Status of the FNAL Neutrino Program and Future Prospects

R. Rameika

Fermilab

Opportunities for Polarized Physics at Fermilab

May 20-22, 2013

This slide has absolutely nothing to do with neutrinos

E620 – Charged Hyperon Polarization and Magnetic Moments

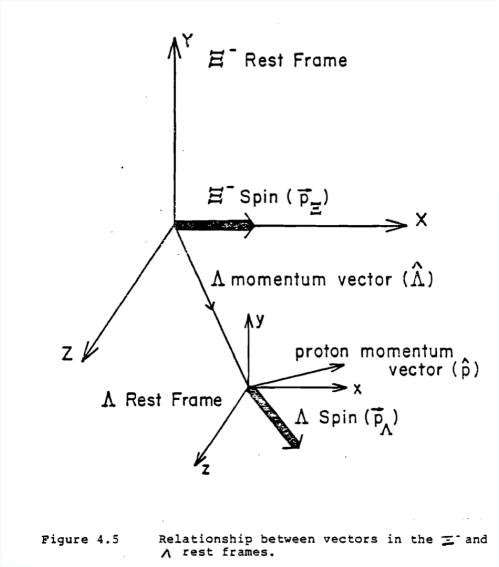


Figure 4.5 Relationship between vectors in the Ξ^- and Λ rest frames.

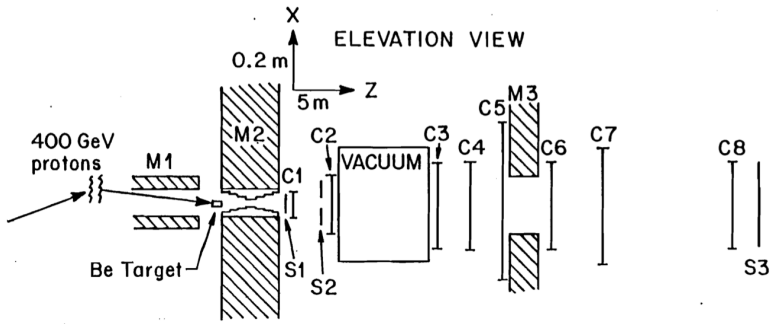


Figure 2.7 Elevation view of the spectrometer.

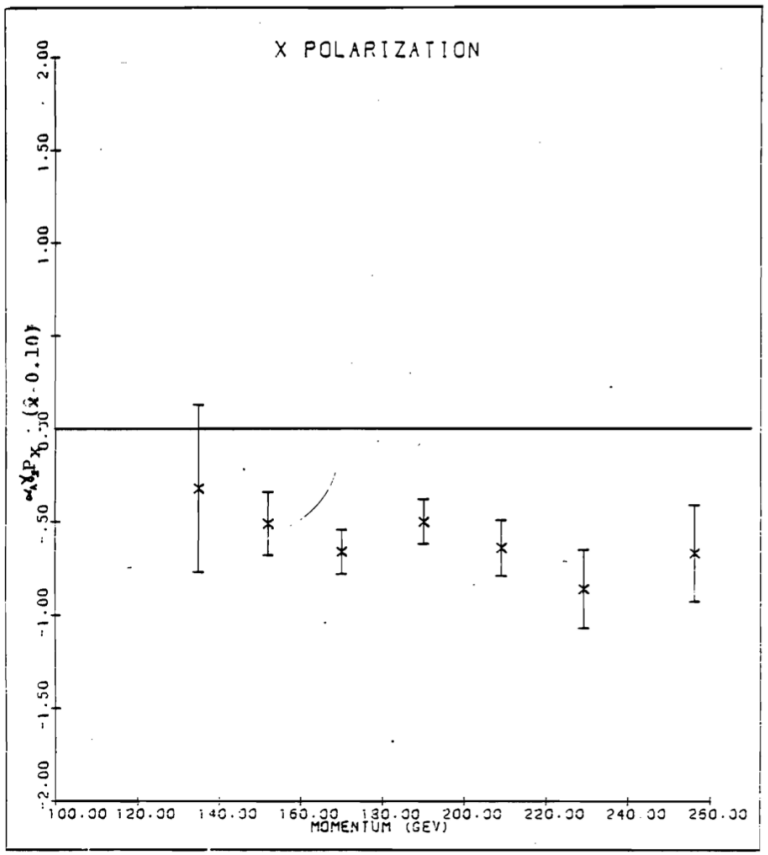


Figure 5.1 $\alpha_\Lambda \gamma_\Xi P_x$ vs. momentum
5 mrad, 6.6 T-m field

R. Rameika, PhD Thesis, 1981

Outline

- The Current and Near Term Program
- Physics goals of the future program
- The Fermilab program in the next decade

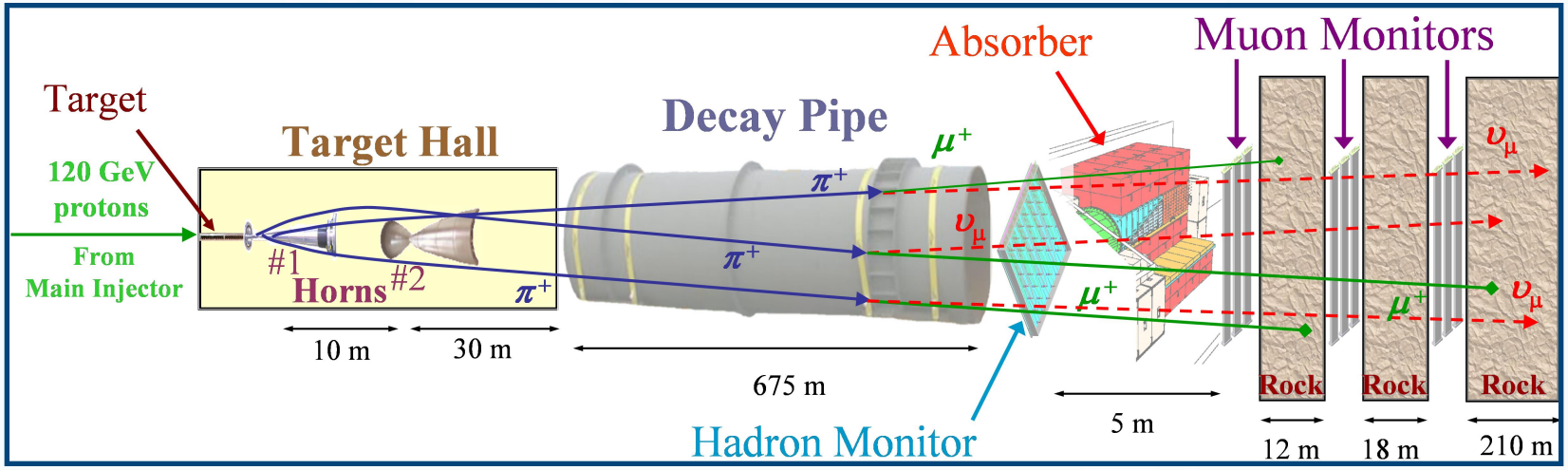
The Current Neutrino Program

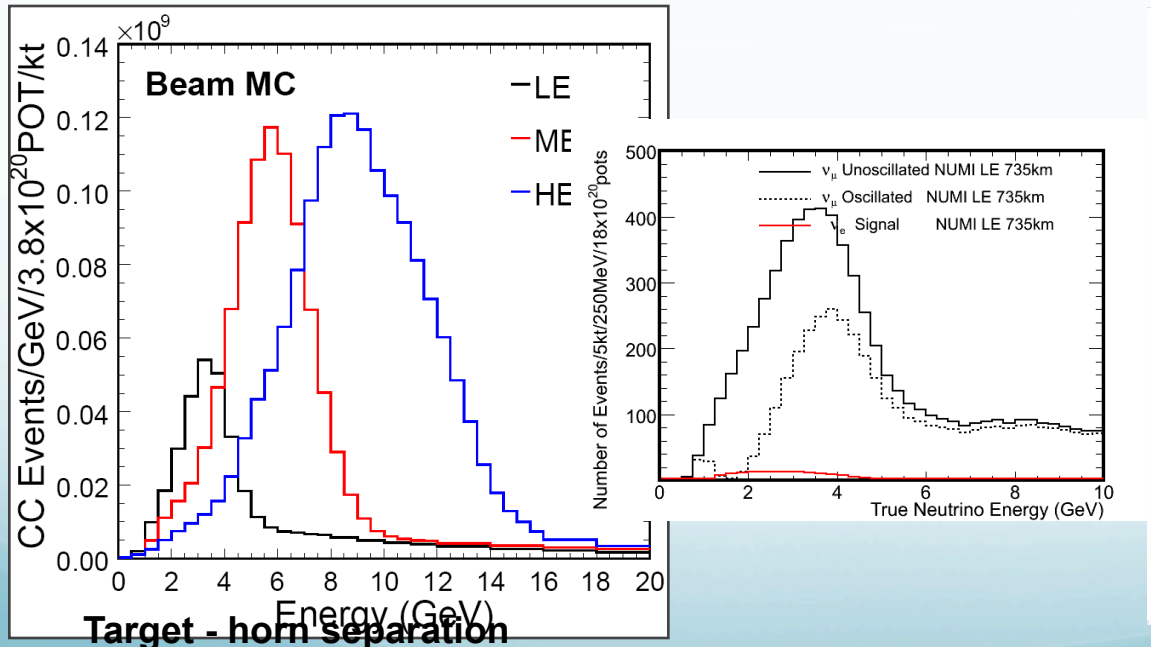
- 120 GeV protons from the Main Injector

  Neutrinos from NuMI
  - To MINOS (2004 - 2012)
  - To ArgoNeuT (data 2009; analysis in progress)
  - To MINERvA (began operation in 2010)
  - To NOvA, MINOS+ (beginning soon)

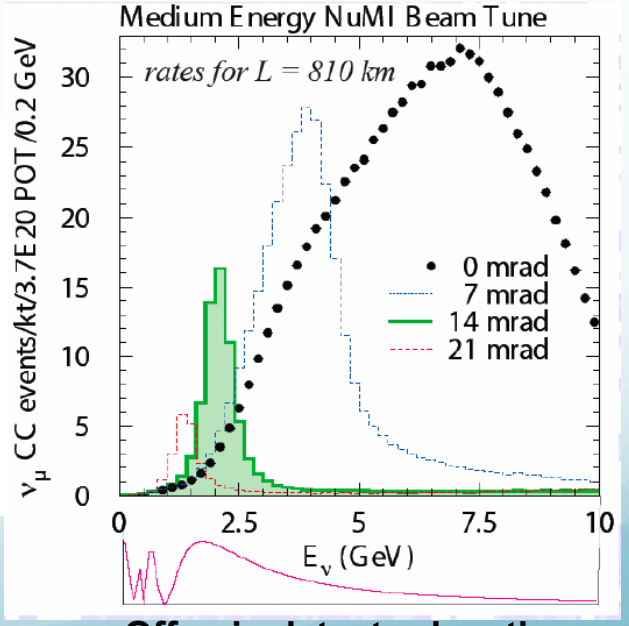
- 8 GeV protons from the Booster
  - Neutrinos from Booster Neutrino Beam (BNB)
    - To MiniBooNE (2002 - 2012)
    - To SciBooNE (completed in August 2008)
    - To MicroBooNE (starting in 2014)

The NuMI Beam



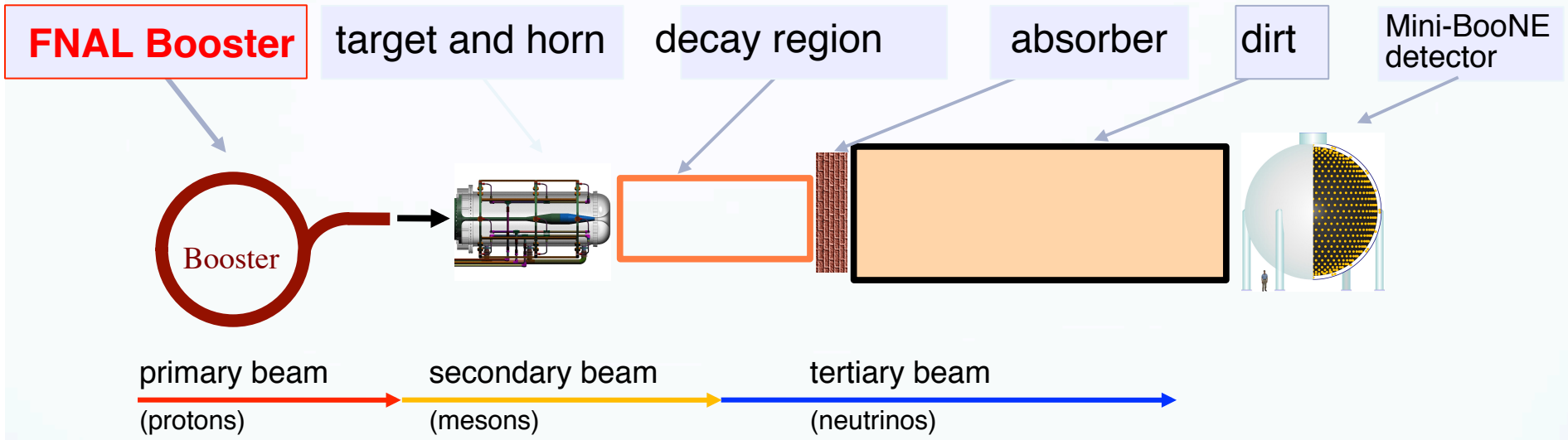


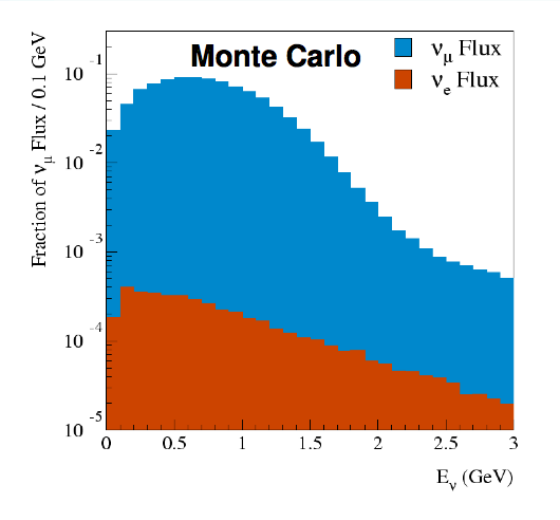
Target - horn separation sets the neutrino energy spectrum.



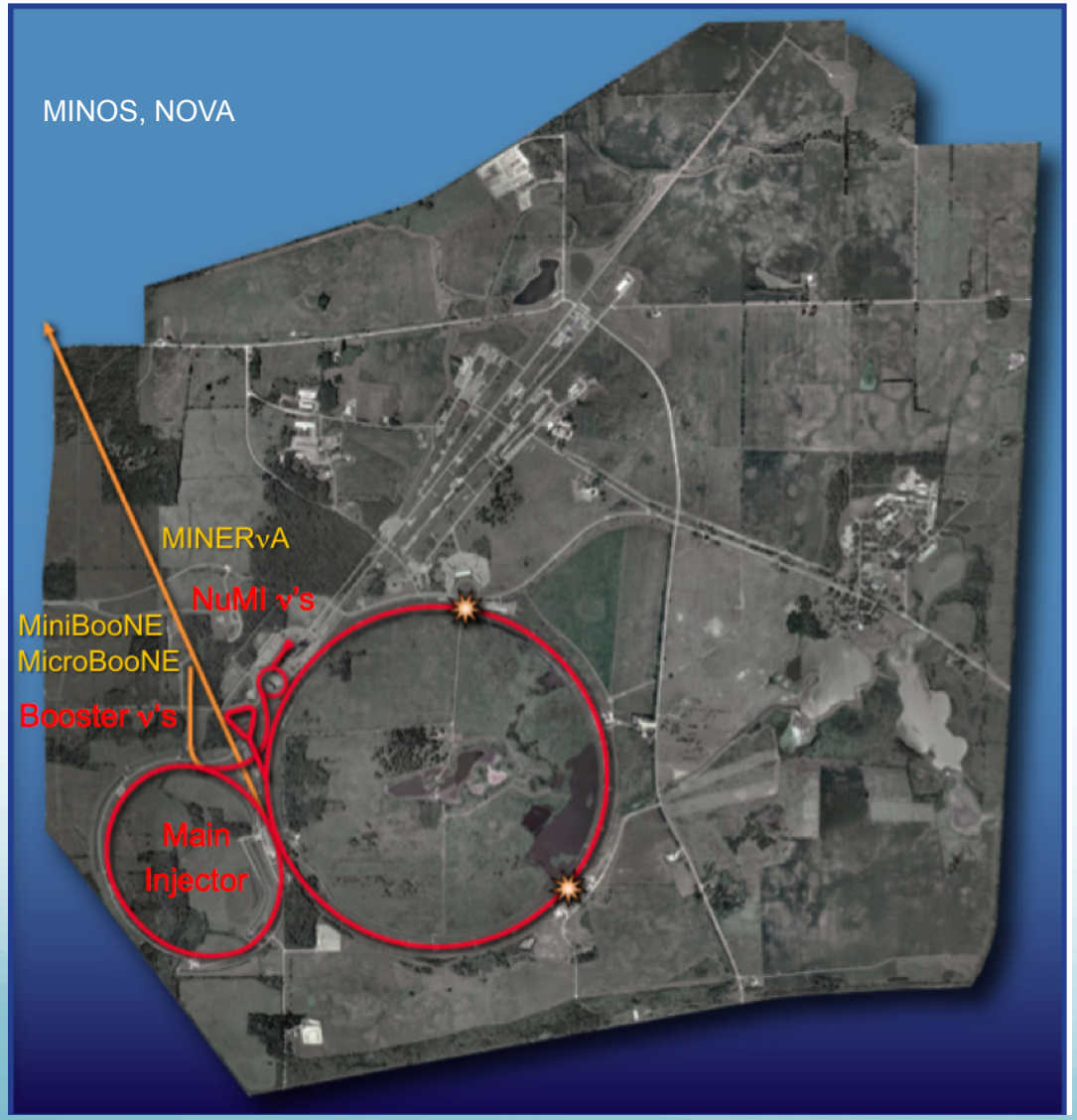
Off-axis detector location sees a narrow band beam

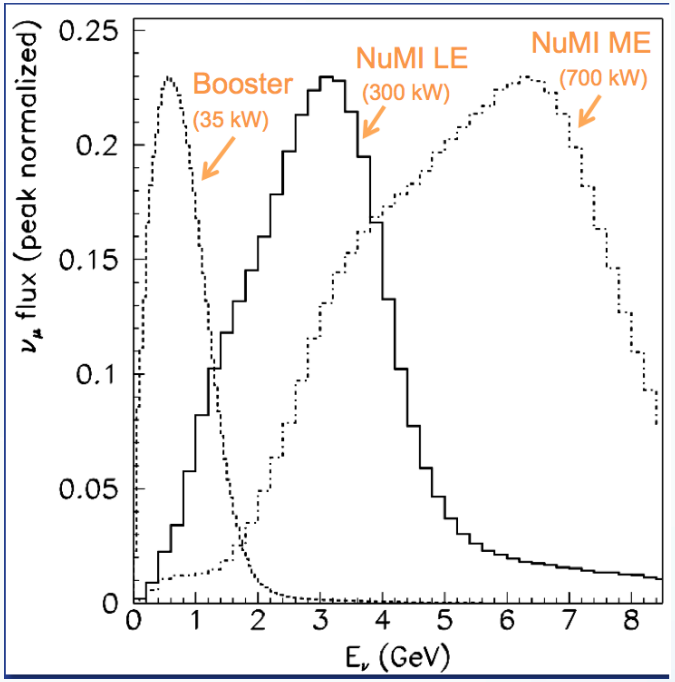
The Booster Neutrino Beam

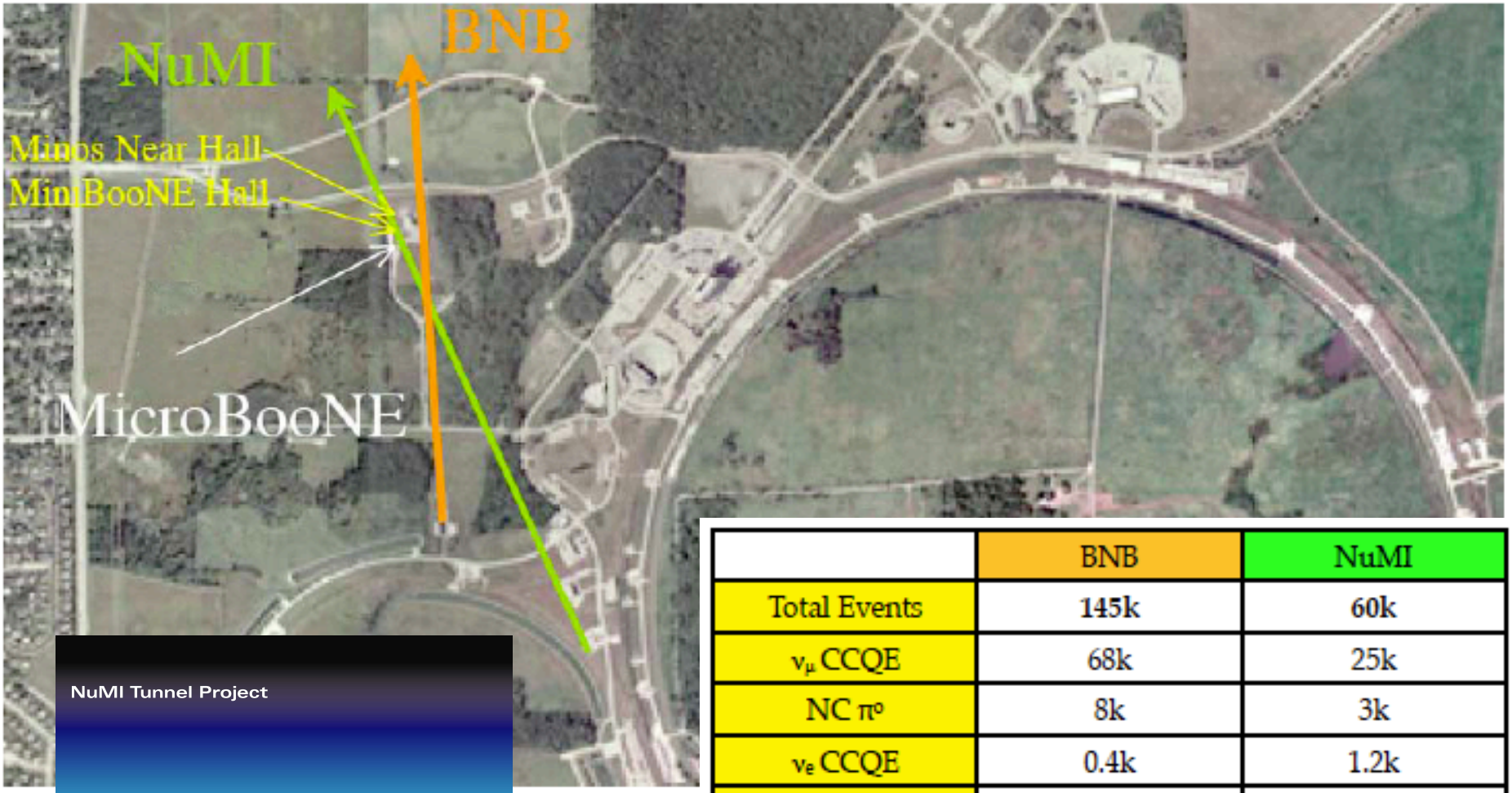


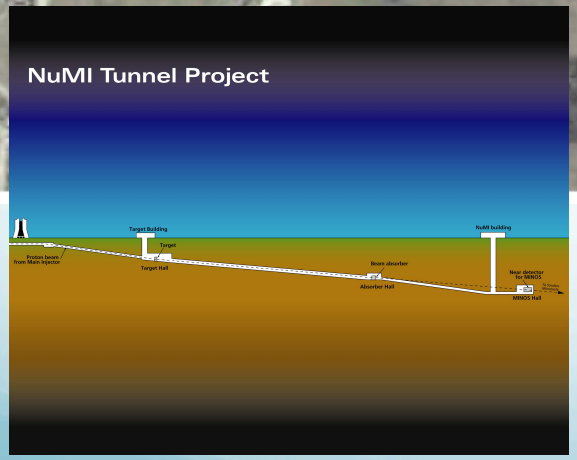


Small intrinsic ν_e rate $\Rightarrow$ Event Ratio $\nu_e/\nu_\mu = 6 \times 10^{-3}$


MINOS, NOVA
MINERνA
NuMI ν's
MiniBooNE
MicroBooNE
Booster ν's
Main
Injector


Booster
(35 kW)
NuMI LE
(300 kW)
NuMI ME
(700 kW)
ν_μ flux (peak normalized)
0.25
0.2
0.15
0.1
0.05
0
0 1 2 3 4 5 6 7 8
E_ν (GeV)





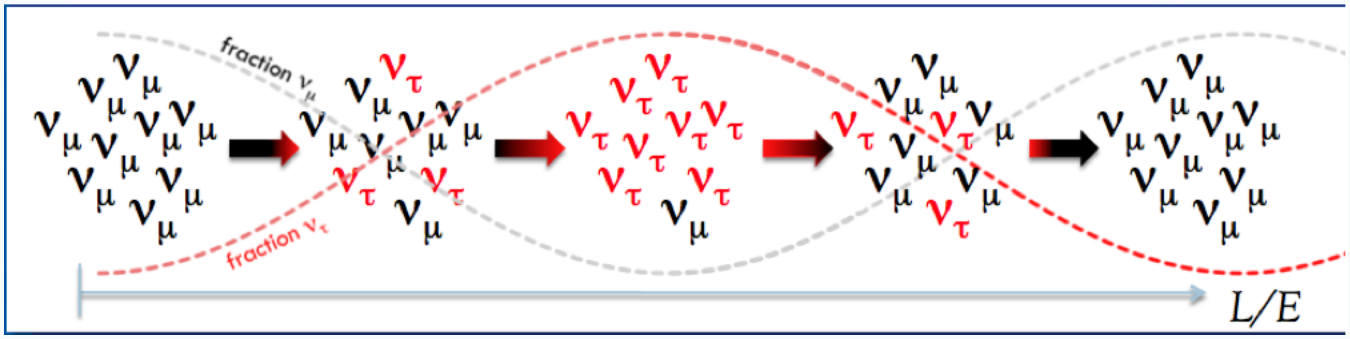
	BNB	NuMI
Total Events	145k	60k
ν_μ CCQE	68k	25k
NC π^0	8k	3k
ν_e CCQE	0.4k	1.2k
POT	6×10^{20}	8×10^{20}

Projected Event Rates for MicroBooNE in 2-3 years.

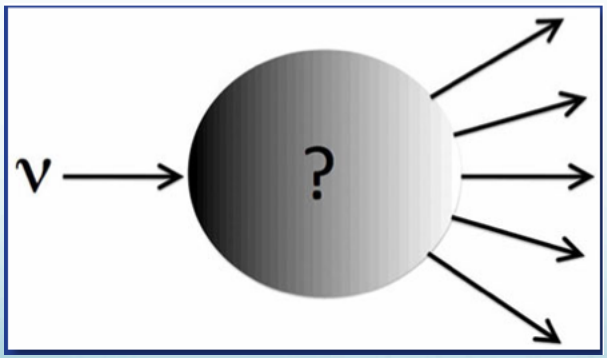
Detectors in either beam see neutrinos from both

Two Major Physics Thrusts

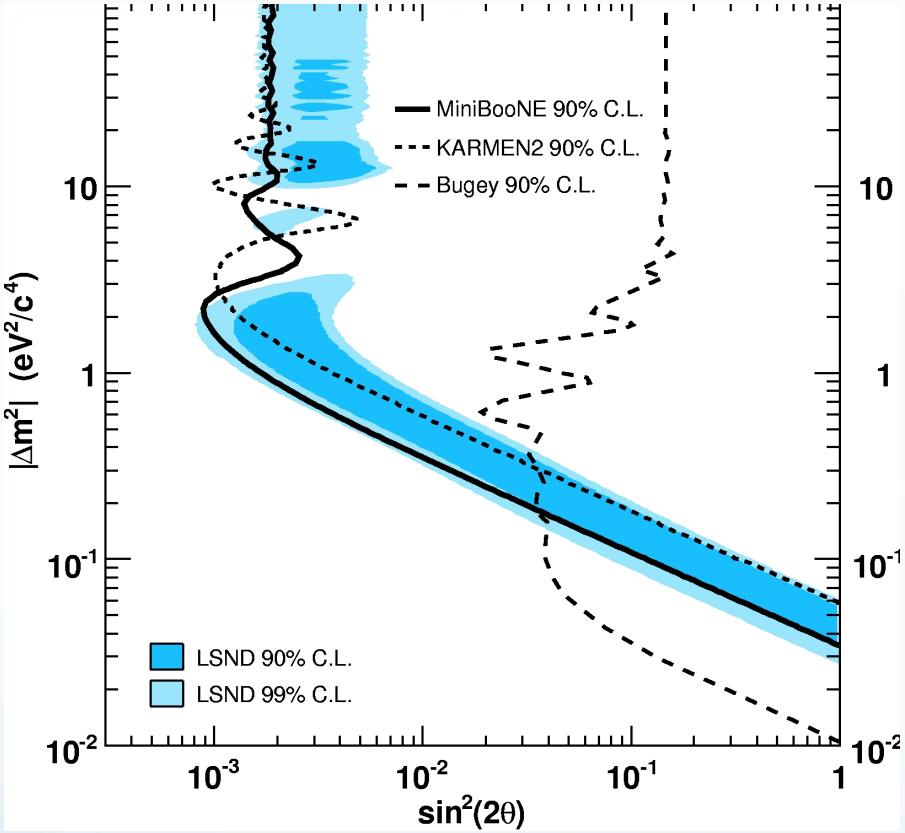
Neutrino Oscillations

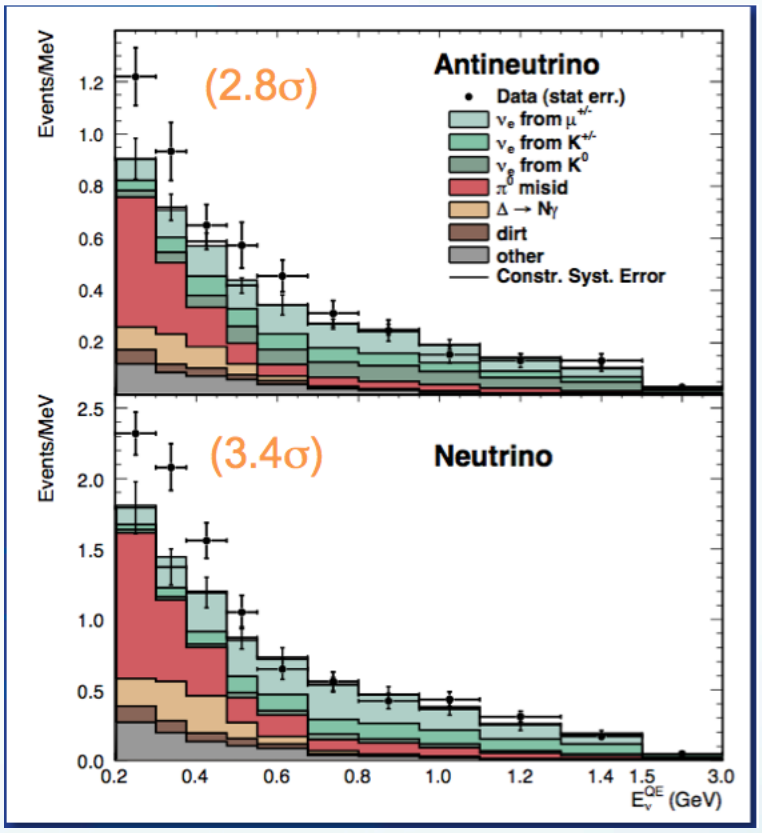


Neutrino Interactions



MiniBooNE Oscillation Results

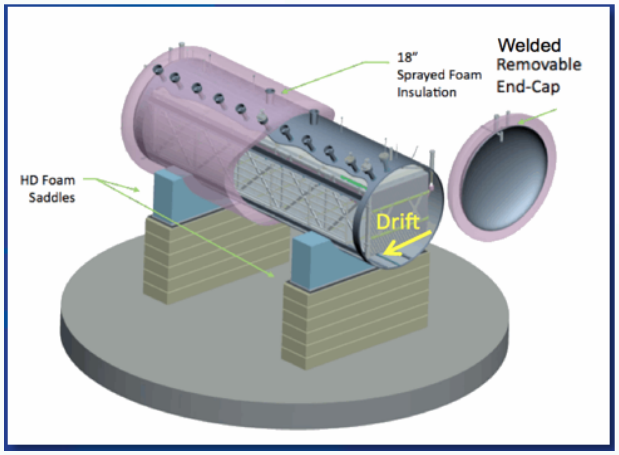


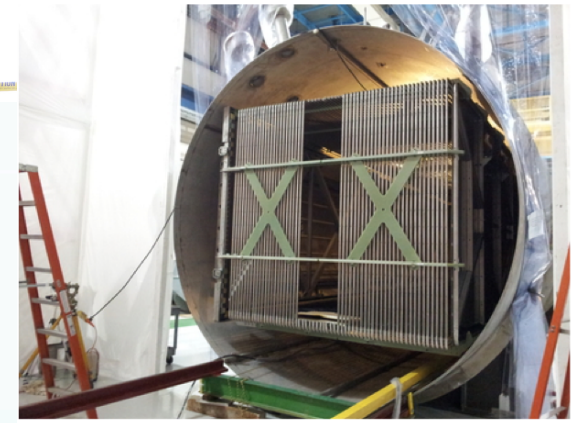


Phys. Rev. Lett. 98, 231801 (2007)

Doesn't confirm LSND oscillation claim; low energy anomalies

MicroBooNE to address anomalies
Data starts in early 2014

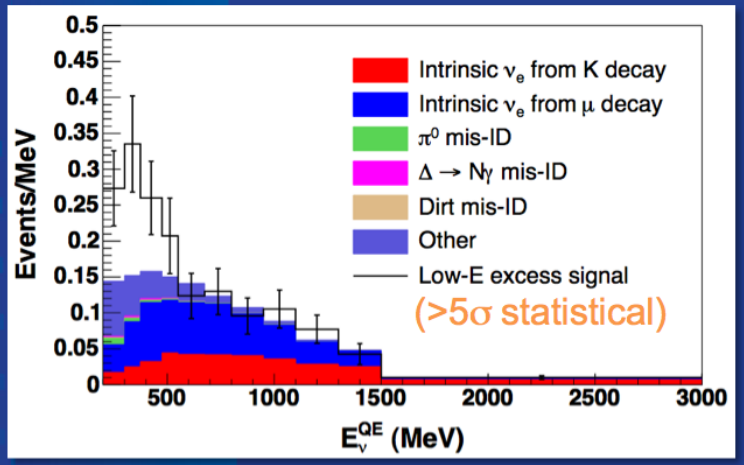




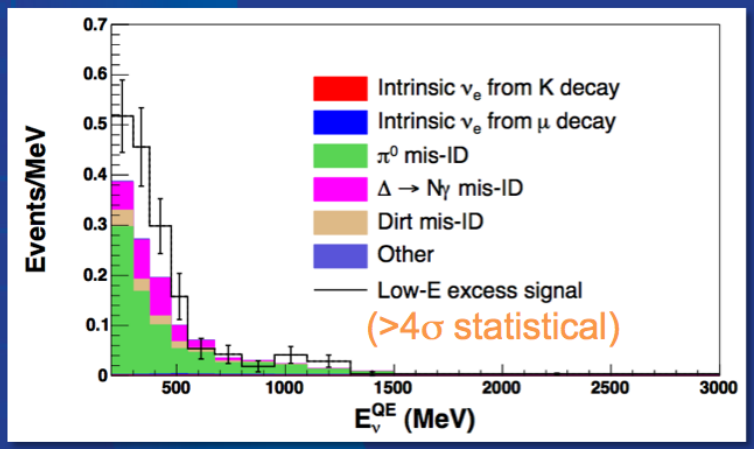
170 ton Liquid Argon
TPC with 2.5 m drift ->
Need 1.4 msec electron lifetime
Not evacuated
Cold electronics for optimized signal to noise
These are all technology advan
the 1st gen ICARUS detector

TPC is size of a school bus

MicroBooNE Oscillation Physics



unlike MiniBooNE, MicroBooNE can distinguish e^-'s from γ's

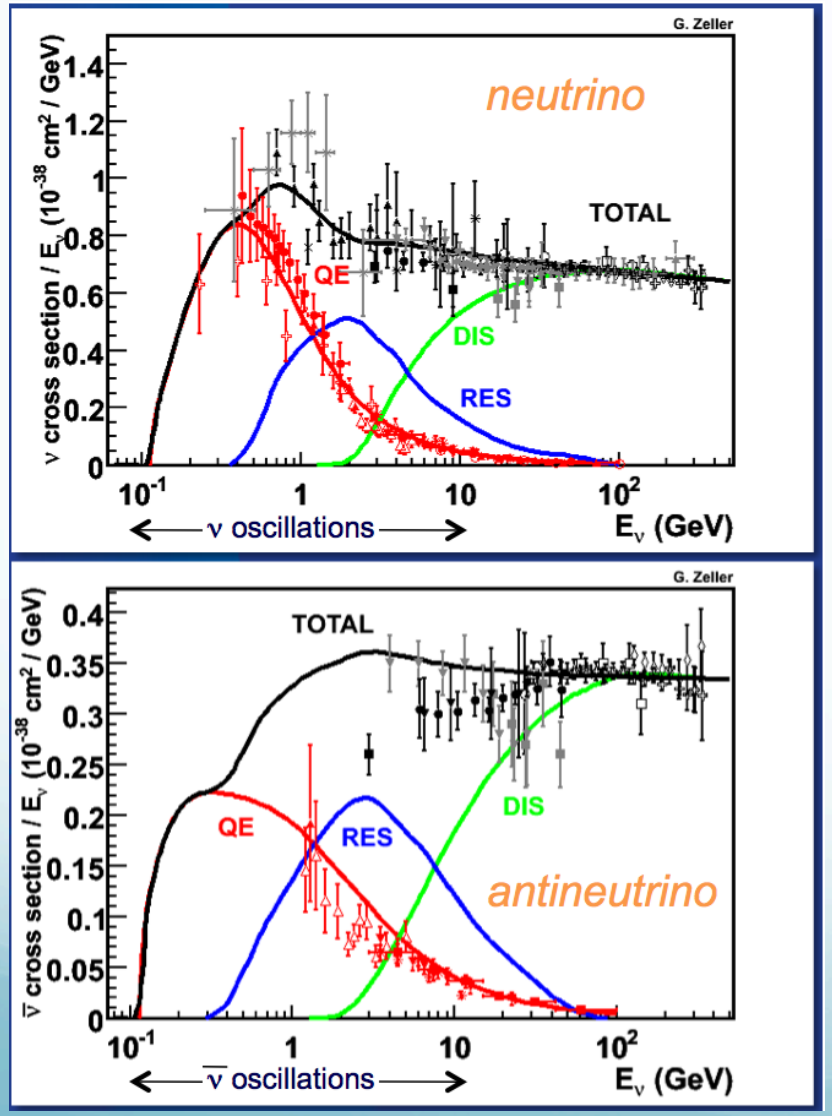


if the MiniBooNE low energy excess is due to electrons

if the MiniBooNE low energy excess is due to photons

(projections for 6.6x10^{20} POT)

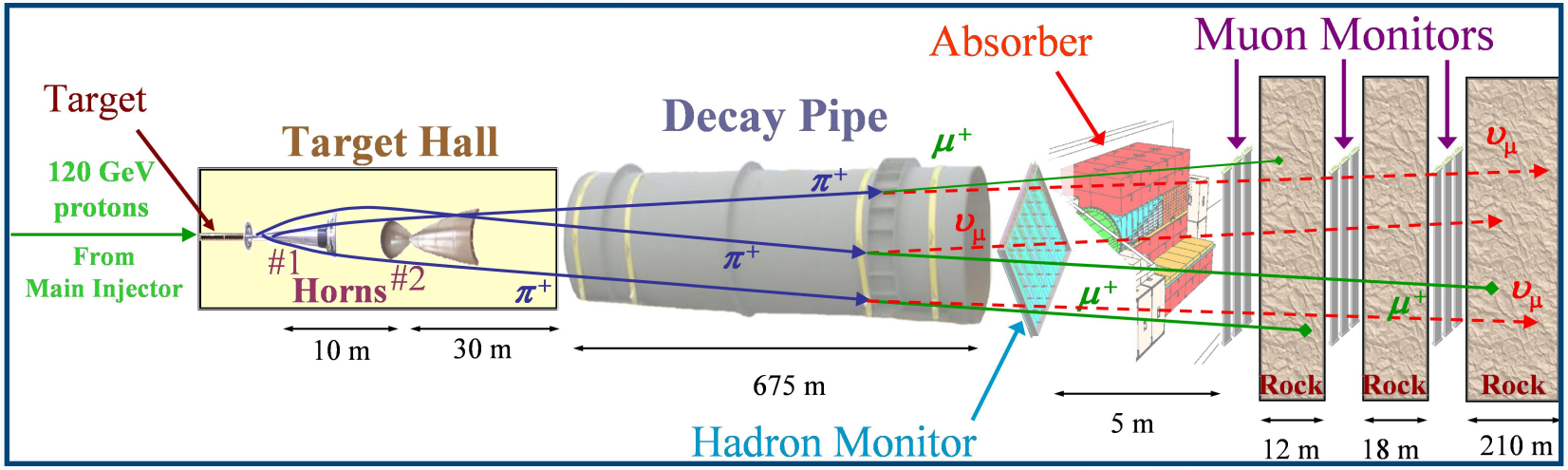
MicroBooNE will also collect high statistics for cross section measurements

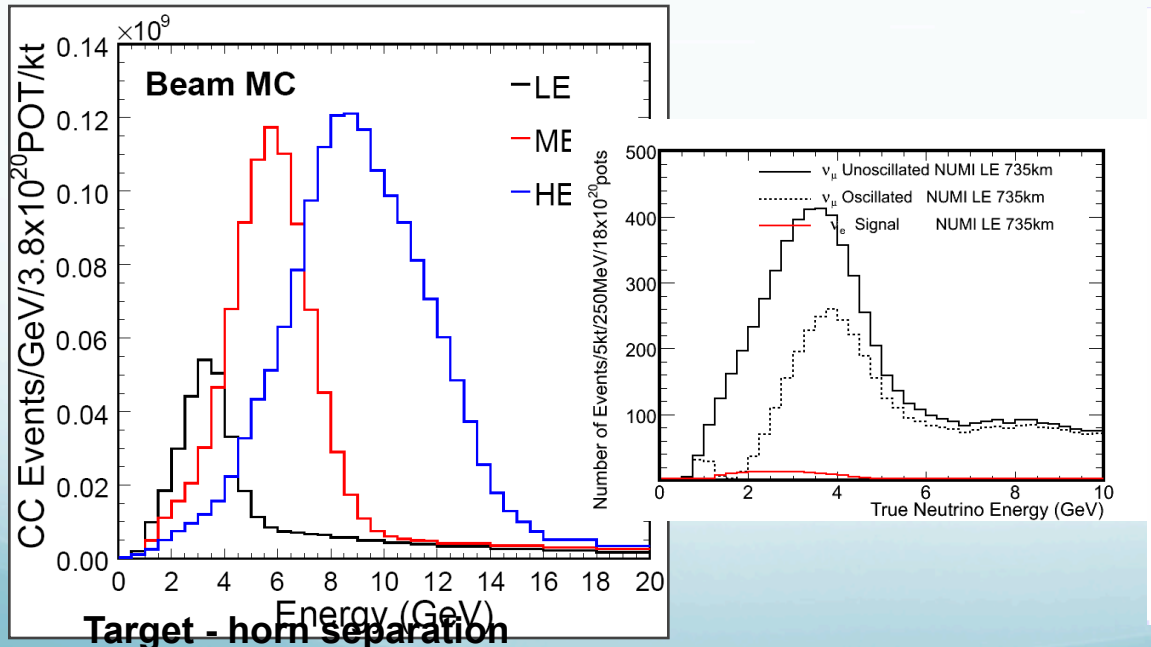


- ν cross sections historically not well-known in the energy range we care about
- nuclear effects are far more complex than we thought

  - has forced a dramatic shift in our thinking

The NuMI Beam





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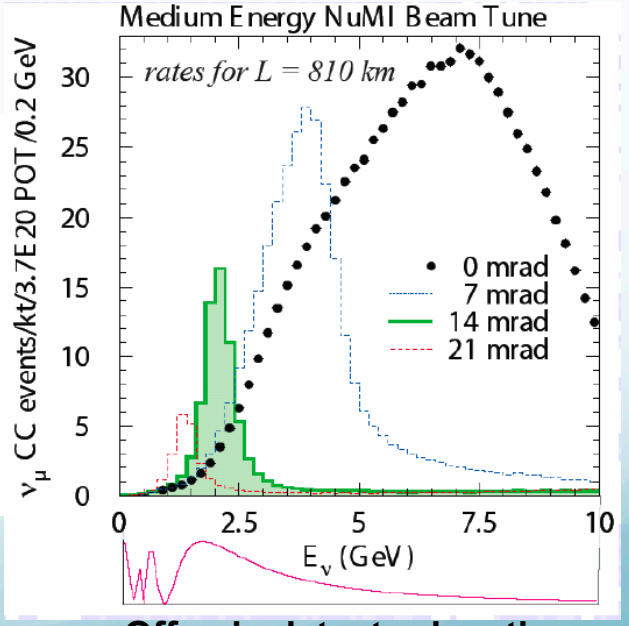
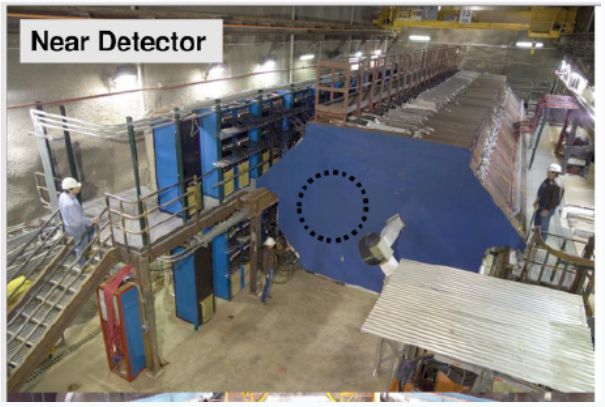
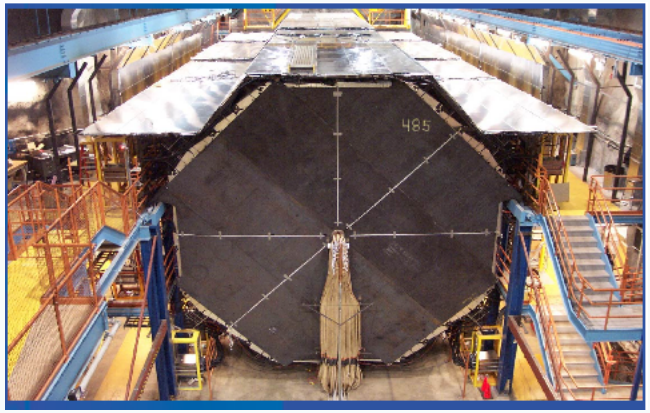
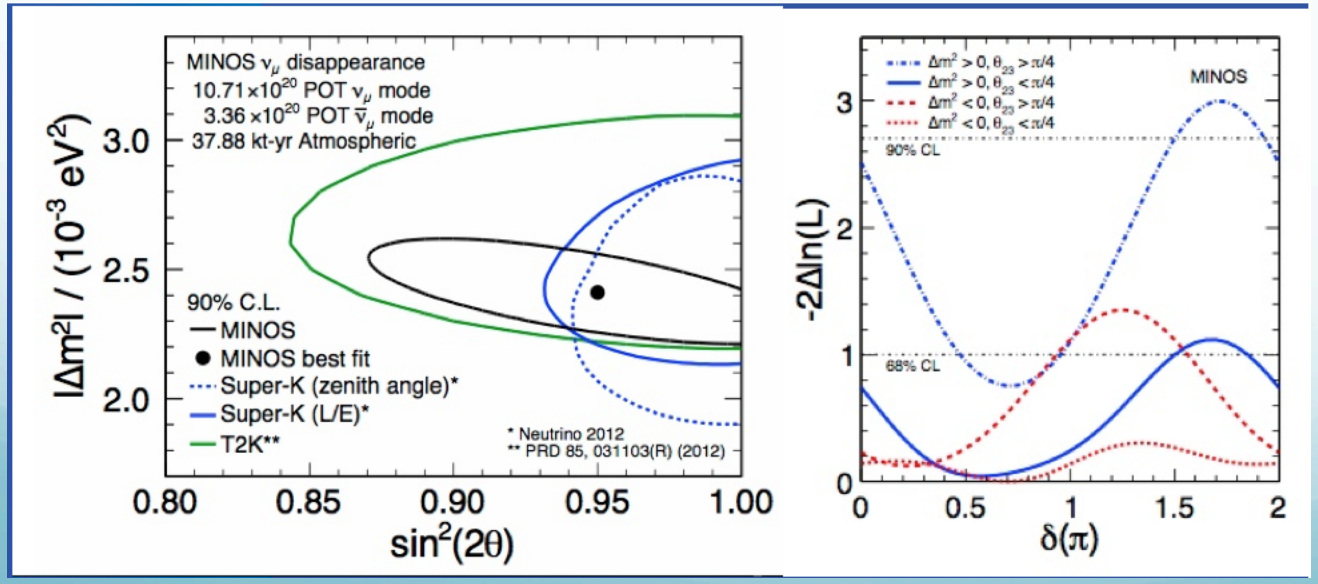


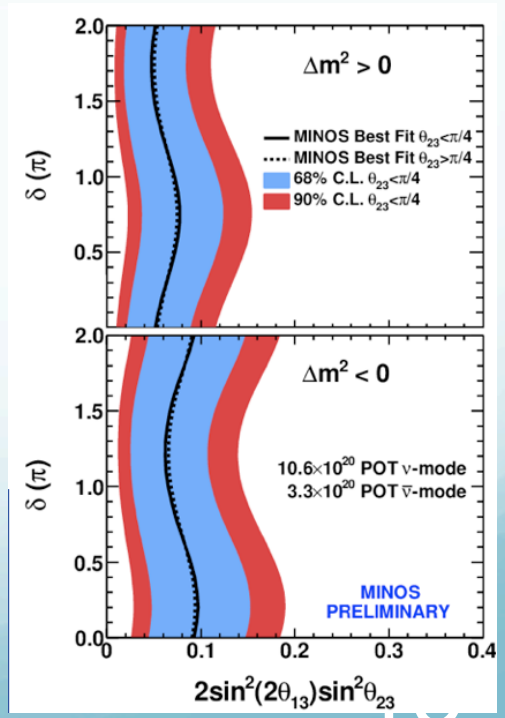
Off-axis detector location sees a narrow band beam

MINOS
Data 2005 - 2012



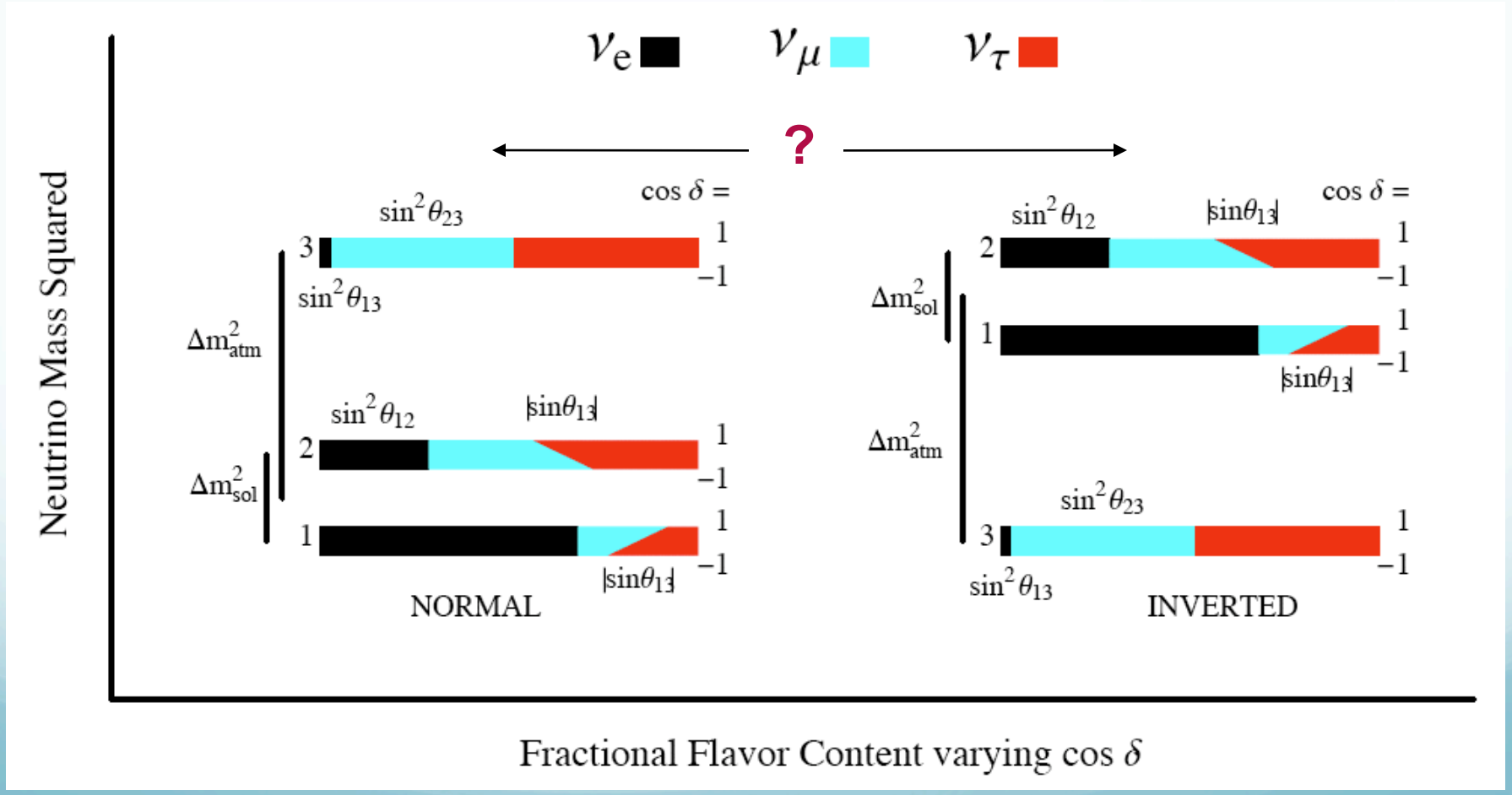




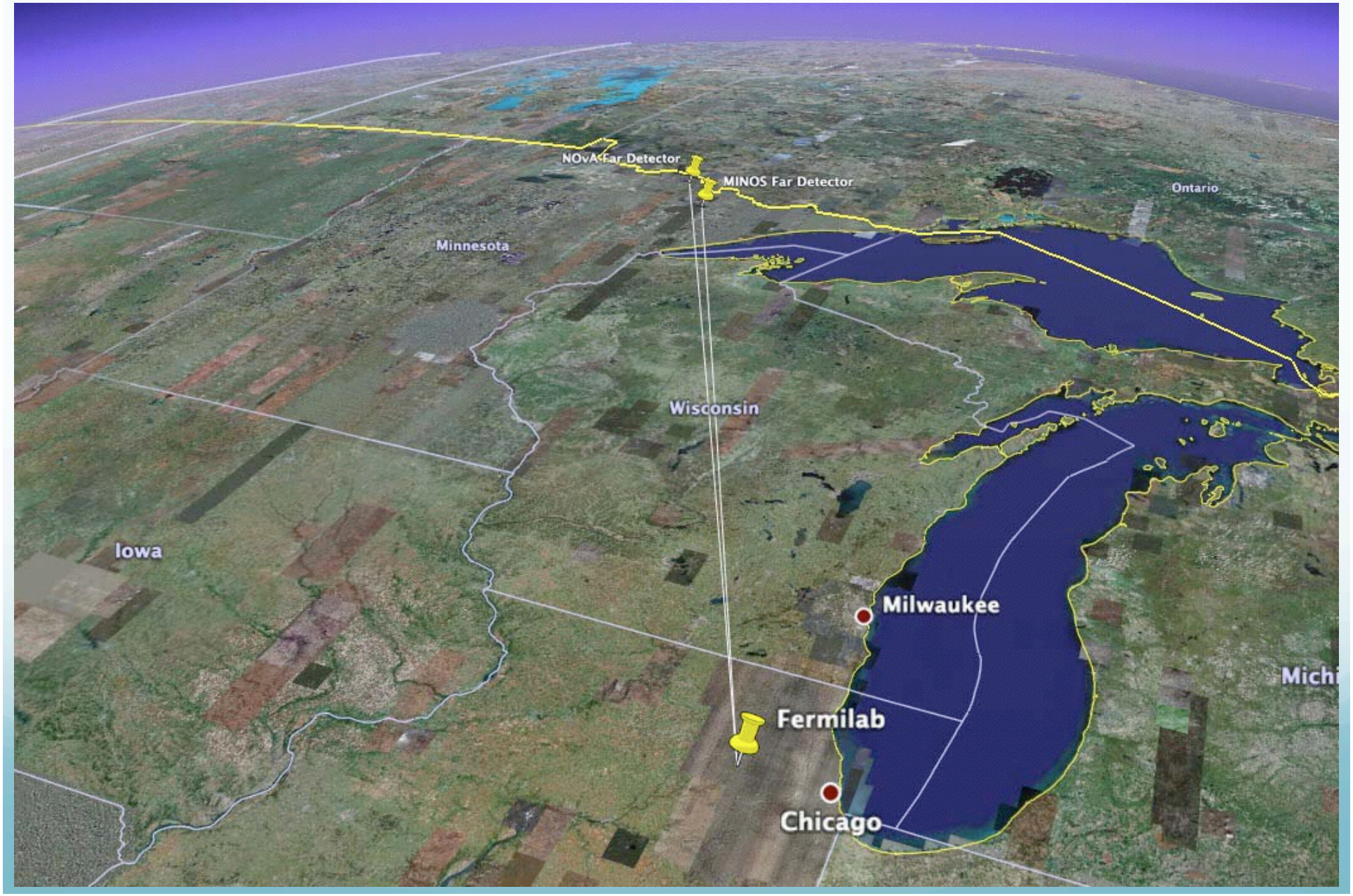


θ_{13} ,mass hierarchy and δ_{CP}

$$P(\nu_a \rightarrow \nu_b) = f(\Delta m^2{}'s, \theta' s, E_\nu, L)$$



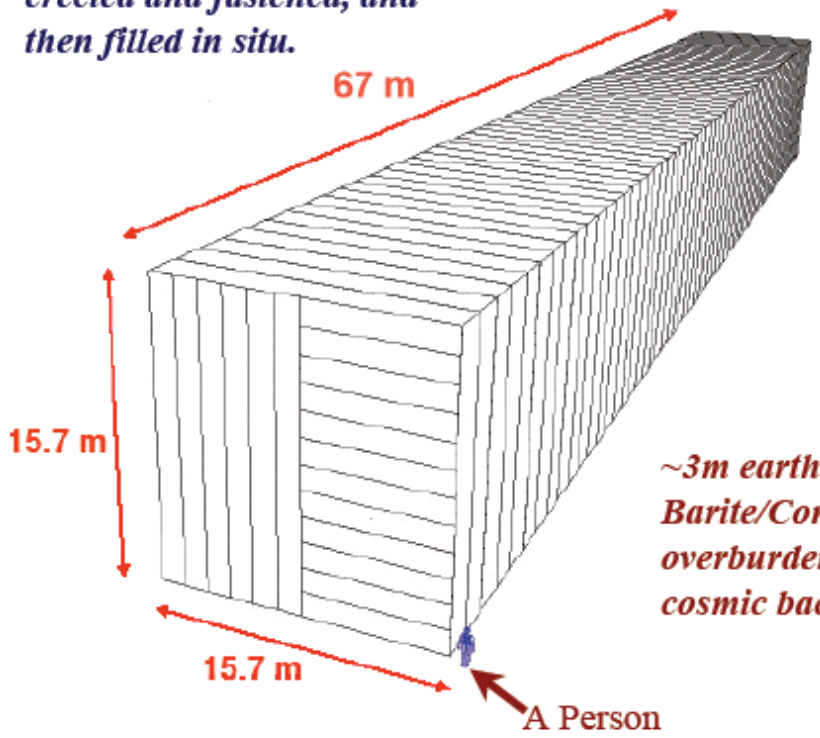
NOνA : NuMI Off-Axis



NOvA

Far Detector

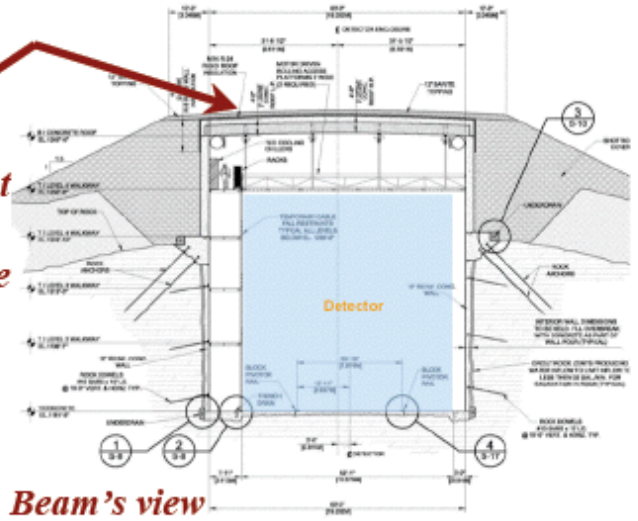
Construction:
Empty planes will be erected and fastened, and then filled in situ.



15kT Total Mass
(70% Scintillator)

1003 planes of detector supported in blocks of 31

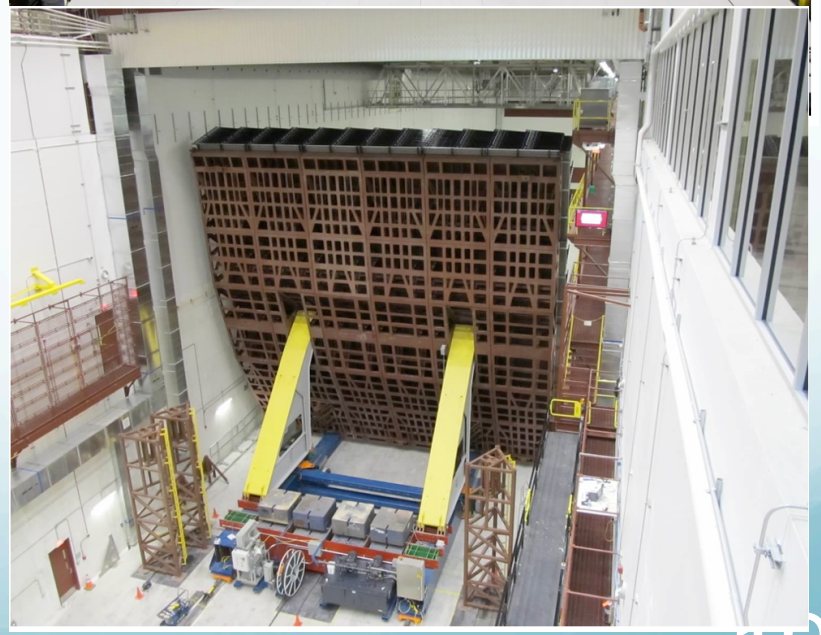
385000+ cells



~3m earth equivalent Barite/Concrete overburden to reduce cosmic backgrounds

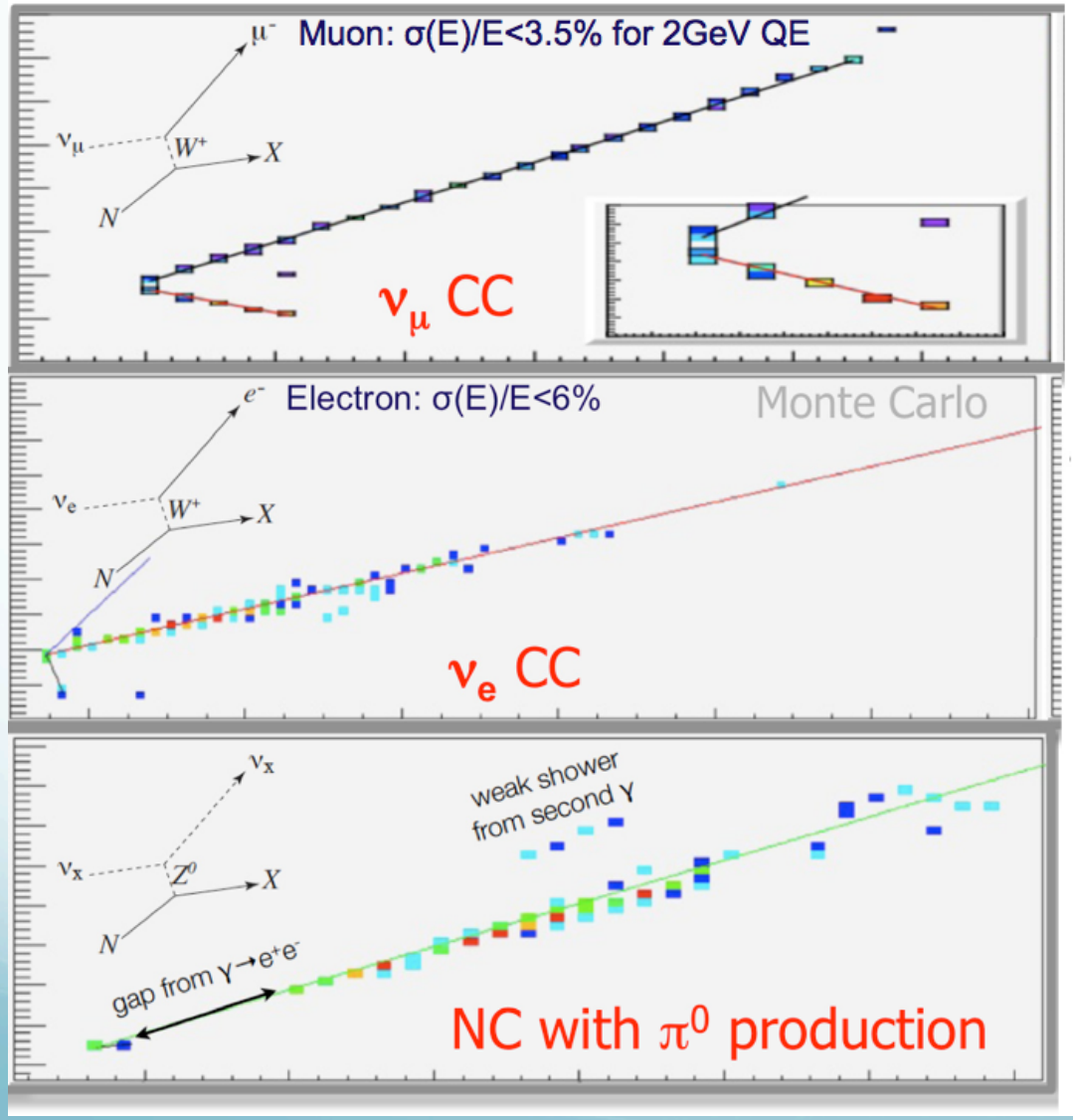
Beam's view

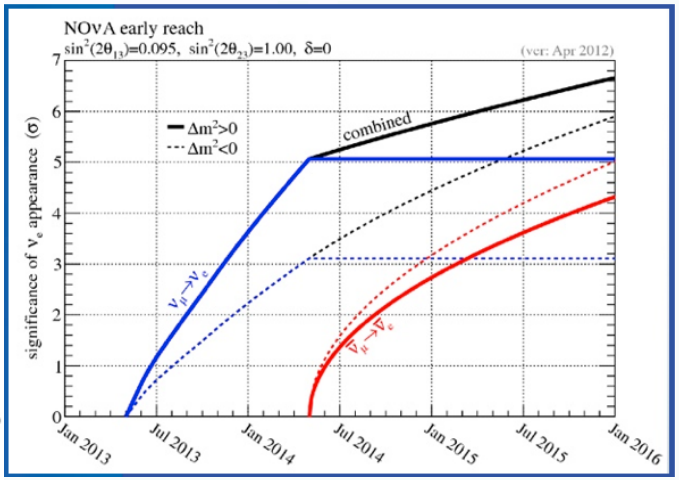
Construction Underway



3kT with beam expected in June

NOvA Topologies and Sensitivities





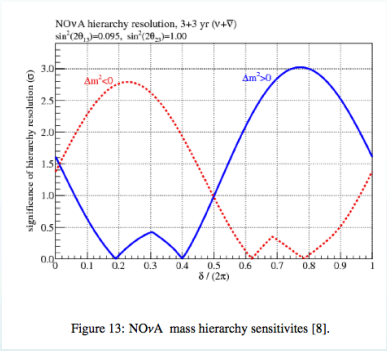
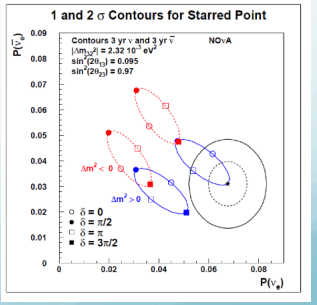
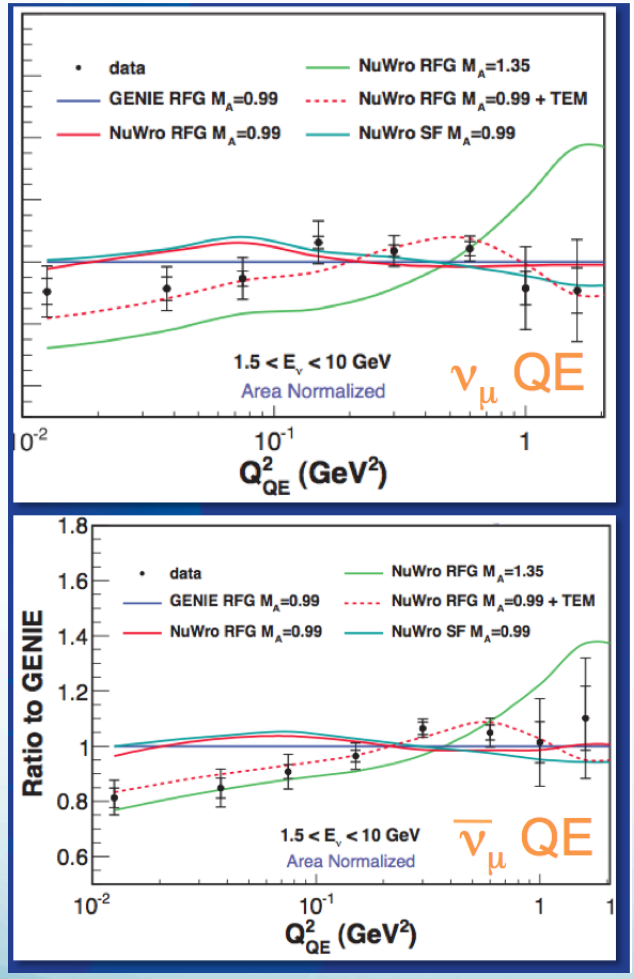


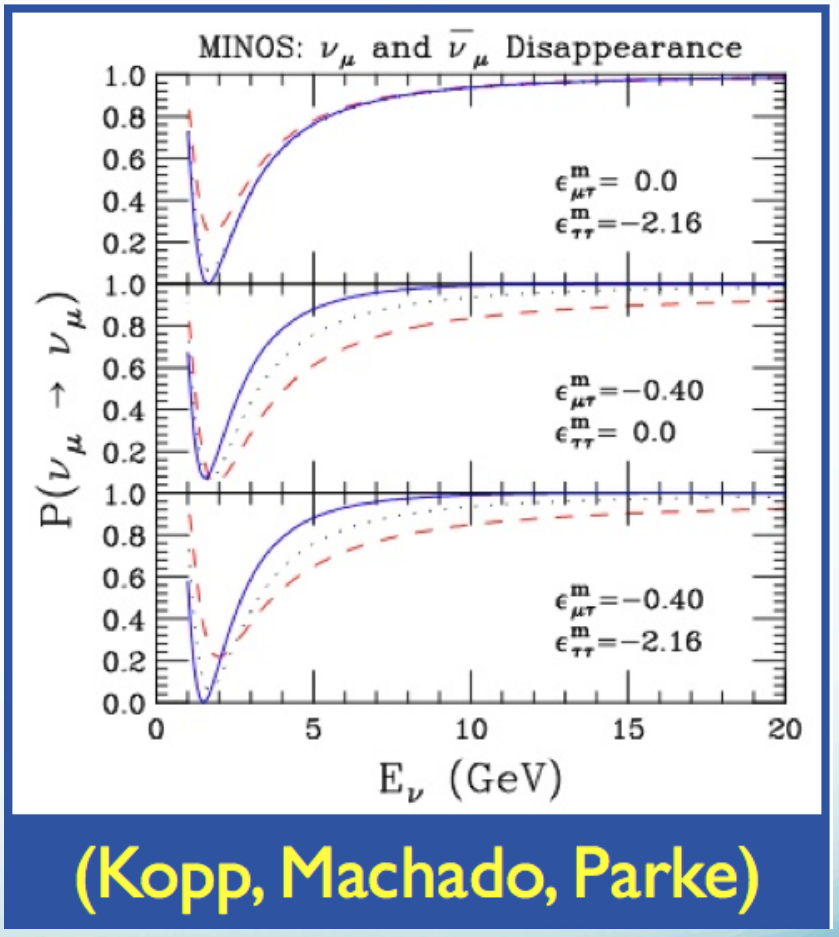
Figure 13: NOvA mass hierarchy sensitivites [8].



Concurrent with NOvA (NuMI in ME tune)



Continued cross section data from MINERvA



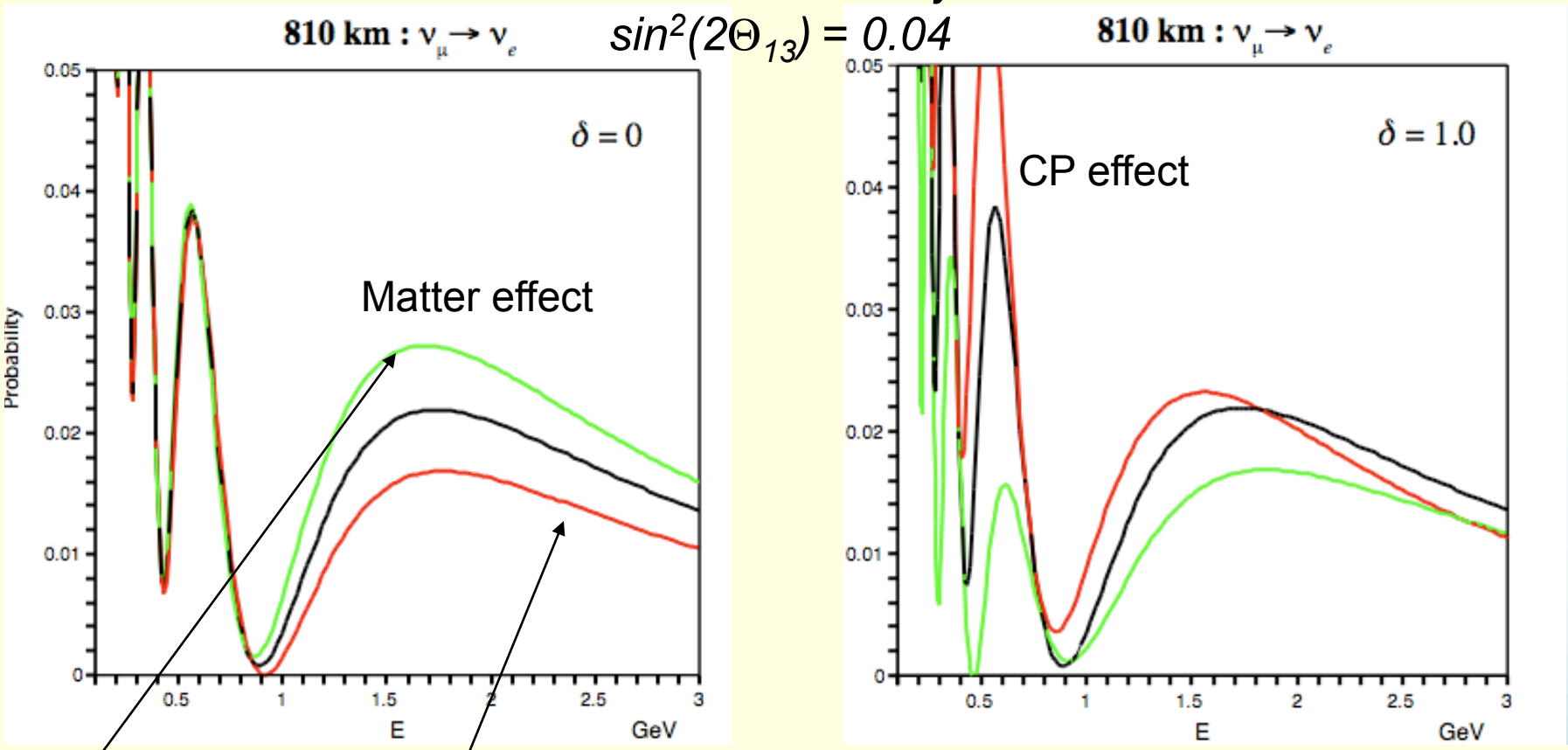
(Kopp, Machado, Parke)

MINOS+ collects data to search for NSI and sterile neutrinos

Matter Effects and CP

Normal hierarchy

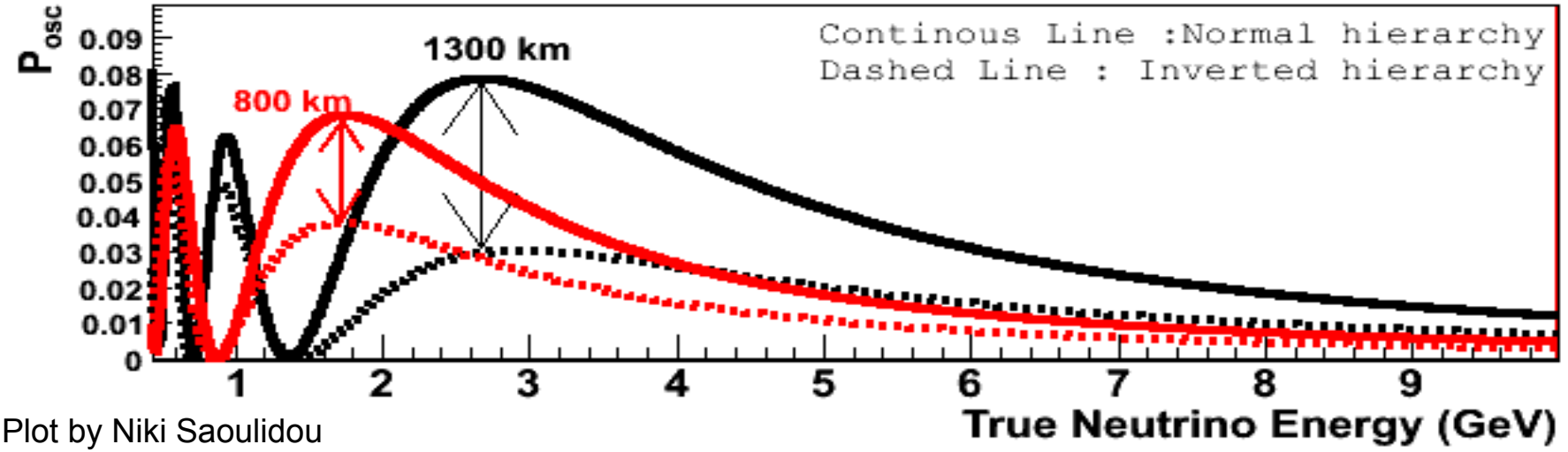
$\sin^2(2\Theta_{13}) = 0.04$



ν's and and anti-ν's can be used to distinguish ambiguities

What happens at the longer baseline?

$P(\nu_\mu \rightarrow \nu_e)$

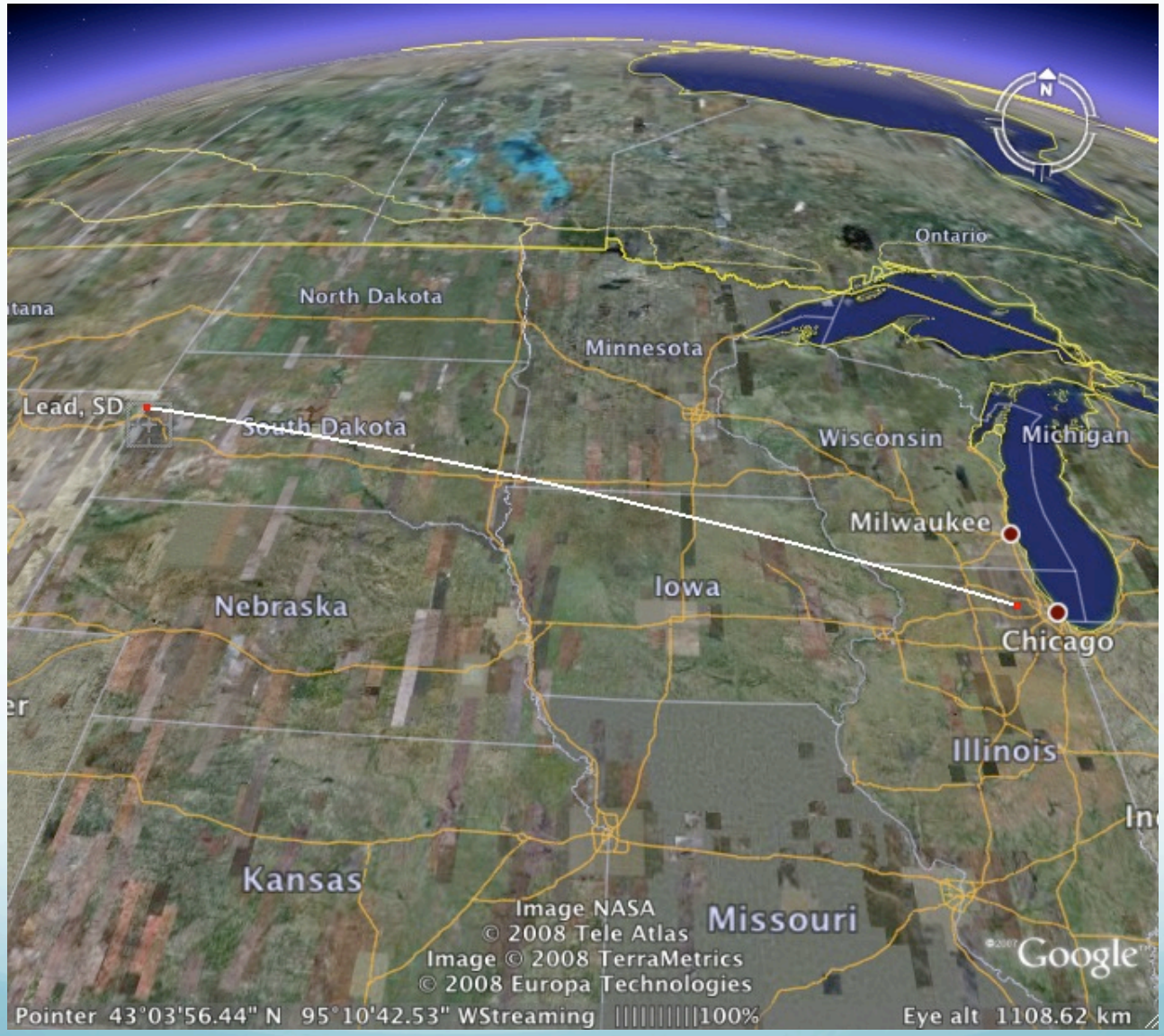


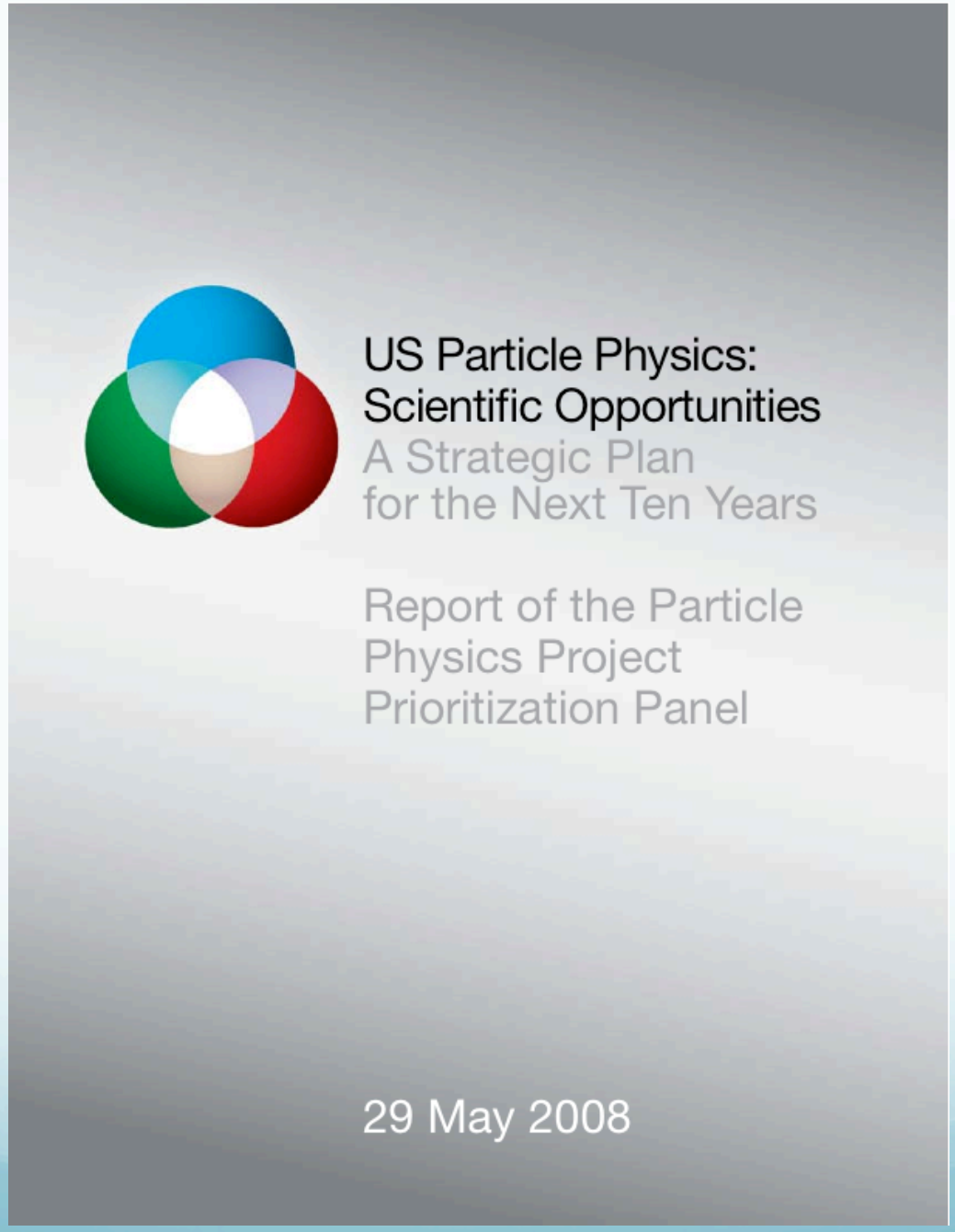
Plot by Niki Saoulidou

- Oscillation maxima are moved to higher energy
- Matter effects are significantly larger

$$P(\nu_\mu \rightarrow \nu_e)_{matter} = f(\theta_{12}, \theta_{13}, \theta_{23}, \delta_{CP}, \Delta m^2_{12}, (sign)\Delta m^2_{23}, E_\nu, L, V_{matter})$$

Fermilab to Homestake SURF (1290km)




US Particle Physics:
Scientific Opportunities
A Strategic Plan
for the Next Ten Years
Report of the Particle
Physics Project
Prioritization Panel
29 May 2008

from P5 report

The Intensity Frontier

The accelerator-based neutrino program

- Measurements of the mass and other properties of neutrinos are fundamental to understanding physics beyond the Standard Model and have profound consequences for understanding the evolution of the universe. The US can build on the unique capabilities and infrastructure at Fermilab, together with the proposed DUSEL, the Deep Underground Science and Engineering Laboratory proposed for the Homestake Mine, to develop a world-leading program in neutrino science. Such a program will require a multi-megawatt proton source at Fermilab.

- The panel recommends a world-class neutrino program as a core component of the US program, with the long-term vision of a large detector in the proposed DUSEL laboratory and a high-intensity neutrino source at Fermilab.

from P5 report

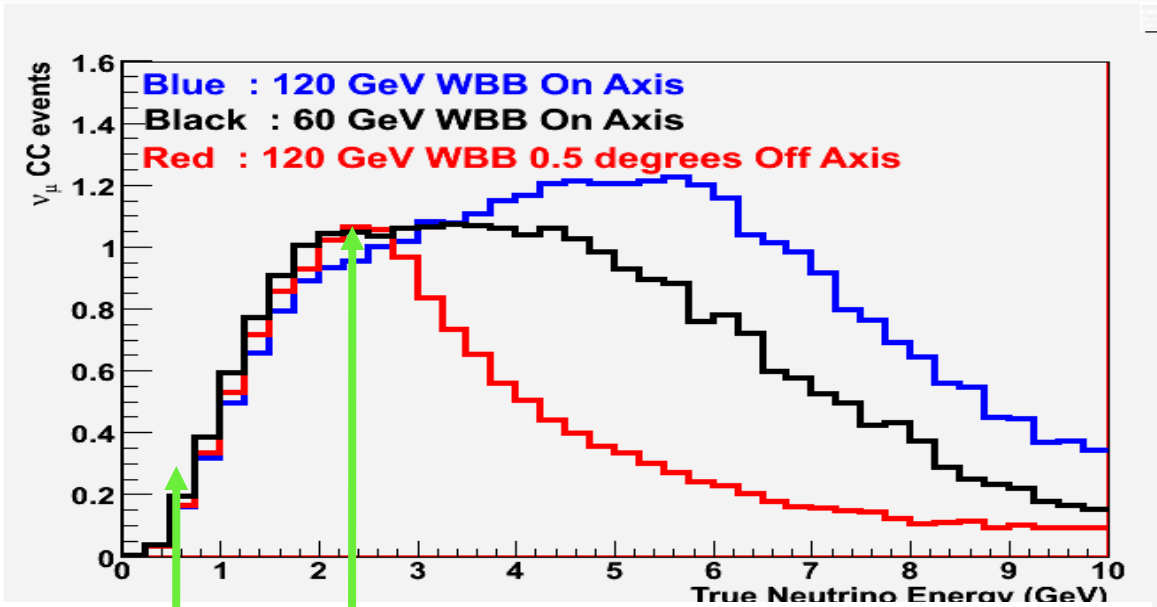
Neutrino Program (cont)

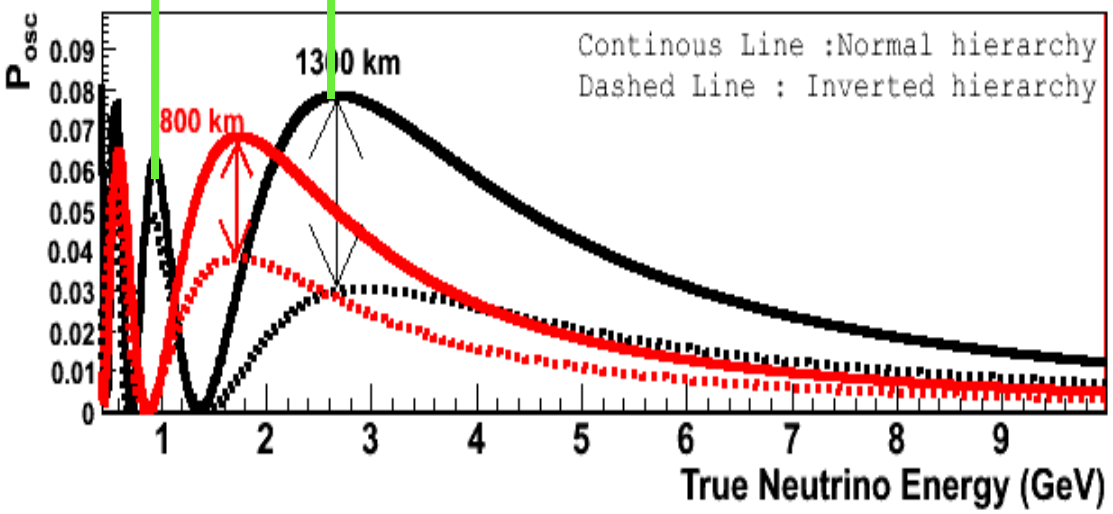
- The panel recommends proceeding now with an R&D program to design a multi-megawatt proton source at Fermilab and a neutrino beamline to DUSEL and recommends carrying out R&D on the technology for a large detector at DUSEL.

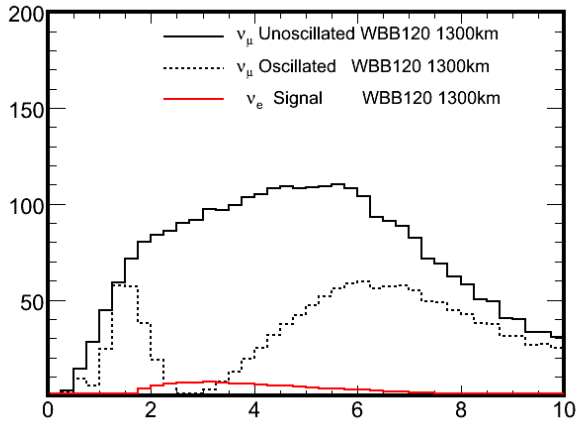
- Construction of these facilities could start within the period considered by this report.

- A neutrino program with a multi-megawatt proton source would be a stepping stone toward a future neutrino source, such as a neutrino factory based on a muon storage ring, if the science eventually requires a more powerful neutrino source. This in turn could position the US program to develop a muon collider as a long-term means to return to the energy frontier in the US

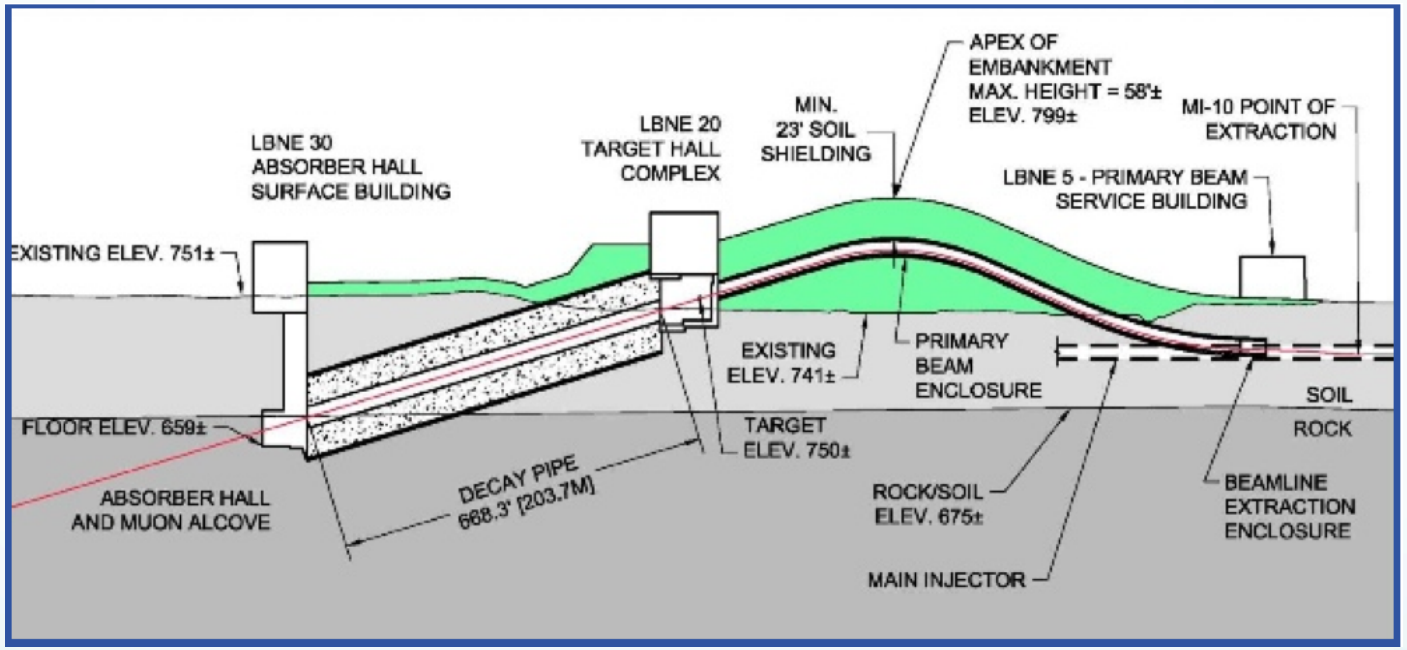
The Experimental Technique : optimize the spectrum to the oscillation probability





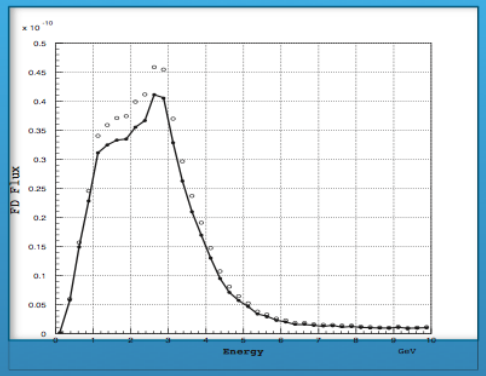


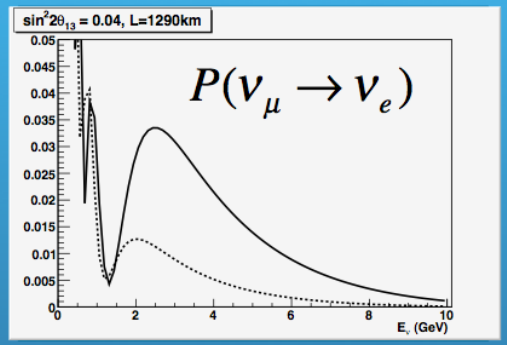
Design for a new Neutrino Beam

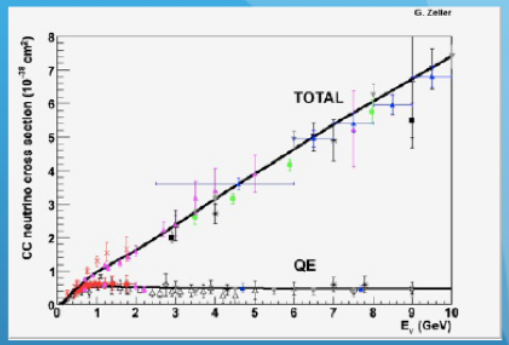


Event rates and detector sizes

$$N_{signal\ produced} = \Phi_{\nu_\mu} \times P(\nu_\mu \rightarrow \nu_e) \times \sigma_{\nu_e}$$



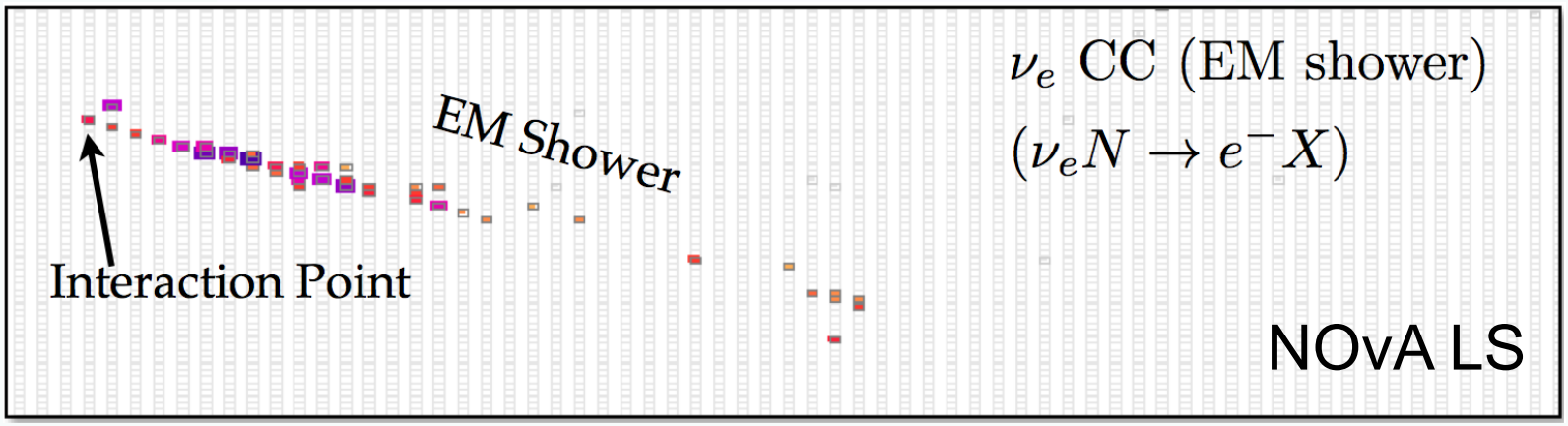


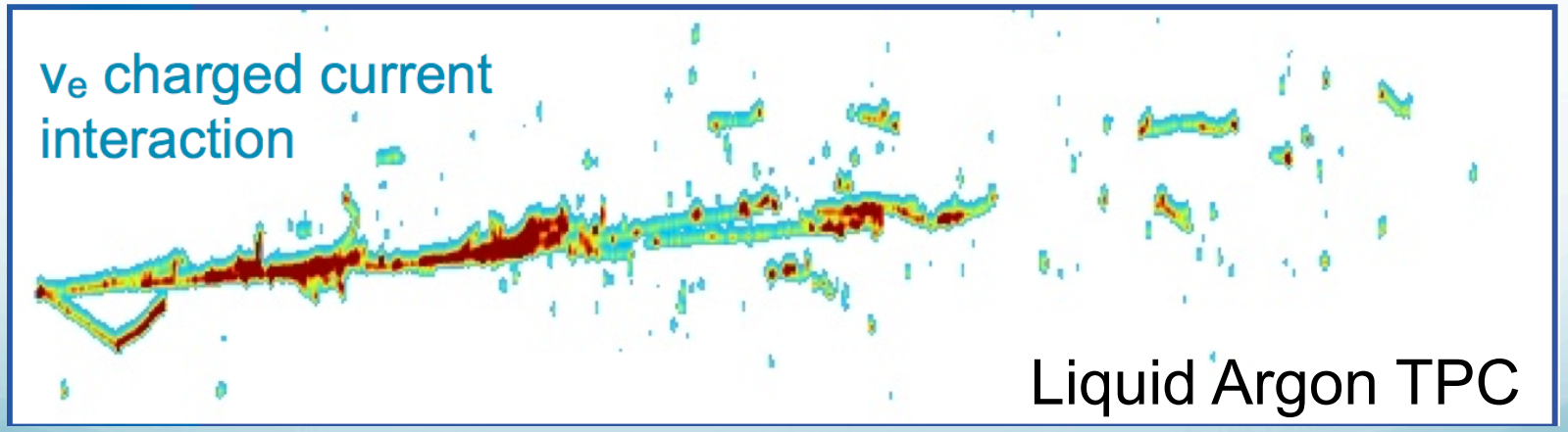


$N_{detected} = N_{produced}$ x detection efficiency

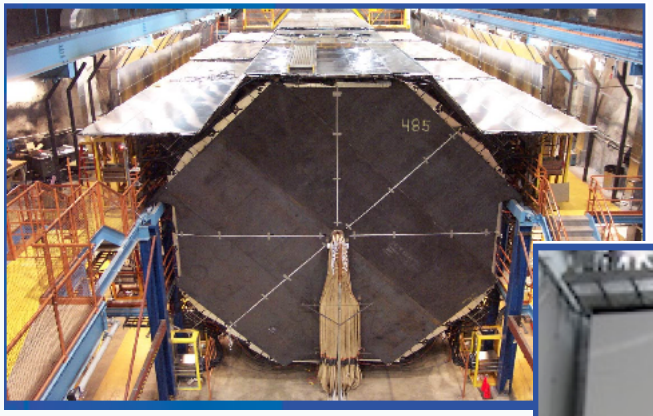
Detection efficiency is a function of the detector technology

The signal : charged current electron neutrino interactions





Progression on Neutrino Mass and Mixing



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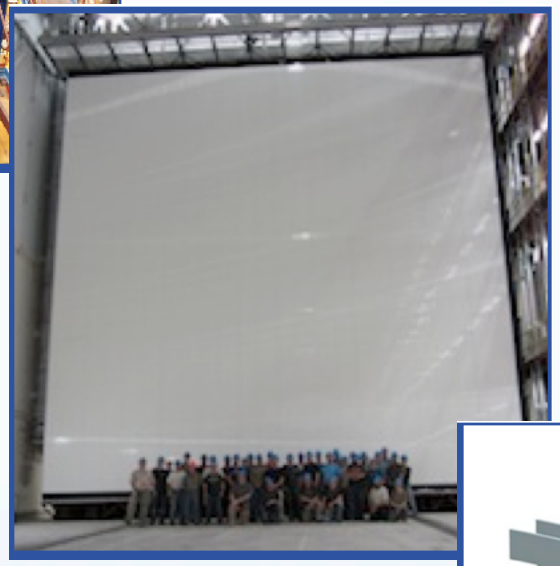

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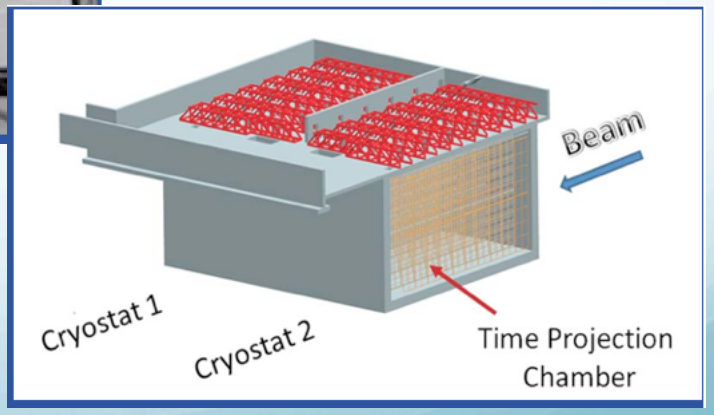
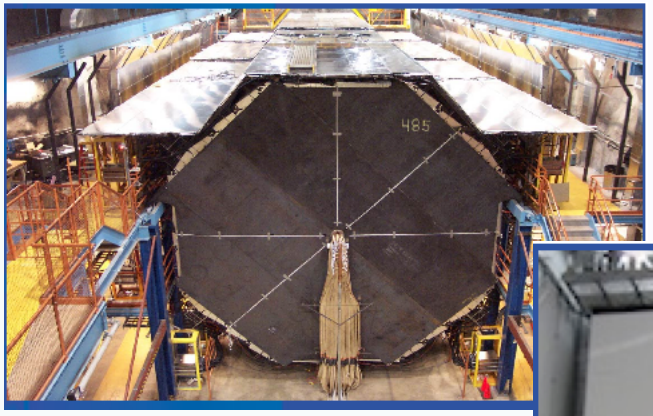


LArTPC for LBNE

Modern Era of Neutrino Experiments at Fermilab



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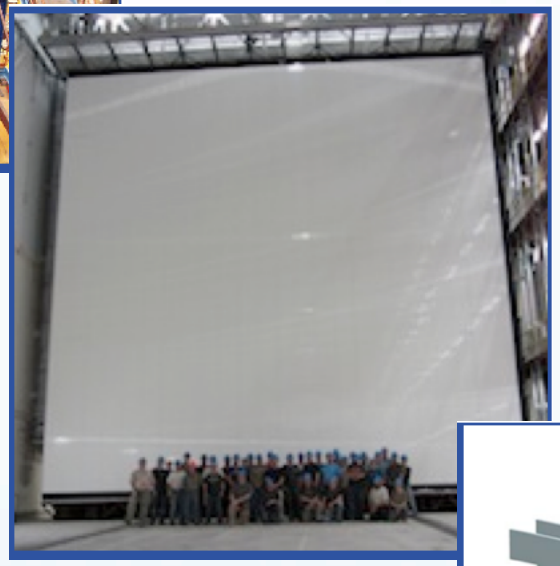

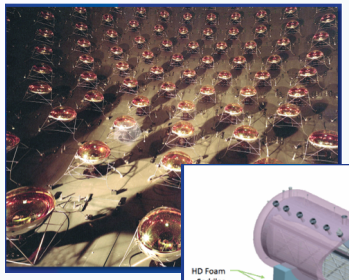

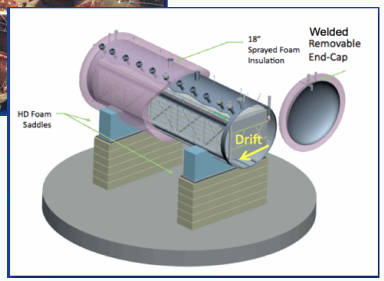

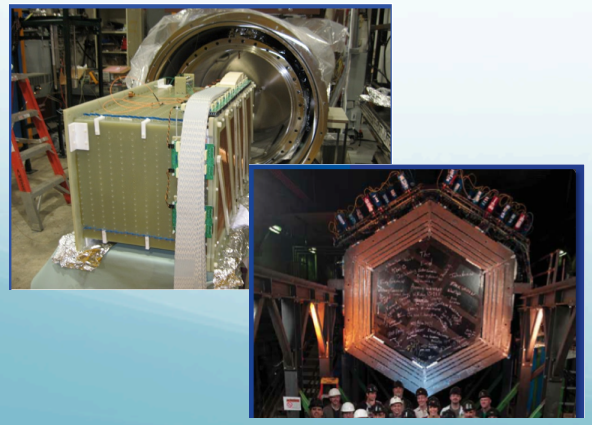

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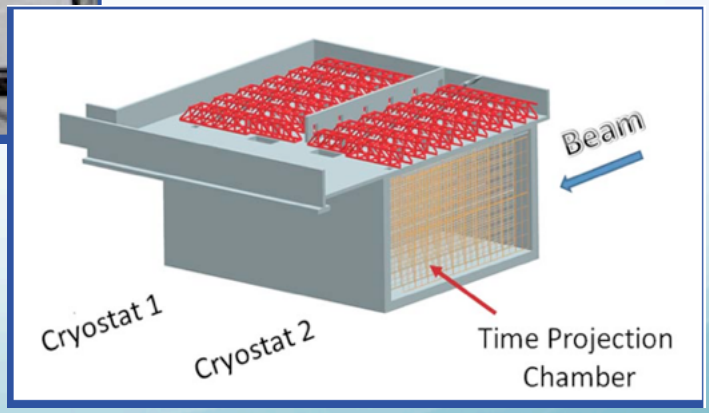
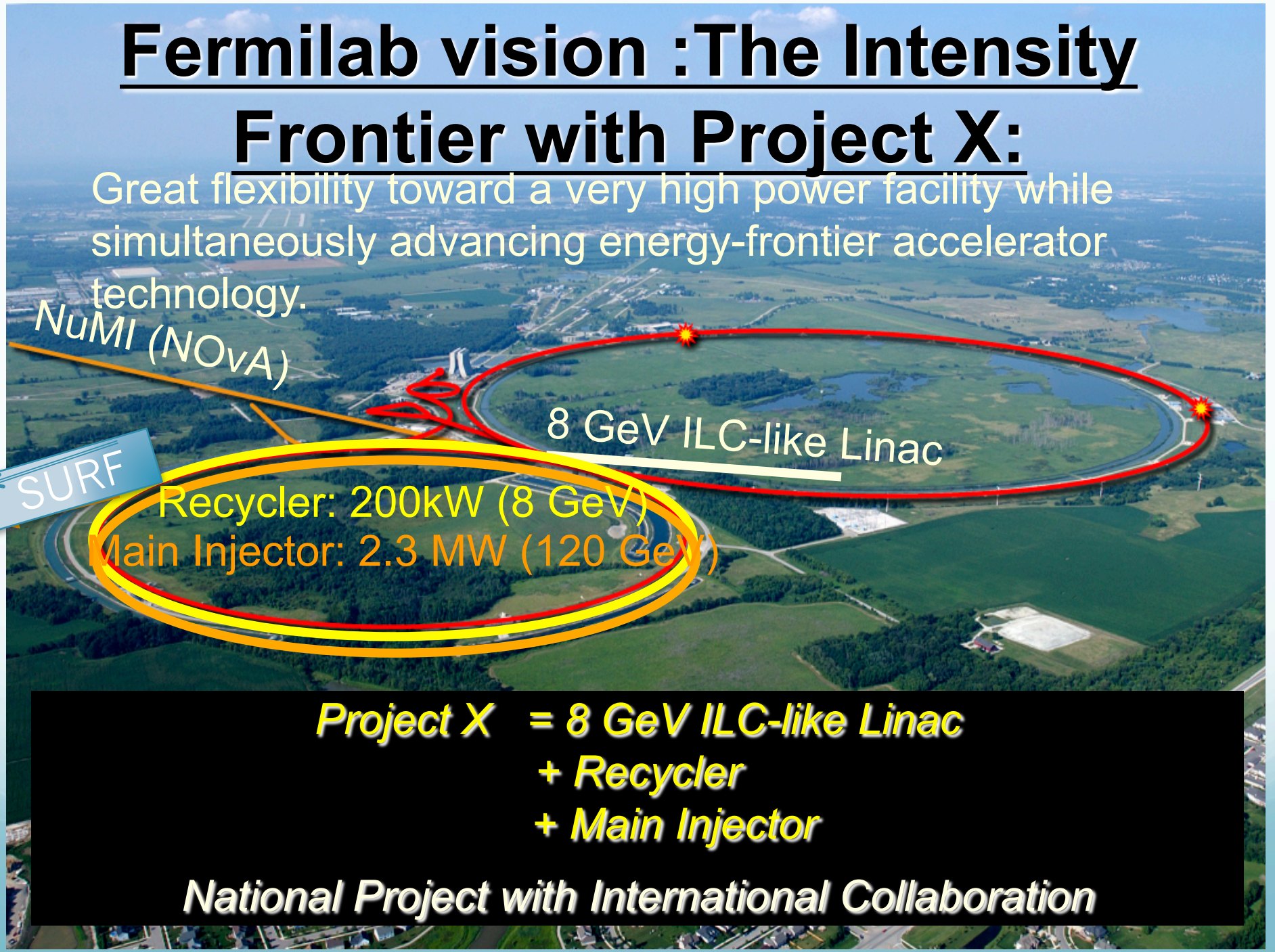


LArTPC for LBNE

Fermilab vision :The Intensity Frontier with Project X:

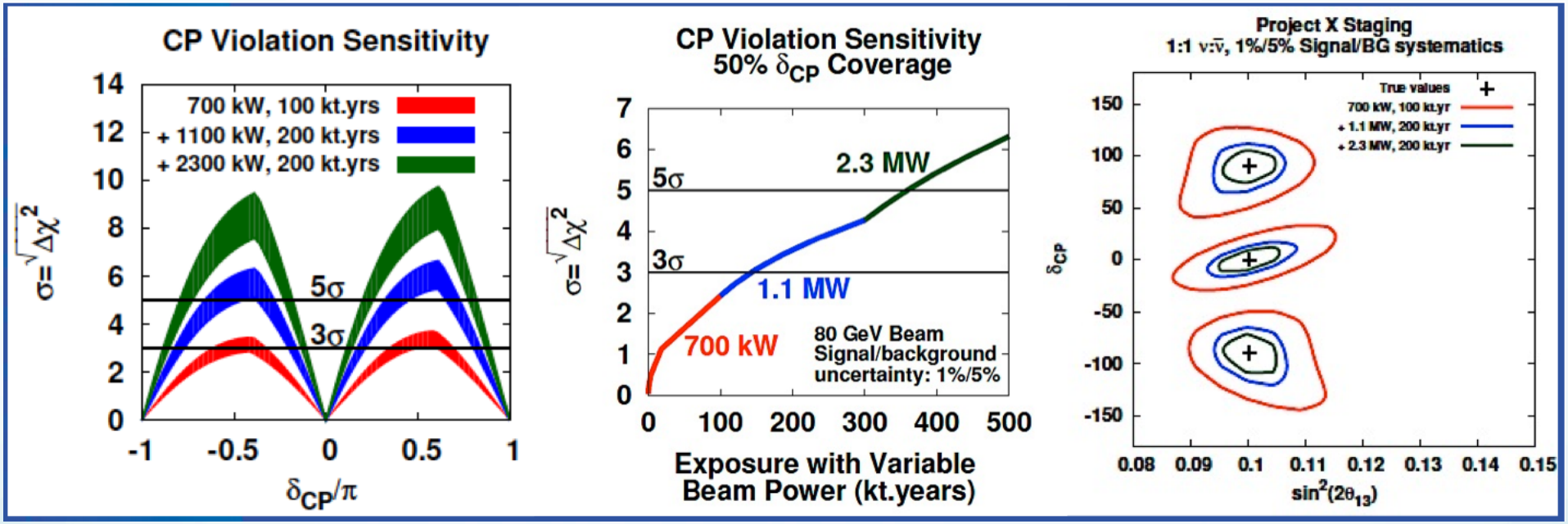
Great flexibility toward a very high power facility while simultaneously advancing energy-frontier accelerator technology.



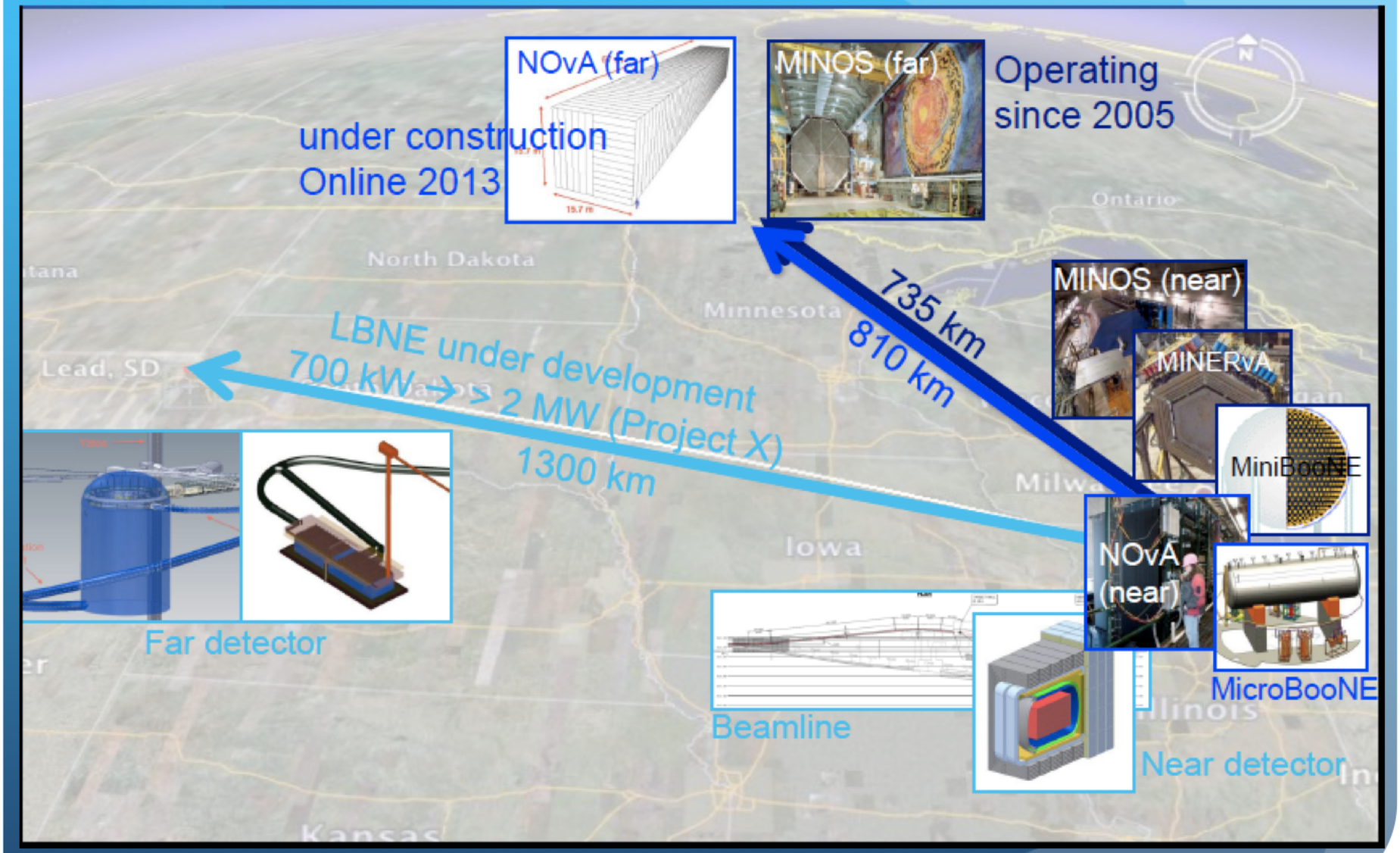
Project X = 8 GeV ILC-like Linac
+ Recycler
+ Main Injector

National Project with International Collaboration

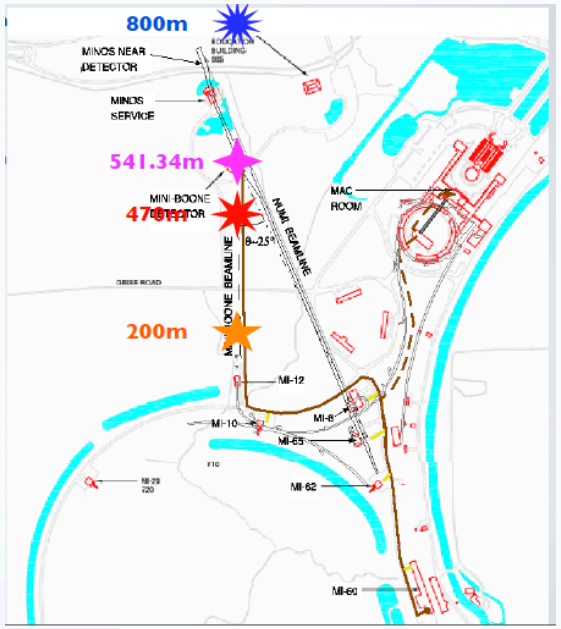
LBNE with Project X



Neutrinos from Fermilab for the next decades

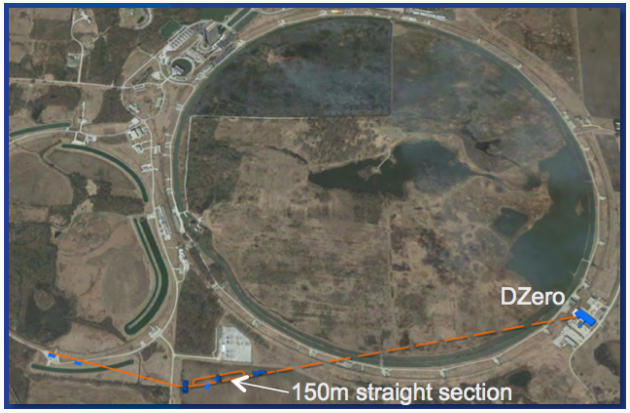


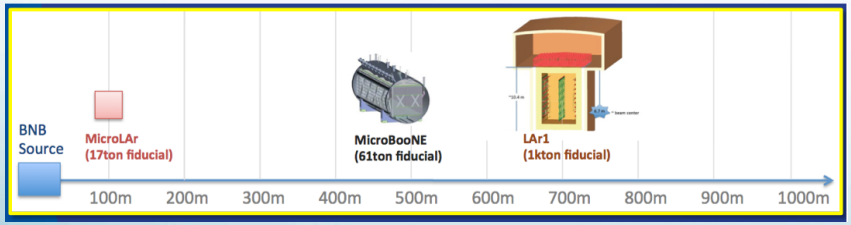
New Short Baseline Proposals

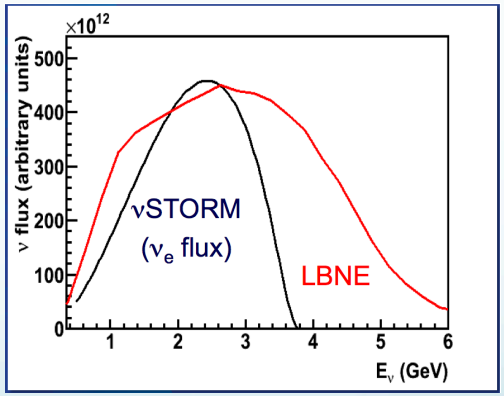


LAr1, NuStorm :

SBL anomalies
Cross sections
New Technologies







No shortage of new ideas; just a shortage of $$s !!