Status of work on a very long baseline neutrino oscillation experiment

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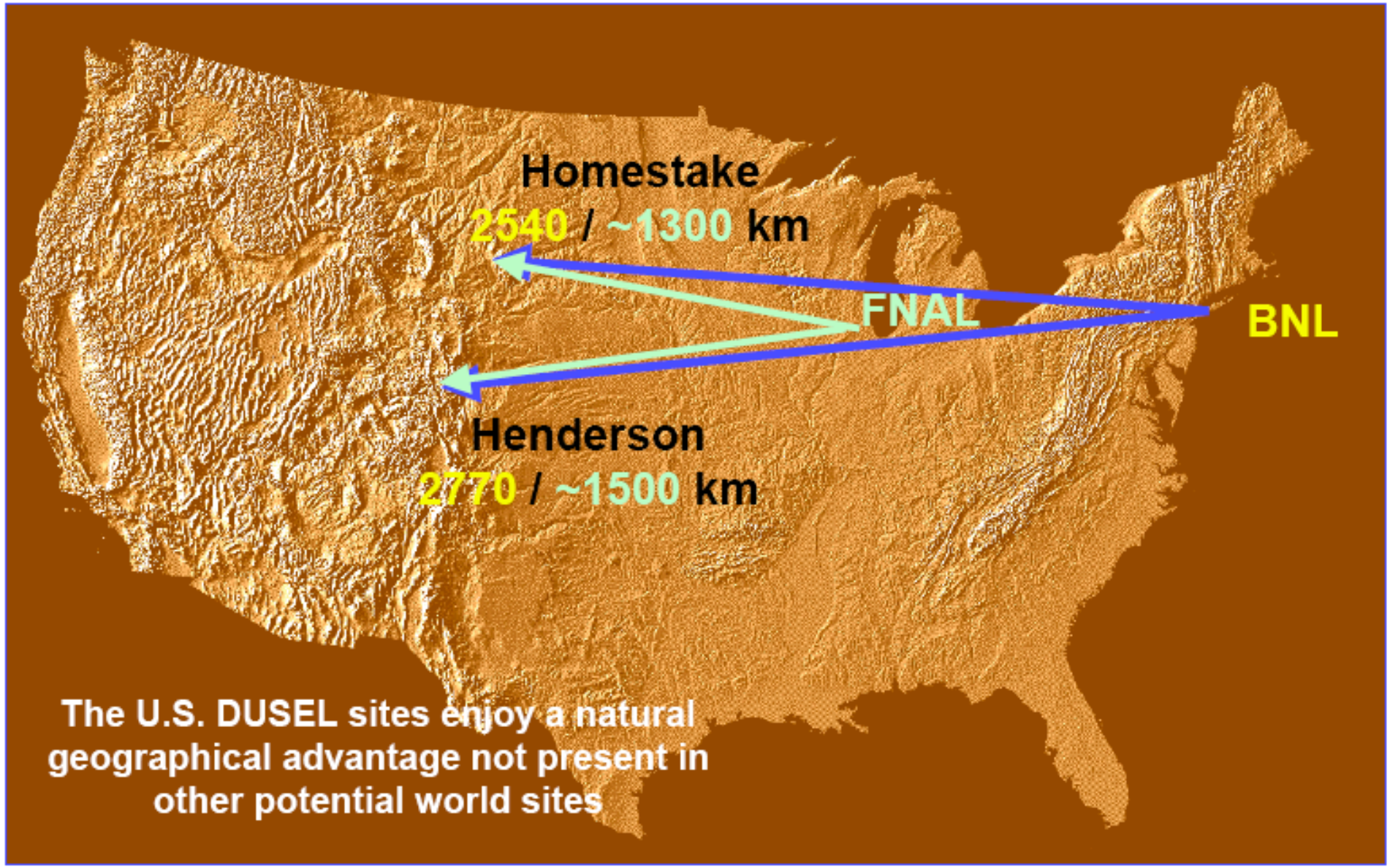
Outline of this talk

- We advocate building at least two 100 kT cavities as soon as possible at DUSEL. The physics case is very strong.
- We need support for participation in the DUSEL TDR, and detector design.
- Physics topics:
  - Very Long Baseline Neutrino Oscillation
  - two ~100 kT water Cherenkov detectors
- Brief of study from the FNAL (Mar 6-7) workshop.
- LDRD support from BNL/ summary of accomplishments.

Super Neutrino Beam to DUSEL Candidate Sites



Why Very Long Baseline?

observe multiple nodes in oscillation pattern

☞ less dependent on flux normalization

neutrino travels larger distance through earth

larger matter effects

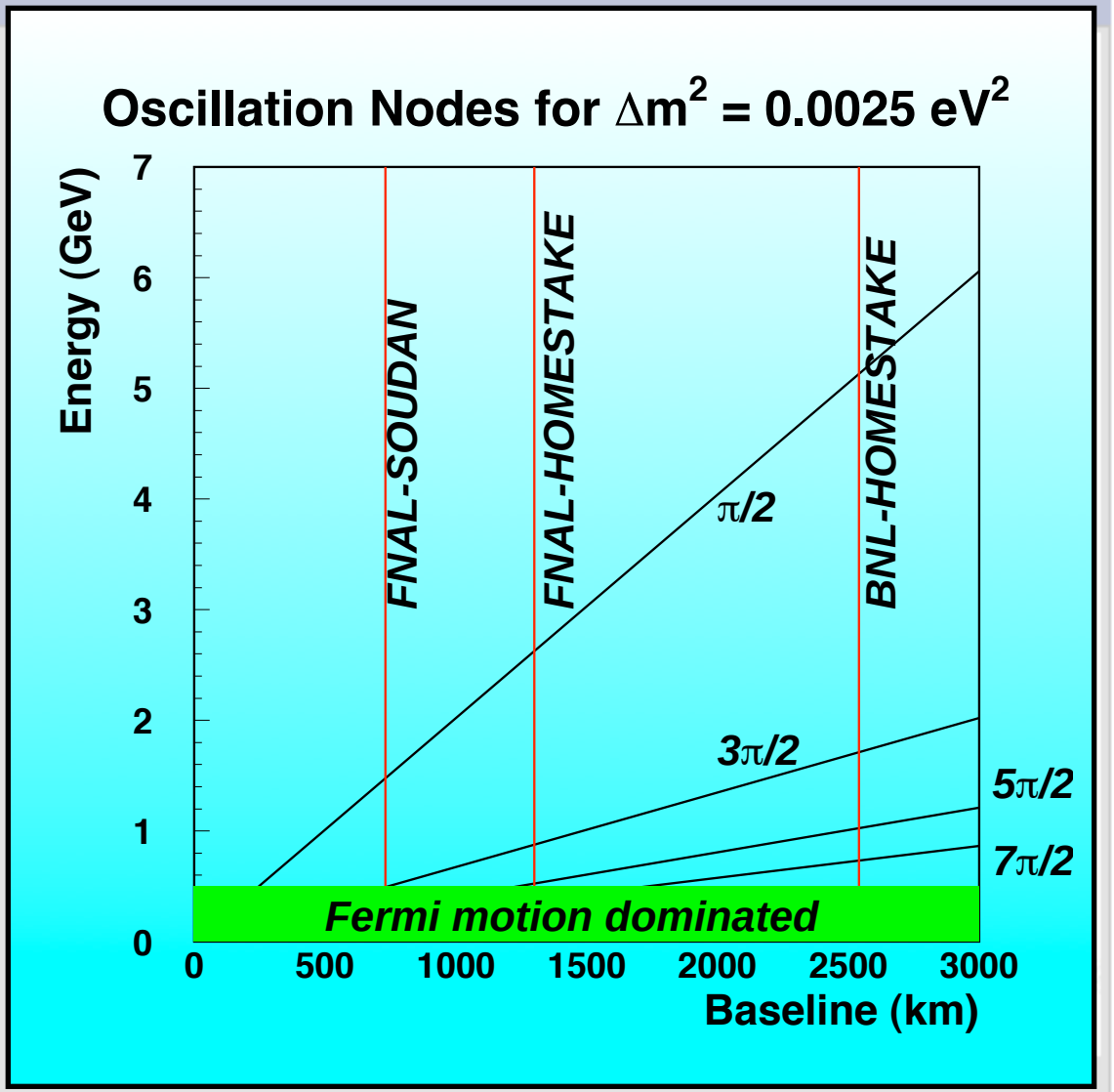
flux ~ L^{-2}: lower statistics

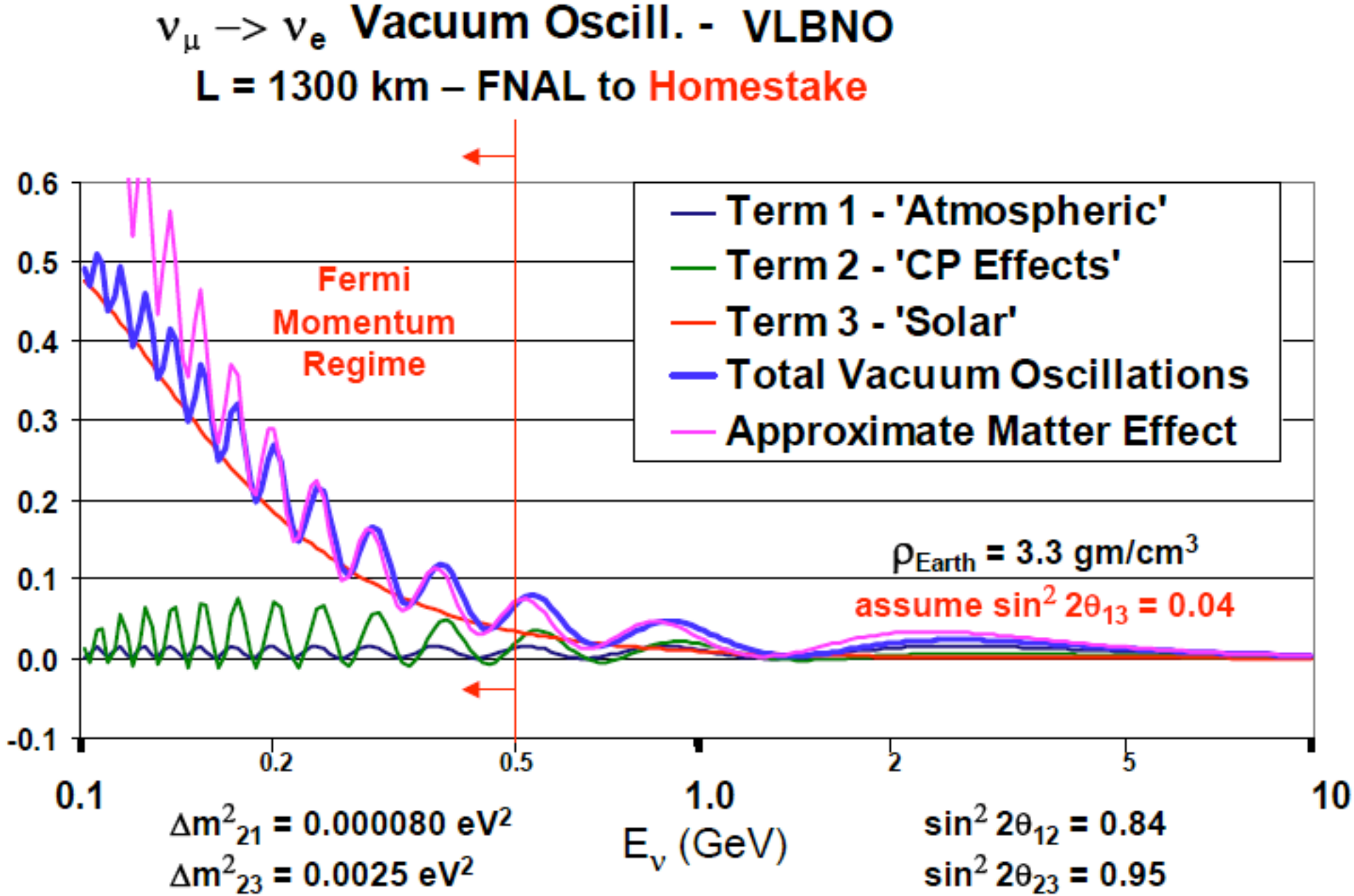
but: CP asymmetry ~ L

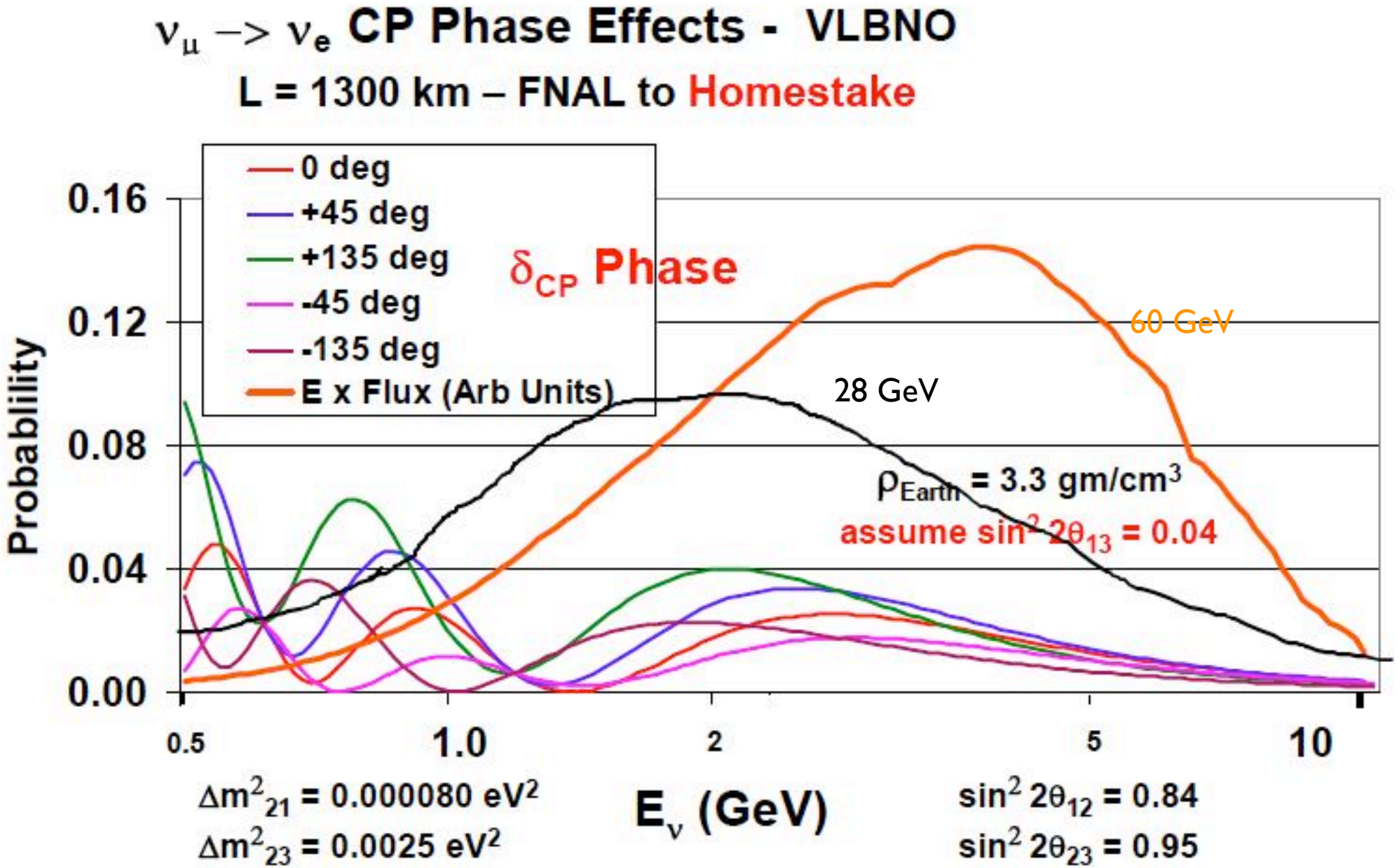
sensitivity to δ_{CP} independent of distance!

better S:B

(Marciano hep-ph/0108181)




$\nu_\mu \rightarrow \nu_e$ Vacuum Oscill. - VLBNO
L = 1300 km – FNAL to Homestake
Fermi Momentum Regime
Term 1 - 'Atmospheric'
Term 2 - 'CP Effects'
Term 3 - 'Solar'
Total Vacuum Oscillations
Approximate Matter Effect
ρ_{Earth} = 3.3 gm/cm^3
assume $\sin^2 2\theta_{13} = 0.04$
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
0.1
0.2
0.5
1.0
2
5
10
E_ν (GeV)
$\Delta m^2_{21} = 0.000080$ eV^2
$\Delta m^2_{23} = 0.0025$ eV^2
$\sin^2 2\theta_{12} = 0.84$
$\sin^2 2\theta_{23} = 0.95$


$\nu_\mu \rightarrow \nu_e$ CP Phase Effects - VLBNO
L = 1300 km – FNAL to Homestake
0 deg
+45 deg
+135 deg
-45 deg
-135 deg
E x Flux (Arb Units)
δ_{CP} Phase
60 GeV
28 GeV
ρ_{Earth} = 3.3 gm/cm^3
assume $\sin^2 2\theta_{13}$ = 0.04
Probability
0.16
0.12
0.08
0.04
0.00
0.5
1.0
2
5
10
E_ν (GeV)
Δm^2_{21} = 0.000080 eV^2
Δm^2_{23} = 0.0025 eV^2
$\sin^2 2\theta_{12}$ = 0.84
$\sin^2 2\theta_{23}$ = 0.95

Observations

- Sensitivity to CP is independent of distance after ~1000km
- Short baseline = high statistics, small effects.
  Longer baseline = bigger effects, small statistics
- The size of detectors and beam power needed does not depend on theta_13 (as long as it is not very small, S. Parke)
- Two narrow band experiments could observe the signal with different strengths, which can be fit by multiple solutions of the parameters.
- We need low energy broad band beam. Must have ~4m wide tunnel. I have assumed 200 m length. Low energy horn also (with target deep inside)

FNAL/BNL study

- Chairs: Hugh Montgomery, Sally Dawson
- First kick-off workshop was on March 6-7
- Very successful ! Very good work reported on physics sensitivity, backgrounds, possible beam from FNAL, etc.
- Study goals and initial work plan sent out.

http://www.fnal.gov/directorate/DirReviews/Neutrino_Wrkshp.html

FUTURE_LONG_BASELINE_LIST@fnal.gov

To get on the list send email to rameika@fnal.gov

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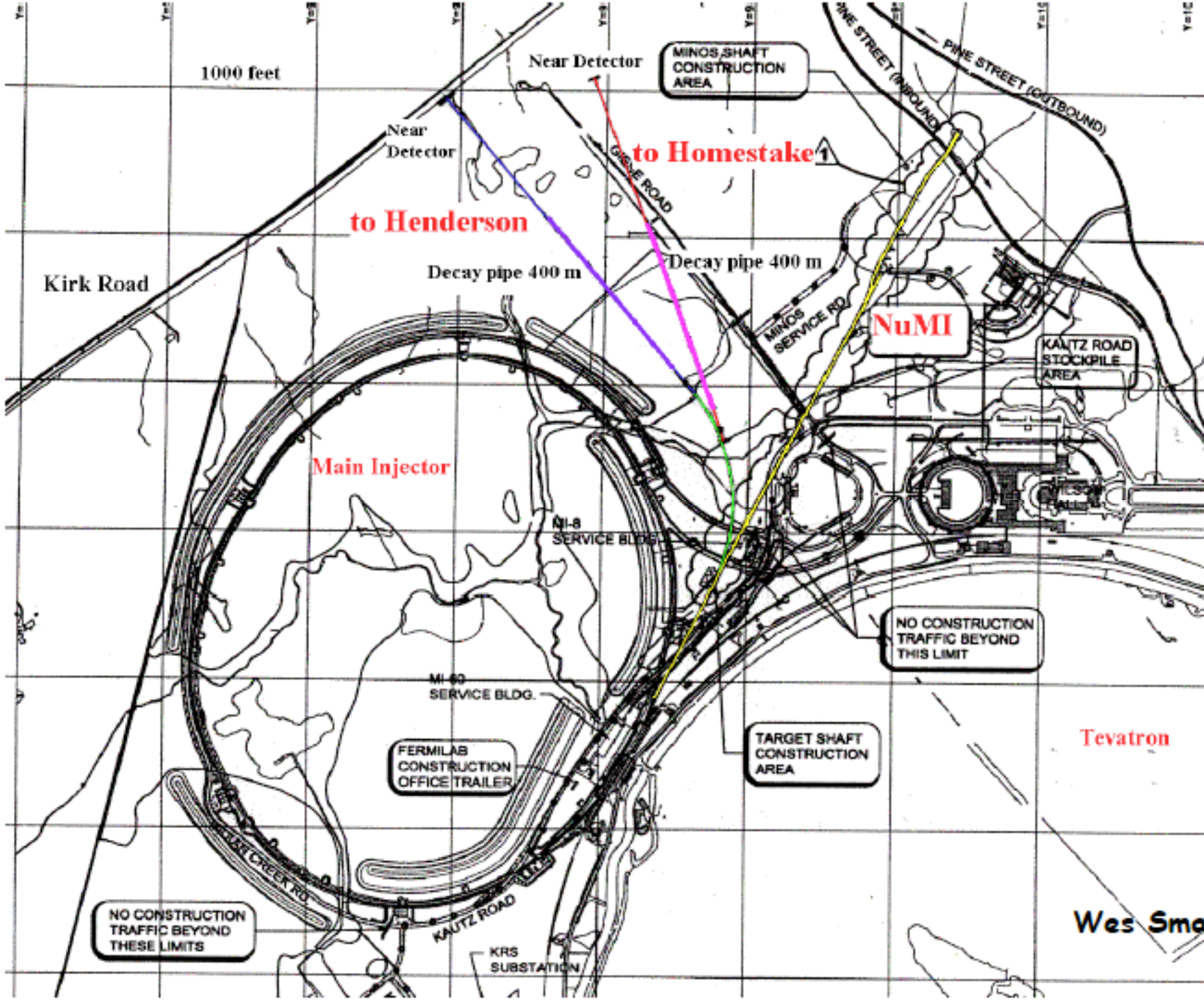
US possibilities for beam

Source	Proton beam energy	Proton beam power	
FNAL MI (upgrade using recycler)	Ep=8-120GeV	<1 MW X(Ep/ 120GeV)	A. Marchionni
FNAL MI (with 8GeV LINAC)	Ep=8-120 GeV	2 MW @ any Ep	G. Apollinari
BNL-AGS (upgrade 2.5- 5 Hz)	Ep=28 GeV	1-2 MW	BNL-73210


1000 feet
Near Detector
Near Detector
to Homestake
to Henderson
Decay pipe 400 m
Decay pipe 400 m
Kirk Road
Main Injector
NuMI
MINOS SHAFT CONSTRUCTION AREA
PINE STREET (INBOUND)
PINE STREET (OUTBOUND)
GROVE ROAD
MINOS SERVICE RD
KAUTZ ROAD STOCKPILE AREA
MI-8 SERVICE BLDG.
MI-60 SERVICE BLDG.
NO CONSTRUCTION TRAFFIC BEYOND THIS LIMIT
TARGET SHAFT CONSTRUCTION AREA
FERMILAB CONSTRUCTION OFFICE TRAILER
Tevatron
OAK CREEK RD.
KAUTZ ROAD
NO CONSTRUCTION TRAFFIC BEYOND THESE LIMITS
KRS SUBSTATION
Wes Smart

Neutrino Event rates

Source-det	Detector size	beam E and power	Event rate for neutrino running
FNAL-HS(1290)	200kT	0.5MW@60GeV	~60,000CC ~20,000NC
FNAL-Hend(1500)	200kT	0.5MW@60GeV	~44,000 ~15000
FNAL-HS(1290)	200kT	1MW@28GeV	78,000CC 27,000NC
BNL-HS(2540)	500kT	1MW@28GeV	50000 CC 17000 NC
NOVA(810)*	30kT	0.65MW@120	~10000 CC ~3000 NC

5 X 10^7 sec of running assumed

For CP violation we assume total exposure of 2500 kT*MW*(10^7) sec

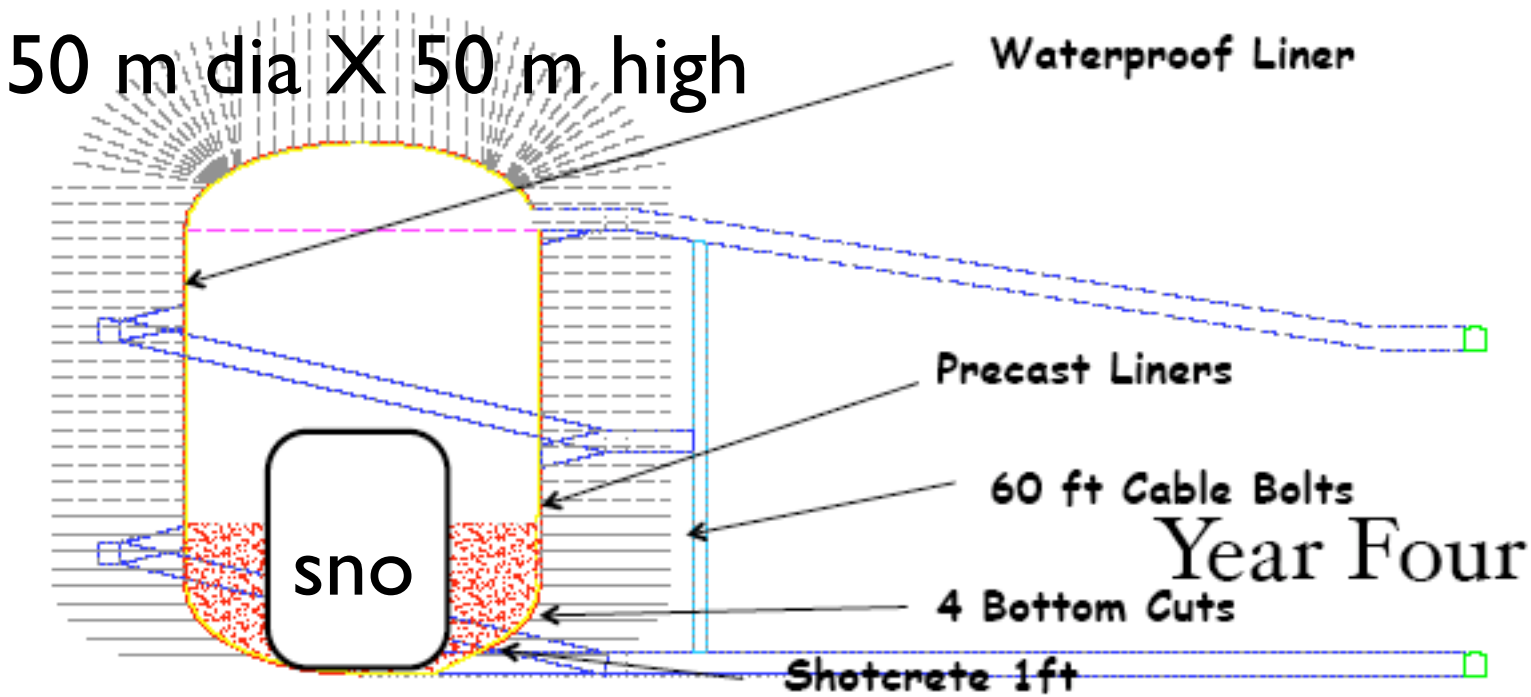
• Detector parameters

- 200 kT => 2 cavities of approximately 50 m dia X 50 m size.
- More detectors for more reach in nucleon decay.
- depth ? May not need anti-counter if deep enough.
- ~10% energy resolution on quasilelastics.
- Threshold of 5 MeV for solar and supernova
- Time res. ~few ns for pattern recognication.
- Good mu/e separation. <1%.
    - 1,2,3 track separation, NC rejection ~X20.

This level of performance can be obtained with water Cherenkov detector with 20-40% PMT coverage.
=> 11000 to 22000 20inch PMTs for 100kT.

Detector Cavity

- Cost and schedule can be developed rapidly with experience from SNO and SK.
- Cavity is larger, but total scope of one detector is similar to SNO.



SNO cost

- Total capital cost in $40M in 1994
- Similar number of channels ~10000
- SNO had very high requirements on cleanliness
- SNO had a complex geometry and a working mine environment.



From K.T Lesko, March7, FNAL

Status of simulations

- Cosmic ray rates at 4850 ft are very low. 1/10 Hz for 100 kT. Finding beam neutrino events does not require extensive reconstruction.
- For complete Monte Carlo simulations and recontruction we are relying on Stony Brook collaborators with SuperK experience. (a paper is in preparation that shows the electron-like background level for a wide band beam. See Chiaki Yanagisawa's talk)
- Sensitivity calculations are done with a fast Monte Carlo that is adjusted to give similar results to above.
- New complete GEANT4 based Monte Carlo is needed and is in development.

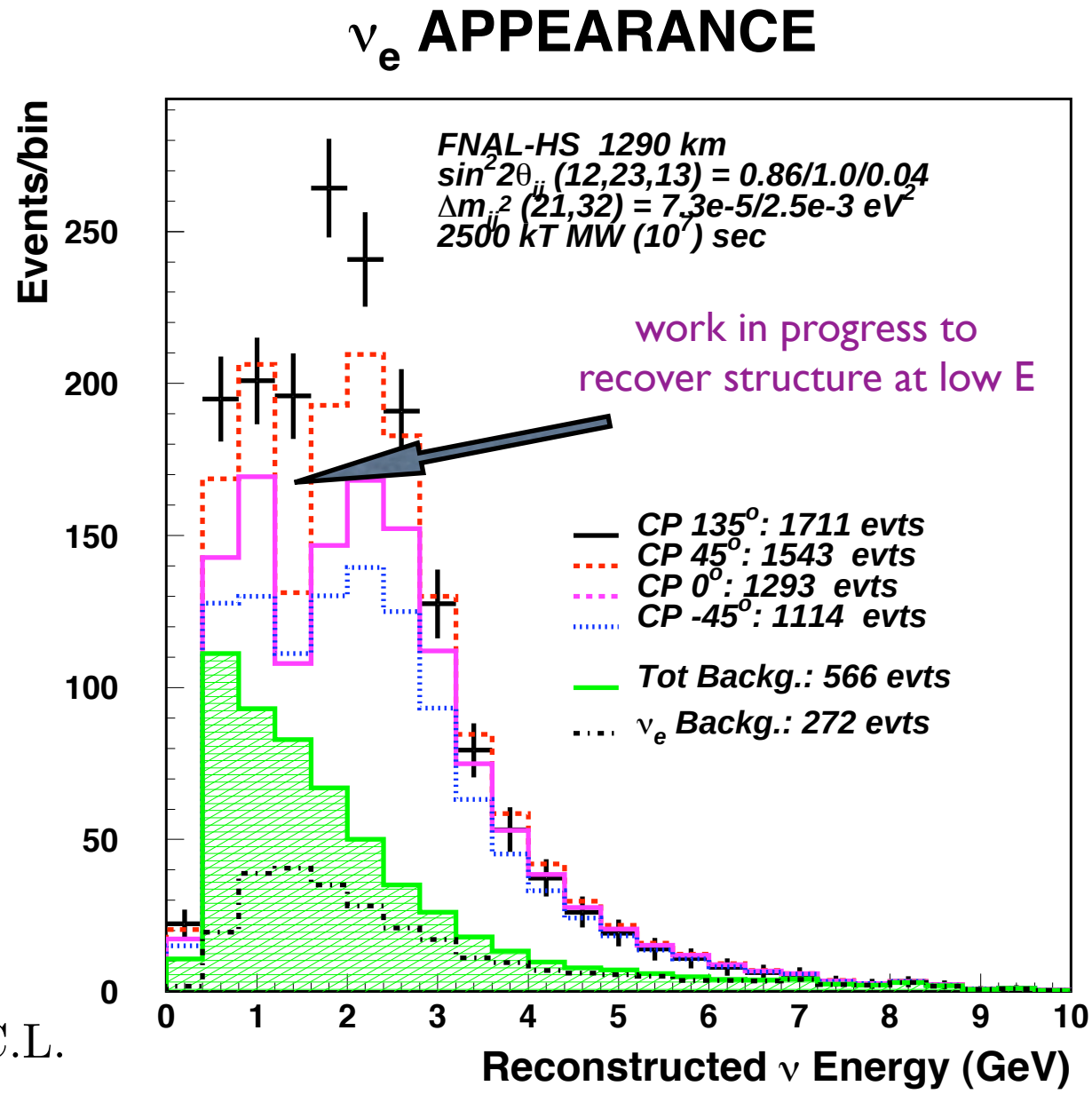
ν_e Appearance

Backgrounds

- beam ν_e
- Neutral current events

ν running

- measure $\sin^2 2\theta_{13}$ and δ_{CP}.
- resolve mass hierarchy for $\sin^2 2\theta_{13} > 0.01$
- with $\bar{\nu}$ running $\sin^2 2\theta_{13} > 0.003$ at 90% C.L.



If $\sin^2 2\theta_{13}$ too small δ_{CP} cannot be measured. (See Patrick's curves).

ν_μ Disappearance

Very easy to get this effect
Does not need extensive pattern recognition. Can enhance the second minimum by background subtraction.

Neutrino Running

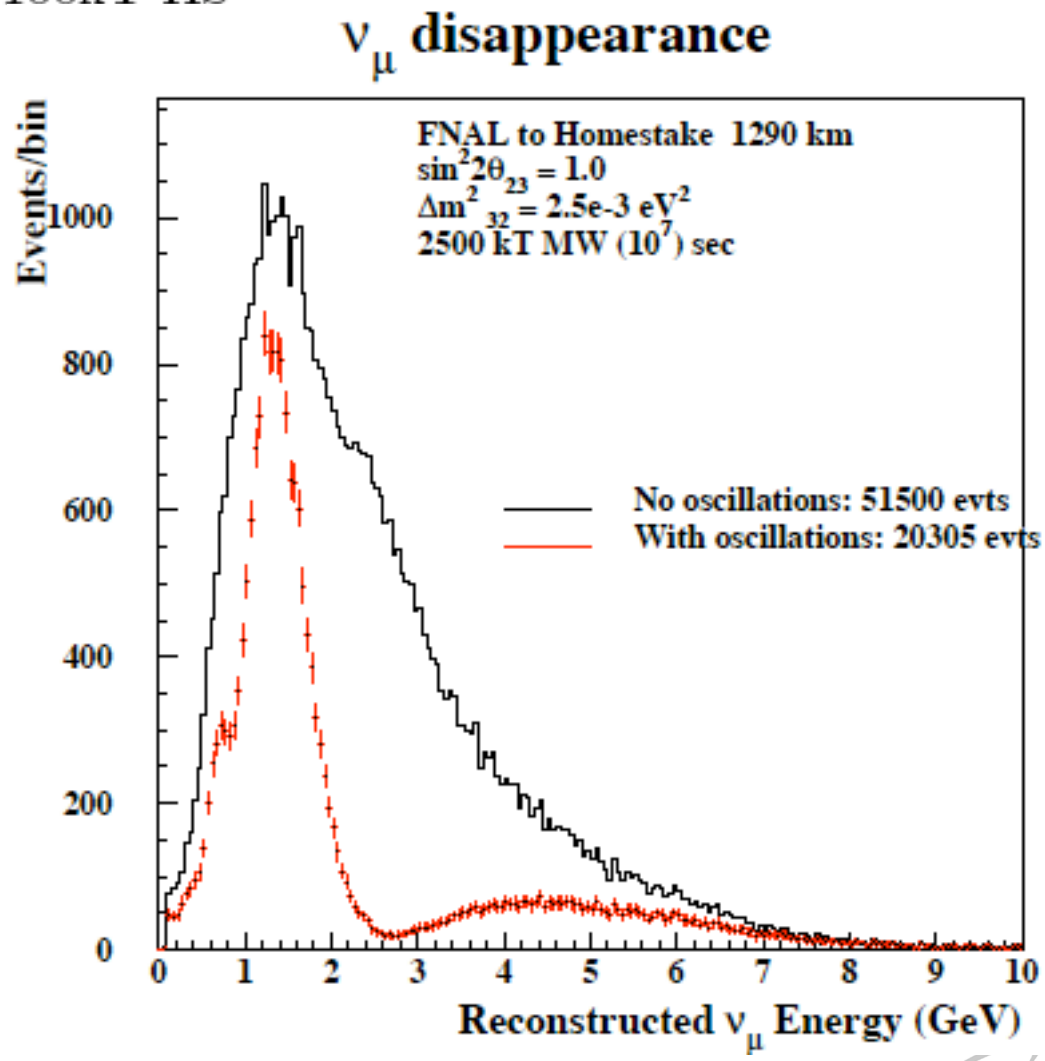
- Total exposure: 2500 kT.MW.(10^7).sec
- 195000 CC evts/6yrs: 2MW-FNAL, 100kT-HS
- Use only clean single muon events.

Measurements

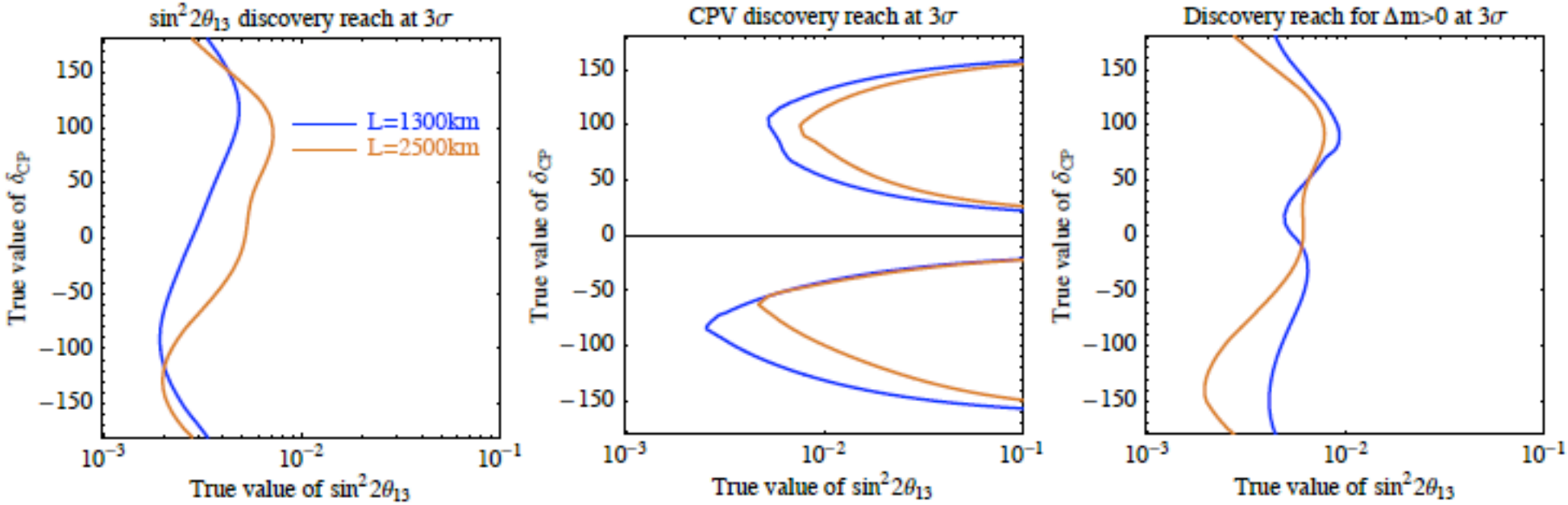
- 1% determination of Δm^2_{32}
- 1% determination of $\sin^2 2\theta_{23}$
- Most likely systematics limited.

$\bar{\nu}$ running

- Need twice the exposure for similar size data set.
- very precise CPT test possible.



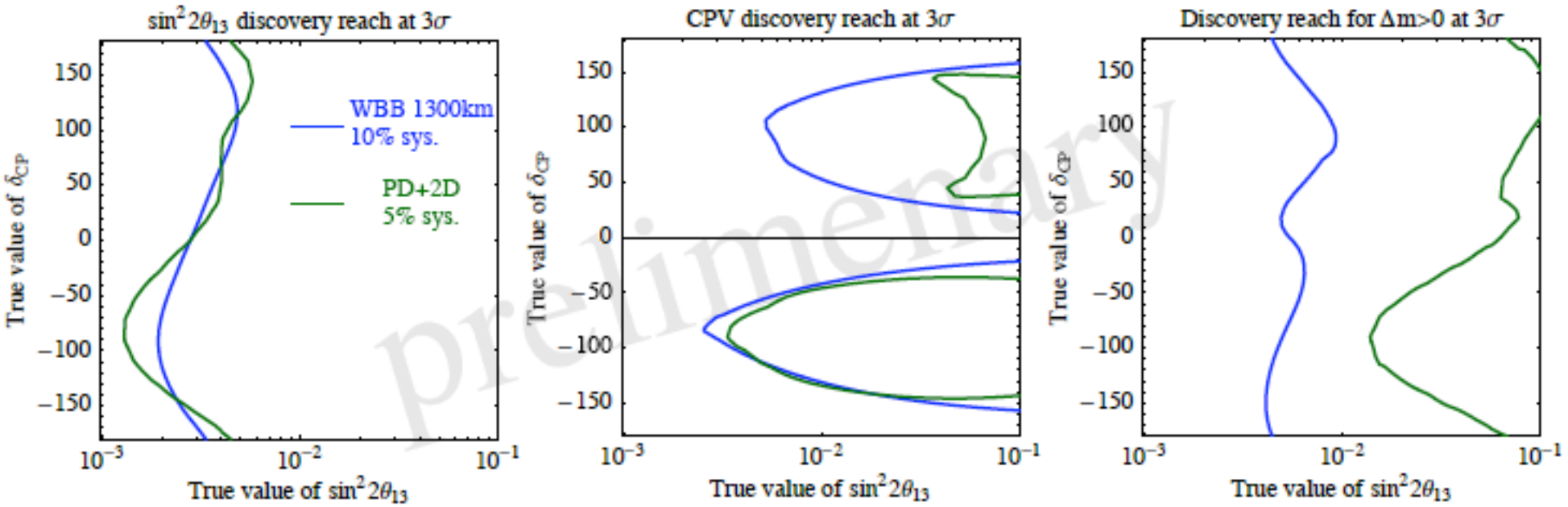
Wide band beam



- very good resolution of the mass hierarchy
- no problems due to π-transit for $\sin\delta > 0$
- Baseline choice is not critical

includes anti running, but large fraction of the result is from nu running for normal hierarchy

Summary

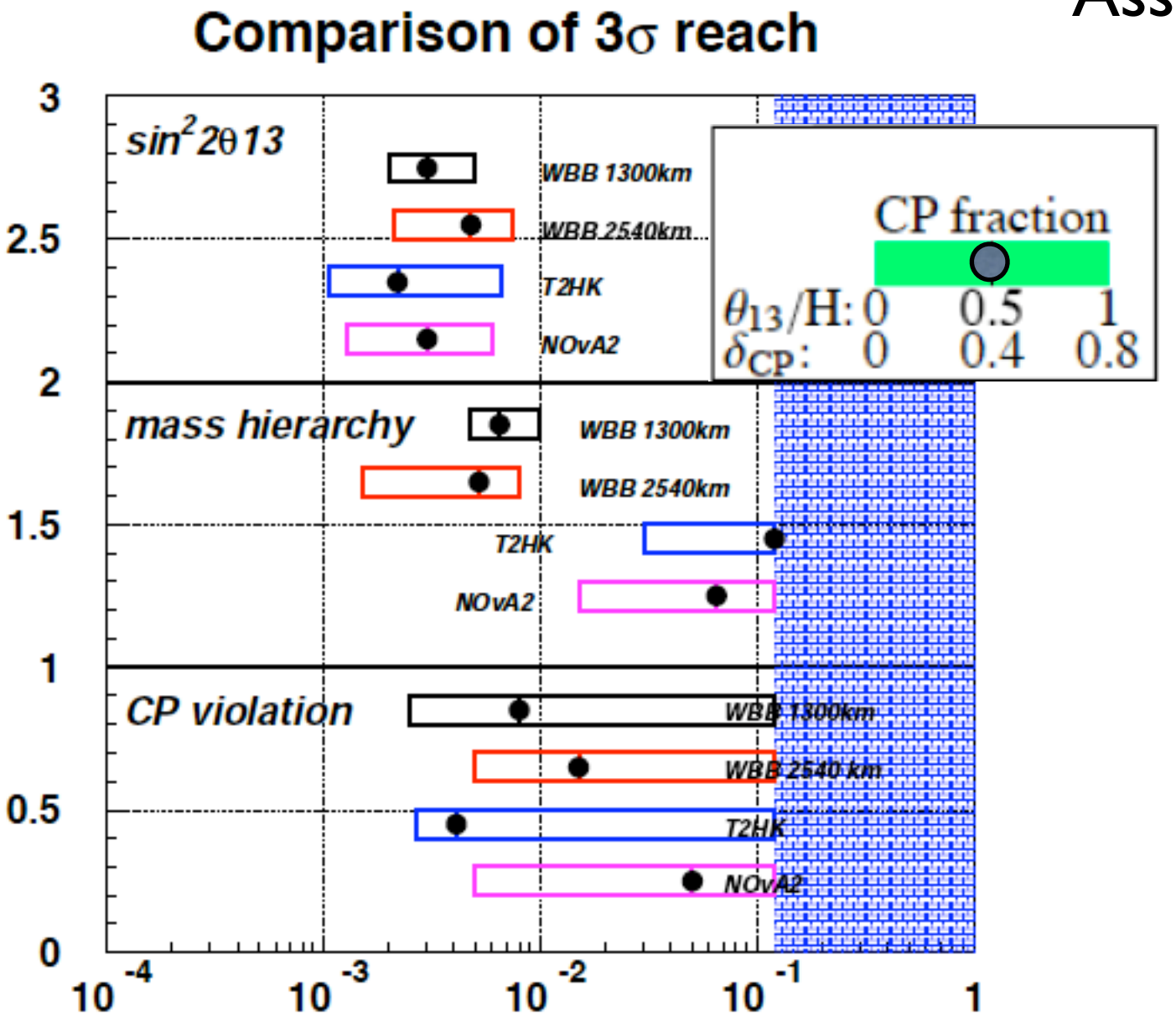


How would that picture look like with

- Liquid Argon
- 2nd peak in the OA spectrum

Preliminary comparison to off-axis program with a second detector

Assumptions



- WBB:
  nu:200kT*1MW*6yr.
  antinu: 200kT*1MW*6yr
  syst: 10% on bck
  Antinu running is over-constraint for normal hierarchy.
- T2HK:
  nu: 1000kT*4MW*3yr
  antinu: 1000kT*4MW*3yr
  syst: 2% on bck
- NOVA2:
  nu:30kT*2MW*6yr+
  80kT*2MW*3yr
  antinu: same*6yr+3yr
  syst: 5% on bck

Preliminary result out of FNAL workshop

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Summary

- Long baseline, nucleon decay, astrophysical neutrinos can be accomplished in a single project. This work has been supported thru LDRD since ~2002. A list of technical papers and documents attached.

- Low risk, cost effective option for a long baseline second generation experiment. Very robust in physics reach (little dependence on parameters, baseline distance, much lower sensitivity to background systematics, etc.)

- We are engaged in the NSF DUSEL process.

- B. Marciano is on the Homestake PAC. MVD is a group leader in the S1 document. MVD is on the exec committee for Homestake, etc.

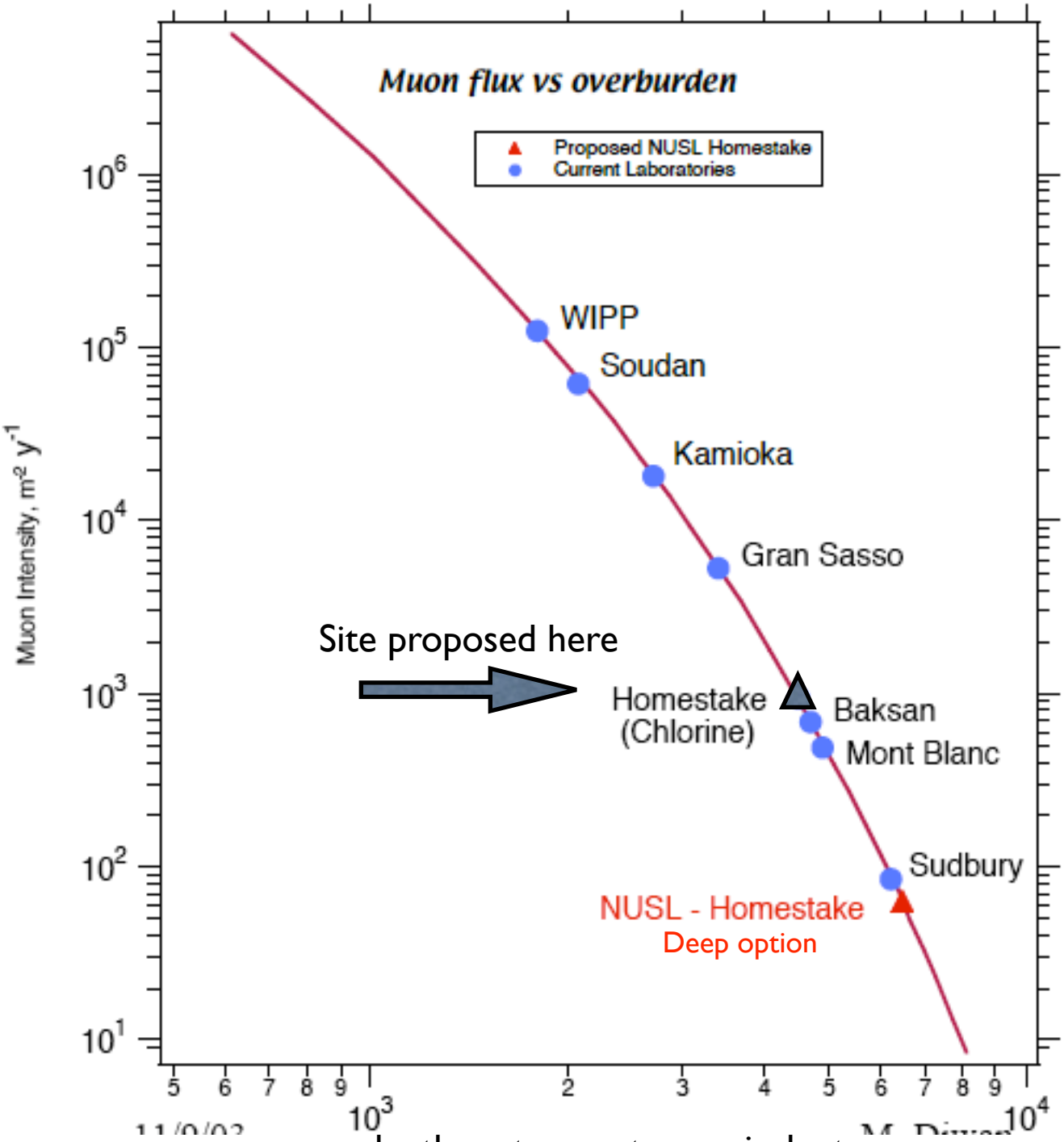
- Need support to address many open issues on detector and beam. Some will be addressed in the joint BNL/FNAL study. Need help from more university groups.

4850ft: 100kT ~3M mu/yr

with rate of 1 mu/10 sec => may not need veto-counter

The Beam neutrinos will be obvious with a rate of 100-200/day in 10 mus spills.

No pattern recognition beyond time cut is needed.



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Working group written material

W. J. Marciano, "Long baseline neutrino oscillations and leptonic CP violation," Nucl. Phys. Proc. Suppl. **138**, 370 (2005).

M. V. Diwan, "The case for a super neutrino beam," Heavy Quarks and Leptons Workshop 2004, San Juan, Puerto Rico, 1-5 Jun 2004. arXiv:hep-ex/0407047.

J. Alessi, et al., "The AGS-based Super Neutrino Beam Facility, Conceptual Design Report," BNL-73210-2004-IR, 1 Oct. 2004.

W. T. Weng *et al.*, J. Phys. G **29**, 1735 (2003).

W. J. Marciano, "Extra long baseline neutrino oscillations and CP violation," BNL-HET-01-31, Aug 2001. 11pp. arXiv:hep-ph/0108181.

R, May 2003. 114pp.

M. V. Diwan *et al.*, "Very long baseline neutrino oscillation experiments for precise measurements of mixing parameters and CP violating effects," Phys. Rev. D **68**, 012002 (2003) [arXiv:hep-ph/0303081].

002. 100pp.

ılar multi-purpose neutrino detector for a program of physics in the Homestake DUSEL," arXiv:hep-ex/0306053.

We are after the science and facilities absolutely central to the US HEP program: Neutrino super beam and a large capable underground detector.

Working group chronology

- December, 2001: Tom Kirk gave us a charge to form a working group.
- ~50 Members from Physics department, CAD, and outside universities.
    - Coordinators: W. Marciano (physics), M.Diwan(simulations), W. Weng(accelerator upgrade)
- BNL HENP PAC (2002)
- Internal AGS review (June 2004)
- HEPAP facilities plan(2003), Absolutely central (super-beam and large detector included in the the 20 yr outlook plan)
- APS neutrino study (2004)(proton driver recommendation)
- NESS workshop(Sep 2002), DUSEL S1(MVD is one of the working group leaders) and S2 workshops, 3 BNL/UCLA workshops(Dec 2003, May 2004, Feb 2005)

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).**

Open issues on detector

- Depth and veto counter - has cost, schedule and physics implications. Perhaps only the first module is built without veto-counter for a fast start.
- Fiducial volume. If SK cut good enough => 75 kT.
- PMT coverage: 20 % adequate from SK experience. 40% if very low threshold is needed.
- PMT size: 13 inch versus 20 inch. Greater number of pixels will give better pattern recognition.
- Size of detector: very difficult to increase span. If made bigger has cost and schedule implications. 50 meter span seems adequate to contain beam events.

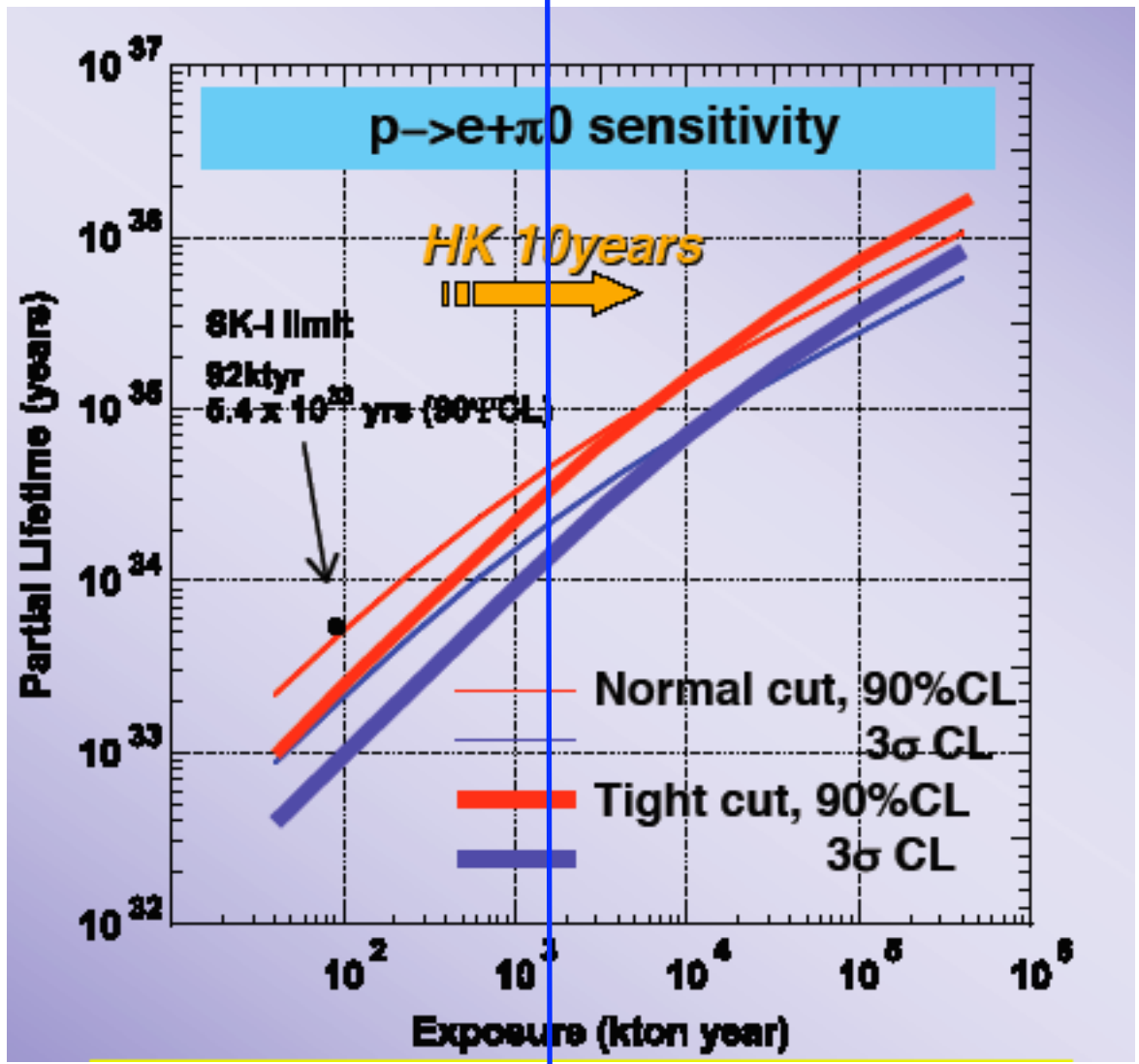
Open issues on beam

- What is the correct proton energy and power level from FNAL
- What is the cost of a new beam
- To get intensity at low energies must have ~4 meters diameter tunnel. I have length of 200 meters to get the spectra in this talk.
- How should we tailor the spectrum for maximum signal/ noise ?
- If tunnel is wide WE CAN ALWAYS RUN OFFAXIS by moving and tilting the horn/target. (upto 1 deg.)
- What is the time sequence ? Proposal on next slide.

Nucleon decay

- Large body of work by HyperK, and UNO.
- background levels for the positron+Pion mode
  - 3.6/MTon-yr (normal)
  - 0.15/MTon-yr (tight)

LMD-I and II (200kT) will hit backg. in ~1.5yrs. It could be important to perform this first step before building bigger. Sensitivity on K-nu mode is about ~8x10^33 yr



Ref: Shiozawa (NNN05) 150kTX10yrs 5X10^34 yrs

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Astrophysical Neutrinos
Event rates. LMD-I&II(200kT), 5 yrs

- Atmospheric Nus: ~20000 muon, ~10000 electrons. (Ref: Kajita nnn05)
- Solar Nus: >120000 elastic scattering E>5MeV (including Osc.) (Ref: uno)
- Galactic Supernova: ~60000/10 sec in all channels. (~2000 elastic events). (Ref: uno)
- Relic Supernova: (ref: Ando nnn05)
  - flux: ~5 (1.1) /cm2/sec Enu>10 (19) MeV
  - rate: 150 (70) events over backg ~200 !

Need analysis with these numbers

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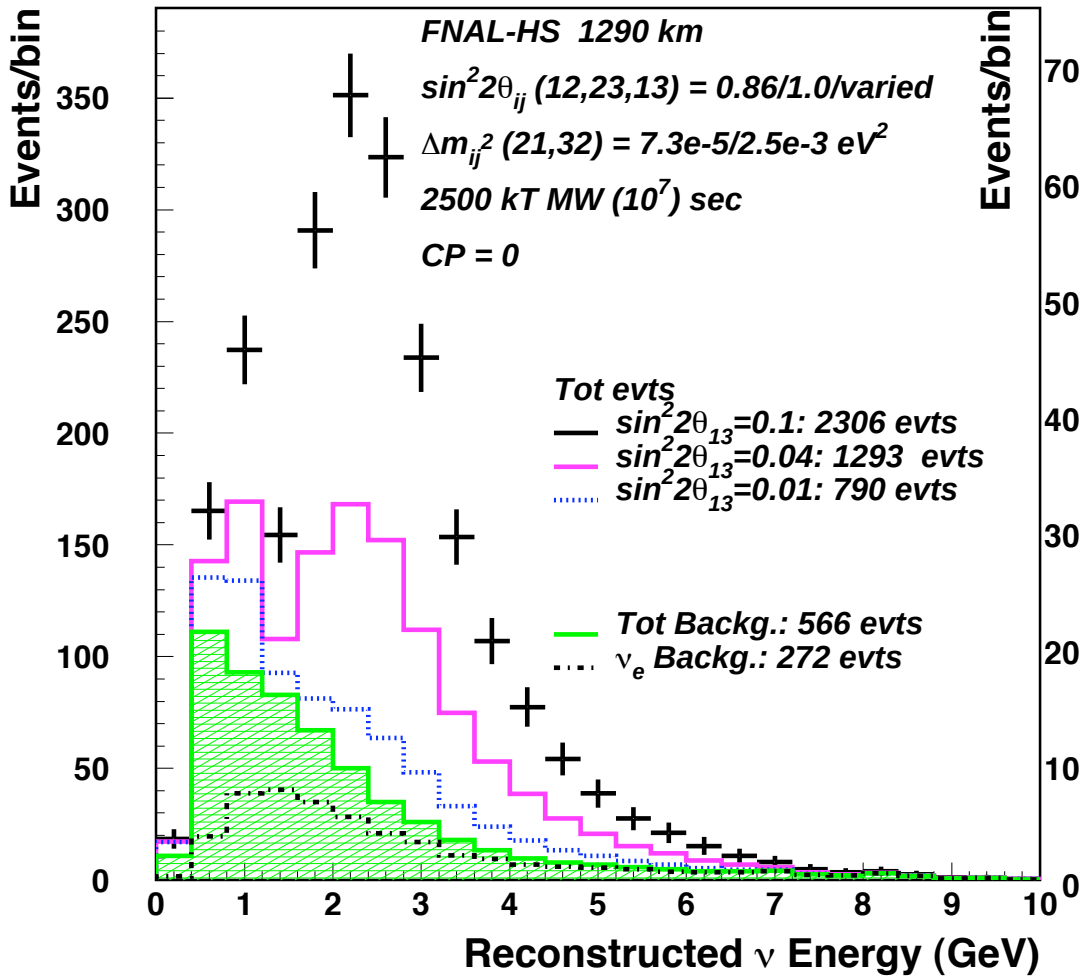
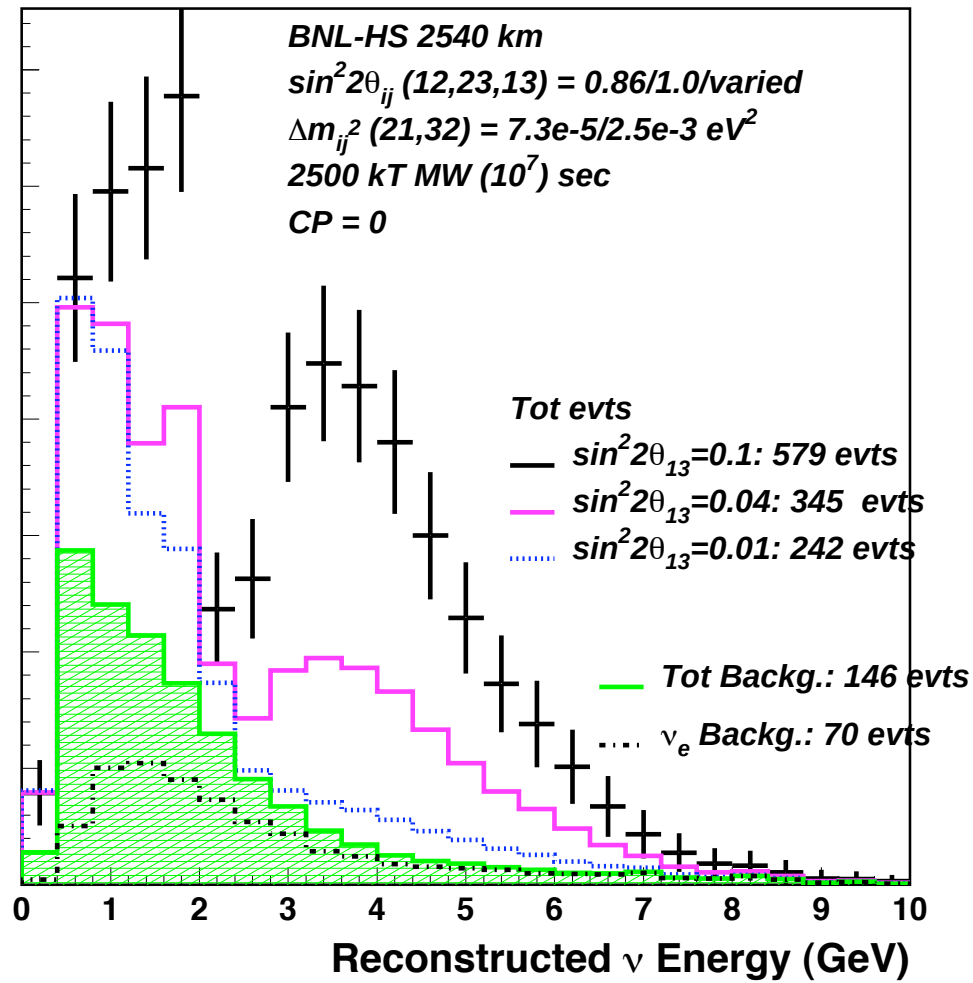
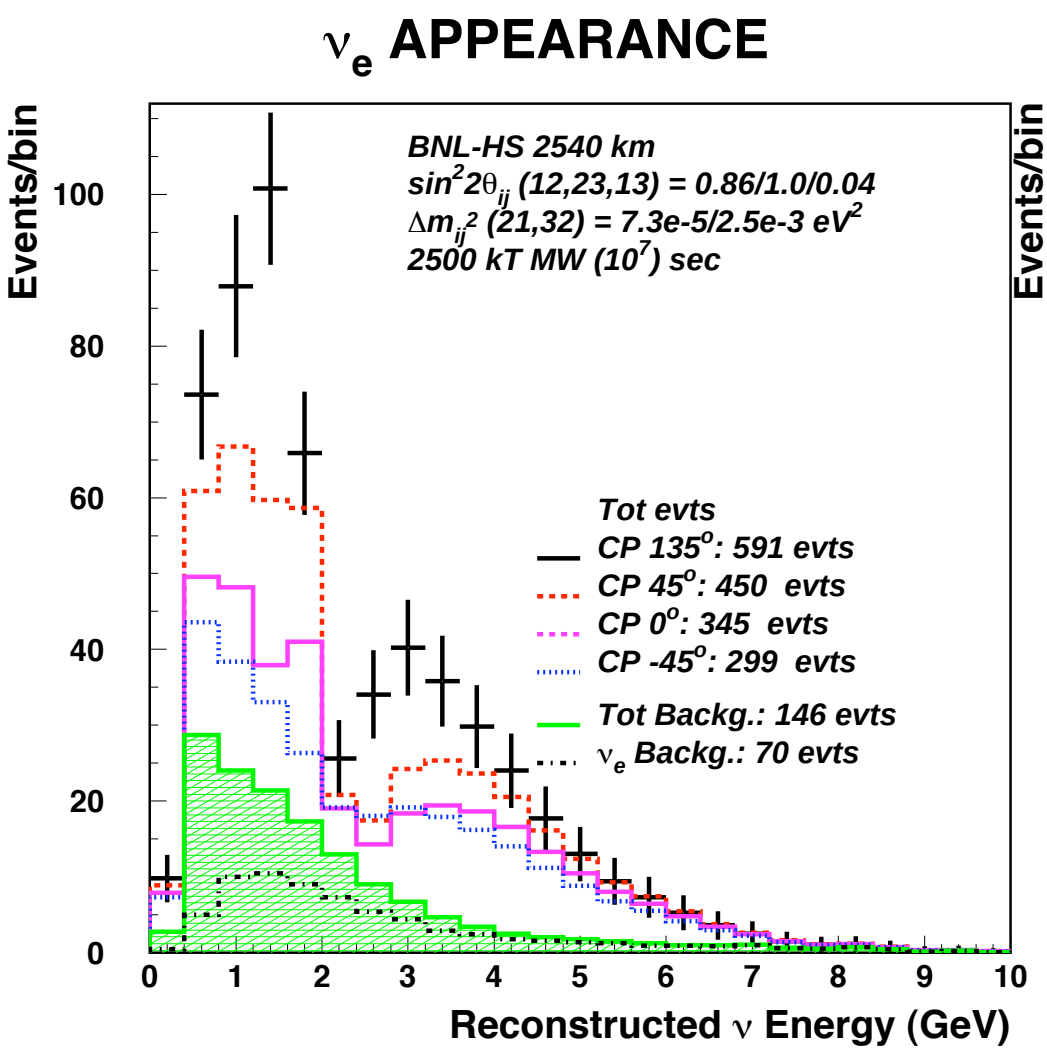
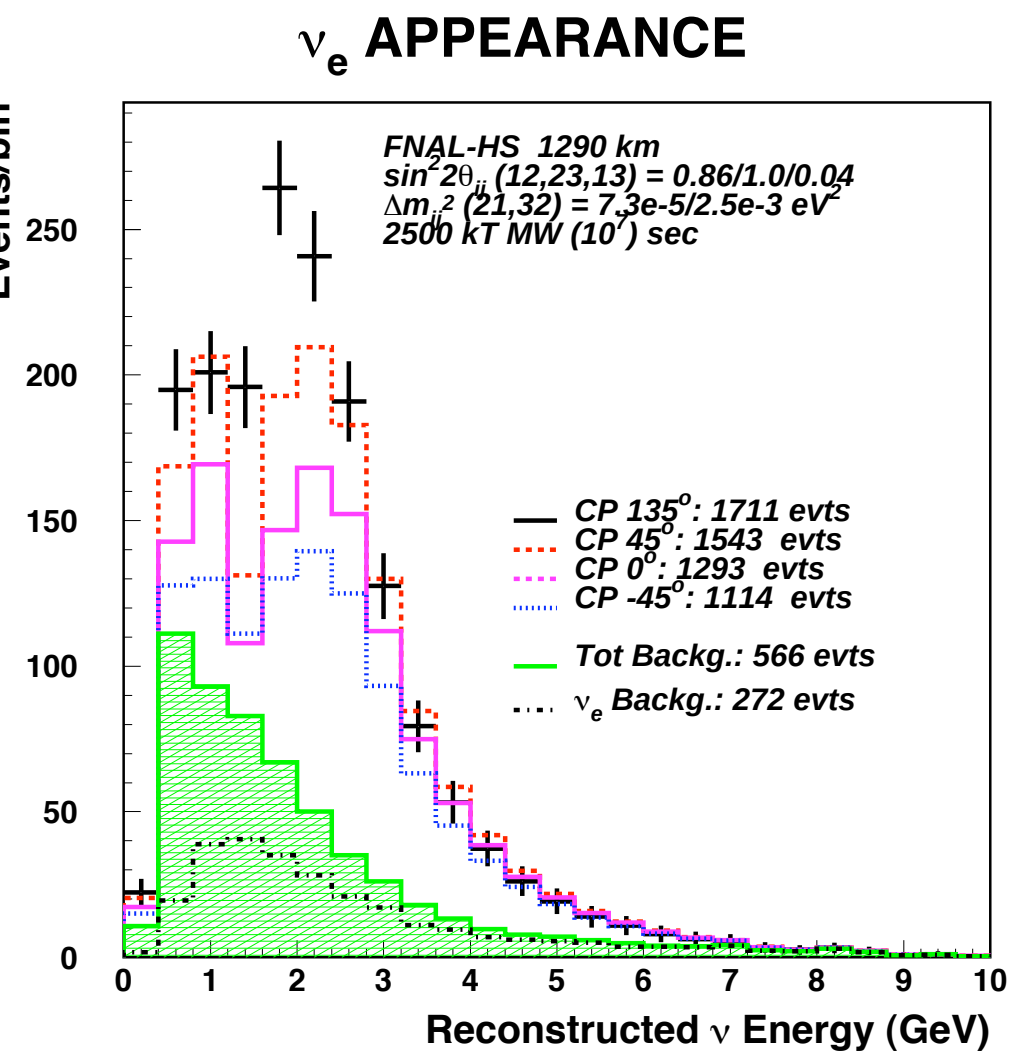
ν_e APPEARANCE



ν_e APPEARANCE







Comparison to 1290 km to 2540 km