Report of the US long baseline neutrino study Part 1

Milind Diwan
Brookhaven National Laboratory

3/29/2007

Talk to the FNAL Physics Advisory Committee

FNAL/BNL study

- Chairs: Hugh Montgomery, Sally Dawson
- Advisory committee: F. Cervelli(INFN), M. Diwan(BNL), M. Goodman(ANL), B. Fleming(Yale), K. Heeger(LBL), T. Kajita (Tokyo), J. Klein(Texas), S. Parke(FNAL), R. Rameika(FNAL)
- Several small workshops were held last year.
- Many reports on physics sensitivity, backgrounds, and beam alternatives.
- Work of approximately 20-30 individuals at various levels.
- ~10 documents. ~2-3 publications could result

http://nwg.phy.bnl.gov/fnal-bnl/

Timescale:

The United States neutrino community is heavily engaged in operation and analysis of its existing program. On the other hand there are active discussions within advisory bodies and the agencies with a view to setting directions for future facilities inside the next year.

It would be desirable to see results of this **U.S. Long Baseline Neutrino Experiment Study** before October 2006, with a preliminary report by July 15, 2006.

Goals of workshop and study

U.S. Long Baseline Neutrino Experiment Study

Compare the neutrino oscillation physics potential of:

1. A broad-band proposal using a either an upgraded beam of around 1 MW from the current Fermilab accelerator complex or a future Fermilab Proton Driver neutrino beam aimed at a DUSEL-based detector. Compare these results with those previously obtained for a high intensity beam from BNL to DUSEL.

2. Off-Axis next generation options using a 1-2 MW neutrino beam from Fermilab and a liquid argon detector at either DUSEL or as a second detector for the Nova experiment.

Considerations of each should include:

i) As a function of θ_{13}, the ability to establish a finite θ_{13}, determine the mass hierarchy, and search for CP violation and, for each measurement, the limiting systematic uncertainties.

ii) The precision with which each of the oscillation parameters can be measured and the ability to therefore discriminate between neutrino mass models.

iii) Experiment Design Concepts including:

Optimum proton beam energy
Optimum geometries
Detector Technology
Cost Guesstimate

A draft report has been assembled and shared with NUSAG panel

List is not yet complete.

Several outside the working group have reviewed the draft.

Report of the US long baseline neutrino experiment study

FNAL-numbers
BNL-numbers-IR

D. Bogert, D. Finley, C. Laughton, S. Pordes, A. Marchionni, R. Rameika, N. Saoulidou, R. Zwaska,[1] M. Bishai, M. Diwan, M. Dierckxsens, H. Kirk, N. Simos, W. Marciano, Z. Parsa, B. Viren,[2] C. Bromberg,[3] B. Flemming, A. Curioni,[4] C. K. Jung, C. Yanagisawa,[5] Fanny Dufour, E. Kearns,[6] T. Kirk, E. Zimmerman,[7] P. Huber, V. Barger,[8] D. Marfatia,[9] K. Lande, A. K. Mann, R. Van Berg,[10] K. Lesko, W. Y. Lee,[11] M. Messier,[12] K. Whisnant,[13] W. Pariseau,[14] P. Litchfield,[15] and R. Potenza[16]

[1]*Fermi National Accelerator Laboratory*
[2]*Brookhaven National Laboratory*
[3]*Michigan State University*
[4]*Yale University*
[5]*State University of New York, Stonybrook*
[6]*Boston University*
[7]*University of Colorado*
[8]*University of Wisconsin*
[9]*University of Kansas*
[10]*University of Pennsylvania*
[11]*Lawrence Berkeley National Laboratory*
[12]*Indiana University*
[13]*Iowa State University*
[14]*University of Utah*
[15]*University of Minnesota*
[16]*University Di Catania*

(Dated: March 29, 2007)

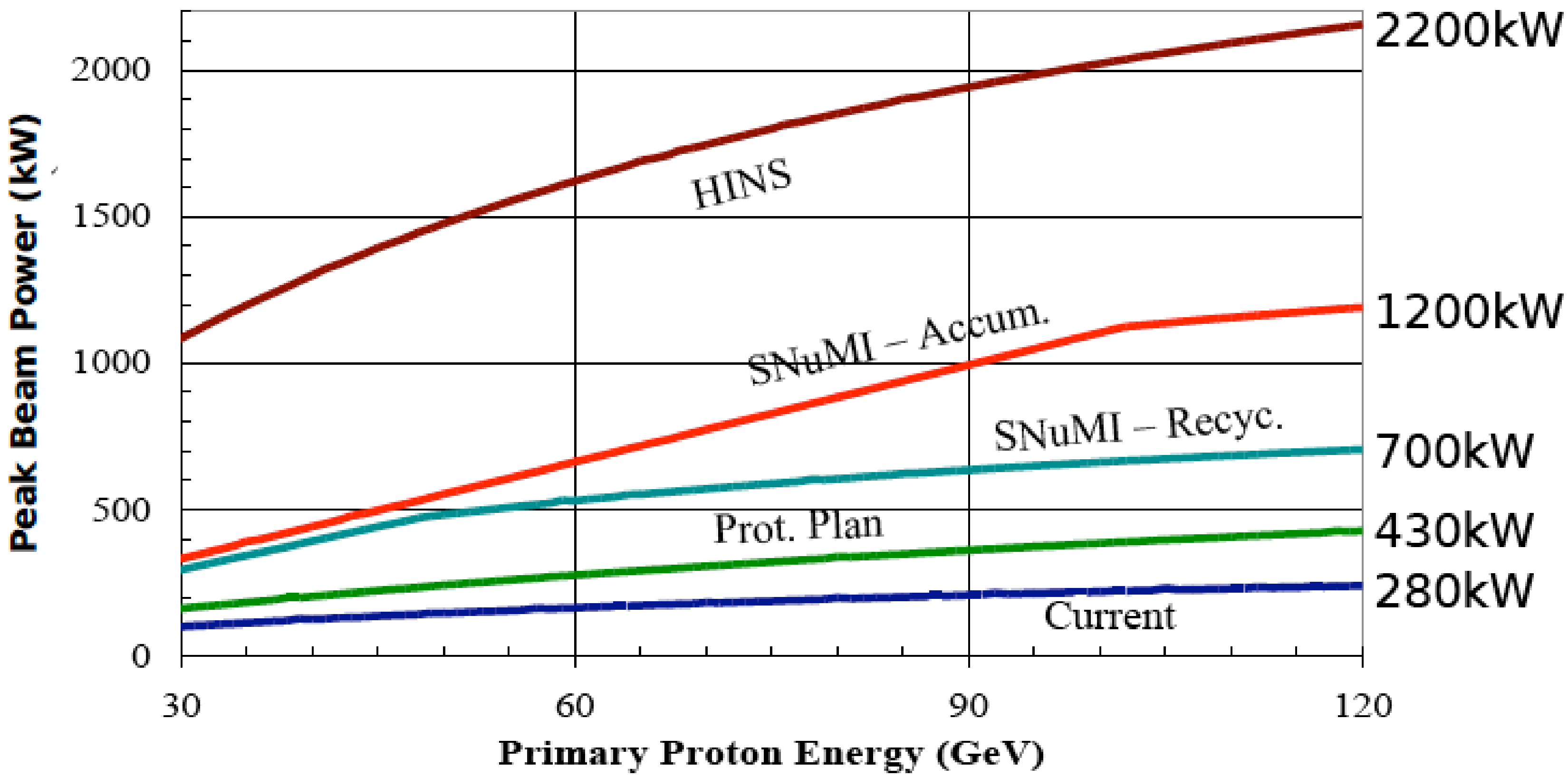
DRAFT

What I will cover

- Event rate calculations for the scenarios in the study.
- Water Cherenkov detector design and performance at DUSEL.
- Liquid Argon technical progress.
- Physics sensitivity with detectors at DUSEL.
- Timeline discussion for DUSEL based project.

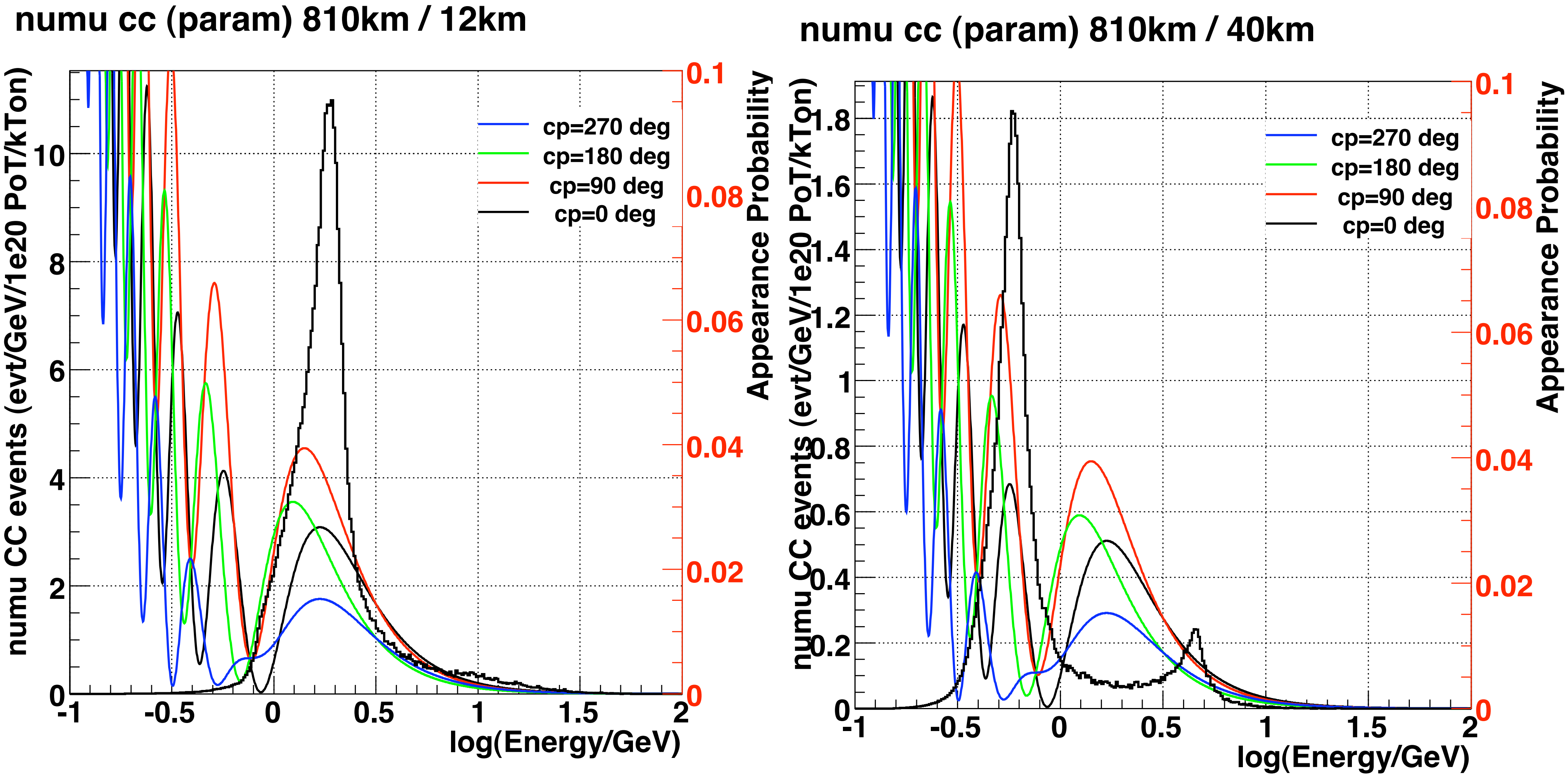
Beam from FNAL

Flexibility of proton energy:



1 MW* 10^7 sec = 5.2 10^20 POT at 120 GeV

off-axis spectra with LE tune



sin^22t13 =0.04

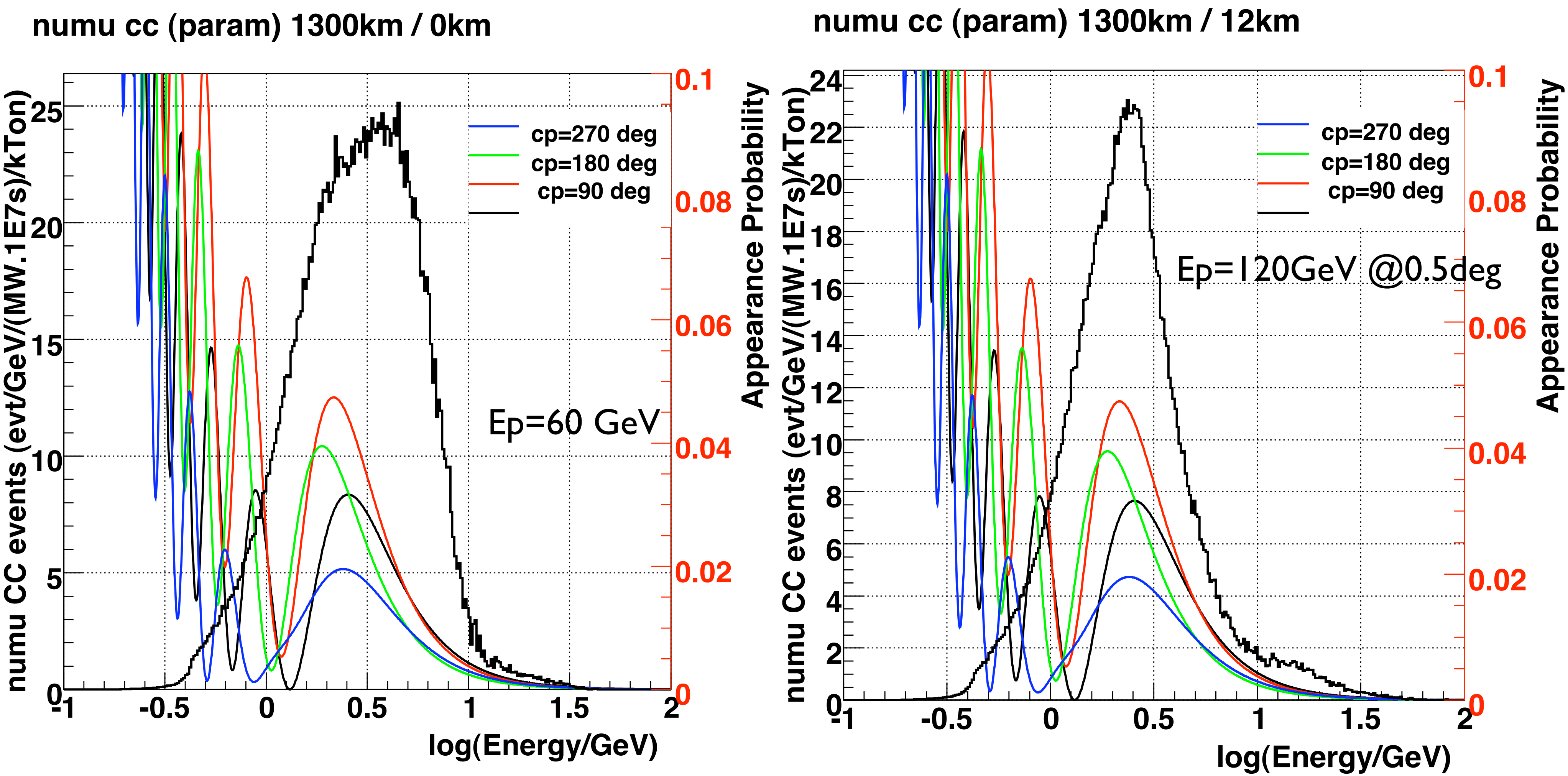
- 12 km (nova-I) CCrate: ~16.2 per (kT*10^20 POT)
- 40 km (nova-II)CCrate: ~1.0 per (kT*10^20 POT)

Office of Science U.S. DEPARTMENT OF ENERGY

M.Diwan

BROOKHAVEN NATIONAL LABORATORY

Spectra FNAL to DUSEL (WBLE:wide band low energy)



- 60 GeV at 0deg: CCrate: 14 per (kT*10^20 POT)
- 120 GeV at 0.5deg:CCrate: 17 per(kT*10^20POT)

Work of M. Bishai and B.Viren using NuMI simulation tools

Office of Science U.S. DEPARTMENT OF ENERGY

BROOKHAVEN NATIONAL LABORATORY

M.Diwan

ν_e Appearance Rates

$\Delta m^2_{21,31} = 8.6 \times 10^{-5}, 2.5 \times 10^{-3}$ 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

Detector design considerations.

- Need ~100kT of fiducial mass with good efficiency.
- At this mass scale cosmic ray rate becomes the driving issue for detector placement and design.

Cosmic rate in 50m h/dia detector in 10 mus for 10^7 pulses

Intime cosmics/yr	Depth (mwe)
5×10^7	0
4230	1050
462	2000
77	3000
15	4400

If detector is placed on the surface it must have cosmic rejection of ~10^8 for muons and 10^4 for gammas beyond accelerator timing.
=> fully active fine grained detector.

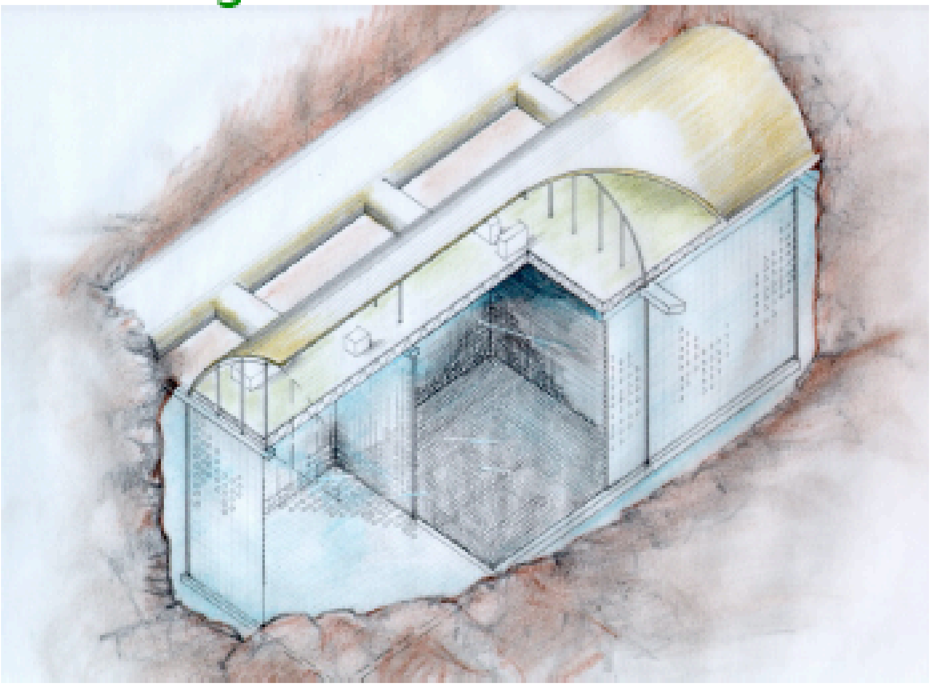
LARTPC
www-lartpc.fnal.gov

- The LAR group has shown an advantage of about a factor 3-4 over a water Cherenkov detector of equal mass due to better background rejection. There is no easy automated event analysis, however.
- A 50 m high/dia tank on surface has 500 kHz of rate. LARTPC could take data around beamtime, but still need rejection of 10^8 on muons and 10^3-10^4 on gammas. This needs further work.
- To reach 100 kT, aggressive R&D path is needed including argon purity, industrial tank technology, readout geometry and signal/noise. First step : 1 kT before cost and schedule could be properly evaluated. Current scaling law is $2.7M+$0.3M/kT + $1M/kTon (for LAR).
- For $p \rightarrow K^+\nu$ decay mode depth is needed simply for data rate, and most likely for background.

Detector at Henderson

UNO detector:

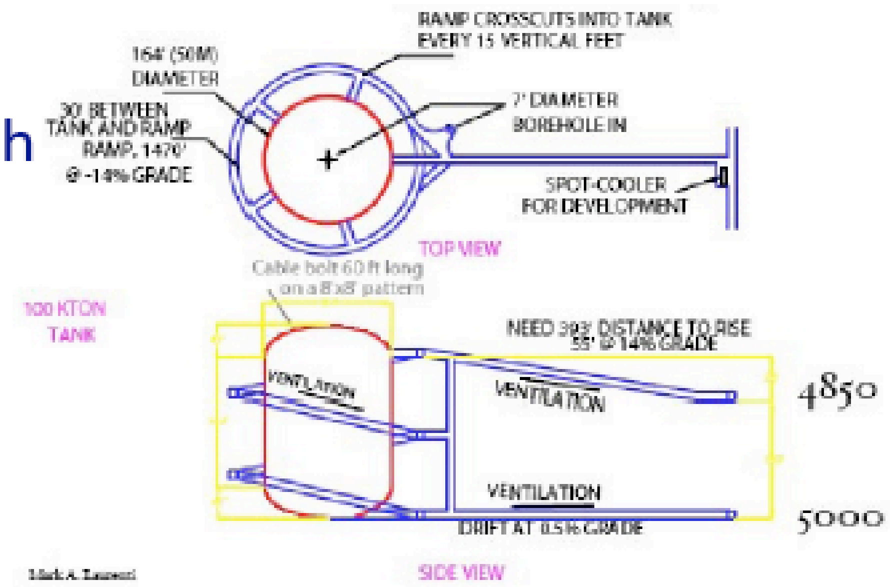
- 1 large cavern
- 3 optically separated modules of 60x60x60 m^3
- total mass 440 kT fiducial
- central module 40% PMT coverage (low E physics)
- outer modules 10% PMT coverage
- optional finer granularity: 20 or 13 inch tubes
- optimal depth 5400mwe (2500 feet)
- construction time: 10 years
- coarse cost estimate scaling Super-K: $500M



Detector at Homestake

Modular detector:

- module: ~50m ∅, ~50m h
- 100kT fiducial
- depth 4850 mwe
- coverage 25%
- 12 inch PMT



cosmic rate
~0.1Hz

- initial detector 3 modules
- expand to 10 modules (or more) to get Mt detector
- detailed cost estimate: $100M/module

"Proposal for an Experimental Program in Neutrino Physics and Proton Decay in the Homestake Laboratory", M. Diwan et al., hep-ex/0608023

Fiducial vol depends on rock stability studies and PMT pressure rating.

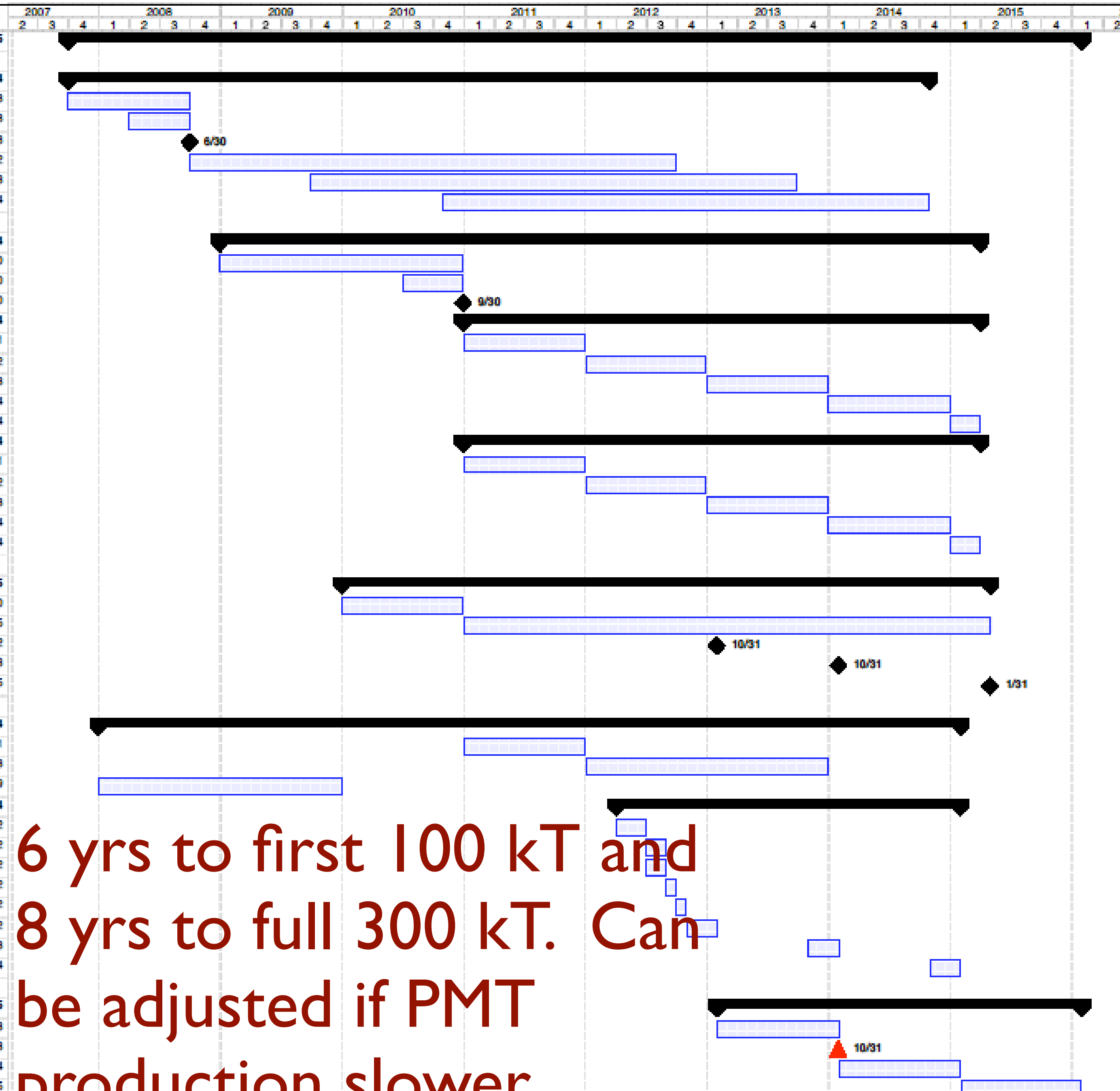
Summary cost ($FY07) for 300kT at Homestake

Cavity construction (30% contingency)	$78.9M
PMT+electronics	$171.3M
Installation+testing	$35.7M
R&D,Water, DAQ, etc.	$8.2M
Contingency(non-civil)	$50.8M
Total	$344.9M

- Cost for 3 modules of ~100kT fiducial mass.
- Civil cost recently reviewed by RESPEC (consultants) and found to be consistent with other projects. (In addition, construction could be faster).
- Consultations with C. Laughton and Homestake on overhead factors (not included in civil).

Long Baseline Neutrinos + PDK
Schedule No. 2

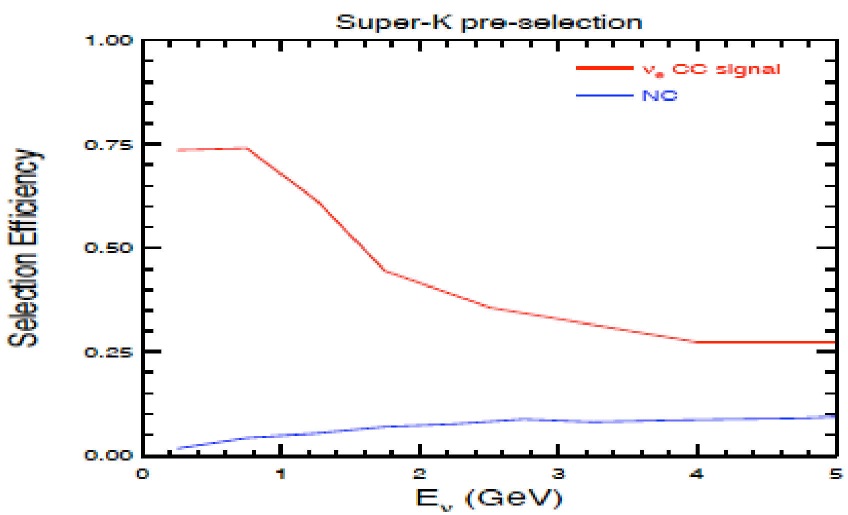
ID	Task Name	Start	Finish
1	**Long Baseline Neutrinos + PDK**	7/2/07	10/30/15
2			
3	**Chamber Construction**	7/2/07	7/30/14
4	Chamber R&D	7/2/07	6/30/08
5	Contract Process	1/1/08	6/30/08
6	Chamber Construction Contract Award	6/30/08	6/30/08
7	Module 1	7/1/08	6/29/12
8	Module 2	7/1/09	6/28/13
9	Module 3	8/2/10	7/30/14
10			
11	**PMs**	10/1/08	12/31/14
12	PM R&D	10/1/08	9/30/10
13	Contract Process	4/1/10	9/30/10
14	PMs Contract Award	9/30/10	9/30/10
15	**Vendor 1**	10/1/10	12/31/14
16	Qty 10,000 PMs	10/1/10	9/30/11
17	Qty 20,000 PMs	10/3/11	9/28/12
18	Qyt 20,000 PMs	10/1/12	9/30/13
19	Qty 20,000 PMs	10/1/13	9/30/14
20	Qty 5,000 PMs	10/1/14	12/31/14
21	**Vendor 2**	10/1/10	12/31/14
22	Qty 10,000 PMs	10/1/10	9/30/11
23	Qty 20,000 PMs	10/3/11	9/28/12
24	Qyt 20,000 PMs	10/1/12	9/30/13
25	Qty 20,000 PMs	10/1/13	9/30/14
26	Qty 5,000 PMs	10/1/14	12/31/14
27			
28	**Testing**	10/1/09	1/31/15
29	Test Facility	10/1/09	9/30/10
30	Testing of PMs	10/1/10	1/30/15
31	1st Module PMs ready for Installation	10/31/12	10/31/12
32	2nd Module PMs ready for Installation	10/31/13	10/31/13
33	Final Module PMs ready for Installation	1/31/15	1/31/15
34			
35	**Other Equipment**	10/1/07	10/31/14
36	Calibration Equipment R&D	10/1/10	9/30/11
37	Calibration Equipment	10/3/11	9/30/13
38	Development Labor	10/1/07	9/29/09
39	**Water Purification**	1/2/12	10/31/14
40	Purchase Order	1/2/12	3/30/12
41	Vendor	4/2/12	5/31/12
42	Shop Conversion	4/2/12	5/31/12
43	Install Water Systems (3 systems)	6/1/12	6/29/12
44	Test Water (to see if suitable)	7/2/12	7/31/12
45	Fill up 1st Chamber	8/1/12	10/31/12
46	Fill up 2nd Chamber	8/1/13	10/31/13
47	Fill up 3rd Chamber	8/1/14	10/31/14
48			
49	**Installation**	11/1/12	10/30/15
50	Module 1	11/1/12	10/31/13
51	Physics Turn-On	10/31/13	10/31/13
52	Module 2	11/1/13	10/31/14
53	Module 3	11/3/14	10/30/15



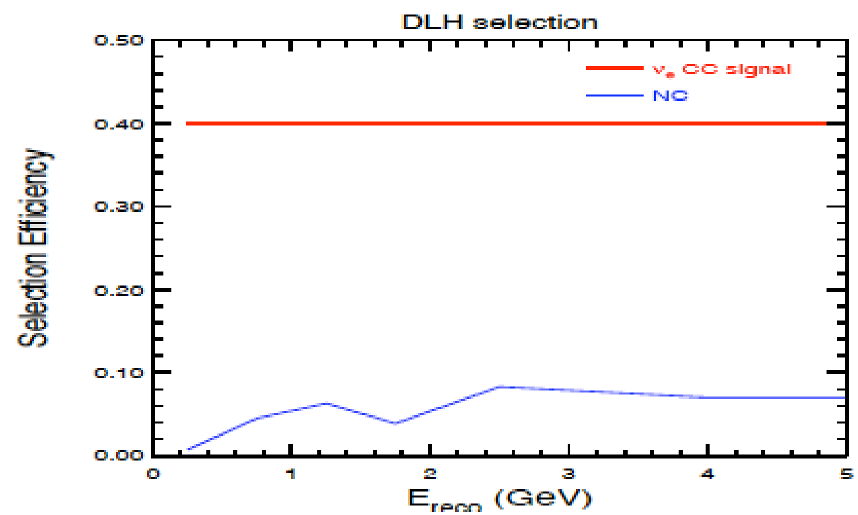
6 yrs to first 100 kT and 8 yrs to full 300 kT. Can be adjusted if PMT production slower.

Water Cherenkov performance

- Full simulation of SuperKamiokande atmospheric neutrino events used in evaluation.
- Study to establish feasibility, not optimized with respect to PMT granularity and coverage.



Standard Super-K pre-selection efficiencies



DLH selection efficiencies (Chiaki Y.)

Delta Likelihood selection allows for tuning S/B.

Work of StonyBrook UNO group: Yanagisawa, Jung, Lee

Office of Science
U.S. DEPARTMENT OF ENERGY

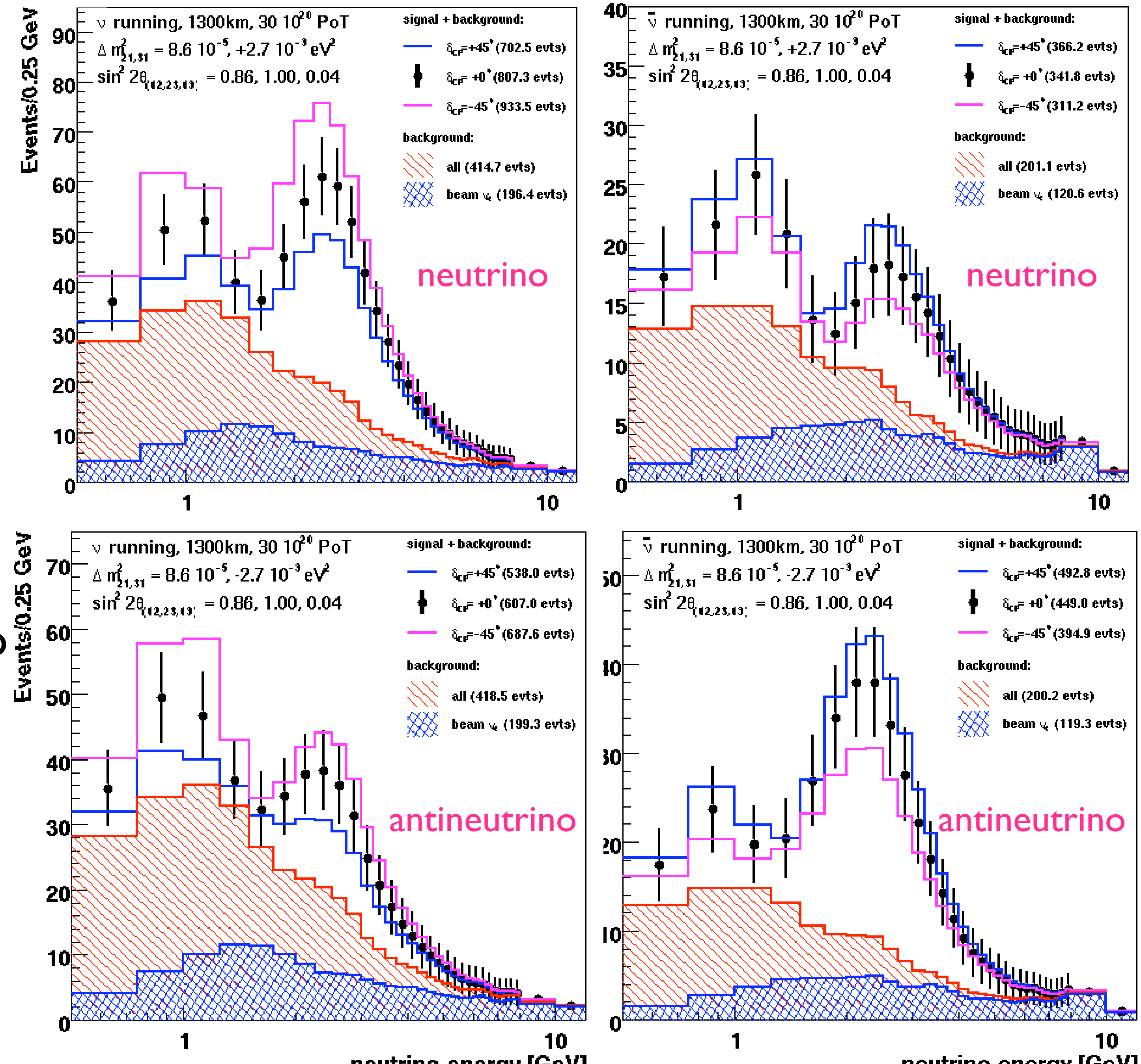
BROOKHAVEN
NATIONAL LABORATORY

Electron neutrino appearance spectra

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

$(-\ \delta_{cp} = -45^\circ,\ -\ \delta_{cp} = +45^\circ)$

- All background sources are included.
- S/B ~ 2 in peak.
- NC background about same as beam nue backg.
- For normal hierarchy sensitivity will be from neutrino running.
- For reversed hierarchy anti-neutrino running essential.
- Better efficiency at low energies expected with higher PMT counts.



Electron neutrino appearance spectra

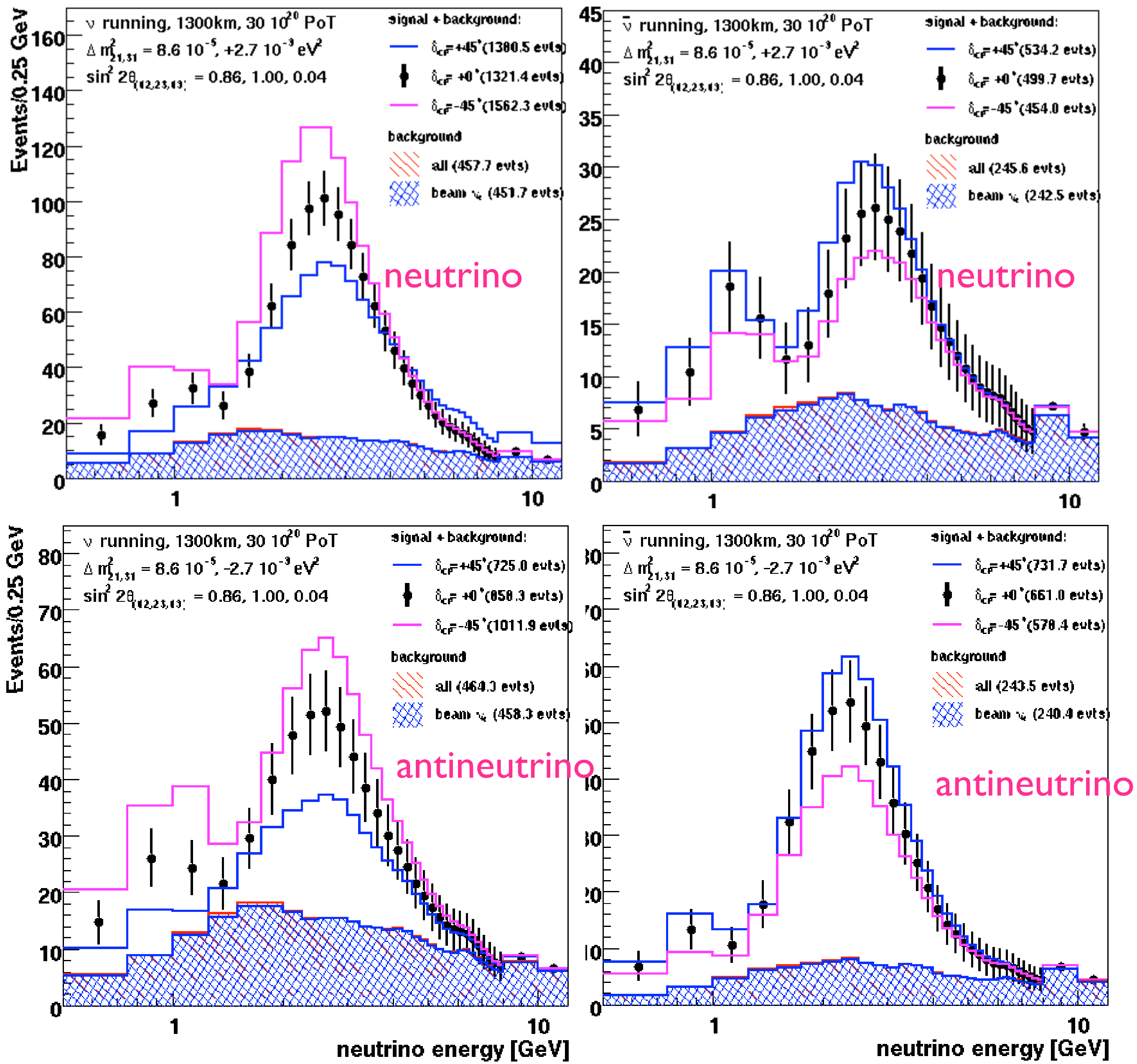
$\sin^2 2\theta_{13} = 0.04$, 100kT LAr. , WBLE 120 GeV, 1300km, 30E20 POT.

$(-\,\delta_{cp} = -45°, -\,\delta_{cp} = +45°)$

- LAR assumptions
- 80% efficiency on electron neutrino CC events.
- sig(E)/E = 5%/sqrt(E) on quasielastics
- sig(E)/E = 20%/sqrt(E) on other CC events

Spectra and sensitivity is the work of Mark Dierckxsens and Patrick Huber + many helpers

Normal | Reversed



WBLE to DUSEL(1300km) 3sig, 5sig discovery regions.

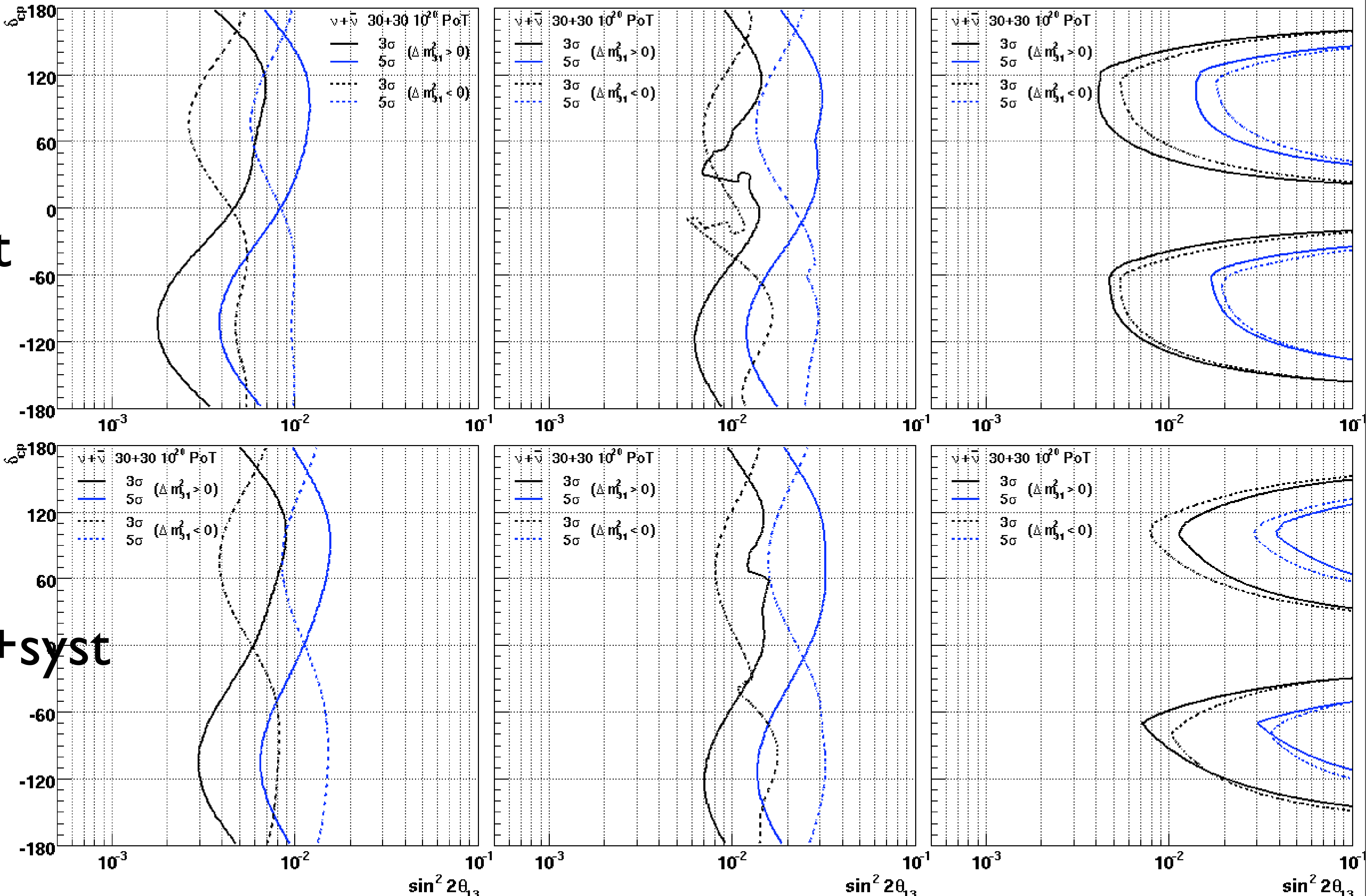
300 kT WCh

30 10^20 POT for each nu and anu

th13 | mass ordering | CP violation

Stat

Stat+syst



WBLE to DUSEL(1300km) 3sig, 5sig discovery regions.

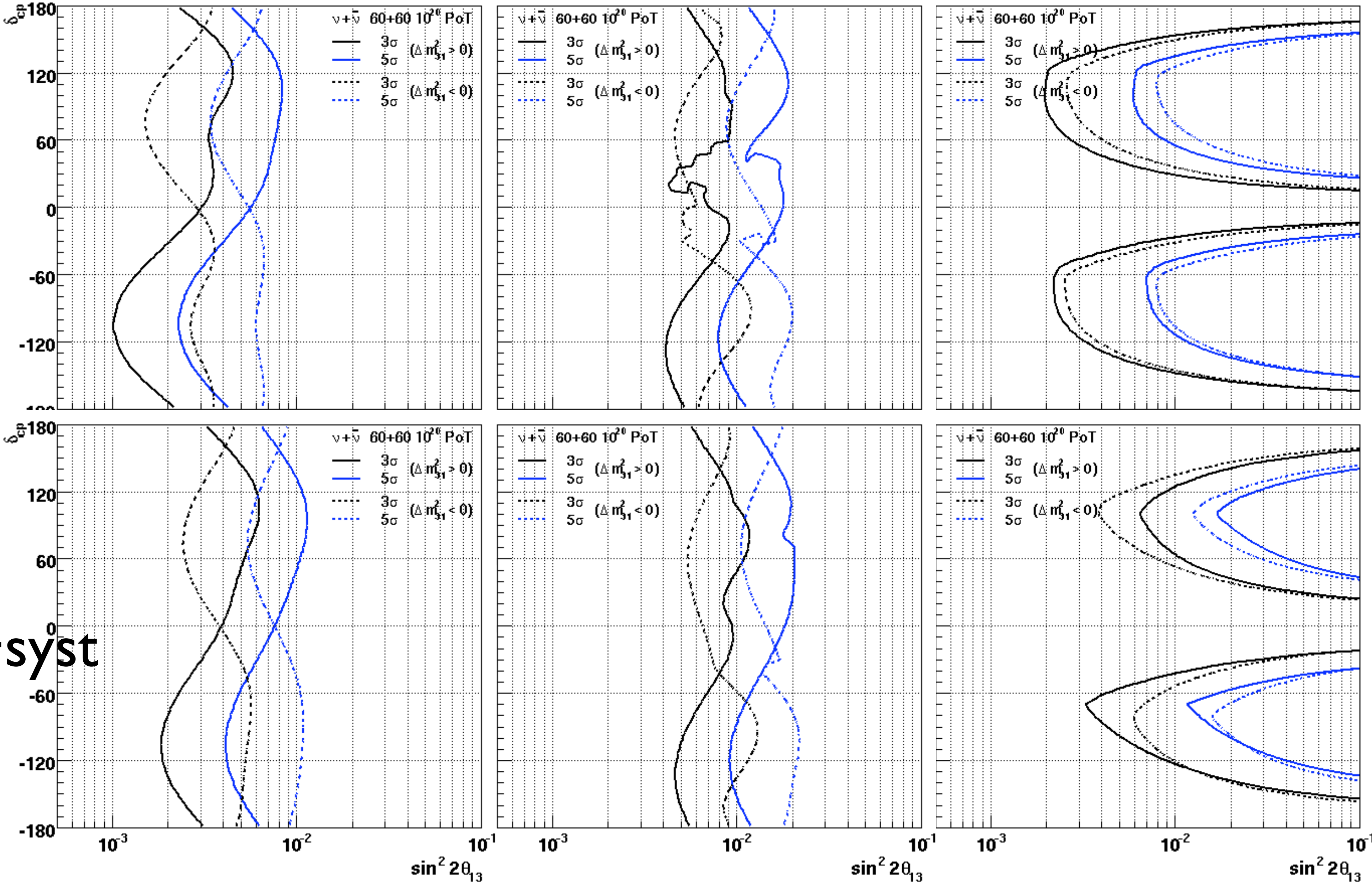
300 kT WCh

60 10^20 POT for each nu and anu

th13 | mass ordering | CP violation

Stat

Stat+syst



WBLE to DUSEL(1300km) 3sig, 5sig discovery regions.

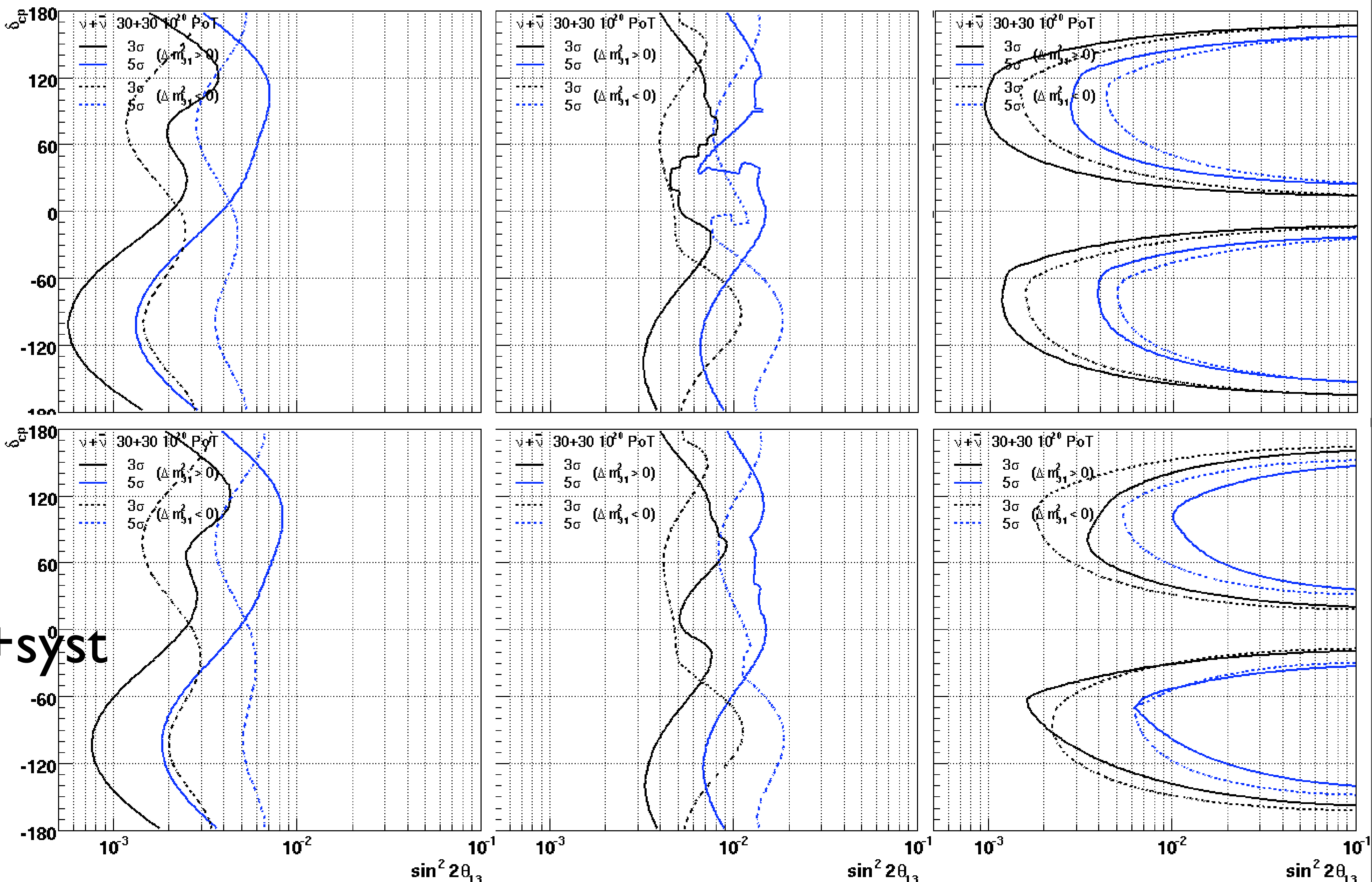
100 kT LAR

30 10^20 POT for each nu and anu

th13 | mass ordering | CP violation

Stat

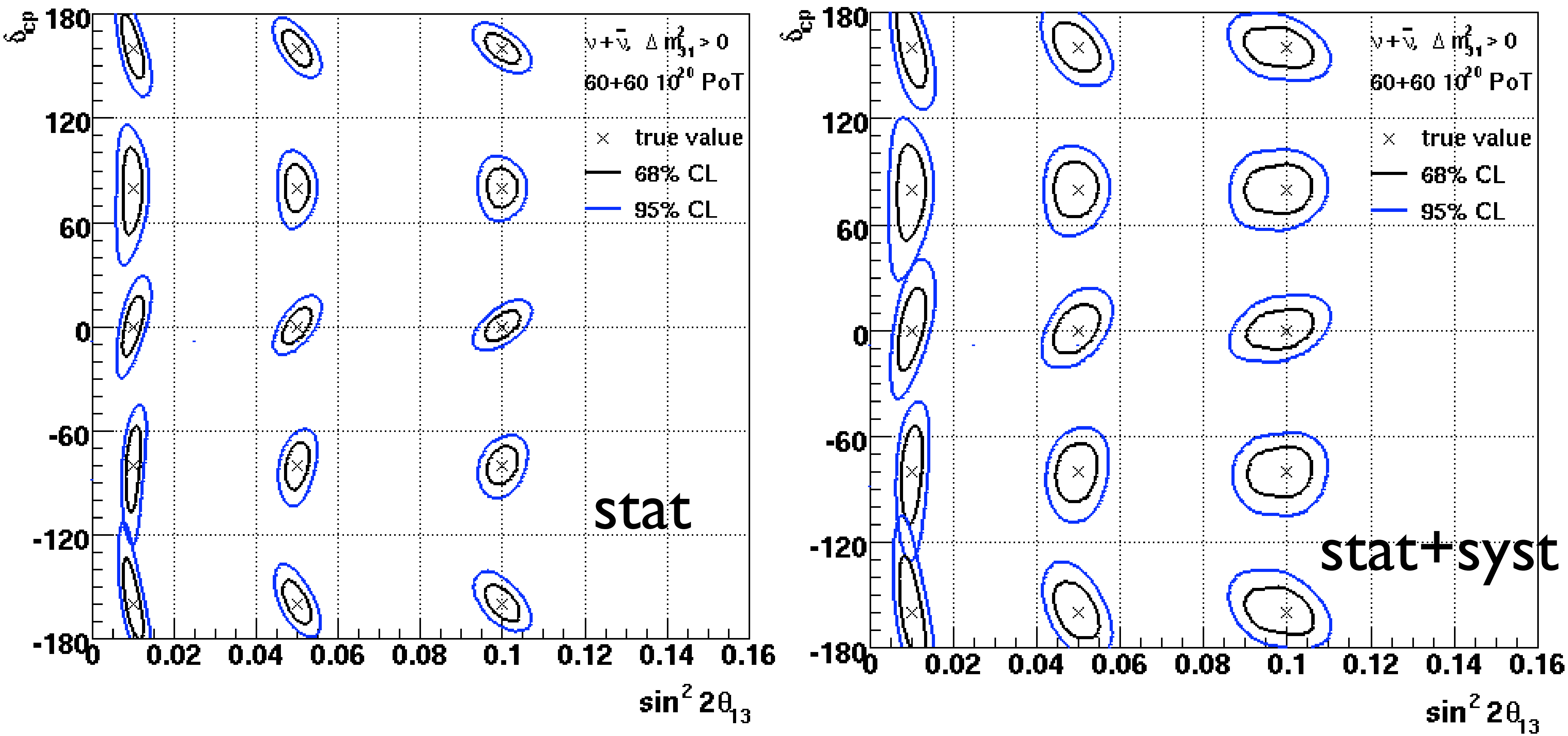
Stat+syst



How well can the parameters be measured

WCC 1300 km 300kT

(—95% CL —68% CL)



Plots are roughly the same for both mass orderings.
The spectral shape is critical in this measurement.

How to phase it in ?

- Possible aggressive timeline of development over over next decade for discussion.

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
WCh					100kT	200kT	300kT			
new beam										
1.2 MW upgrade										
1.2 MW run										
2 MW LINAC										
2 MW run										
LAR R&D										
50kT LAR										

Make decision on final 100 kT WCh detector.

Summary

- CP violation in neutrinos should guide the Long baseline program in the future. Program is doable with known technology (water Cherenkov detector) and current understanding of accelerator intensity.
- A new MW class proton machine in the US remains well-motivated at FNAL if coupled to a capable large detector.
- There are two choices for the program: NuMI based with off-axis surface detectors or DUSEL based with underground detectors that could carry out nucleon decay and other high priority science.
- A very large detector ~100 kT efficient mass is needed to carry out the program no matter where.
- For a broad program need >2000 mwe.

Exploring the possibility of neutrino beams towards a DUSEL site

W. Smart

	Latitude	Longitude	Vertical angle from FNAL (deg)	Distance from FNAL (km)
Homestake	44.35	-103.77	-5.84	1289
Henderson	39.76	-105.84	-6.66	1495

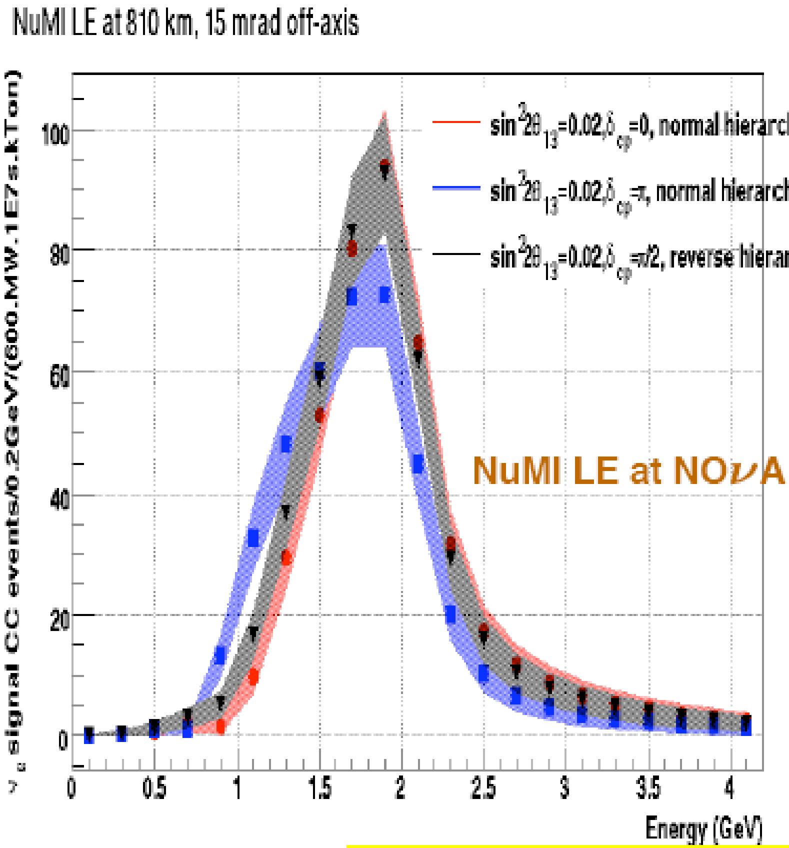
- Use of the present extraction out of the Main Injector into the NuMI line
- Construction of an additional tunnel, in the proximity of the Lower Hobbit door in the NuMI line, in order to transport the proton beam to the west direction
- Radius of curvature of this line same as the Main Injector, adequate for up to 120 GeV/c proton beam with conventional magnets
- Assumptions:
    - **a target hall length of ~45 m (same as NuMI for this first layout, probably shorter)**
    - **decay pipe of 400 m (adequate for a low energy beam), we would gain in neutrino flux by increasing the decay pipe radius (> 1 m)**
    - **distance of ~300 m from the end of the decay pipe to a Near Detector (same as NuMI).**

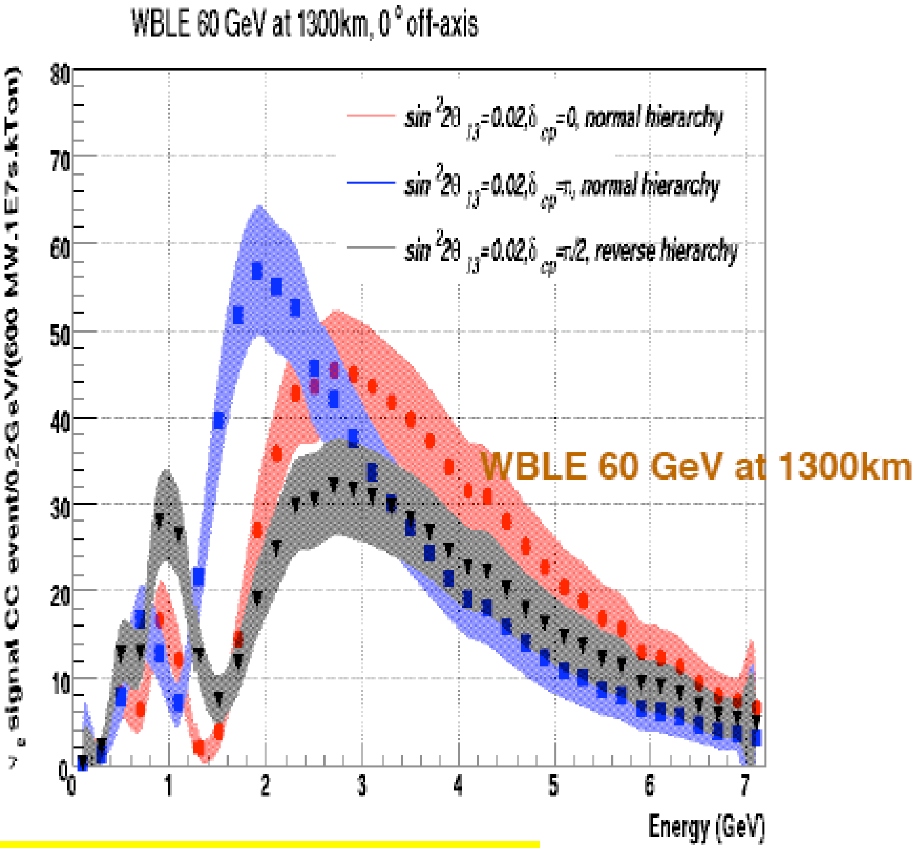
ν_e Appearance Spectra

–- $\sin^2 2\theta_{13} = 0.02, \delta_{cp} = 0$, 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





Spectral information = resolves degeneracies

Sensitivity comparison

Barger, Huber, Marfatia, Winter

Physics reach with same LAR 100 kT detector 120 GeV WBLE-DUSEL, Off-axis. Also compare to T2KK on same plot versus beam power