LBNE configuration options

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Outline

- We prefer that under the present financial constraint the highest priority is to preserve the 1300 km option, and development of a complete phasing plan.
  - Current scientific landscape regarding neutrino oscillations.
  - Why the preference for a longer baseline ?
  - Options that may fit within the understanding of affordability.
  - Comparison of options from phasing perspective.

LBNE phased approach

Brinkman/DOE:

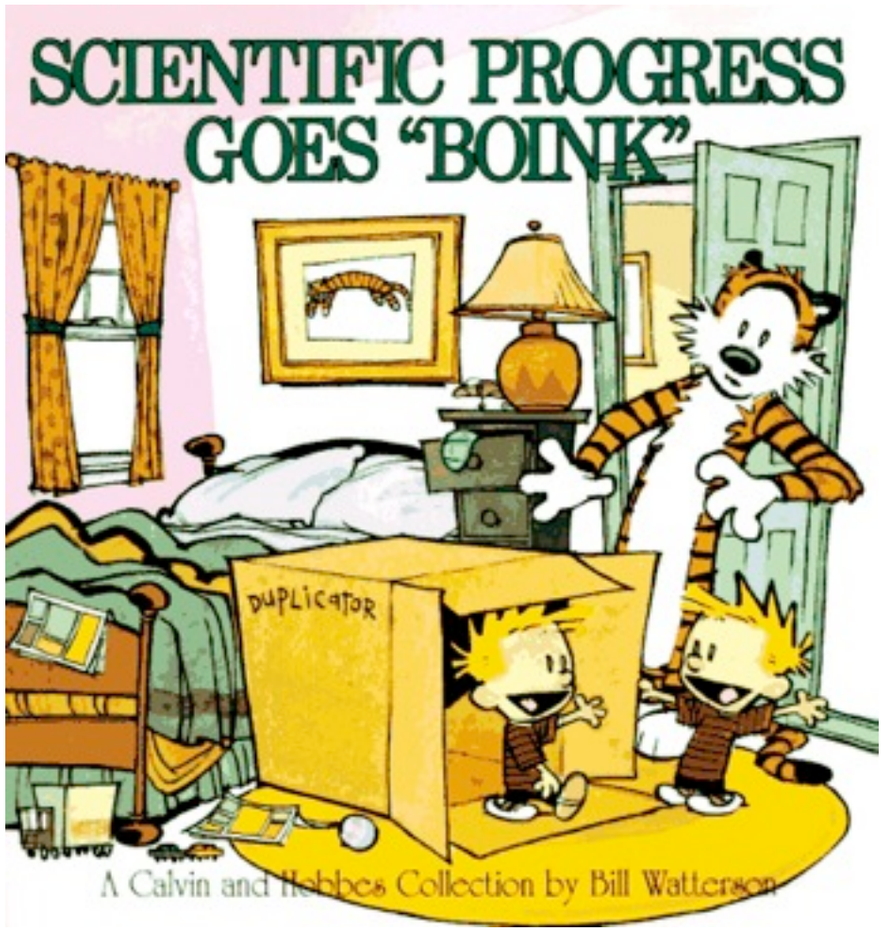
In order to advance this activity on a sustainable path, I would like Fermilab to lead the development of an affordable and phased approach that will enable important science results at each phase. Alternative configurations to LBNE should also be considered. Options that allow us to independently develop the Homestake Mine as a future facility for dark matter experiments should be included in your considerations.

- As the first priority the phased approach in which all phases for LBNE are examined must be considered. So far we have not seen any true phasing approach.
- The phased approach needs to be considered by this committee !

LBNE configuration

We promised θ_{13} by 2012, and we have delivered !

The investment in LBNE over the last 4 yrs was absolutely the correct scientific decision. Further investment was predicated on a non-zero θ_{13}. It is important to make decisions that use this physics in the best possible way.



- LBNE configuration:1300 km, 34 kTon of LAr @ 4850 ft with broadband 700 kW beam.
- This configuration is scientifically superb.
- With the value of θ_{13} as known, this configuration will deliver stunning, unambiguous science.

LBNE ultimate performance

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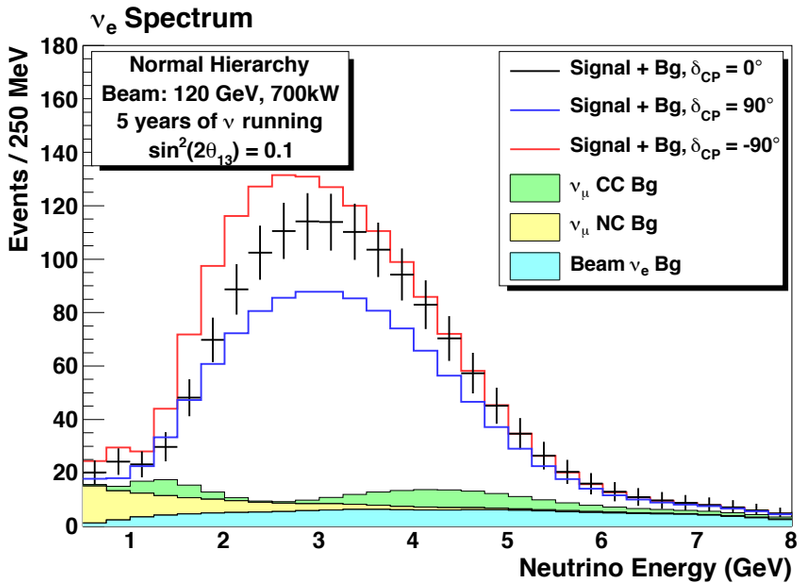

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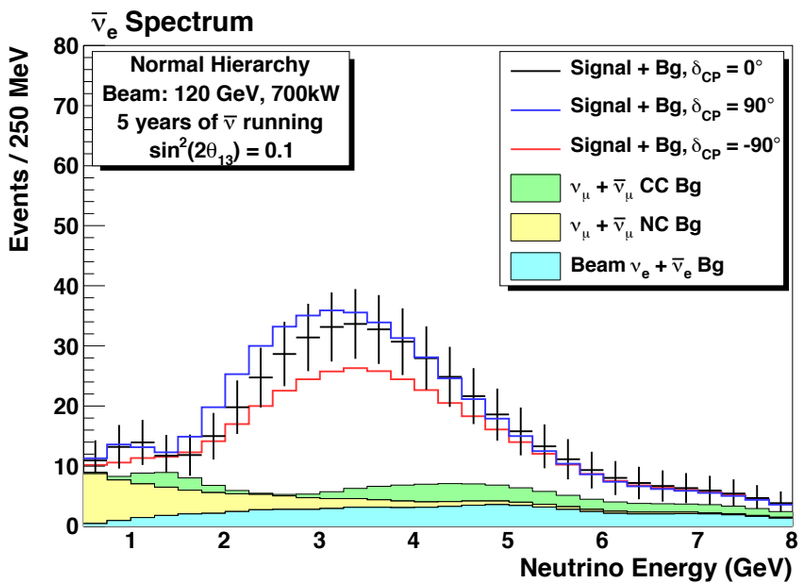

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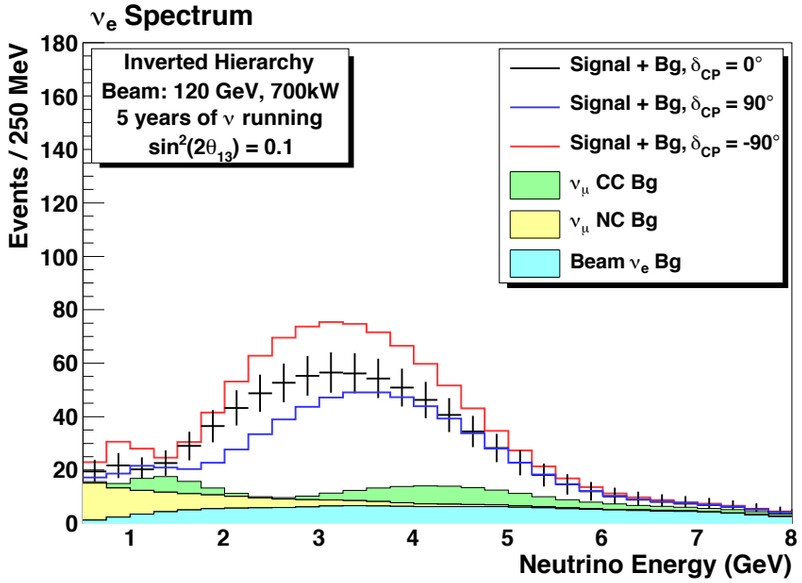

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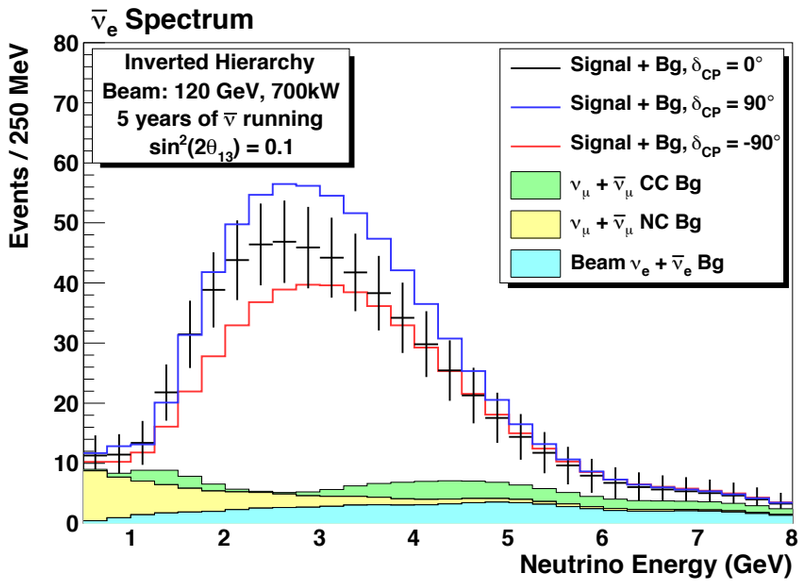

This result is now guaranteed. And there is virtually no competition of comparable quality. We need to find a phased approach to get to this.

Why long baseline ?

Non-collider experiments and astronomical observations have given us our first hints of physics beyond the Standard Model, via the discoveries of neutrino oscillations, dark energy, and dark matter. The implication of these discoveries for fundamental physics is still unknown. The energy scale of the new degrees of freedom giving rise to neutrino oscillations could be as high as 10^{16} GeV, as in Grand Unified theories, or as low as 0.05 eV, as in Dirac neutrino mass models. Even more mysterious is the nature of dark energy and dark matter, and the associated energy scale or scales. If the new physics is light, it must be very weakly coupled to the Standard Model, or it would already have been discovered. Neutrino oscillation measurements offer an unmatched portal into any new nonstandard sectors containing light fermions, because neutrinos can mix with neutral spin 1/2 particles, and because oscillations over long baselines are extraordinarily sensitive to extremely tiny effects.

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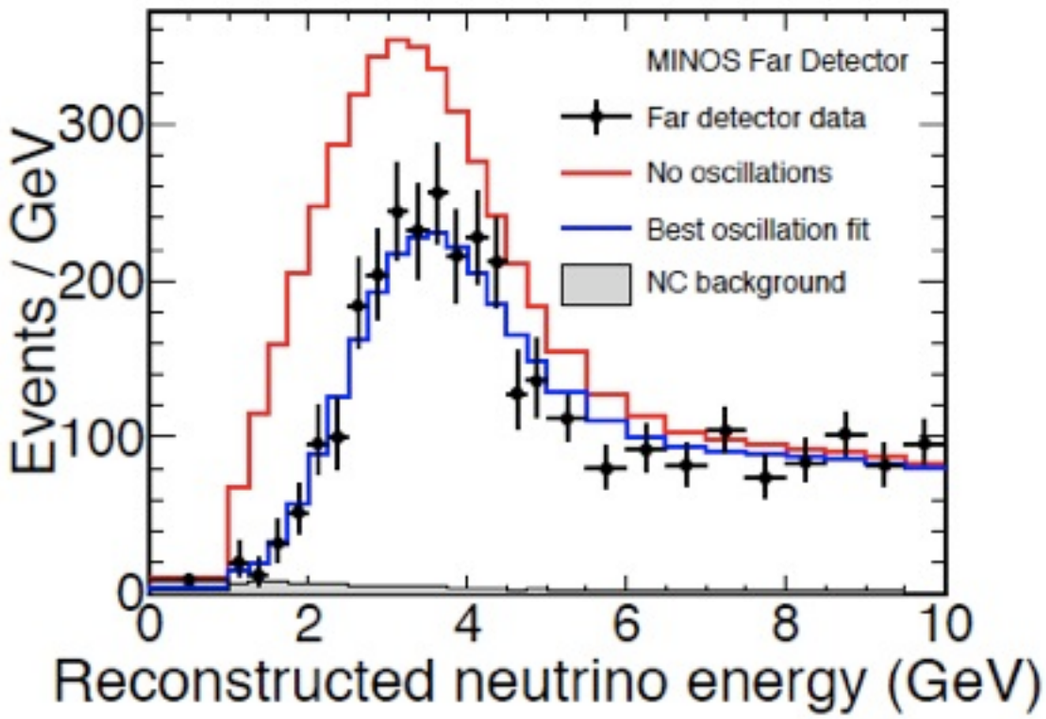
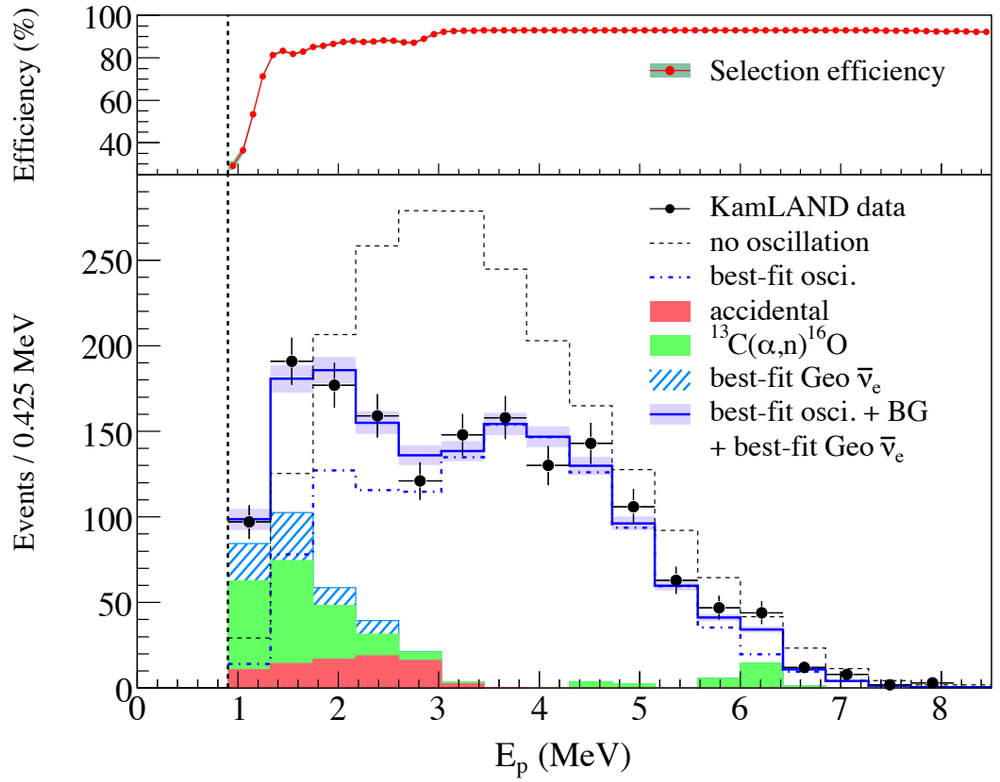
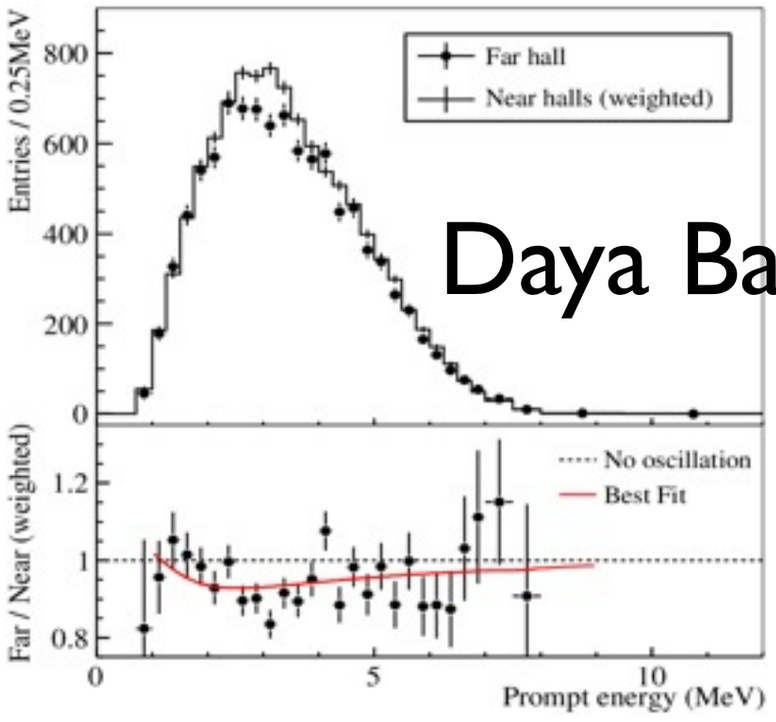
Capability Gap

There is a capability gap in the U.S. High Energy Physics program and world-wide particle physics program for neutrino physics. Further progress in the investigation of neutrino mass ordering and matter-antimatter asymmetry requires a combination of larger detectors and more powerful beams capable of observing an order of magnitude more neutrino interactions where the beam and detector(s) must be separated by 1000-1500 km. No existing or planned facility in the U.S. or internationally fills this capability gap.

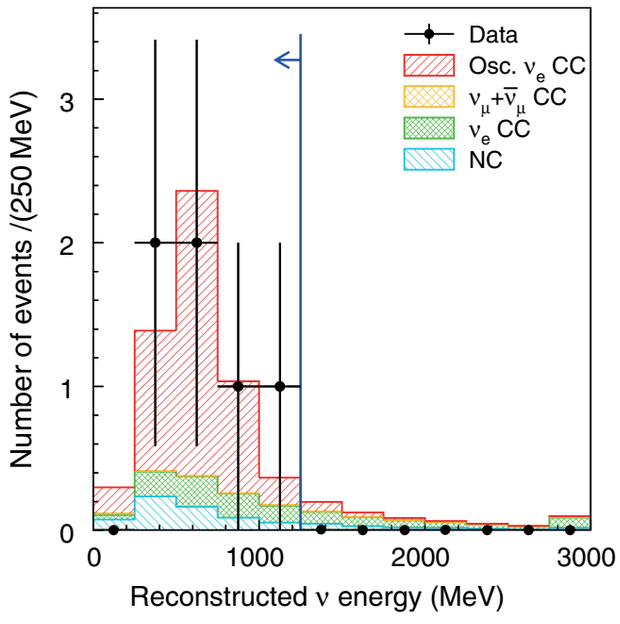
Current terrestrial evidence







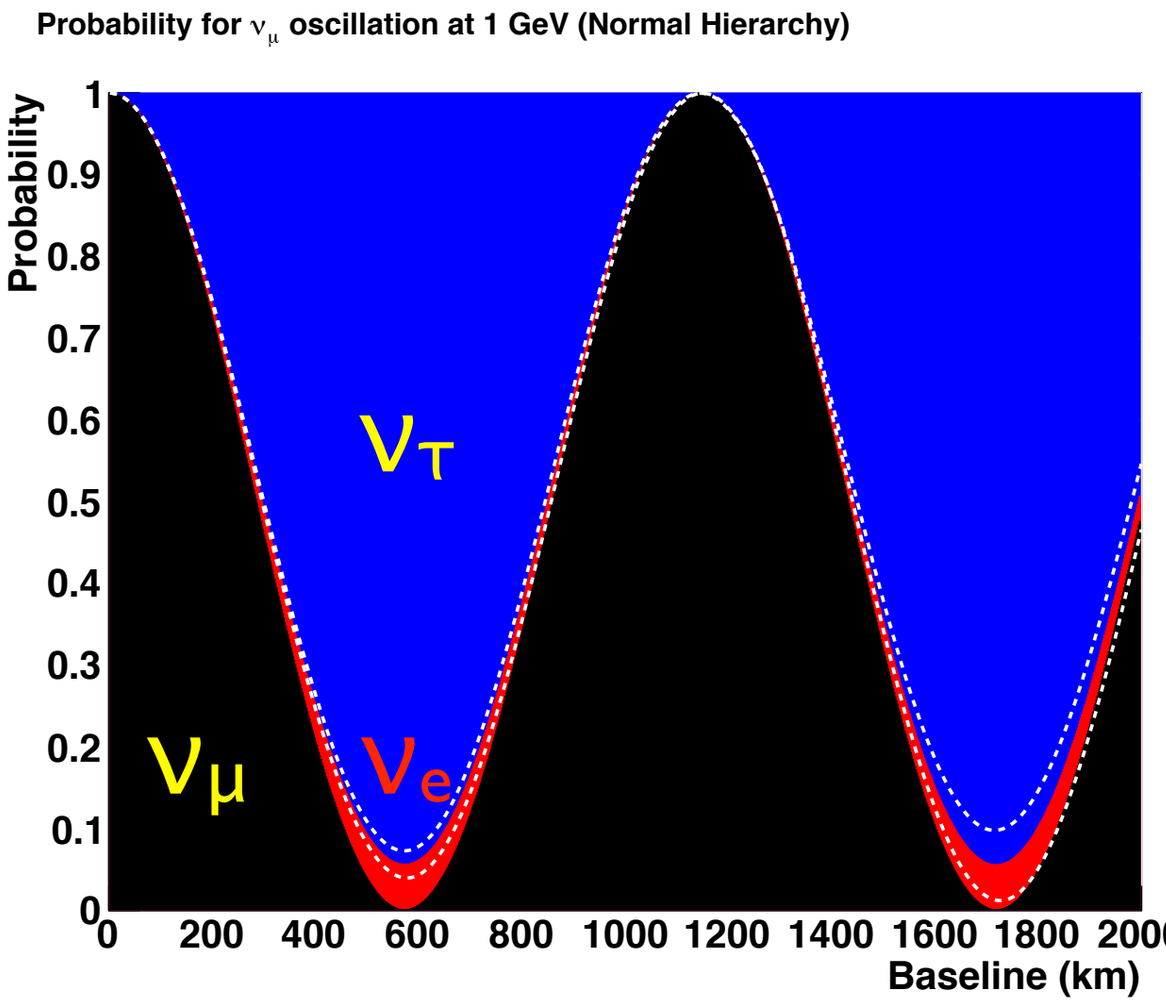
Daya Bay

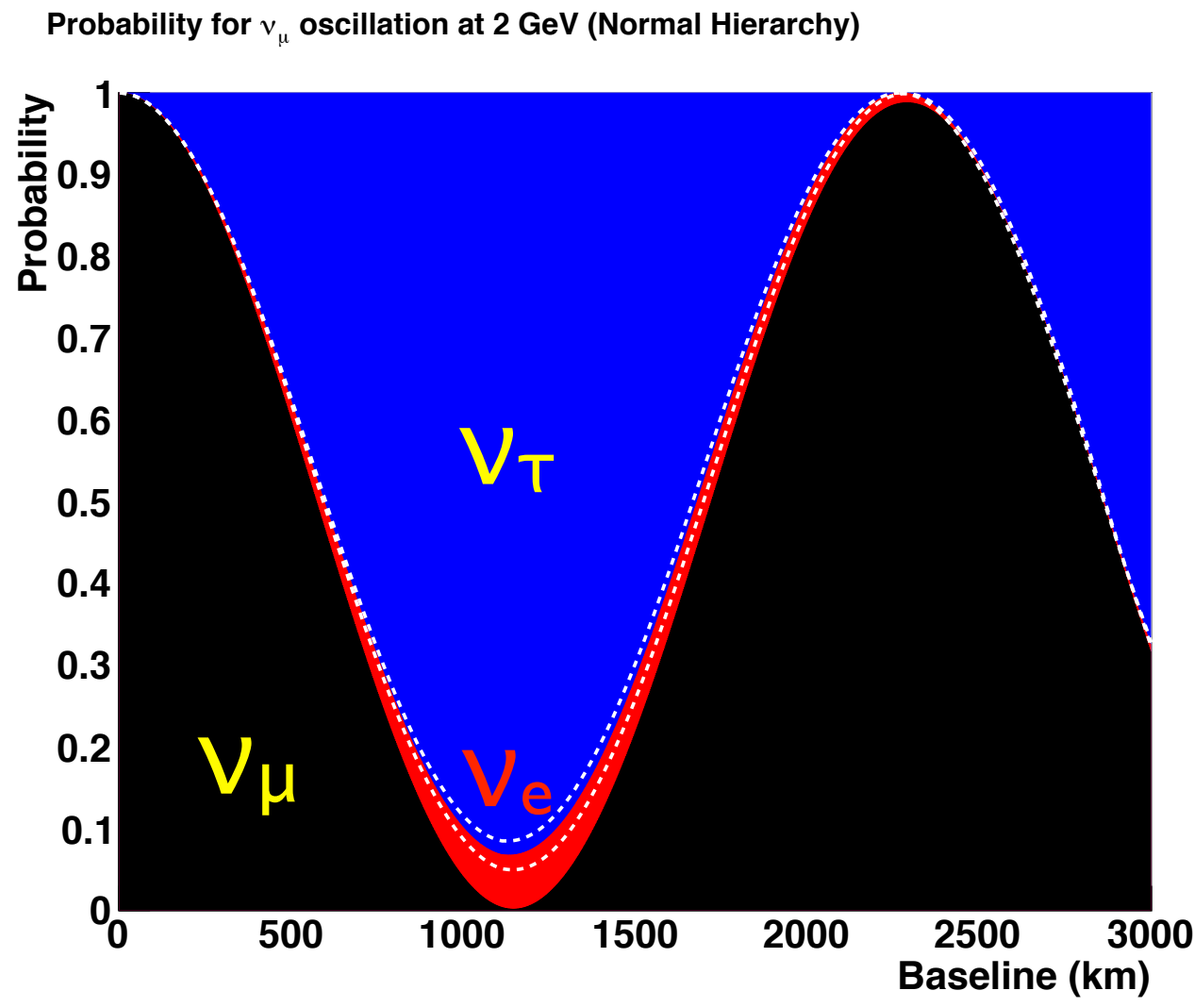


Atmospheric and Solar data is also important.

Total amount of data is rather sparse.

Complete picture assembled

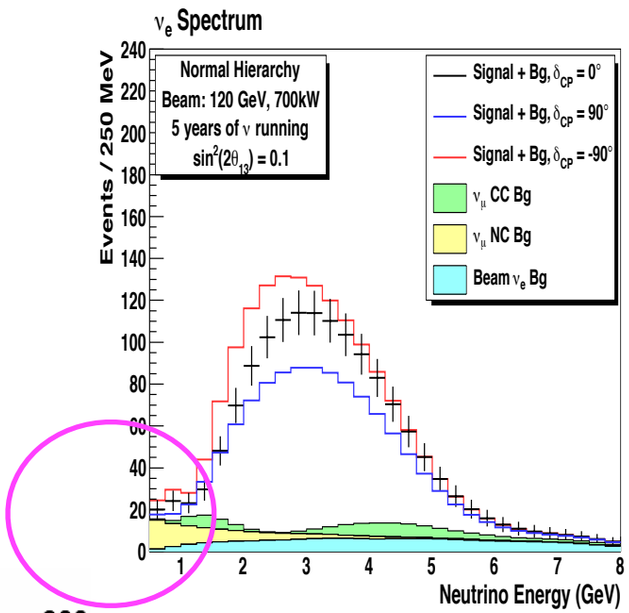


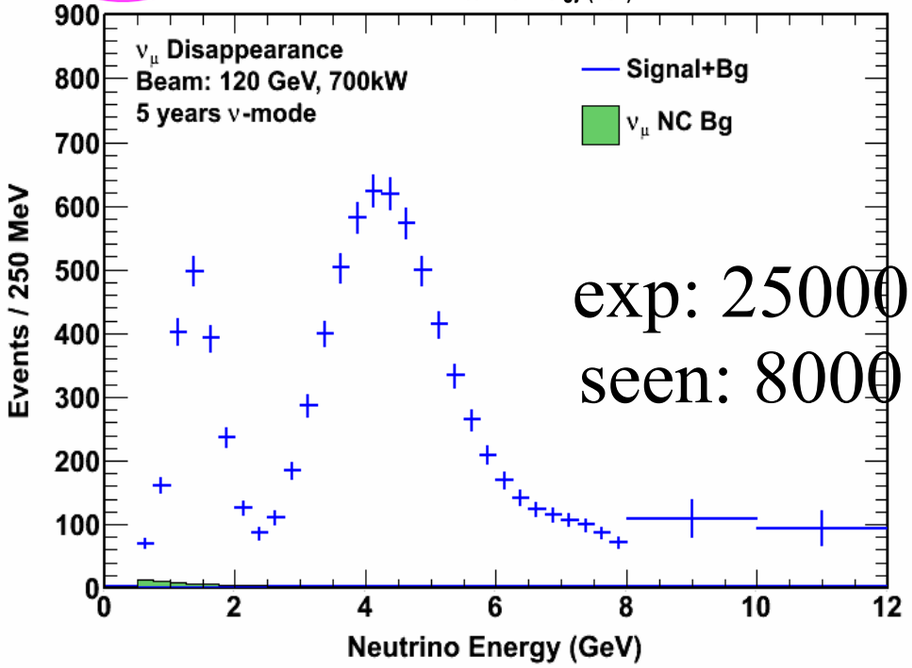


The white lines indicate CP asymmetry for $\delta = \pm\pi/2$

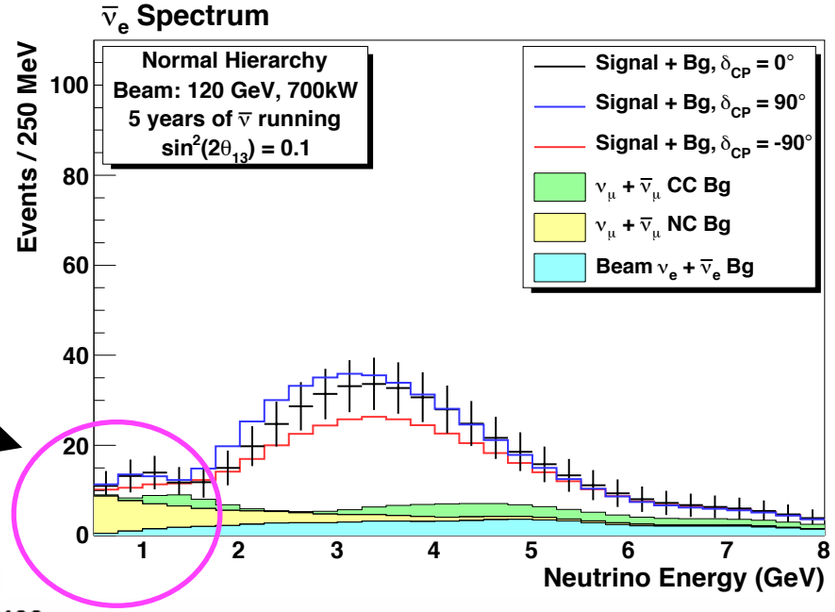
- This elaborate picture of interference from the current data set needs to be tested in an oscillation experiment that is optimized properly.

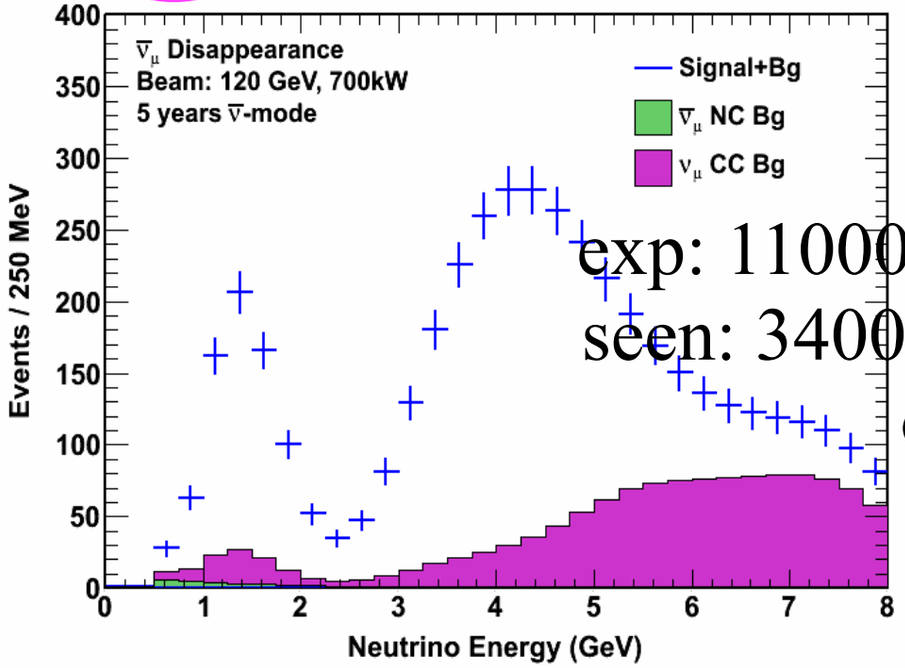
1300 km expectation





These events are very important





For each bin, conversion fraction of electrons can be calculated. Matter effect can be substracted to obtain explicit CP signal.

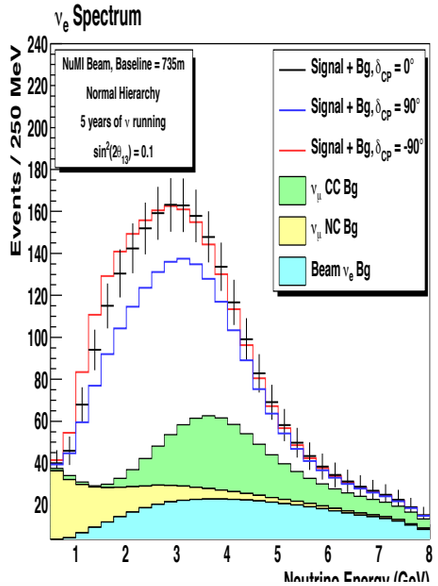
Potential surprises:

Matter effect is not what is expected !

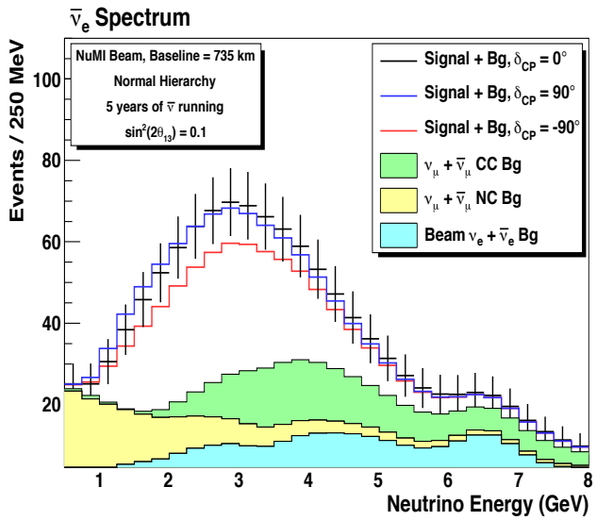
CPV does not have the proper energy 1/E dependence.

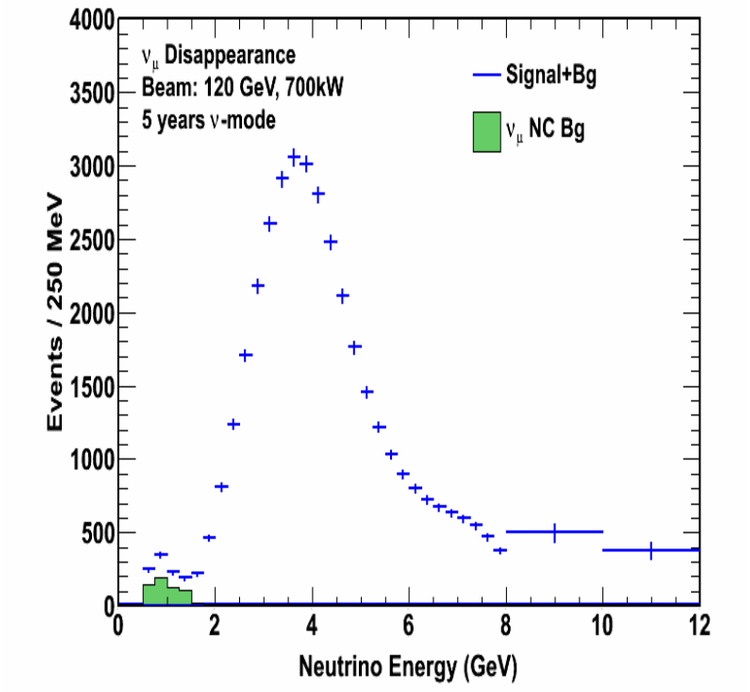
- With 1300 km the full structure of oscillations is visible in the energy spectrum. This spectral structure provides the unambiguous parameter sensitivity in a single experiment.

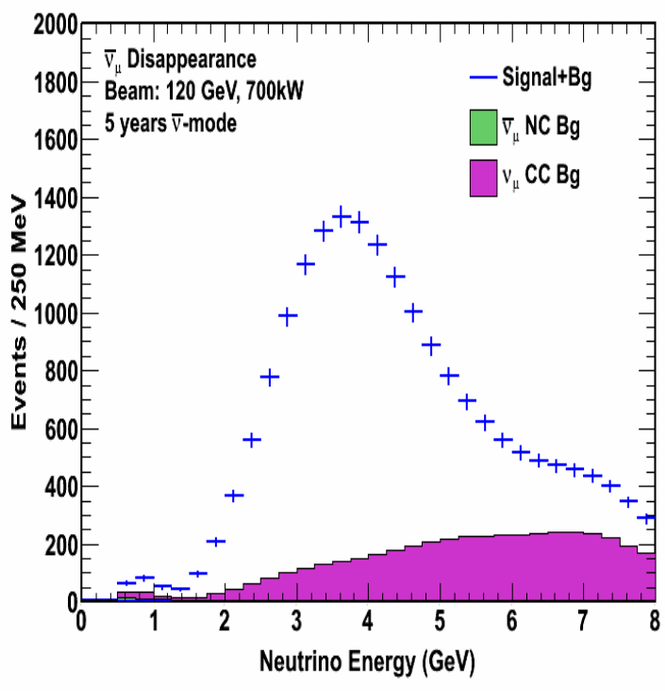
735 km expectation



difficult to obtain information from spectrum







- No oscillations, larger backgrounds. Smaller asymmetries due to smaller distance and energy spectrum.

Technical misunderstanding

- The event rate for electron neutrino appearance at shorter distance is NOT higher. For very short distances it actually decreases per unit mass.
- A large θ_{13} does not mean it is better to perform a shorter baseline experiment.
- If nature has handed you a gift such as θ_{13}, the best way to use it is to send the beam as far as you can.
- A large θ_{13} does not mean we can make the detector smaller for a CP measurement. The asymmetry gets smaller for larger θ_{13}.

LBNE approach

- CP violation measurement in neutrinos is monumental science and we should demonstrate the CP violation phenomena.
- A neutrino oscillation experiment should see oscillations !
- The parameters should be measured unambiguously in a single experiment.
- Must lead to a facility with a long future. Therefore the emphasis on underground physics and proton decay.
- Motivate future intensity upgrades including Project-X. Should have scientific reason and the capability to use the increased intensity.
- Has more potential for international participation because it is unique compared to any other setup.

NuMI based approach

- The beam exists and works.
- The NuMI beam spectrum is not well matched to 735 km. No oscillations.
- The appearance signal spectrum does not have enough dynamic range leading to ambiguities.
- 735/810 km is not far enough to get sufficient separation of mass hierarchies leading to poor resolution of MH, which affects CP phase.
- Ambiguity resolution needs both the T2K data and Reactor θ_{13} data to extract the CP phase. In combination, the parameter sensitivity is roughly equal.
- This is not a true demonstration of CP violation as a phenomena.

Two choices

- The two choices for phase I that could fit the understanding of funding and the beam physics constraints are:
  - A new beam with a 10 kTon detector at Homestake.
  - A detector at Soudan/Ash River of ~20kTon mass.
- The option for building only the detector at Homestake at 4850 first also is possible. It has many advantages, but it requires a phase II with a beam.

Comparison of choices

	Beam+10kTon at Homestake	20kTon at Soudan/Ash River
MH (without T2K)	>2.5 sigma	2-4 sigma for half of phase space.
δ resolution (with θ_{13} constraint)	20^o at 0^o 30^o at 90^o	25^o at 0^o 30^o at 90^o
δ resolution (no θ_{13} constraint)	20^o at 0^o 30^o at 90^o	25^o at 0^o 50^o at 90^o
$\sin^2 2\theta_{13}$ resolution	0.008 at $\delta = 0, 90^o$	0.008 at $\delta = 0$, 0.012 at $\delta = 90^o$
Oscillations	Sees Oscillations !	No oscillations
Future physics	Second oscillation for appearance has huge CP effects	Will never get to the second oscillation.

The U_{e3} matrix element is a single complex number. Must consider resolution of both real and imaginary parts in an appearance measurement.

Further comparisons

Beam+10kTon at Homestake	20kTon at Soudan/Ash River
Needs a new beamline	Has an existing beamline
Does not need external constraints.	Needs constraints from T2K and reactor data to get MH and δ
Large investment in the deep site already made by the community.	If detector is to be deep, this will require large investment.
Will lead to a better beam matched to intensity upgrades.	NuMI beam is constrained for future intensity upgrades
1300 km is unmatched. More likely to attract foreign contribution.	730 km beam exists in Europe. Capability could be matched.

How to get there

- Phase I
  - Build a beam and a 10 kTon detector at Homestake.
- Phase II
  - Increase the detector mass at Homestake, put it underground if not done in phase I.
  - Or build Project-X (Phase I) to supply more intensity.
- Phase III
  - Enlarge the detector if Project-X was chosen in phase-II

The committee will only have ballpark cost figures at this point.

Conclusion

- Committee must include a true phasing plan for LBNE as the charge letter asked.
- There are two options that might fit: Beam+10kTon at Homestake or 20 kTon at Soudan/Ash River.
- The longer baseline (1300 km) offers more flexibility and opportunity for growth. The 1300 km baseline enables the possibility of seeing unexpected physics in oscillations.
- A NuMI based approach is not optimal. The results need global fit of data. This will make it vulnerable to criticism from outside HEP community.
- A phasing plan for 1300 km baseline is possible with the current understanding of funding.