The U.S. Long Baseline Neutrino Experiment Study

NuFACT 07, Okayama, Japan, Aug 6-11, 2007

Mary Bishai (BNL)

mbishai@bnl.gov

BROOKHAVEN NATIONAL LABORATORY

Outline

- Introduction to The US Long Baseline Neutrino Experiment Study
- Beam and baseline options
- Detector designs and simulations
- Sensitivity estimates
- Construction costs/timelines
- Conclusions of the study

U.S. Long Baseline ν Study

When: Initiated in a series of meetings late 2005/early 2006.

The Chairs: Sally Dawson (BNL) and Hugh Montgomery (FNAL).

Advisory Committee: Franco Cervelli (INFN) Milind Diwan (BNL); co-leader, Maury Goodman (ANL), Bonnie Fleming (Yale), Karsten Heeger (LBL), Takaaki Kajita (Tokyo), Josh Klein (Texas), Steve Parke (FNAL), Gina Rameika (FNAL); co-leader

The Charge: Compare the neutrino oscillation physics potential of:

1) A broad-band proposal using either an upgraded beam of around 1 MW from the current Fermilab accelerator complex or a future Fermilab Proton Driver (PD) neutrino beam aimed at a DUSEL-based detector (Water Cerenkov and/or liquid Argon TPC).

2) Off-Axis next generation options using a 1-2 MW neutrino beam from Fermilab and a LAr-TPC as a second detector for the NOVA experiment.

Final report released May, 2007, arXiv:0705.4396 http://nwg.phy.bnl.gov/fnal-bnl

Presentations to FNAL PAC March, 2007

US DOE/NSF Committees

HEPAP: **High Energy Physics Advisory Panel advises the Federal Government on the national program in HEP. HEPAP** *reports directly to the Associate Director, Office of High Energy Physics, Office of Science (DOE) and the Assistant Director, Mathematical & Physical Sciences Directorate (NSF).*

NSAC: **Nuclear Science Advisory Committee provides official advice to the DOE and NSF on the national program for basic nuclear science research**

NuSAG: **A joint sub-committee established by HEPAP/NSAC to advise DOE on specific questions concering the U.S. neutrino physics program.**

P5: **Particle Physics Project Prioritization Panel. A HEPAP subpanel which evaluates the merits of specific proposals and** *makes recommendations concerining their priority standing within the context of available resources.*

NUSAG Charge, March 3, 2007

Address APS Study's recommendation for a next generation neutrino beam and detector configurations

U.S. Department of Energy
and the
National Science Foundation

March 3, 2006

Professor Eugene Beier
Co-Chair, NuSAG
University of Pennsylvania
209 South 33rd Street
Philadelphia, PA 19104

Professor Peter Meyers
Co-Chair, NuSAG
Princeton University
306 Jadwin Hall
Princeton, NJ 08544

Dear Professors Beier and Meyers:

We would like to thank you and the Neutrino Scientific Assessment Group (NuSAG) for your timely and thoughtful responses to the initial questions that were posed to you, concerning neutrinoless double beta decay, reactor experiments and accelerator-based experiments to determine fundamental neutrino properties. They have already been very useful and will help us put together a strong US program in neutrino physics.

We would now like your group to address the APS Study's recommendation for a next-generation neutrino beam and detector configurations. Assuming a megawatt class proton accelerator as a neutrino source, please answer the following questions for accelerator-detector configurations including those needed for a multi-phase off-axis program and a very-long-baseline broad-band program. This assessment will be used as one of the key elements to guide the direction and timeline of such a possible next generation neutrino beam facility.

In your assessment, NuSAG should look at the scientific potential of the facility, the timeliness of its scientific output, and its place in the broad international context. Specifically:

- **Scientific potential:** What are the important physics questions that can be addressed at the envisioned neutrino beam facility?
- **Associated detector options:** What are the associated detector options which might be needed to fully realize the envisioned physics potentials? What are the rough cost ranges for these detector options?
- **Optimal timeline:** What would be the optimal construction and operation timeline for each accelerator-detector configuration, taking the international context into account?
- **Other scientific considerations:** What other scientific considerations, such as results from other neutrino experiments, are important in order to [illegible] design parameters? What would be additional important physics questions that can be addressed in the same detector(s)?

The DOE and the NSF would like a preliminary draft of your report by December 2006, with a final report by February 2007.

NuSAG final report to HEPAP/NSAC

released July 27th, 2007 at

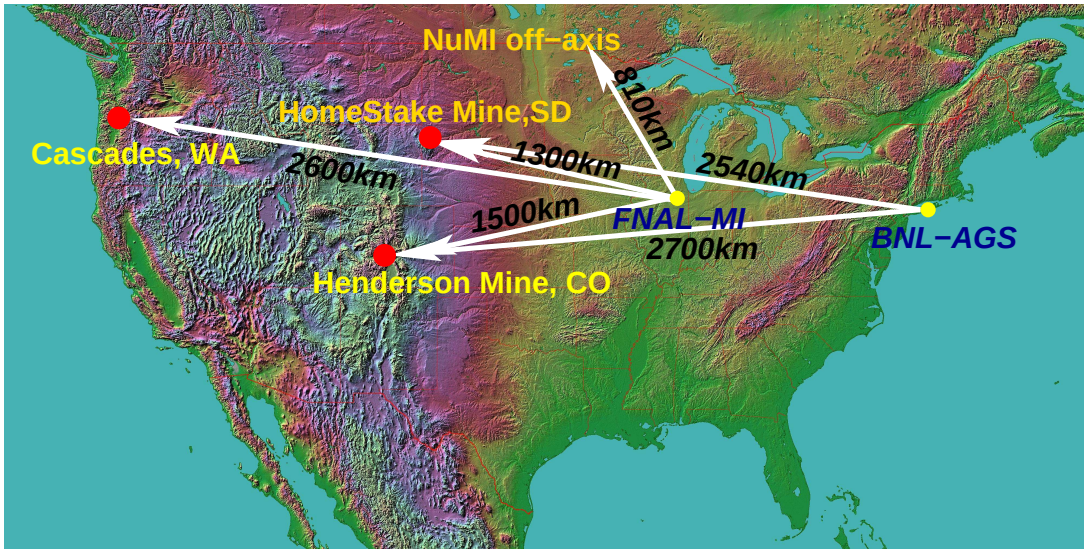
http://www.science.doe.gov/hep/hepap_report.shtm

- **What are the physics questions to be addressed?**
- **What are the detector options needed to realize the physics? Rough Costs?**
- **What is the optimal construction and operation timeline?**
- **What would be additional impt. physics questions that can be addressed by the same detector?**

US LBν Study results heavily utilized by NuSAG to address APS

Beam Options/Baselines

The following beam options and baselines were considered:



Off axis beams using the 120 GeV NuMI beamline at FNAL to sites at 810km.

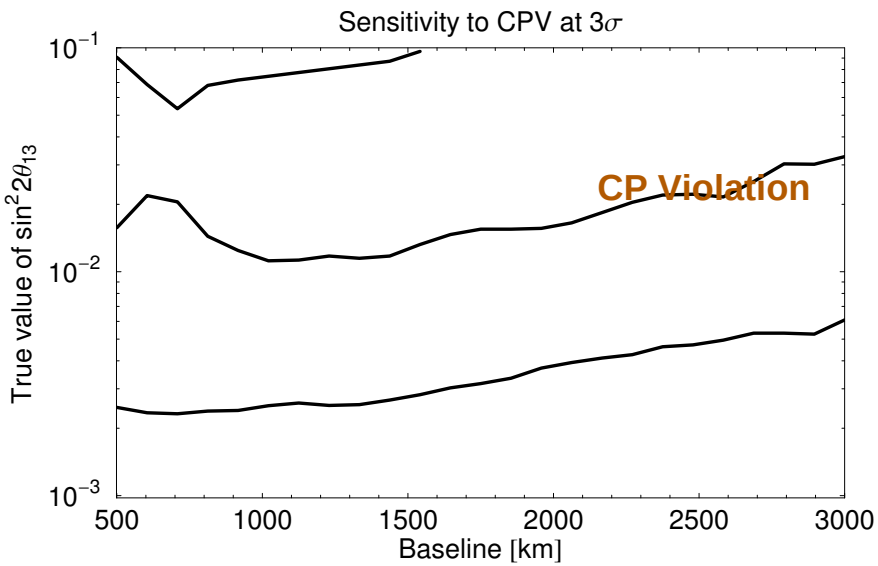
A 28 GeV on-axis Wide-Band Beam (WBB) beam from the BNL AGS to DUSEL candidate sites at 2540 and 2700 km.

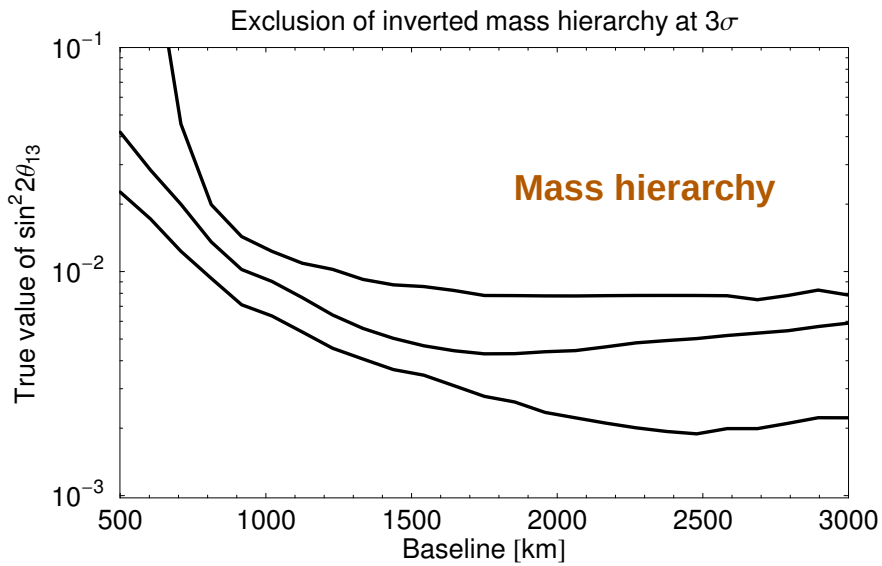
A newly designed on-axis ≤ 120 GeV Wide Band Low Energy (WBLE) beam and beamline from the FNAL MI to DUSEL sites at 1300km, 1500 and 2600km.

The study concentrated primarily on beam options from FNAL

Physics sensitivity vs baseline

Using a broad-band beam with a peak interaction rate at 2 GeV, FWHM=3 GeV, a parameterized water Cerenkov detector and exposure of 5MW.yr (ν) + 10 MW.yr ($\bar{\nu}$) (V. Barger *et al.*. Phys. Rev. D 74, 073004 2006):





Minimum value of $\sin^2(2\theta_{13})$ for which the sensitivity is $> 3\sigma$ for (best,50%, worst) of δ_{cp} values

Best sensitivity is for baselines 1200 - 2500km

DUSEL Status

NSF Press Release 07-075, July 10, 2007: *"The National Science Foundation (NSF) today announced selection of a University of California-Berkeley proposal to produce a technical design for a Deep Underground Science and Engineering Laboratory (DUSEL) at the former Homestake gold mine near Lead, S.D."*

The NSF Science Board, Congress and the President must approve the DUSEL project, estimated at $\approx$ $500M, half of which would be used to develop scientific instrumentation for the laboratory.

FNAL-Homestake is 1297km, BNL-Homestake is 2540km

Beam Design Requirements

The design specifications of conventional neutrino beams based at the Fermilab MI are driven by the physics of $\nu_\mu \rightarrow \nu_e$ oscillations:

Requirements:

-Maximal possible neutrino fluxes to encompass the 1st and 2nd oscillation nodes. For narrow-band beams $\Rightarrow$ 2 detectors at each maxima.

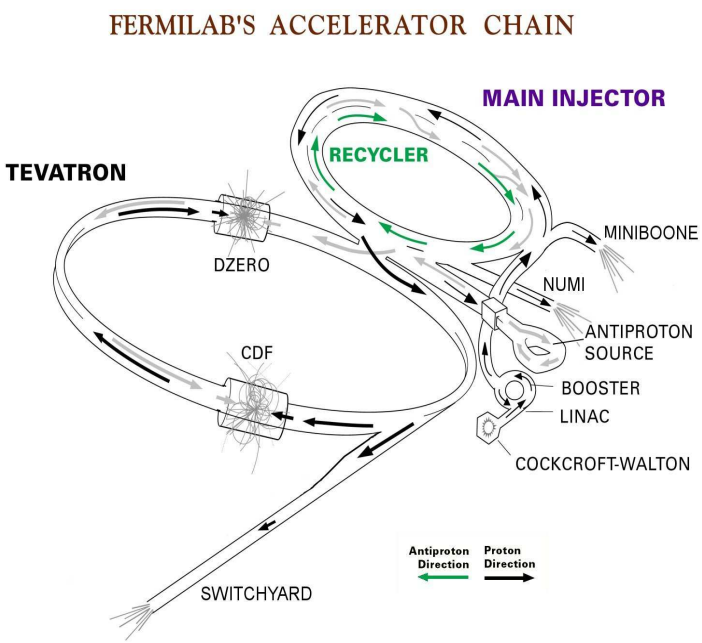
-For broad-band beams: Minimize the neutral-current feed-down contamination at lower energy, therefore minimizing the flux of neutrinos with energies greater than 1st maxima where there is no sensitivity to the oscillation parameters is highly desirable.

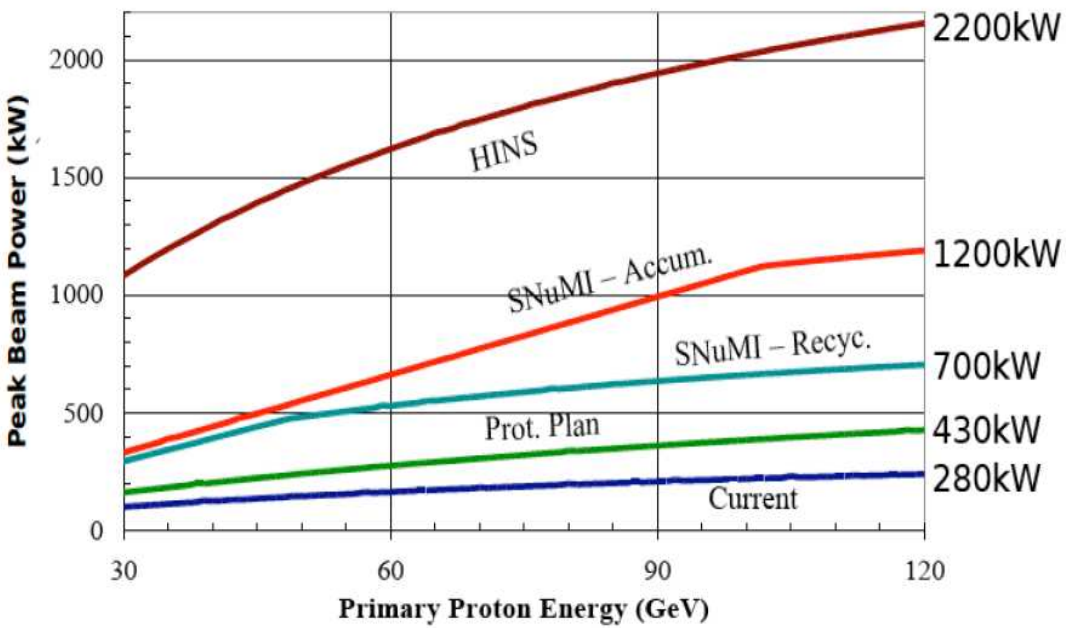
-High purity ν_μ beam with negligible ν_e

FNAL Beam Specs: E & Power

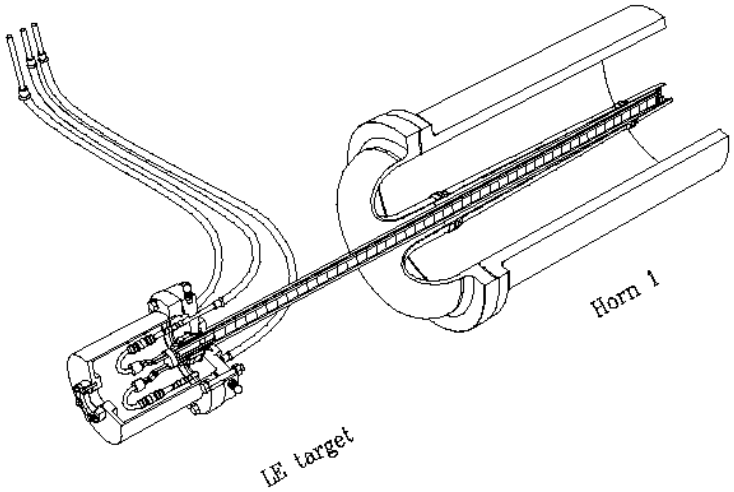
SNuMI (Bob Zwaska's talk next): **Use the *existing* recycler and anti-proton accumulator to store protons from the 8 GeV 15 Hz Booster during the MI cycle then inject to MI $\longrightarrow$ increases MI intensity up to 6×10^{13} protons $\Rightarrow$ 1.2 MW at 120 GeV.**

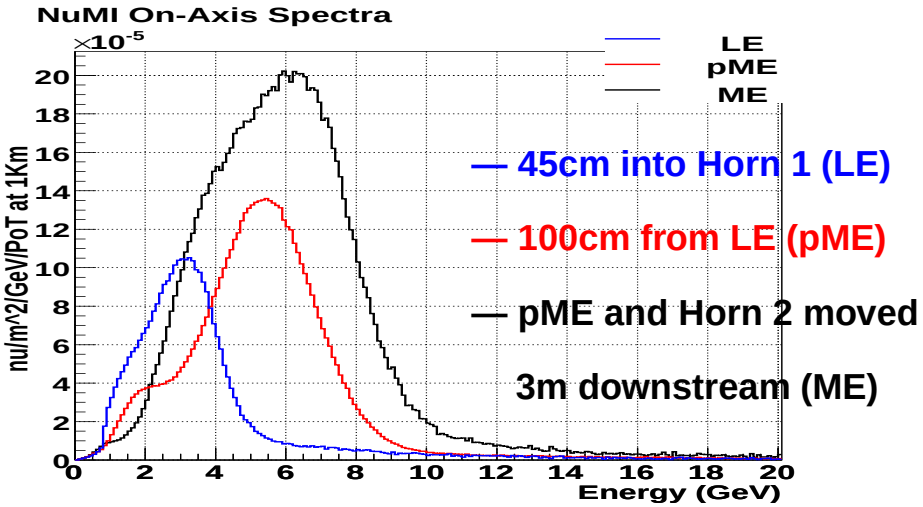
Proton driver (HINS): **S.C. Linac replaces 8 GeV Booster, MI upgrades $\Rightarrow$ 2.2MW at 120GeV**



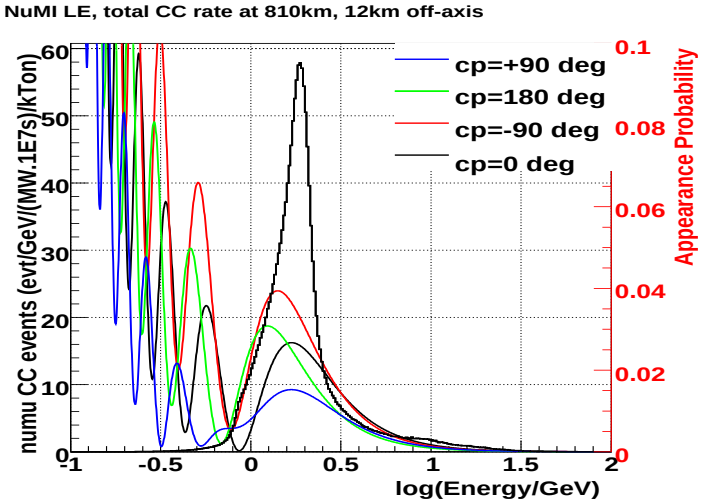


NuMI Beamline Spectra



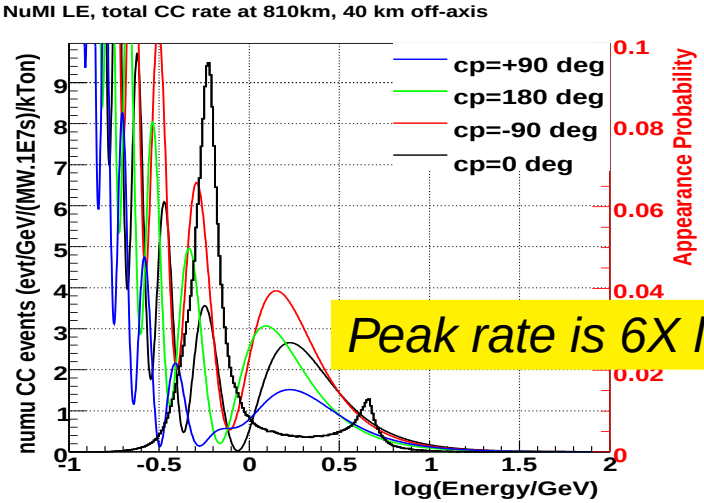


LE/ME 0.8° off-axis at 810 km



$\log_{10}(E_\nu)$

LE 3° off-axis at 810km

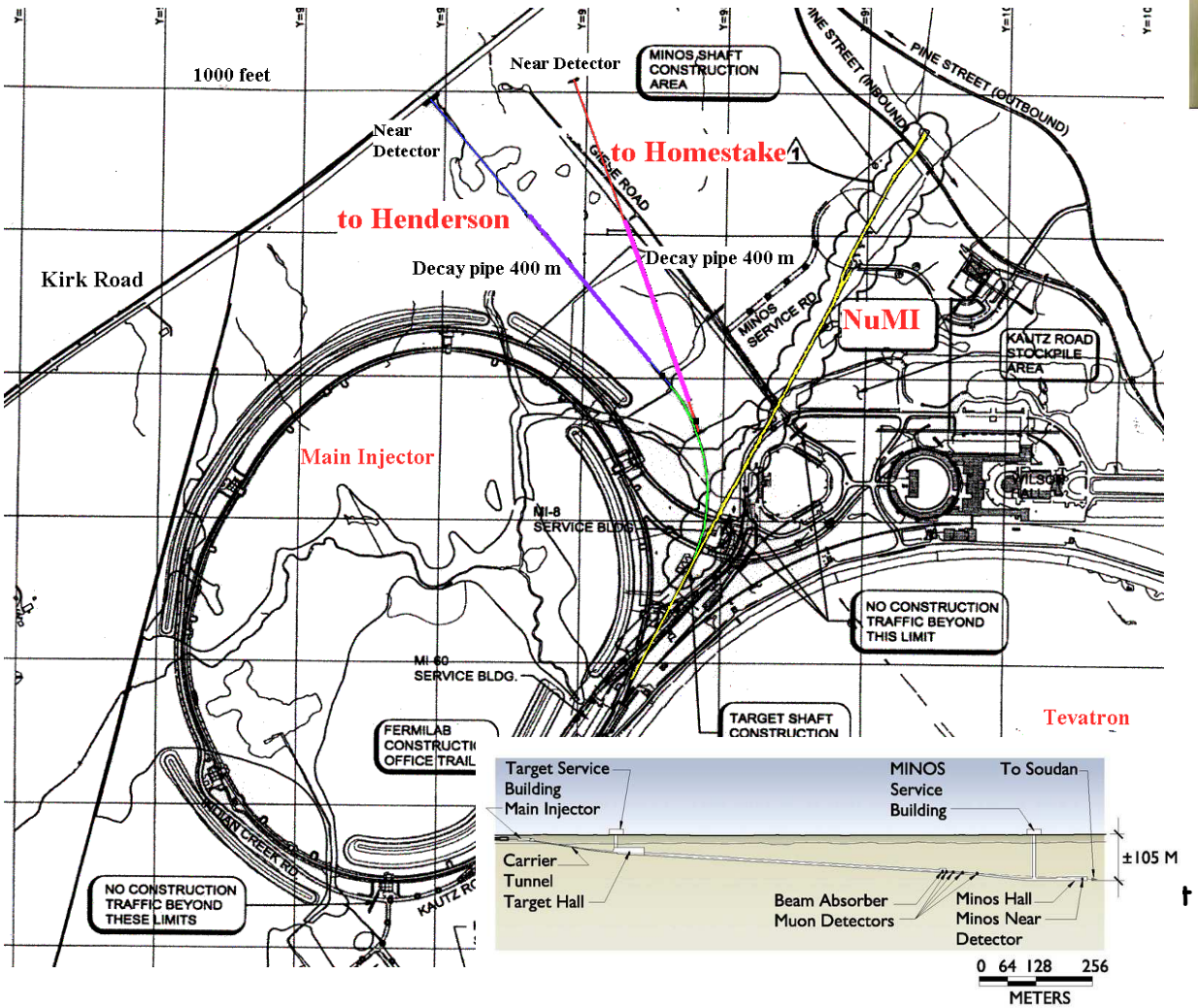


Peak rate is 6X lower.

$\log_{10}(E_\nu)$

DUSEL Beamline Siting at FNAL

Greg Bock, Dixon Bogert, Wes Smart (FNAL)



NuMI in MI

Angle down by 8.9°

Carrier tunnel

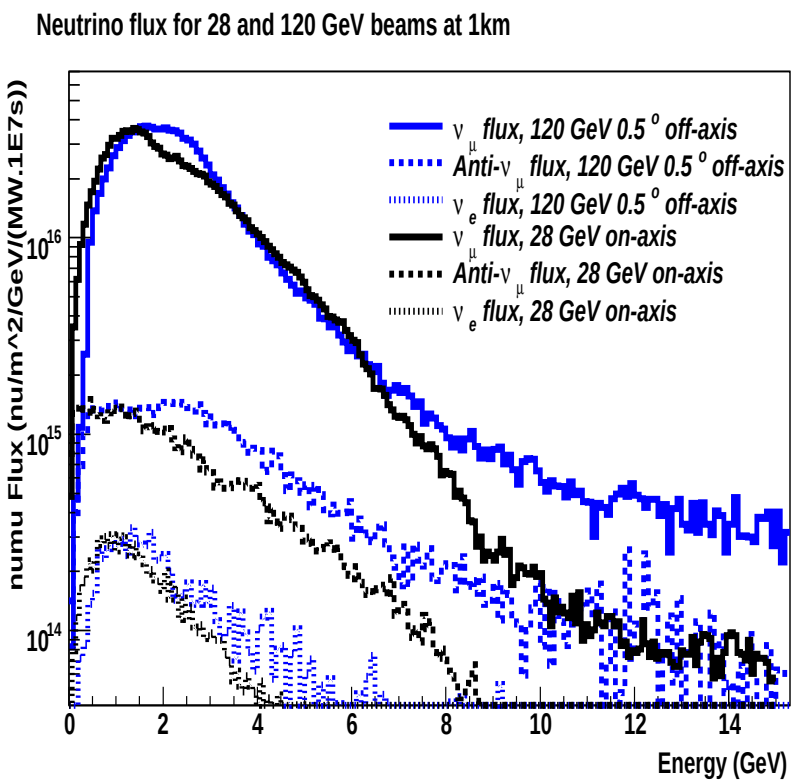
Beamlines to DUSEL can accomodate a decay tunnel with $L \leq 400$m on-site

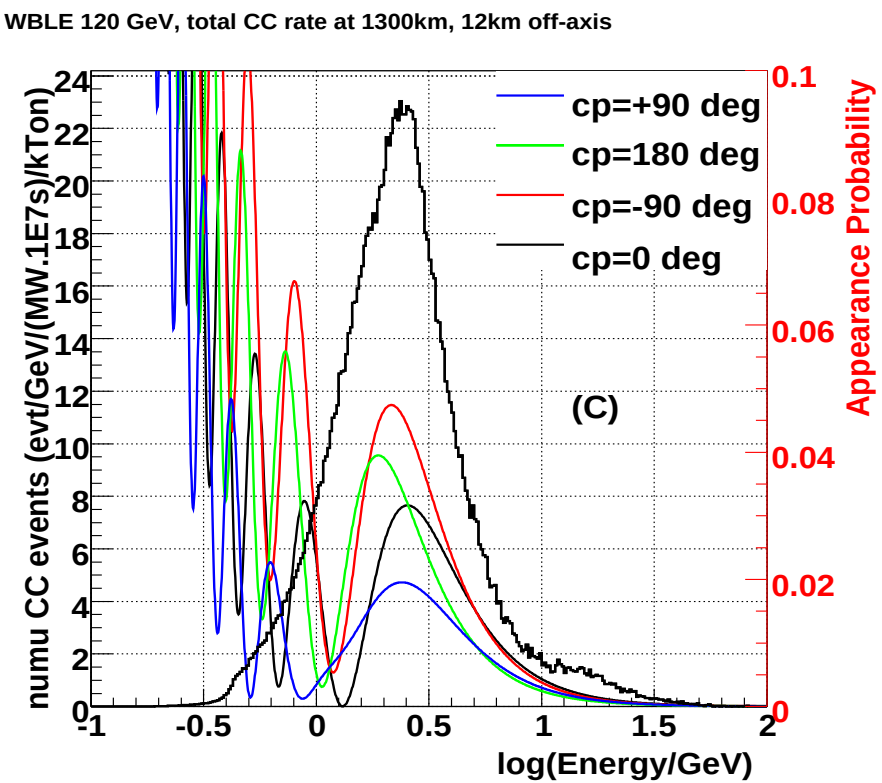
Wide-Band Low-Energy Spectra

Decay pipe radius chosen to be 2m = the maximum that can be accomodated in FNAL rock with concrete shielding for a MW class beam.

Siting restrictions at FNAL ⇒ decay pipe length is 380m

A wide-band 2-horn design is used coupled with a dense carbon target:





GEANT 3.21 simulation of wide-band horns+decay pipe, with FLUKA '05 for target hadro-production.

Based on NuMI simulation which matches observed MINOS event rate to 10% in 0 - 7 GeV range

$\nu_\mu \longrightarrow \nu_e$ Appearance Rates

Exposure: 100 kT $\times$ 1MW $\times$ 1 yr (1.7×10^7 seconds).

$\sin^2(2\theta_{13}) = 0.02, |\Delta m^2_{31}| = 2.5 \times 10^{-3}\mathrm{eV}^2$

Rate = $\sigma_{\mathrm{CC}} \times$ Flux $\times P_{\mu e}$, NO DETECTOR EFFECTS INCLUDED!

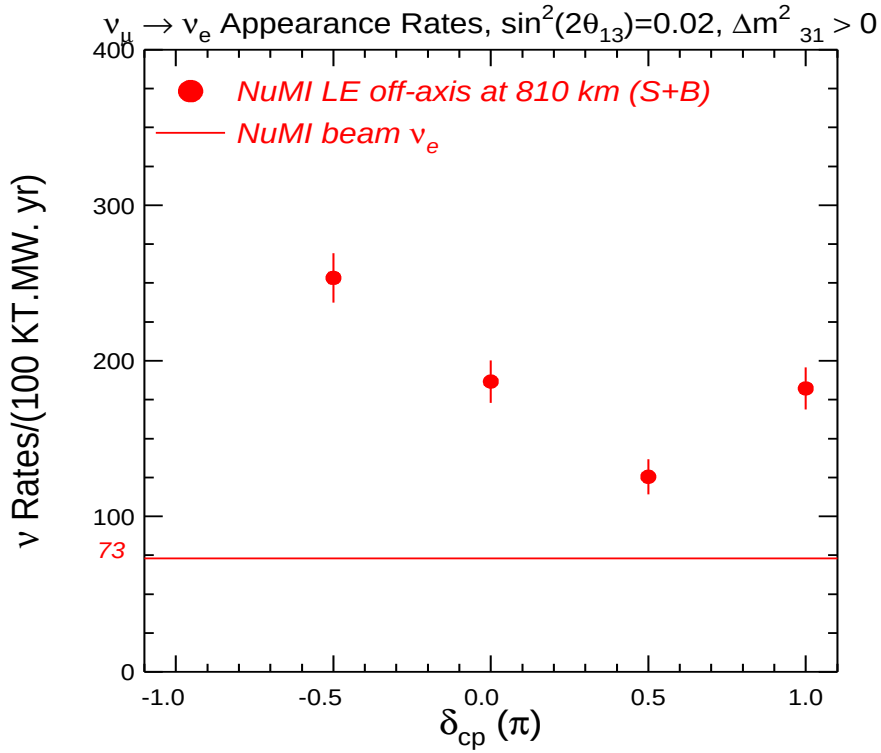
$\nu_\mu \longrightarrow \nu_e$ Appearance Rates

Exposure: 100 kT $\times$ 1MW $\times$ 1 yr (1.7×10^7 seconds).

$$\sin^2(2\theta_{13}) = 0.02, |\Delta m^2_{31}| = 2.5 \times 10^{-3}\mathrm{eV}^2$$

Rate = $\sigma_{\mathrm{CC}} \times$ Flux $\times P_{\mu e}$, NO DETECTOR EFFECTS INCLUDED!

Normal Hierarchy



Even at 810km $\Rightarrow$ we need a LARGE detector

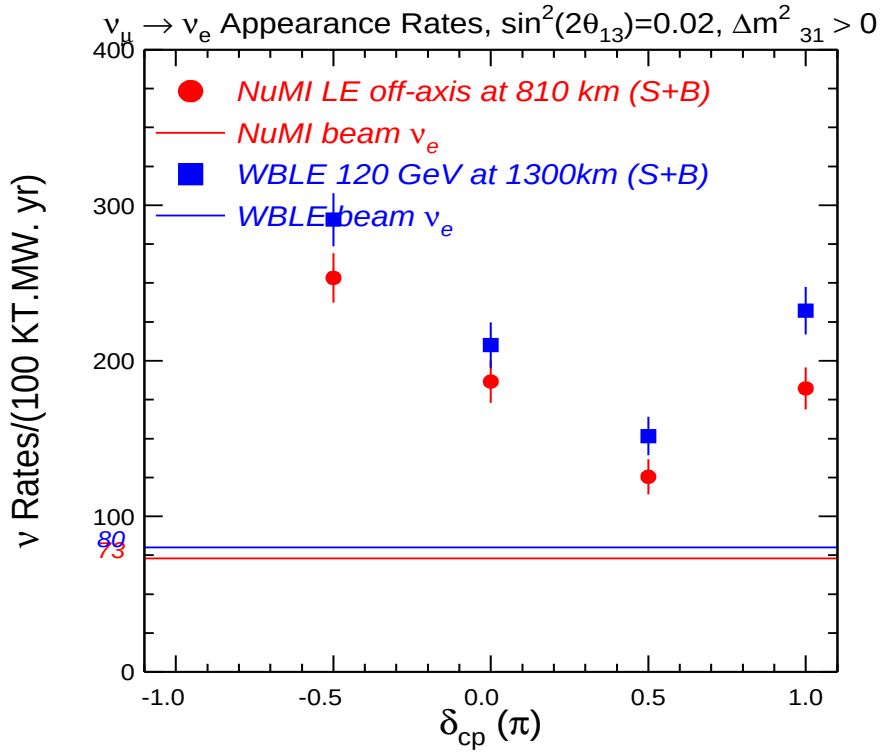
$\nu_\mu \longrightarrow \nu_e$ Appearance Rates

Exposure: 100 kT $\times$ 1MW $\times$ 1 yr (1.7×10^7 seconds).

$$\sin^2(2\theta_{13}) = 0.02, |\Delta m^2_{31}| = 2.5 \times 10^{-3}\mathrm{eV}^2$$

Rate = $\sigma_{\mathrm{CC}} \times$ Flux $\times P_{\mu e}$, NO DETECTOR EFFECTS INCLUDED!

Normal Hierarchy



NuMI 0.8° o.a. rates at 810km $\sim$ WBLE 120GeV 0.5° o.a. at 1300km

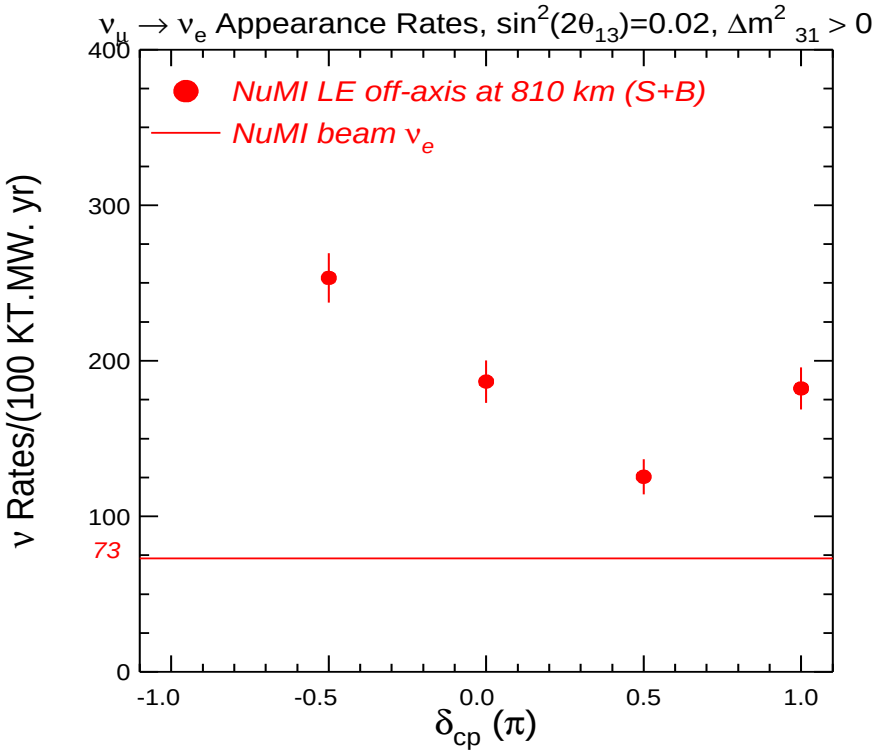
$\nu_\mu \longrightarrow \nu_e$ Appearance Rates

Exposure: 100 kT $\times$ 1MW $\times$ 1 yr (1.7×10^7 seconds).

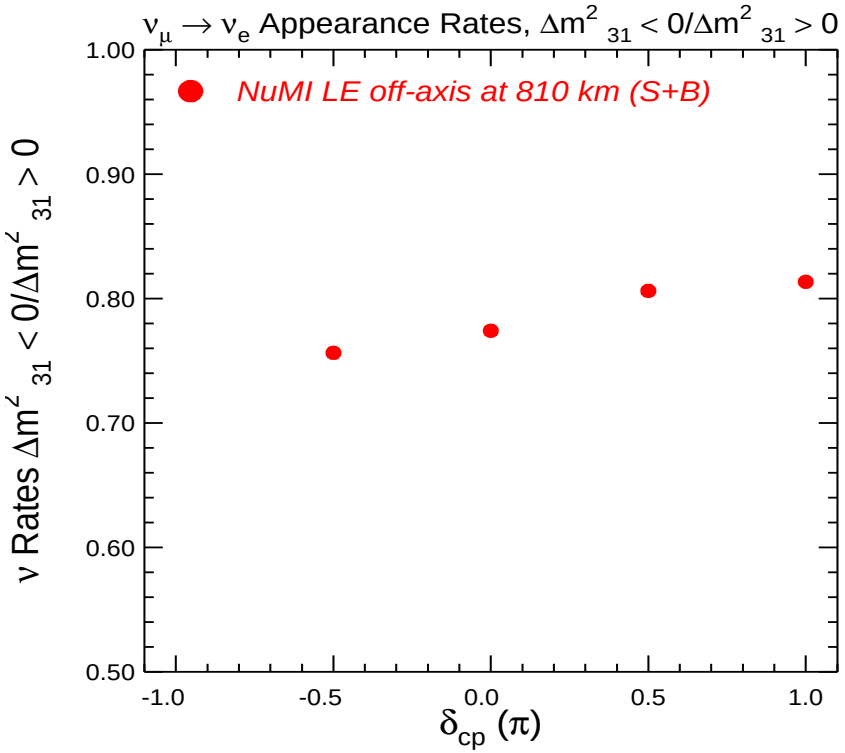
$$\sin^2(2\theta_{13}) = 0.02, |\Delta m^2_{31}| = 2.5 \times 10^{-3}\mathrm{eV}^2$$

Rate = $\sigma_{\mathrm{CC}} \times$ Flux $\times P_{\mu e}$, NO DETECTOR EFFECTS INCLUDED!

Normal Hierarchy



Reverse/Normal



Reverse hierarchy $\Rightarrow$ lower ν rates

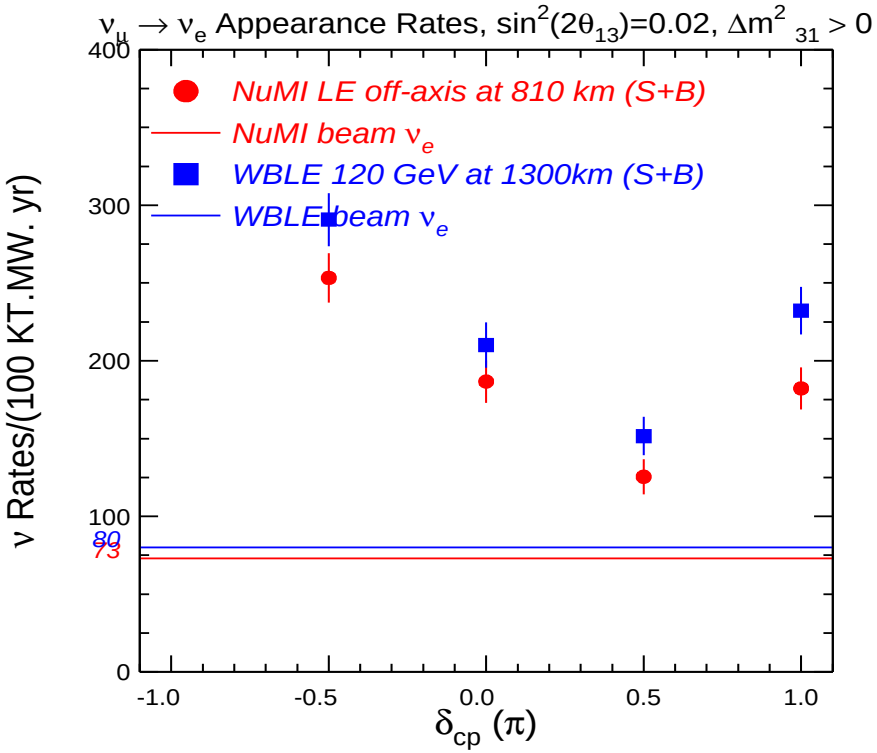
$\nu_\mu \longrightarrow \nu_e$ Appearance Rates

Exposure: 100 kT $\times$ 1MW $\times$ 1 yr (1.7×10^7 seconds).

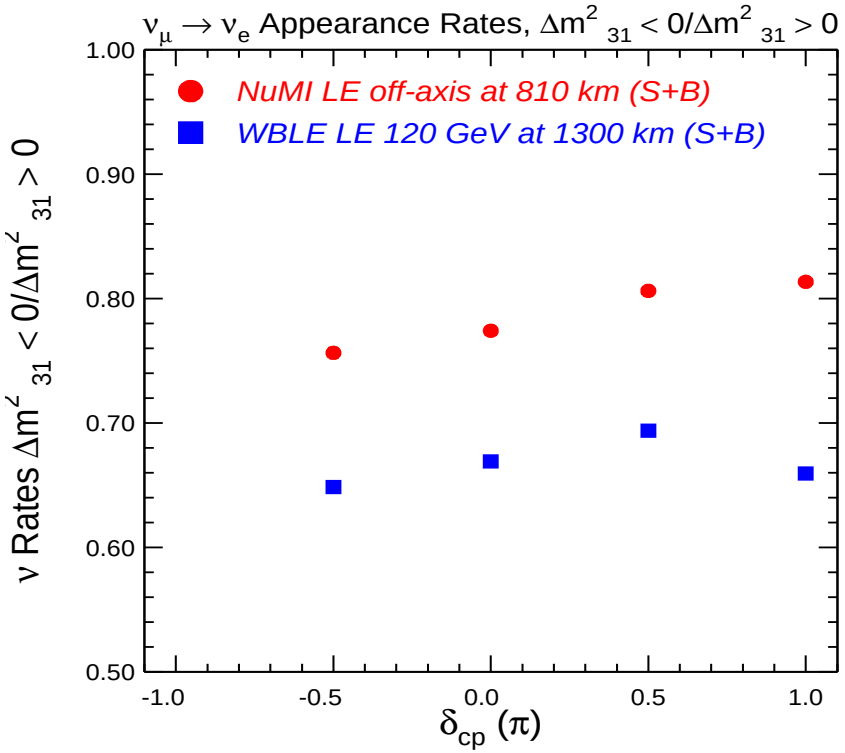
$$\sin^2(2\theta_{13}) = 0.02, |\Delta m^2_{31}| = 2.5 \times 10^{-3}\mathrm{eV}^2$$

Rate = $\sigma_{\mathrm{CC}} \times$ Flux $\times P_{\mu e}$, NO DETECTOR EFFECTS INCLUDED!

Normal Hierarchy



Reverse/Normal



Matter effects are larger at 1300km

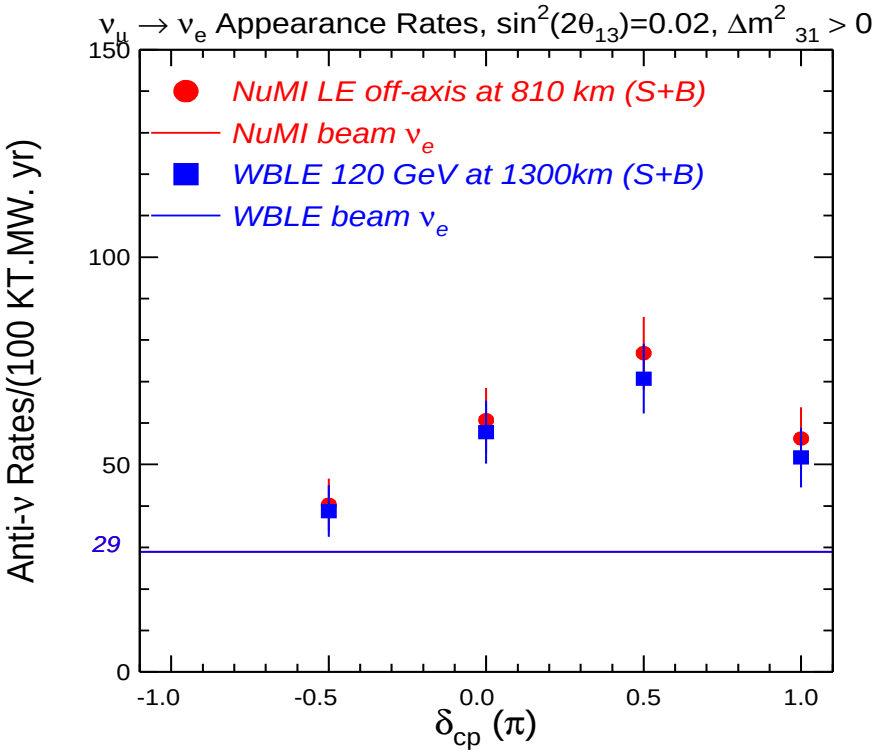
$\bar{\nu}_\mu \longrightarrow \bar{\nu}_e$ Appearance Rates

Exposure: 100 kT $\times$ 1MW $\times$ 1 yr (1.7×10^7 seconds).

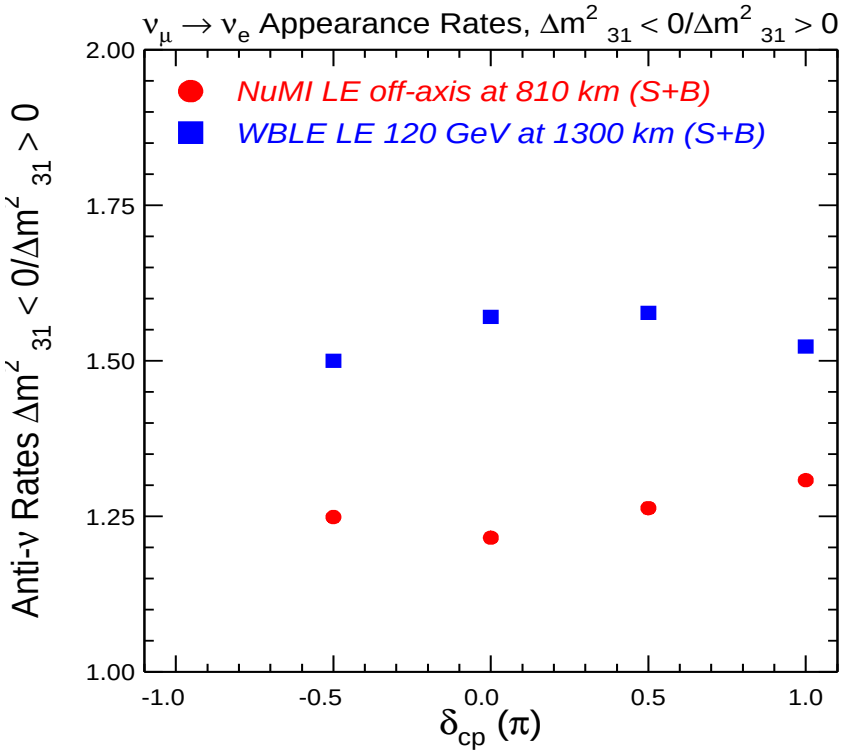
$$\sin^2(2\theta_{13}) = 0.02, |\Delta m^2_{31}| = 2.5 \times 10^{-3}\mathrm{eV}^2$$

Rate = $\sigma_{\mathrm{CC}} \times$ Flux $\times P_{\mu e}$, NO DETECTOR EFFECTS INCLUDED!

Normal Hierarchy



Reverse/Normal



Anti-ν $\Rightarrow$ lower rates, reverse matter effects

Rate Summary

$\Delta m^2_{21,31} = 8.6 \times 10^{-5}, 2.5 \times 10^{-3}$ eV^2, $\sin^2 2\theta_{12,23} = 0.86, 1.0$

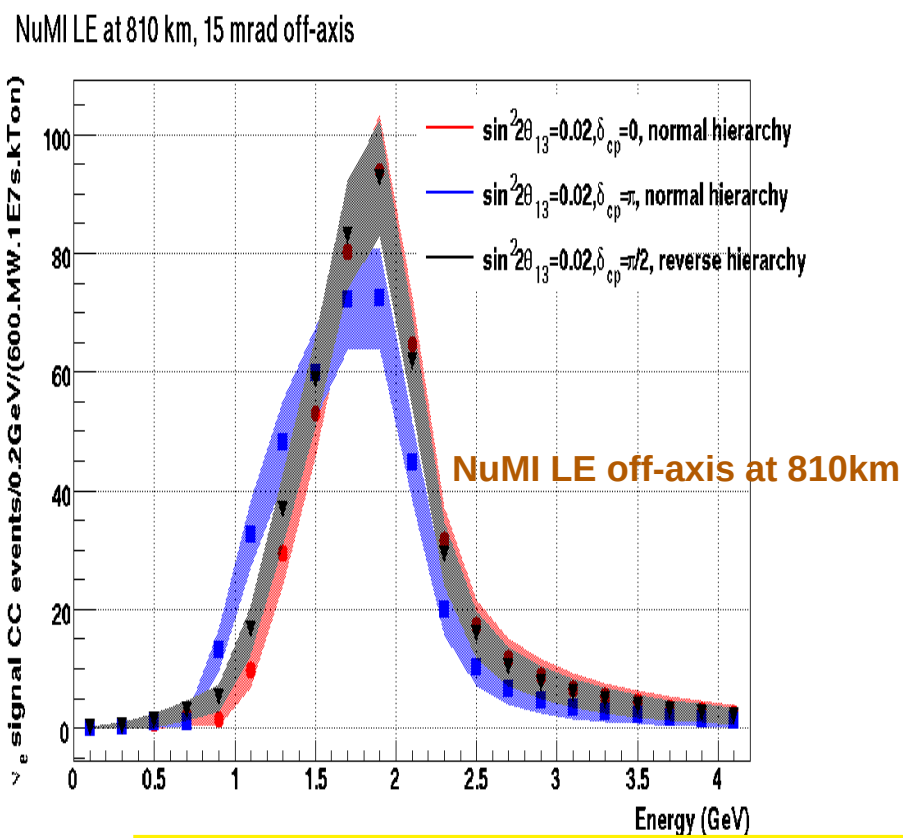
		$\nu_\mu \longrightarrow \nu_e$ rate				$\bar{\nu}_\mu \longrightarrow \bar{\nu}_e$ rates			
(sign of Δm^2_{31})	$\sin^2 2\theta_{13}$	δ_{CP} deg.							
		0°	-90°	180°	+90°	0°	-90°	180°	+90°
NuMI LE beam tune at 810km, per 100kT. MW. 10^7s									
15 mRad off-axis		Beam ν_e = 43*				Beam $\bar{\nu}_e$ = 17*			
(+)	0.02	76	108	69	36	20	7.7	17	30
(-)	0.02	46	77	52	21	28	14	28	42
50 mRad off-axis		Beam ν_e = 11*				Beam $\bar{\nu}_e$ = 3.4*			
(+)	0.02	5.7	8.8	5.1	2.2	2.5	1.6	0.7	3.3
(-)	0.02	4.2	8.0	5.7	2.0	2.3	2.2	0.8	3.6
WBLE 120 GeV beam at 1300km, per 100kT. MW. 10^7s									
9 mRad off-axis		Beam ν_e = 47**				Beam $\bar{\nu}_e$ = 17**			
(+/-)	0.0	14	N/A	N/A	N/A	5.0	N/A	N/A	N/A
(+)	0.02	87	134	95	48	20	7.2	15	27
(-)	0.02	39	72	51	19	38	19	33	52

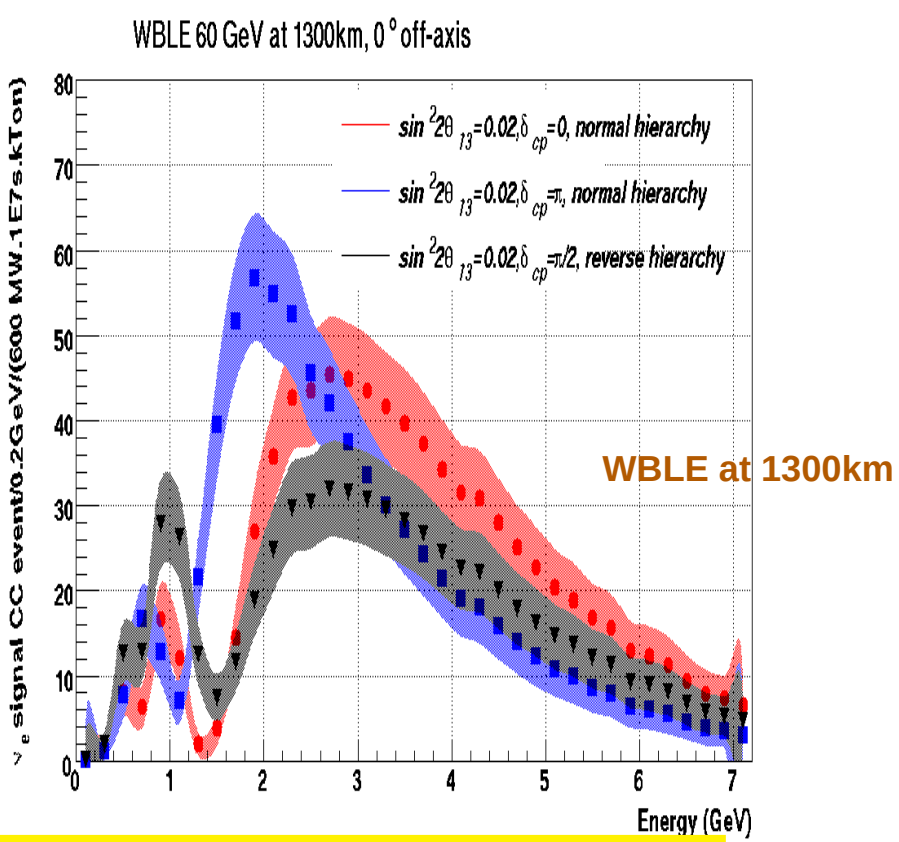
* = 0-3 GeV ** = 0-5 GeV, 1 MW. 10^7s = 5.2×10^{20} POT at 120 GeV, 1yr $= 1.7 \times 10^7 s$

ν_e Appearance Spectra

Assuming an exposure of 350 kT.MW.yr, with no detector effects:

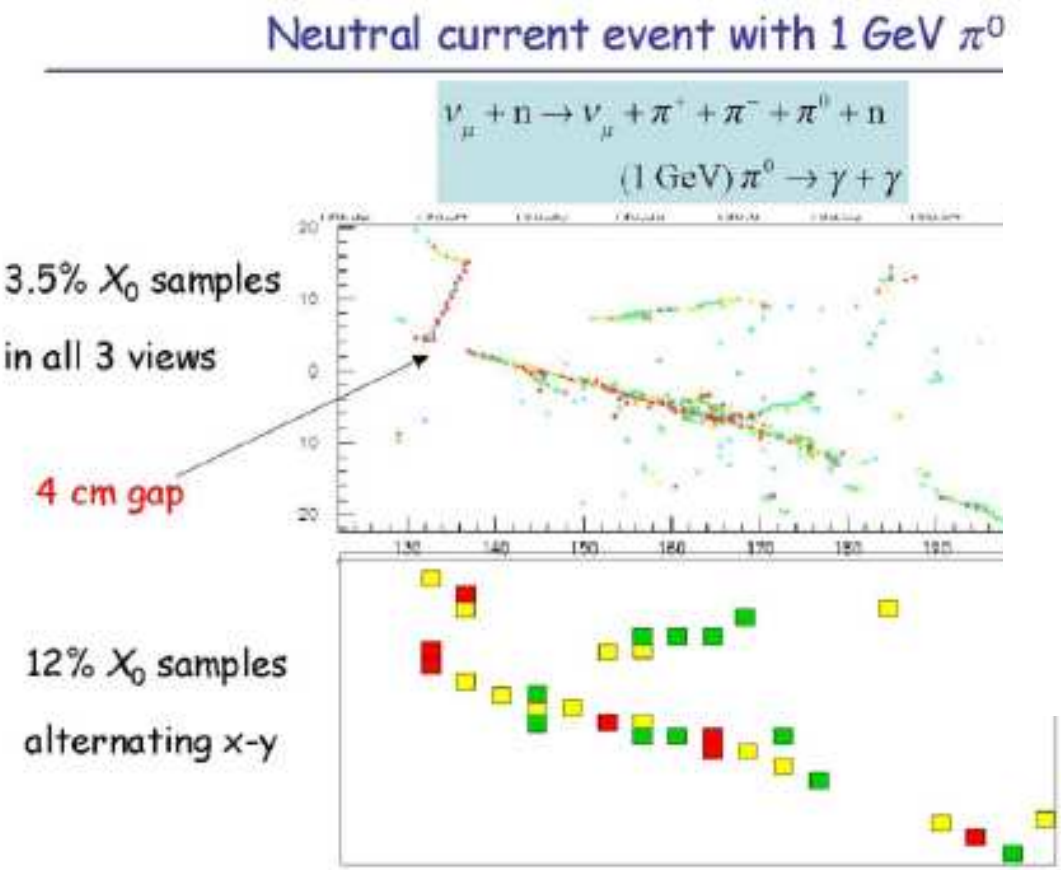
- $\sin^2 2\theta_{13} = 0.02, \delta_{cp} = 0$, normal hierarchy
- $\sin^2 2\theta_{13} = 0.02, \delta_{cp} = \pi$, normal hierarchy
- $\sin^2 2\theta_{13} = 0.02, \delta_{cp} = -\pi/2$, reverse hierarchy

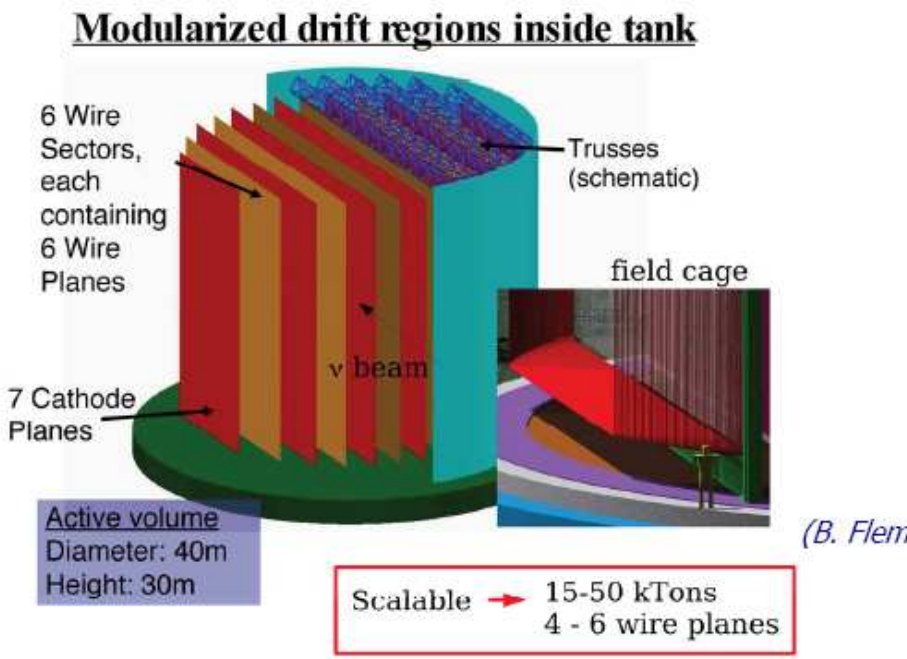




Wide-band beam spectral information = resolves degeneracies

Liquid Argon Simulations





(B. Flem

LAr parameterized simulation used:

(B. Flemming) ν_e **CC efficiency = 80%**

$$\sigma(E)_{QE} = 5\%.\sqrt{E}$$

$$\sigma(E)_{CC} = 20\%.\sqrt{E}$$

Handscanning indicates good π^0 rejection.

ν_μ QE event reconstruction in MC.

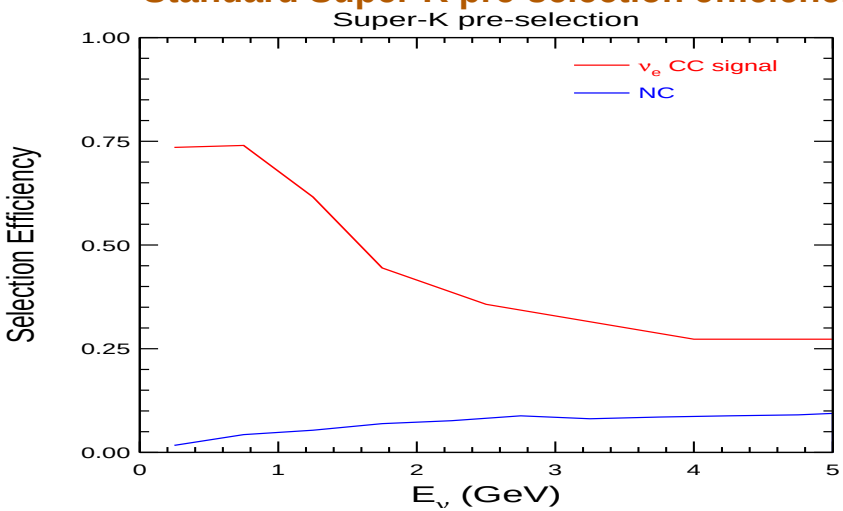
Negligible NC backgrounds

Water Cerenkov Simulation

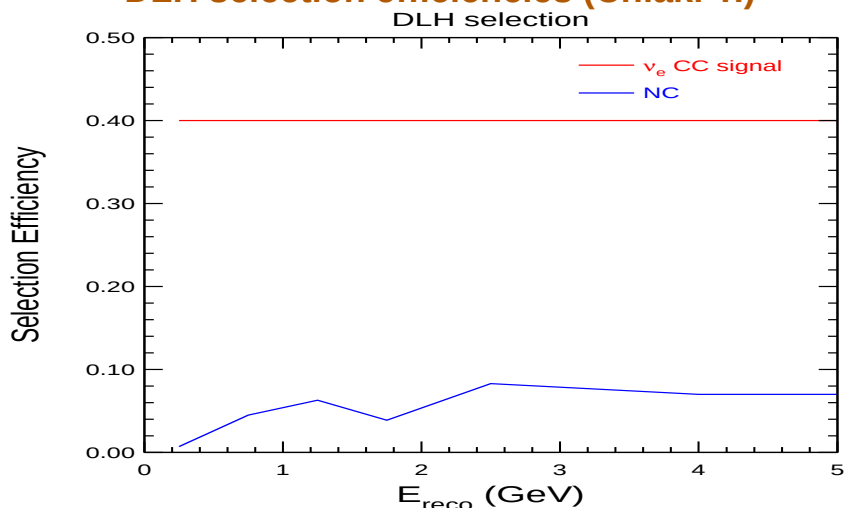
The ν_{atm} GEANT simulation of SuperKamiokande is used.

An π^0 reconstruction algorithim called "Pattern Of Light Fit" is used as input to a likelihood (DLH) analysis to reconstruct $\pi^0 \rightarrow \gamma\gamma$ by looking for the 2nd ring. **Studies by Chiaki Yanagisawa, Ed Kearns and Fanny Dufour for a FNAL-DUSEL wide-band beam produce similar efficiency for signal and background.**

Standard Super-K pre-selection efficiencies



DLH selection efficiencies (Chiaki Y.)



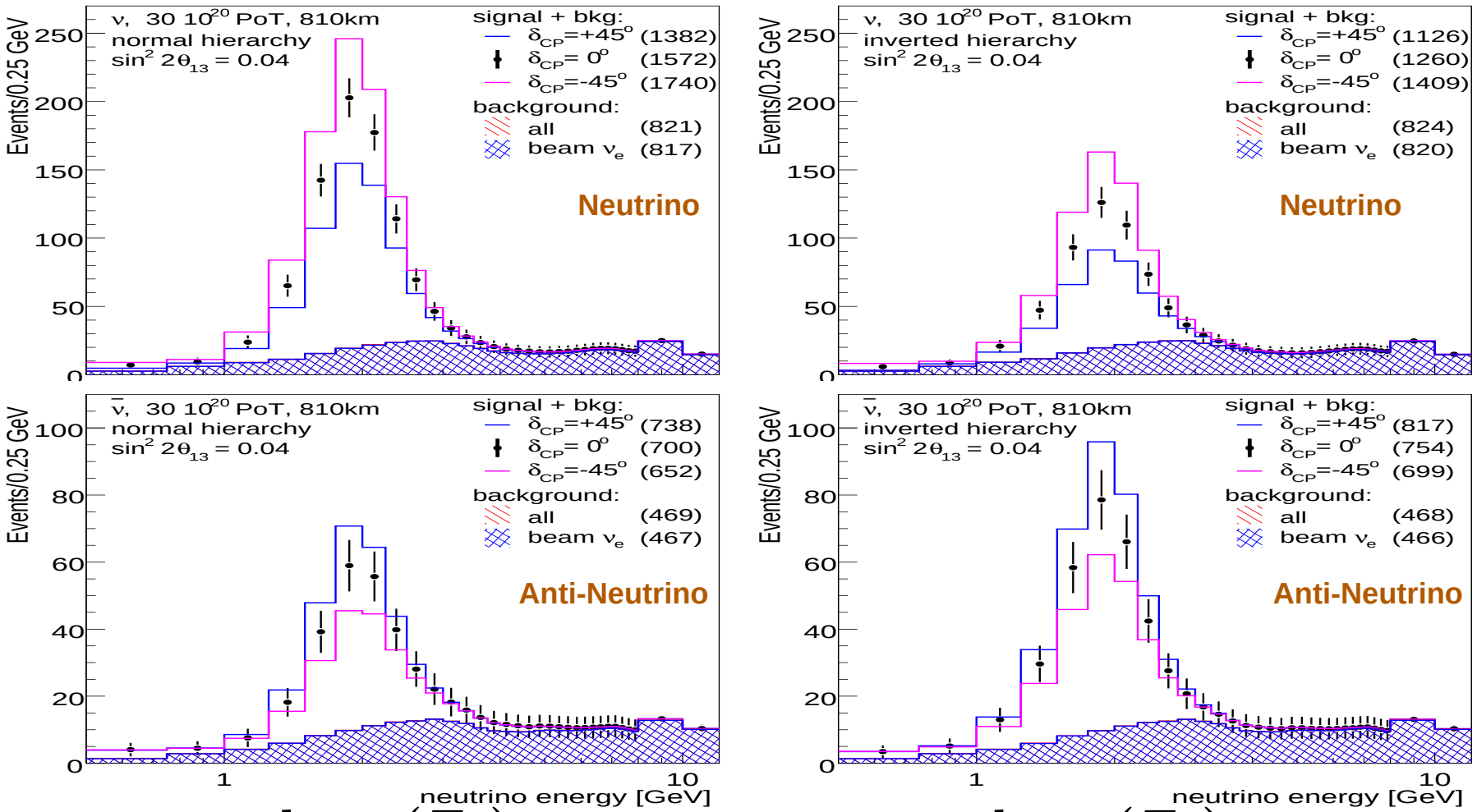
Total efficiency = Preselection eff. $\times$ DLH eff. ($\sim 15\%$ for WBLE ν_e CC signal, $\sim 0.4\%$ for NC)

WCe. energy dependent efficiencies and smearing implemented in GLoBeS.

ν_e Appearance Spectra (Dierckxsens, WG1, Fri. PM)

$\sin^2 2\theta_{13} = 0.04$, **100kT LAr.**, NuMI ME 0.8°, 810km, 30E20 POT.

Normal hierarchy $(-\delta_{cp} = -45^\circ, -\delta_{cp} = +45^\circ)$ **Reversed hierarchy**

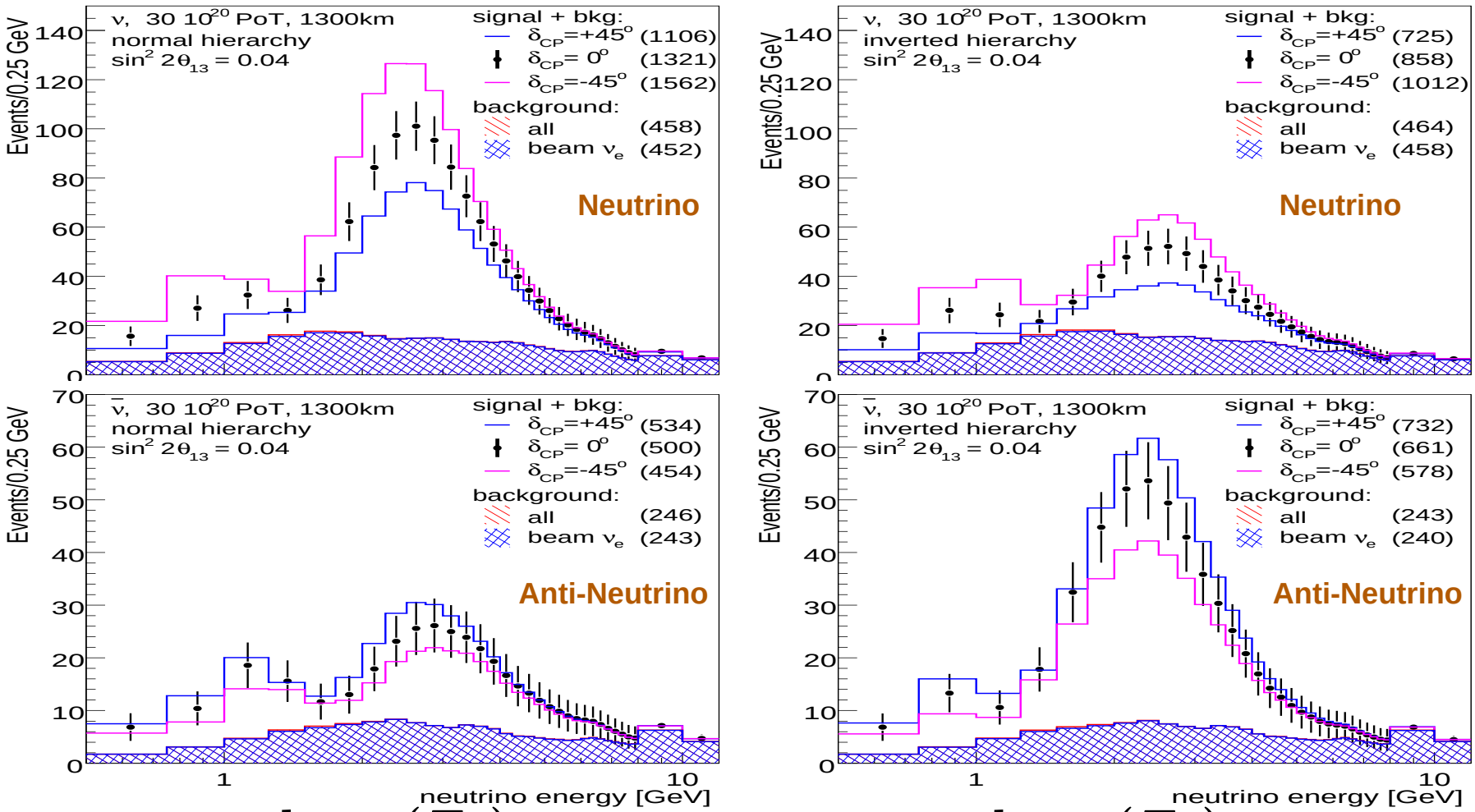


$\log_{10}(E_\nu)$ $\log_{10}(E_\nu)$

ν_e Appearance Spectra (Dierckxsens, WG1, Fri. PM)

$\sin^2 2\theta_{13} = 0.04$, **100kT LAr.**, WBLE 120 GeV, 1300km, 30E20 POT.

Normal hierarchy $(-\delta_{cp} = -45°, -\delta_{cp} = +45°)$ **Reversed hierarchy**

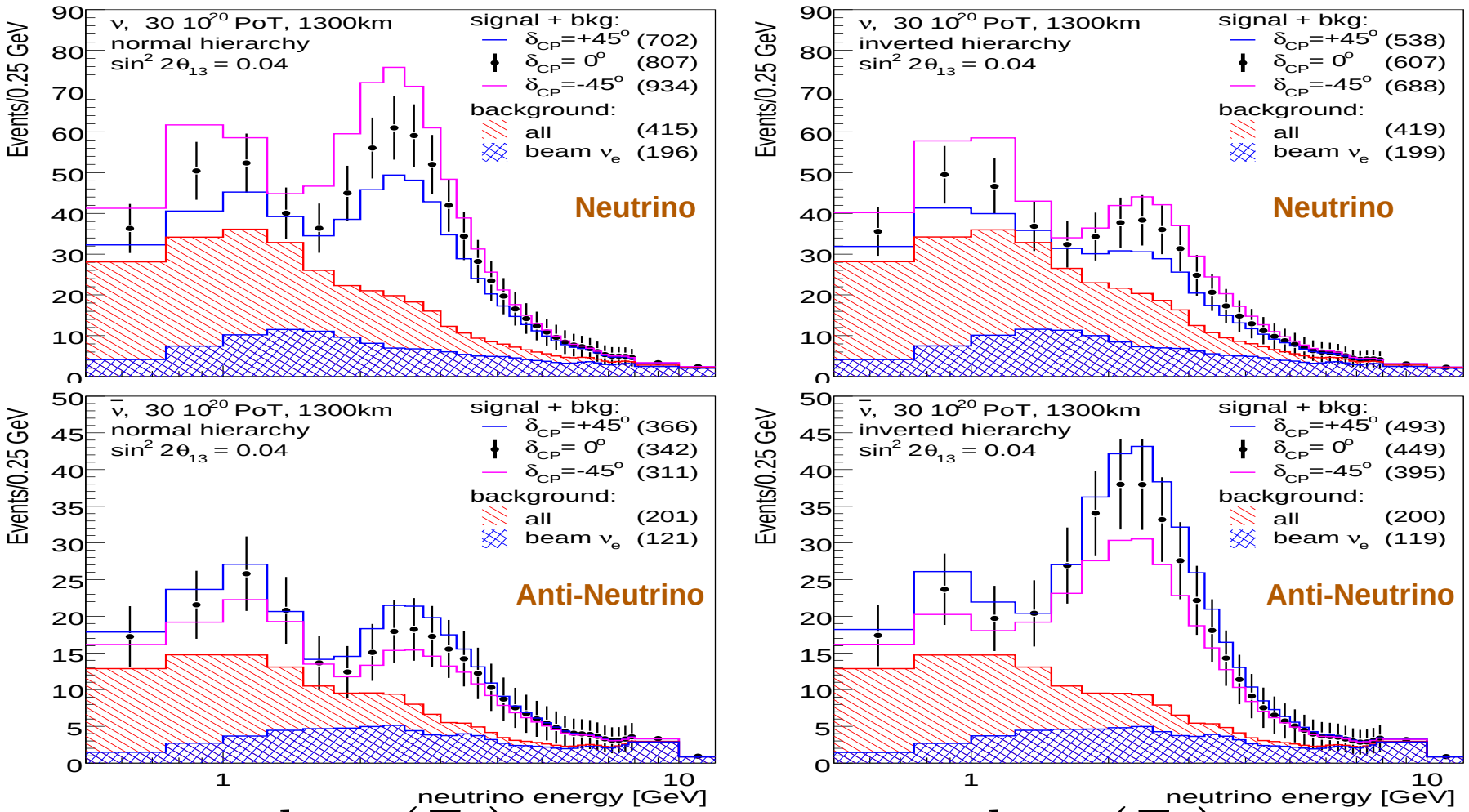


$\log_{10}(E_\nu)$ $\log_{10}(E_\nu)$

ν_e Appearance Spectra (Dierckxsens, WG1, Fri. PM)

$\sin^2 2\theta_{13} = 0.04$, **300kT WCe.**, WBLE 120 GeV, 1300km, 30E20 POT.

Normal hierarchy $(-\delta_{cp} = -45°, -\delta_{cp} = +45°)$ **Reversed hierarchy**



$\log_{10}(E_\nu)$ $\log_{10}(E_\nu)$

Estimating Sensitivities

Details in Mark Dierckxsens presentation, WG1 Fri PM Aug 8th

Matrix parameters used & systematic uncertainties (FNAL-DUSEL):

-$\Delta m^2_{21,31} = 8.6 \times 10^{-5}(5\%), 2.7 \times 10^{-3}$ eV^2 (uncertainty determined from fit to disappearance mode) -$\sin^2 2\theta_{12,23} = 0.86(5\%), 1.0$(uncertainty determined from fit to disappearance mode) -Matter density (5%) -Background (10%) - Mass hierarchy fixed.

Systematic uncertainties (NuMI Off-axis):

-Negligible uncertainties on known matrix parameters and matter density - Background (5%) - Mass hierarchy is allowed to vary.

Determining θ_{13} sensitivity: Fit the appearance spectrum generated for a particular θ_{13}, δ_{cp} to the oscillation hypothesis with $\theta_{13} = 0$.

CP-violation sensitivity: Fit the appearance spectrum to the oscillation hypothesis with $\delta_{cp} = 0$ and π. Take the worst χ^2. θ_{13} floats in the fit.

sign(Δm^2_{31}): Fit the appearance spectrum to the oscillation hypothesis with the opposite mass hierarchy. BOTH θ_{13} and δ_{cp} float in the fit.

Sensitivity comparison

The sensitivity reach is given as

the *minimal* value of $\sin^2 2\theta_{13}$ at which 50% of δ_{cp} values have $\geq 3\sigma$ reach

for the choice of mass hierarchy with worst sensitivity.

Total exposure assumes equal amounts of ν and $\bar{\nu}$:

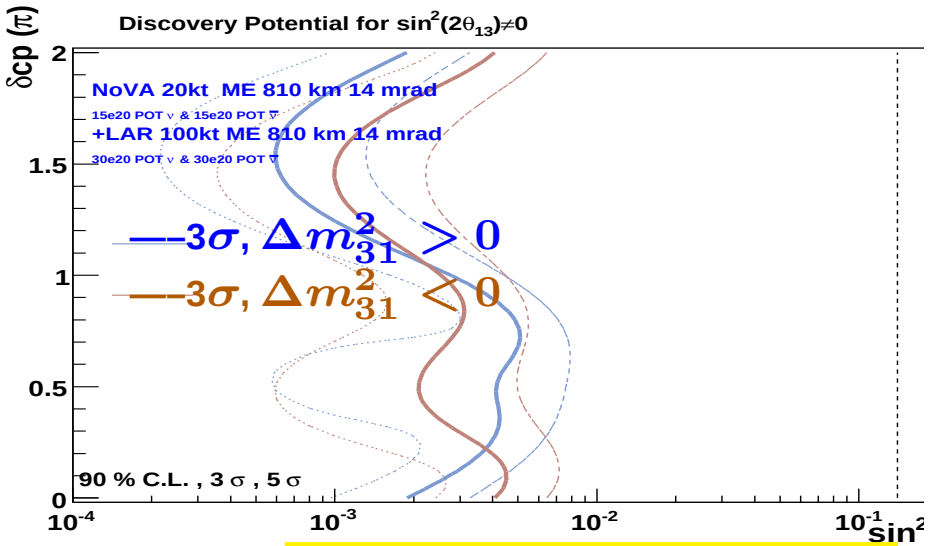
Beam	Baseline	Detector	Exposure (MW.yr*)	$\theta_{13} \neq 0$	CPV	$sign$ (Δm^2_{31})
NuMI ME, 0.9°	810 km	NOνA 20 kT	6.8	0.015	$>$ 0.2	0.15
NuMI ME, 0.8°	810 km	LAr 100 kT	6.8	0.002	0.03	0.05
NuMI LE, 0.8°, 3°,	810,700 km	LAr 2 $\times$ 50 kT	6.8	0.005	0.04	0.04
WBLE 120GeV, 0.5°	1300km	LAr 100 kT	6.8	0.0025	0.005	0.006
WBLE 120GeV, 0.5°	1300km	WCe 300 kT	6.8	0.006	0.03	0.011
WBLE 120GeV, 0.5°	1300km	WCe 300 kT	13.6	0.004	0.012	0.008

The best sensitivity is FNAL-DUSEL with a LAr-TPC

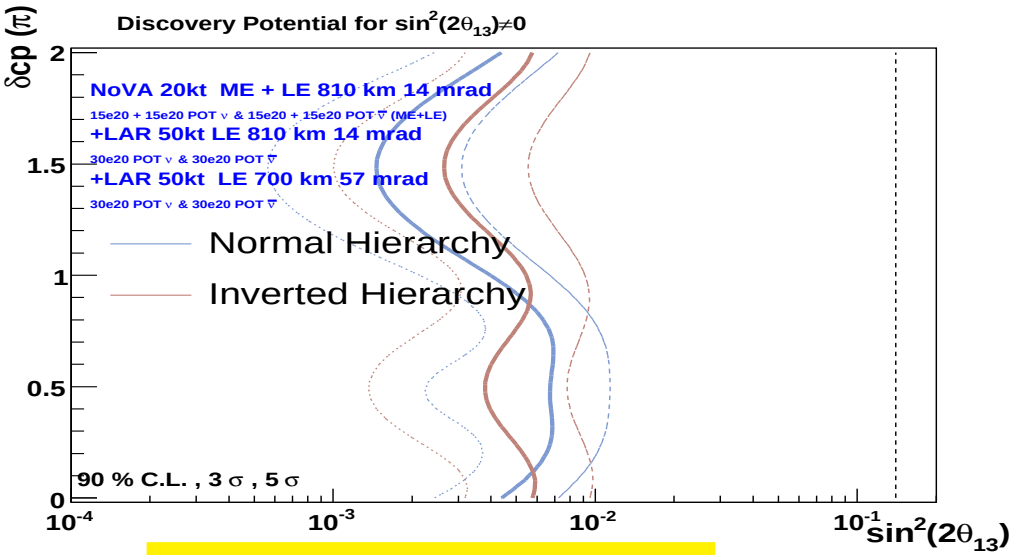
The 2$^{\rm nd}$ best is FNAL-DUSEL w/ 300 kT WCe. and NuMI off-axis w/ 100kT LAr

Sensitivity to $\theta_{13} \neq 0$ (6.8 MW.yr)

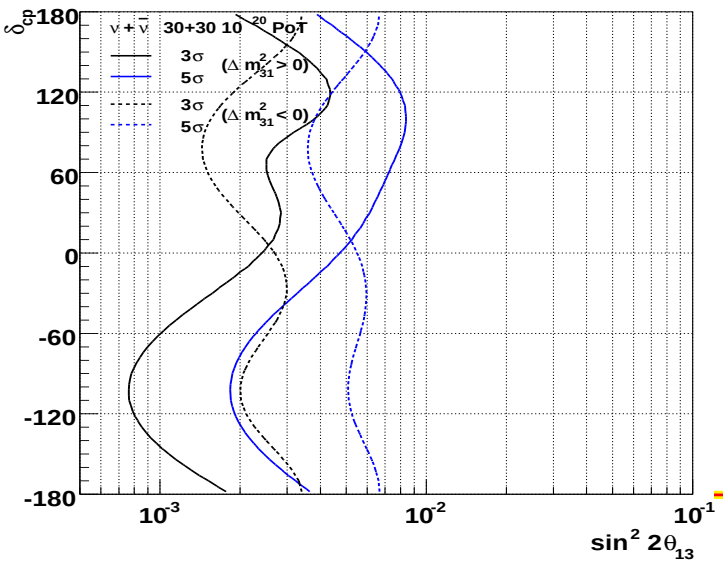
NuMI 100kT LAr-TPC at 0.8° off-axis



NuMI 2x50 kT LAr-TPC at $0.8, 3.3^\circ$ off-axis



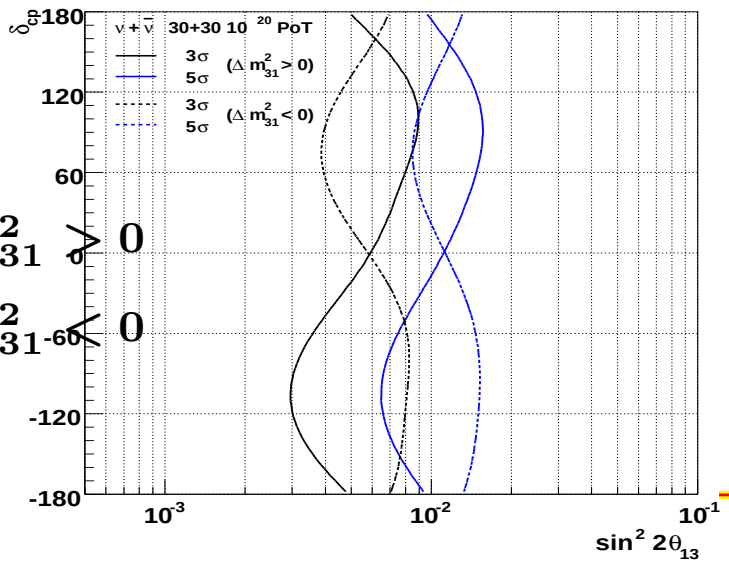
FNAL-Homestake, 100kT LAr-TPC



—3σ, $\Delta m^2_{31} > 0$

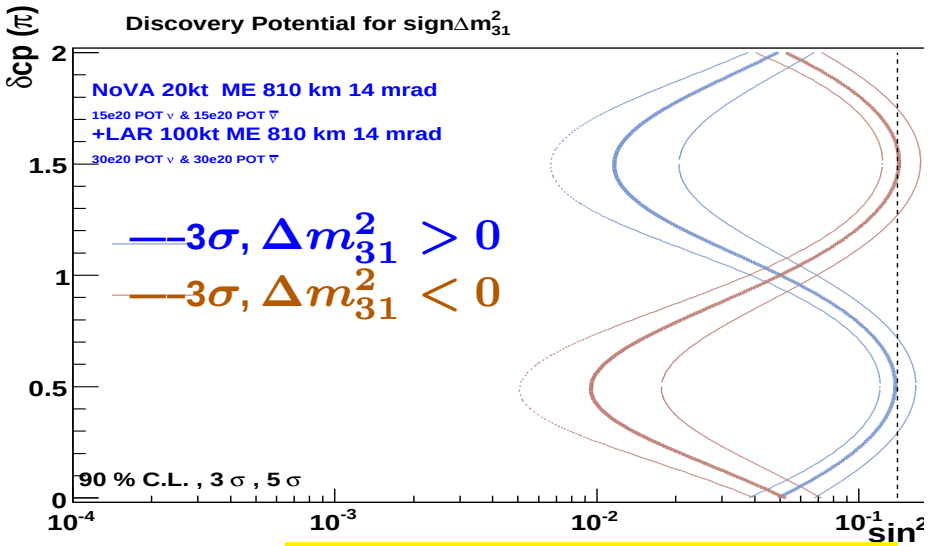
- - -3σ, $\Delta m^2_{31} < 0$

FNAL-Homestake, 300 kT WCe.

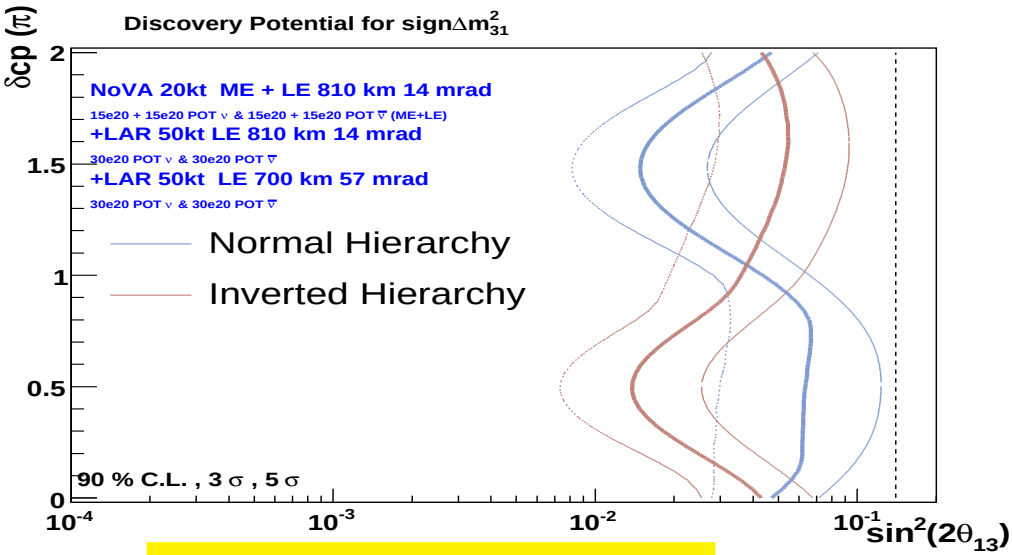


Sensitivity to Mass Hierarchy (6.8 MW.yr)

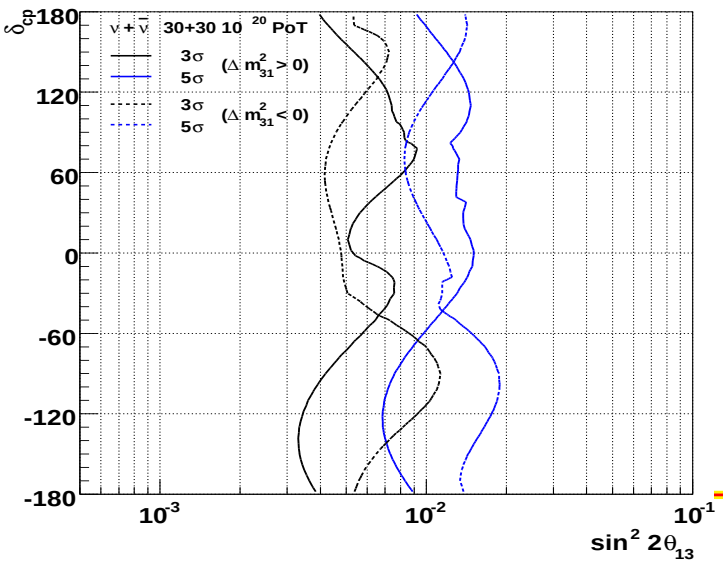
NuMI 100kT LAr-TPC at 0.8° off-axis



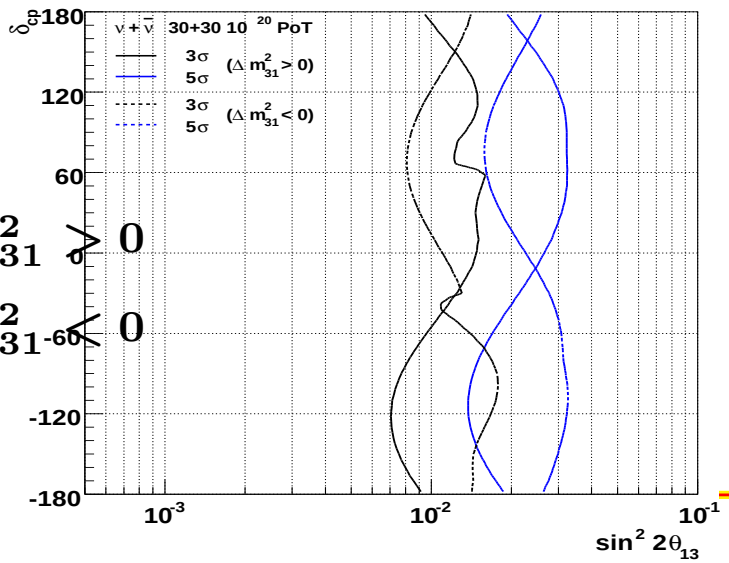
NuMI 2x50 kT LAr-TPC at $0.8, 3.3^\circ$ off-axis



FNAL-Homestake, 100kT LAr-TPC



FNAL-Homestake, 300 kT WCe.

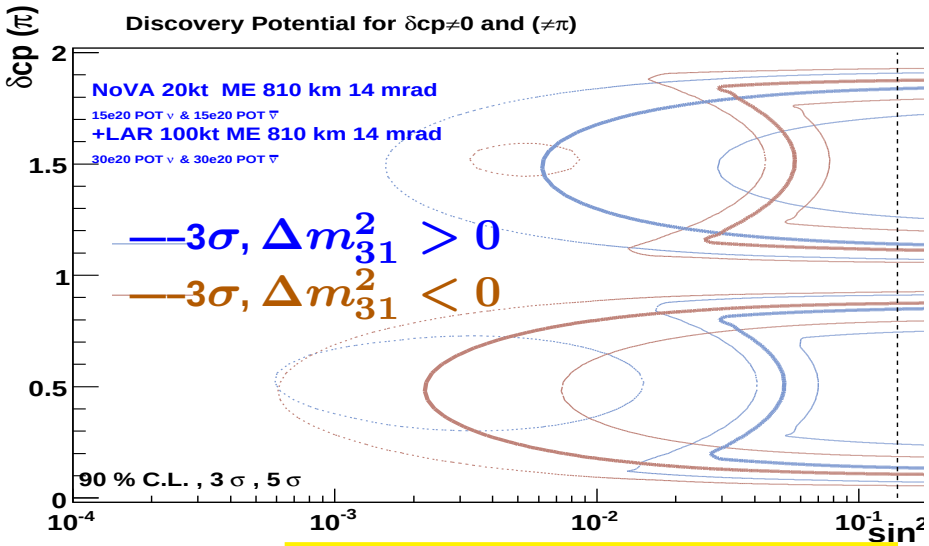


—–$3\sigma, \Delta m^2_{31} > 0$

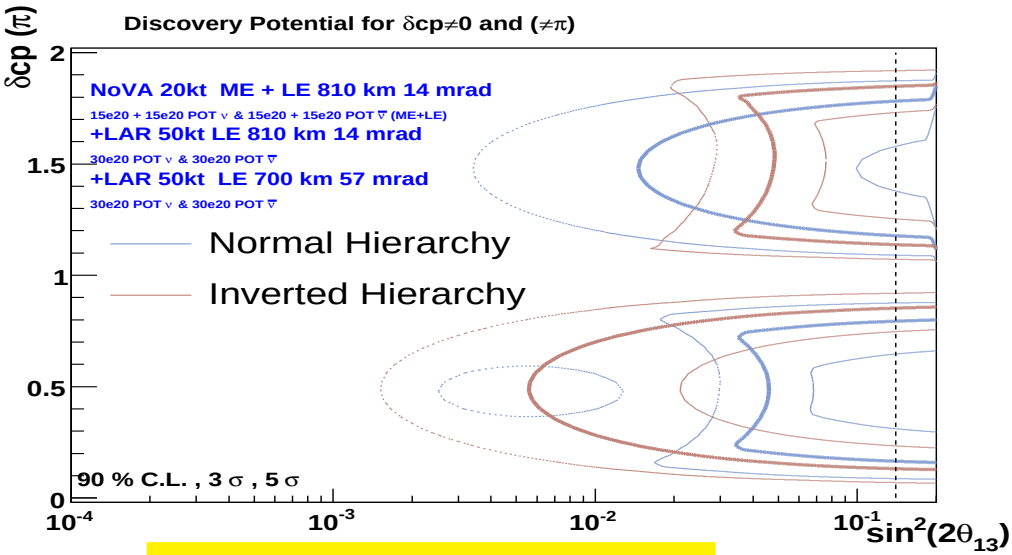
- - -$3\sigma, \Delta m^2_{31} < 0$

Sensitivity to CPV (6.8 MW.yr)

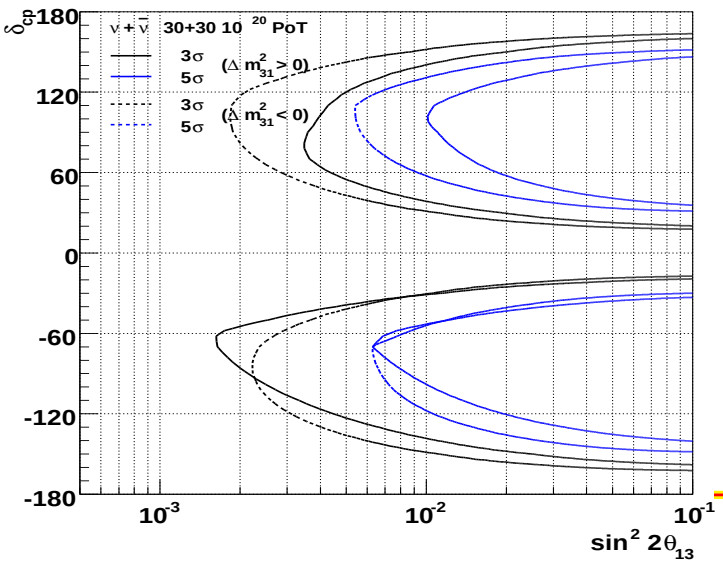
NuMI 100kT LAr-TPC at 0.8° off-axis



NuMI 2x50 kT LAr-TPC at $0.8, 3.3^\circ$ off-axis



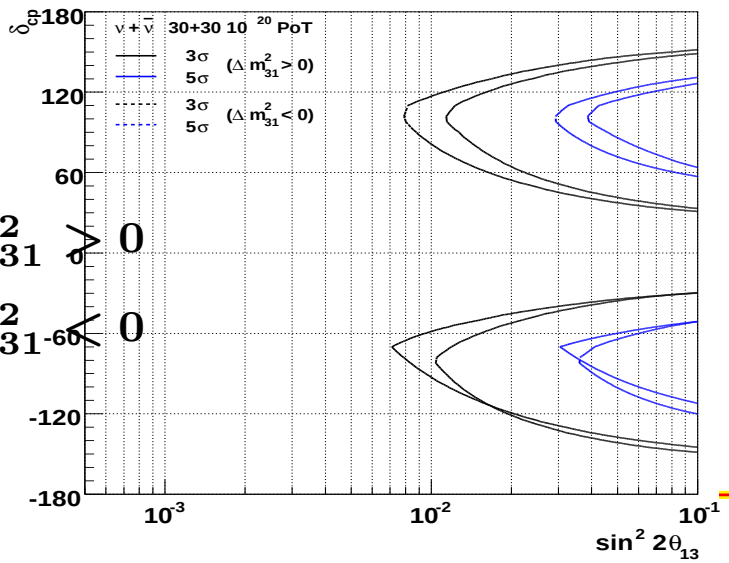
FNAL-Homestake, 100kT LAr-TPC



—3σ, $\Delta m^2_{31} > 0$

- - -3σ, $\Delta m^2_{31} < 0$

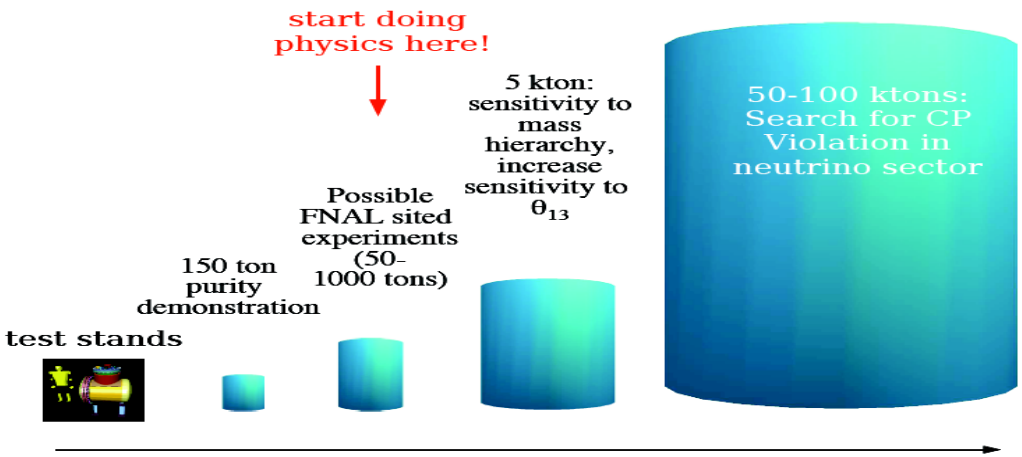
FNAL-Homestake, 300 kT WCe.



LAr-TPC Construction Challenges

The largest LAr-TPC built is 0.6 kT (ICARUS T600). For the next generation LB experiments need $\mathcal{O}(100\ \mathrm{kT})$:

Long drift distances: Construction of long drift wires, signal to noise, Ar purification



2007 ⟶

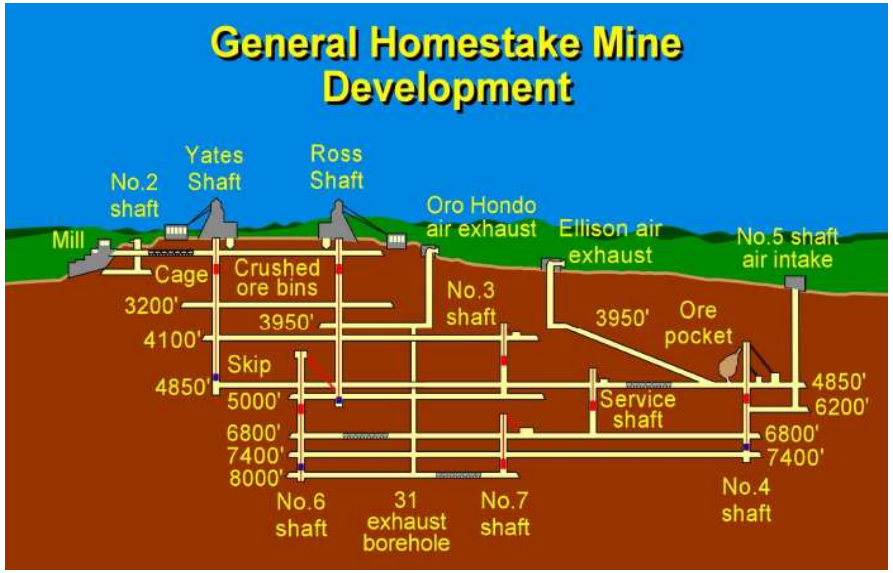
Timescale ?????

Operation on the surface: For a 50 kT module, signal collected over 3 drift times after beam pulse = 10^8 rejection factor needed for cosmic μ.

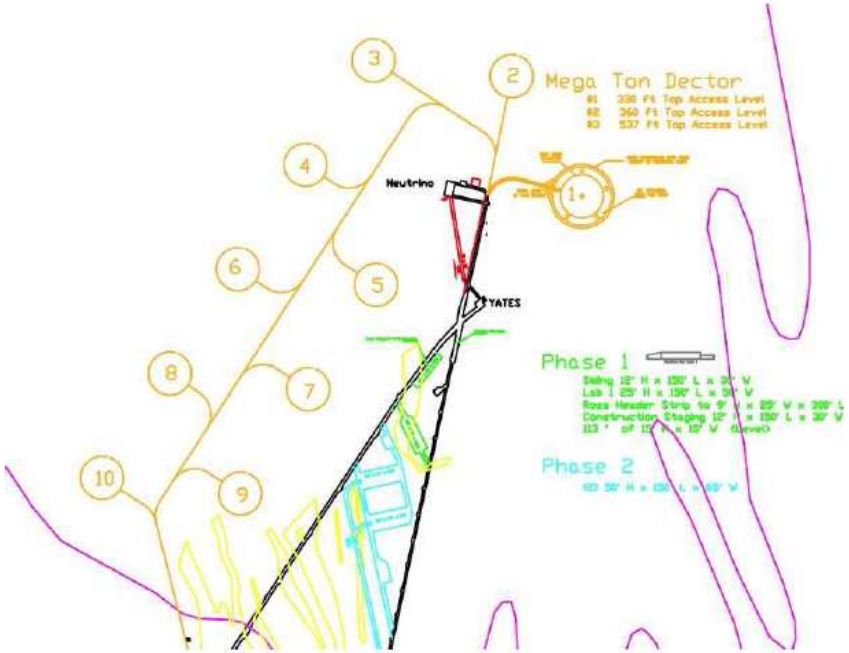
Operation underground: More expensive LNG storage and purification. Extensive safety systems. Cavern R& D?

Cost and schedule: for 50 kT, cost of LAr+commercial LNG containment tank on the surface = $68M. Additional cost of wire, wire planes, purification system, electronics are still being evaluated $\Rightarrow \geq$ $200M for 100 kT ???.

Homestake Mine WCe. Proposal



The first modules will be located near the original cavern for the Ray Davis expt.

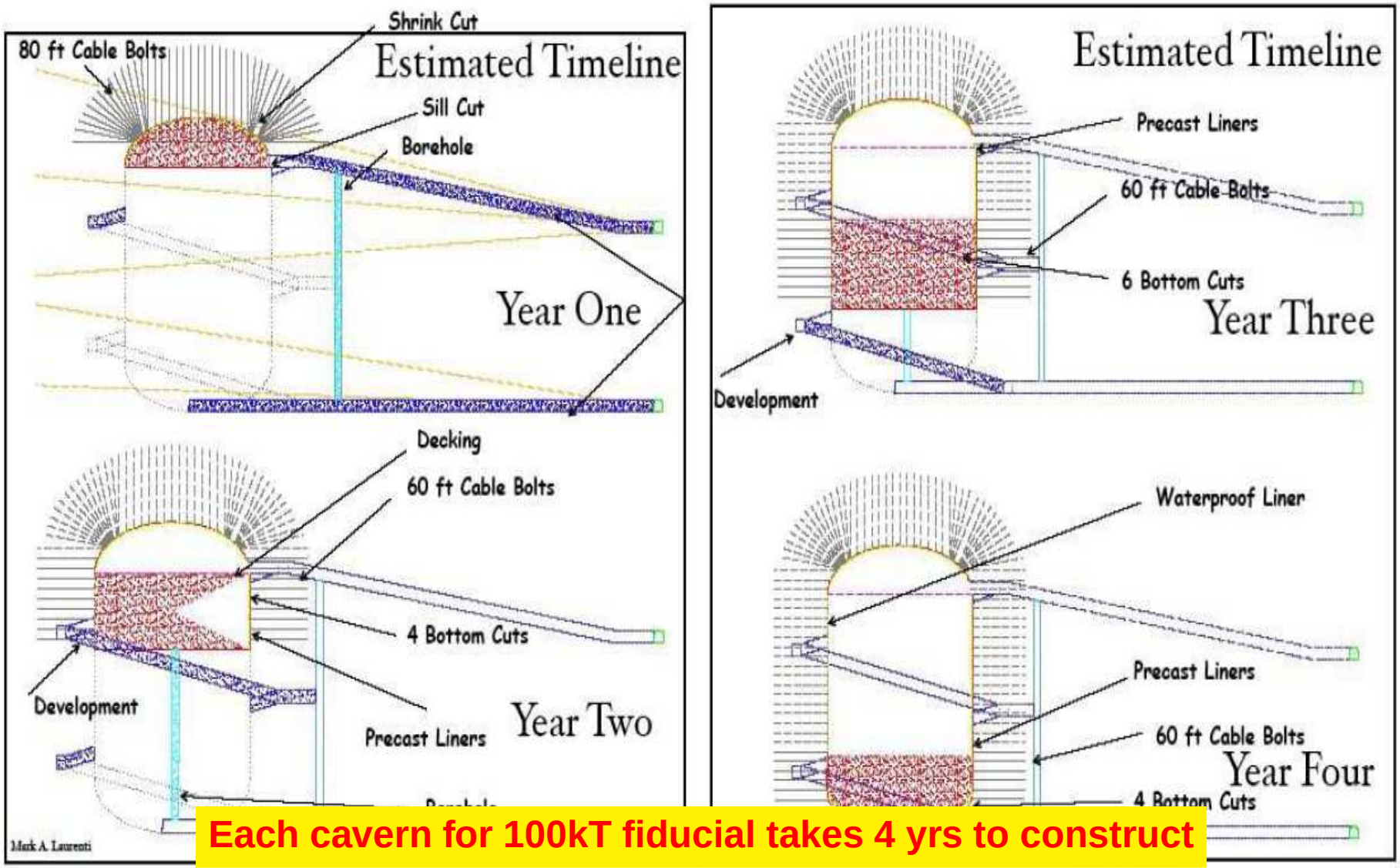


The detector system will be deployed in the 4850 ft level as seperate 100kT fiducial Water Cerenkov detector modules (53m high, 53m diameter) to allow a staged approach with potential for expansion.

Each module is a modest scale up from SuperK which is 50 kT total (41.4m high, 39.3m diameter)

Cavern Construction Timeline

Mark Laurenti, Chief Mine Engineer for Homestake till 2001



Each cavern for 100kT fiducial takes 4 yrs to construct

Cost Estimates for 300 kT (fiducial)

Construction costs for 3 caverns:

Cost Description	Amount
Labor/benefits	$19.3M
Minig equipment	$5.30M
Mining equipment operations	$4.55M
Supplies	$15.8M
Precast concrete liner	$11.4M
Plastic liner	$0.79M
Outside contractor (bore holes)	$0.42M
Rock removal	$3.18M
Contingency (30%)	$18.2
Total for 3 chambers	$78.9

Detector costs

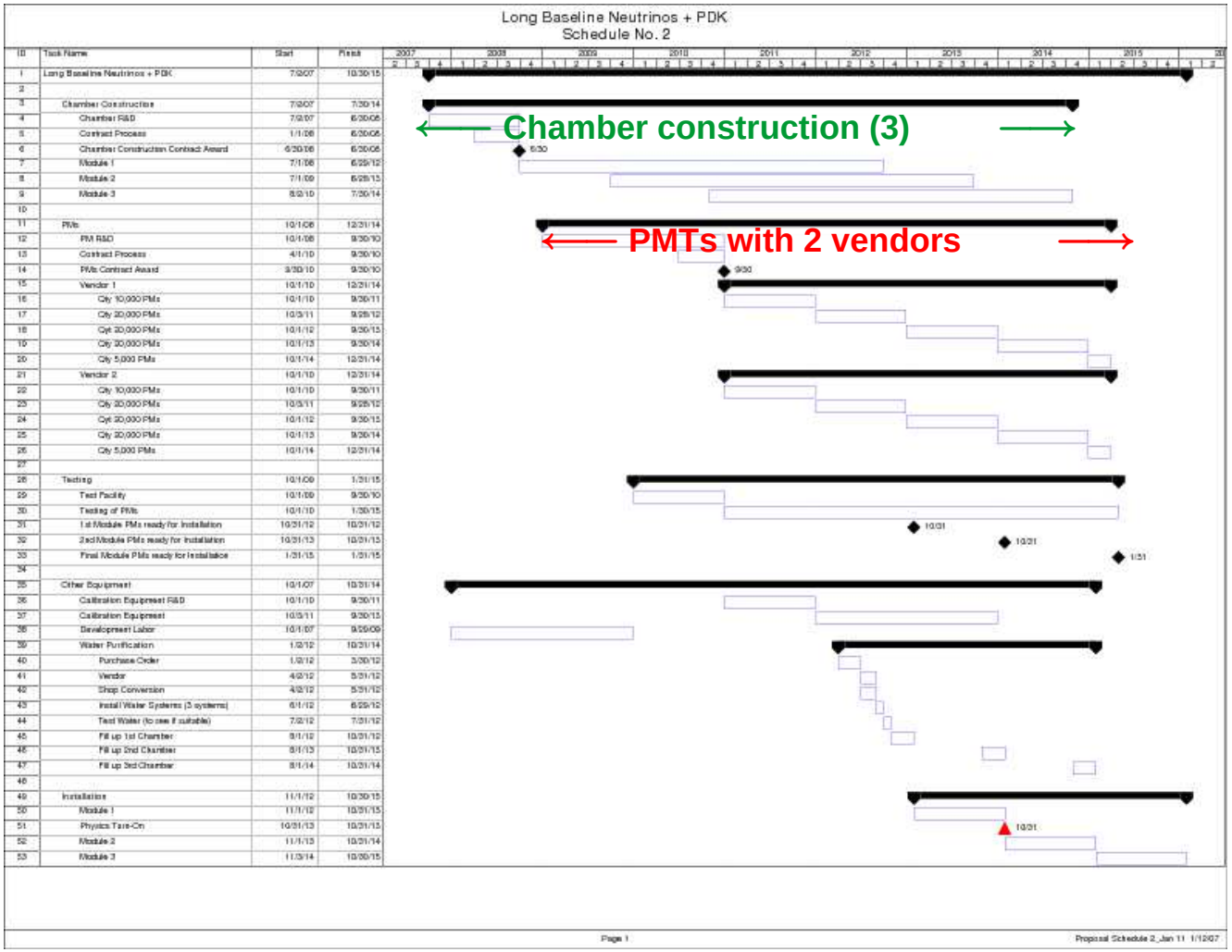
For 25% PMT coverage of 11,000m^2 using 12" PMTs. Extrapolated from SNO.

Cost Description	Amount
PMT+electronics	$171.3M
R&D,Water,DAQ, etc	$8.2M
Installation+testing	$35.7M
Contingency (non-civil,25%)	$50.8M
Total detector cost (3 Modules)	$266.0M

Total cost for 300kT (2007) : $345M

Costs DO NOT include managment overheads.

Overall Timeline (Homestake)



6 yrs from start of construction to physics turn on with Module 1

8 yrs from start of construction to data taking with all 3 modules

Conclusions of the Study

- The experimental options considered improve the sensitivity to CPV and θ_{13} by at least an order of magnitude over the current program (NOνA, T2K).

- The FNAL to DUSEL program with a wide-band beam has significantly better overall sensitivity to CPV and the mass hierarchy when compared to a shorter baseline NuMI based program with an off-axis beam.

- The FNAL to DUSEL expt. with a 300 kT water Cerenkov (low technical risk, known cost) detector has similar sensitivity to CPV when compared to a NuMI off-axis expt. with a 100 kT LAr-TPC (high technical risk, cost unknown), and significantly better sensitivity to the sign of Δm^2_{31}, BUT requires a new neutrino beamline to be built at additional cost.

-A large DUSEL based underground neutrino detector can support a wider physics program including proton decay, supernova neutrinos...

NuSAG Recommendations

Recommendation 1. The US should prepare to proceed with a long baseline neutrino oscillation program to extend sensitivity to $\sin^2 2\theta_{13}$, to determine the mass ordering of the neutrino spectrum, and to search for CP violation in the neutrino sector. Planning and R&D should be ready for a technology decision and a decision to proceed when the next round of results on $\sin^2 2\theta_{13}$ becomes available, which could be as early as 2012. A review of the international program in neutrino oscillations and the opportunities for international collaboration should be included in the decision to proceed.

Recommendation 2. Research and development towards an intense, conventional neutrino beam suitable for these experiments should be supported. This R&D may be to support intensity upgrades to the existing NuMI beam, as well as development of a new beam directed towards DUSEL, which would likely employ the wide-band beam approach.

Recommendation 3. Research and development required to build a large water Cherenkov detector should be supported, particularly addressing questions of minimum required photocathode coverage, cost, and timescale.

Recommendation 4. A phased R&D program with milestones and using a technology suitable for a 50-100 kton detector is recommended for the liquid argon detector option. Upon completion of the existing R&D project to achieve purity sufficient for long drift times, to design low noise electronics, and to qualify materials, construction of a test module that could be exposed to a neutrino beam is recommended.

FOR FURTHER DISCUSSION

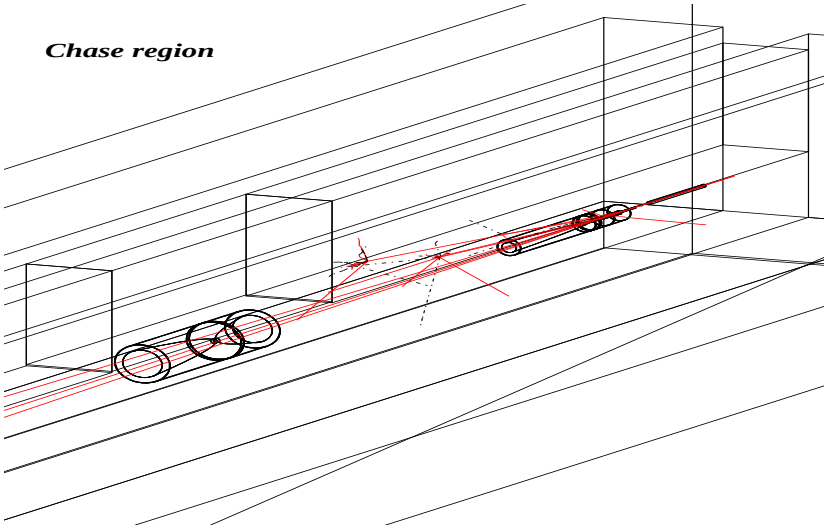
BEAMLINE DESIGN/SIMULATIONS

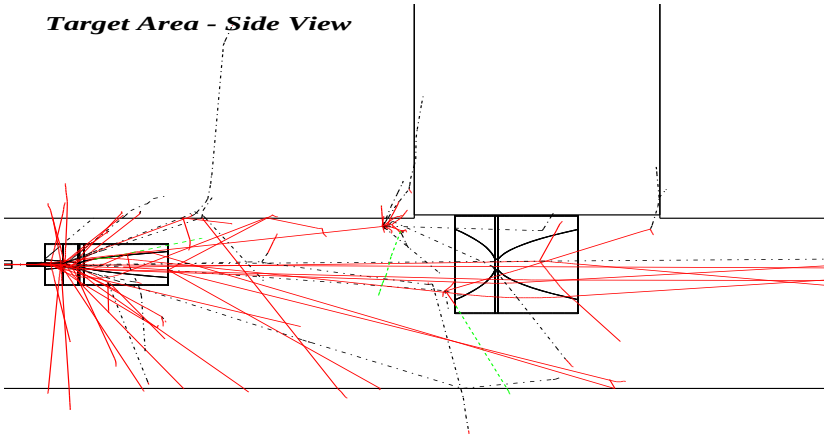
”Target System for a Long Baseline Neutrino Beam,” N. Simos, H. Kirk, J. Gallardo, S. Kahn, N. Mokhov. June 26, 2006.

“Simulation of a Wide-band Low-Energy Neutrino Beam for Very Long Baseline Neutrino Oscillation Experiments,” M. Bishai, J. Heim, C. Lewis, A. D. Marino, B. Viren, F. Yumiceva, July 20, 2006

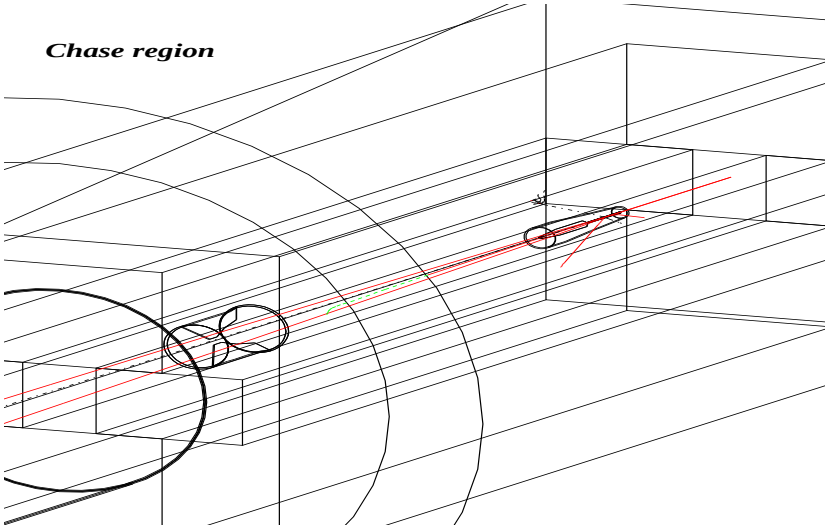
NuMI/WBLE simulation

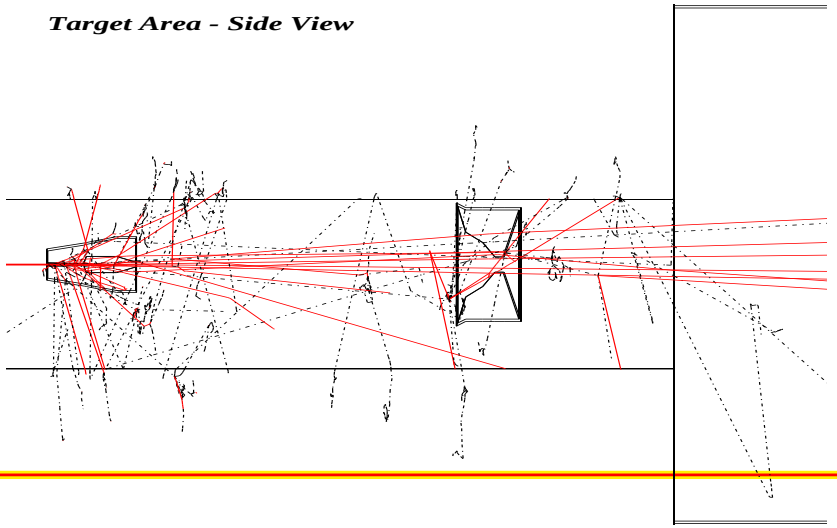
NuMI horns/target with 120 GeV p+





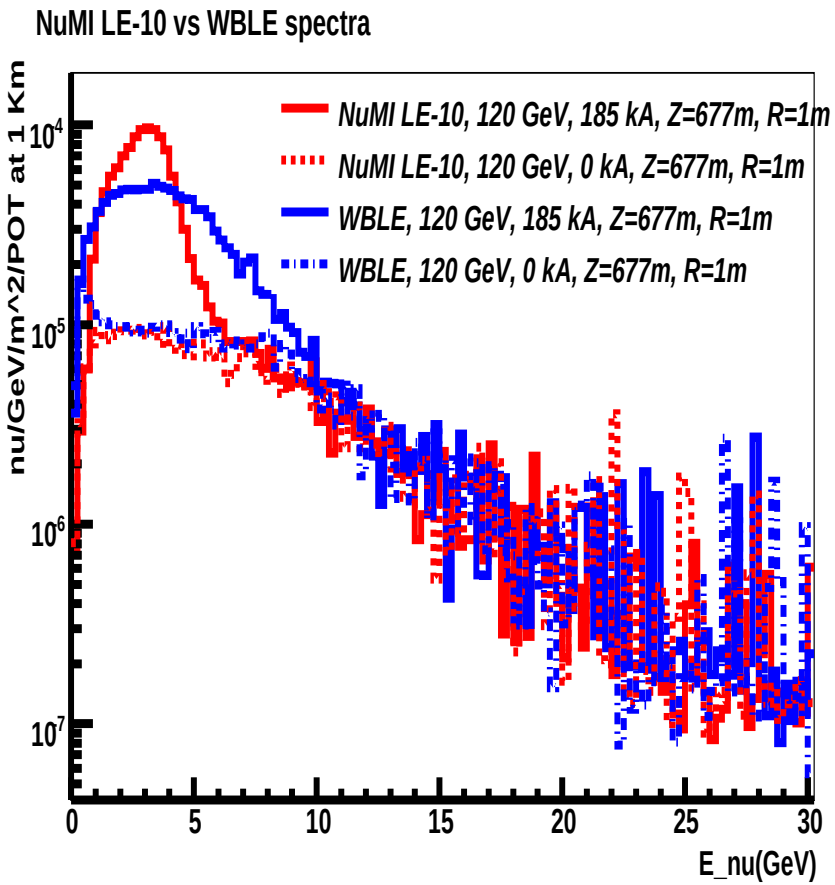
WBLE horns/target with 120 GeV p+

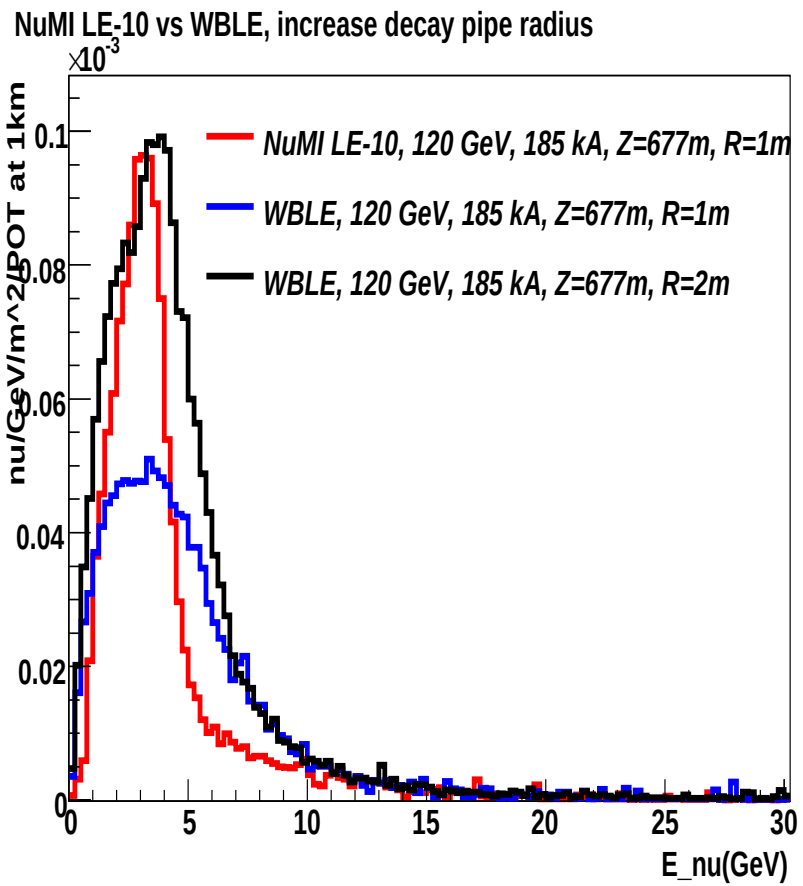




NuMI LE vs WBLE

R and Z refer to the geometry of the decay volume which is cylindrical.





1m radius decay pipe **increase to 2m radius q**

Larger diameter decay pipe = more flux at low E.

PHYSICS SENSITIVIES

” V. Barger, M. Dierckxsens, M. Diwan, P. Huber, C. Lewis, D. Marfatia, B. Viren, Jul 17, 2006 hep-ph/0607177

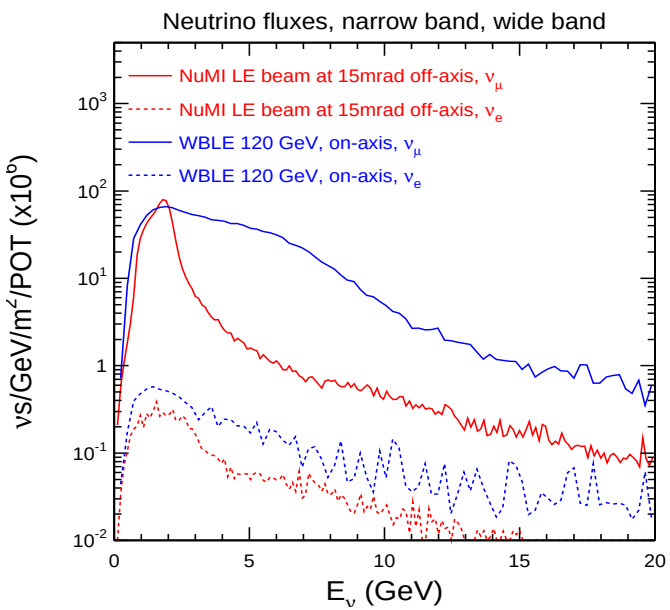
for a local copy BNL-76797-2006-JA

WCe. Background Composition

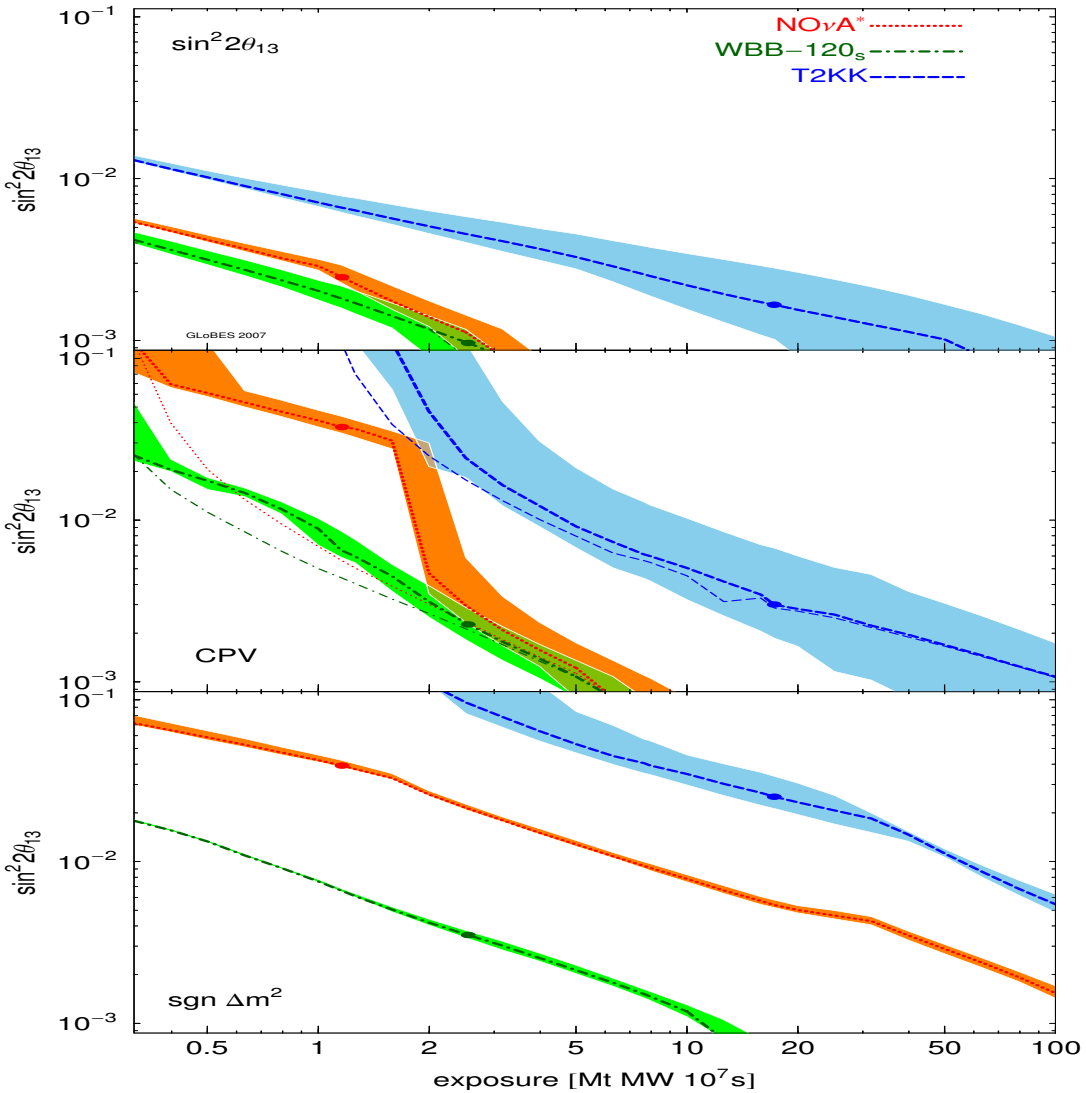
Interaction	E_{rec} range (GeV)					
Sig	0.0-0.5	0.5-1.0	1.0-1.5	1.5-2.0	2.0-3.0	3.0-
CC QE	80%	78%	36%	53%	58%	55%
CC π^0	3%	3%	9%	5%	4%	5%
CC $\pi^\pm$	15%	15%	39%	30%	27%	27%
CC $n\pi$	1%	3%	14%	10%	9%	10%
CC others	0%	2%	4%	2%	5%	4%
Bkg 1	0.0-0.5	0.5-1.0	1.0-1.5	1.5-2.0	2.0-3.0	3.0-
CC QE	7%	4%	1%	3%	0%	0%
CC π^0	0%	2%	6%	4%	0%	0%
CC $\pi^\pm$	5%	5%	0%	1%	1%	0%
CC $n\pi$	0%	0%	1%	6%	7%	1%
CC others	0%	0%	2%	0%	0%	0%
NC π^0	20%	54%	62%	50%	26%	0%
NC $\pi^\pm$	53%	9%	6%	0%	0%	0%
NC $n\pi$	0%	13%	5%	21%	62%	99%
NC others	15%	14%	16%	21%	1%	0%

Sensitivity vs Exposure

The potential physics reach from studies with the 120 GeV WBLE-DUSEL at 1300km using a LAr detector, the NOνA experiment and the T2KK experiment:*



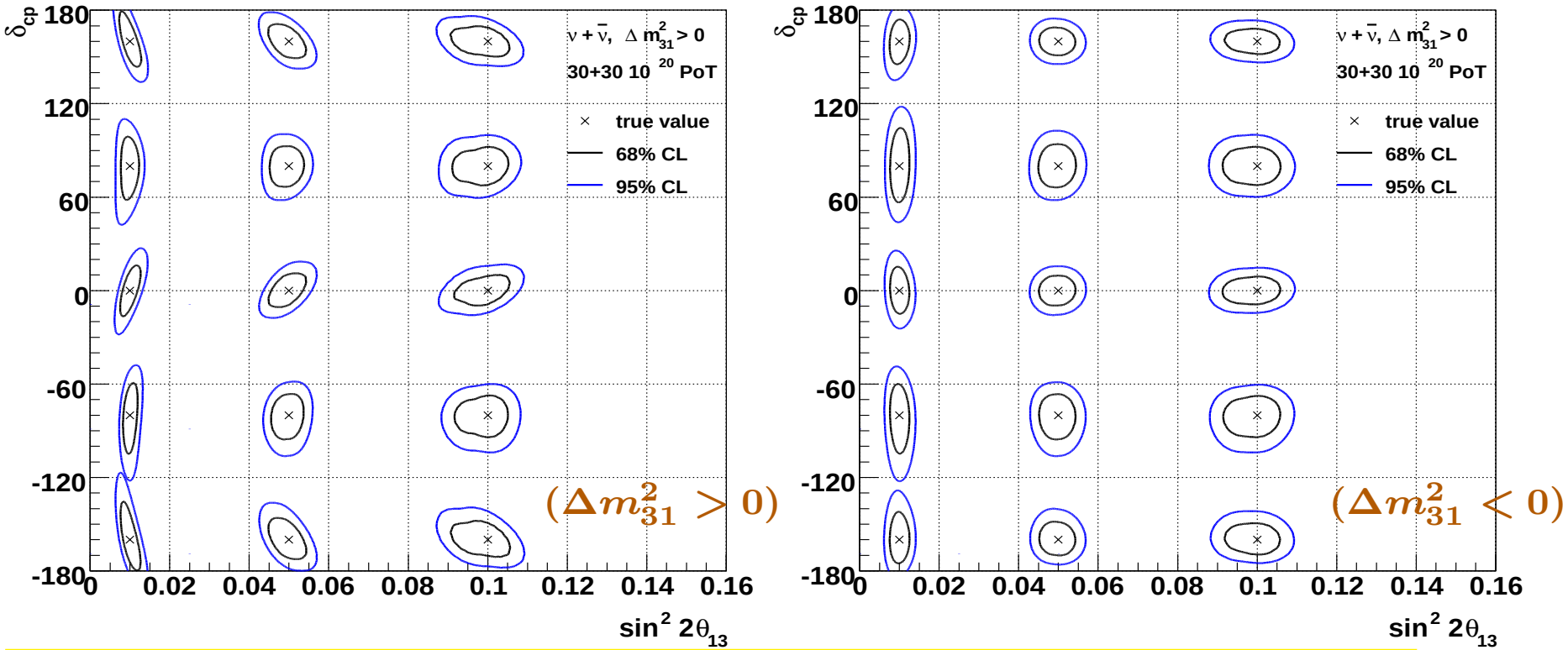
From hep-ph/0703029:



Measuring the PMNS parameters

For the wide-band approach with a large detector at $\geq$ 1000 km, the degeneracies are resolved and the PMNS matrix parameters can be accurately measured.

Measurement (—95% CL —68% CL). LAr. 100 kT, 1.2 MW, 6yrs:

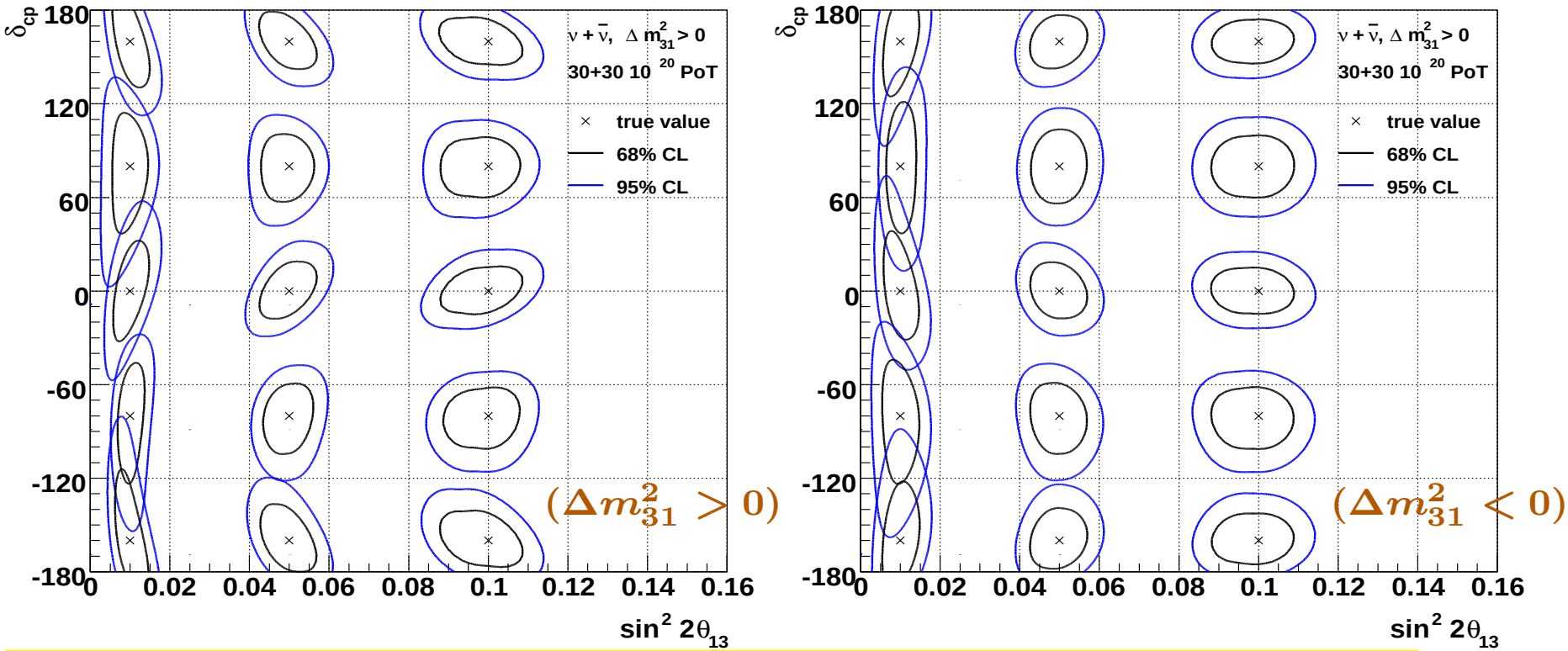


For values of $\sin^2(2\theta_{13}) > 0.01$ the measurement of δ_{cp} is approx independent of θ_{13}

Measuring the PMNS parameters

For the wide-band approach with a large detector at $\geq$ 1000 km, the degeneracies are resolved and the PMNS matrix parameters can be accurately measured.

Measurement (—95% CL —68% CL). WCe. 300 kT , 1.2 MW, 6yrs:

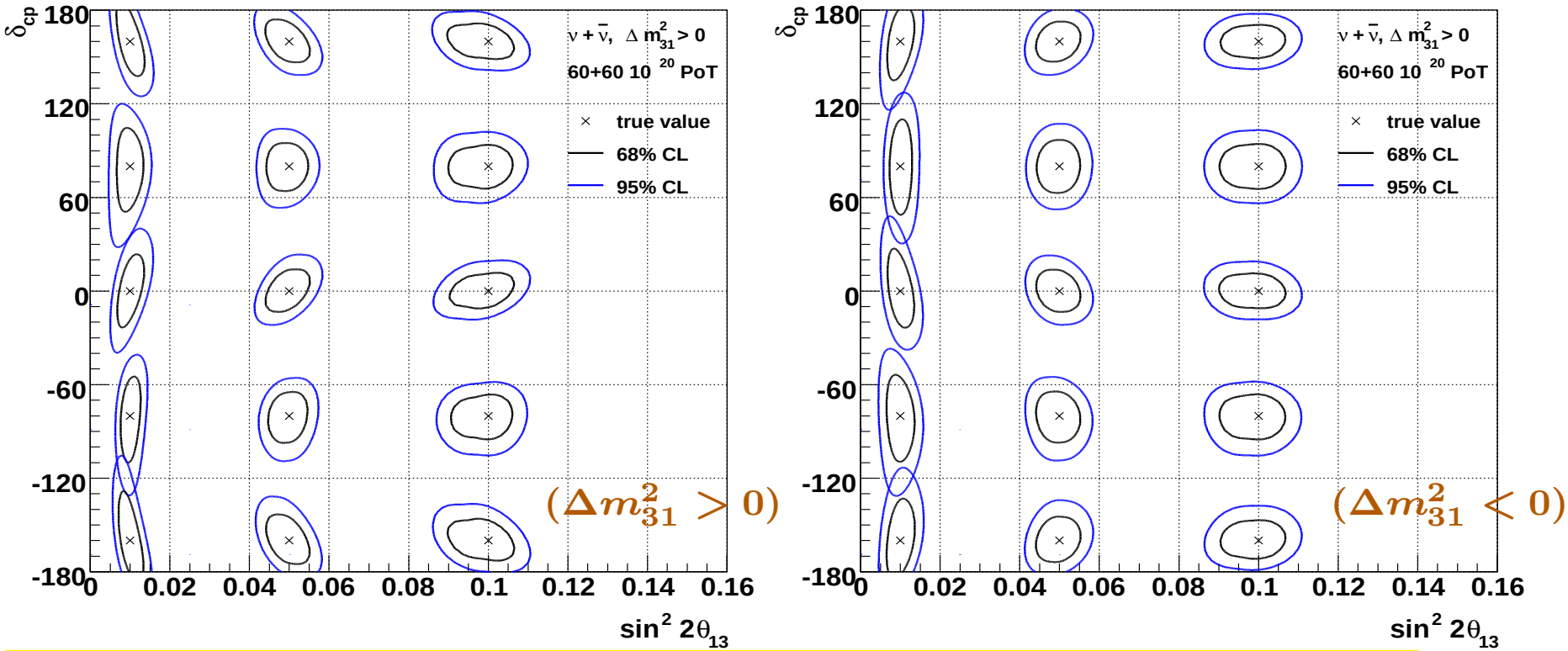


For values of $\sin^2(2\theta_{13}) > 0.01$ the measurement of δ_{cp} is approx independent of θ_{13}

Measuring the PMNS parameters

For the wide-band approach with a large detector at $\geq$ 1000 km, the degeneracies are resolved and the PMNS matrix parameters can be accurately measured.

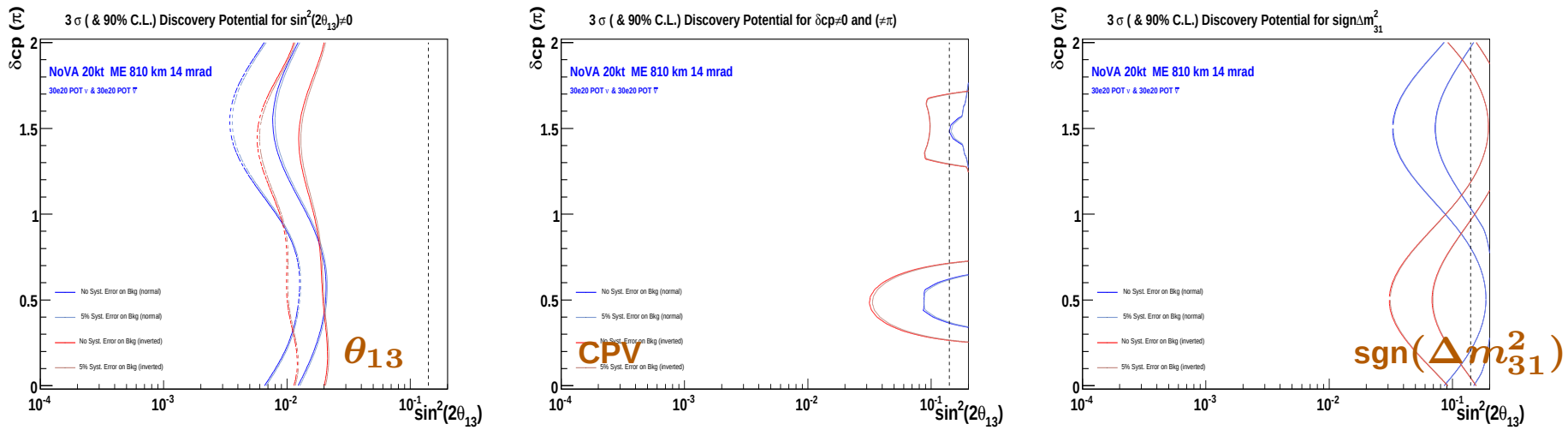
Measurement (—95% CL —68% CL). WCe. 300 kT , 1.2 (2) MW, 12 (7) yrs:



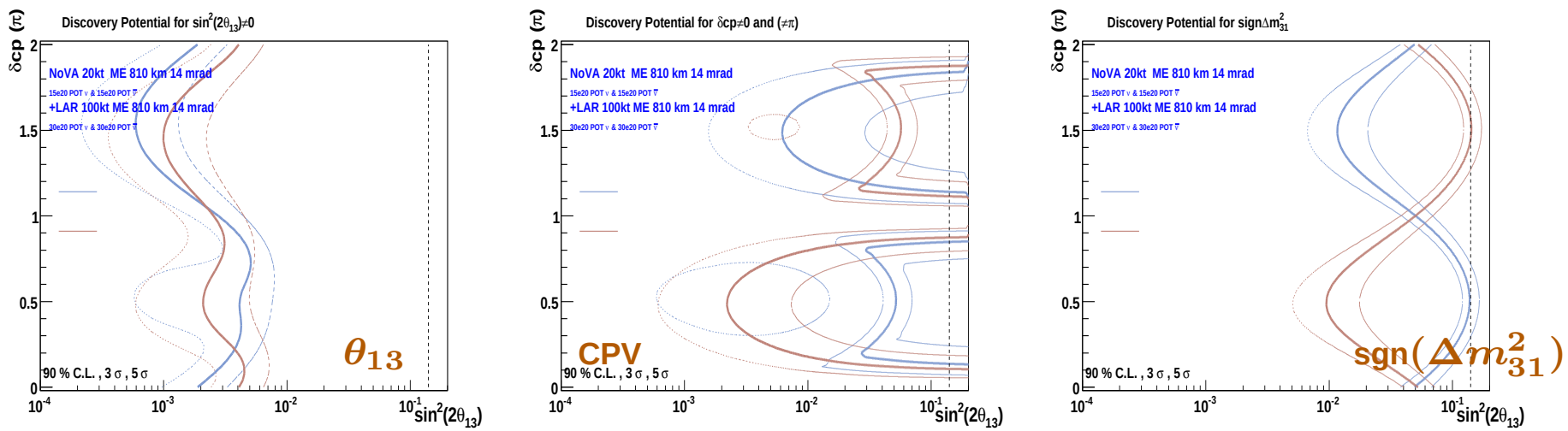
For values of $\sin^2(2\theta_{13}) > 0.01$ the measurement of δ_{cp} is approx independent of θ_{13}

PhaseI/II Sensitivities

Discovery potential (90% C.L,3σ) NOνA, 20 kT at 810km, 700 kW, 10yrs:

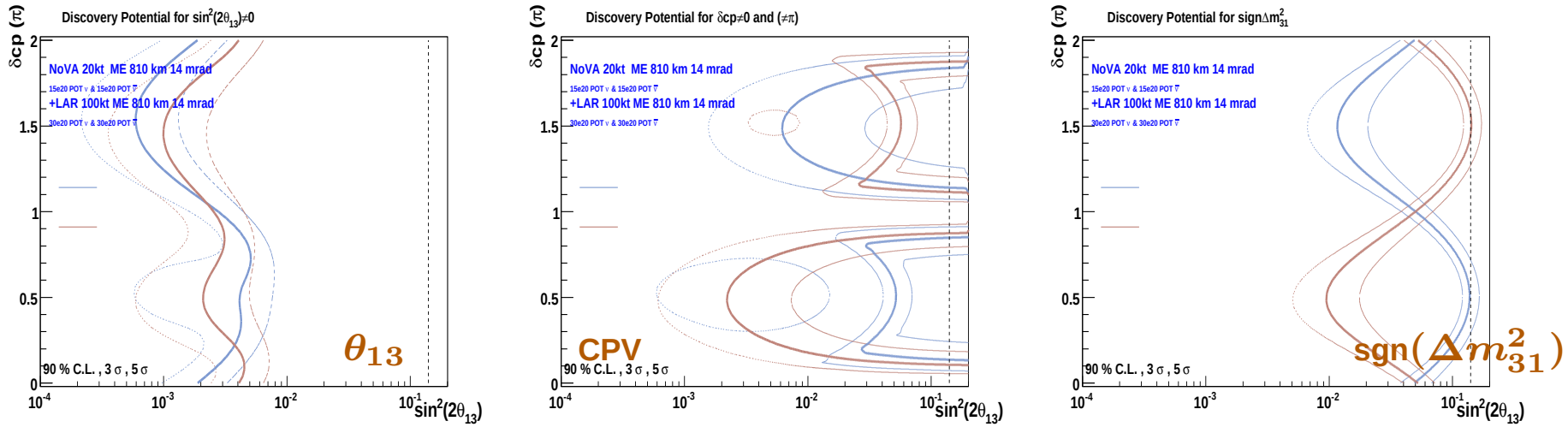


Discovery potential (90% C.L,3σ, 5σ) LAr. 100 kT at 810km, 1.2 MW, 6yrs:

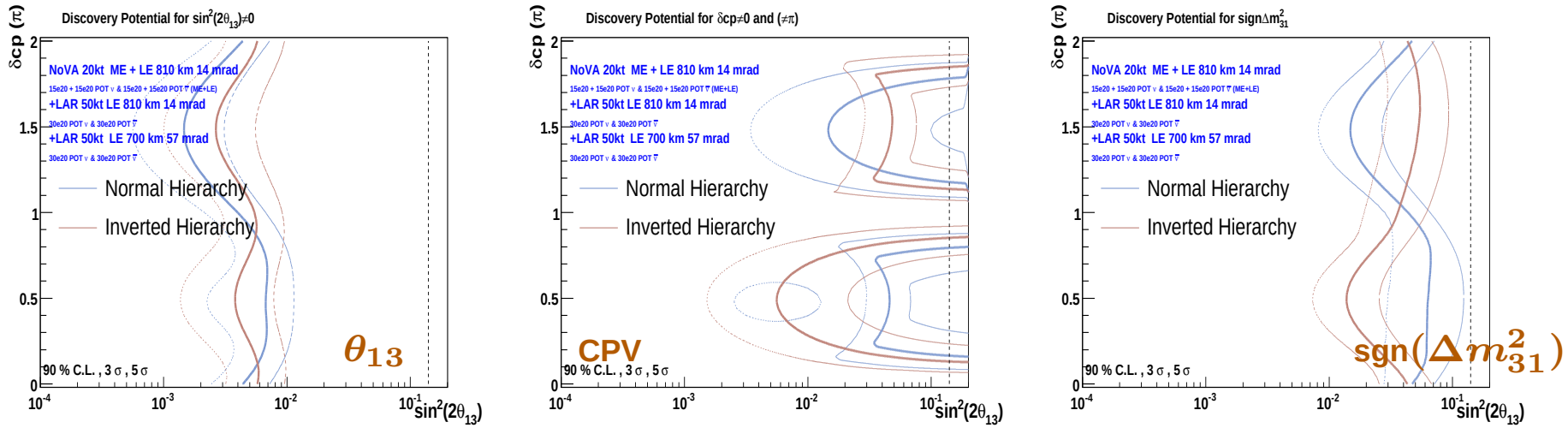


NuMI Off-axis

Discovery potential (90% C.L,3σ, 5σ) LAr. 100 kT at 810km , 1.2 MW, 6yrs:

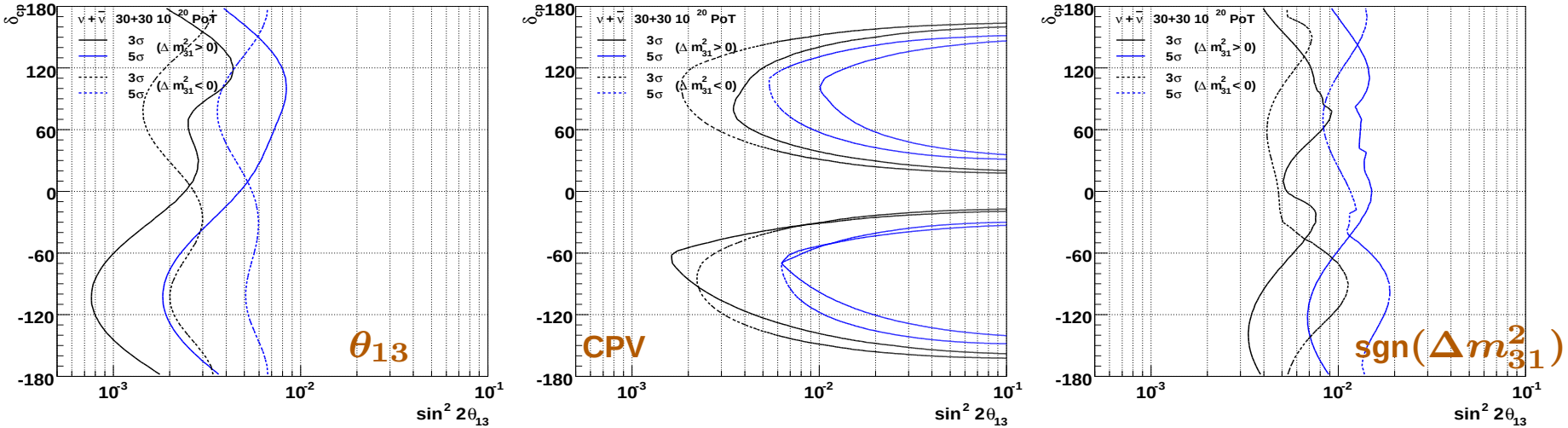


Discovery potential (90% C.L,3σ, 5σ) LAr. 2X50 kT at 700,810km , 1.2 MW, 6yrs:

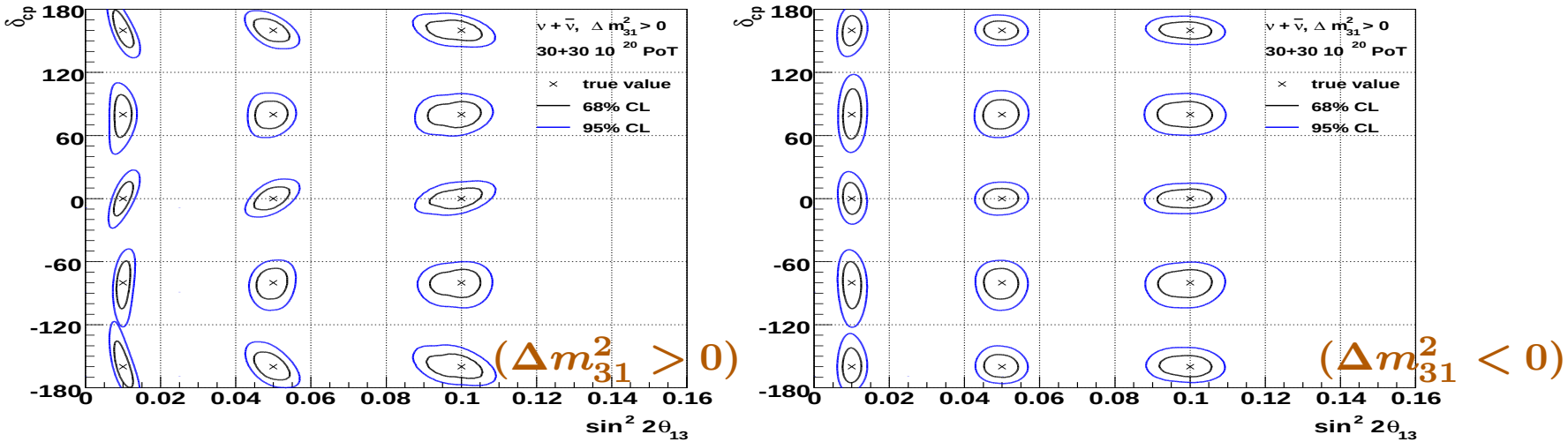


WBLE FNAL to DUSEL (1300km)

Discovery potential (— 5σ —3σ). LAr. 100 kT , 1.2 MW, 6yrs:

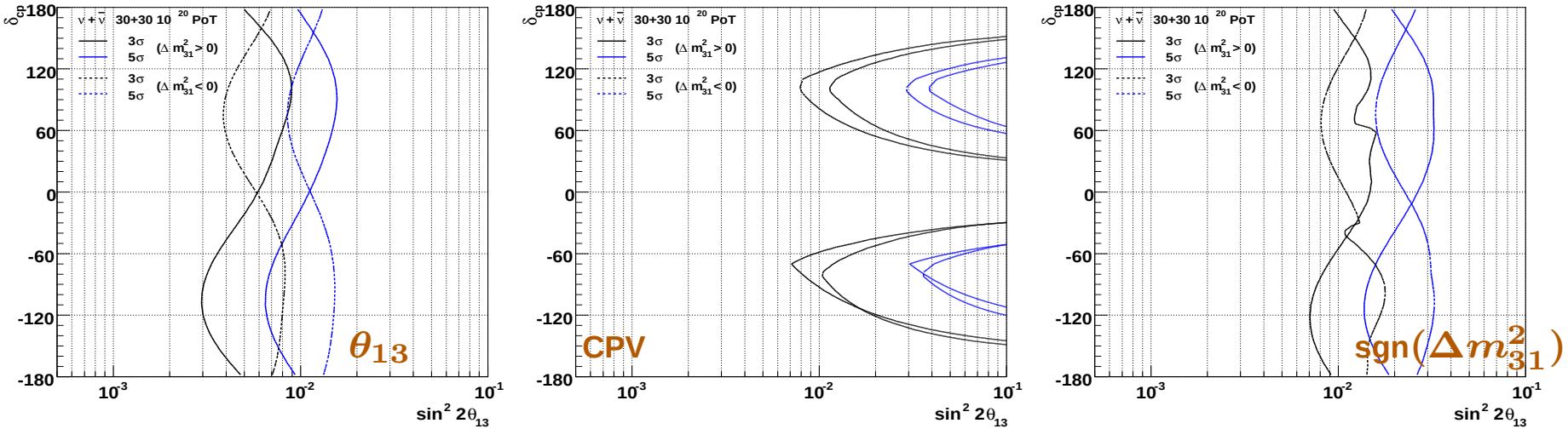


Measurement (—95% CL —68% CL) :

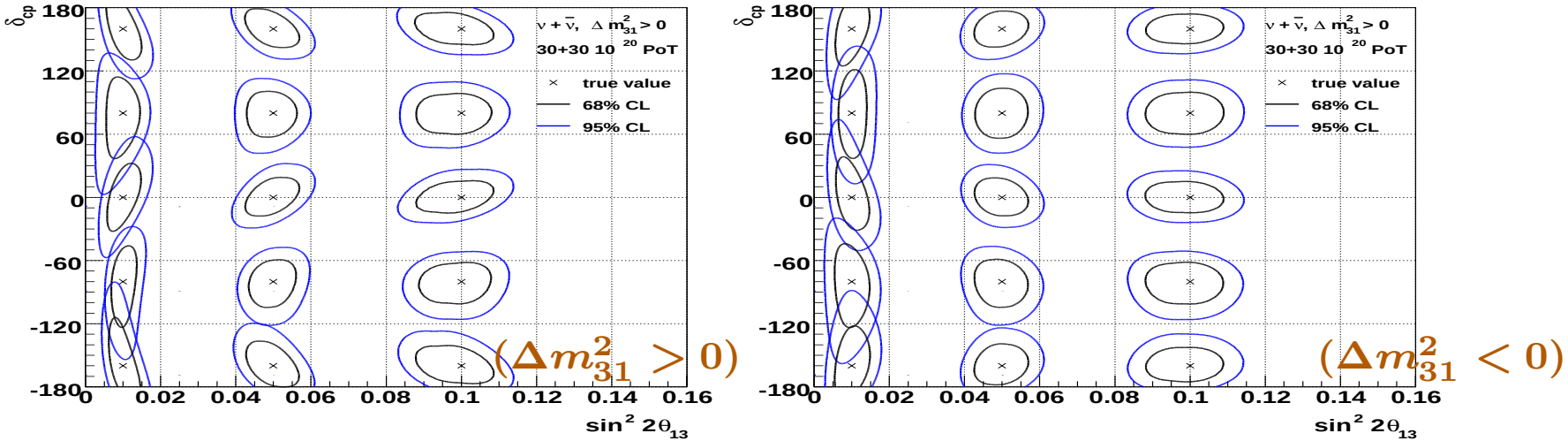


WBLE FNAL to DUSEL (1300km)

Discovery potential (—5σ —3σ). WCe. 300 kT , 1.2 MW, 6yrs:

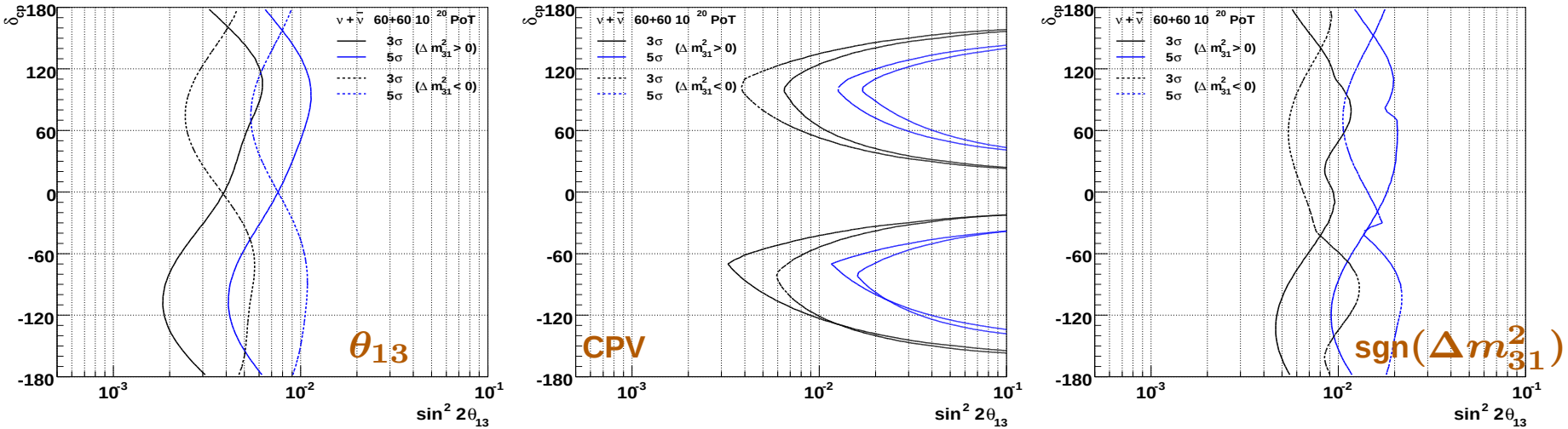


Measurement (—95% CL —68% CL) :

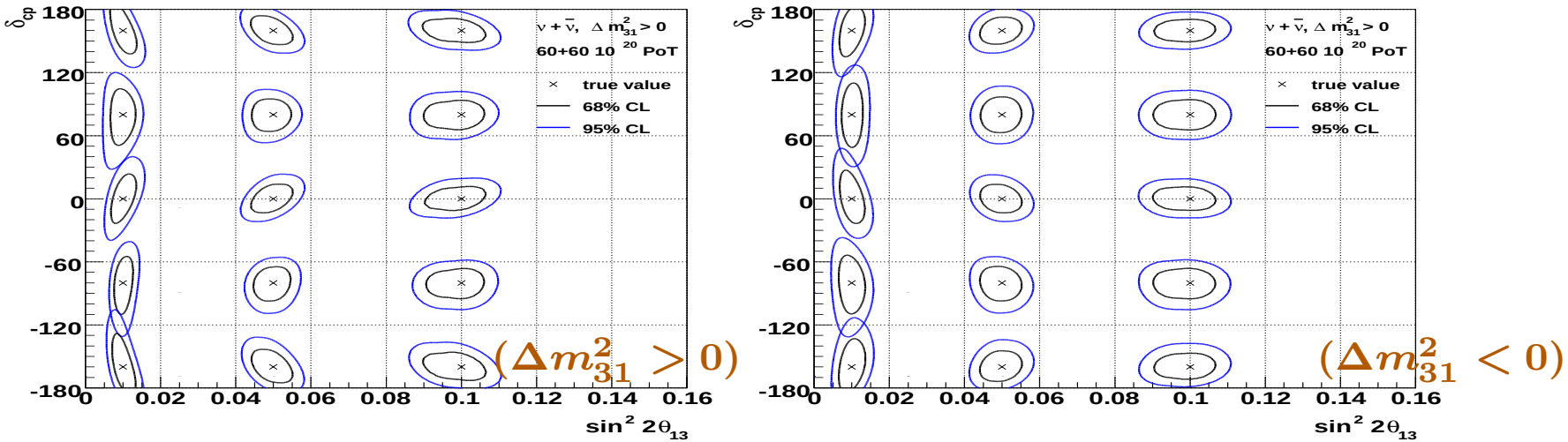


WBLE FNAL to DUSEL (1300km)

Discovery potential (— 5σ —3σ). WCe. 300 kT , 1.2 (2) MW, 12 (7) yrs:

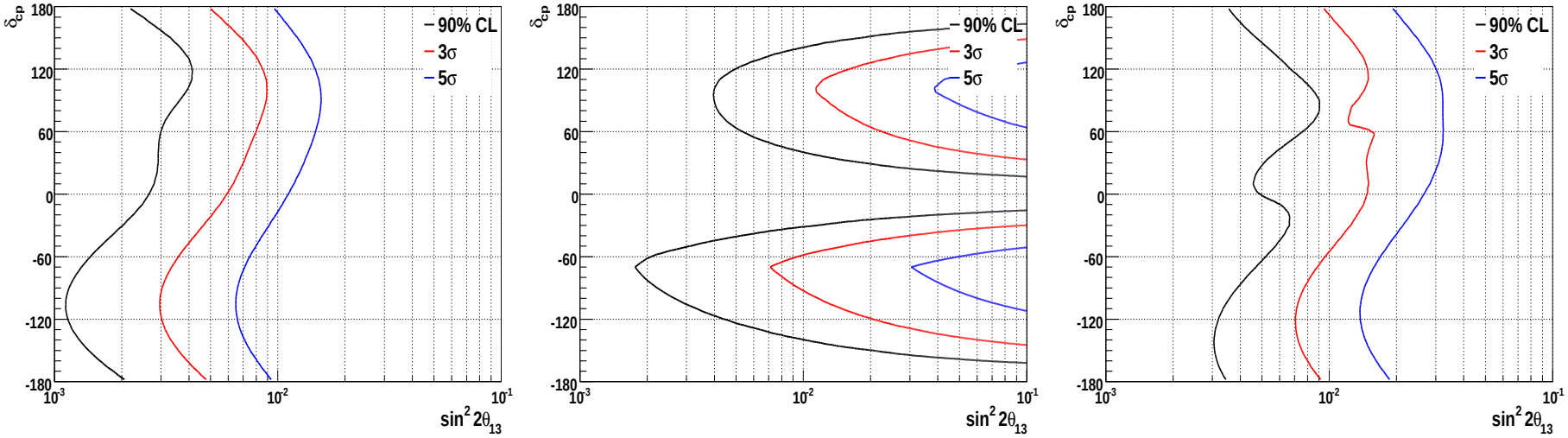


Measurement (—95% CL —68% CL) :

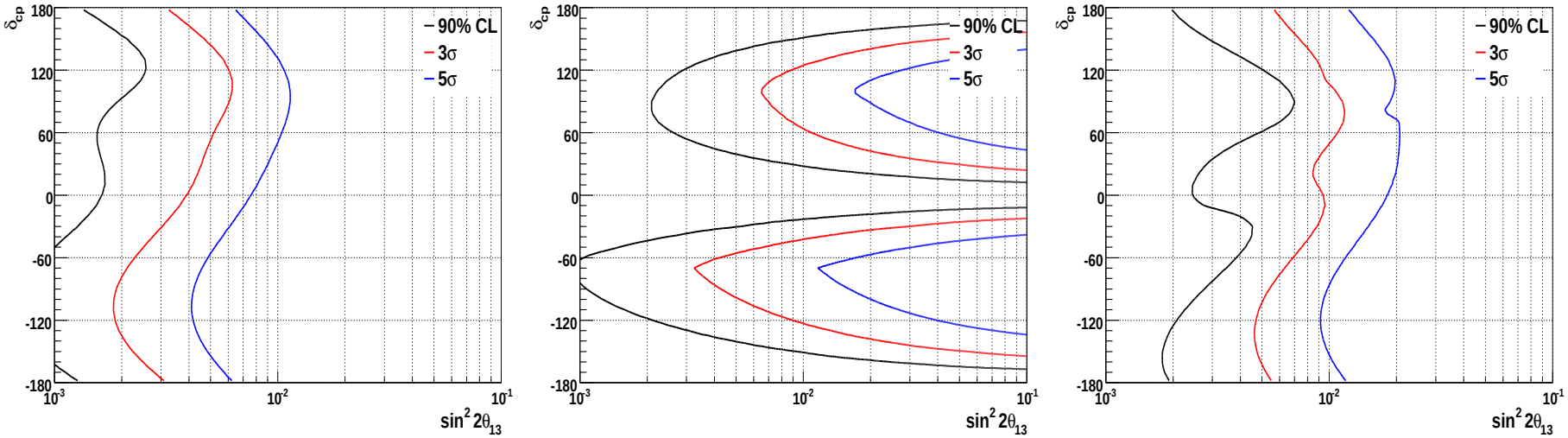


WBLE to DUSEL (1300km) + WCe

ν 30×10^{20} POT+ same for $\bar{\nu}$. WCe. 300 kT, 1.2 MW, 6yrs, normal.:

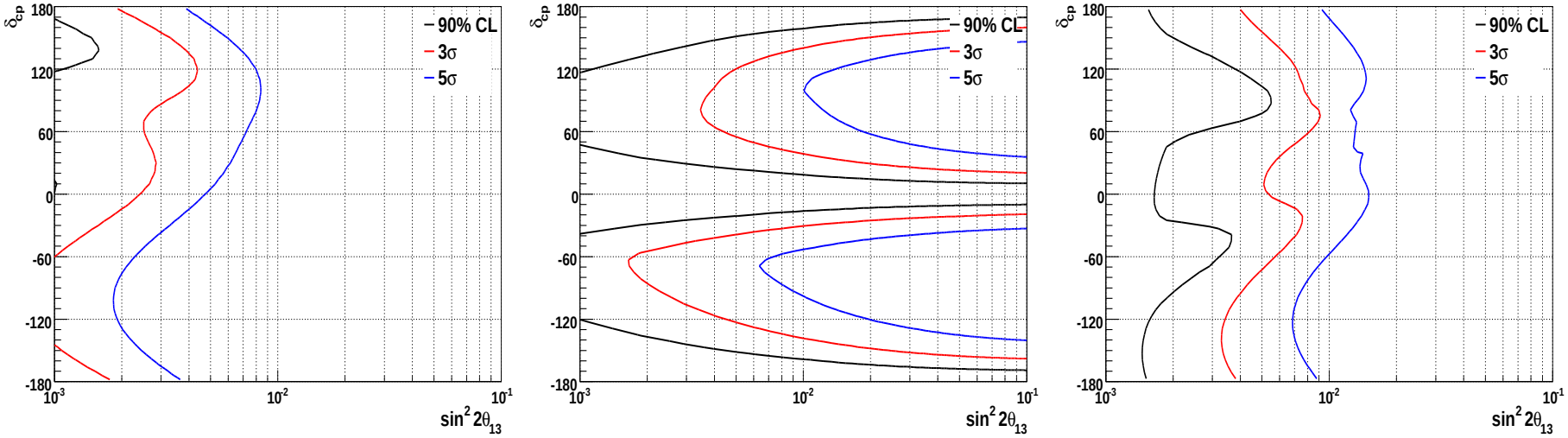


ν 60×10^{20} POT+ same for $\bar{\nu}$. WCe. 300 kT, 1.2 (2) MW, 12 (7) yrs, normal:



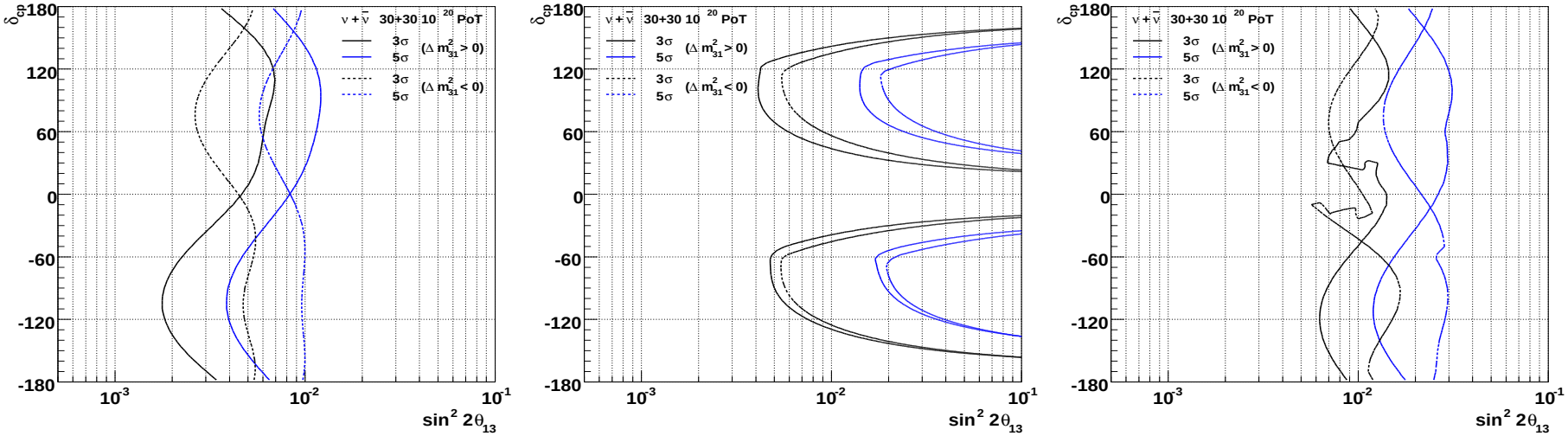
WBLE to DUSEL (1300km) + LAr

ν 30×10^{20} POT+ same for $\bar{\nu}$. LAr 100 kT, 1.2 MW beam, 6yrs, normal:

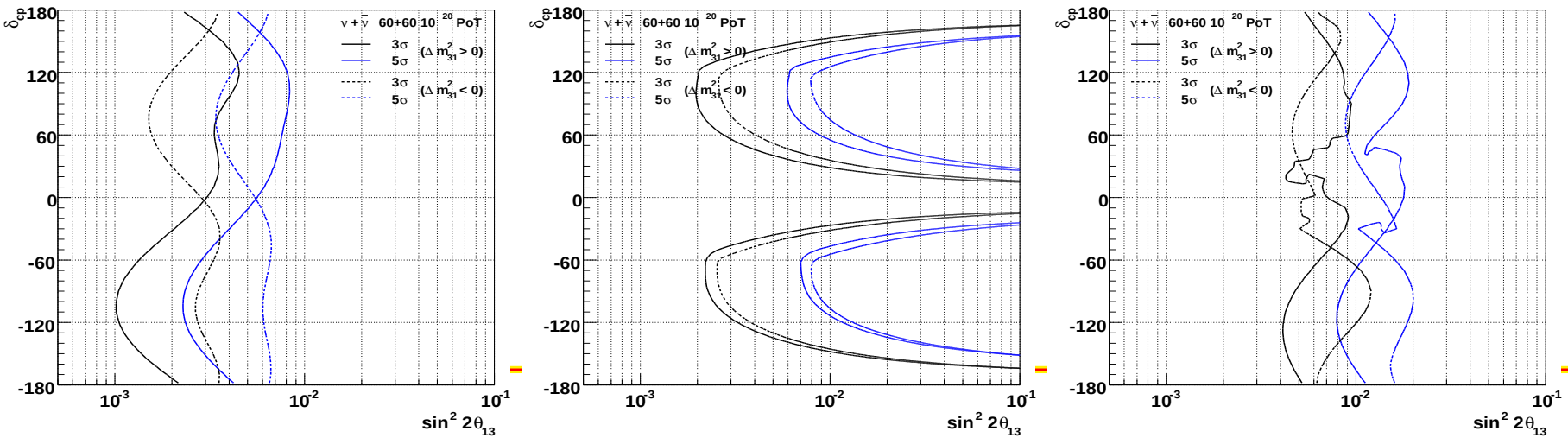


WBLE to DUSEL (1300km) + WCe

ν 30×10^{20} POT+ same for $\bar{\nu}$. WCe. 300 kT, 1.2 MW, 6yrs, stat only:

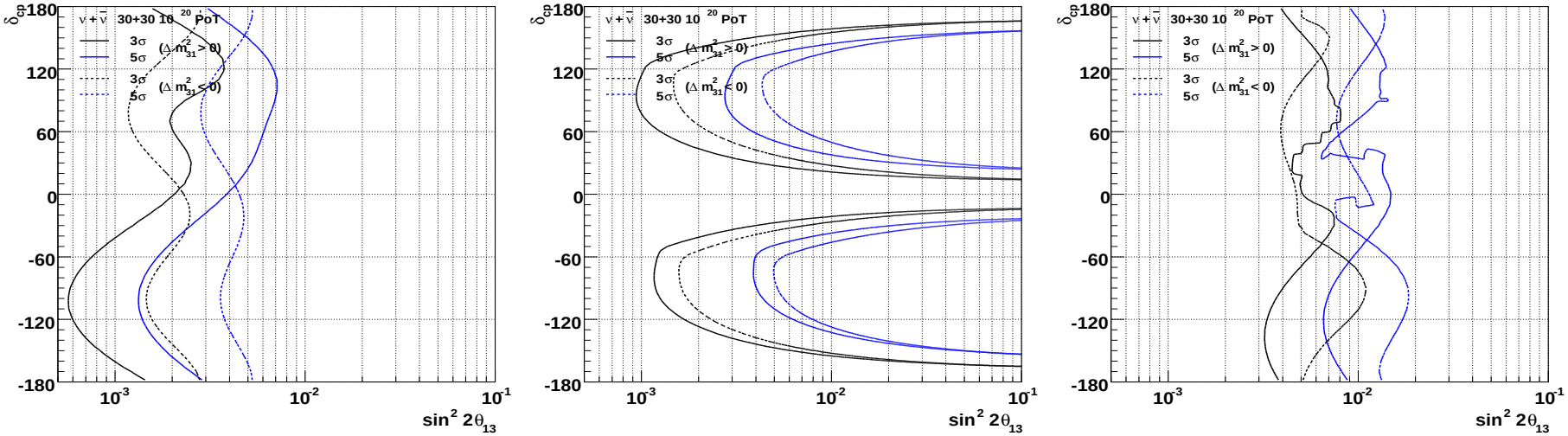


ν 60×10^{20} POT+ same for $\bar{\nu}$. WCe. 300 kT, 1.2 (2) MW, 12 (7) yrs, stat only:

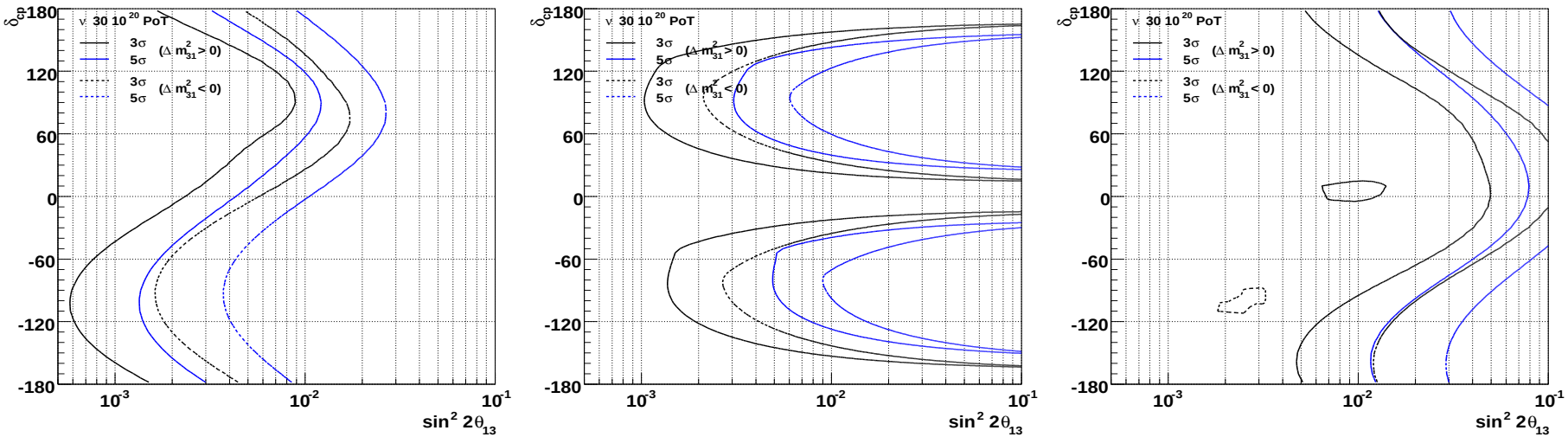


WBLE to DUSEL (1300km) + LAr

ν 30×10^{20} POT+ same for $\bar{\nu}$. LAr 100 kT, 1.2 MW beam, 6yrs, stat only:

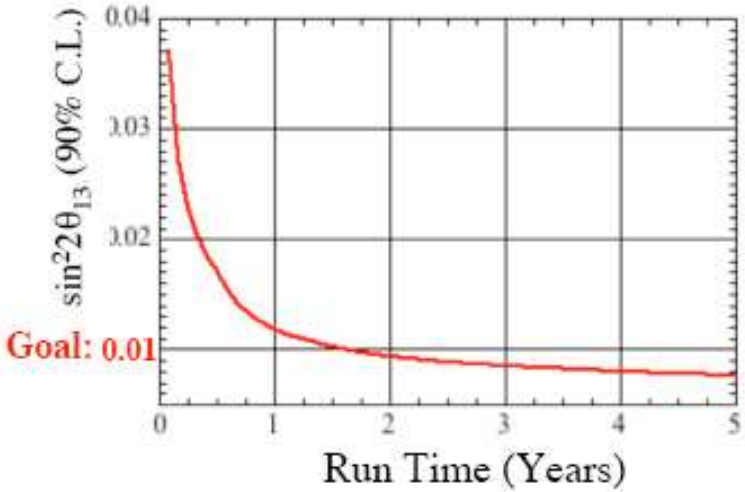


ν 30×10^{20} POT ONLY. LAr 100 kT, 1.2 MW beam, 3yrs, stat only:

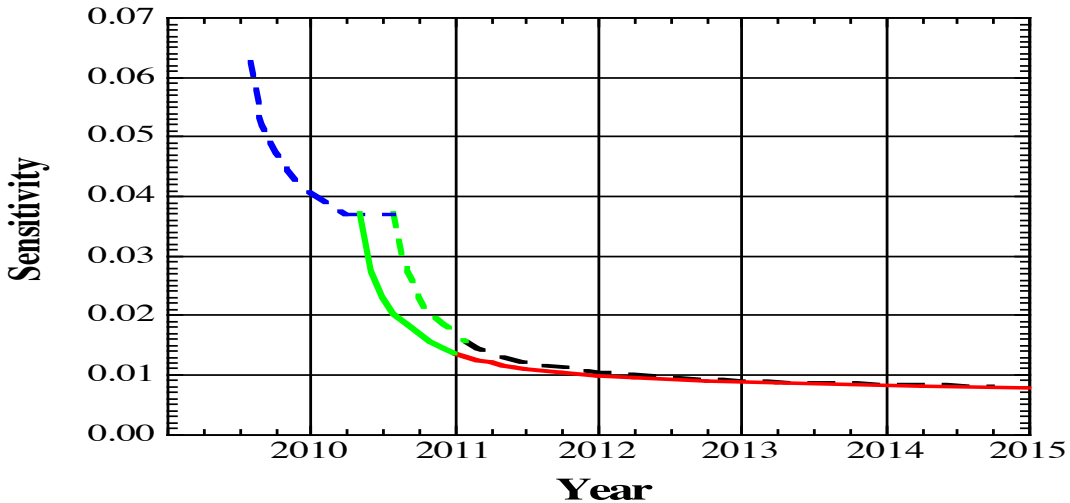


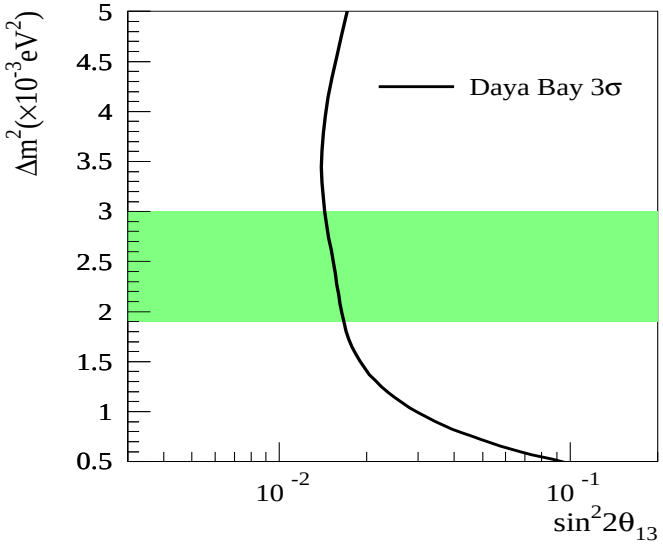
Daya Bay: Status and Plan

• Passed DOE scientific review	Oct 06
• Passed US CD-1 review	Apr 07
• Passed final nuclear safety review in China	Apr 07
• Began to receive committed project funding for 3 years from Chinese agencies	Apr 07
• Start civil construction	Jun 07
• Anticipate US CD-2/3a review	Oct 07
• Start data taking with 2 detectors at Daya Bay near hall	May 09
• Begin data taking with 8 detectors in final configuration	Apr 10



Daya Bay Sensitivity





Sensitivity reach at 90% CL

After 3 yrs of running

90% C.L. sensitivity limit for $\sin^2 2\theta_{13}$ at $\Delta m^2_{31} = 2.5 \times 10^{-3}$ eV^2 for different assumptions of detector related systematic uncertainties. 3 years running for each scenario:

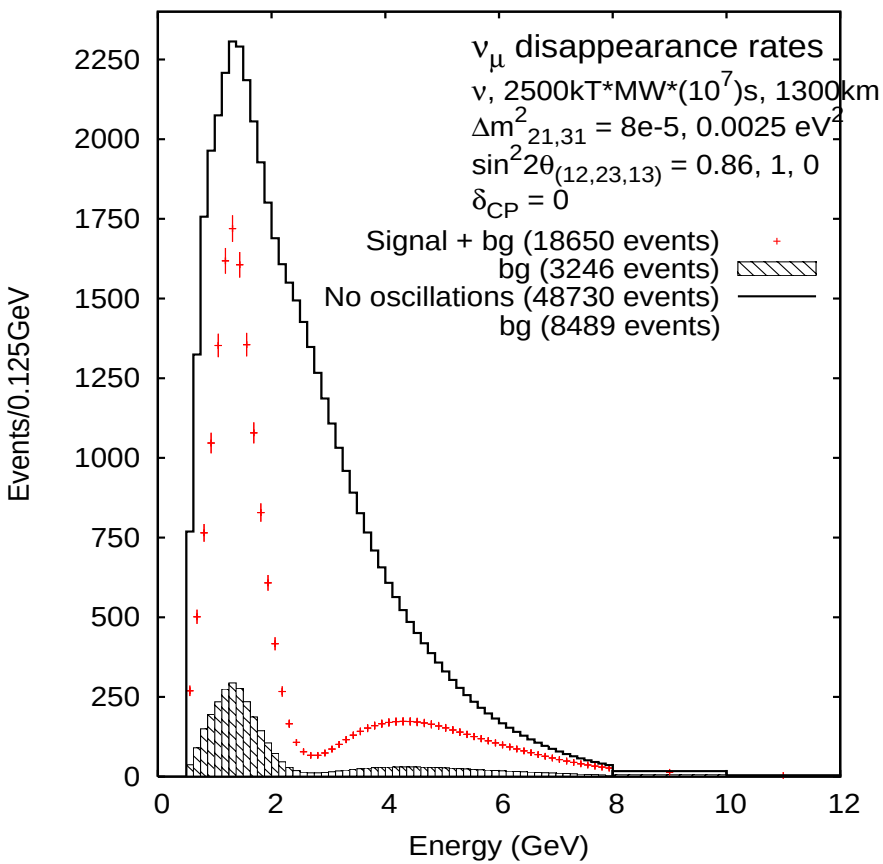
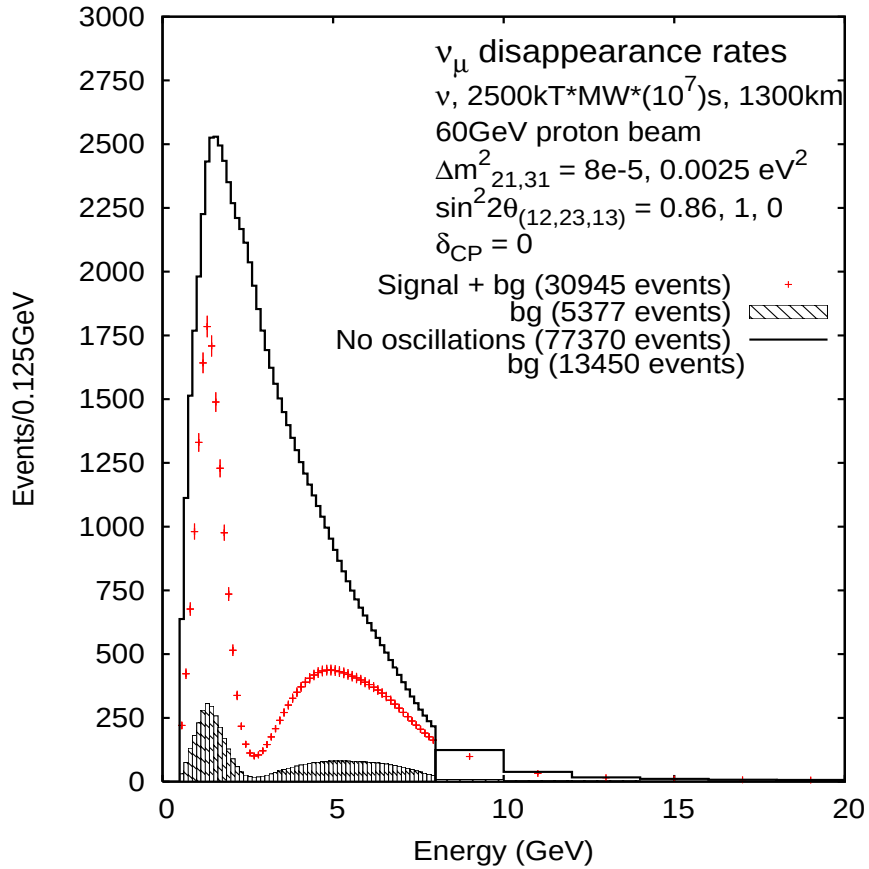
Systematic Uncertainty Assumptions:	Baseline	Goal	Goal with swapping
90% C.L. Limit:	0.008	0.007	0.006

WBLE ν_μ Disappearance Spectra

Parameterized WCe. Model in GLoBES.

1300km at 2500 MW.kT.10^7s.

WBB 28 GeV



WBLE 60 GeV