Report Discussion

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Fermilab Sep 17, 2006

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authorship

* Everyone who contributed in presentations and written material.
* All who attended the meetings and participated in report discussion.
* List everyone that signed up in the appendix.

gina

Introduction

* history of the study, scope and refer to nusag charge in the appendix.
  * Look at Gina's talk from yesterday.

gina

physics goals

Out of these measurements the study of leptonic CP violation in neutrino oscillations is of primary importance for several reasons. First, the degree of experimental difficulty required to establish CP violation is demanding but doable. As such, that effort will also provide precision measurements of all parameters of 3 generation neutrino mixing as well as a sensitive probe of "new physics" effects from sterile neutrinos, extra dimensions, possible dark energy effects etc. Since neutrinos only interact weakly, new physics that affects how particles interact is more likely to be detected in the neutrino sector. Unfolding the neutrino mass ordering via matter effects should be a straightforward byproduct. Second, CP violation has, so far, only been observed in the quark sector of the Standard Model. Discovery in the leptonic sector should shed additional light on the role of CP violation in Nature. Is it merely a consequence of inevitable phases in mixing parameters or something deeper? Perhaps, most important, unveiling leptonic CP violation is a particularly compelling goal because of its potential connection with the observed matter-antimatter asymmetry of our Universe, a fundamental problem at the heart of our existence. The leading explanation is

accelerator req.

All phases of the envisioned US neutrino accelerator program, Phase-I, Phase-II(option A), or Phase-II(option B), *require* upgrades to the existing proton accelerator infrastructure in the US.

We have used beam power in the range of ∼0.5 to 2 MW for high energy protons (>30 GeV) because this level of beam power is now considered the next frontier for current accelerator technology [9, 10] and also necessary to obtain sufficient event rate to perform the next stage of neutrino oscillation physics. The technical limitations arise from the need to control radiation losses, limit the radiation exposure of ground water and other materials, and the feasibility of constructing a target and horn system that can survive the mechanical and radiation damage due to high intensity proton pulses [17].

talk briefly about how this is done at FNAL. The BNL AGS design is also described briefly. with appropriate references and rough cost and time numbers.

target/horn/technical

make a pitch for R&D for these items. Very brief.

There is currently good experience in building and operating high intensity neutrino beam-lines in the US. The study group has found no reasons why either an old or new super neutrino beam-line based on current technology or extensions of current technology cannot be operated for the physics program described in this report. In the following we summarize the status of US high energy accelerator neutrino beam-lines.

describe NuMI, possible beamlines to DUSEL, etc.

detector req.

offaxs

- Size: To approach the exposure criteria of 2000MW $\times$ kT(10^7)sec over the course of 5 yrs, the fiducial mass of the detectors at the first and second oscillation maxima needs to be $\sim$ 200 kT. With 100 kT at the first location (12 km off-axis) and 100kT at the second location (40km off-axis), the total yearly (10^7 sec) charged current event rate in the absence of oscillations at the two locations will be 9400, and 446, respectively.

- Cosmic ray rejection: Off-axis detectors will likely be on the surface or have a small amount of overburden. As pointed out in section 10 a surface detector needs to a) have sufficiently data acquisition bandwidth to collect all events near the beam spill time, b) eliminate cosmic ray tracks so that the beam events can remain pure, c) tag events due to cosmic rays so that no cosmic ray induced events mimic an in-time beam event. These requirements force surface detector to be a segmented detector with active cosmic ray veto shielding.

- Background rejection: There are two contributions to the background from the neutrino beam: neutral current events as well as contamination of electron neutrino events. The narrow band nature of the neutrino beam is important for rejection of both of these backgrounds. The neutral current events which tend to have a falling energy distribution can come from both the main peak of the neutrino spectrum and the tails. In the case of location (2) the large kaon peak will contribute background. The ν_e contamination has a broad distribution for both off-axis locations [16]. To use the narrow band nature of the beam effectively to suppress backgrounds, the detector must have the capability to measure neutrino energy (total charged current event energy) with good resolution, which is approximately the same as the width of the narrow band beam. It should also be able to reject π^0 or photon induced showers.

DUSEL det.

- Size: To approach the exposure criteria of 2000MW $\times$ kT(10^7)sec over the course of 5 yrs, the fiducial mass of the detector needs to be $\sim 200kT$. In the case of DUSEL all of this mass can be in the same place exposed to a beam that contains both oscillation maxima. The total yearly (10^7 sec) charged current event rate in the absence of oscillations at 1300 km (1495 km) will be between 20000 to 40000 events for 1 MW of running. The exact number depends on the proton energy adapted for the running as well as the optimization of the beam spectrum.

- Cavern: Because of the size required for the detectors, a stable large cavity (or cavities) that can house $\sim 100kT$ of fiducial mass will be needed. From preliminary studies it appears that both Henderson and Homestake satisfy this criteria.

- Cosmic ray rejection: Since the cosmic ray rate at the deep sites proposed for DUSEL detectors is very low, it will not be a major factor in detector design. A cosmic ray veto for such a detector might be needed for physics other than accelerator neutrino physics; for example, detection of solar neutrinos. But it is not required for the physics discussed here.

- Background rejection: There are two main contributions to the in-time background from the beam: neutral current events, and electron neutrino contamination in the beam. It is expected that majority of the NC background at low energies will be from single π^0 events that will have to be rejected. In the case of using a wide band beam, there are two tools for signal extraction. Pattern recognition with good capability will be needed to reduce neutral current, especially single π^0 events. The oscillation pattern in the energy spectrum will also be used to extract the signal. The first oscillation node, in particular, will form a peak above 2 GeV with a well known shape. To allow such a signal extraction, the detector must have good energy resolution for neutrino energy. From the work reported here $\sim 10\%$ energy resolution above 0.5 GeV including Fermi motion effects will be needed.

detector simulations

* water Cherenkov: state status and work on background rejection
* for LAR, status is needed.

detector design

* water Cherenkov: the cavern and detector is buildable upto 300 kT fiducial. identify key issues.
* liquid Argon: describe status. can we do 100 kT ?

shielding

* Large water Cherenkov will not work on the surface.
* rates and requirements for a 100 kT LAR on the surface are clear. Not yet proven that it can work.
* how much shielding needed ?

Event rates

* have ME. LE rates lower at small angles, double at high angles. can we have similar table for LE.

km o.a.	ν_μ CC	ν_μ CC osc	ν_e CC beam	ν_e QE beam	NC-1π^0	$\nu_\mu \to \nu_e$ CC	numunue QE
0	248.0	225.0	1.80	0.0914	6.96	1.40	0.188
6	71.6	47.0	1.068	0.0770	3.194	0.879	0.171
12	18.1	7.33	0.443	0.0485	1.168	0.305	0.099
30	1.84	1.12	0.0730	0.0152	0.135	0.0216	0.0108
40	0.860	0.479	0.0378	0.0097	0.0605	0.0121	0.0057

Table 2: Summary of event rates per-kTon per-10^{20} PoT for detectors placed 810 km from the target and various distances off-axis (o.a.).

WBLE

Beam	ν_μ CC	ν_μ CC osc	ν_e CC beam	ν_e QE beam	NC-1π0	$\nu_\mu \to \nu_e$ CC	$\nu_\mu \to \nu_e$ QE
WBLE 120 GeV	39.0	26.0	0.427	0.030	1.624	0.566	0.105
WBLE 60 GeV	15.1	7.4	0.099	0.012	0.722	0.250	0.052
WBLE 40 GeV	7.28	3.02	0.042	0.007	0.403	0.134	0.031

Sensitivity estimates

* work completed in hep-ph/0607177 for DUSEL /add LAR plots on top with caveat that it is 1/3 size detector. This is done.
* Need something similar for offaxis

17 Appendix A: Answers to questions raised by NUSAG

1. Noting the existence of discrepant sensitivity calculations even for the same detector, it would be most useful to have any such calculations performed with consistent assumptions and methodologies.

a) Fixed, common, stated values of the mixing parameters not explicitly under study.

b) Common, stated and plotted, cross sections vs. En. Common, stated nuclear models.

c) Stated assumptions about energy resolution, background rejection.

d) If appropriate, common total p.o.t. If sensible, use a common proton energy and anti-nu running fraction. If not, state the optima chosen.

e) What methods are used to extract the oscillation parameters from the final event sample (counting? fitting the spectrum?)

f) Standardized, stated method for defining sensitivity.

2. Give sufficient detail in tables and/or plots to allow a reader to understand how the numbers for rates or sensitivities are obtained. We would expect that many of the results would be easily accessible to a physicist with a calculator. Here are some useful inputs that come to mind (meant as a guide only):

a) Specify the signal channel(s). (We will assume here that it is quasi-elastic.) b) What simple cuts (energy, etc.), if any, do you apply?

c) The number of INTRINSIC ν_e events reconstructed as signal, and their reconstructed energy spectrum (in reconstructed Enu(QE) or Evis, or Ee, or whatever you'll use.)

d) What is the purity of the QE selection, that is, for true ν_e events, what fraction of those selected as QE are actually QE (as a function of E)?

e) The total number of NC π^0 events, and spectra vs. true Enu and π^0 momentum.

f) The number of NC π^0 events reconstructed as signal, and their reconstructed energy spectrum. What is the true Enu spectrum for the NC pi0 events reconstructed as signal?

g) The NC π^0 rejection assumed, as a function of... (π^0 momentum?)

h) The assumed systematic errors on each of the backgrounds, with any relevant dependence on energy. How are these estimates arrived at?

i) The assumed signal efficiency as a function of energy. How are these estimates arrived at?

j) Provide tables and spectra (vs. true and reconstructed E_ν) giving the initial population of events, before cuts, by process (QE, CCpi+, DIS,...), how these numbers diminish as the cuts are applied, and in the final sample at the various oscillation parameter test points. An entry at the 3-s sensitivity limit would be informative. Scatter-plots of reconstructed vs. true En for individual signal and background channels may be informative.

3. Specify the level of simulation that goes into your currently-generated sensitivity estimates. For example:

a) How is energy resolution treated? Give a plot of the assumed energy resolution (electron energy and neutrino energy) vs. energy.

b) How is the selection of QE events treated?

c) How is the rejection of pi0's modeled?

4. What near detector location/size/technology/performance/cost is assumed/need to achieve the assumed systematic errors?

5. If possible, for comparison purposes, use the same methodologies to make parallel sensitivity estimates for NoVA (single detector) and T2K. What sensitivity for NoVA do you calculate for the same number of p.o.t. assumed in question 1?

6. All sensitivity calculations for off-axis configurations must include events from neutrinos in the high-energy peak from kaon decay.

7. What detector technologies are still worth pursuing for a 2nd off-axis detector – Liquid scintillator? Water Cerenkov? Liquid Argon? Other?

8. There were several references to the possibility of a detector at ∼250 km in the NuMI beam. Is this being pursued by the Working Group? What are the general properties of this approach?

Shorter baseline lengths for NuMI offaxis detectors have been considered in the literature [8]. For example, for a baseline of 250 km, the first and second oscillation maxima are at 0.50 GeV and 0.17 GeV, respectively. There are two reasons for considering shorter baselines: small matter effects and larger numbers of events because of the closer distance. This solution, however has several difficulties. The main ones are: i) The low energies needed forces us to consider large offaxis angles ($> 40mrad$) where the flux of neutrinos is rather poor and the contamination from high energy neutrinos from kaon decay large. This largely negates the advantages of the larger flux because of the closer distance. The event rate can be easily obtained from [16] by scaling. ii) Natural choice for a detector at these energies is a water Cherenkov counter. Since most of the events at these energies are quasielastics for which a water Cherenkov detector has good efficiency, little is gained by utilizing a liquid argon TPC. The water cherenkov detectors needed are too large for operation on the surface as explained in section 10. iii) Lastly, an experiment with almost identical parameters is already being carried out in Japan (T2K). Combining the results of T2K and Phase-I of the US program is a subject of various reviews[7].

9. Provide cost and schedule estimates for the same fiducial mass and PMT coverage/channel count used for sensitivity estimates. (We realize that fiducial/total mass ratios may be hard to estimate, but the assumptions should be stated.)

answered

10. For the modular water Cerenkov approach, are you defining 3 modules as your baseline detector?

The authors of report [14] reply:

"Yes, there are three main reasons we believe 3 modules is an optimum choice to start with. First, because of the longer running times possible at FNAL it appears that a 300 kT fiducial mass is sufficient to reach the desired sensitivity for neutrino oscillations. Second, it is clear that for proton decay searches a larger detector is needed, but for current background projections a few background events are expected in favored decay modes after exposure of 1 MT-yr. We believe that proton decay searches will benefit from further detector and analysis improvements after reaching this level of sensitivity. Any modules built after the first 3 modules will benefit from this knowledge. Third, there is considerable cost saving by starting the simultaneous construction of 3 cavities in the region of relatively well-known Homestake rock near the Ray Davis Chlorine chamber as explained in [14]. "

11. For the water Cerenkov counters, we will be eager to hear of progress in algorithms for rejecting π^0s (and the testing of them). What is the increase in π^0 rejection over that achieved by Super-K (as a function of π^0 energy) assumed in your current calculations? What have you reached with your own simulations/algorithms? Describe briefly the algorithmic improvements. Does this rejection depend more on total photo-cathode coverage, or on granularity?

don't know yet, but granularity helps

12. Though the worldwide community of proponents of large water Cerenkov detectors seems to cooperate in simulations, algorithms, etc., we do not see evidence that there is any global planning (site-independent design studies or physics programs, etc.) underway for such a detector. Please comment.

chiaki/jung will answer
not true !

For Liquid Argon:

13. NuSAG recommends that the Liquid Argon group reweight its emphasis from sensitivity/reconstruction/pattern recognition to hardware issues and cost estimates. We realize that a full switch cannot occur if the LAr group is a big part of the more generic off-axis calculations in the Working Group, but, for example, LAr-specific reconstruction and particle ID algorithms seem less pressing than technical feasibility.

14. What has actually been measured on purity of the Ar in a tank made with industrial technology? If not yet tried, when will the first tests be?

15. When do you expect to have tried 3-m drifts and long wires in the US? What effect will the capacitance of very long wires have on electronic noise?

16. What are the R&D milestones, with an estimated schedule, that would lead to a first realistic cost estimate for a detector of the 2nd-off-axis or wide-band class?

results/conclusions

* Accelerator/beam requirements understood and achievable. Already being planned at FNAL for Phase I. (make more robust, and positive, MD's job)

* Need water cherenkov detector of size 300 kT no matter where the experiment is done. Water Cherenkov is an established technology. Signal extraction and background rejection are understood but not full optimized. Key issues for increasing the size and locating it at DUSEL have been identified.

* High signal efficiency and excellent background rejection in a LARTPC allows the size of the detector to be smaller by a factor of 3. Key technical issues have been identified and a development path towards massive detectors has been laid out.

results/conclusions

* Surface operation of the proposed massive detectors has been examined. Water Cherenkov detectors are suitable for deep underground operation. Surface or near surface operation of liquid argon TPCs requires that adequate rejection of cosmic rays be demonstrated.

results/conclusion

* For an offaxis program, baselines of about 800 km and offaxis angles of 10-40 mrad were considered for CP violation physics. Since the detector location is on the surface the best choice is a LARTPC. For ? kT of fiducial mass and ? amount of exposure, CP violation can be established in ? region.

* For a wideband program to DUSEL (either at Henderson (1497 km) or Homestake (1300km)), two choices for detector technology were considered: a deep sited 300 kT water Cherenkov detector or a 100 kT LARTPC (which may be located either on the surface or underground). These have equivalent sensitivity for CP violation after ? exposure. CP violation can be establlished in ? region.

* The sensitivity calculations include correlations, degeneracies, and parameter sensitivity. The wideband program has robust sensitivity against changes in the input parameters. The offaxis program parameter sensitivity is ?

* Baselines shorter than 500 km from FNAL have severe technical limitations for performing the CP violation science because of the low energy of the oscillated events and surface location of the massive detectors.

* These massive detectors have the potential to provide a rich long term physics program such as nucleon decay, supernova and other astrophysical neutrinos beyond accelerator neutrino physics.

results/conclusions

* The timelines we describe are technically driven only.
* sNUMI timeline (Alberto gives sentences)
* Beam to DUSEL timeline(Dixon/Rameika)
* water Cherenkov timeline (two options, homestake, henderson, MD)
* LARTPC detector surface timeline (Dave Finley/Bonnie)
* LARTPC detector underground timeline (Finley/bonnie)

Sensitivity plots

* Maury Goodman brought up the point of making sure we show sensitivity plots for 3 cases in the report
  * The Wideband to DUSEL approach,
  * Running of Phase-I (just NOVA) with 1.1 MW, 5 yrs (NUSAG wants this anyway)
  * Running of NOVA-II.
  * Therefore we collected plots that we know and placed them on the next few pages.

FNAL-to-DUSEL

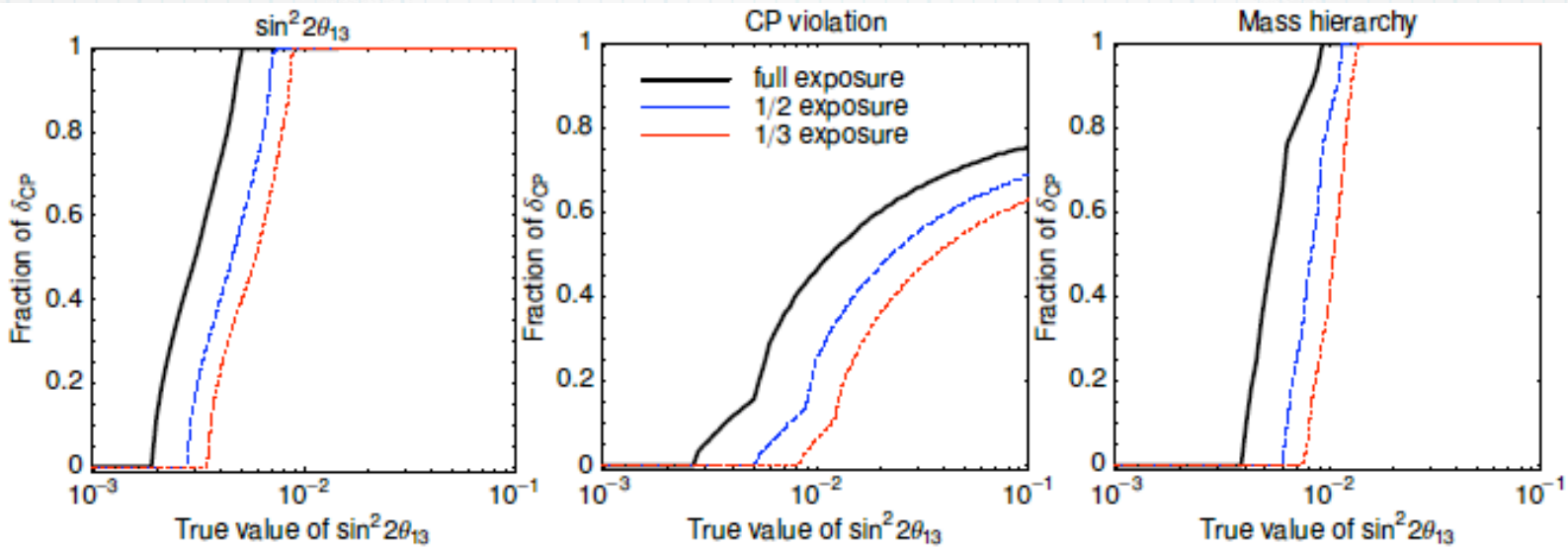
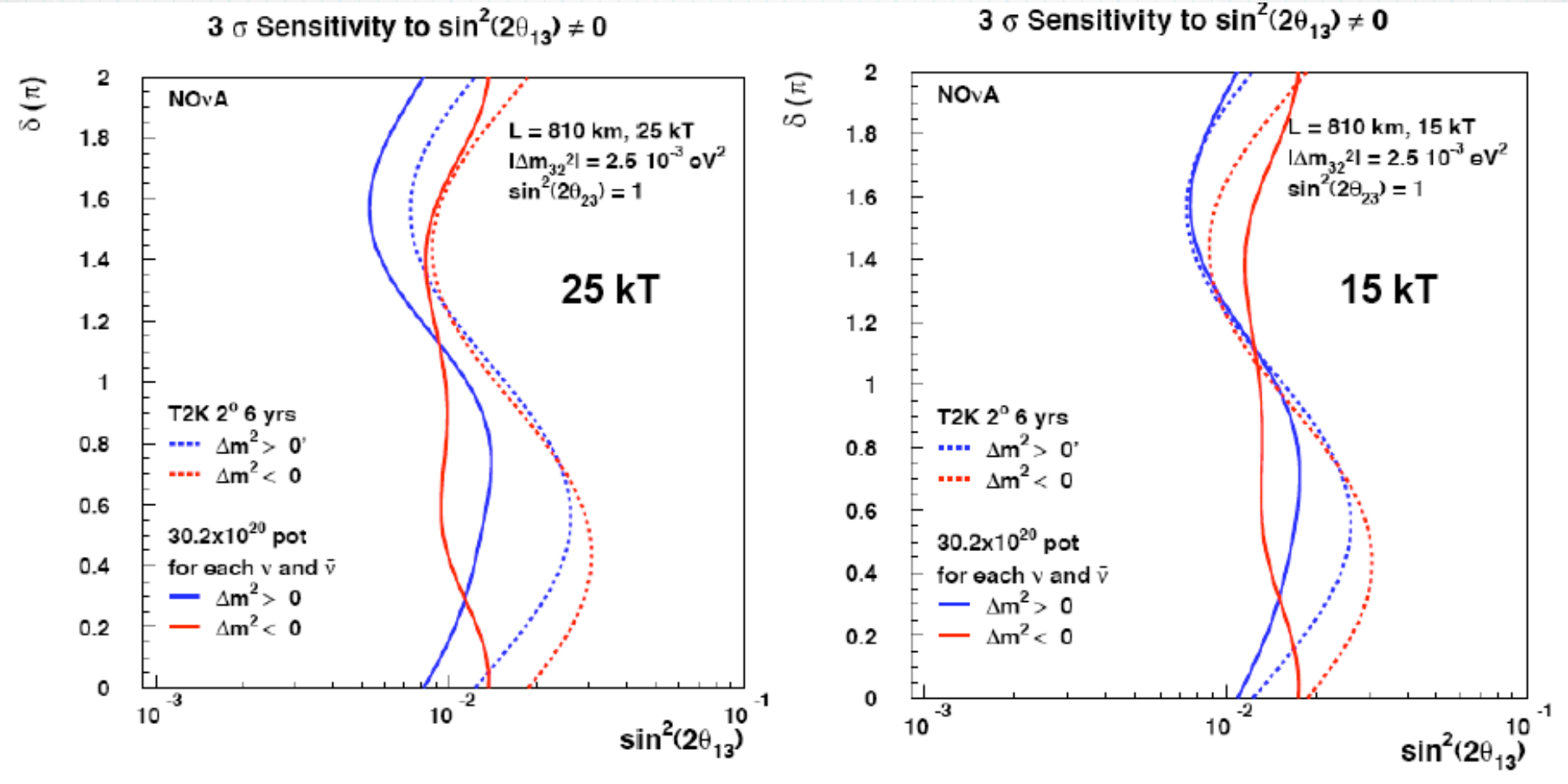
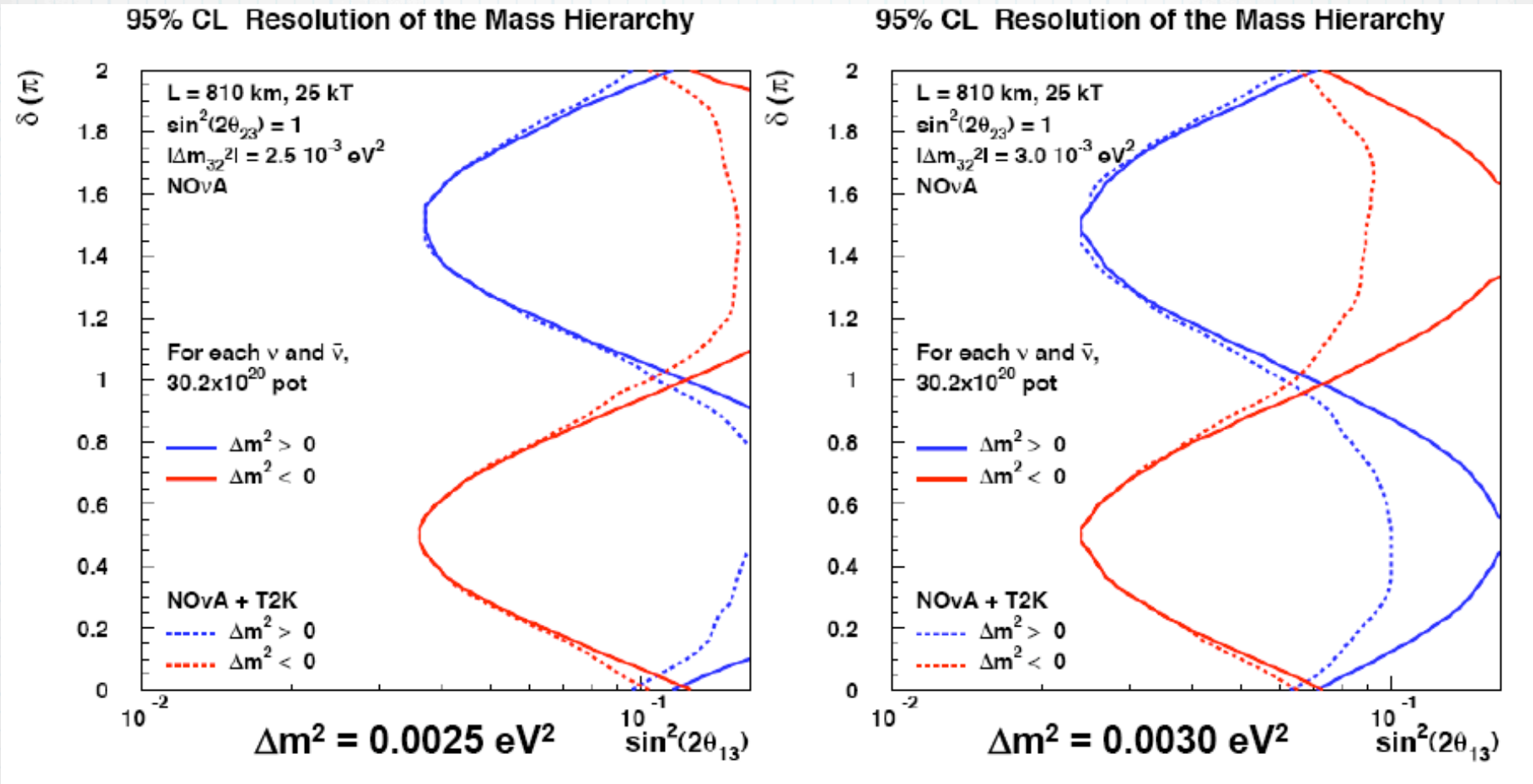


Figure 10: Dependence of the 3σ sensitivities on exposure for an experiment with 1300 km baseline. The two cases considered are 1/2 and 1/3 of the (full) exposure we have used throughout.

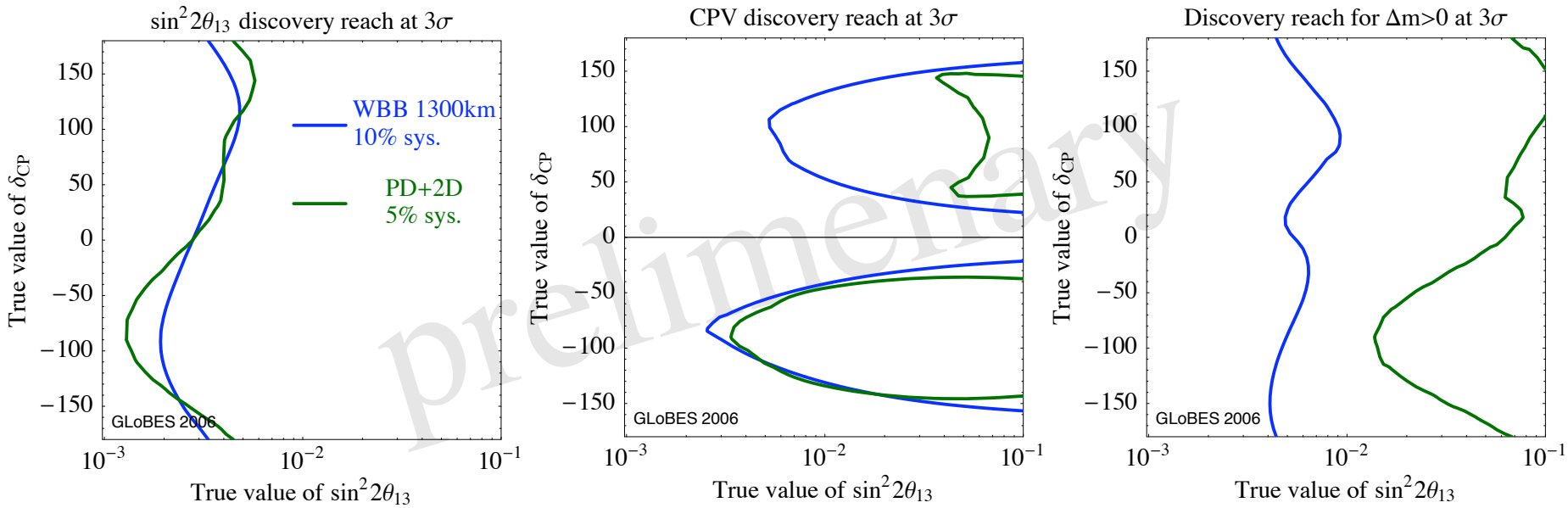
th13 for NOVA alone



mass hierachy for NOVA



WBLE vs NOVA-2

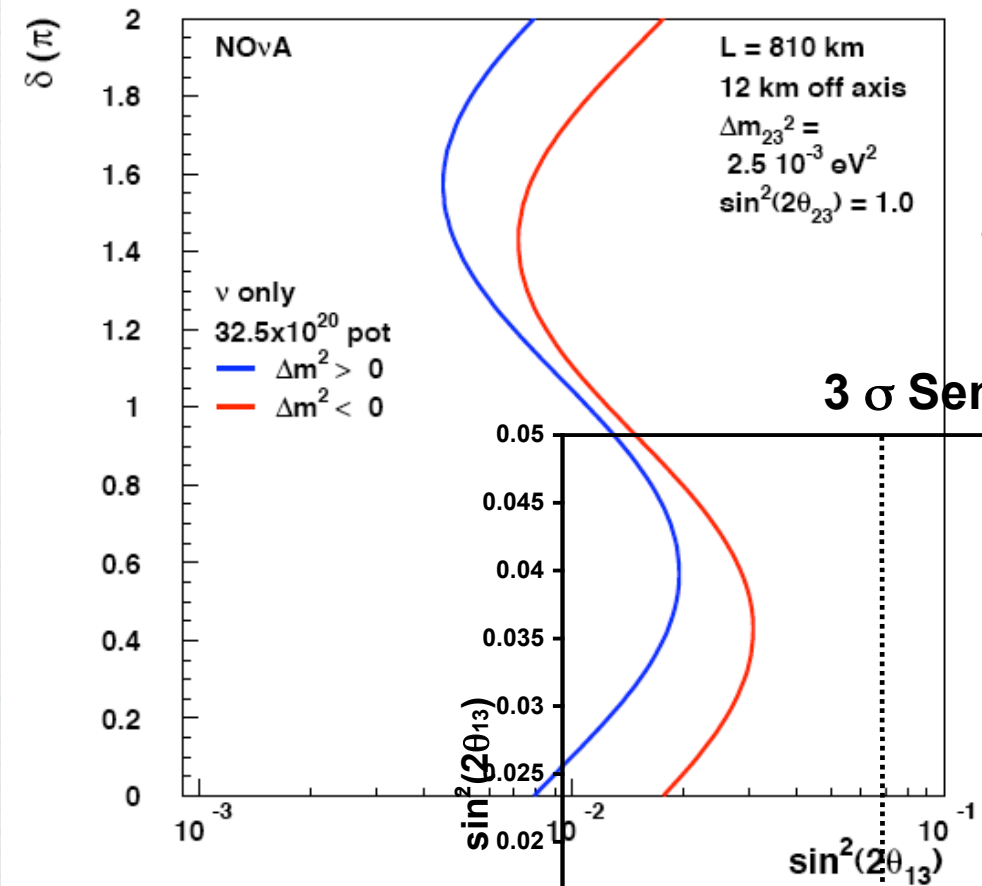
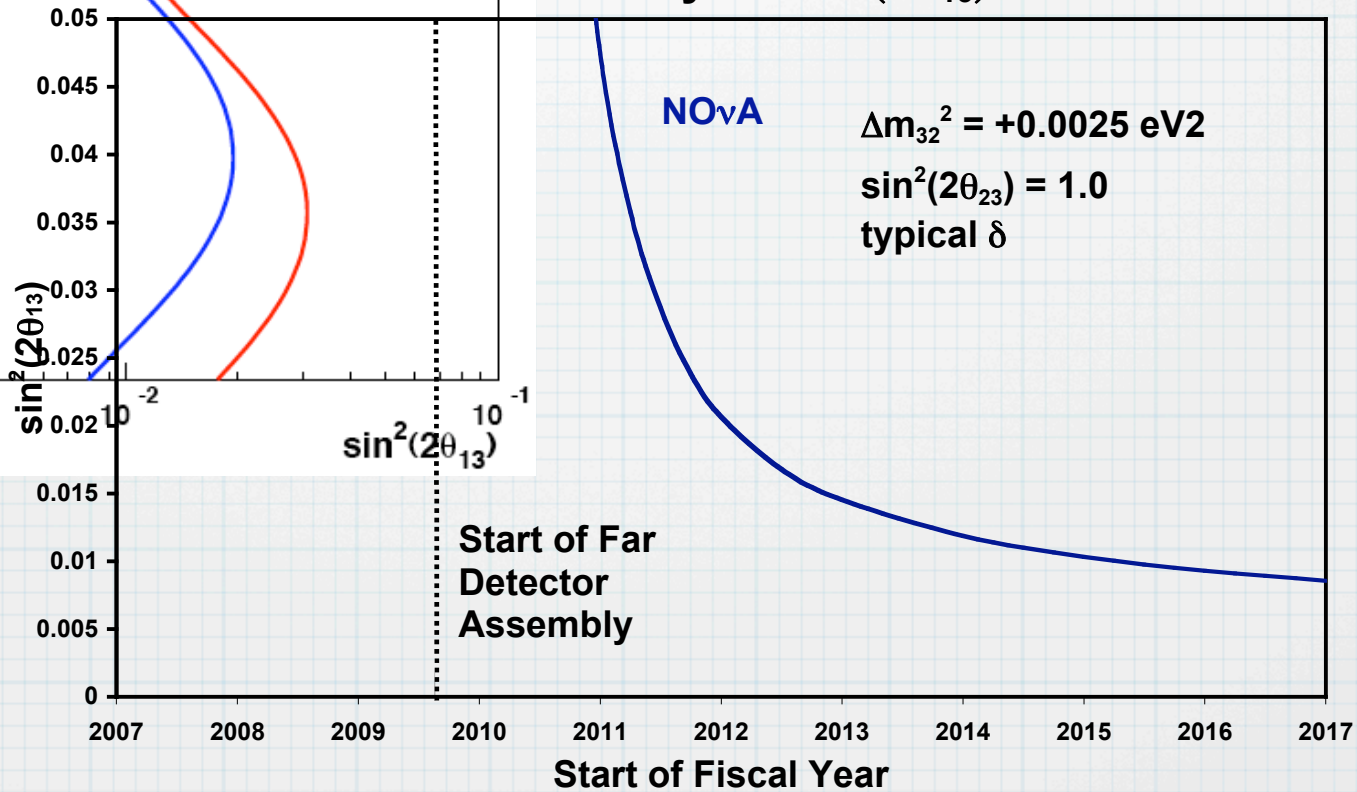


nu only running

NOVA only

typical delta =pi ?

what is the worst possible?



3 σ Sensitivity to $\sin^2(2\theta_{13})$