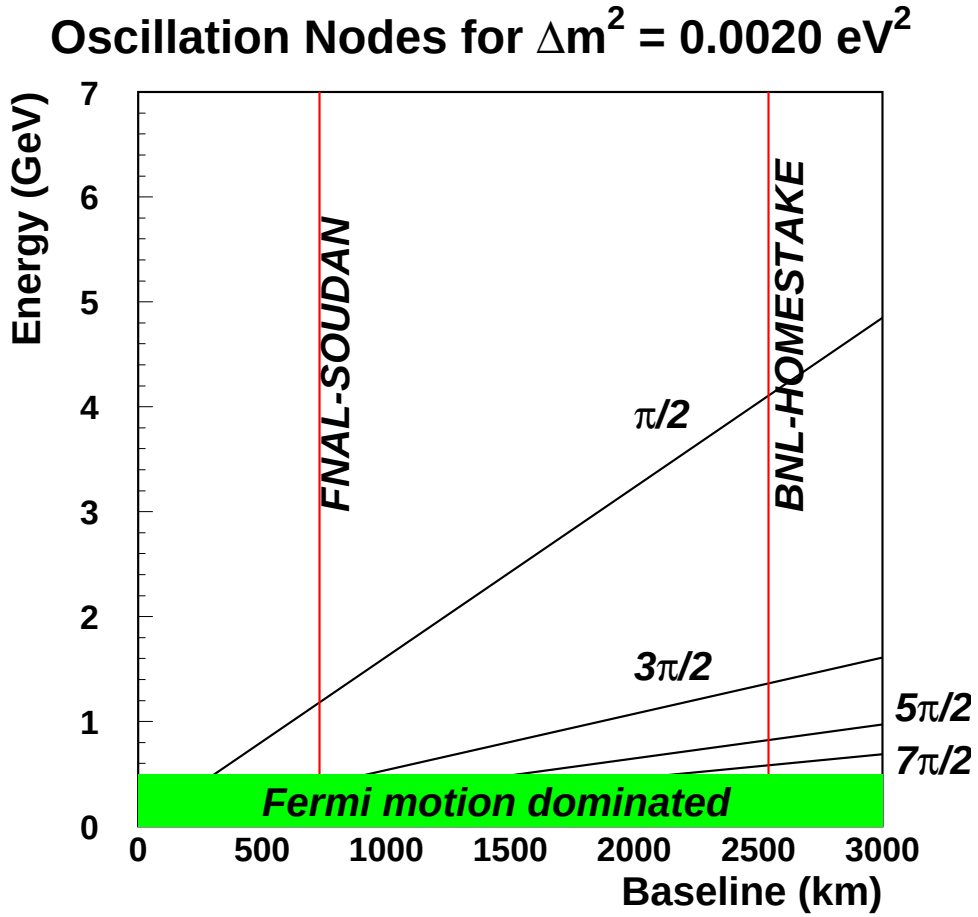
Very Long Baseline Simulation Update

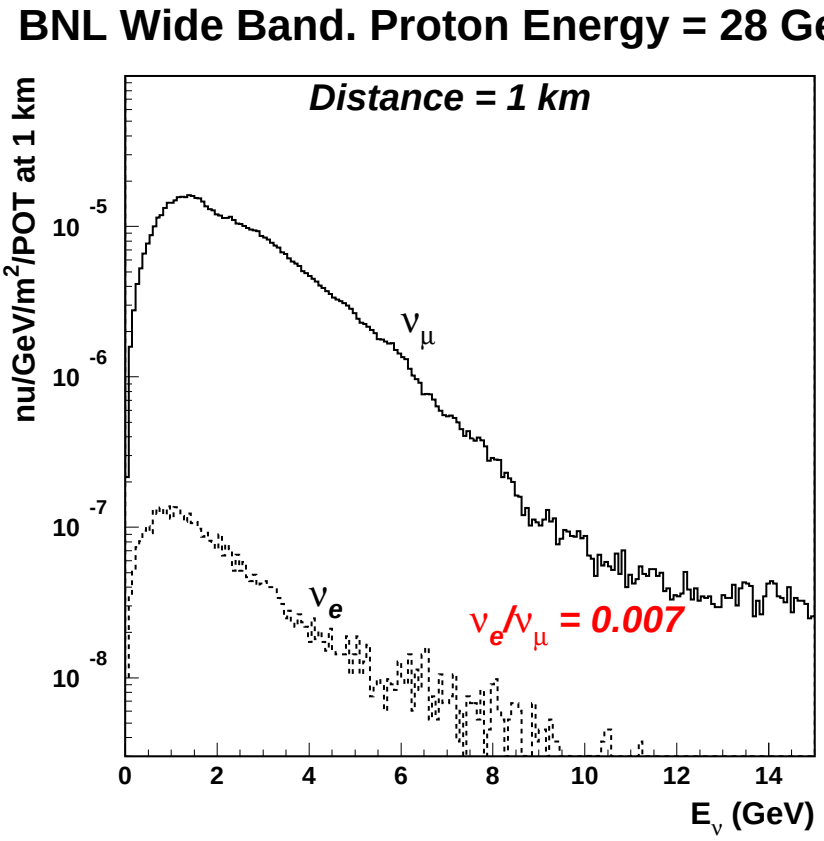
Milind Diwan FOR BNL Neutrino Working Group. January 30, 2004 APS superbeam study Fermilab

- Physics Understanding
- Detector Requirements
- Detector Simulation and Ideas

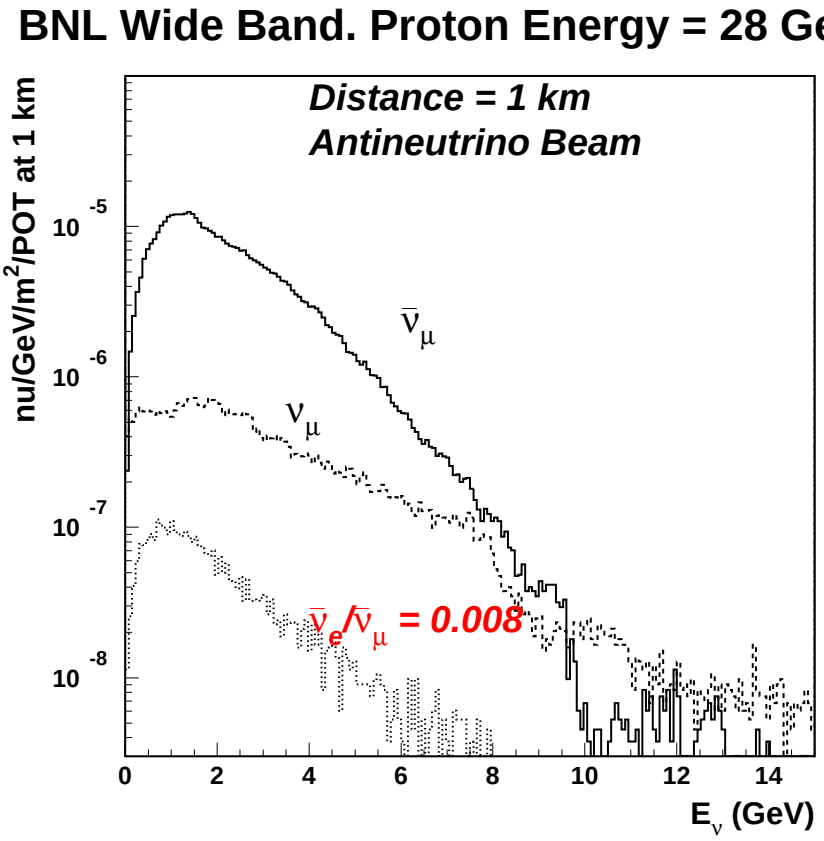


- Large effects: Multiple oscillation nodes.
- Low cross section at low energies
- Fermi motion limits resolution at low energies: wide band beam ($0.5 \rightarrow 8$ GeV).
- $\Delta m^2 \approx 0.002 eV^2$: Baseline > 2000 km.

ref: PRD68, 012002 (2003)

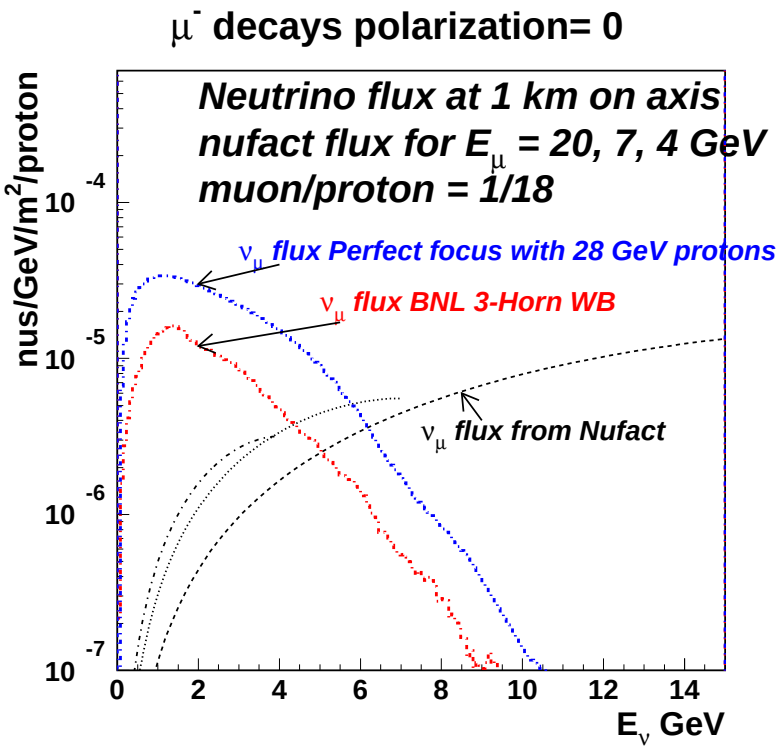


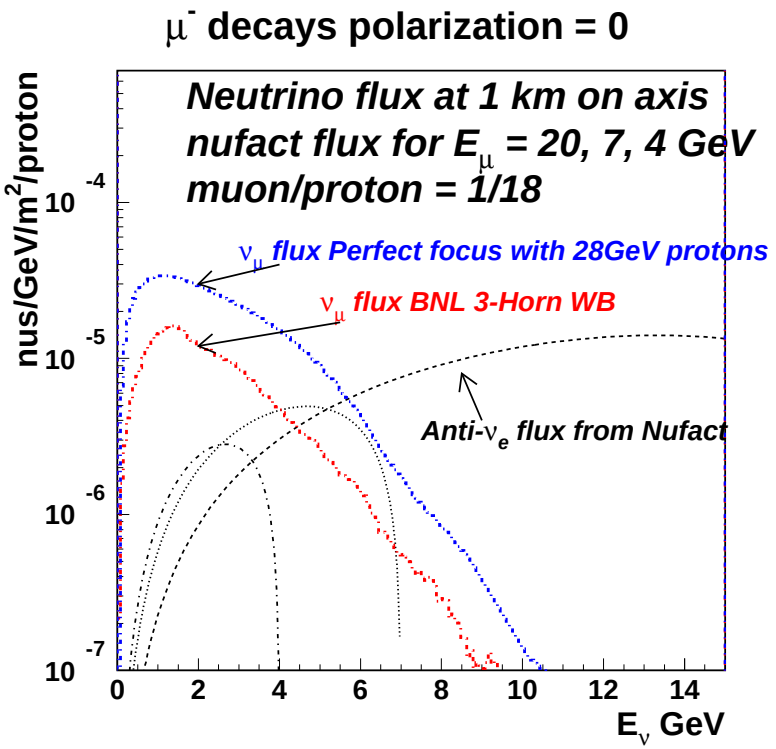
- New design spans 0.5-6 GeV
- Low ν_e background 0.7%
  0.0073 ± 0.0014 (E734 1986).
- Low background from high energies (NC and ν_τ for ν_e)
- 200 m decay tunnel
- Graphite target embedded in horn
- Target cooling achievable for 1 MW

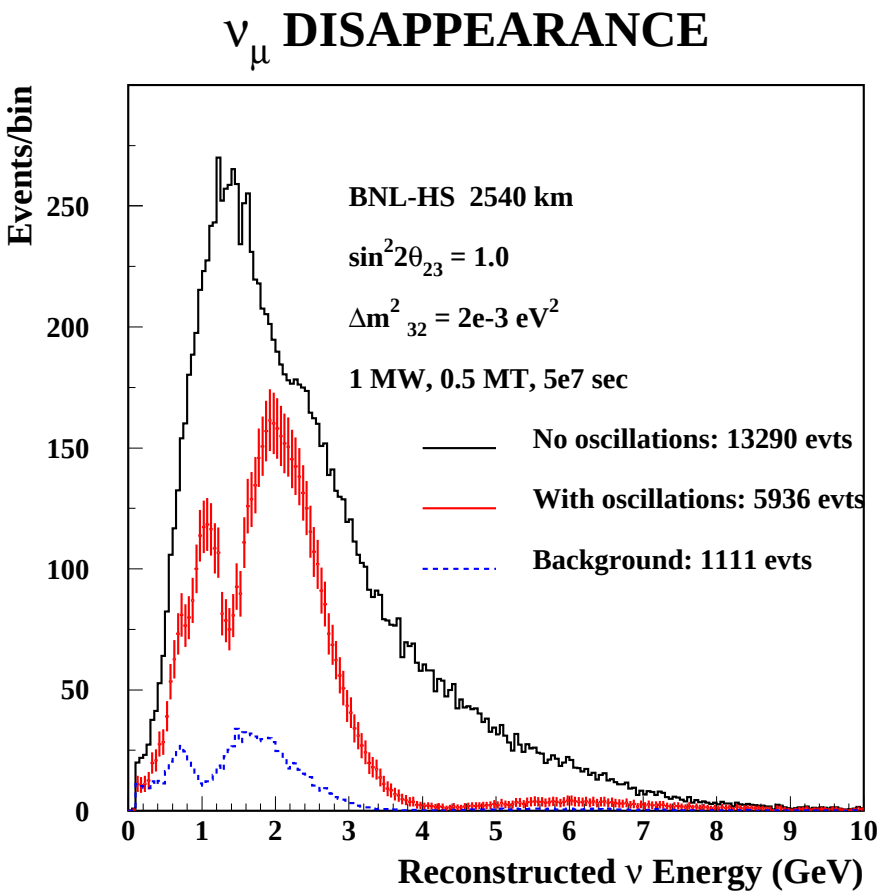


- Antineutrino beam has larger neutrino contamination.
- Will need to go to 2 MW to get statistics equal to neutrino.

Wide band flux comparison to Nufact



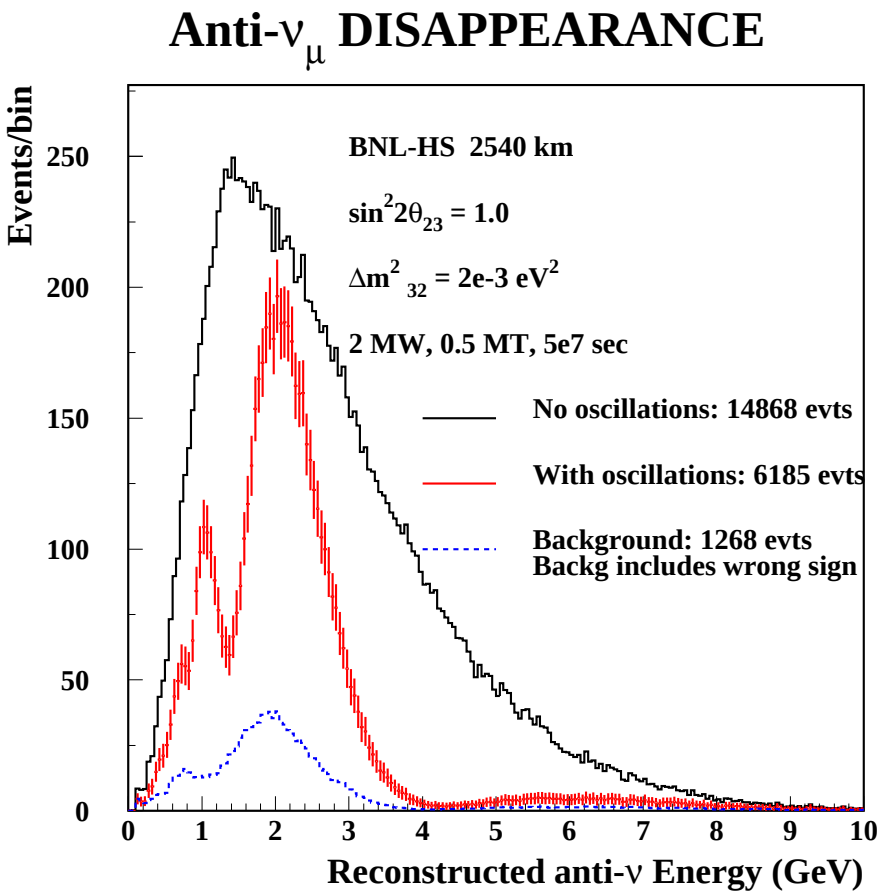




Node pattern provides high Δm^2_{32} resolution.
Energy calibration is very important.

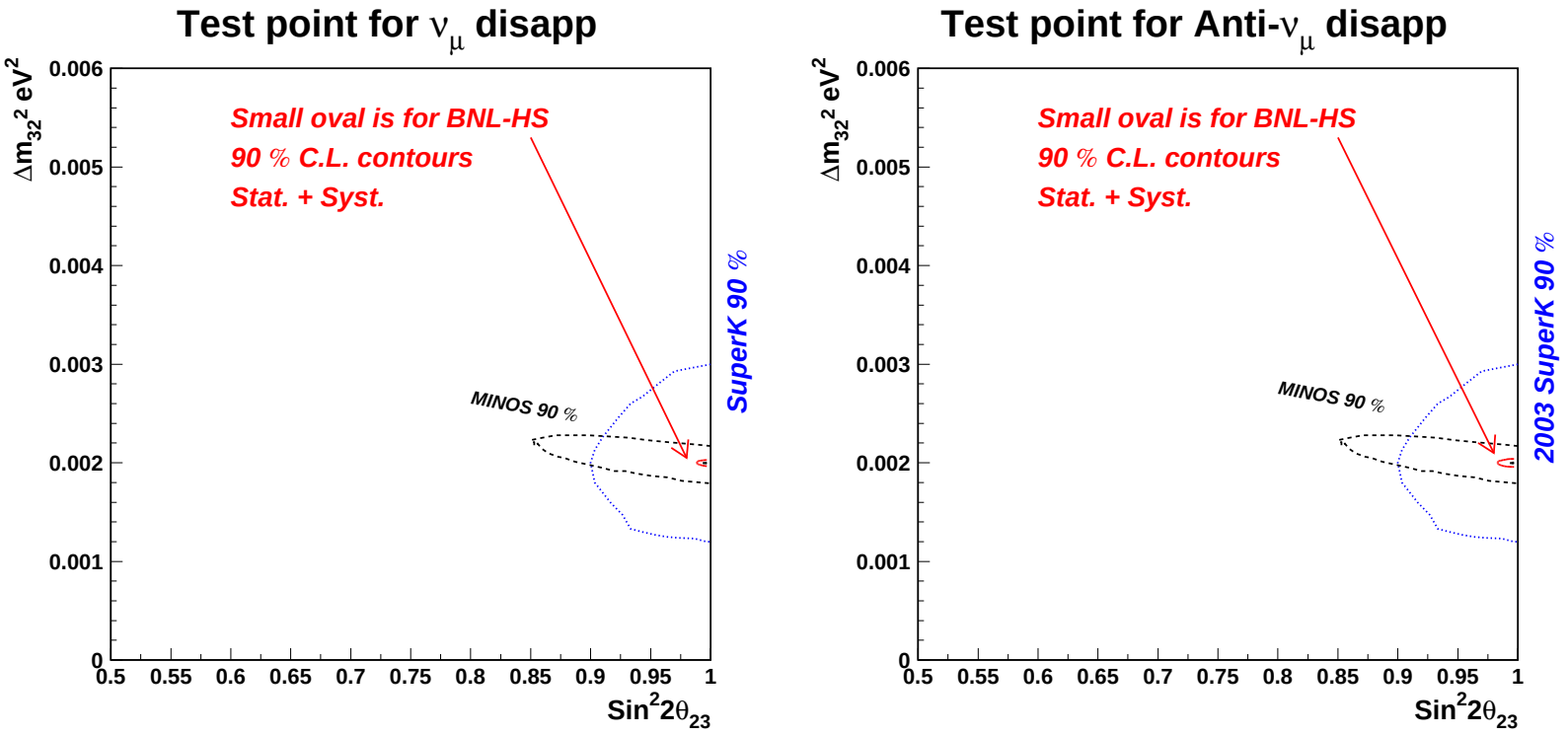
Flux normalization not important for measurement of $\sin^2 2\theta_{23}$

Background shape can be measured independently
Minimum systematics in ν_μ and $\bar{\nu}_\mu$ comparison



For anti-neutrinos low energy nodes have less statistics because of cross section.

Disappearance resolution

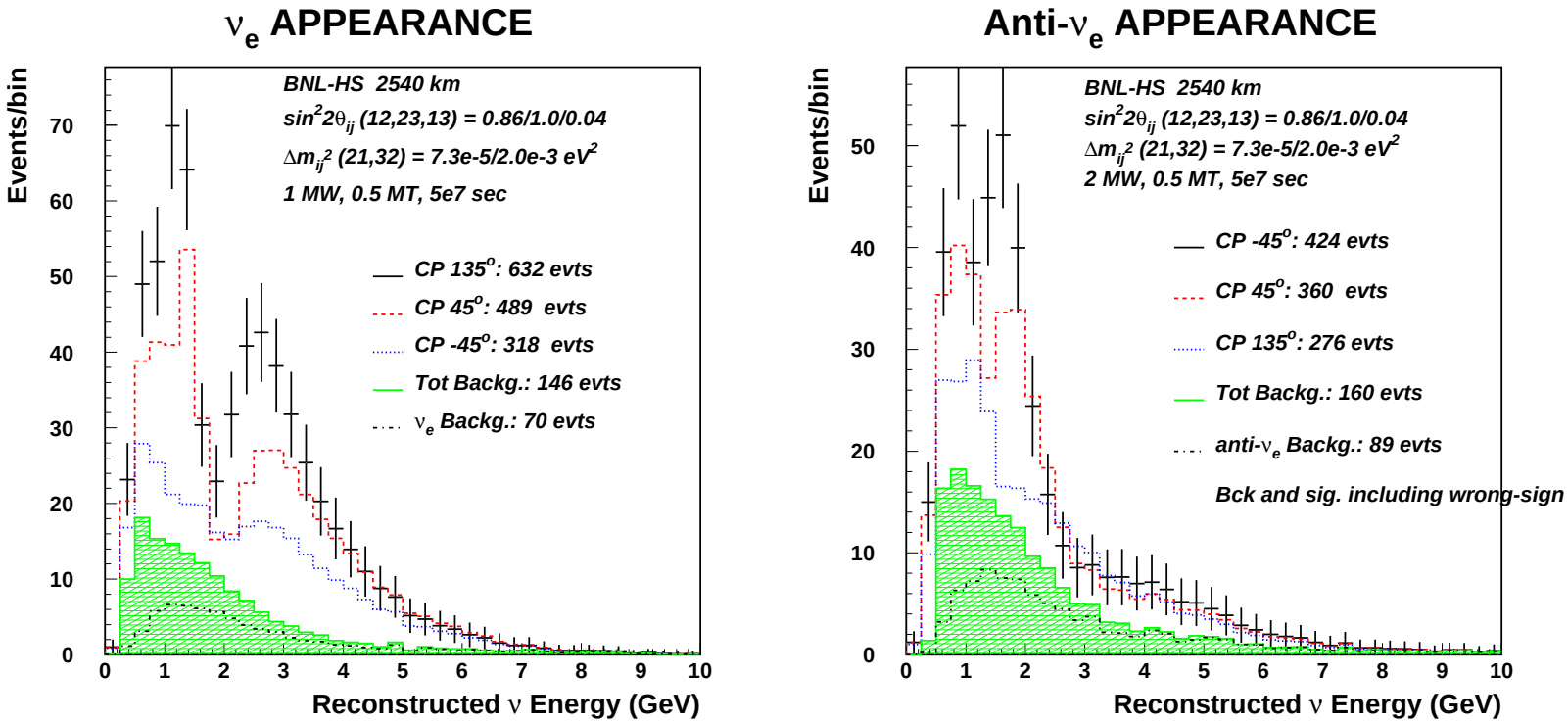


$\sim 1\%$ resol. on Δm^2_{32} and $\sin^2 2\theta_{23}$ over broad range.

Need to understand detector energy scale to 1%.

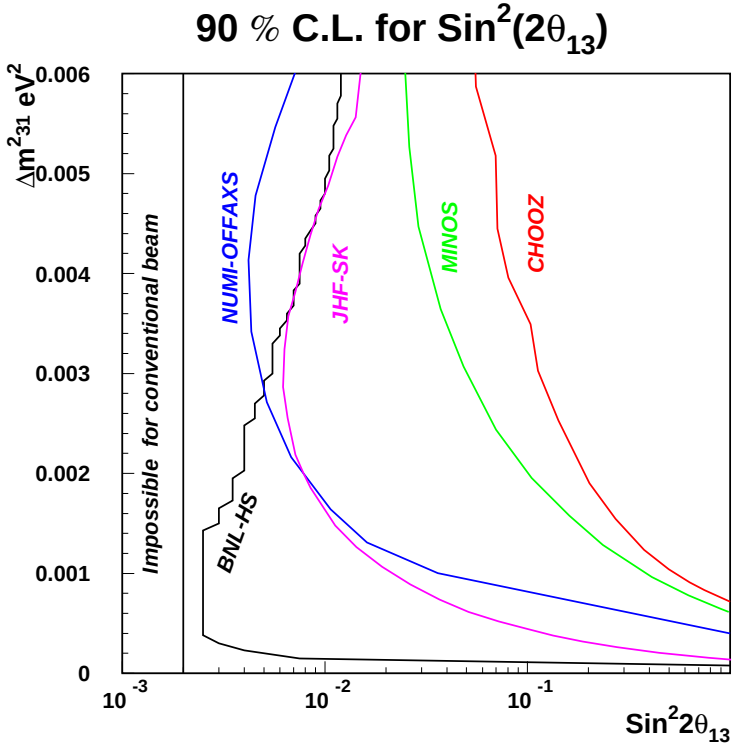
Robust against normalization, shape, resolution, and background.

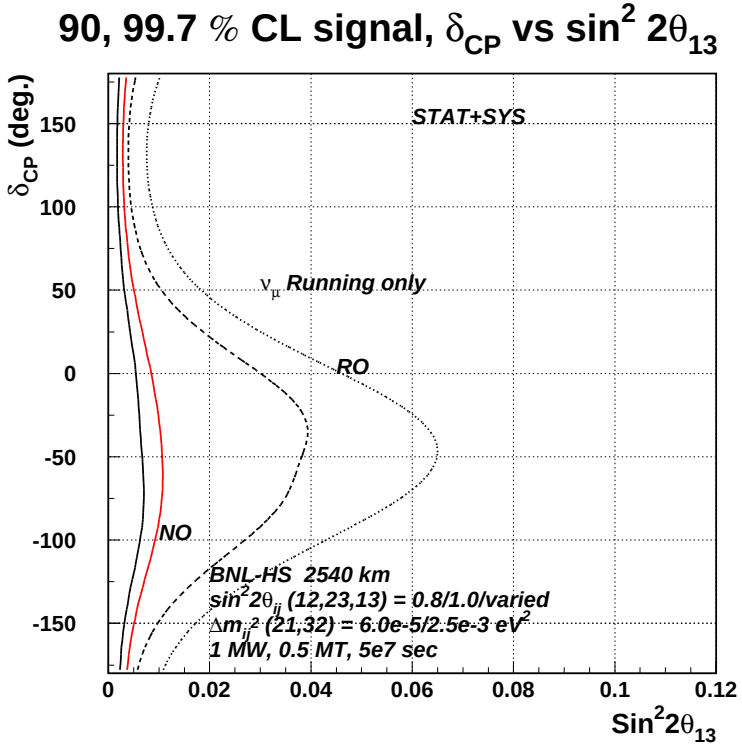
Running for $\sin^2 2\theta_{13}$



$\Delta m^2_{32} = 0.002 eV^2$, $\sin^2 2\theta_{13} = 0.04$. Assume normal mass hierarchy. $m_3 > m_2 > m_1$ Matter effects included.

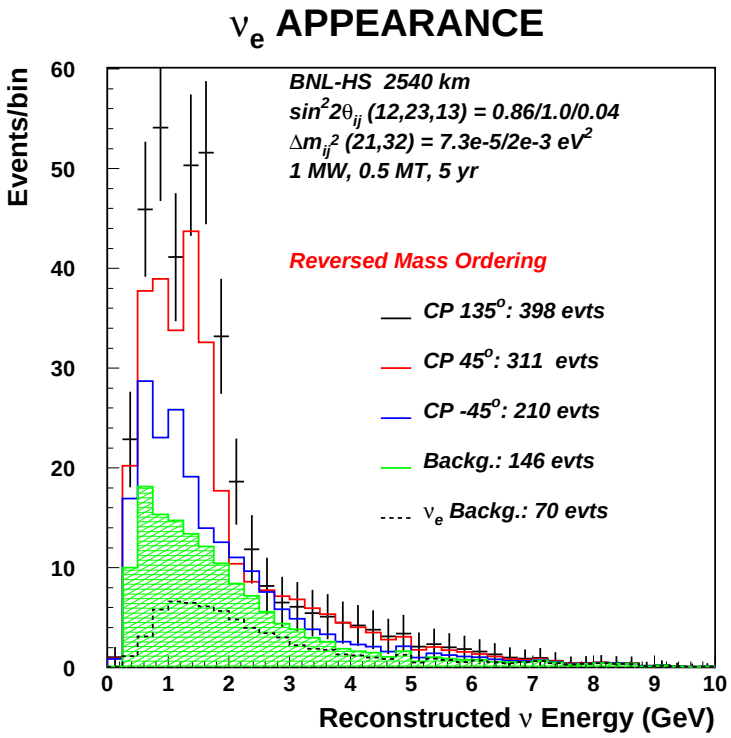
$\sin^2 2\theta_{13}$ sensitivity

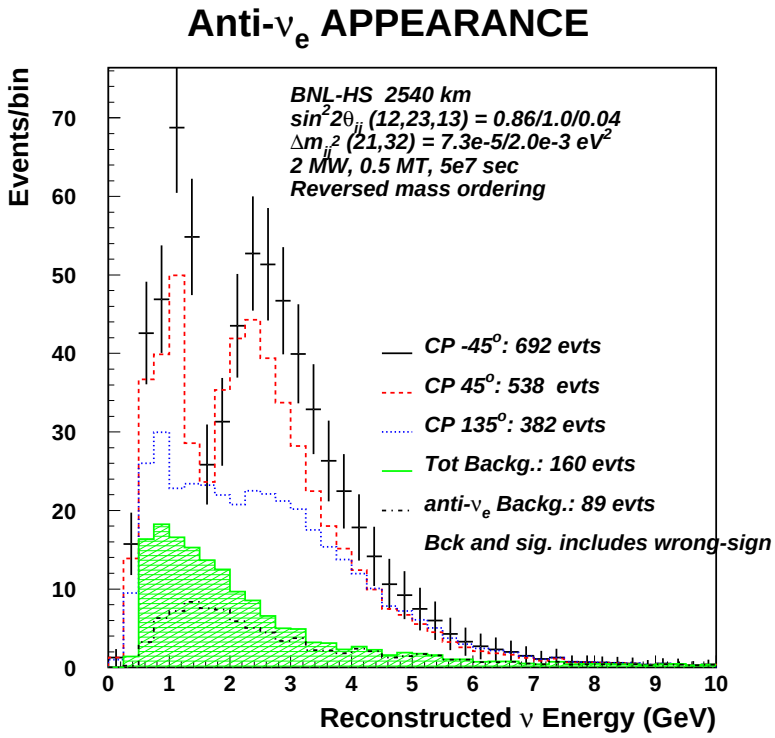




If reversed hierarchy and in the unlucky region, need to run anti-neutrinos.

Running for $\sin^2 2\theta_{13}$



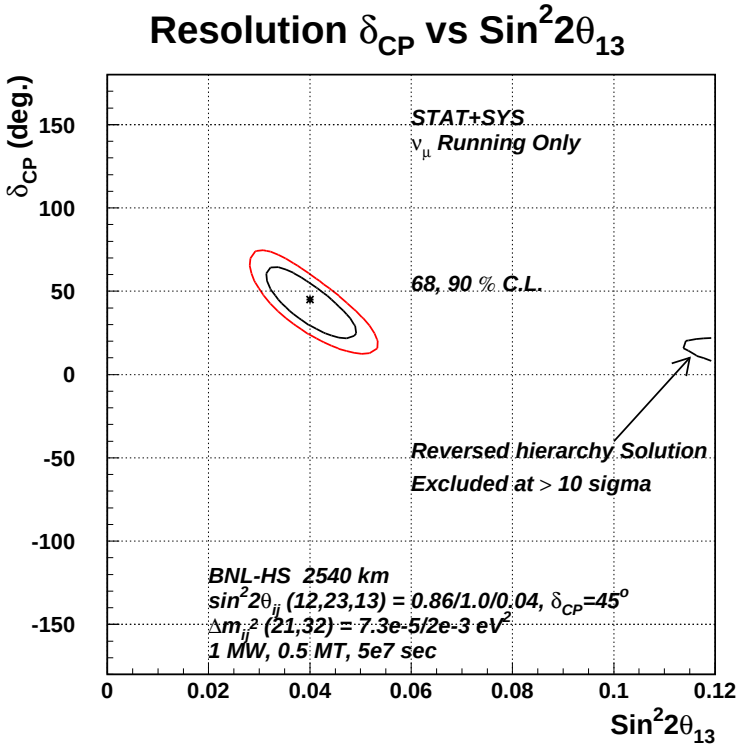


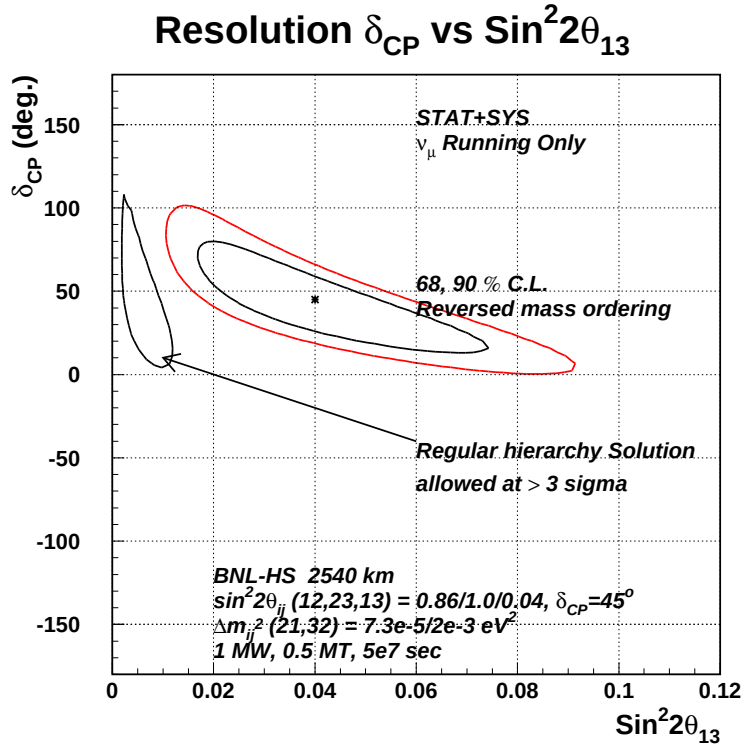
$\Delta m^2_{32} = 0.002 eV^2$, $\sin^2 2\theta_{13} = 0.04$.

Reversed Mass Hierarchy

Matter effects included.

Mass hierarchy after neutrino running

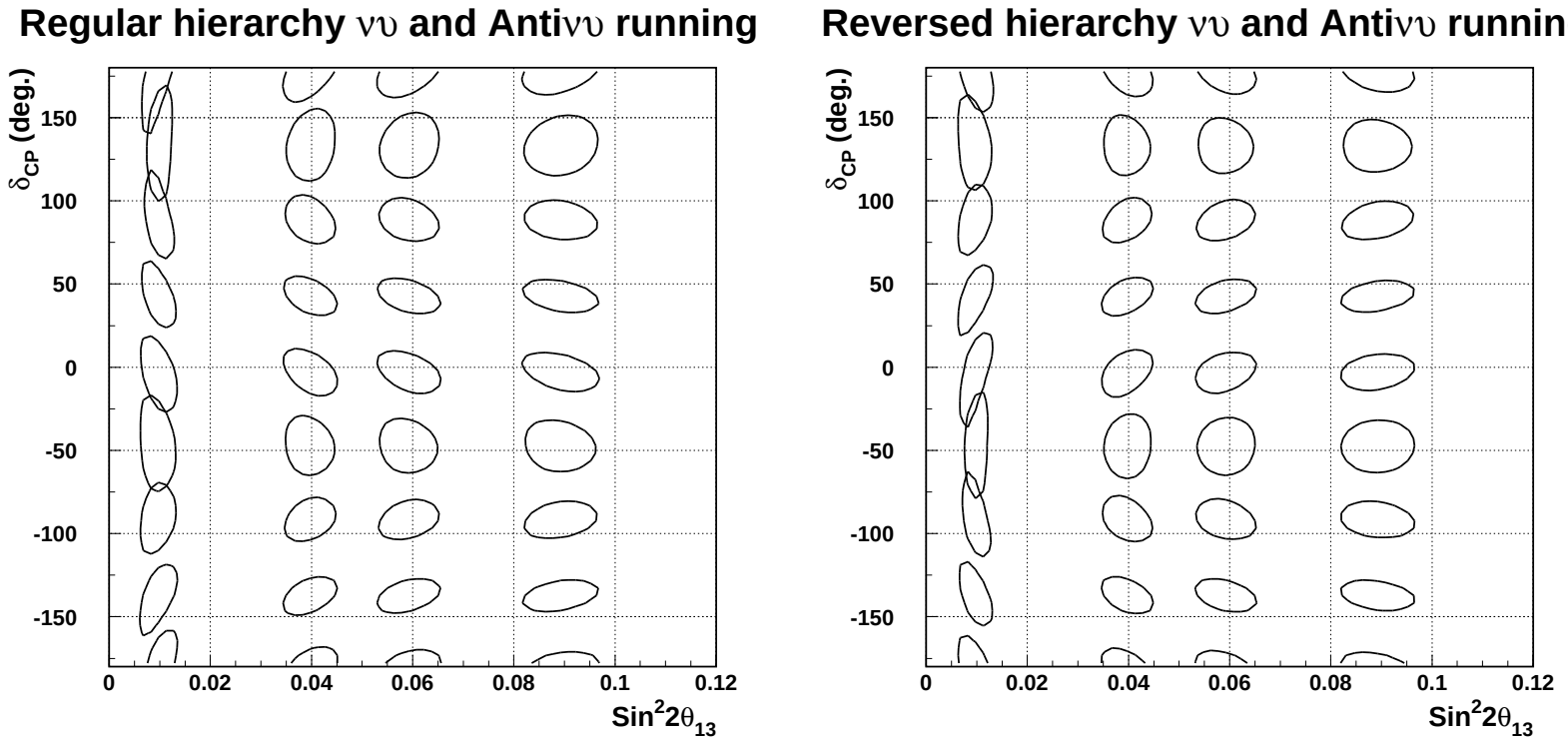




Left: Regular mass hierarchy Right: reversed mass hierarchy.

Mass hierarchy is resolved to 3 sigma with only neutrino running in large part of the parameter space.

CP measurement after nu and anti-nu



Left: Regular mass hierarchy Right: reversed mass hierarchy.

Only the θ_{23} ambiguity is left.

If exactly 45 deg. no effect can be used to find it.

Event Rates with Neutrinos

Assume 1 MW, 500 kT Fiducial, 5×10^7 sec running. (1.22×10^{22} Protons at 28 GeV.)

Assume Water Cerenkov detector.

CC $\nu_\mu + N \to \mu^- + X$	51800 (15025)
NC $\nu_\mu + N \to \nu_\mu + X$	18323 (5770)
CC $\nu_e + N \to e^- + X$	380 (103)
QE $\nu_\mu + n \to \mu^- + p$	11767 (5934)
QE $\nu_e + n \to e^- + p$	84 (40)
CC Single π	22053 (5936)
CC Two π	10143 (1668)
CC > 2 π	4882 (250)
CC $\nu_\tau + N \to \tau^- + X$ (depends on Δm^2)	~ 110 (20)

Low τ production.

Low Multiplicity.

Anti-neutrino rate in (brackets) for 1 MW. Neutrino contamination in antineutrinos: 3848 CC and 1300 NC.

Neutral Current Events Neutrinos(Anti-Neu)

Assume 1 MW, 500 kT Fiducial, 5×10^7 sec running. (1.22×10^{22} Protons at 28 GeV.)

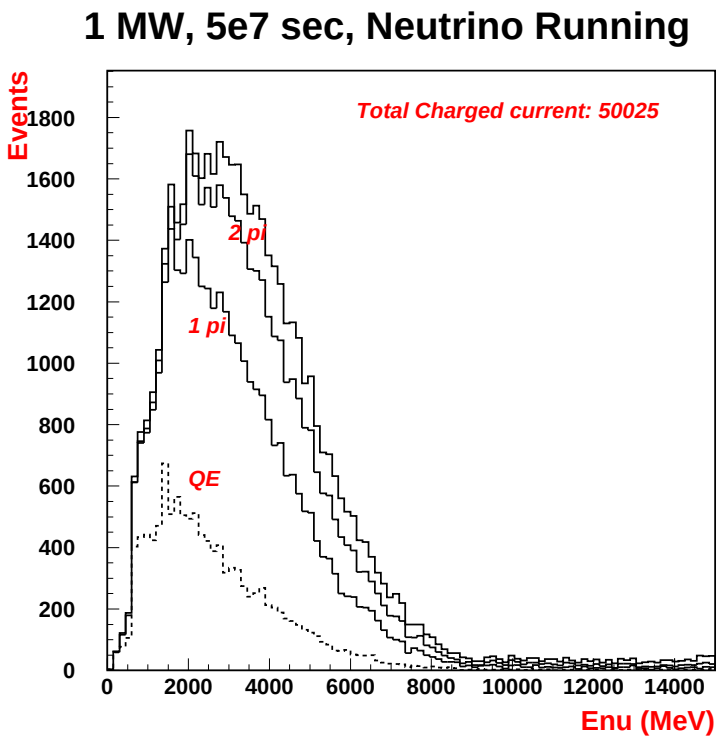
NC $\nu_\mu + N \rightarrow \nu_\mu + X$	18323 (6061+1383)
NC elastic	4575 (1941+295)
Single π	7741 (2537+560)
Two π	3557 (815+302)
$> 2\pi$	1729 (280+175)
Single π^0	3295 (1019+228)
$> 1\pi$ with π^0	4041 (789+372)

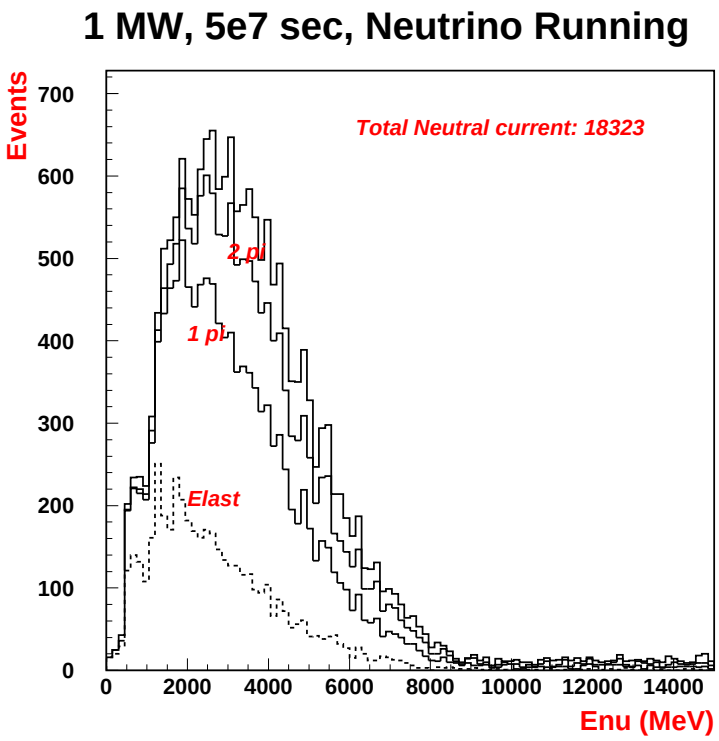
Antinu rate: rate + nu-contamination.

Multiple pion events should be suppressed better than single π^0 events.

Both single and multi-pi event rate display the same tendency to fall rapidly with energy.

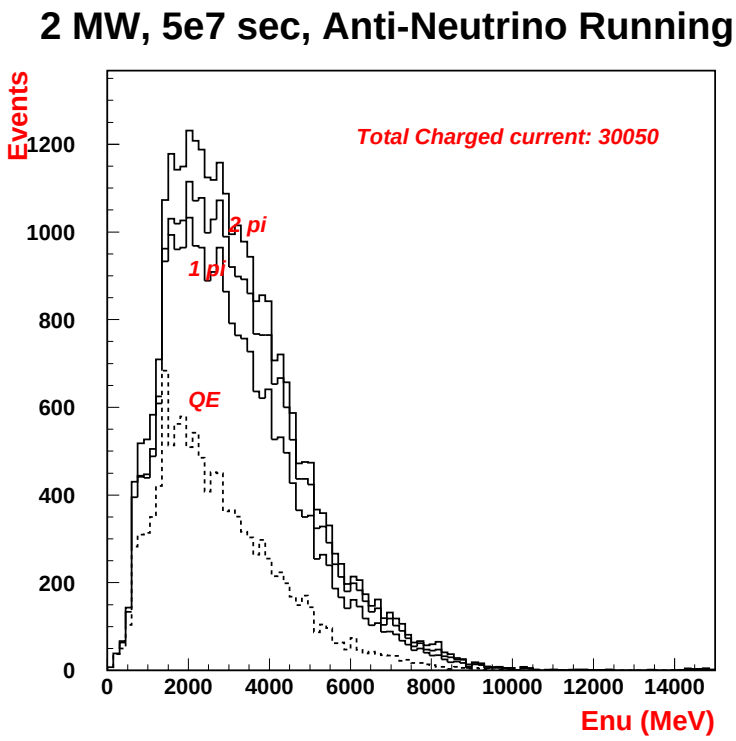
Event mix, neutrinos

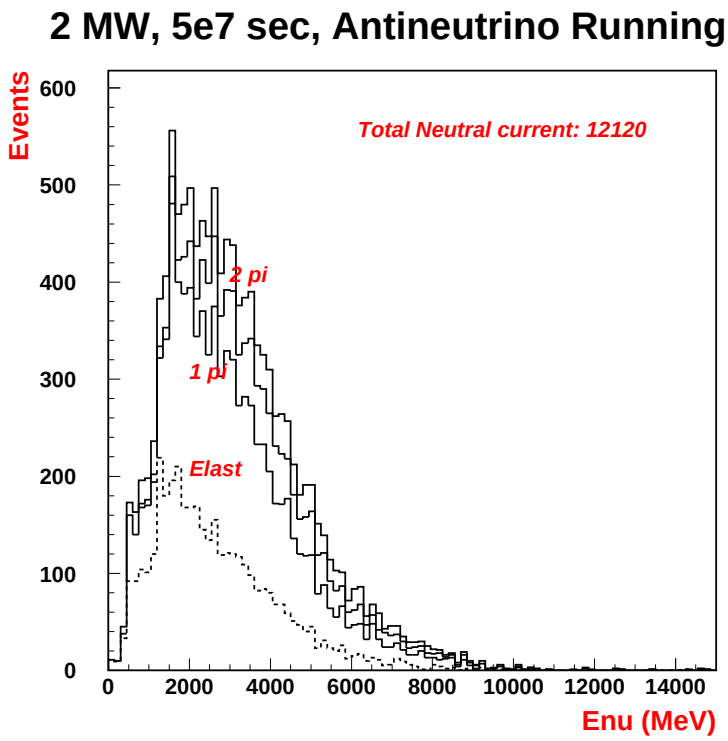




Left: Charged Current, Right: Neutral Current

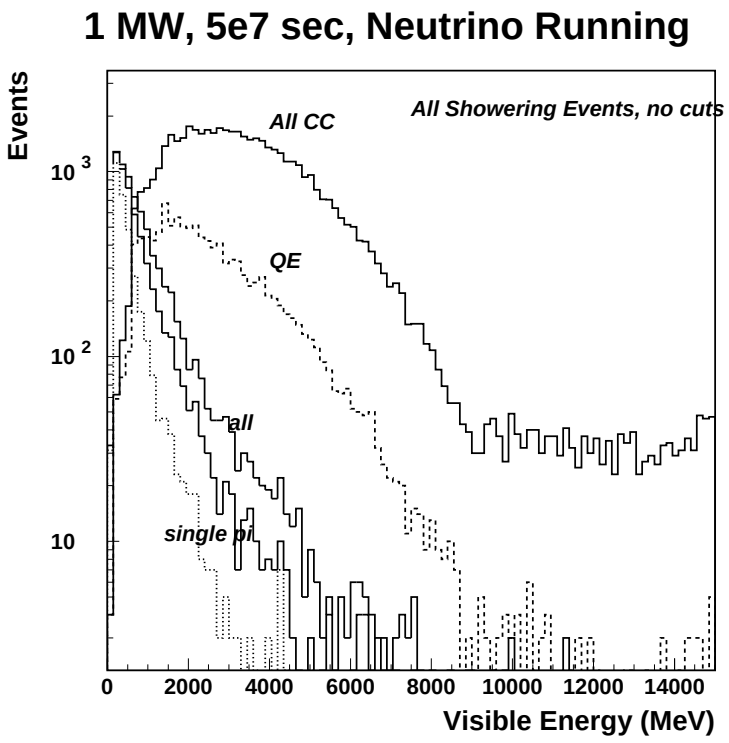
Event mix, antineutrinos

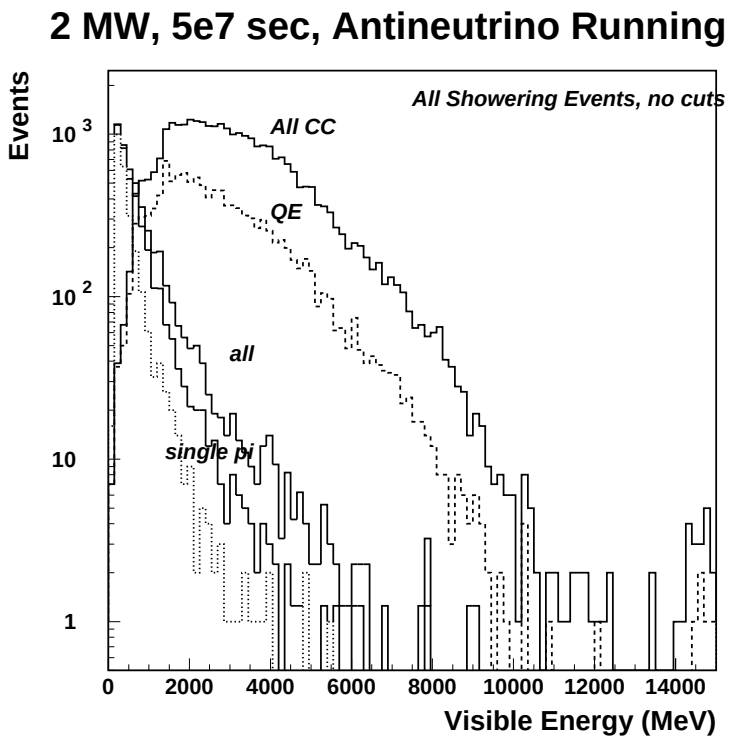




Left: Charged Current, Right: Neutral Current

Showering Events





Left: Neutrino, Right: Anti-neutrino

Milind Diwan

Very long baselines with a superbeam

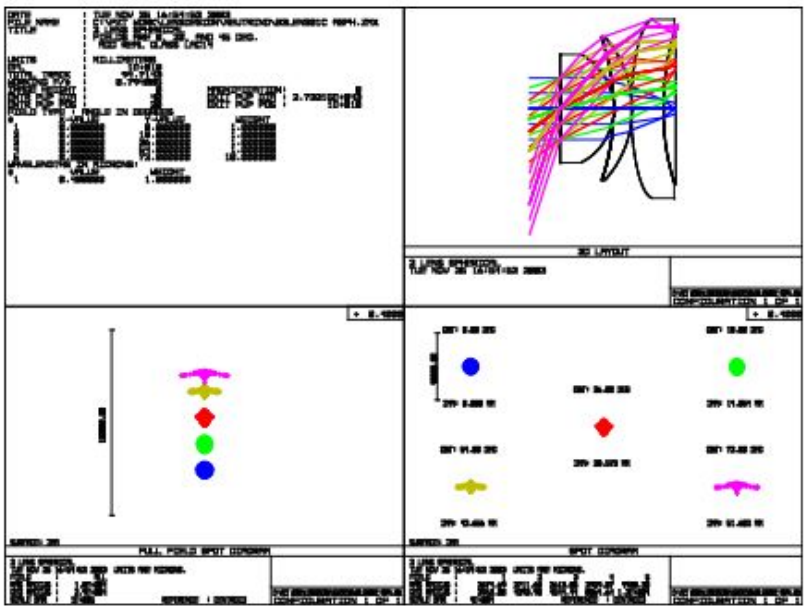
Detector Requirements

- Fiducial Mass:
  - $>$ 500 kT if using only "clean" events.
    Also needed for proton decay and neutrino astrophysics.
  - $\sim$ 100 kT if fine grain and use all CC events.
    Selected proton decay modes still at the frontier.
- Threshold: $\sim$ 10 MeV
- Energy resolution: $\sim$ 10 %
- muon/electron discrimination: $<$ 1 %
- Pattern recognition:
  - 1, 2, 3 track separation
  - showering vs. multitrack separation.
  - need factor of 20-30 rejection capability around 1-2 GeV.
- Timing: few ns.
- Affordability: 300 M$ – 1000 M$

Some comments on detector

- Detector studies have started. Need more manpower.
- Water Cherenkov
  - 50 kT SuperK is existence proof.
  - Background rejection ? need another $\times 3 \rightarrow 5$
  - Additional imaging capability ?
- Liquid Argon TPC
  - scale up to 100 kT module ?
  - Current size 300Ton.
  - Needs detailed simulations.
- Any other technology ?

Preliminary Wide Angle Lense Design



P. Tacaks

What is Next ?

- Note describing anti-neutrino spectra, CP sensitivity, and new physics.
- Monte Carlo studies of non-imaging water Cherenkov
- Studies of imaging water Cherenkov.
- Monte Carlo studies of liquid Argon.