LBNE

Jim Strait
Fermilab

NuFact 2012
27 July 2012

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347 Members
62 Institutions
25 US States
5 Countries

19 July 2012 (347)

Outline

- Long-term goals and plans of the LBNE program
- Reality and Vision collide:
  The Reconfiguration of LBNE
- A phased approach to LBNE (and Project X)
- LBNE Project status and next steps
- Conclusions

LBNE – Neutrino Oscillation Goals

LBNE plans a comprehensive program to measure neutrino oscillations, to:

- Measure full oscillation patterns in multiple channels, precisely constraining mixing angles and mass differences.
- Search for CP violation both by measuring the parameter δ_{CP} and by observing differences in ν and $\bar{\nu}$ oscillations.
- Cleanly separate matter effects from CP-violating effects.

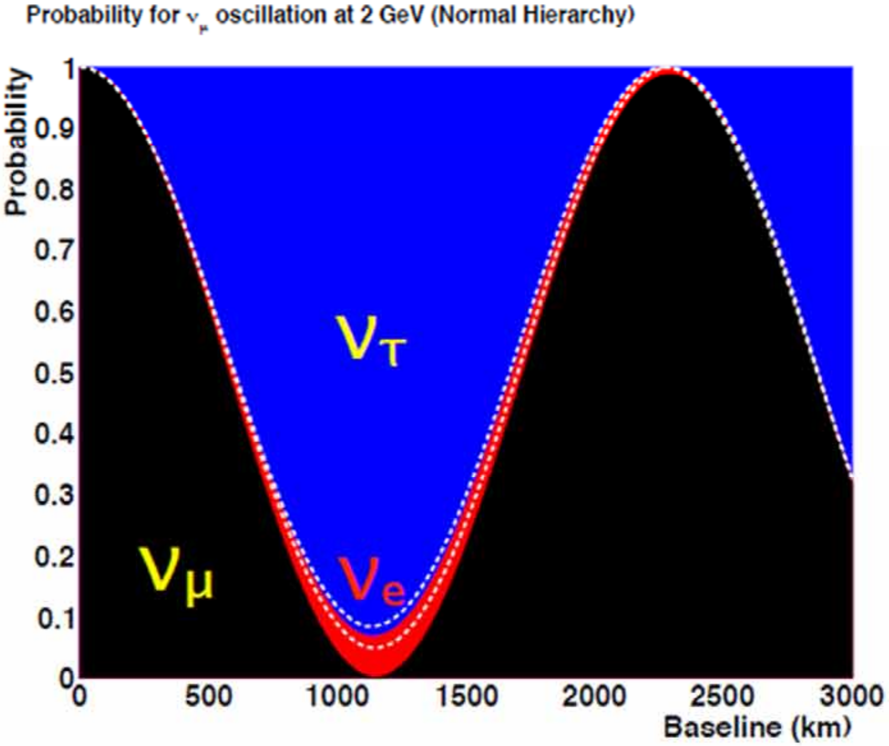
Complete picture assembled

$\nu_\mu \rightarrow \nu_\mu$ => θ_{23}, $|\Delta m^2_{32}|$

$\nu_\mu \rightarrow \nu_e$ => θ_{13}, sign(Δm^2_{32}), δ_{CP}

$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ => explicitly observe CP violation

$\nu_\mu \rightarrow \nu_\tau$ => does it all add up?



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.

The Baseline

To do this we need the right baseline

- Long enough to cleanly separate the ν / $\bar{\nu}$ oscillation asymmetry due to the matter effect from CP-violating effect.
- Long enough to put the first and if possible second oscillation maxima at “practical” energies.
- Short enough that the matter effect does not dominate over the CP-violating effect.
- Short enough that the beam is not too difficult to build (pitch angle).

=> 1300 km (Fermilab to Homestake) is “just right.”

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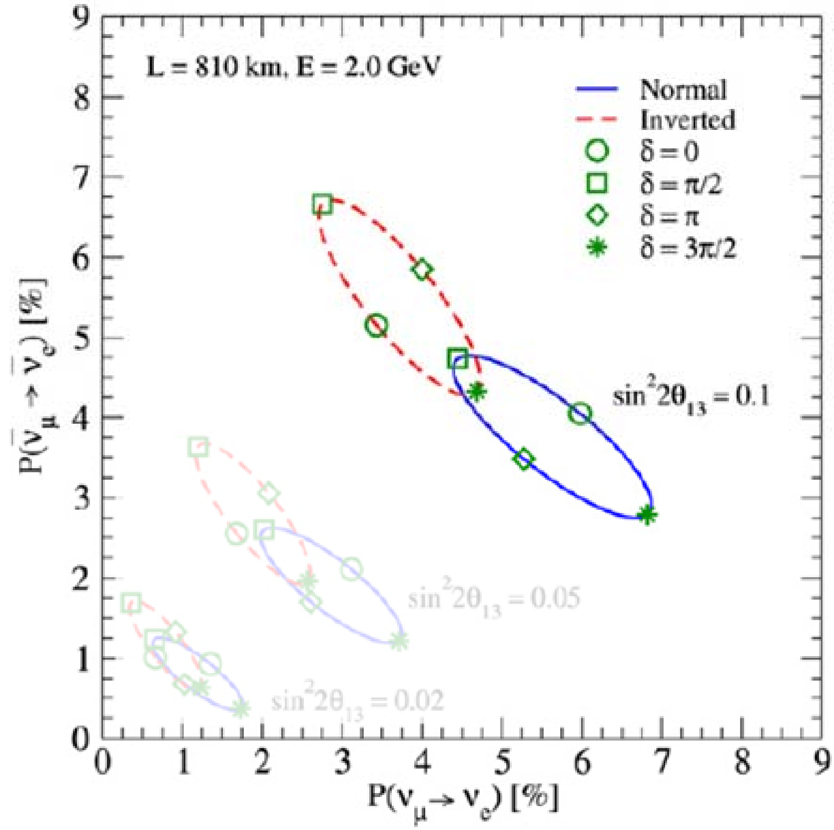

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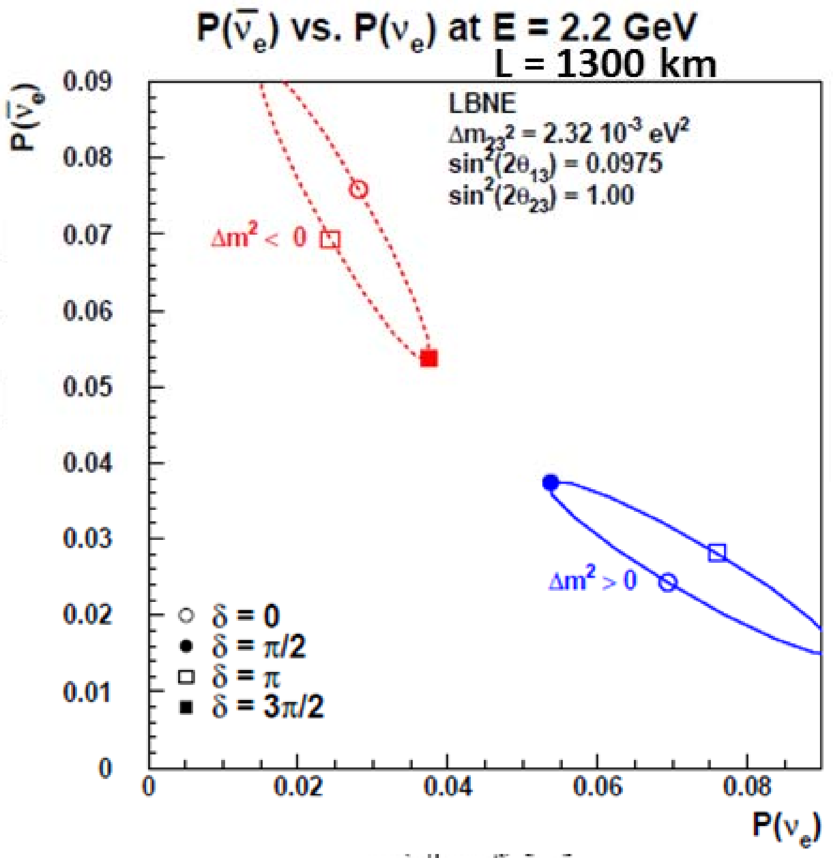

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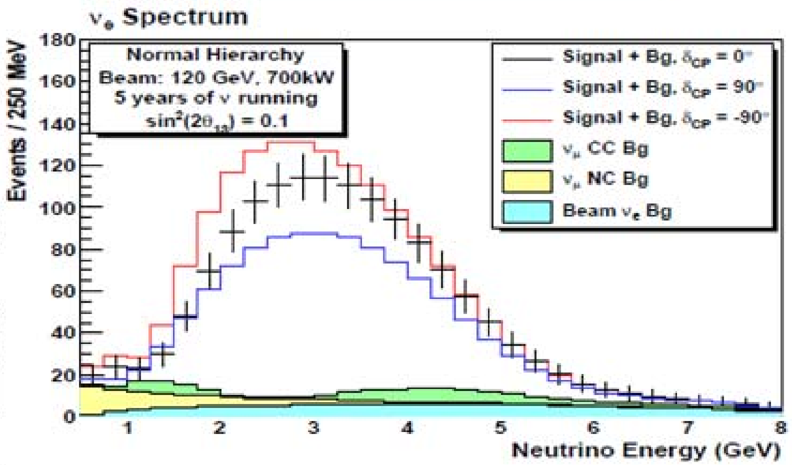
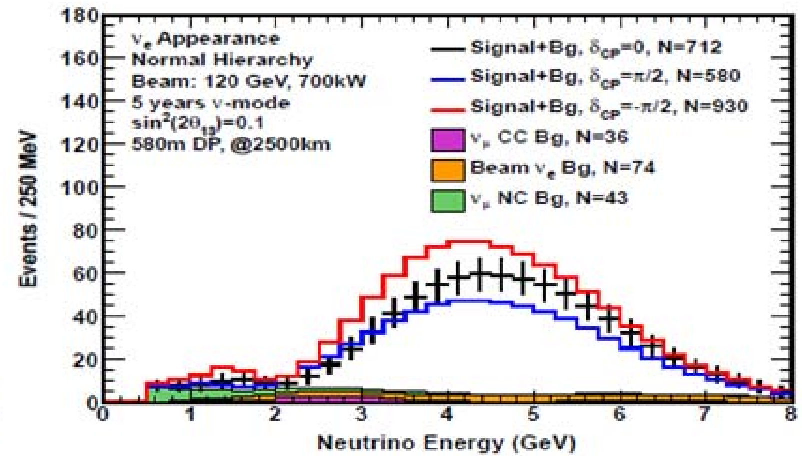
1300km, LBNE LE at Hmstk



2500km, LBNE pME (580m DP)



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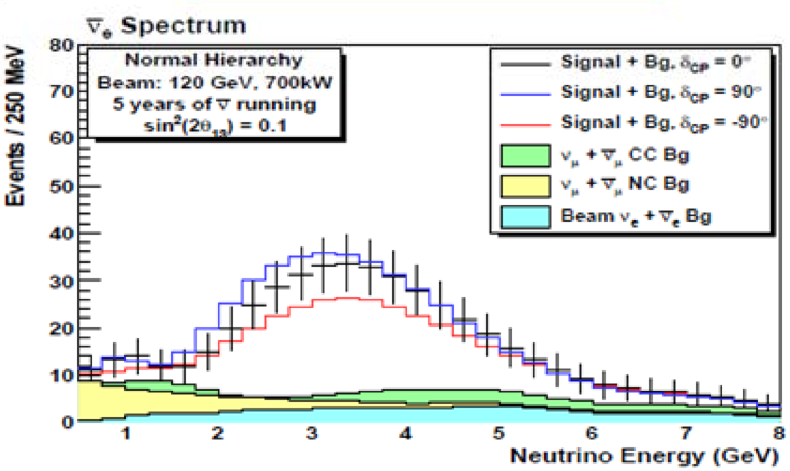

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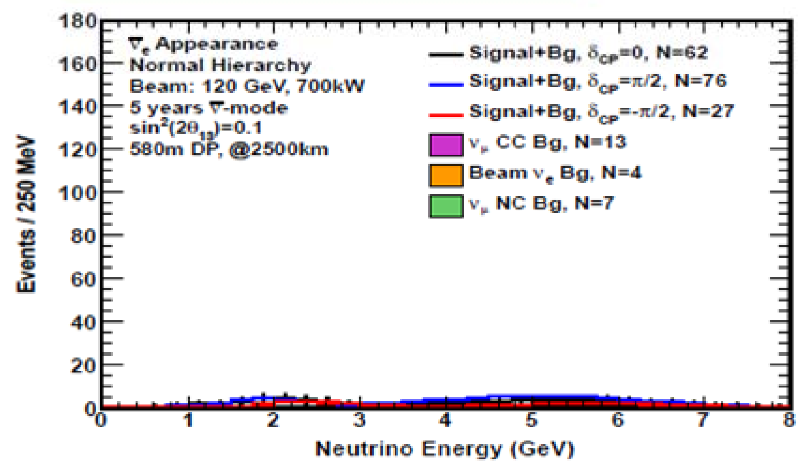

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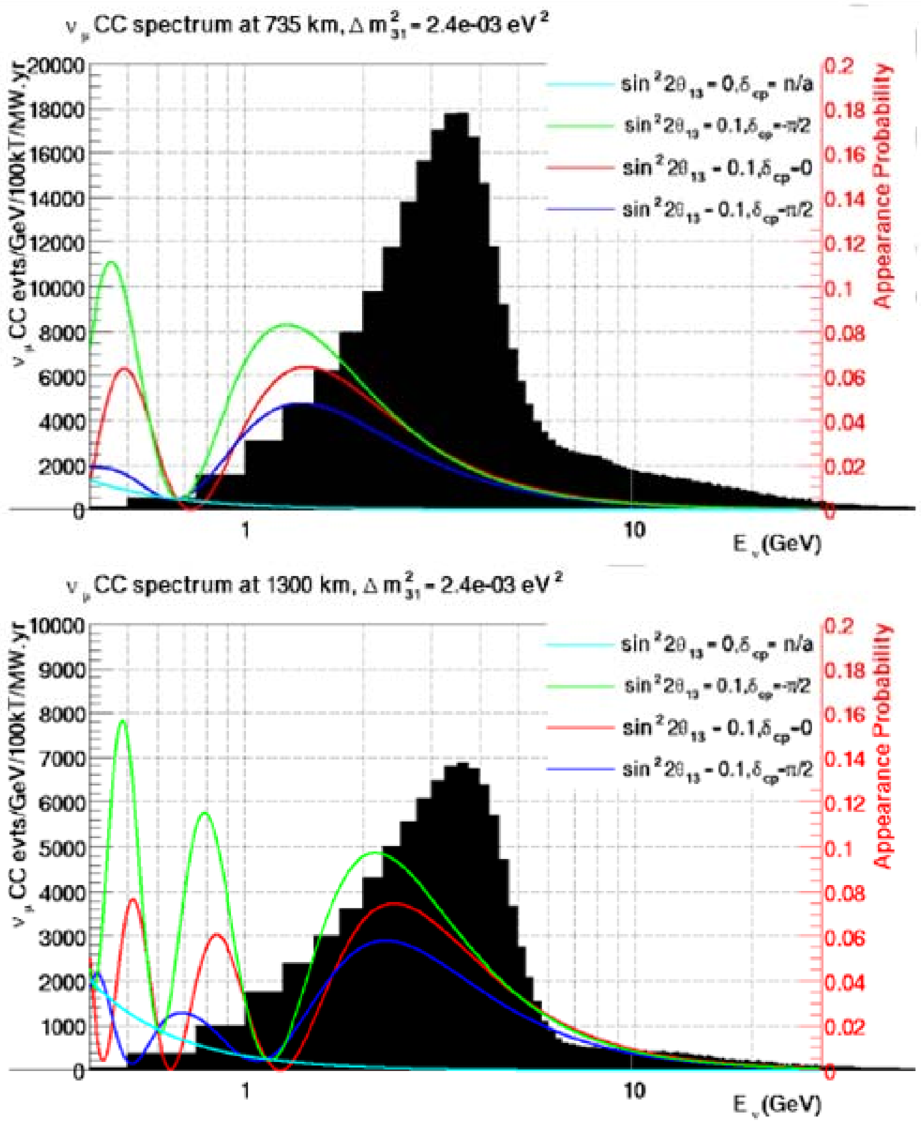

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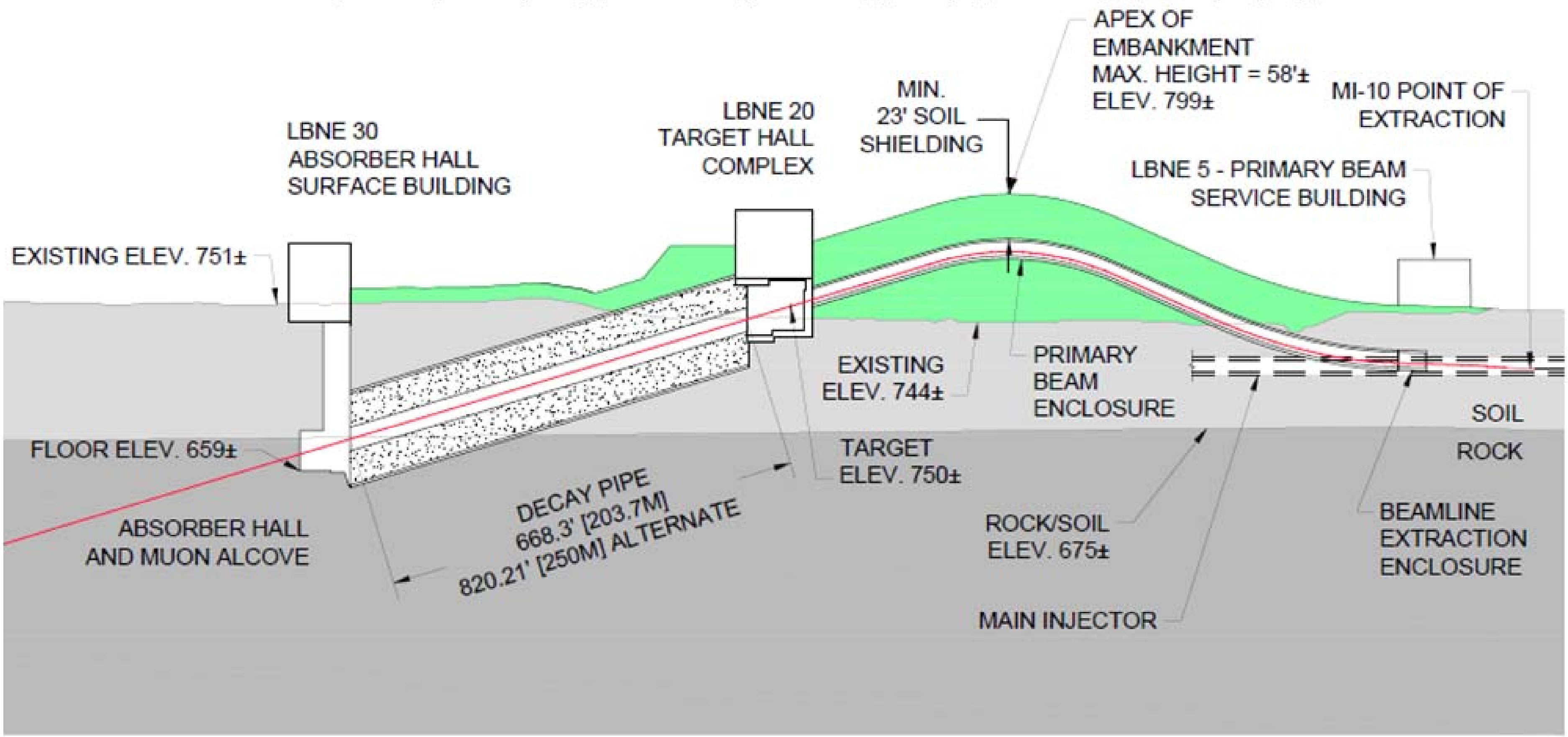

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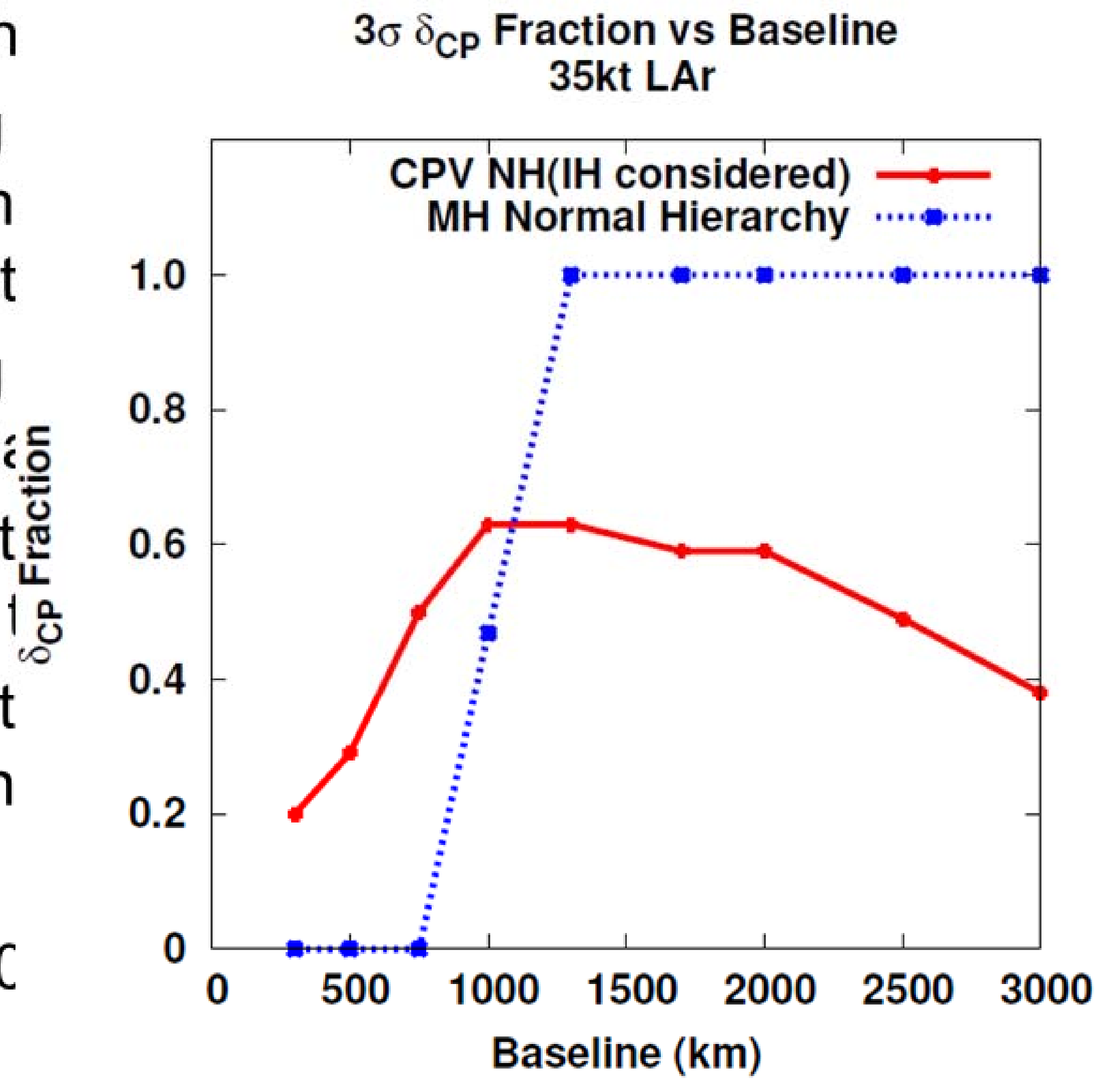
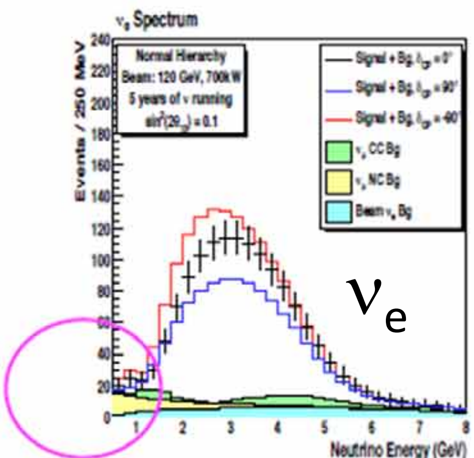
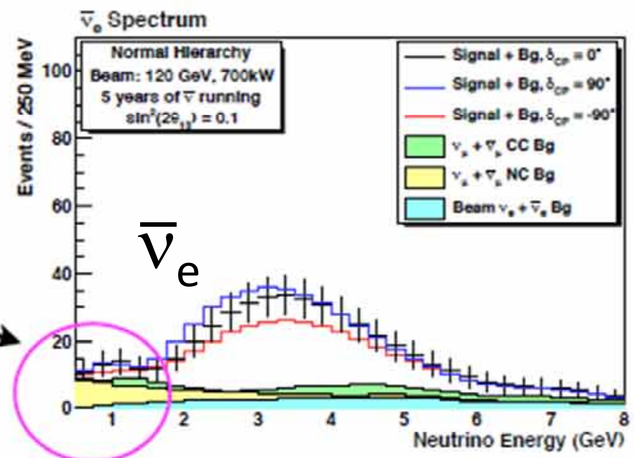


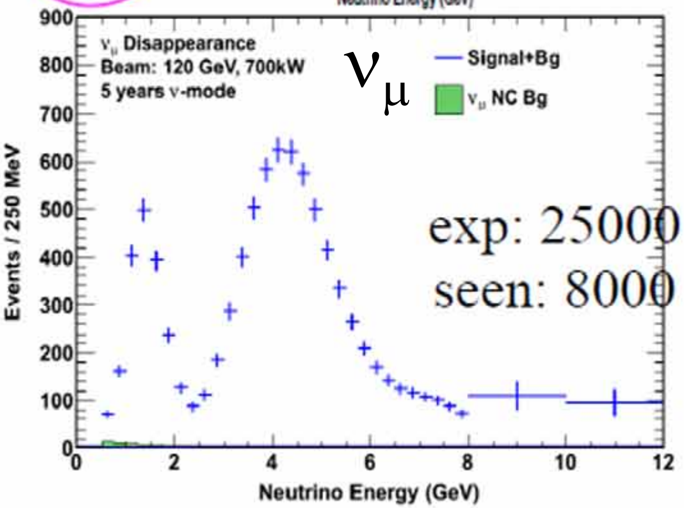
1300 km expectation

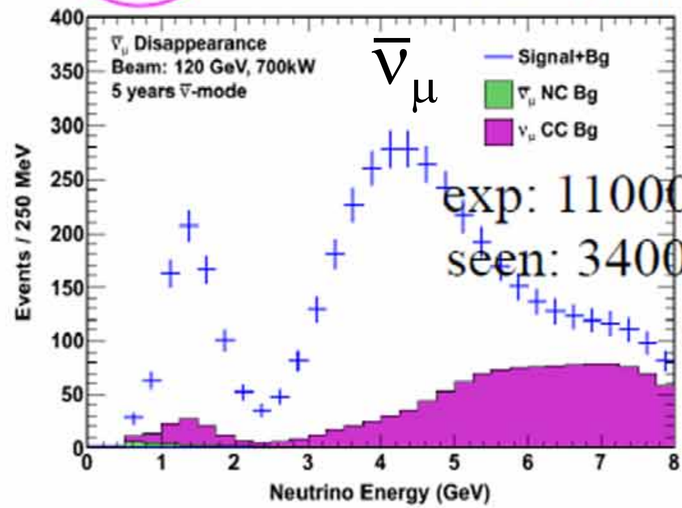


These events are very important



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.

The Far Detector

We need a large, highly capable detector to provide:

- High statistics for rare events (ν_e appearance and ν_μ survival at oscillation max)
- Efficient detection of signal and rejection of backgrounds.
- Reconstruction of complex final states
- Placed at sufficient depth to suppress cosmic ray backgrounds to a negligible level.

=> 34 kton LAr TPC underground at Homestake.

- Such a detector would be a powerful tool for other physics, including proton decay and supernova neutrinos.

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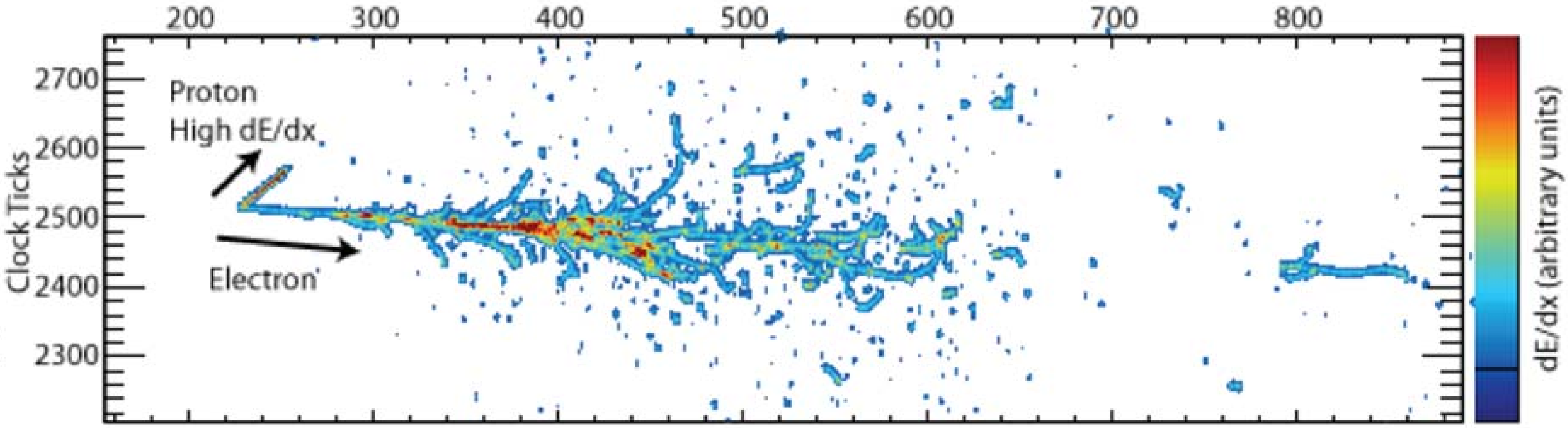

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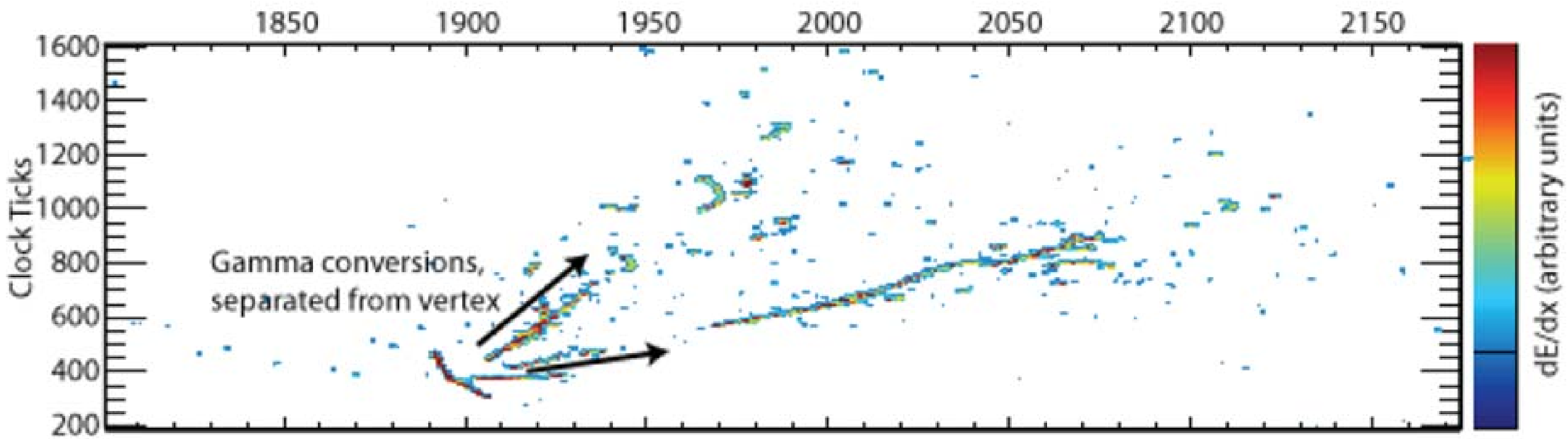

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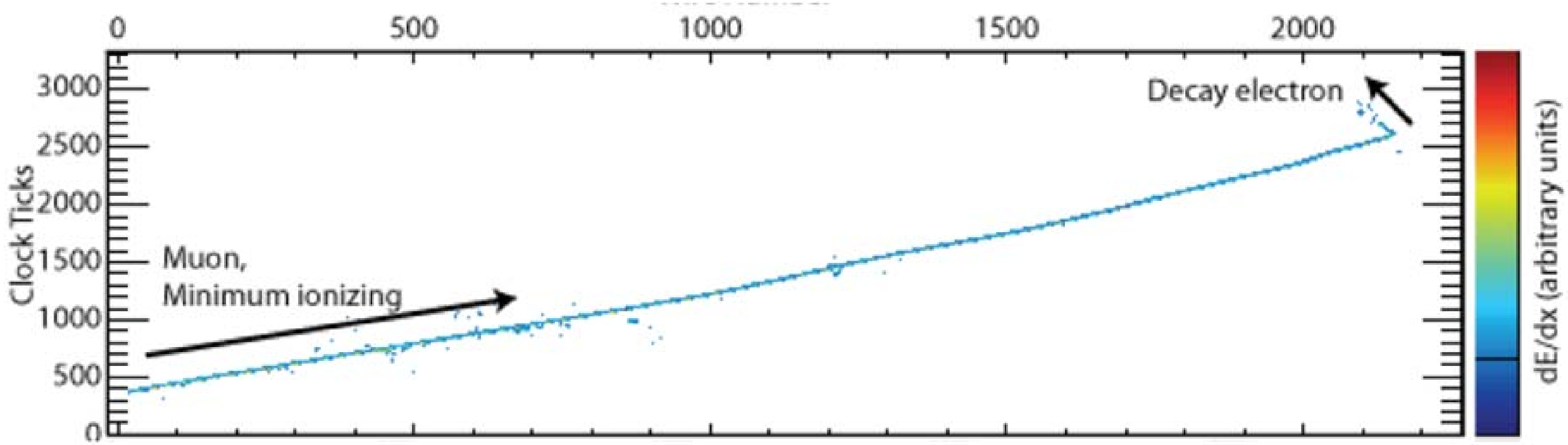

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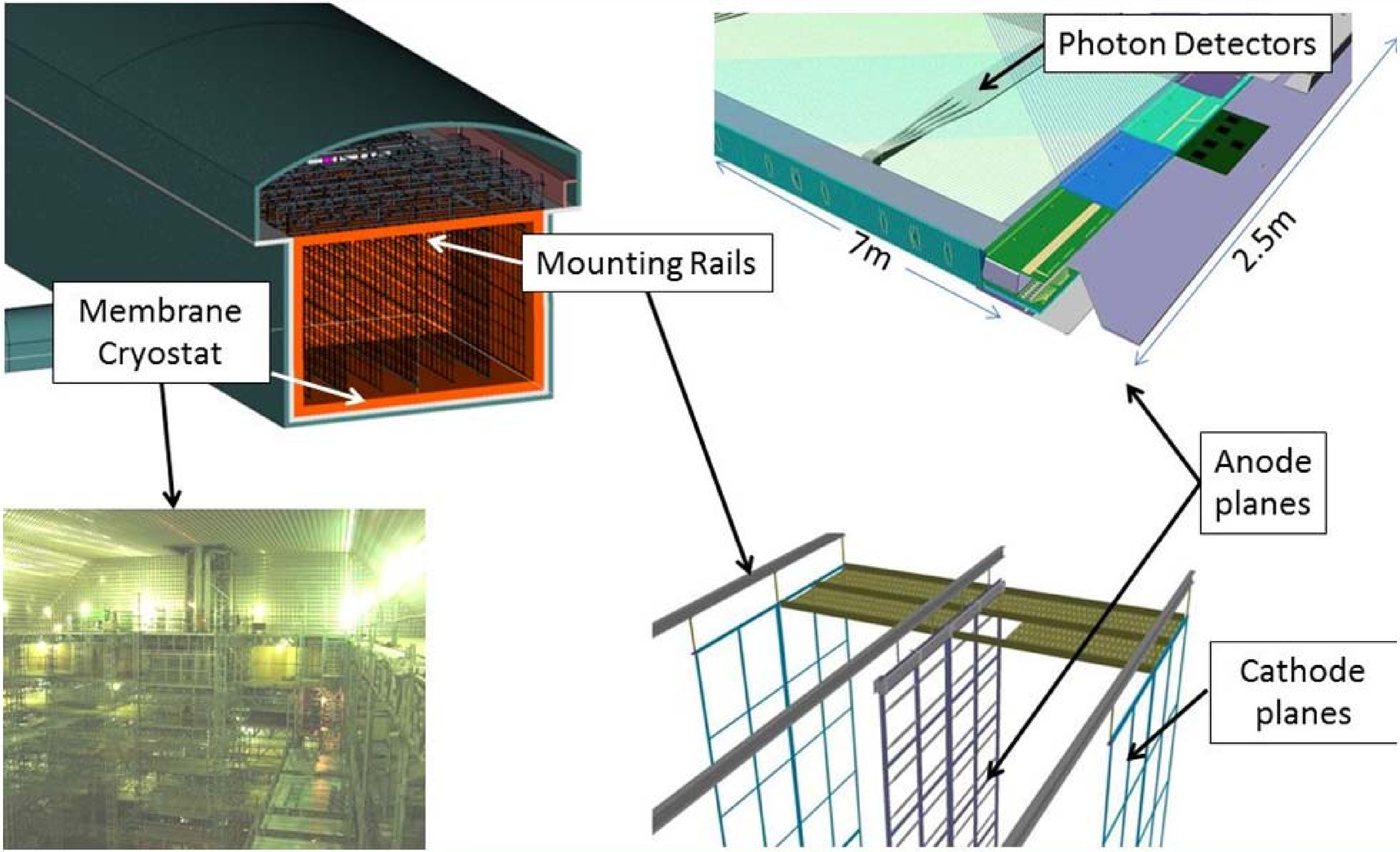

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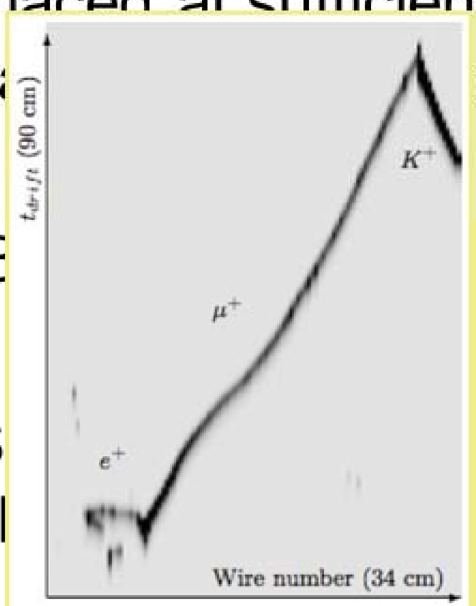

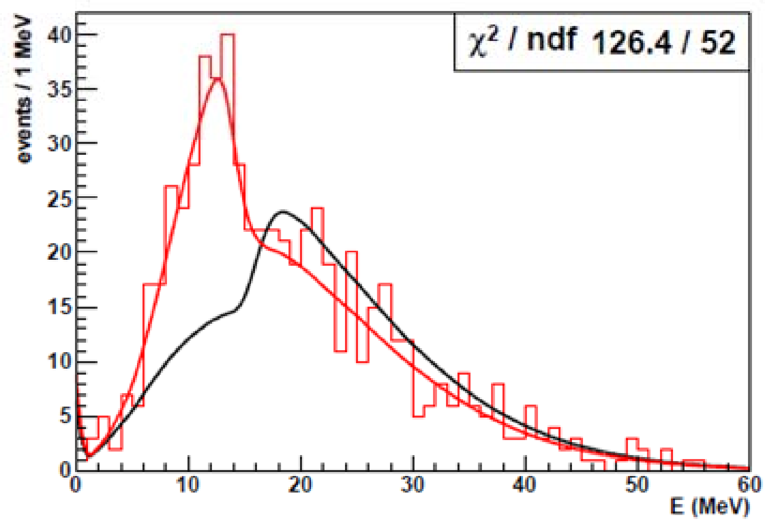

The Neutrino Beam

We need a high-power, broad-band, high-purity neutrino beam, sign-selected beam.

- Broad-band, sign-selected => Horn Focused
- Cover first and if possible second oscillation max
  => large diameter decay pipe to collect low energy pions
- High purity => shorter decay pipe to reduce high-energy tail and minimize $\mu^{\pm} \rightarrow e^{\pm} \overset{(-)}{\nu}_e \overset{(-)}{\nu}_\mu$ decay in flight.
- Tunable over wide range of primary proton energy and tunable spot size to optimize flux and allow study systematics.
- Capable of handling ≥ 2.3 MW from Project X.

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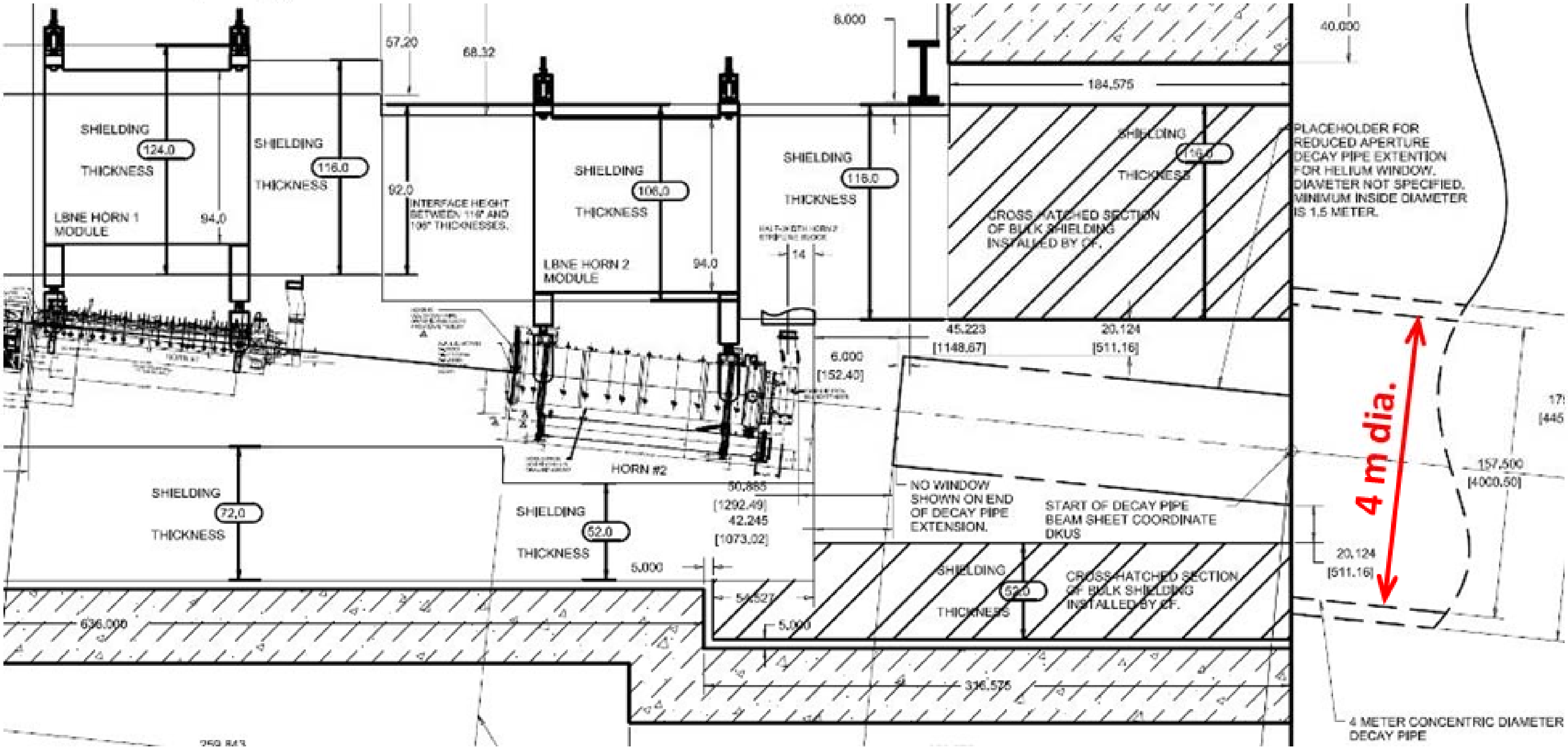

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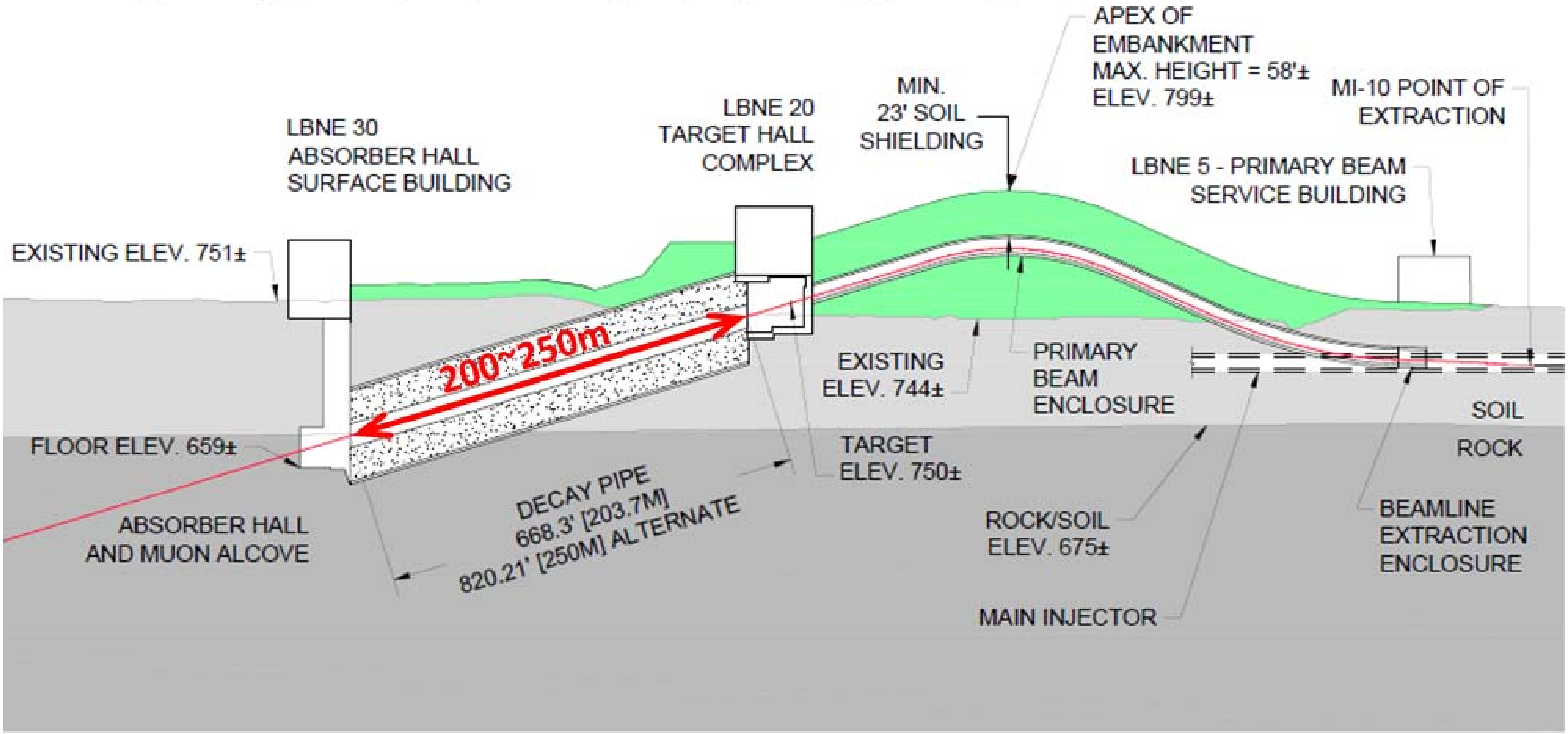

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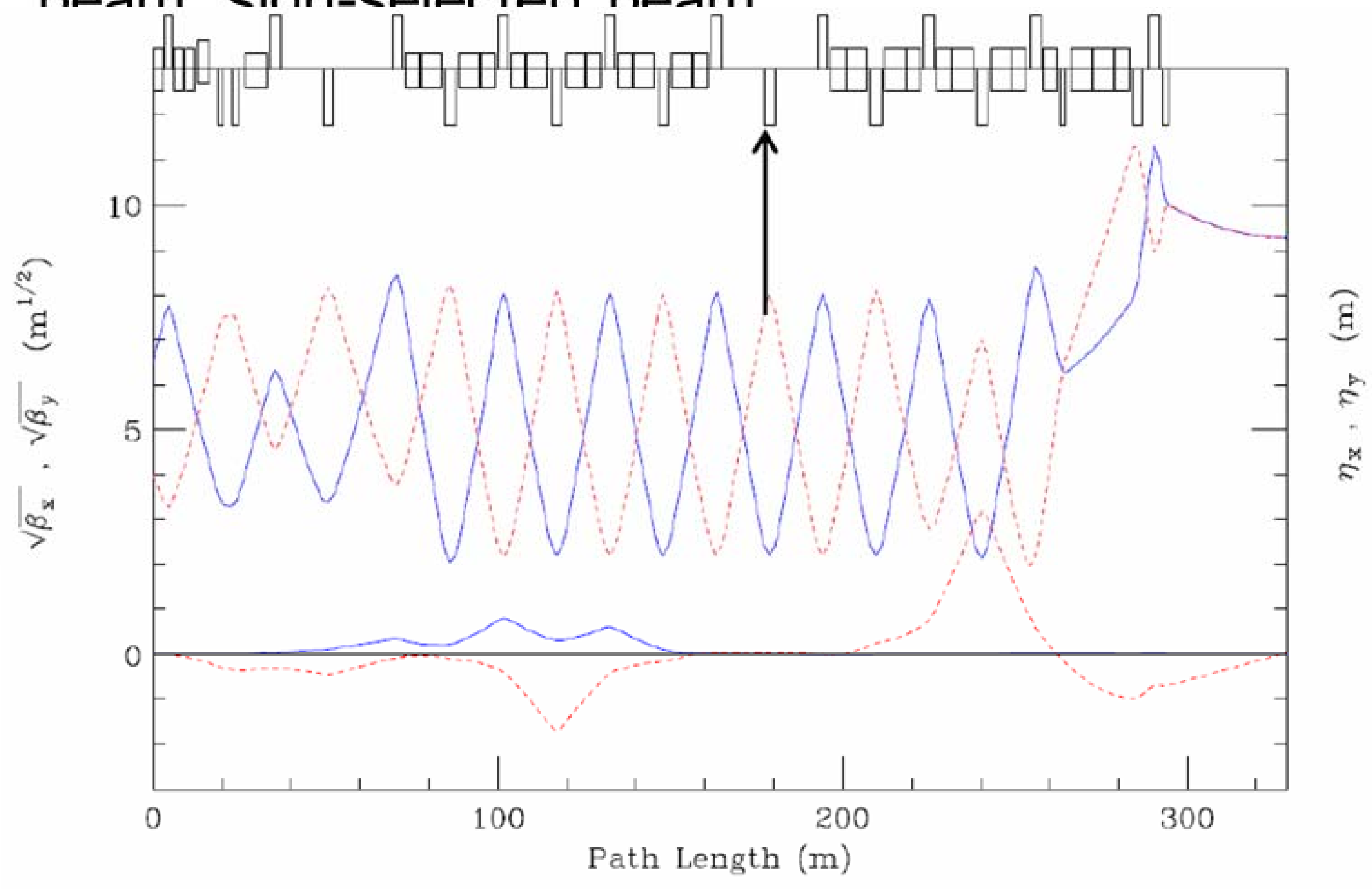

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The Near Detector

We need a highly capable near detector to:

- Measure the spectra of all species: ν_μ, ν_e, $\bar{\nu}_\mu$, $\bar{\nu}_e$
  => magnetized detector with good $e^\pm$ capability.
- Measure events from the same target nucleus (Ar) and the same technique as the far detector.
- Measure cross-sections necessary for oscillation measurements.
- Two candidate detectors:
  - LAr TPC or
  - Straw Tube Tracker with embedded Ar Targets

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- Measure the spectra of all species: $\nu_\mu, \nu_e, \bar{\nu}_\mu, \bar{\nu}_e$
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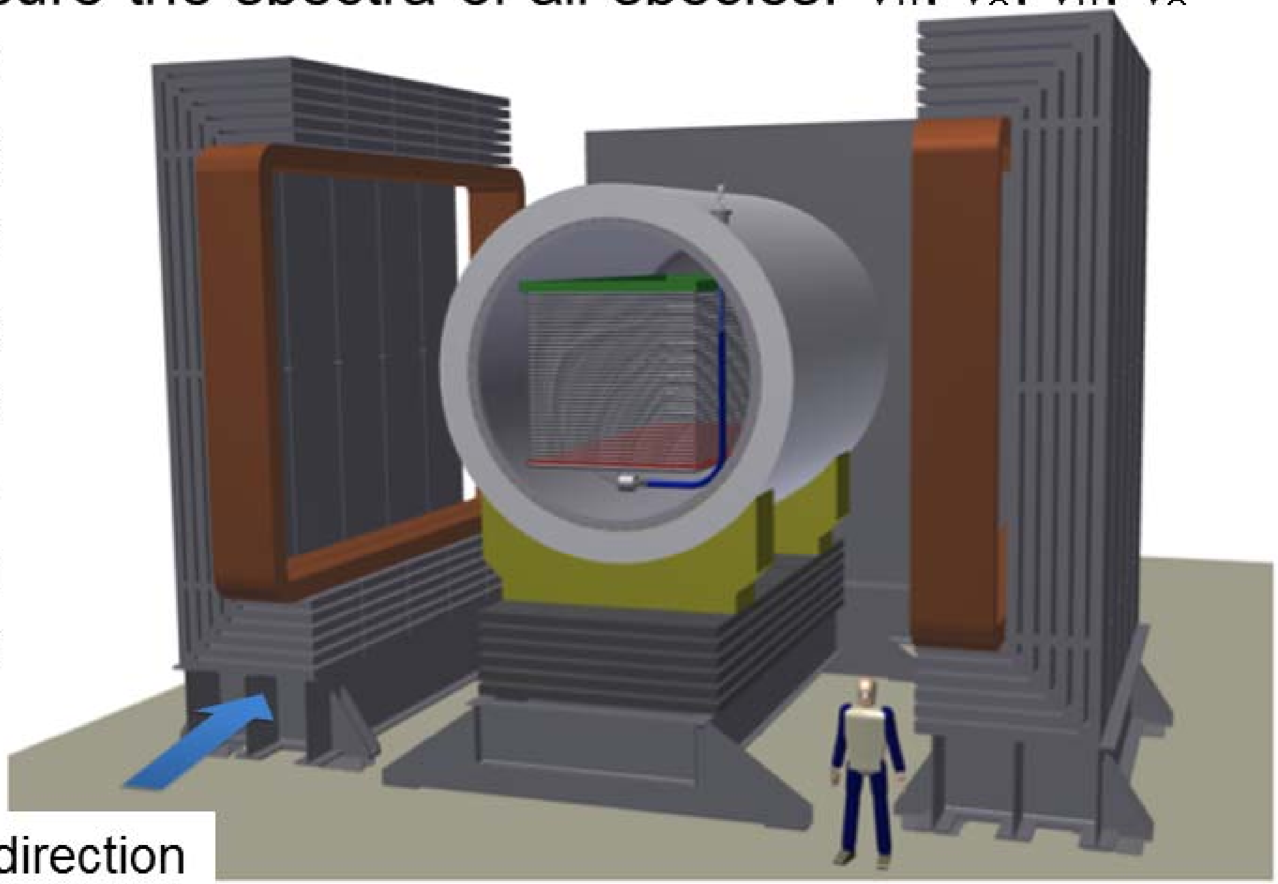

Beam direction

The Near Detector

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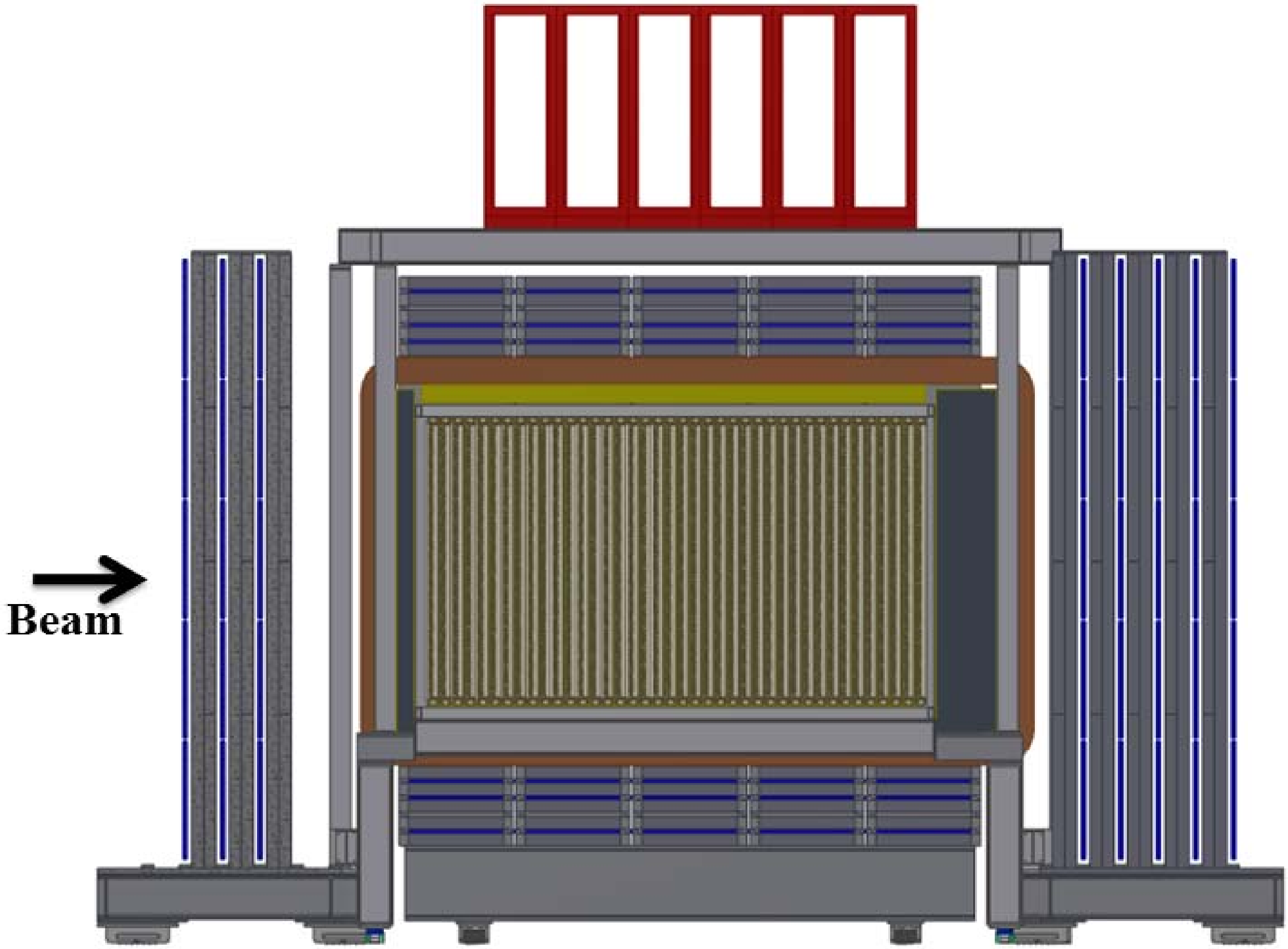

Vision Encounters Reality

Department of Energy
Office of Science
Washington, DC 20585

Office of the Director

March 19, 2012

Received on March 26

Dr. Pier Oddone
Director
Fermilab
Wilson and Kirks Road
Batavia, IL 60510-5011

Dear Pier,

Thank you for your recent presentation on the status and plans for the Long Baseline Neutrino Experiment (LBNE). The project team and the scientific collaboration have done an excellent job responding to our requests to assess the technology choices and refine the cost estimates for LBNE. We believe that the conceptual design is well advanced and the remaining technical issues are understood.

The scientific community and the National Academy of Sciences repeatedly have examined and endorsed the case for underground science. We concur with this conclusion, and this has been the motivator for us to determine a path forward as quickly as possible following the decision of the National Science Board to terminate development of the Homestake Mine as a site for underground science.

We have considered both the science opportunities and the cost and schedule estimates for LBNE that you have presented to us. We have done so in the context of planning for the overall Office of Science program as well as current budget projections.

Based on our considerations, we cannot support the LBNE project as it is currently configured. This decision is not a negative judgment about the importance of the science, but rather it is a recognition that the peak cost of the project cannot be accommodated in the current budget climate or that projected for the next decade.

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.

A report outlining options and alternatives is needed as soon as practical to provide input to our strategic plan for the Intensity Frontier program. OHEP will provide additional details on realistic cost and schedule profiles and on the due date for the report.

Thank you,

W. F. Brinkman
Director, Office of Science

Reconfiguring LBNE

http://www.fnal.gov/directorate/lbne_reconfiguration/index.shtml

LBNE Reconfiguration

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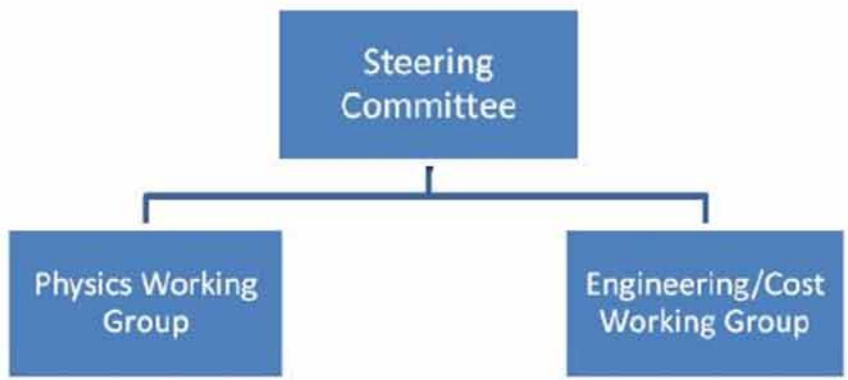
e following groups to deliver on the charge:



roups, one to study the physics reach of the possible configurations in a consistent way and a second group to study
e costs of the various options in a uniform way. The study requested by Bill Brinkman for the independent
e Homestake site will be undertaken by subcommittees in both the physics and cost groups.

06/2012

LBNE Reconfiguration

Steering Committee
Interim Report

June 5, 2012

Final Report nearly ready …
no changes in the conclusions

https://indico.fnal.gov/conferenceDisplay.py?confId=5622

Reconfiguration Interim Report

Interim Conclusions

To achieve all of the fundamental science goals listed above, a reconfigured LBNE would need a very long baseline (>1,000 km from accelerator to detector) and a large detector deep underground. However, it is not possible to meet both of these requirements in a first phase of the experiment within the budget guideline of approximately $700M – $800M, including contingency and escalation. The committee assessed various options that meet some of the requirements, and identified three viable options for the first phase of a long-baseline experiment that have the potential to accomplish important science at realizable cost. These options are (not priority ordered):

- Using the existing NuMI beamline in the low energy configuration with a **30 kton** liquid argon time projection chamber (LAr-TPC) **surface detector** 14 mrad off-axis at Ash River in Minnesota, **810 km** from Fermilab.
- Using the existing NuMI beamline in the low energy configuration with a **15 kton** LAr-TPC **underground (at the 2,340 ft level) detector** on-axis at the Soudan Lab in Minnesota, **735 km** from Fermilab.
- Constructing a new low energy LBNE beamline with a **10 kton** LAr-TPC **surface detector** on-axis at Homestake in South Dakota, **1,300 km** from Fermilab.

The committee looked at possibilities of projects with significantly lower costs and concluded that the science reach for such projects becomes marginal.

Pros and Cons

30 kton surface detector at Ash River in Minnesota (NuMI low energy beam, 810 km baseline)

Pros	• Best Phase 1 CP-violation sensitivity in combination with NOvA and T2K results for the current value of θ_{13}. The sensitivity would be enhanced if the mass ordering were known from other experiments. • Excellent (3σ) mass ordering reach in nearly half of the δ_{CP} range.

Cons	• Narrow-band beam does not allow measurement of oscillatory signature.
	• Shorter baseline risks fundamental ambiguities in interpreting results.
	• Sensitivity decreases if θ_{13} is smaller than the current experimental value.
	• Cosmic ray backgrounds: impact and mitigation need to be determined.
	• Only accelerator-based physics.
	• Limited Phase 2 path:
	  ○ Beam limited to 1.1 MW (Project X Stage 1).
	  ○ Phase 2 could be a 15-20 kton underground (2,340 ft) detector at Soudan.

15 kton underground (2,340 ft) detector at the Soudan Lab in Minnesota (NuMI low energy beam, 735 km baseline)

Pros	• Broadest Phase 1 physics program:
	  ○ Accelerator-based physics including good (2σ) mass ordering and good CP-violation reach in half of the δ_{CP} range. CP-violation reach would be enhanced if the mass ordering were known from other experiments.
	  ○ Non-accelerator physics including proton decay, atmospheric neutrinos, and supernovae neutrinos.
	• Cosmic ray background risks mitigated by underground location.

Cons	• Mismatch between beam spectrum and shorter baseline does not allow full measurement of oscillatory signature.
	• Shorter baseline risks fundamental ambiguities in interpreting results. This risk is greater than for the Ash River option.
	• Sensitivity decreases if θ_{13} is smaller than the current experimental value.
	• Limited Phase 2 path:
	  ○ Beam limited to 1.1 MW (Project X Stage 1).
	  ○ Phase 2 could be a 30 kton surface detector at Ash River or an additional 25-30 kton underground (2,340 ft) detector at Soudan.

10 kton surface detector at Homestake (new beamline, 1,300 km baseline)

Pros	• Excellent (3σ) mass ordering reach in the full δ_{CP} range. • Good CP violation reach: not dependent on *a priori* knowledge of the mass ordering. • Longer baseline and broad-band beam allow explicit reconstruction of oscillations in the energy spectrum: self-consistent standard neutrino measurements; best sensitivity to Standard Model tests and non-standard neutrino physics. • Clear Phase 2 path: a 20 – 25 kton underground (4850 ft) detector at the Homestake mine. This covers the full capability of the original LBNE physics program. • Takes full advantage of Project X beam power increases.
Cons	• Cosmic ray backgrounds: impact and mitigation need to be determined. • Only accelerator-based physics. Proton decay, supernova neutrino and atmospheric neutrino research are delayed to Phase 2. • ~10% more expensive than the other two options: cost evaluations and value engineering exercises in progress.

Fundamental Trade-offs

- Larger detector on the surface *vs.* smaller underground
- Use existing beamline => more $ for detectors in first phase *vs.* new beamline with desired baseline and upgrade path => less $ for detectors in first phase.

Steering Committee Conclusions

While each of these first-phase options is more sensitive than the others in some particular physics domain, the Steering Committee in its discussions strongly favored the option to build a new beamline to Homestake with an initial 10 kton LAr-TPC detector on the surface. The physics reach of this first phase is very strong; more over this option is seen by the Steering Committee as a start of a long-term world-leading program that would achieve the full goals of LBNE in time and allow probing the Standard Model most incisively beyond its current state. Ultimately this option would exploit the full power provided by Project X. At the present level of cost estimation, it appears that this preferred option may be ~10% more expensive than the other two options, but cost evaluations and value engineering exercises are continuing.

But there are risks:

In the next few months the LBNE collaboration and external experts will be studying the operation of LAr-TPCs on the surface to verify that the cosmic ray backgrounds are manageable. The operation on the surface may require shorter drift times than required for underground operations and the localization of the event in the TPC coincident with the ten microsecond-long beam from Fermilab. The Phase 1 experiment will use the existing detectors (MINOS near detector, MINERvA, and NOvA near detector) as near detectors for the two NuMI options, and use muon detectors to monitor the beam for the Homestake option. The Physics working group is currently studying the impact of near detectors on the physics reach.

First studies suggest that the risks are manageable, but work continues

Steering Committee Conclusions

Limitations:

Although the preferred option has the required very long baseline, its major limitation of the preferred option is that the underground physics program including proton decay and supernova collapse cannot start until later phases of the project. Placing a 10 kton detector underground instead of the surface in the first phase would allow such a start, and increase the cost by about $135M.*

Opportunities:

Establishing a clear long-term program will make it possible to bring the support of other agencies both domestic and foreign. The opportunities offered by the beam from Fermilab, the long baseline and ultimately underground operation are unique in the world. Although the contributions from other agencies could substantially reduce the cost to the DOE or enhance the science capabilities for the first phase of the project, they are not taken into account in the present cost estimates.

* Note that the cost increase of moving the detector underground is only ~15% of the total cost of the project. The cost of adding a high-performance near detector, including all civil construction, is similar.

DOE Responds

Department of Energy
Office of Science
Washington, DC 20585

Office of the Director

June 29, 2012

Dear Pier,

I would like to thank you and your management team for your recent presentation on the revised plans for the Long Baseline Neutrino Experiment (LBNE). The steering group and project team have done an excellent job responding to our request to reconfigure the project in ways that lead to an affordable and phased approach that will enable important science results at each phase. The report of the LBNE steering group outlining the options and alternatives considered provides clear and thoughtful input to our strategic plan for the Intensity Frontier program.

We would like you to proceed with planning a Critical Decision 1 review later this year based on the reconfigured LBNE options you presented. Please work with Jim Siegrist and Dan Lehman on the timing of this review.

I am hopeful that we can put the LBNE project on a sustainable path and thereby secure a leadership position for Fermilab in the Intensity Frontier. We look forward to working with you to achieve this goal.

Sincerely yours,

W.F. Brinkman

Phased Program

The preferred configuration would be the first step in a phased program.

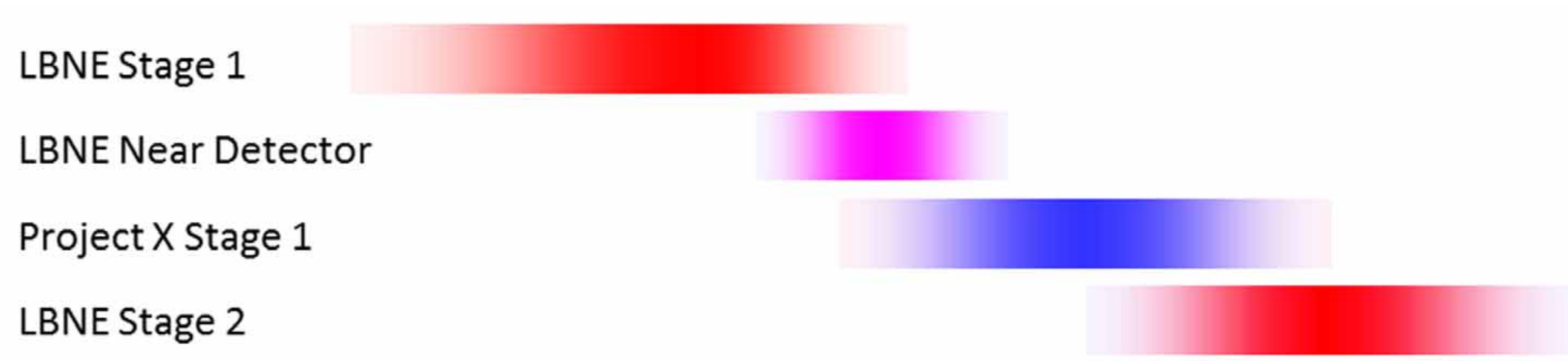
In the 1st phase, LBNE would determine the sign(Δm^2_{32}) and measure δ_{CP}, as well as measuring other oscillation parameters: θ_{13}, θ_{23}, and $|\Delta m^2_{32}|$. Subsequent phases would include:

- Build a highly capable near neutrino detector,
  - reduce systematic errors on the oscillation measurements
  - enable a broad program of non-oscillation neutrino physics.
- Increase the detector mass or increase the beam power (Project X)
  - add statistical precision to all of the neutrino measurements.
- Add a large detector at the 4850 foot (4300 mwe) level at Homestake
  - enable proton decay, supernova neutrino, and other non-beam physics
  - further improve the precision of the main oscillation measurements
  - enable use of more difficult channels for a fully comprehensive program of oscillation measurements

The actual order and scope of the next phases would, of course, depend on physics, resources, and the interests of current and new collaborators.

Phased Program: Possible Example

1) 10 kt LAr detector on surface at Homestake + LBNE beamline (700 kW)
2) Near Neutrino Detector at Fermilab
3) Project X stage 1 → 1.1 MW LBNE beam
4) Additional 20-30 kt detector deep underground (4300 mwe)



Additional national or international collaborators could help accelerate the implementation of the full LBNE program.

The LBNE Project

The LBNE Project is to deliver the first phase of this program:

- A new neutrino beam at Fermilab:
  - Aimed at Homestake
  - Spectrum optimized for this distance
  - Upgradeable to ≥ 2.3 MW proton beam power
- A 10 kt LAr TPC detector on the surface at Homestake
  - In a pit just below the natural grade
  - Shielded against hadronic and EM component of CR showers
- Tertiary muon detector to monitor the neutrino beam
  - Ionization chambers
  - Variable pressure gas Cherenkov detectors
  - Stopped muon detectors

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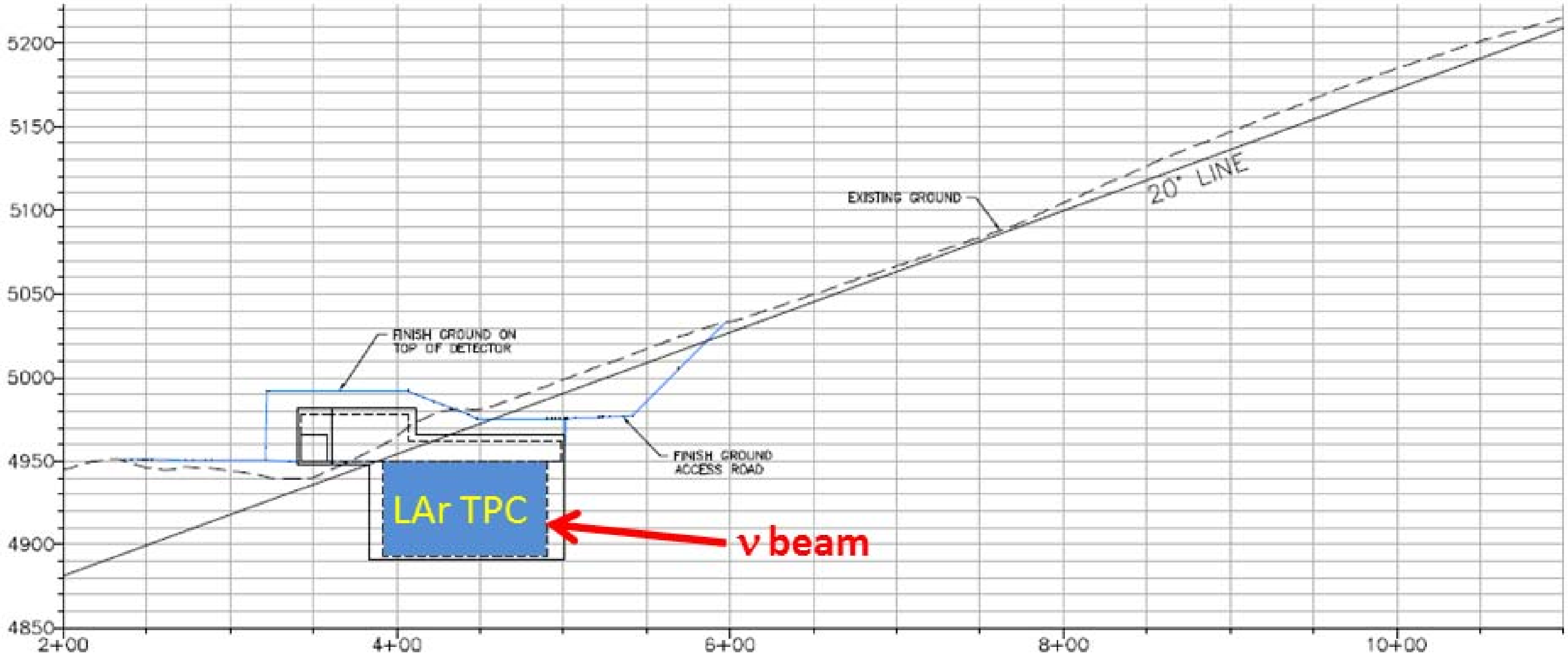

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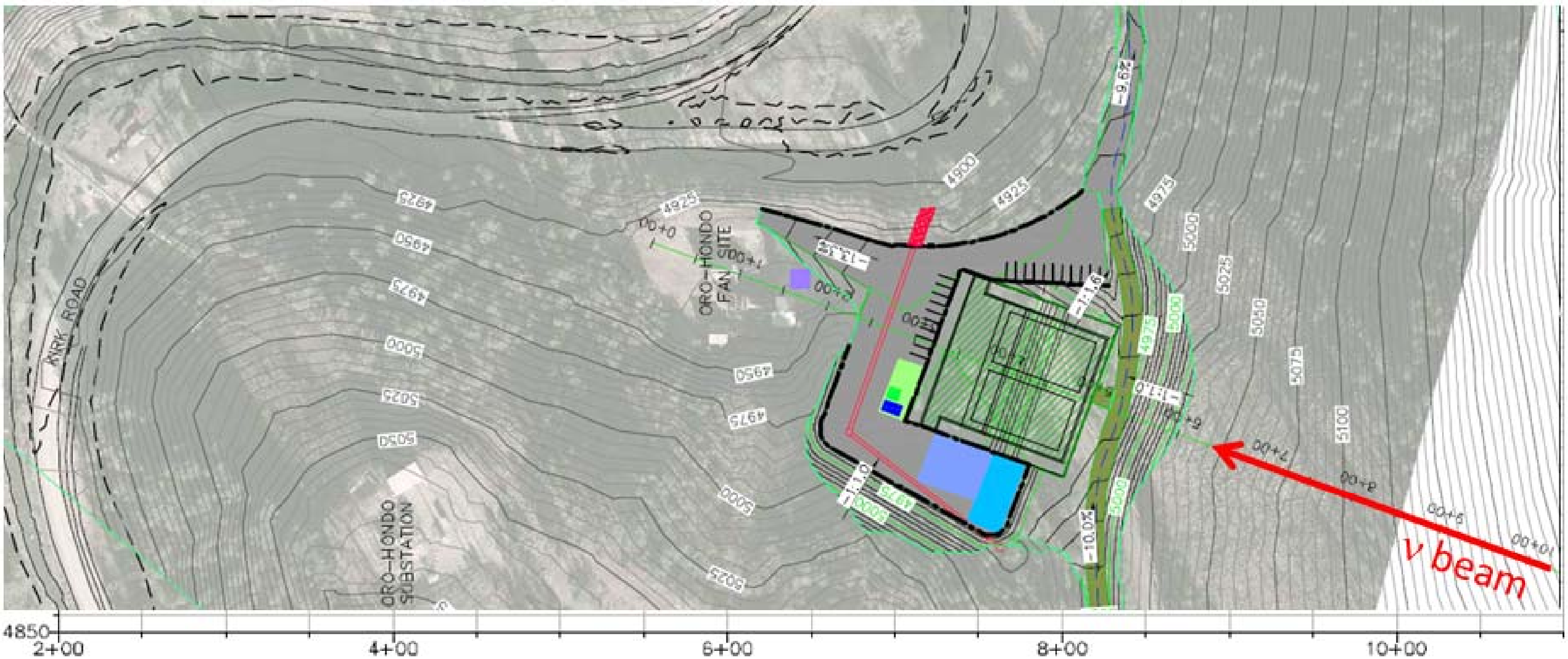

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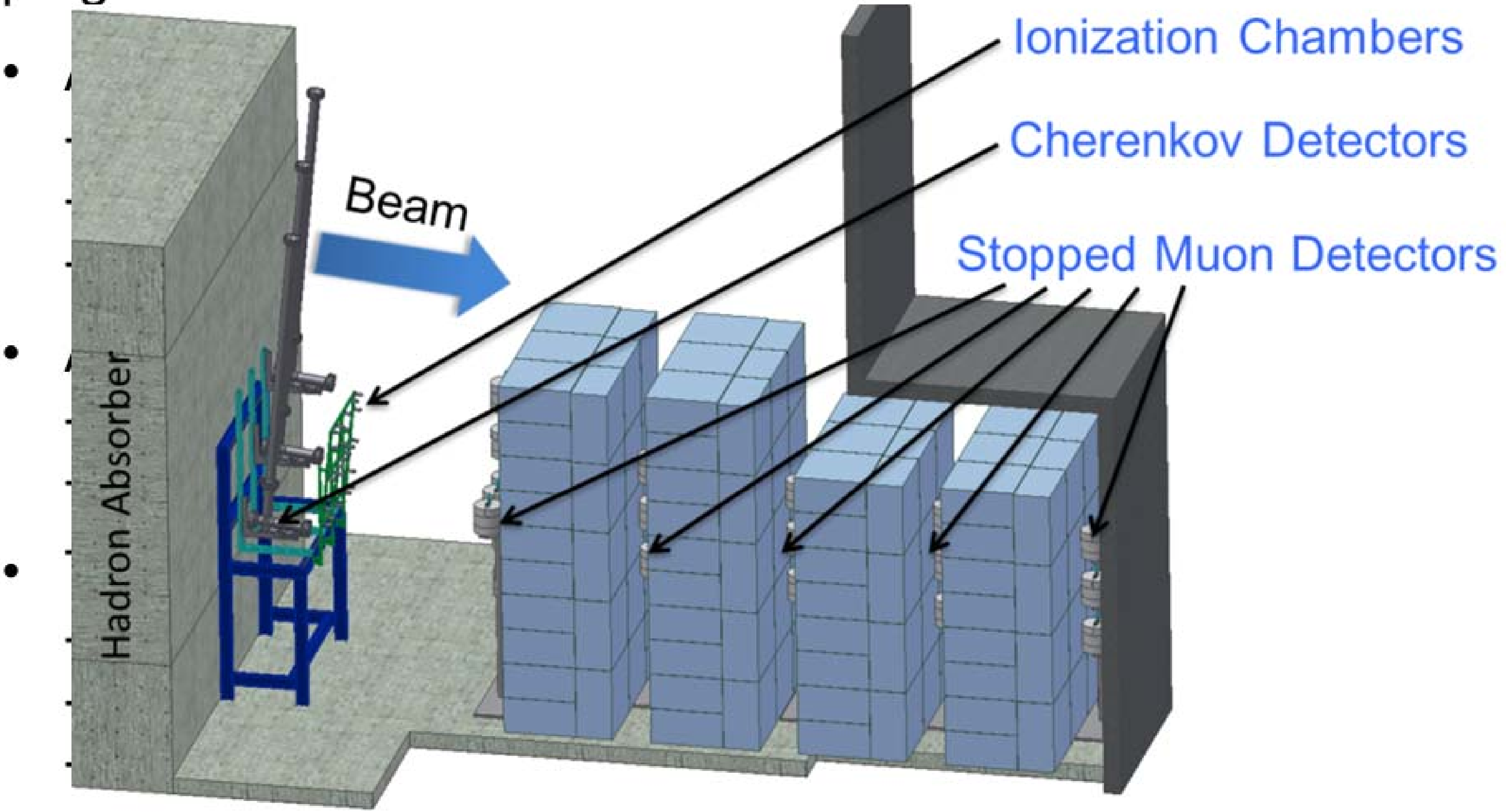

The LBNE Project – Next Steps

- The next step in the DOE project approval process is "CD-1," which approves the conceptual design and overall cost scale and schedule of the Project.
- We have been encouraged by DOE to achieve this milestone by the end of December 2012.
- A prerequisite is to pass two major reviews:
  - Fermilab Director's Review 25-27 September
    - Validates the design
  - DOE ("Lehman") Review 30 October – 1 November
    - Validates the project plan
- CD-1 will allow us to move forward to complete the design and to prepare for construction.

Summary

- LBNE remains focused on its long-term goals:
  a) Comprehensive program to measure neutrino oscillations
     - determine the mass hierarchy and look for CP violation
     - precision measurement of other oscillation parameters
     - test the validity of the three-neutrino mixing model
  b) Search for baryon number violating processes
  c) Measure neutrinos from astrophysical sources, especially from a core-collapse supernova in our galaxy
- Fiscal constraints require us to approach our goals in a phased program
- The LBNE Project will build the first phase, and is expecting DOE approval of "CD-1" this year.
- New national or international collaborators could add scope to phase 1 or accelerate the implementation of later phases.