700 kW upgrade in commissioning**
  - **1.2 MW by the time of LBNE start**
  - **Further upgrades to >2.3 MW**
- **An operating world-class underground lab at SURF (Dark Matter and Double Beta Decay experiments have started at 4850L)**
- **Optimal baseline for a comprehensive oscillation program.**

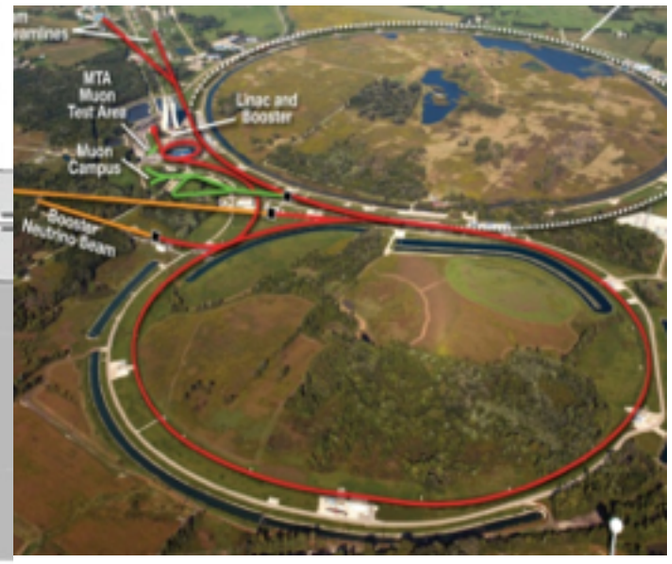


- Snowmass detailed-whitepaper arXiv:1307.7335
- To be updated annually and printed.

Some pictures

LBNE beam design





LUX @ SURF