Proposal for a Large Multipurpose Detector(LMD) at Homestake

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first phase: LMD-1
100kT water Cherenkov, Fiducial:75kT

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Participants in LOI

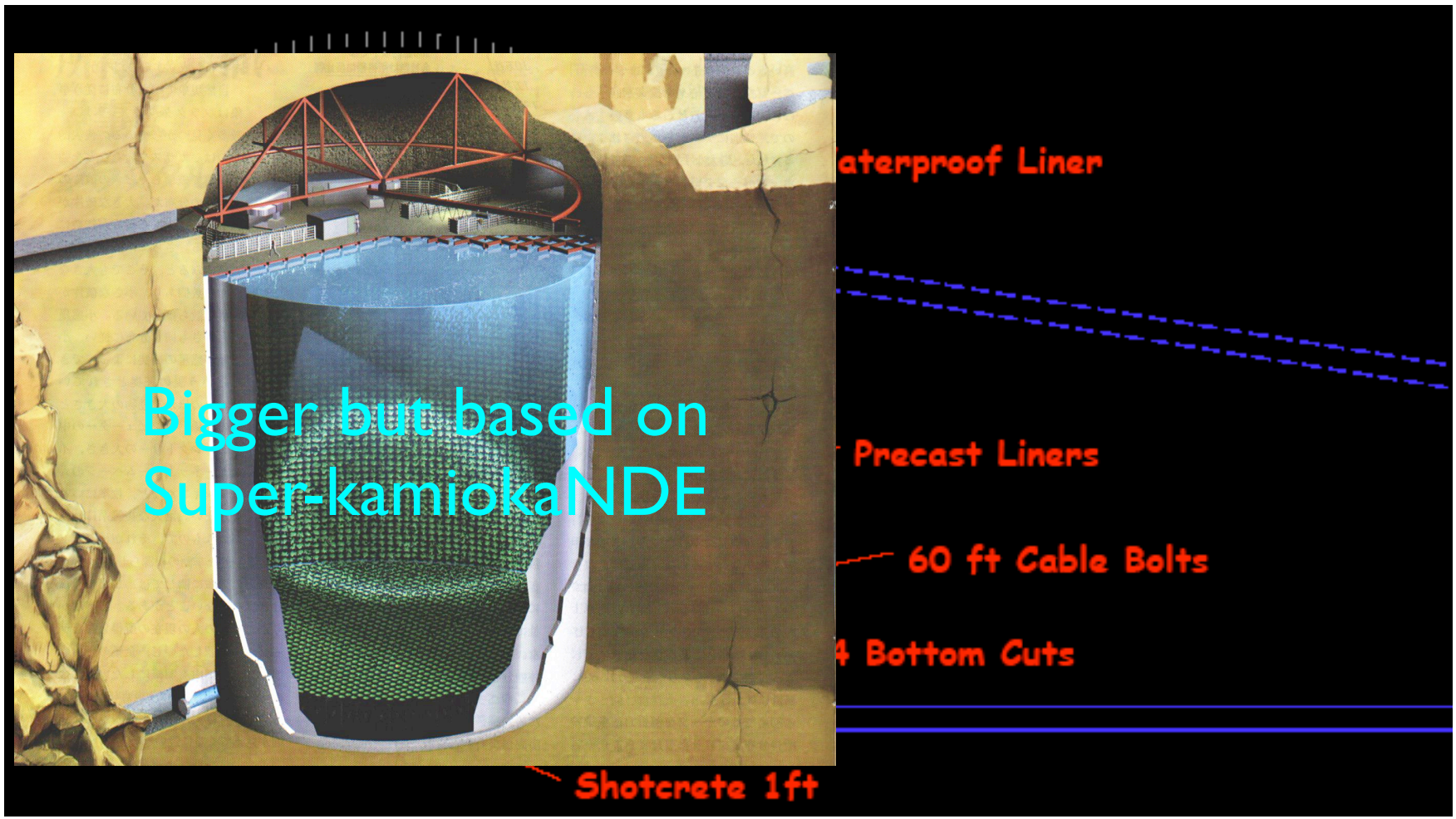
- D. Cline, M. Diwan, K. Lande, R. Lanou, A.K. Lanou, W. Marciano
- Speaking for many others. All are welcome.
- Close cooperation with Henderson and UNO on the science.
- We advocate building a 100 kT cavity as soon as possible.

Outline of this talk

- Will focus on LMD-1, 100 kT water Cherenkov detector.
- Physics topics:
  - Very Long Baseline Neutrino Oscillation
  - Nucleon decay
  - Astrophysical neutrinos
- Brief details of study on accelerator beams.

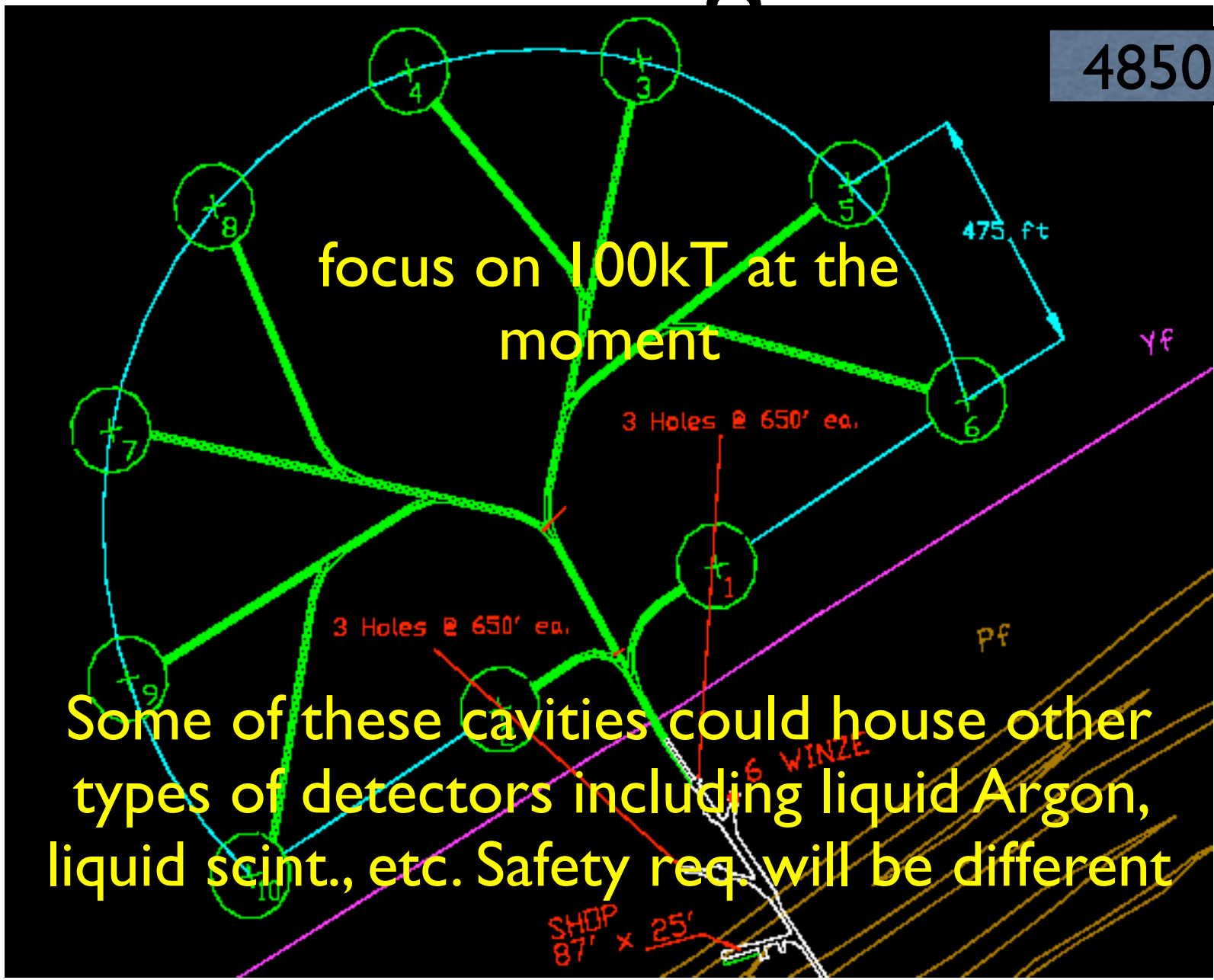
What does it look like

50 m diameter and 50 m tall

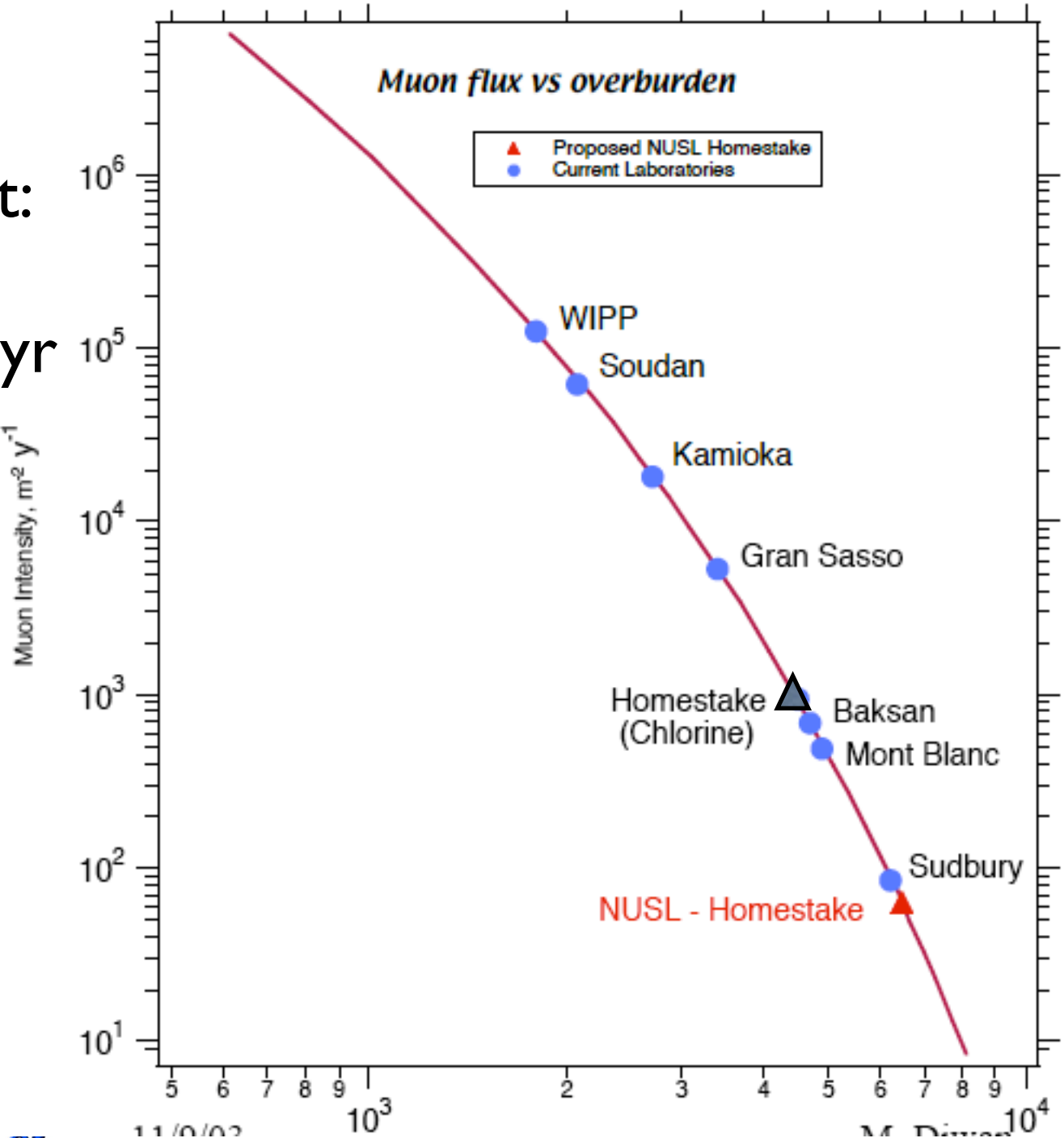


SuperKamiokaNDE: 22.5-50kT LMD-1: ~75-100kT

We want to grow to..



at 4850ft:
100kT
~3M mu/yr



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Detector parameters

- Need 500 kT fiducial mass for proton decay, neutrino astrophysics.
- 100 kT is initial step => 50 m dia X 50 m high tank.
- 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.

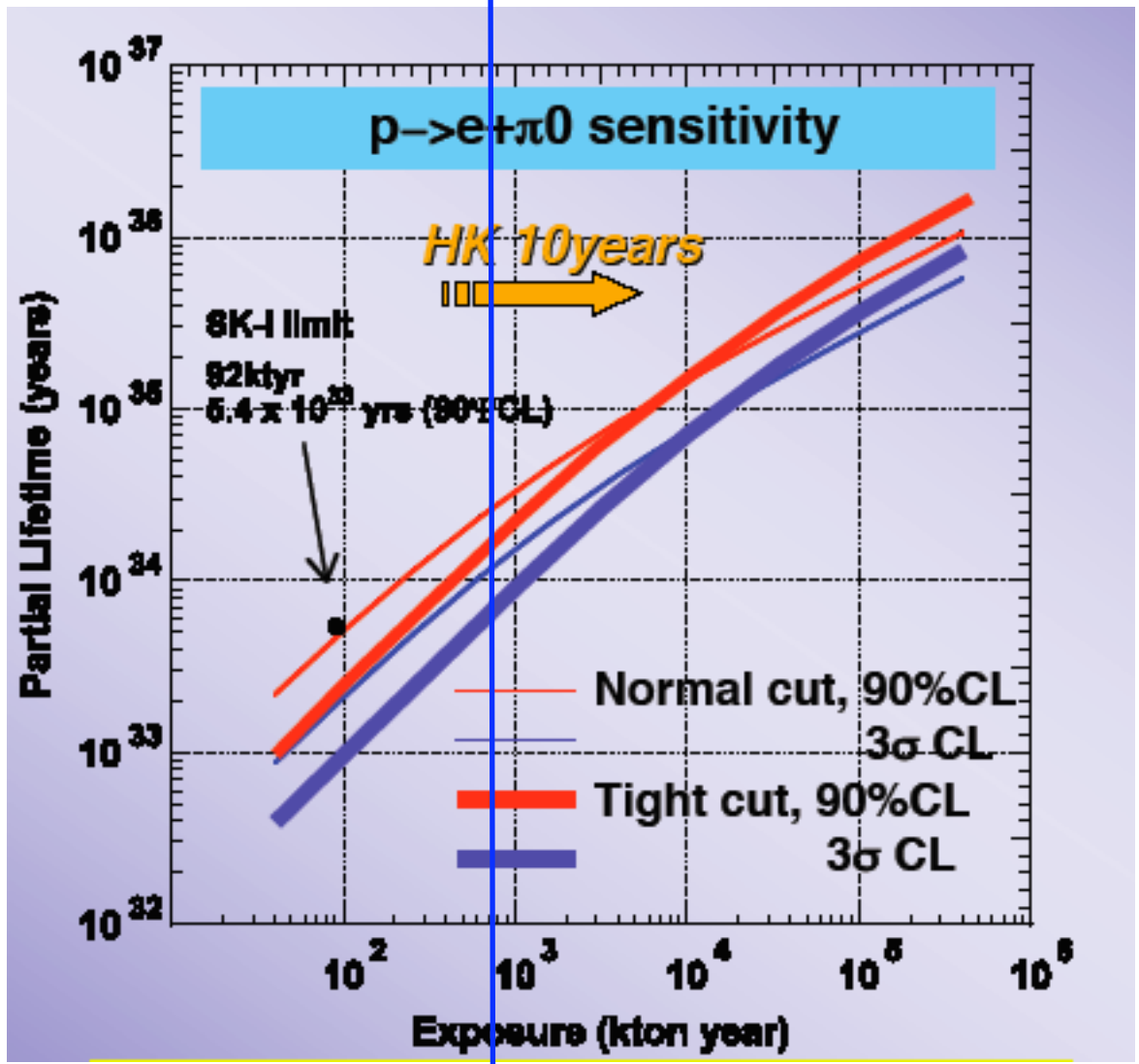
This level of performance can be obtained with water Cherenkov detector with 20-40% PMT coverage.
=> 11000 to 22000 20inch PMTs for 100kT.

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-1 will hit backg. in ~3yrs. It could be important to perform this first step before building bigger.

Sensitity on K-nu mode is about 5x10^33 yr



Ref: Shiozawa (NNN05)

LMD-1X10yrs 3X10^34 yrs

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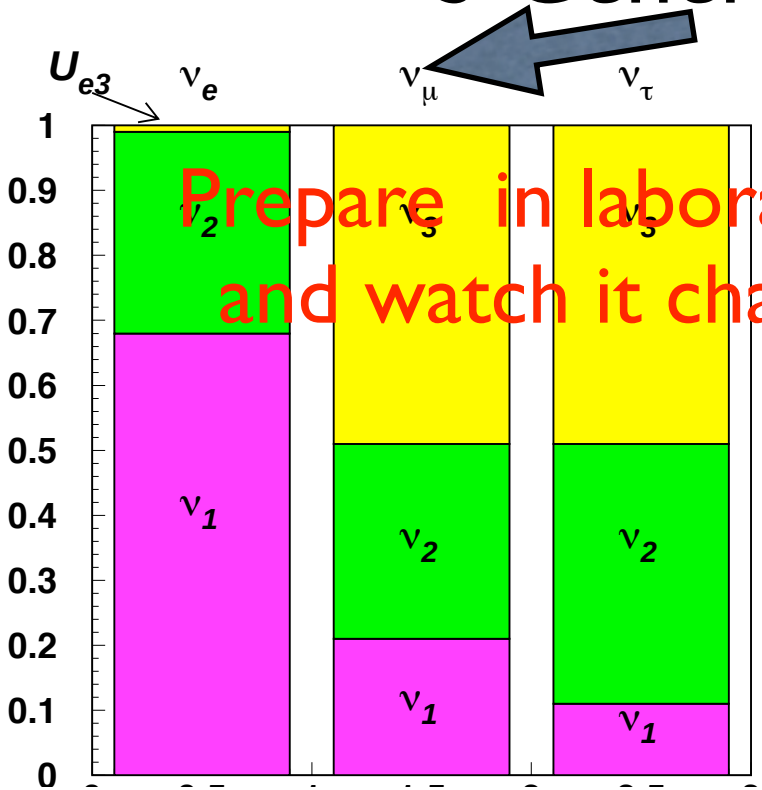
Astrophysical Neutrinos
Event rates. LMD-1, assume 5 yr exposure

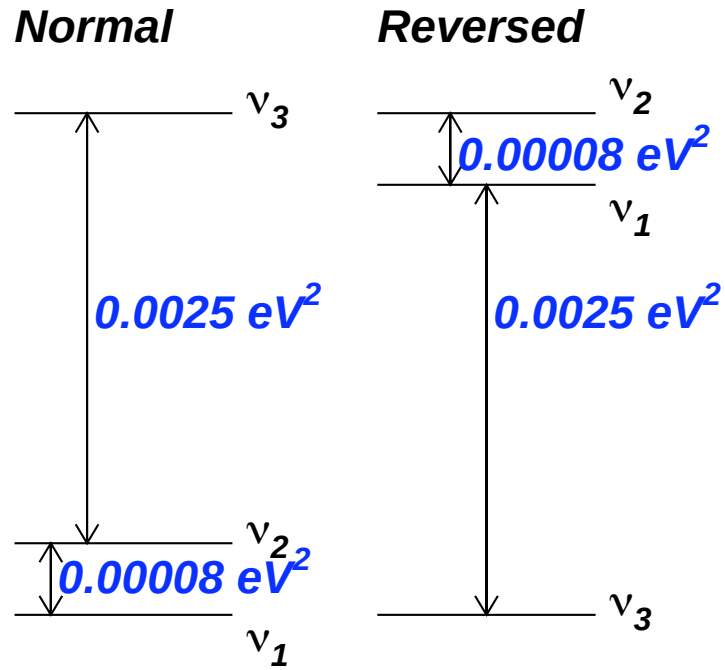
- Atmospheric Nus: ~10000 muon, ~5000 electrons. (Ref: Kajita nnn05)
- Solar Nus: >63000 elastic scattering E>5MeV (including Osc.) (Ref: uno)
- Galactic Supernova: ~30000/10 sec in all channels. (~1000 elastic events). (Ref: uno)
- Relic Supernova: (ref: Ando nnn05)
  - flux: ~5 (1.1) /cm2/sec Enu>10 (19) MeV
  - rate: 75 (35) events over backg ~100 !

Need analysis with these numbers

3 Generation oscillations



Prepare in laboratory and watch it change



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:

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

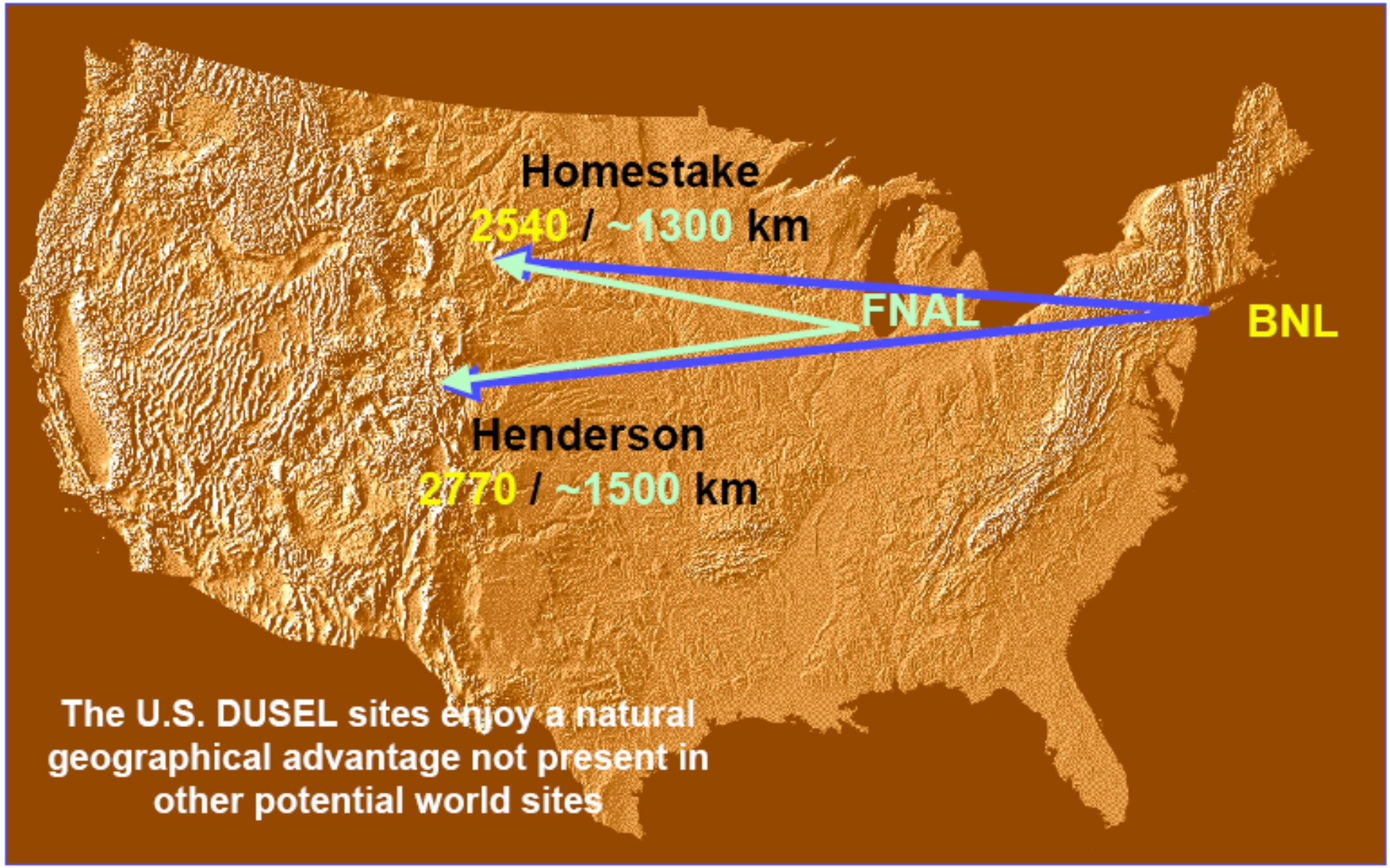
CP phase

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~15000km

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

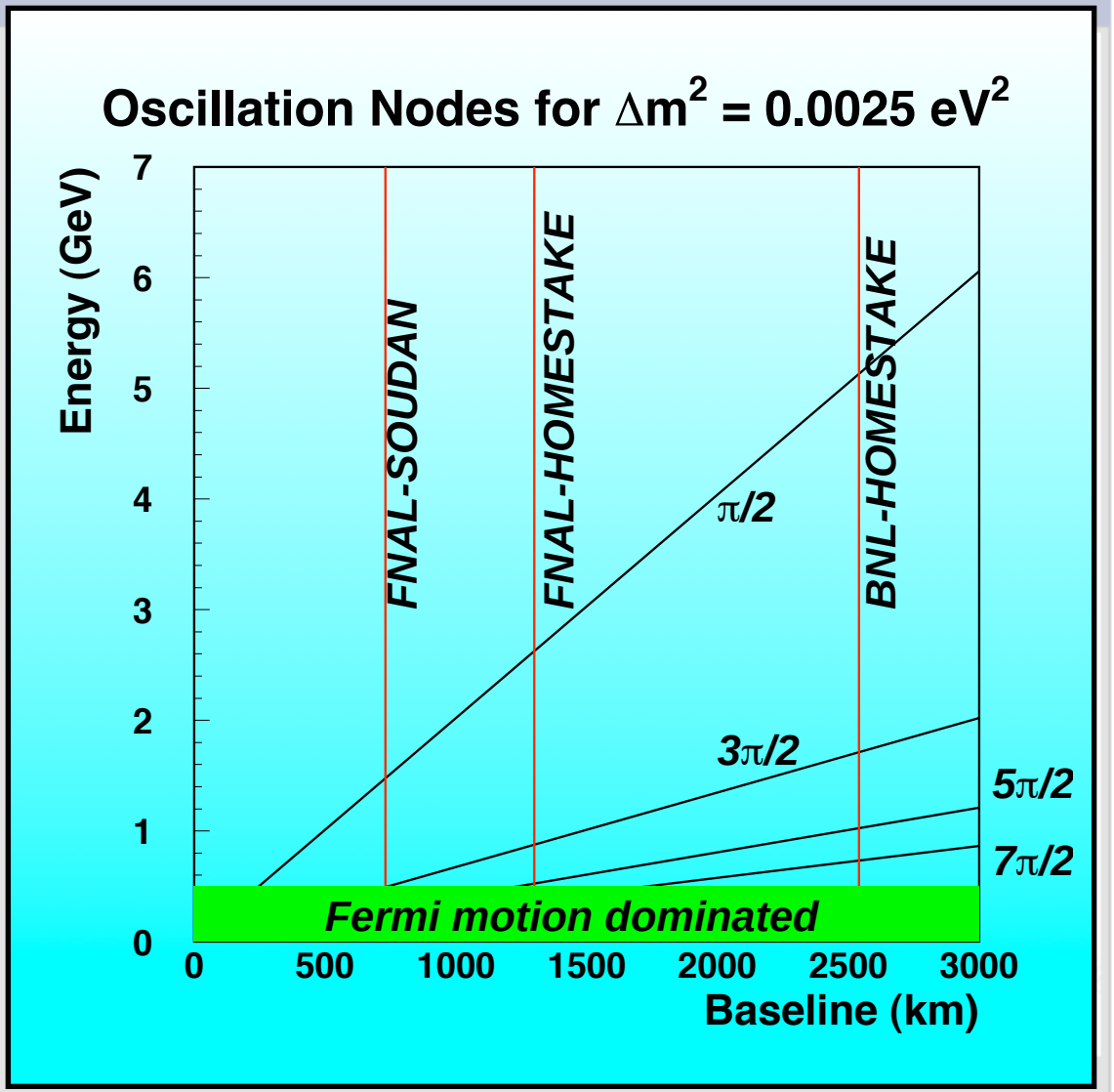
flux ~ L^{-2}: lower statistics

but: CP asymmetry ~ L

sensitivity to δ_{CP} independent of distance!

better S:B

(Marciano hep-ph/0108181)



Electron neutrino appearance physics parameter extraction

For 1000 - 2000 km baseline effects across energy band.

	$E_\nu < 1$ GeV	$1 < E_\nu 2 <$GeV	$E_\nu > 2$ GeV
$\sin^2 2\theta_{13}$	$\surd$	$\surd$	$\surd$
$sign(\Delta m^2_{32})$	-	-	$\surd\surd\surd$
δ_{CP}	$\surd$	$\surd\surd$	$\surd$
solar	$\surd\surd\surd$	$\surd$	-

- It's a complex picture with many effects!
- But, effects have different strength at different energies.
- Measuring across the wide energy band makes it possible to sort them out.

US possibilities for beam

Source	Proton beam energy	Proton beam power
FNAL MI (McGinnis upgrade)	Ep=8-120GeV	1-2 MW X (Ep/120GeV)
FNAL MI (with 8GeV LINAC)	Ep=8-120 GeV	2 MW @ any Ep
BNL-AGS (upgrade 2.5- 5 Hz)	Ep=28 GeV	1-2 MW

US possible baselines

Source	Detector	Distance	Depth	Comment
FNAL	Homestake	1290 km	7700ft	no beam, DUSEL site, capable of large exca.
FNAL	Henderson	1500km	5000 ft	no beam, DUSEL site, capable of large exca.
BNL	Homestake	2540km	7700 ft	study of beam and physics exists and documented
BNL	Hendersn	2767km	5000 ft	--

shorter baseline means more events.

longer baseline means bigger effects.

Study of new beam from FNAL has started

Event rates

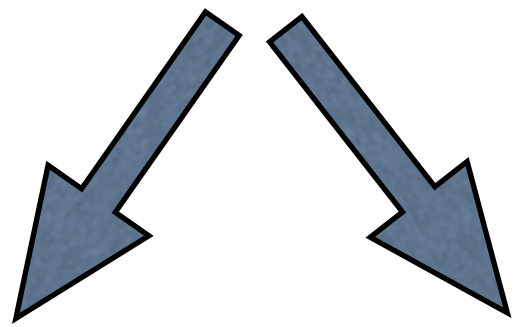
Source-det	Detector size	beam E and power	Event rate for neutrino running
FNAL-HS(1290)	100kT	0.5MW@60GeV	~30,000CC ~10,000NC
FNAL-Hend(1500)	100kT	0.5MW@60GeV	~22,000 ~7500
FNAL-HS(1290)	100kT	2MW@28GeV	78,000CC 27,000NC
FNAL-HS(1290)	200kT	2MW@8GeV using Miniboone data	2188 CC 850 NC
NOVA(810)*	30kT	0.65MW@120	~10000 CC ~3000 NC

5 X 10^7 sec of running assumed = 2 years at FNAL

*rescaled: NOvA assumes 5 yrs of running in their proposal

How to achieve the total exposure

- For CP violation we need (indep. of baseline or size of theta_13) (Marciano)
  - 2500 kT*MW*(10^7) sec for neutrinos



1 yr ~ 3 10^7 sec

500kT
1 MW
5 yrs

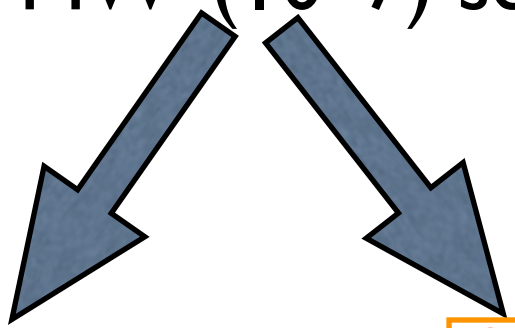
Past approach

100kT
2 MW
5yrs

Possible at FNAL with new Proton driver

What about anti-nu running

- Depends on mass hierarchy.
- To be completely risk-free need
  - 5000 kT*MW*(10^7) sec



1 yr ~ 3 10^7 sec

500kT
2 MW
5 yrs
Past approach

200kT
2 MW
5yrs
Possible at FNAL with new Proton Driver

ν_μ disappearance

neutrino running:

1MW beam
0.5Mt water Cerenkov d
1290km distance
5e7s running time
190000 tot CC events

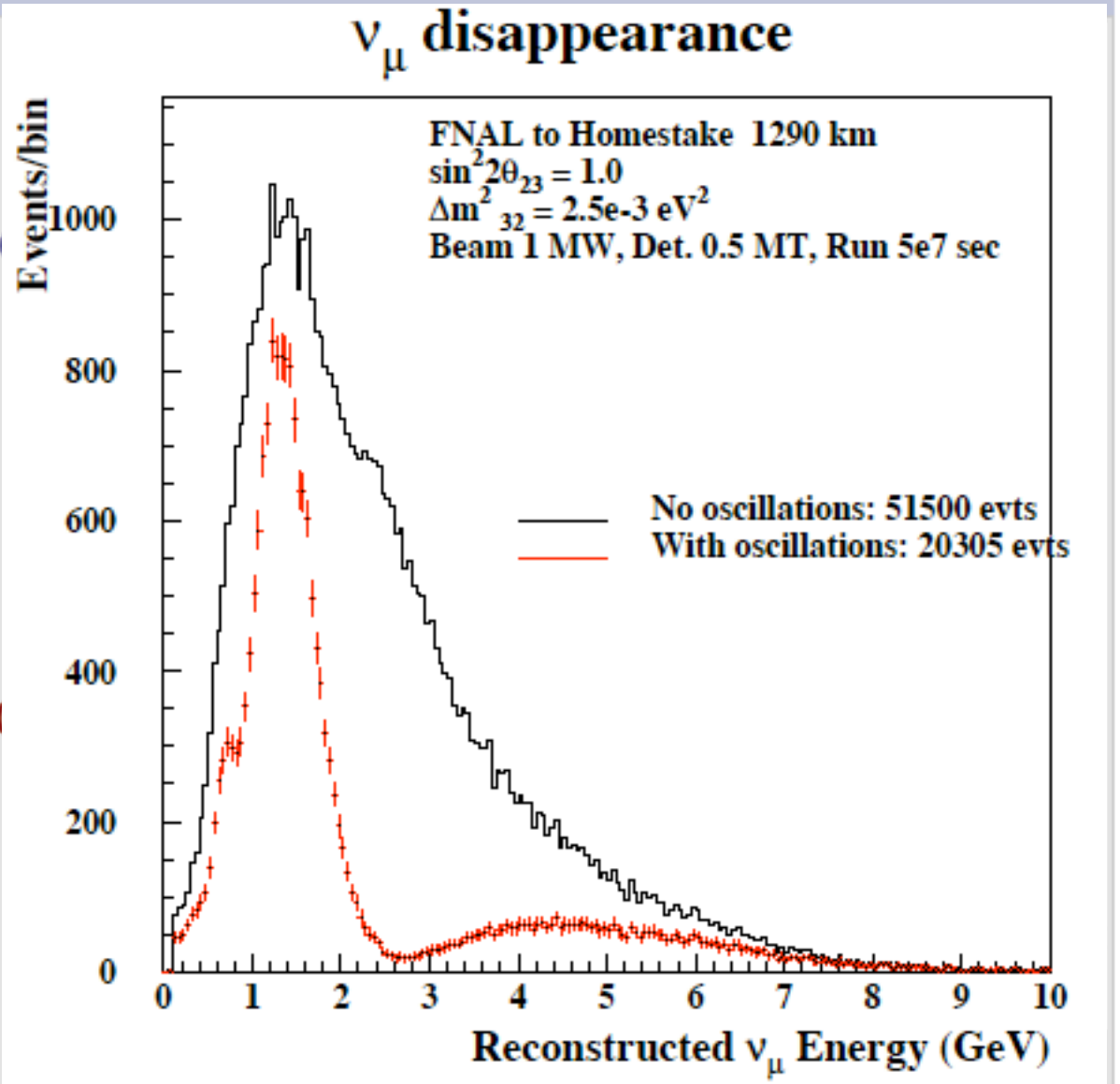
determine Δm^2_{32}
& $\sin^2 2\theta_{23}$ to 1%
systematics dominate

anti-neutrino running:

same as ν but with
2MW beam

including anti-ν running:

- CPT test possible
- errors below 1% achievable



ν_e Appearance

<u>backgrounds:</u>

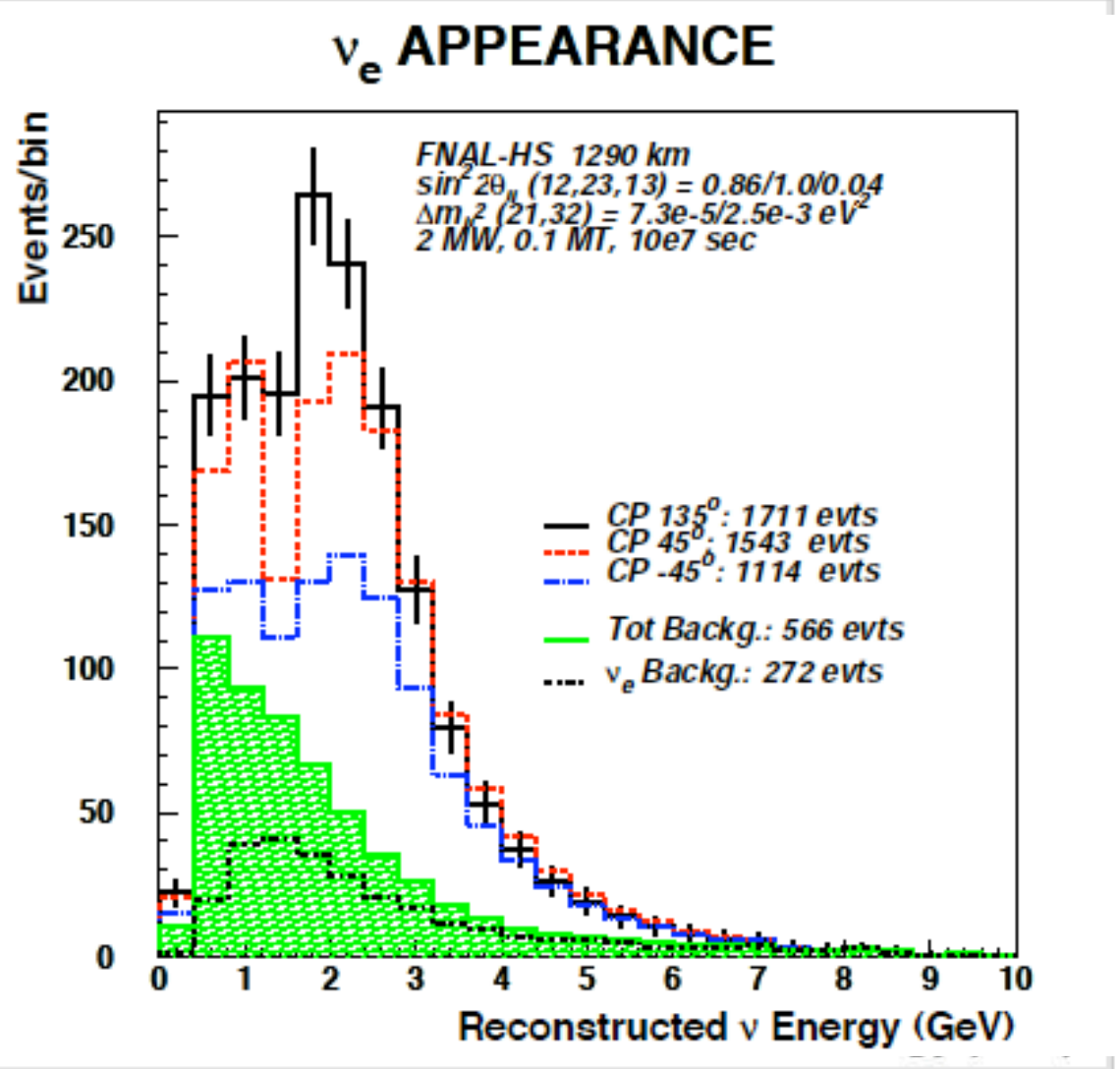
- beam ν_e
- NC ν_μ

<u>neutrino running:</u>

measure $\sin^2 2\theta_{13}$ and δ_{CP}
for $\sin^2 2\theta_{13} > 0.01$
resolve mass hierarchy

<u>include anti-neutrino run:</u>

exclude $\sin^2 2\theta_{13} > 0.003$



if $\sin^2 2\theta_{13}$ too small → δ_{CP} measurement not possible
observation ν_e appearance possible through solar term

Summary

- Physics case for a 100 kT detector at Homestake.
- nucleon decay, astrophysical neutrinos, long baseline.
- Lowest risk most cost effective option for a long baseline second generation experiment.
- Money ? It will cost money, but time and scientific manpower issues more important.
- Possible time sequence:
  - 100 kT detector + 0.5 MW beam
  - 100 kT detector + 2 MW beam
  - 200 kT detector + 2 MW beam