Progress on a future US long baseline neutrino

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Seminar at the University of Chicago

Talk outline

- Physics motivation
- Experimental considerations
- The US long baseline neutrino study
- Accelerator and beam considerations
- Detector considerations

Apologies

- I will not cover the Japanese program which is based on the new JPARC facility and possible detectors in Japan and Korea.
- There is an international scoping study (ISS) in progress focussed on muon storage and beta beam based ideas.
- My focus on conventional beams only. And emphasis what is currently doable.
- First part of talk should be general about the physics.

- Physics motivation

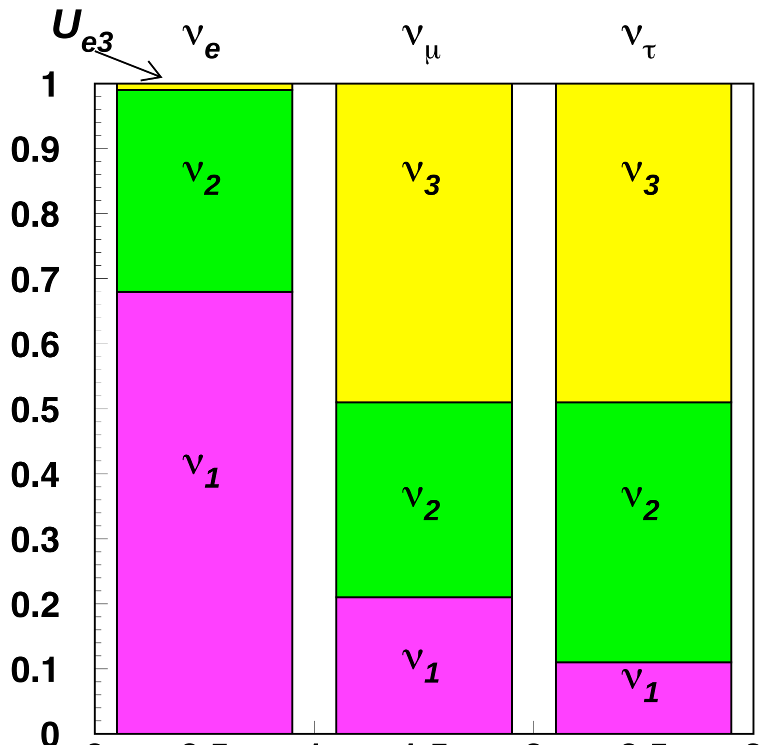
Physics motivation

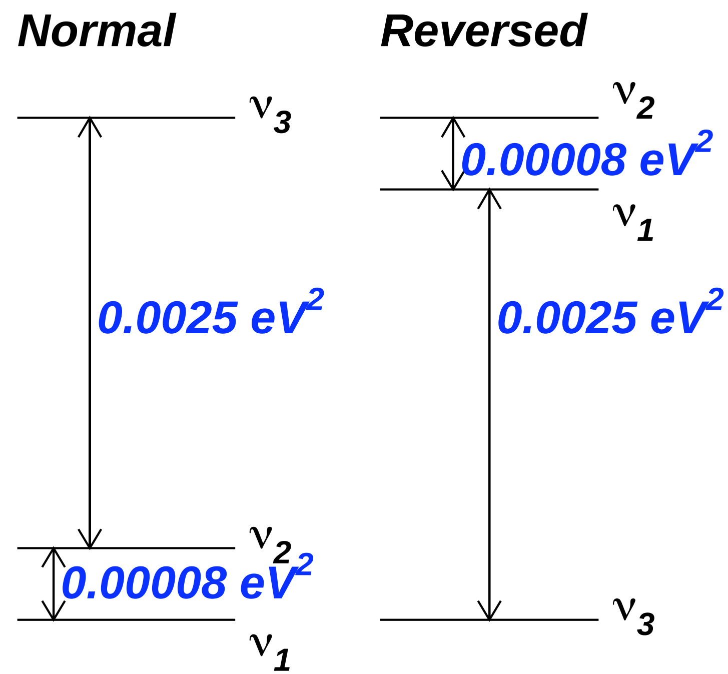
- CP violation in neutrino physics is the driving motivation for a future program. The program to achieve this goal will also makes all other measurements of interest in this physics.
- Observe matter/antimatter asymmetry in muon to electron neutrino conversion.
- Leptogenesis is the leading explanation for BAU. It needs some confirmation of its components: very heavy right handed neutrinos and lepton number and CP violation in their decays. This is unlikely with current technology.
- Neutrinoless double beta decay and ordinary CP violation in oscillations is possible. This could be the only connection to leptogenesis.

- need connection between Ue3 and th13
- show matrix.

3 Generation oscillations

CP phase





Difference in mass squares: $(m_2^2 - m_1^2)$

2-nu: $$P(\nu_a \to \nu_b) = \sin^2 2\theta \sin^2 \frac{1.27((m_2^2 - m_1^2)/eV^2)(L/km)}{(E/GeV)}$$

3-nu: CP phase

$$\begin{aligned} P(\nu_a \to \nu_b) \quad = \quad & \sum_i |U_{ai}|^2 |U_{bi}|^2 \\ & +2Re(U_{a1}^* U_{b1} U_{a2} U_{b2}^* \times exp(-i\Delta m_{21}^2 L/2E) \\ & +2Re(U_{a1}^* U_{b1} U_{a3} U_{b3}^* \times exp(-i\Delta m_{31}^2 L/2E) \\ & +2Re(U_{a2}^* U_{b2} U_{a3} U_{b3}^* \times exp(-i\Delta m_{32}^2 L/2E) \end{aligned}$$

no matter effects

Oscillation nodes at $\pi/2, 3\pi/2, 5\pi/2, \ldots$ $(\pi/2)$: $\Delta m^2 = 0.0025 eV^2$, $E = 1GeV$, $L = 494km$.

Solar : L~15000*km*

- Experimental considerations: general grounds

$\nu_\mu \to \nu_e$ with matter effect

Approximate formula (M. Freund)

$$P(\nu_\mu \to \nu_e) \approx \sin^2\theta_{23}\frac{\sin^2 2\theta_{13}}{(\hat{A}-1)^2}\sin^2((\hat{A}-1)\Delta)$$
$$+\alpha\frac{8J_{CP}}{\hat{A}(1-\hat{A})}\sin(\Delta)\sin(\hat{A}\Delta)\sin((1-\hat{A})\Delta)$$
$$+\alpha\frac{8I_{CP}}{\hat{A}(1-\hat{A})}\cos(\Delta)\sin(\hat{A}\Delta)\sin((1-\hat{A})\Delta)$$
$$+\alpha^2\frac{\cos^2\theta_{23}\sin^2 2\theta_{12}}{\hat{A}^2}\sin^2(\hat{A}\Delta)$$

~7500 km
no CPV.
magic bln

CPV term
approximate
dependence
~L/E

solar term

linear dep.

$$J_{CP} = 1/8\sin\delta_{CP}\cos\theta_{13}\sin 2\theta_{12}\sin 2\theta_{13}\sin 2\theta_{23}$$

$$I_{CP} = 1/8\cos\delta_{CP}\cos\theta_{13}\sin 2\theta_{12}\sin 2\theta_{13}\sin 2\theta_{23}$$

$$\alpha = \Delta m^2_{21}/\Delta m^2_{31},\ \Delta = \Delta m^2_{31}L/4E$$

$\hat{A} = 2VE/\Delta m^2_{31} \approx (E_\nu/GeV)/11$ For Earth's crust.

ν_e appearance

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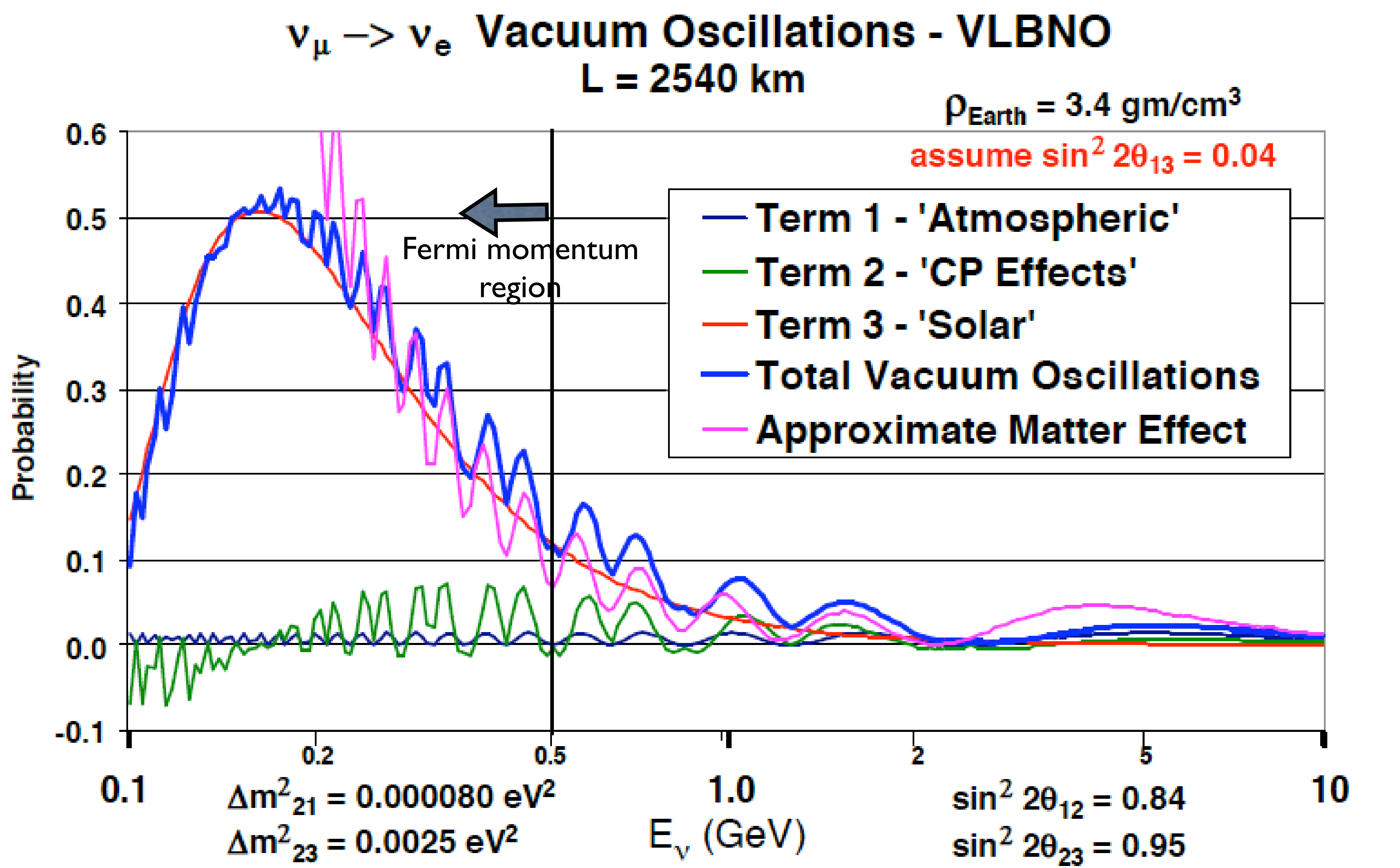
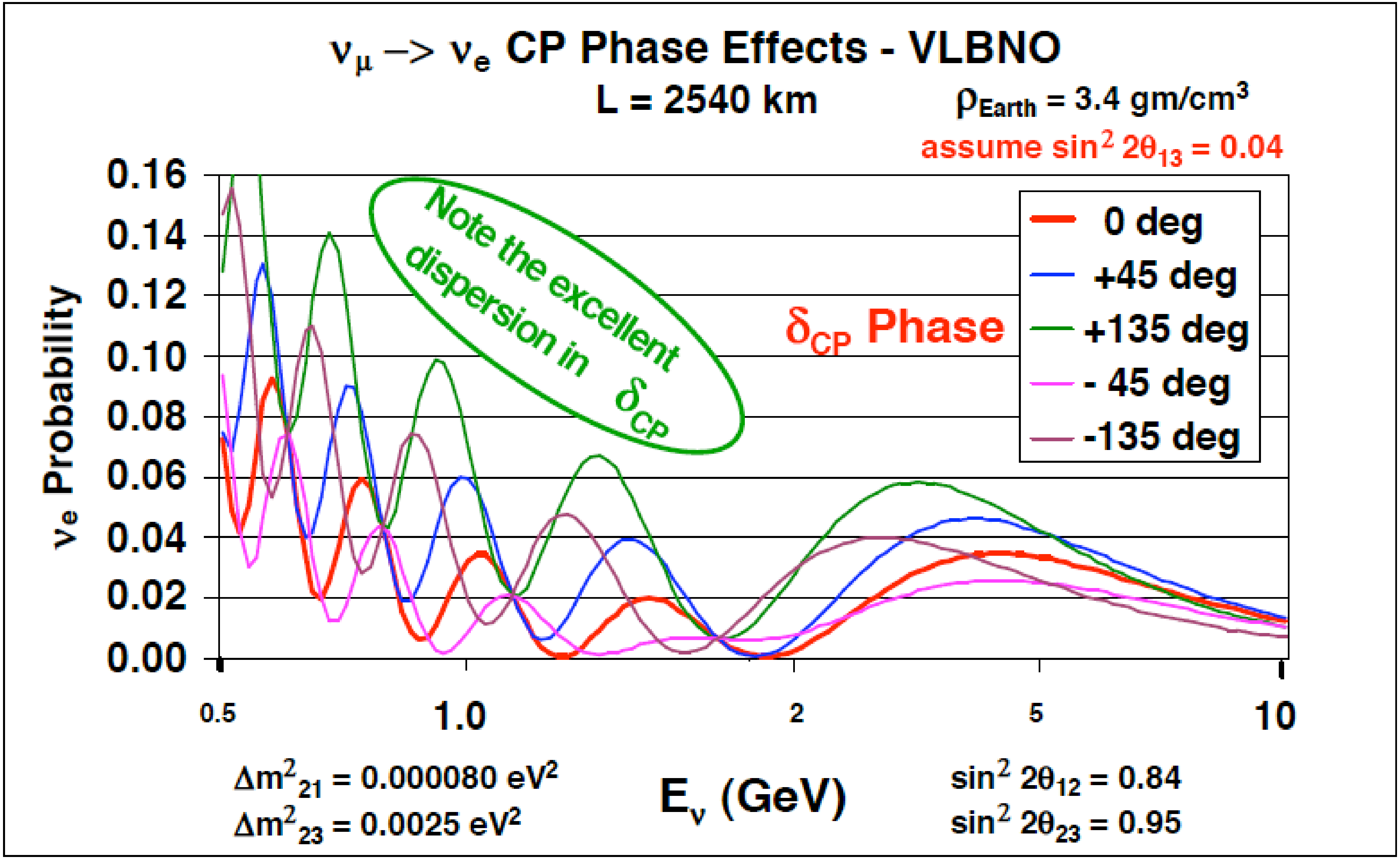
- ✔ $P(\nu_\mu \to \nu_e)$ depends on all oscillation parameters and has following degeneracies:
  - ✗ intrinsic $(\theta_{13},\delta_{CP}) \leftrightarrow (\theta'_{13},\delta'_{CP})$
  - ✗ sign $\Delta m^2_{32} \leftrightarrow -\Delta m^2_{32}$
  - ✗ octant $\theta_{23} \leftrightarrow \pi/2-\theta_{23}$
- ✔ atmospheric term has effect of $\sin^2\theta_{13}$ and matter effects (~L)
- ✔ CP violating term ~L/E, flux ~L^{-2}

  $\rightarrow$ sensitivity to δ_{CP} independent of distance

  (Marciano hep-ph/0108181)
- ✔ solar term dominated by Δm^2_{21} and grows as ~ $(L/E)^2$



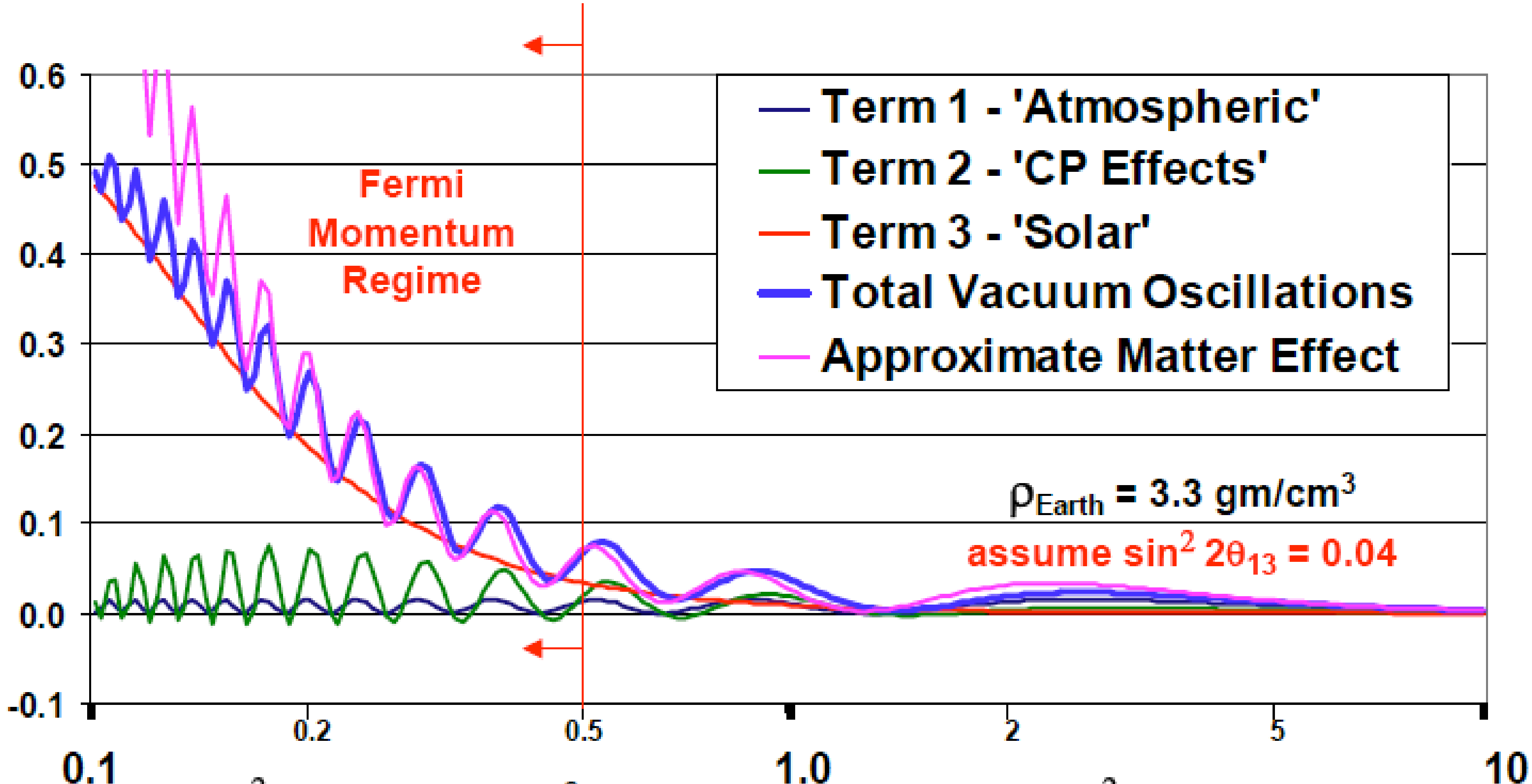
$\nu_\mu \rightarrow \nu_e$ Vacuum Oscillations - VLBNO
L = 2540 km
ρ_{Earth} = 3.4 gm/cm^3
assume $\sin^2 2\theta_{13} = 0.04$
Term 1 - 'Atmospheric'
Term 2 - 'CP Effects'
Term 3 - 'Solar'
Total Vacuum Oscillations
Approximate Matter Effect
Fermi momentum region
Probability
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
0.1
0.2
0.5
1.0
2
5
10
$\Delta m^2_{21} = 0.000080$ eV^2
$\Delta m^2_{23} = 0.0025$ eV^2
E_ν (GeV)
$\sin^2 2\theta_{12} = 0.84$
$\sin^2 2\theta_{23} = 0.95$



νμ -> νe CP Phase Effects - VLBNO
L = 2540 km
ρEarth = 3.4 gm/cm3
assume sin2 2θ13 = 0.04
Note the excellent dispersion in δCP
δCP Phase
0 deg
+45 deg
+135 deg
- 45 deg
-135 deg
νe Probability
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0.5
1.0
2
5
10
Eν (GeV)
Δm2 21 = 0.000080 eV2
Δm2 23 = 0.0025 eV2
sin2 2θ12 = 0.84
sin2 2θ23 = 0.95

$\nu_\mu \rightarrow \nu_e$ Vacuum Oscill. - VLBNO

L = 1300 km – FNAL to Homestake

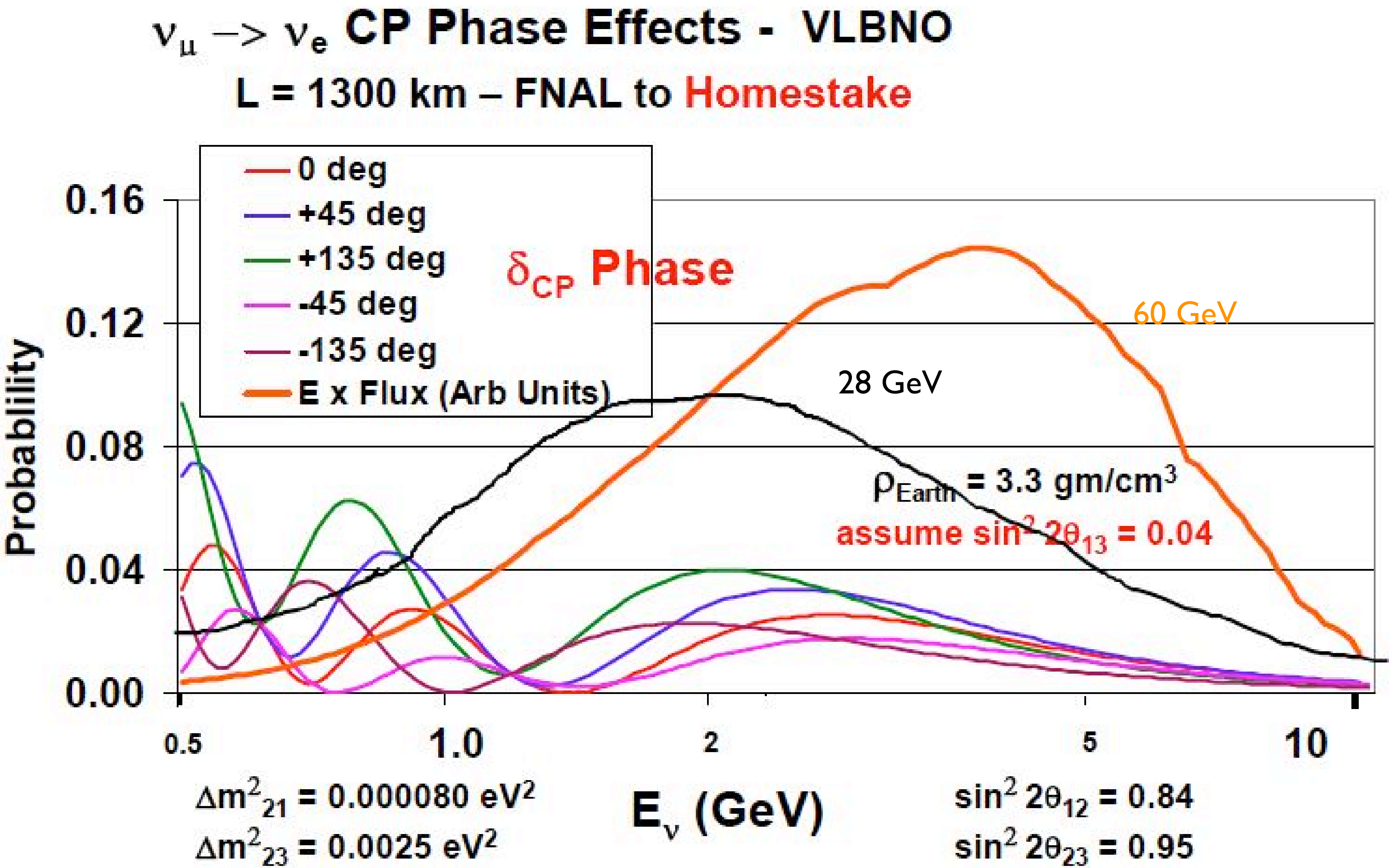


Δm^2_{21} = 0.000080 eV^2

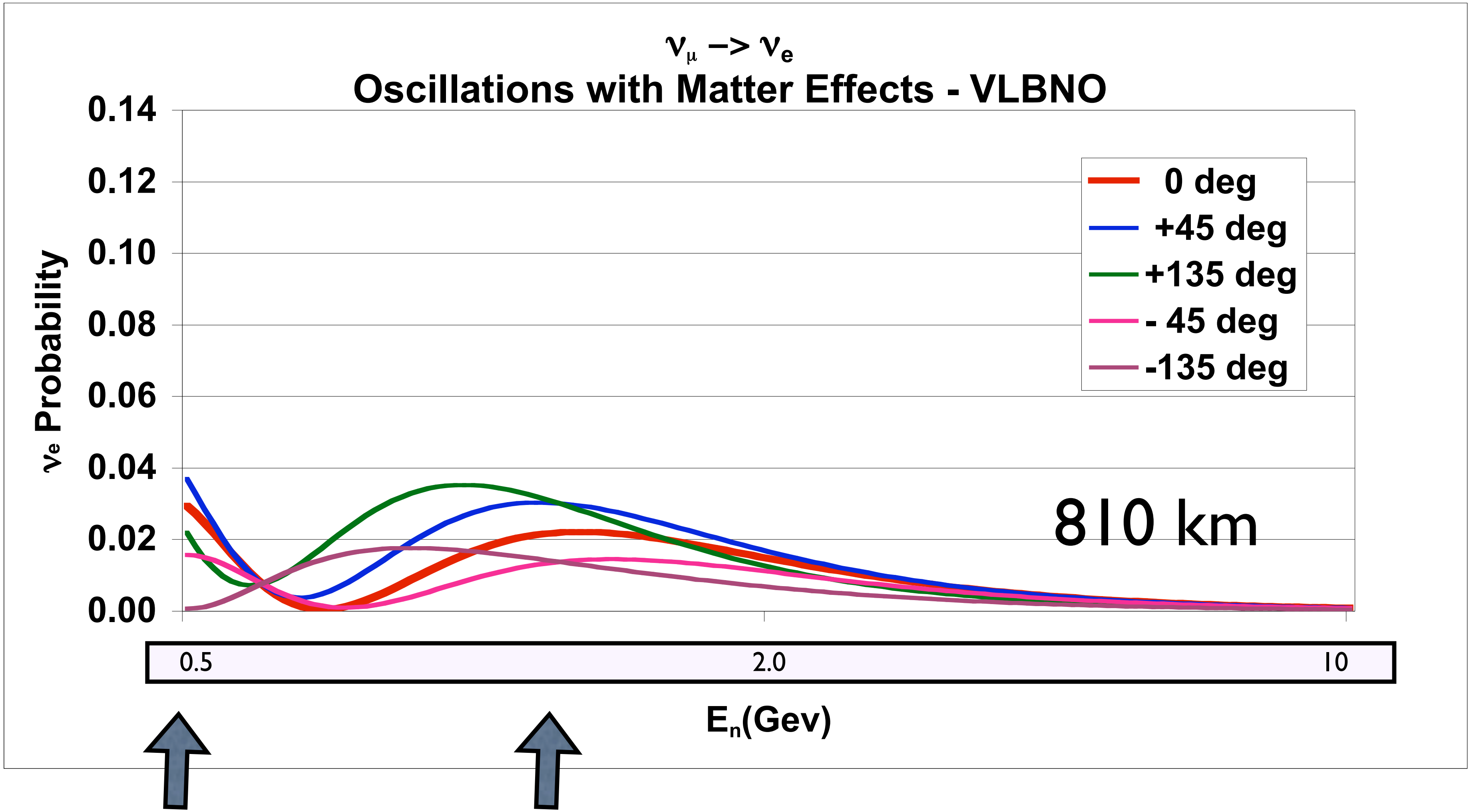
Δm^2_{23} = 0.0025 eV^2

$\sin^2 2\theta_{12}$ = 0.84

$\sin^2 2\theta_{23}$ = 0.95



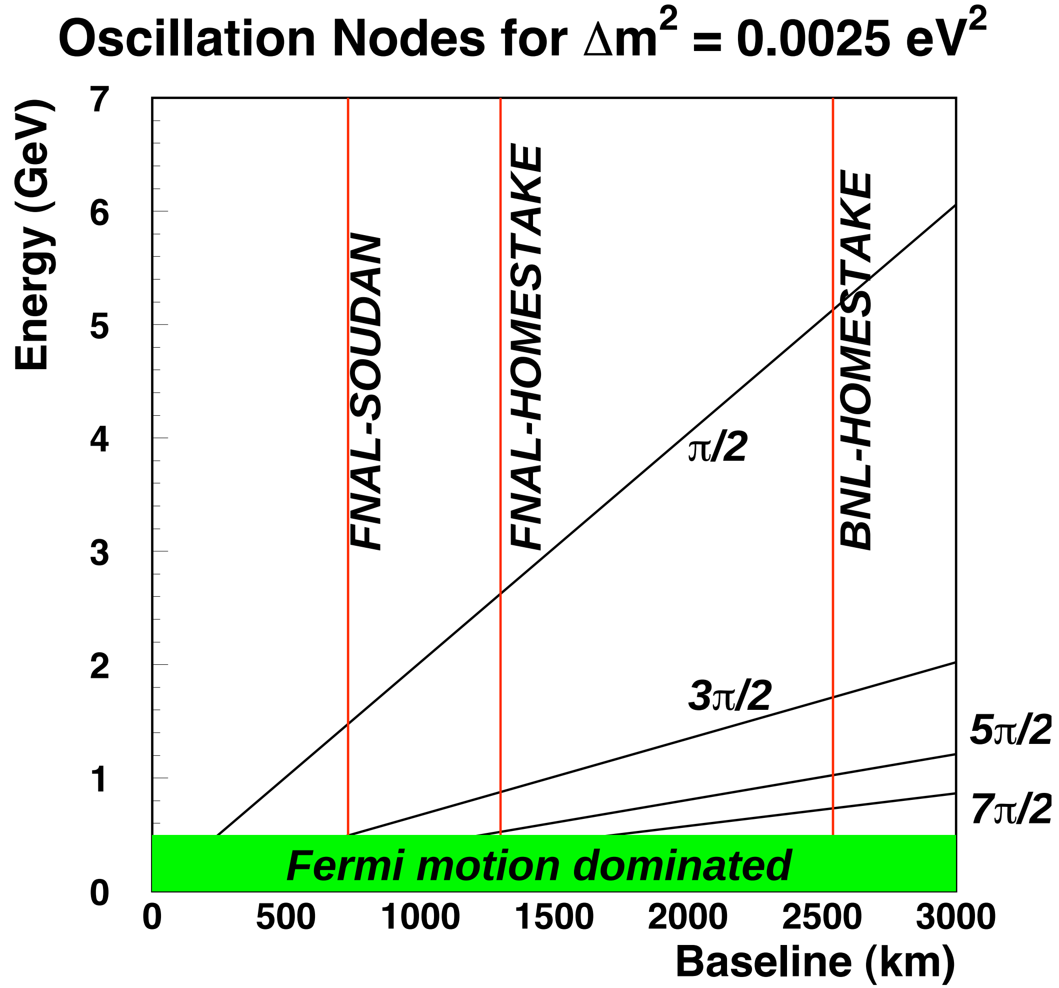
$\nu_\mu \rightarrow \nu_e$ CP Phase Effects - VLBNO
L = 1300 km – FNAL to Homestake
0 deg
+45 deg
+135 deg
-45 deg
-135 deg
E x Flux (Arb Units)
δ_{CP} Phase
60 GeV
28 GeV
ρ_{Earth} = 3.3 gm/cm^3
assume $\sin^2 2\theta_{13} = 0.04$
Probability
0.16
0.12
0.08
0.04
0.00
0.5
1.0
2
5
10
E_ν (GeV)
$\Delta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



second max ~0.5GeV

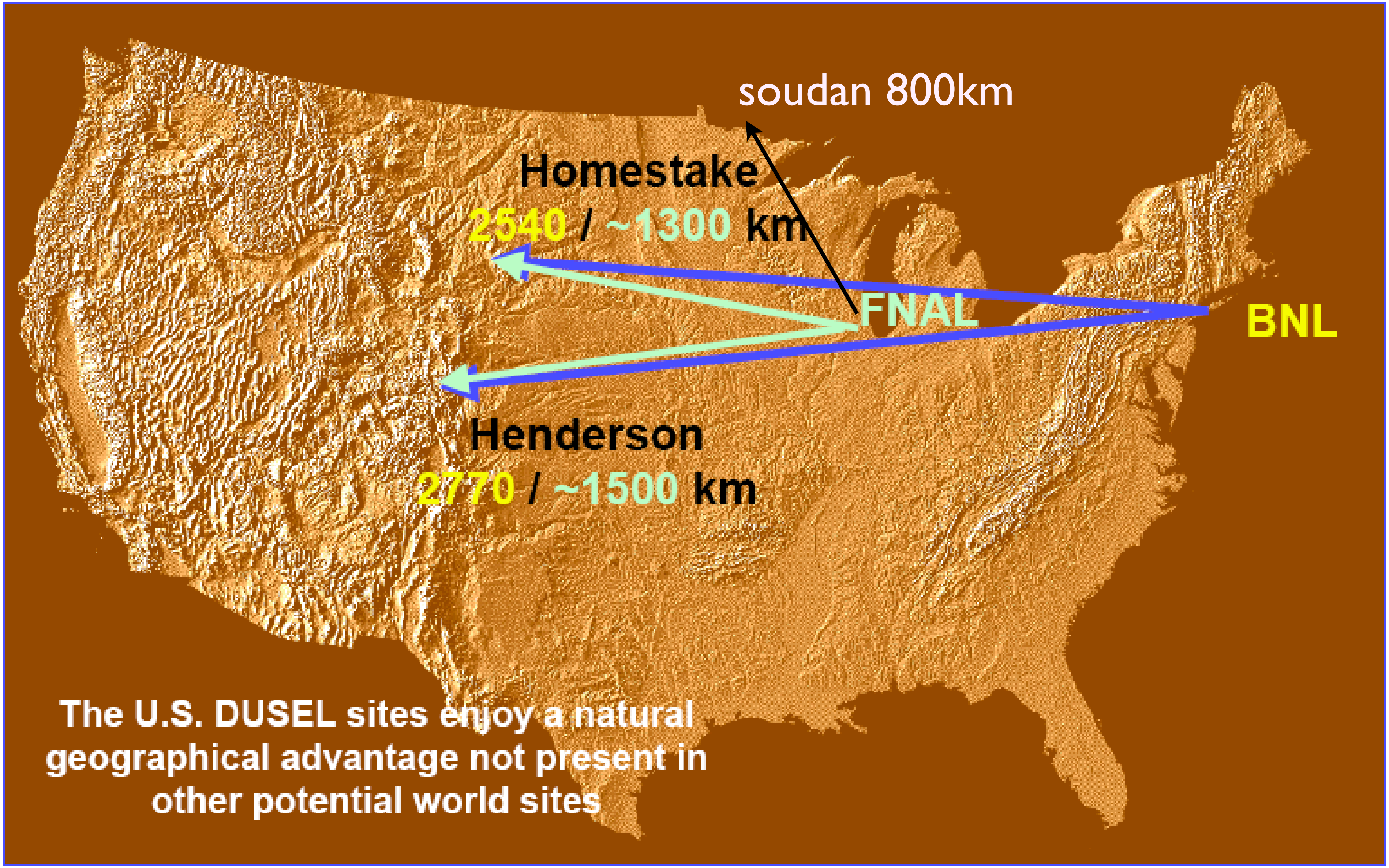
first max ~1.5 GeV

Same parameters as before



Oscillation Nodes for Δm² = 0.0025 eV²
Energy (GeV)
Baseline (km)
0
1
2
3
4
5
6
7
0
500
1000
1500
2000
2500
3000
FNAL-SOUDAN
FNAL-HOMESTAKE
BNL-HOMESTAKE
π/2
3π/2
5π/2
7π/2
Fermi motion dominated

Super Neutrino Beam to DUSEL Candidate Sites



What is DUSEL ?

- NSF-led initiative to establish a US Deep Underground Science and Engineering Laboratory
- www.dusel.org
- Initiative in 3 stages:
  - S1: (science case) completed with a report.
  - S2: (Site selection) downselect completed with selection of Homestake and Henderson as candidate sites.
  - S3: (complete CDRs) final site selection with conceptual design reports. Due April 2007.
  - Detector R&D initiative from both NSF/DOE (oct 31, 2006)

- US joint study focusses on two options in the US.

- The following is a very preliminary review of all the work. There is a lot more to be done to finish the report.

Two approaches

No new beam, but restricted physics because of surface det.

- Off axis: Use existing NUMI beam. NOvA(25kT) will be built ~10mrad offaxis for the first maximum. NOvA2(50kT LAR) will be built at 40 mrad for second maximum. Both detectors will be on the surface. Combine the results to extract th13, mass hierarchy, and CPV.

New beam, but detector capable of Nucleon Decay

- Low energy wide band: Couple the long baseline program to a new deep underground laboratory (DUSEL). Site a large detector (~200kT if water Cherenkov) at approximately 5000 mwe. Build a new wide beam with a spectrum shaped to be optimum (0.5-6 GeV). Use detector resolution to extract multiple nodes.

- Concerns: event rate, NC background, resolution, parameter sensitivity, total cost and timeliness.

FNAL/BNL study

- Chairs: Hugh Montgomery, Sally Dawson
- Several small workshops have been held
- Very good work reported on physics sensitivity, backgrounds, and beam alternatives.

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

FUTURE_LONG_BASELINE_LIST@fnal.gov

To get on the list send email to

rameika@fnal.gov

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

- Beam and event rates
- This has been the most successful part of this study.

Beam from BNL

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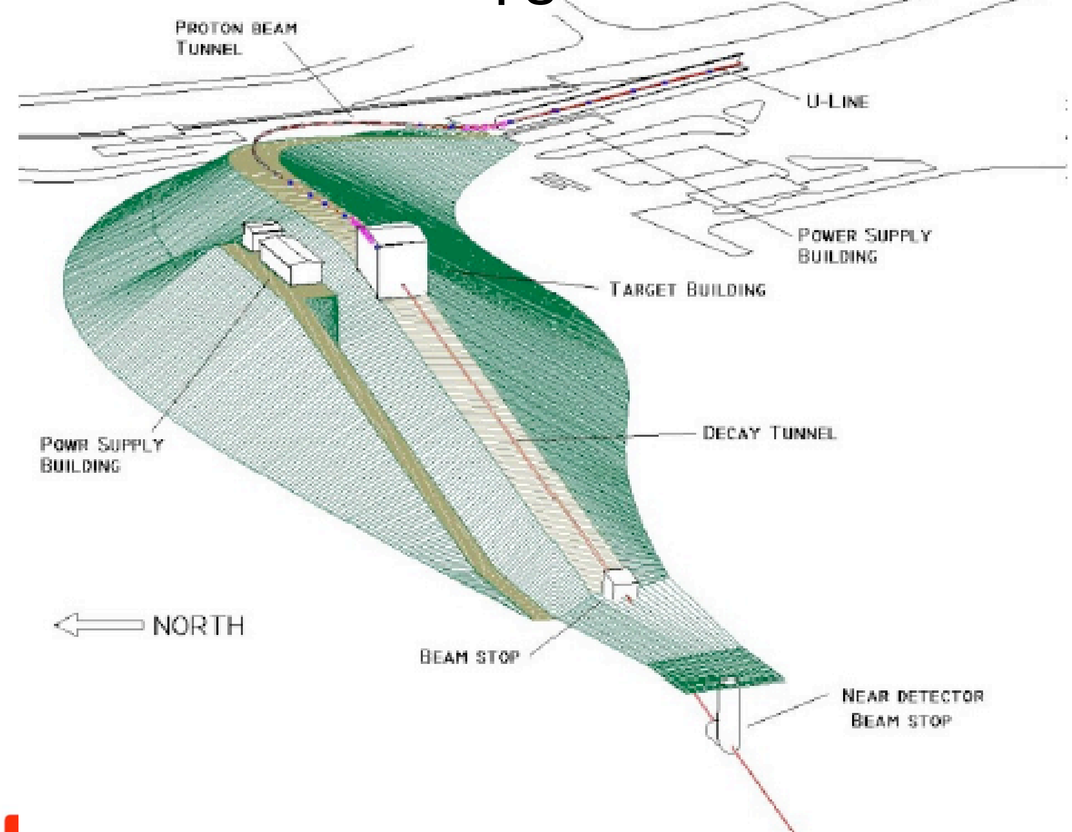
AGS upgrade: 28 GeV 1MW neutrino beam

- Increase intensity and repetition rate
- Needs new power supply, RF and replacing booster with 1.2 GeV SC linac

Upgrade 70×10^{12}/2sec to 90×10^{12}/0.4 sec



neutrino beamline on a hill:

- keep radiation above water table
- 45m high
- target on top
- 200 m decay pipe
- pointing ~11° down

Total cost estimate: $273M (excl. contingency)

"The AGS-Based Super Neutrino Beam Facility Conceptual Design Report", Weng, Diwan, Raparia et al., BNL-73210-2004-IR

Beam from FNAL

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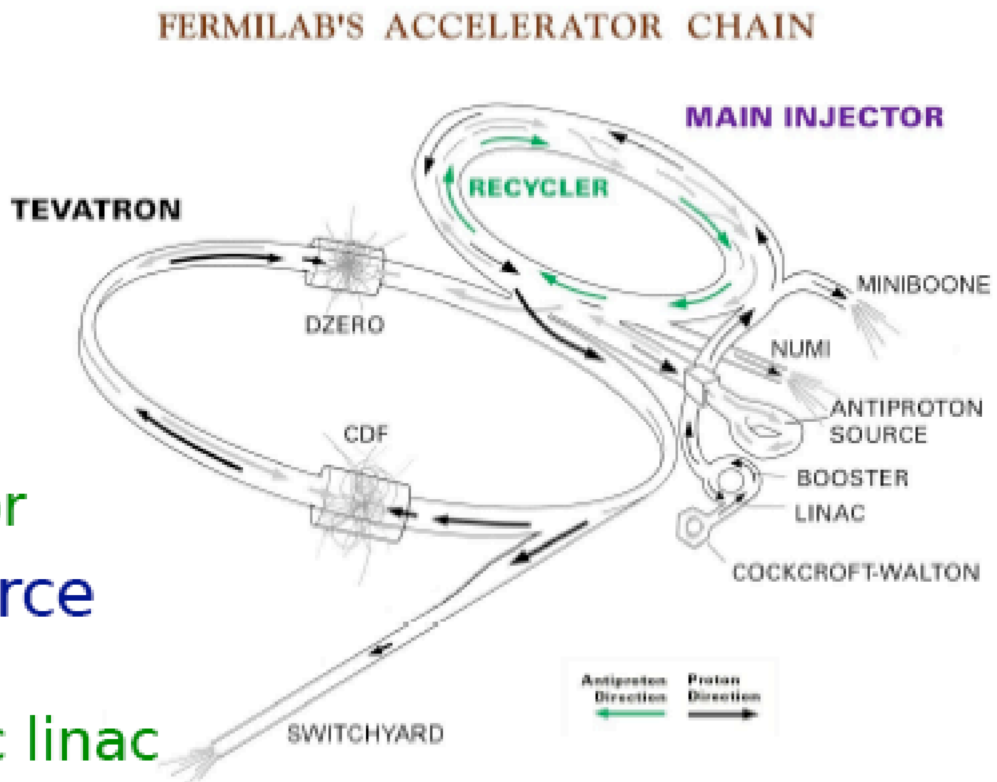
Possible proton beam power upgrades:

a) Proton plan:
- ✔ More protons in MI
- ✔ After Tevatron: batches pbar production available

b) Super NuMI: after Tevatron
- ✔ Phase I: use Recycler as pre-injector
- ✔ Phase II: also use Accumulator

c) High Intensity Neutrino Source (a.k.a. Proton driver):
- ✔ Replace booster with 8GeV sc linac



Phase II of sNuMI is part of the plan for the NOVA-I

"Fermilab Proton Projections for Long-Baseline Neutrino Beams", Bob Zwaska, FNAL-BEAM-DOCS-2393

	Protons (10^{12})	Cycle time (sec)	Power (kw)
Current complex			
No improvements			
- Shared beam	25	2.4	200
- NuMI alone	30	2.0	280
Proton plan			
Slip-stacking			
-Shared beam	37	2.2	320
-NuMI alone	49	2.2	430
SNuMI -Recycler slip-stack; reduce cycle	49	1.33	700
SNuMI -Accumulator momentum stack;	82	1.33	1200
High Intensity Source 8 GeV SC LINAC injector (maj. upgrades to MI-RF)	150	1.33	2200

SNuMI: depends on the current booster

Beam from FNAL

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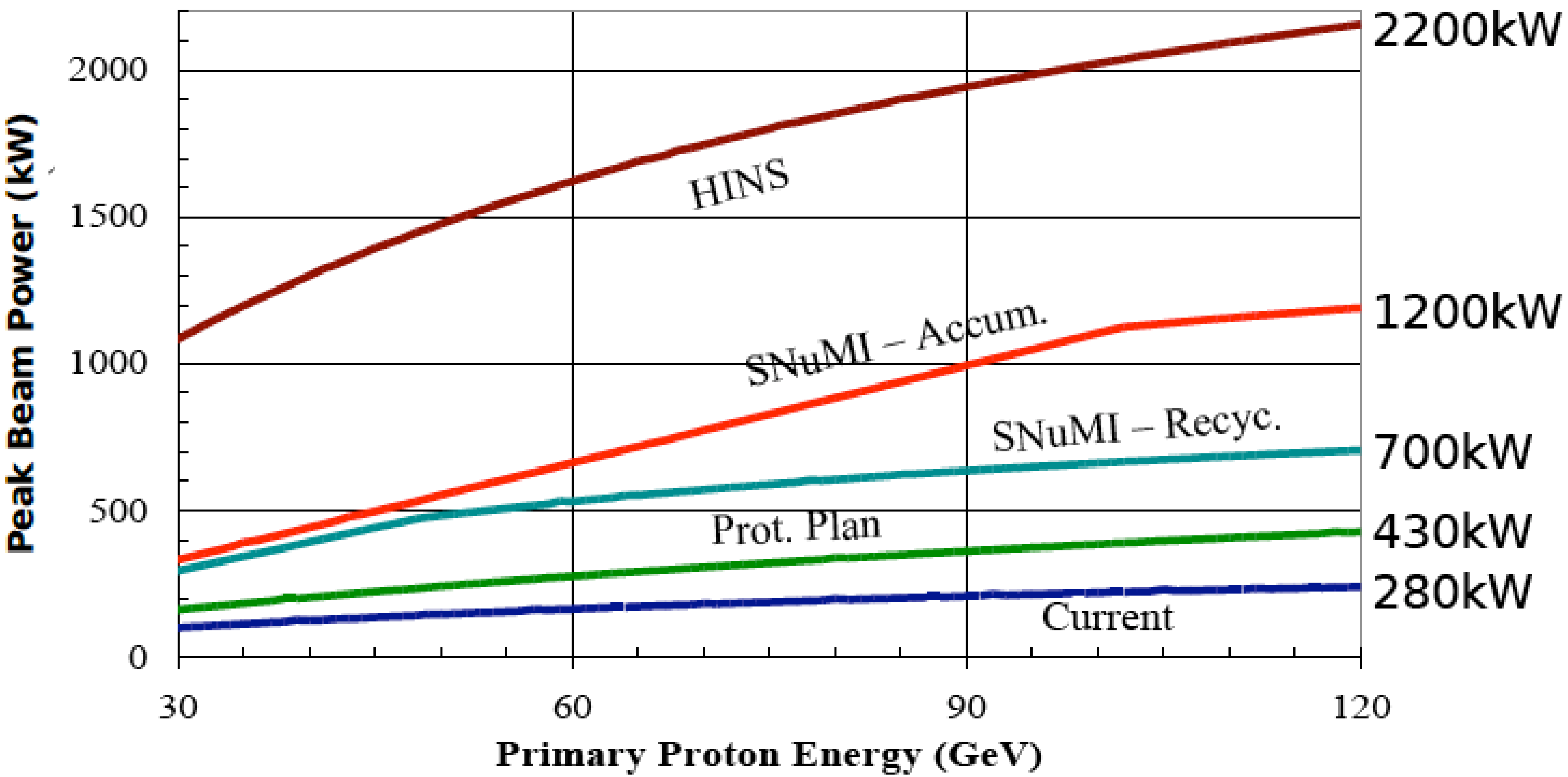
Flexibility of proton energy:



U.S. DEPARTMENT OF ENERGY

Beam from FNAL

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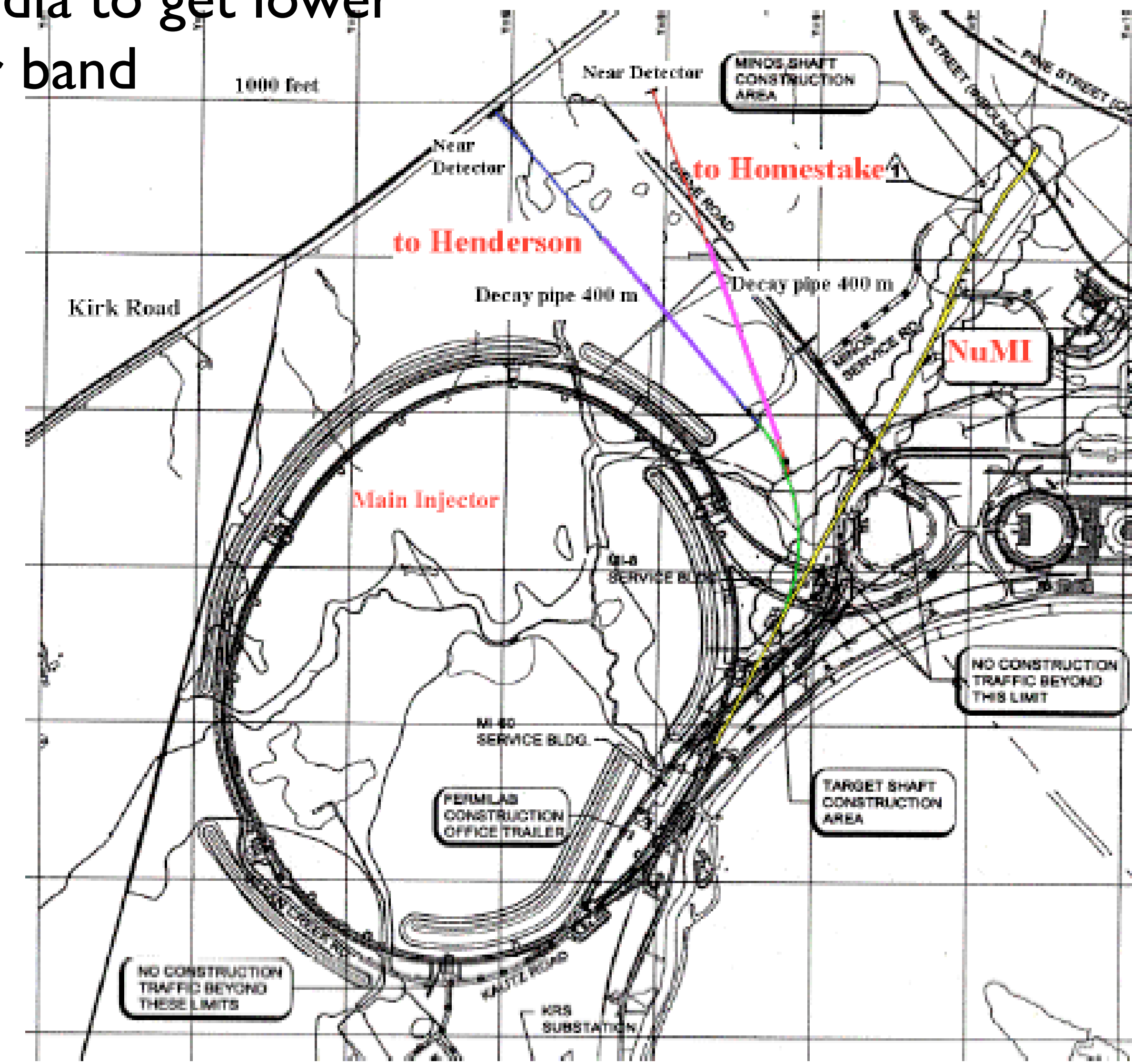
Beamline: use existing NuMI extraction

Make new decay pipe 4m dia to get lower energy broader band

- target hall: 45m
- decay pipe: 400m
- near detector: 300m from end decay pipe



Cost ~Numi = $109 M/5yrs

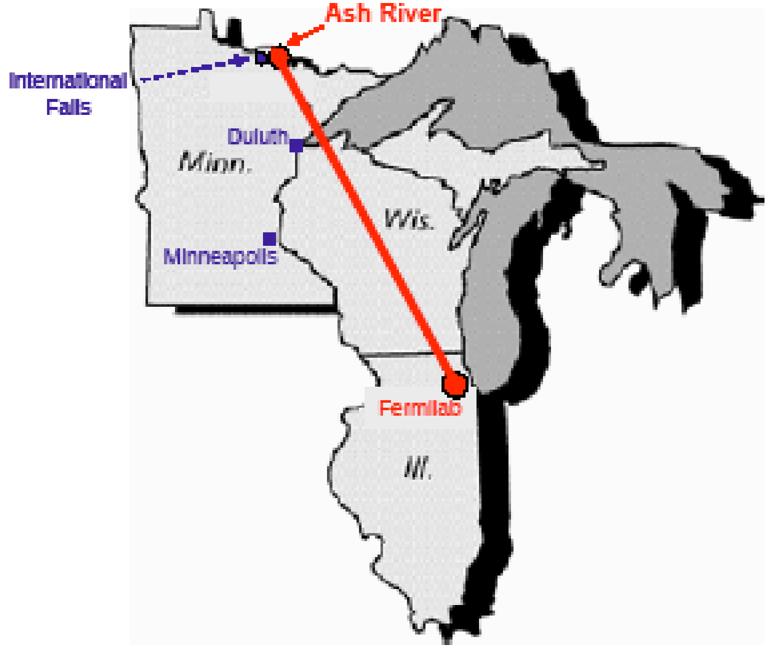
Angles to:

- Homestake: 5.8°
- Henderson: 6.7°

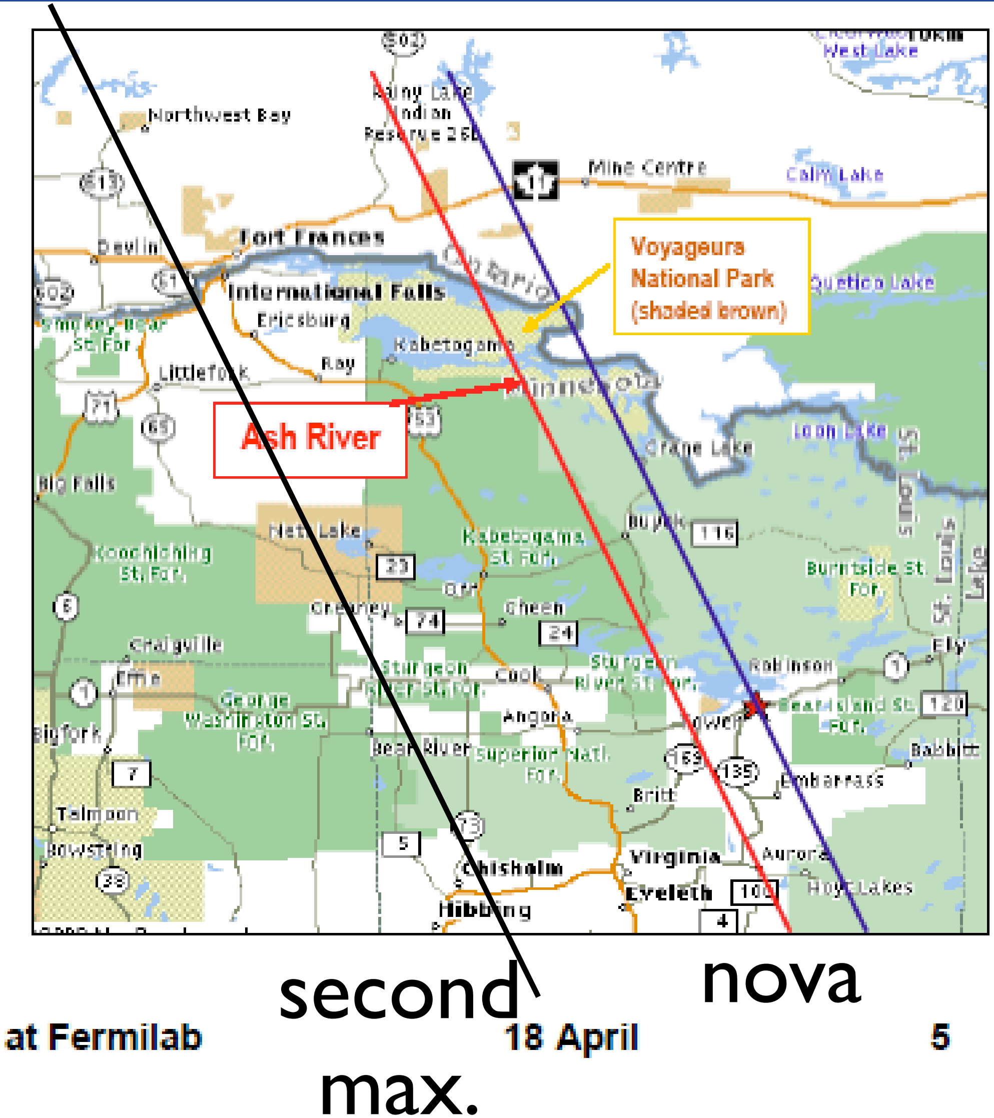
HS:1289 km, HE:1495km

U.S. DEPARTMENT OF ENERGY

- spectra and event rates



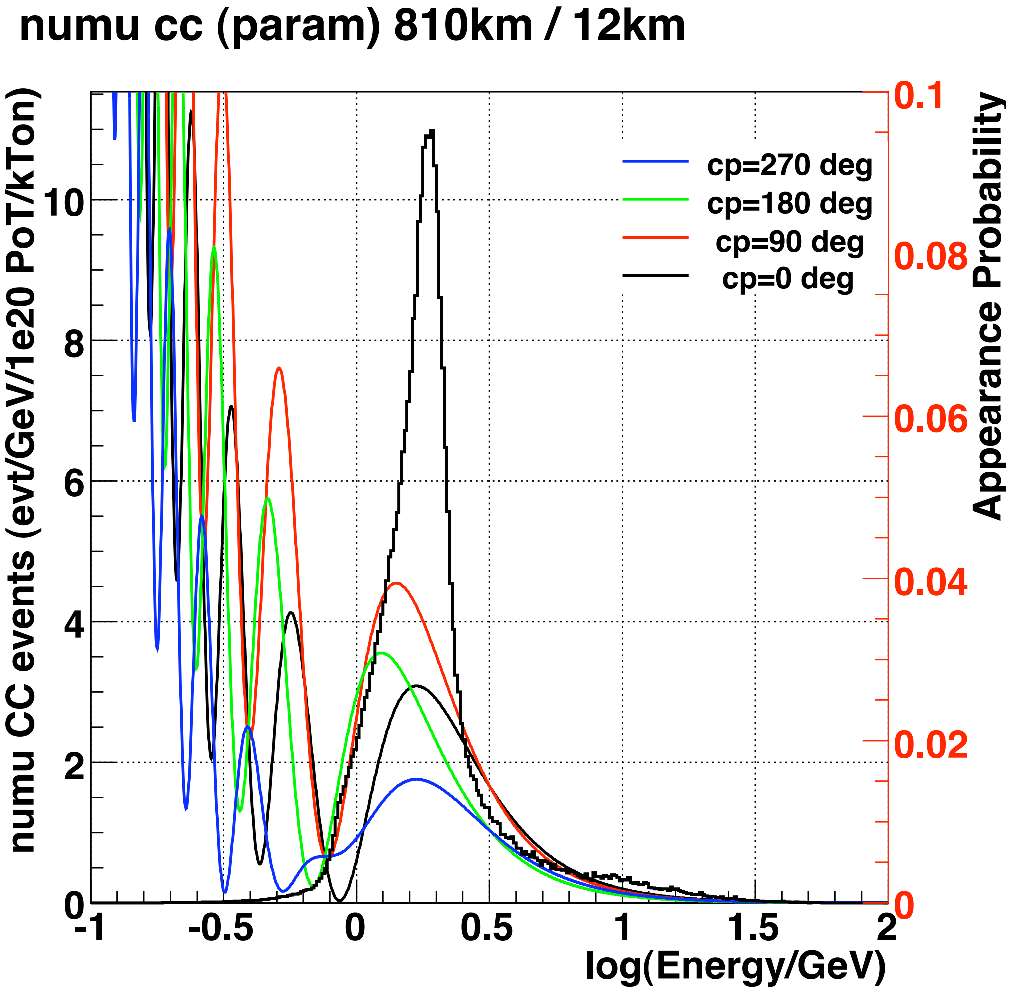
The Ash River site is the furthest available site from Fermilab along the NuMI beamline. This maximizes NOνA's sensitivity to the mass ordering.

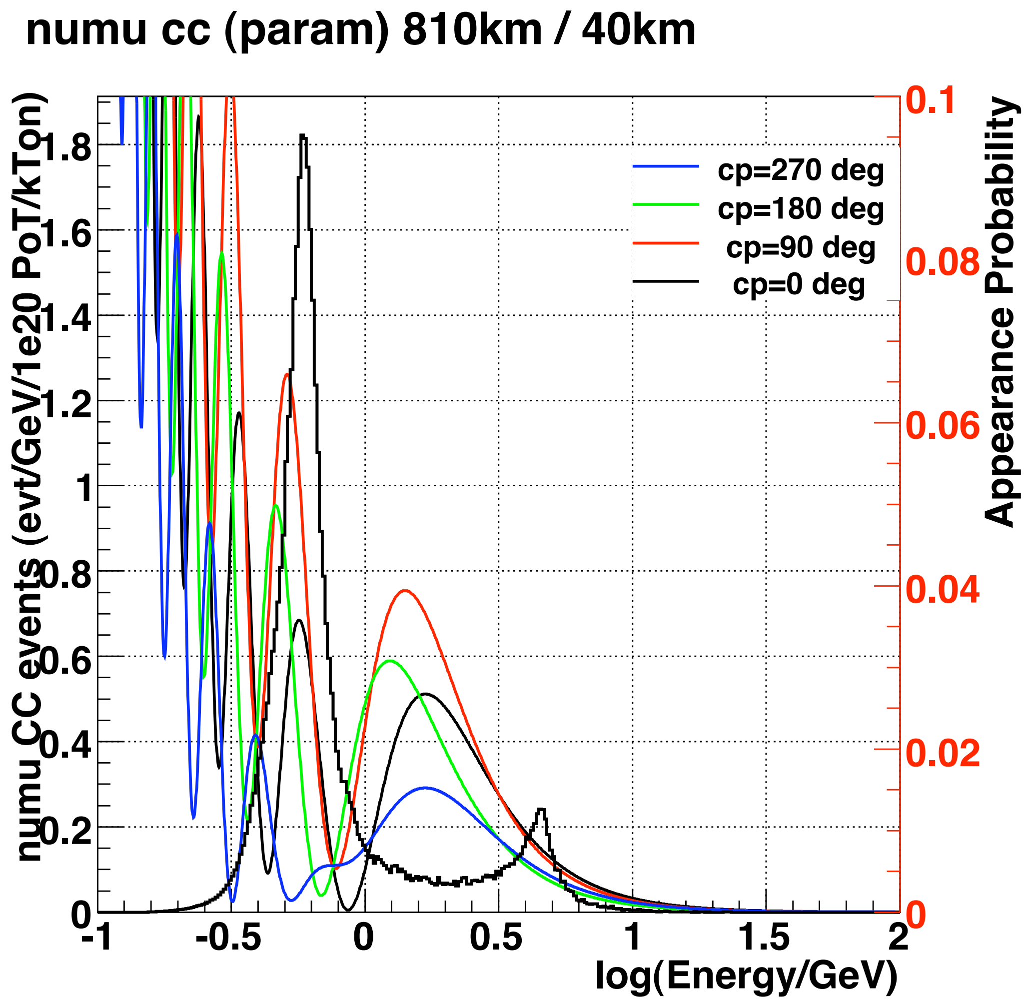


Gary Feldman P5 at Fermilab 18 April 5

NOVA1 and NOVA2 locations

off-axis spectra with LE tune

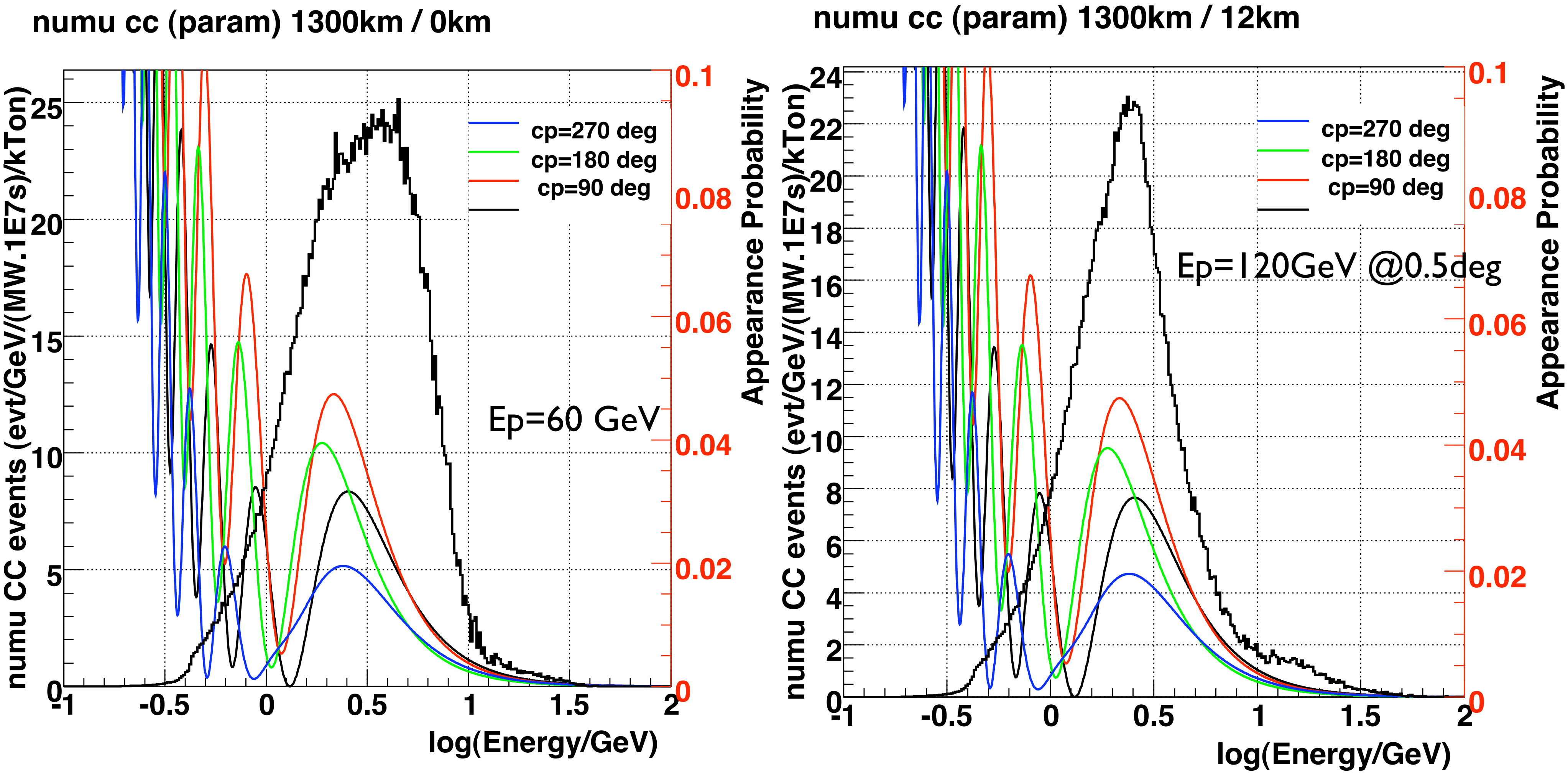




sin^22t13 =0.04

- 12 km (nova-I) CCrate: ~17.6 per (kT*10^20 POT)
- 40 km (nova-II)CCrate: ~1.1 per (kT*10^20 POT)

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



- 60 GeV at 0 deg: CCrate: 16 per (kT*10^20 POT)
- 120 GeV at 0.5^0:CCrate: 20.5 per(kT*10^20POT)

Beam (mass ordering)	$sin^2 2\theta_{13}$	δ_{CP} deg.			
		0	90	180	270
12 km offaxs (+)	0.02	76	108	69	36
12 km offaxs (-)	0.02	46	77	52	21
12 km offaxs (+)	0.1	336	408	320	248
12 km offaxs (-)	0.1	210	280	224	153
40 km offaxs (+)	0.02	5.7	8.8	5.1	2.2
40 km offaxs (-)	0.02	4.2	8.0	5.7	2.0
40 km offaxs (+)	0.1	17	24	15	9.4
40 km offaxs (-)	0.1	12	21	16	7.7
WBLE 1300 km (+)	0.02	141	192	128	77
WBLE 1300 km (-)	0.02	58	111	88	35
WBLE 1300 km (+)	0.1	607	720	579	467
WBLE 1300 km (-)	0.1	269	388	335	216
WBLE 2500 km (+)	0.02	61	103	88	46
WBLE 2500 km (-)	0.02	16	36	33	13
WBLE 2500 km (+)	0.1	270	361	328	238
WBLE 2500 km (-)	0.1	47	92	85	39

After 1 year with 100kT (efficient mass) a max of ~2-3 sigma without any consideration of matter effects/backgrounds/ systematics, etc.

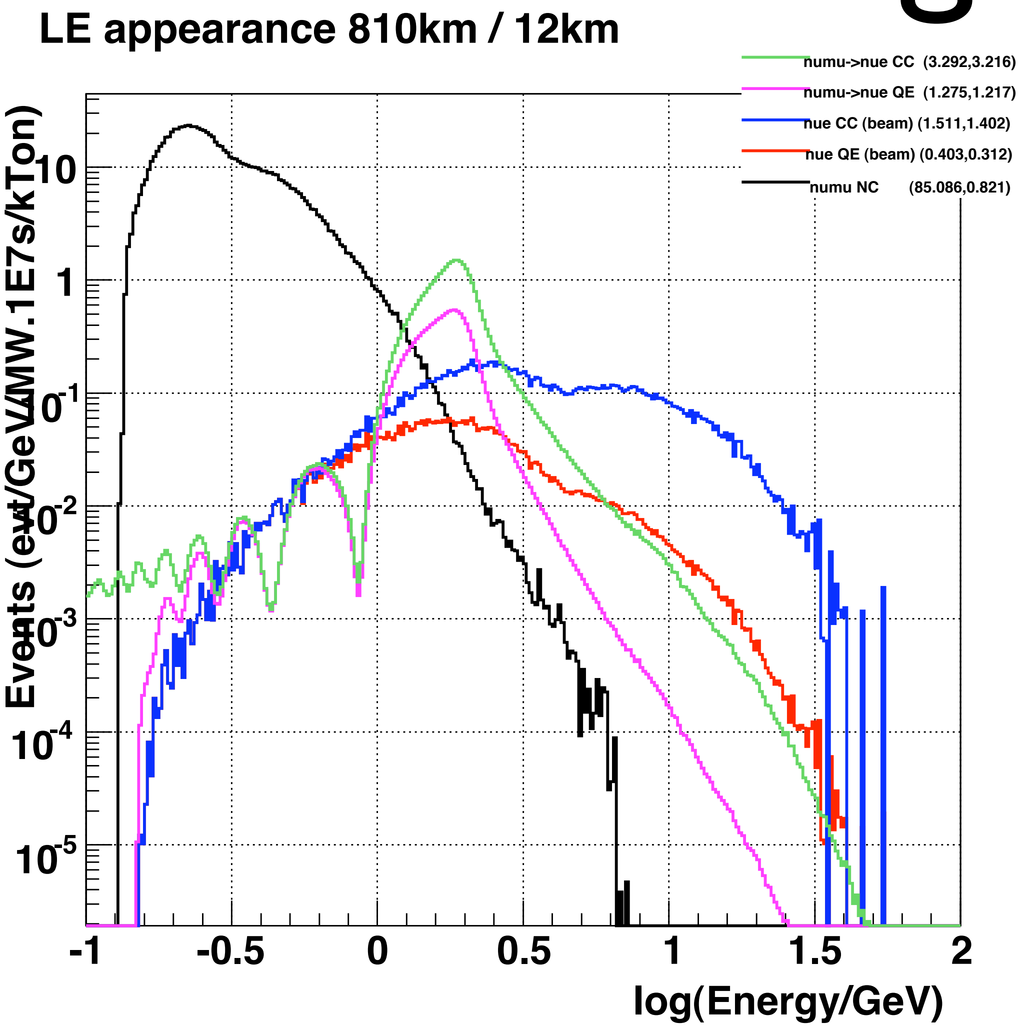
To get rough numbers for anti-nus, divide by 2 and exchange +/- mass order and delta to -delta

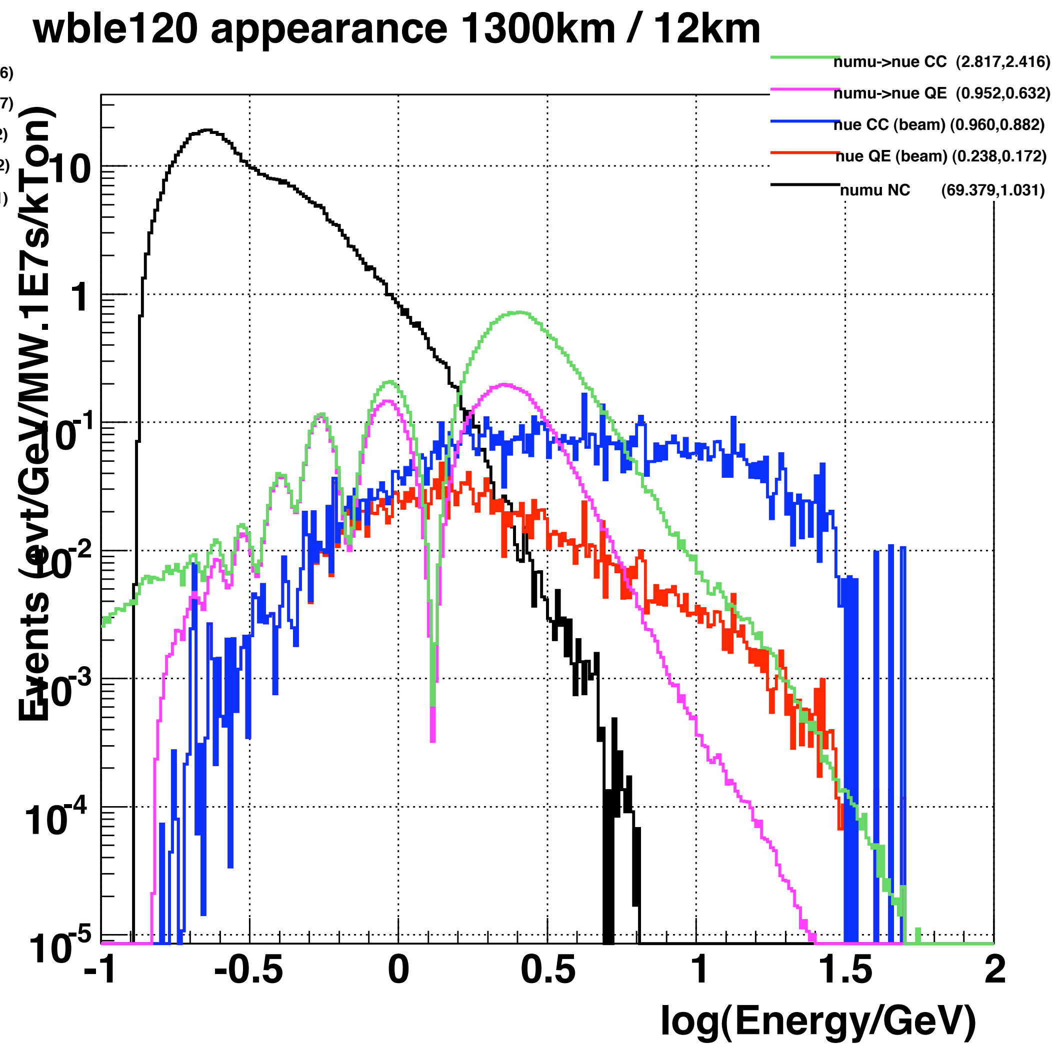
Number of numu->nue events. Per 100kTon per 1 MW*10^7 sec. This assumes 100% detector efficiency.

Beam/rates summary

- Higher confidence in event rates with new Monte Carlo.
- To get enough signal events at ANY location to perform the CP measurement, you must have a detector with efficient mass >100 kT and running times of several years.

Backgrounds





No detector effects. green(signal), magenta(signal QE only), blue(nue bck in beam), black(NC pi0 bck.)

Summary with bck.

Distance off-axis	ν_μ CC	ν_μ CC osc	ν_e CC beam	ν_e QE beam	NC-1π^0	$\nu_\mu \rightarrow \nu_e$ CC	$\nu_\mu \rightarrow \nu_e$ QE
NuMI LE tune at 700 km							
0 km	92.6	68.2	1.104	0.074	3.67	0.672	0.167
40 km	1.002	0.547	0.038	0.013	0.078	0.015	0.010
NuMI LE tune at 810 km							
0 km	68.8	47.0	0.838	0.056	2.733	0.606	0.142
6 km	43.3	25.5	0.614	0.053	2.101	0.492	0.131
12 km	17.6	7.44	0.326	0.042	1.195	0.273	0.096
30 km	2.333	1.695	0.071	0.018	0.220	0.022	0.012
40 km	1.104	0.593	0.039	0.012	0.093	0.018	0.012

Degrees off-axis	ν_μ CC	ν_μ CC osc	ν_e CC beam	ν_e QE beam	NC-1π^0	$\nu_\mu \rightarrow \nu_e$ CC	$\nu_\mu \rightarrow \nu_e$ QE
WBLE 120 GeV at 1300 km with decay pipe 2m radius 380 m length							
0°	44.3	26.0	0.427	0.030	1.624	0.566	0.105
0.5°	20.4	9.5	0.216	0.025	1.004	0.317	0.078
1.0°	7.66	4.11	0.114	0.019	0.525	0.092	0.034
2.5°	1.10	0.487	0.023	0.008	0.093	0.020	0.013

Everything normalized to 10^20 POT per kTon

- Detector issues
    - What detector ?
    - Can it be built ?
    - How does it perform ?

Detectors for off-axis

- NOVA is about 20 kTon with signal efficiency of about 25%.
- Off axis at NuMI has to be on the surface. There is no easy underground location.
- Forced to consider fine grained detectors.
- Liquid Argon TPC could be the choice

LARTPC

www-lartpc.fnal.gov

- The LAR group has shown an advantage of about a factor 3 over a water Cherenkov detector of equal mass due to better background rejection.
- 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.
- To reach 100 kT, 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).

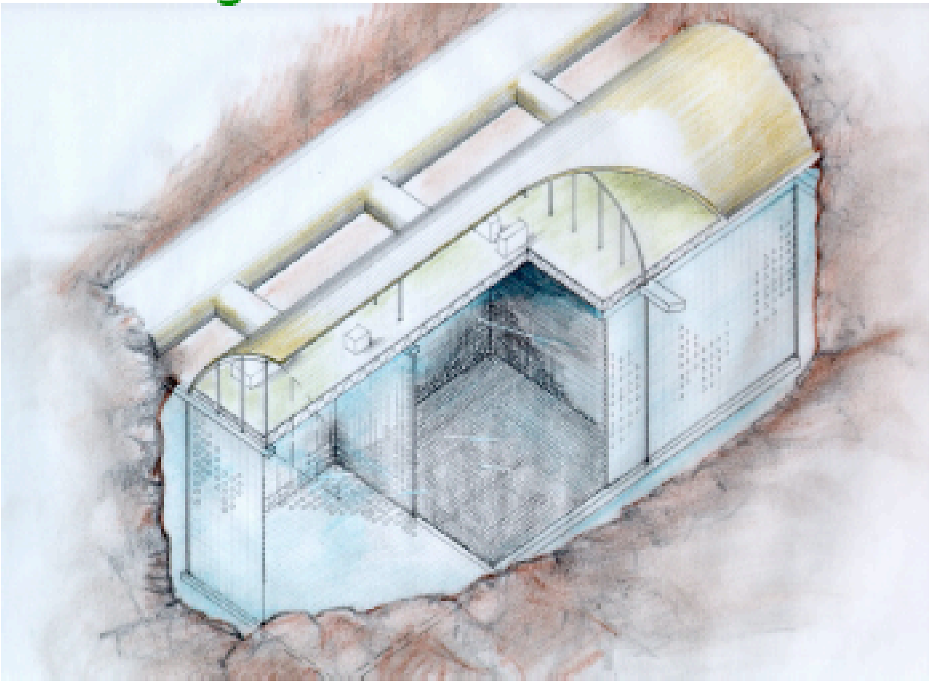
Water Cherenkov detector

- well established technique
- scale few times Super-K 50kT (22.5kT fiducial)
- several 100kTs (depends on physics)
- 20%-40% PMT coverage (depends on physics)
- 10% energy resolution on quasi-elastic ν_e interactions
- rejection neutral current interactions x10-20
- underground to reduce cosmics (no veto counter needed if deep enough)

Detector at Henderson

UNO detector:

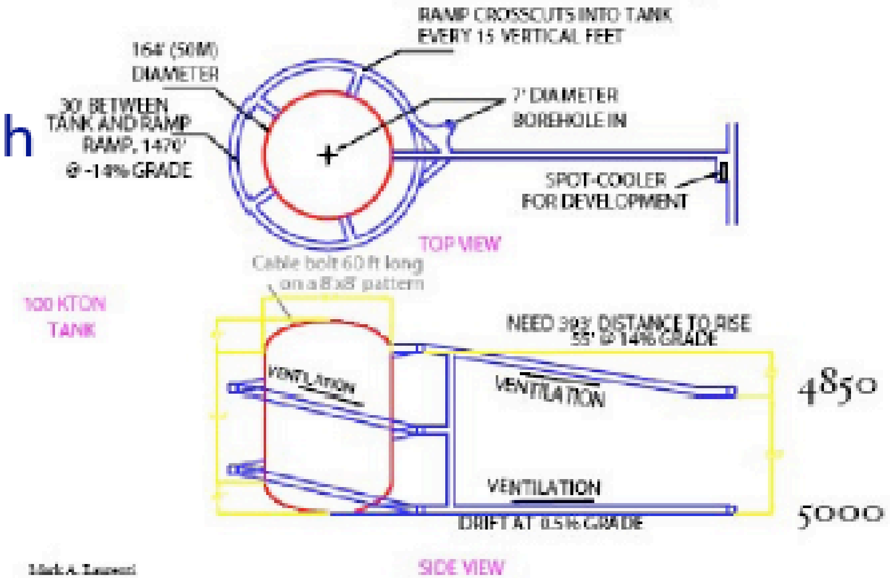
- 1 large cavern
- 3 optically separated modules of 60x60x60 m^3
- total mass 440 kT fiducial
- central module 40% PMT coverage (low E physics)
- outer modules 10% PMT coverage
- optional finer granularity: 20 or 13 inch tubes
- optimal depth 5400mwe (2500 feet)
- construction time: 10 years
- coarse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



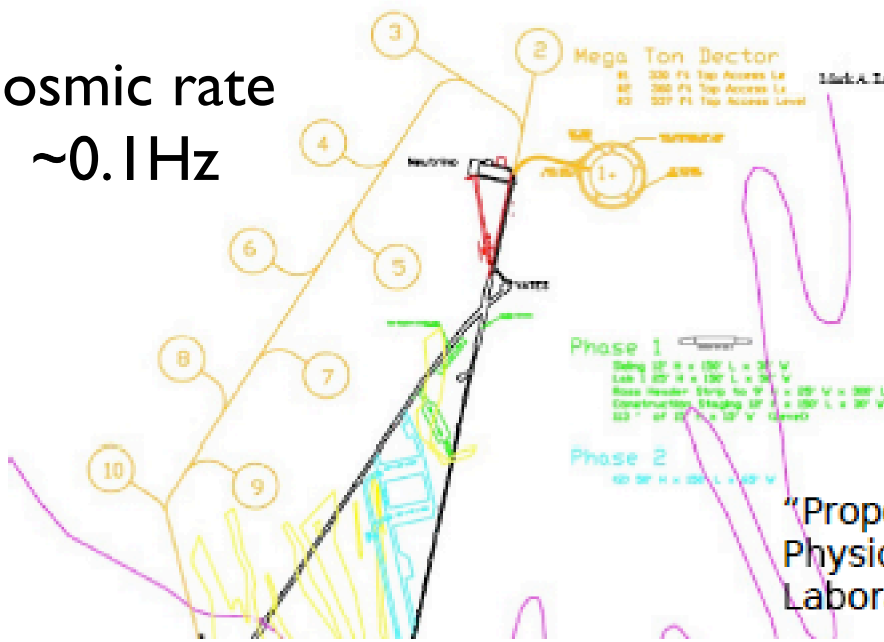
Detector at Homestake

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

Chamber Excavation

	One Chamber	Three Chambers
Labor & benefits	$6.060M	$12.030M
Mining Equipment Operation	1.430M	4.279M
Supplies	4.961M	14.685M
Precast concrete liner	3.575M	10.725M
Outside contractor	0.132M	0.396M
Plastic liner	0.250M	0.750M
Rock removal	1.000M	3.000M
Mining Equipment-Purchase	5.000M	5.000M
Contingency-30%	6.722M	15.260M
TOTAL	**29.130M**	**66.125M**

Photomultipliers & Electronics

	Cost for one PM
28 cm dia PM tube	$880
Installation/PM	$165
Electronics/PM	$120
Cable/PM	$77
Total per photomultiplier tube	**$1242**

One 100 kiloton Detector	**$62.1M**
Three 100 kiloton Detectors	**186.3M**

Homestake detector Summary

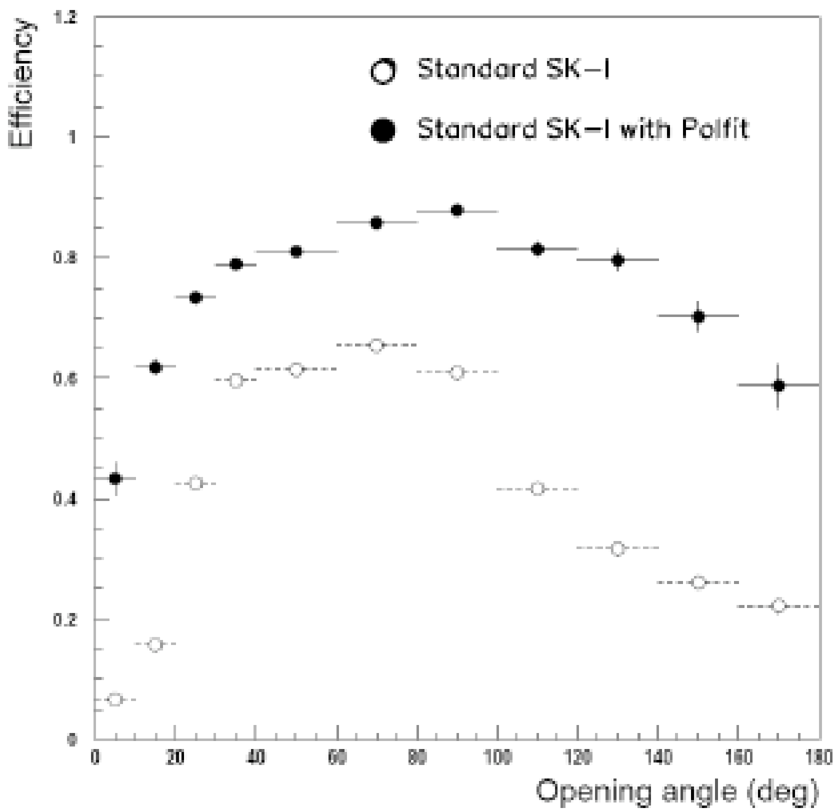
- Three 100 kTon (fiducial mass) modules
- Each 53 m high/dia right cylinders
- ~25 % photo-cathode coverage
- ~50000 PMTs/modules with 10-12 inch diameter
- Cosmic rate 0.1 Hz
- ~$100M per module
- First module in 5 yrs, each add. mod. +1 yr later.

Water Cherenkov Simulation

- Full GEANT simulation of Super-KamiokaNDE used
- 40% PMT coverage
- atmospheric neutrino MC reweighted to match expected flux 28GeV AGS beam

"Pattern of Light" fit improves standard Super-K π^0 finder

Improvements at lower opening angles with finer granularity expected



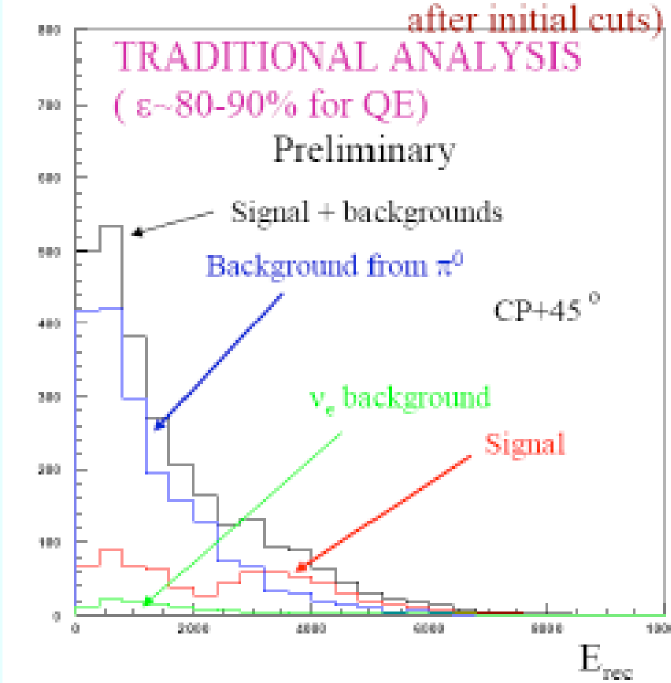
"Background Rejection Study in a water Cherenkov detector", C. Yanagisawa, C. K. Jung, P.T. Le, B. Viren, July 18, 2006

Water Cherenkov Simulation

BROOKHAVEN NATIONAL LABORATORY

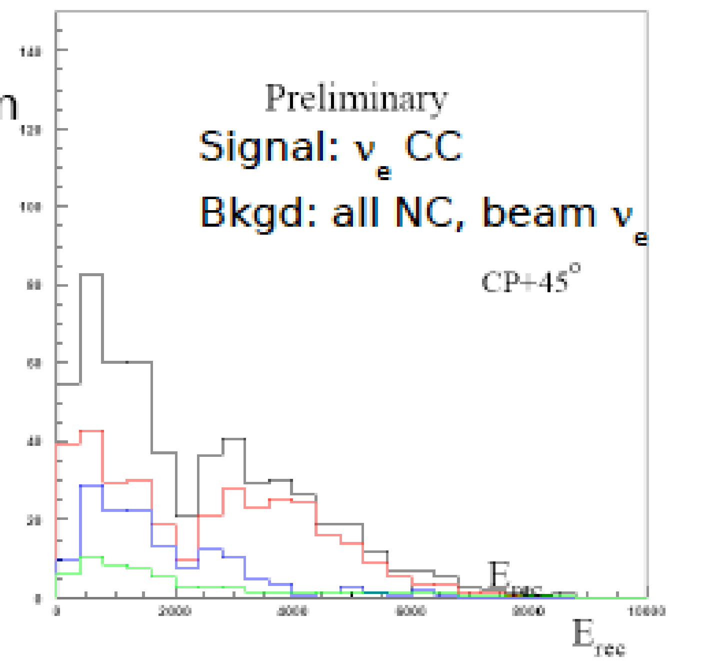
- Select single ring events and electrons
- Analysis of single ring pattern

No Δ log-likelihood cut (100% signal retained after initial cuts)



1300km
440kT

Δ log-likelihood cut (~50% signal retained)



- likelihood cut keeping 50% signal: S/B: 700/2004 → 350/169
- confirmed using T2K MC

"T2KK Project and Likelihood study", Fanny Dufour, U.S. Long Baseline Neutrino Experiment Study Workshop, September 16-17, 2006

Background Rejection

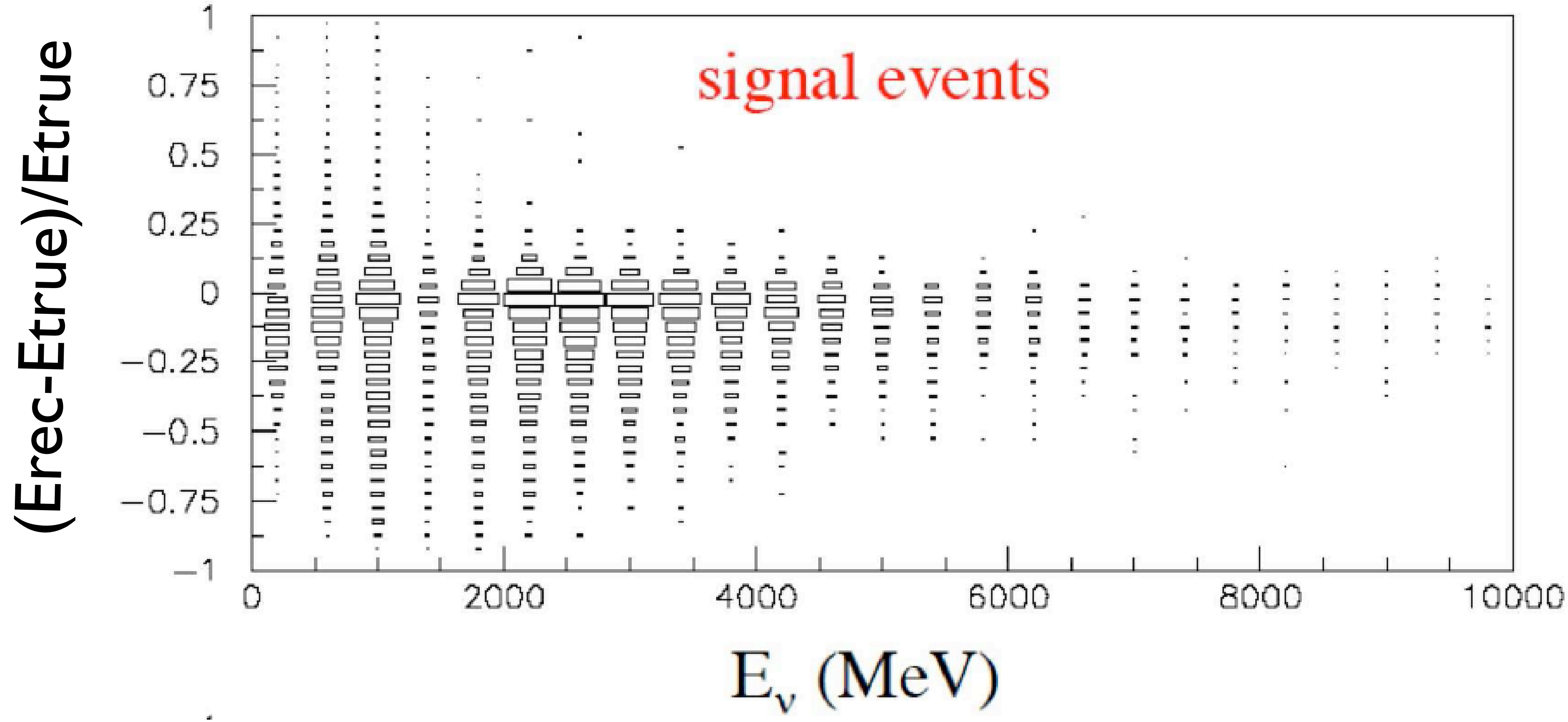
This analysis performed with superK MonteCarlo and reconstruction programs

Eff. adjustable →

Cut	Energy Bin (GeV)					
	0-0.5	0.5-1.0	1.0-1.5	1.5-2.0	2.0-3.0	>3
Traditional cuts/E_{visibl}						
ν_e signal	0.63	0.43	0.27	0.32	0.35	0.38
CCν_μ bkg	0.44%	0.68%	0.87 %	0.72%	0.43 %	0.53%
NC bckg.	0.11	0.15	0.15	0.16	0.21	0.26
Beam ν_e bkg.	0.66	0.51	0.42	0.37	0.31	0.27
Likelihood cuts/E_{rec}						
ν_e signal	0.40	0.40	0.40	0.39	0.40	0.40
CCν_μ bkg.	6.8%	13.6%	6.3%	8.0%	6.5%	2.2%
NC bkg.	0.72%	4.5%	6.3%	3.9%	8.3%	7.0%
Beam ν_e bkg.	0.37	0.41	0.40	0.37	0.39	0.34

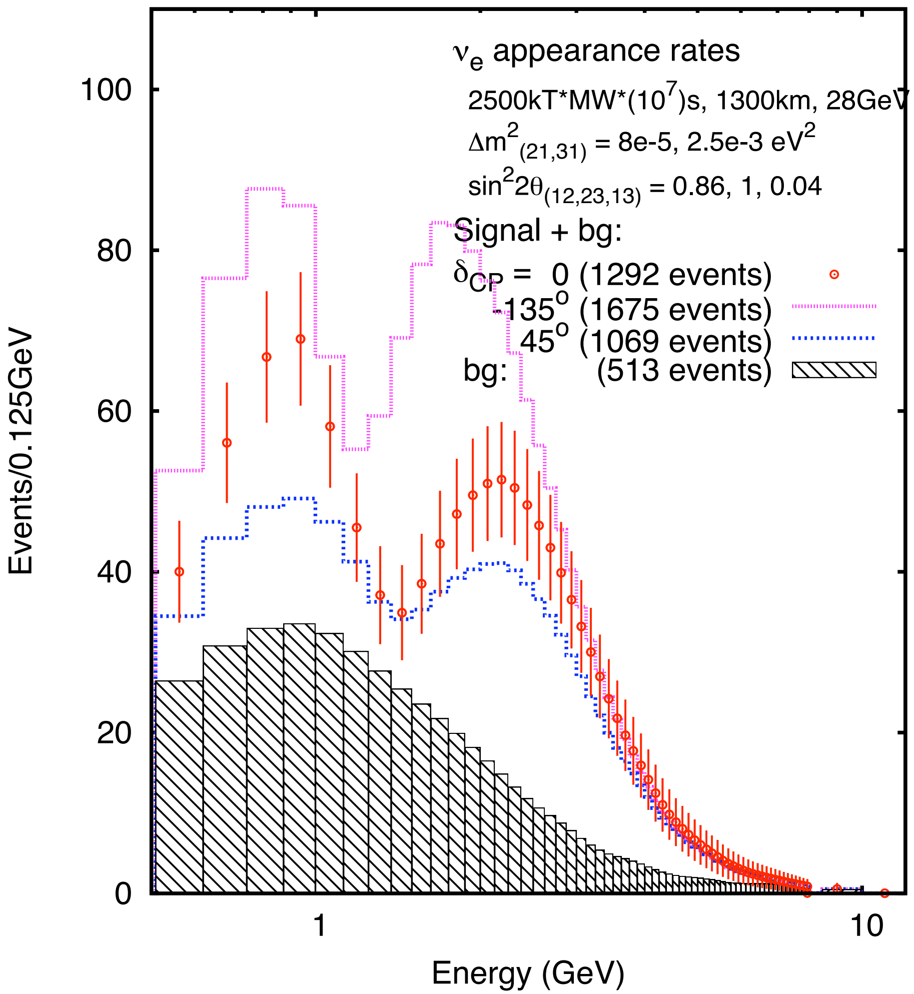
Upper table: traditional cuts from superKamiokande
Lower table: New likelihood method from Yanagisawa.
Events remaining after cut are dominated by Quasielastics
No entries for nu_tau because most of the beam <3.5GeV

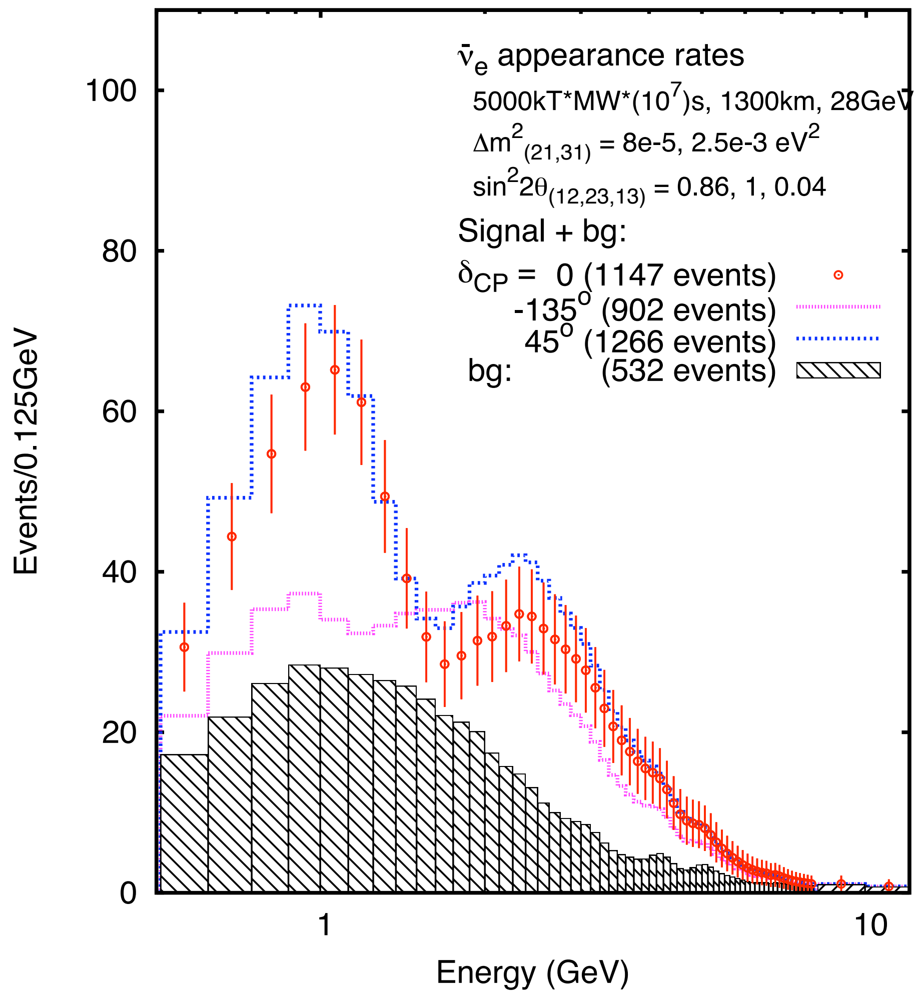
Resolution



Resolution with full simulation; Low tail due to non-quasielastics.
(Depletion at 1.5 GeV due to oscillations)

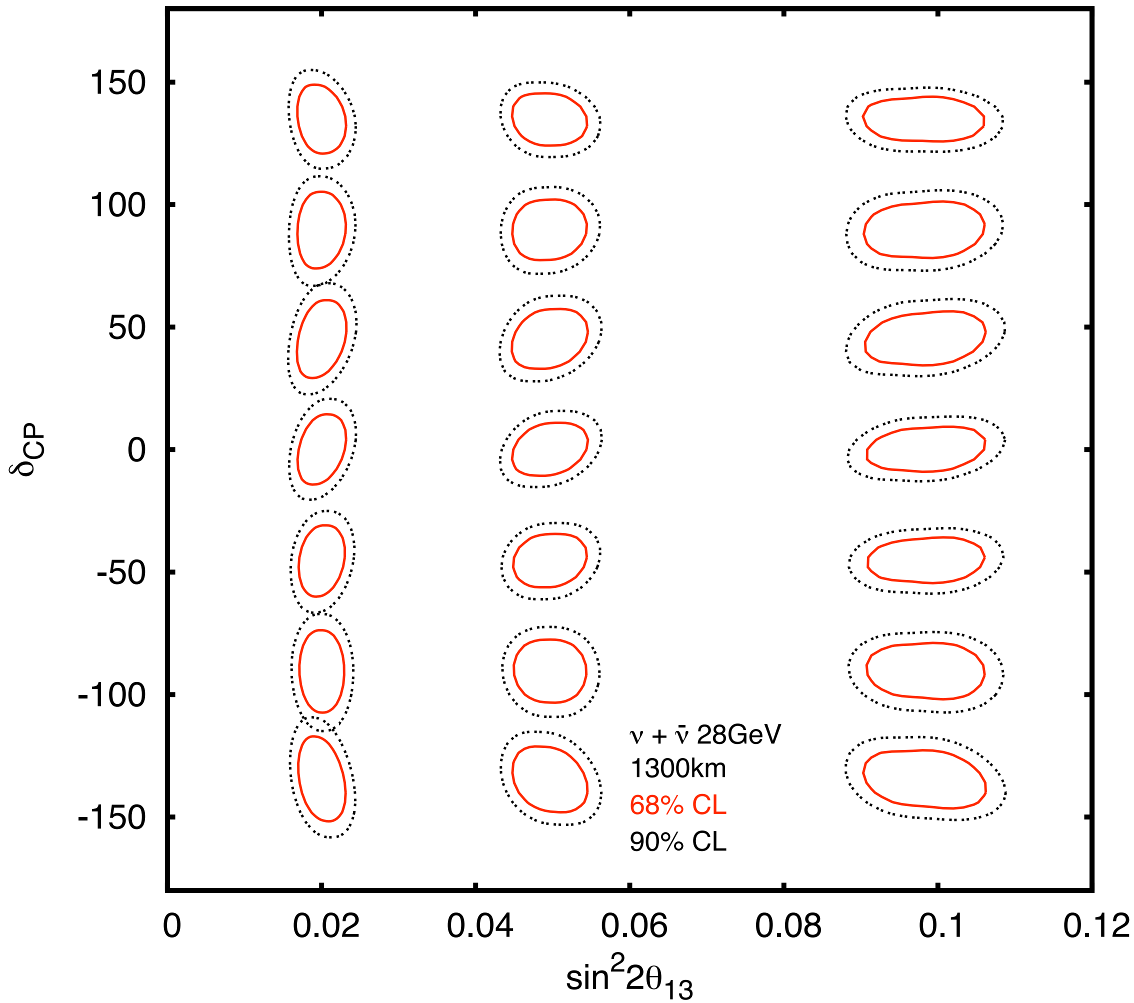
Appearance Spectra using Parameterized Detector





Signal	779	615
bck	513	532

CP measurement(FNAL-DUSEL)



- Result of combining neutrino and anti running
- Notice how Cp res. is roughly indep. of th13
- This plot is for normal mass ordering, but for reversed it is same.

Sensitivity comparison to offaxis still in progress

- Nonaccelerator physics
    - All other physics needs depth
    - What is the minimum depth needed ?
    - Hank Sobel (International Workshop on a Far Detector in Korea)
    - Driving consideration: spallation backgrounds to low energy events. e.g. SK solar neutrino is 20% deadtimed even with a 1km of rock on top !

Summary of depth vs physics/Sobel

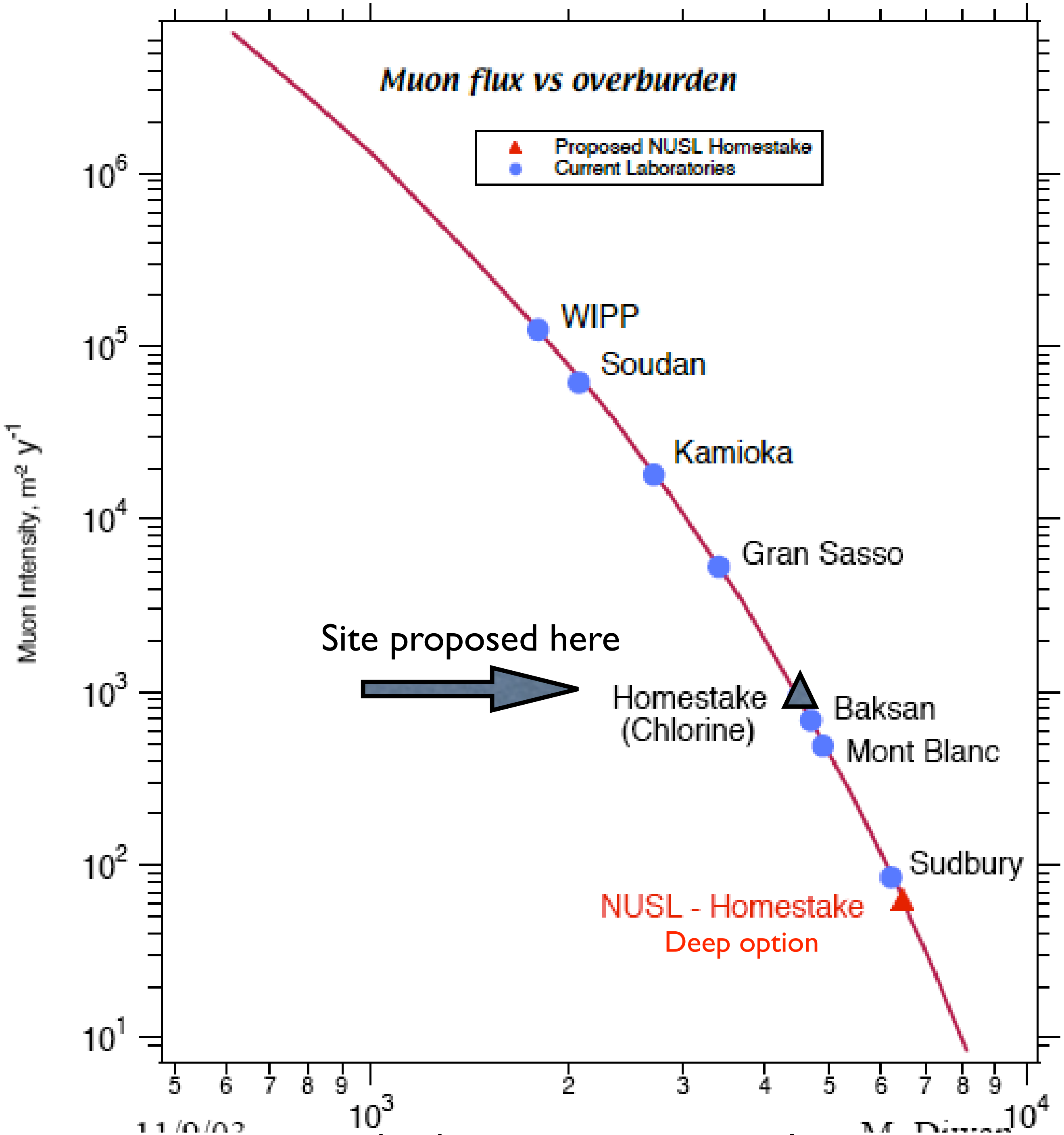
- High energy signals; PDK, atmospheric neutrinos, depth ~ <1600 mwe required.
- Supernova in our galaxy S/B still ~10^3 at 500 mwe. Andromedia S/B ~1 at 1300 mwe.
- Relic neutrinos without Gd needs SK depth – with Gd could possibly go as shallow as ~2000 mwe.
- Reactor neutrinos need ~2000 mwe.
- Solar neutrinos deadtime ~40% at 2360mwe, much less not useful.

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.

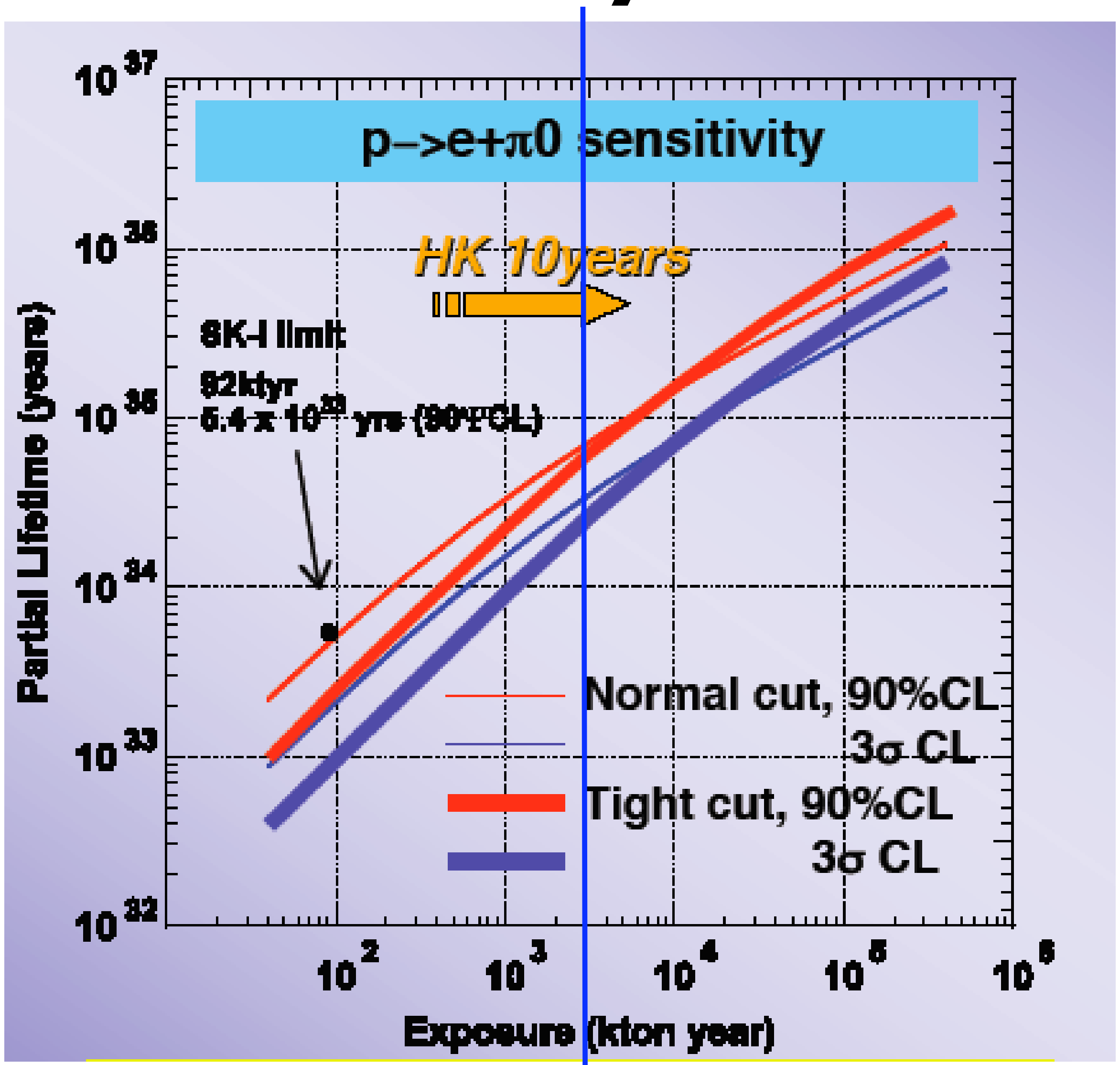
No pattern recognition beyond time cut is needed.



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) 300kTX10yrs 7X10^34 yrs

Astrophysical Neutrinos
Event rates. LMD-1&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 !

Summary

- I reviewed the physics considerations for long baseline program. CP violation in neutrinos could guide the program in the future.
- A new MW class proton machine in the US remains well-motivated and possible at FNAL.
- 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.
- A new joint laboratory (FNAL/BNL)study has been evaluating these and will report soon.

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).**