Reactor & Accelerator ν

Thanks to Bob McKeown for many of the slides

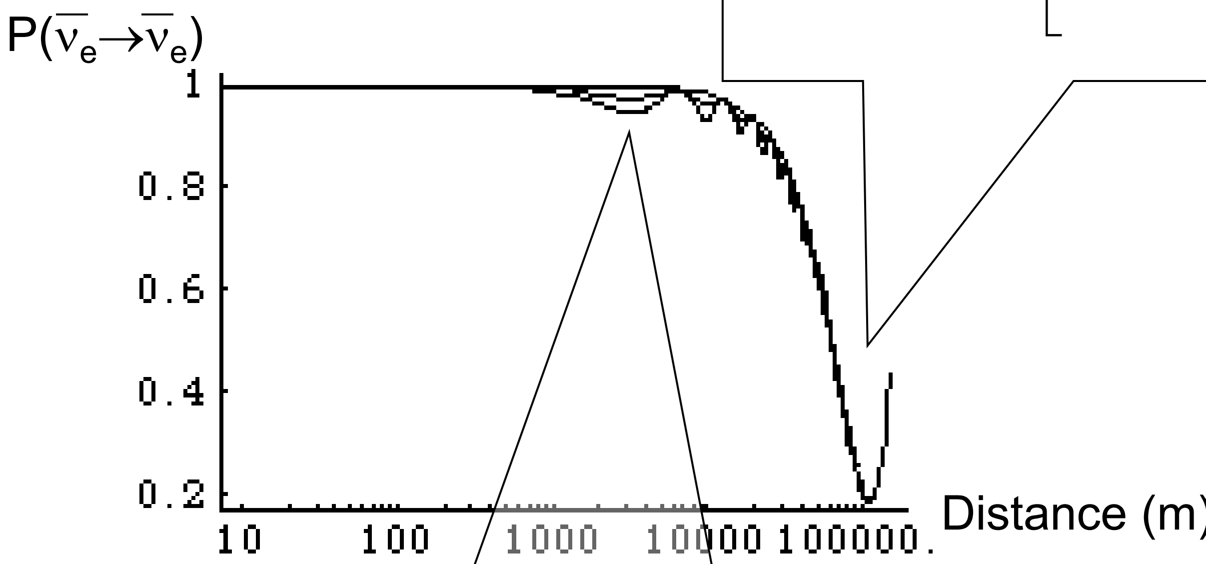
Outline

- Reactor Neutrinos
  - The neutrinos
  - Past experiments
  - What we know and what we want to learn
- Accelerator Neutrinos
  - The neutrinos
  - Past experiments
  - What we know and what we want to learn

$\overline{\nu}_e$ Disappearance

Dominant θ_{12} Oscillation

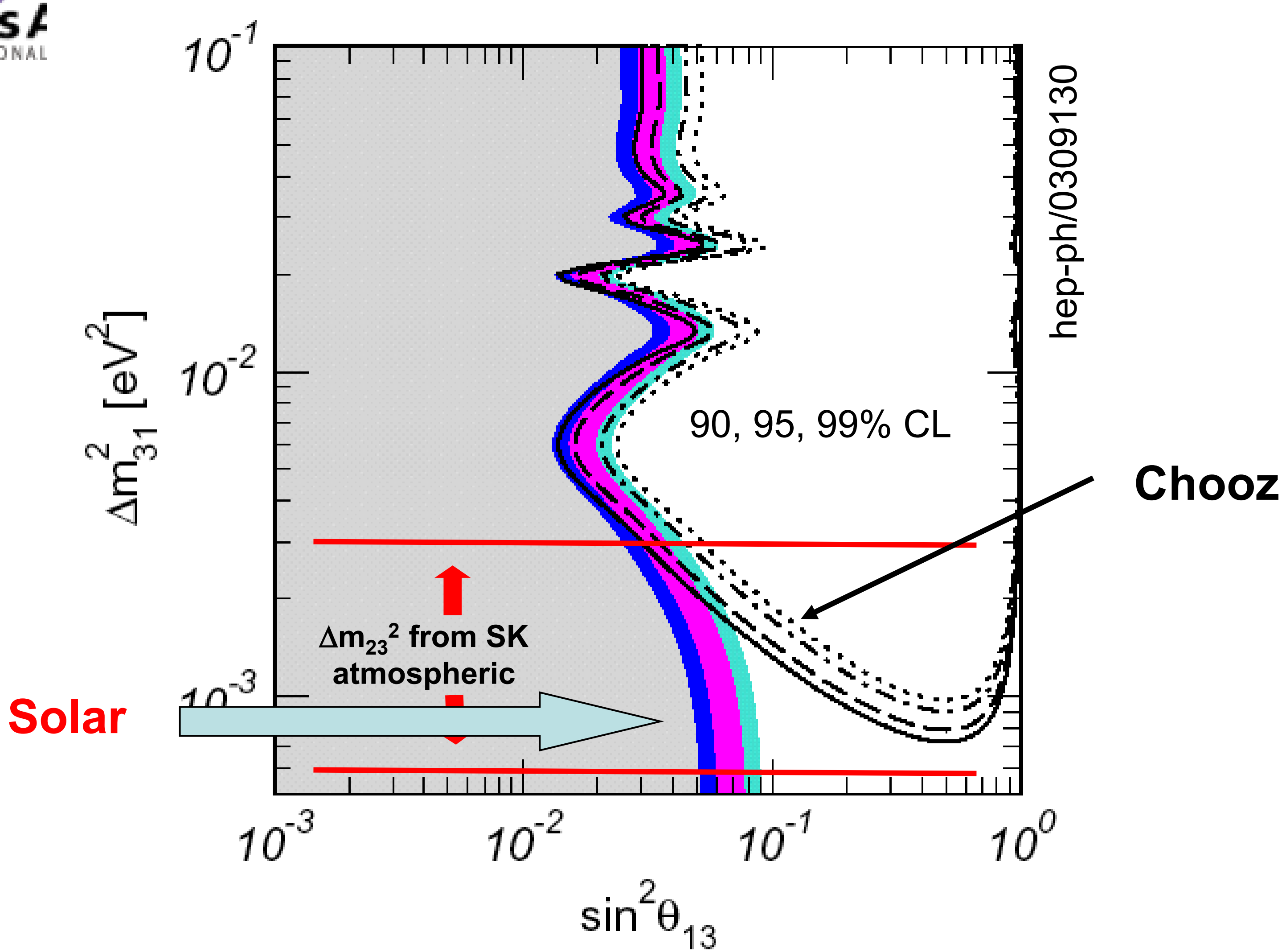
$$P_{ee} \approx 1 - \cos^4\theta_{13}\left[1 - \sin^2\theta_{12}\sin^2\left(\frac{\Delta m_{12}{}^2 L}{4E_\nu}\right)\right]$$



Subdominant θ_{13} Oscillation

$$\boxed{P_{ee} \approx 1 - \sin^2 2\theta_{13}\sin^2\frac{\Delta m_{31}{}^2 L}{4E_\nu}} + \left(\frac{\Delta m_{21}{}^2 L}{4E_\nu}\right)\cos^4\theta_{13}\sin^2 2\theta_{12}$$

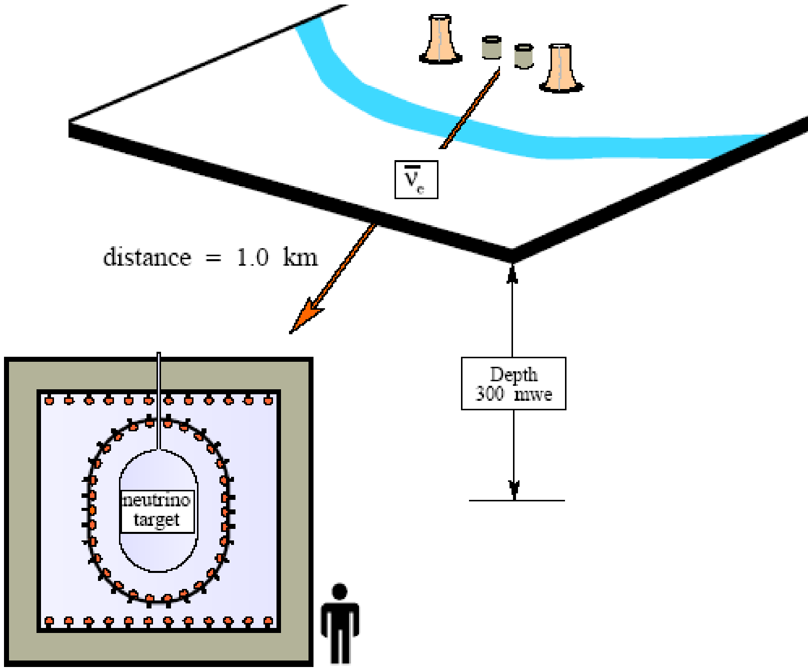
θ_{13}



$$\Phi_{CC} / \Phi_{NC} \approx \cos^4\theta_{13}\sin^2\theta_{12} + \sin^4\theta_{13} \approx \sin^2\theta_{12}$$

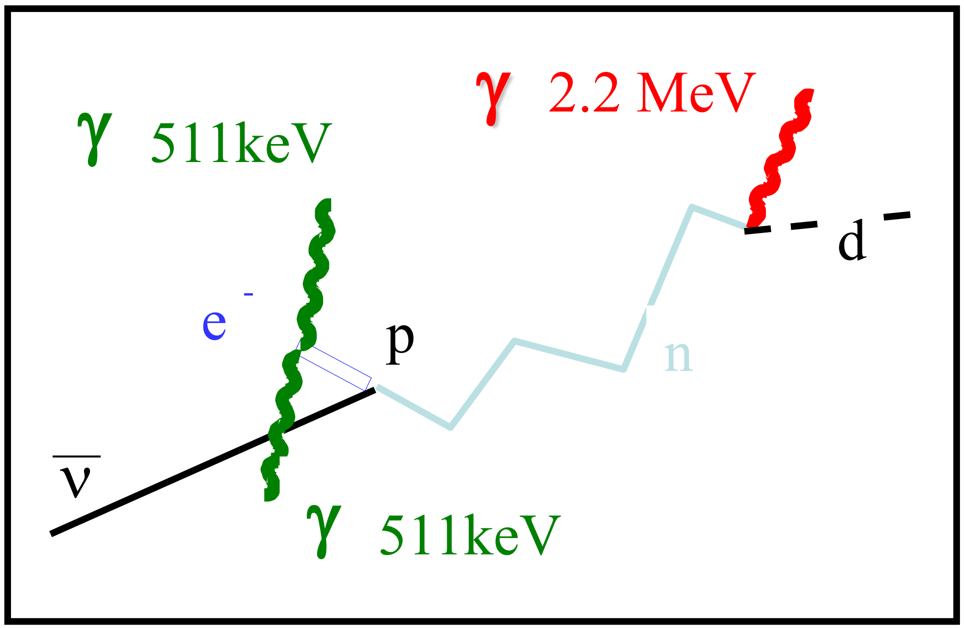
Los Alamos
NATIONAL LABORATORY

Neutrino Oscillation Studies with Nuclear Reactors



- $\bar{\nu}_e$ from n-rich fission products
- detection via inverse beta decay ($\bar{\nu}_e$+p→e^++n)
- Measure flux and energy spectrum
- Improve detectors, reduce background
- Variety of distances L= 10m-250km

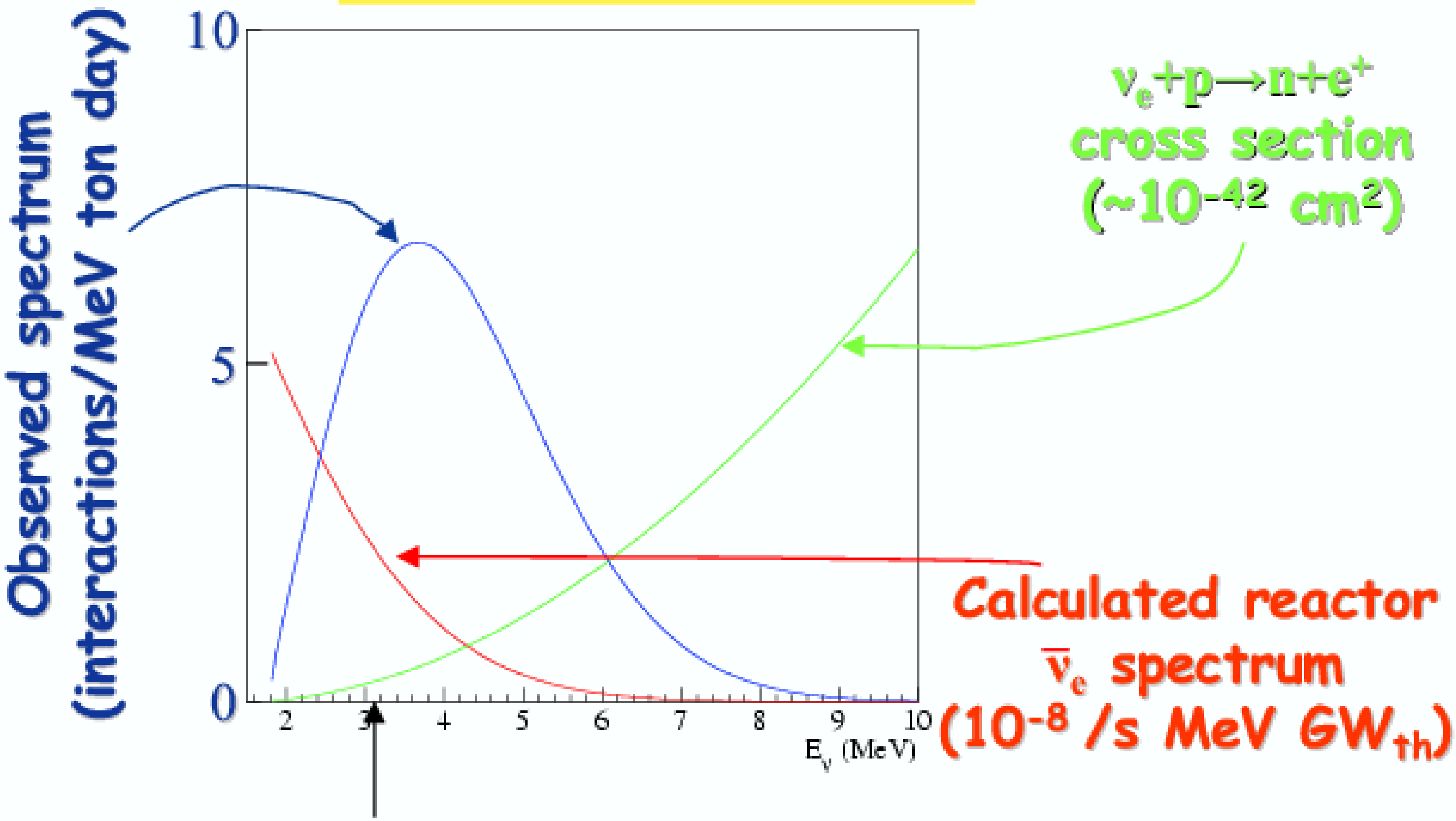
Detection Signal



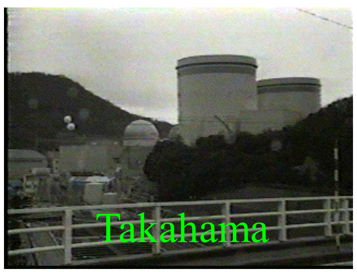
Coincidence signal: detect

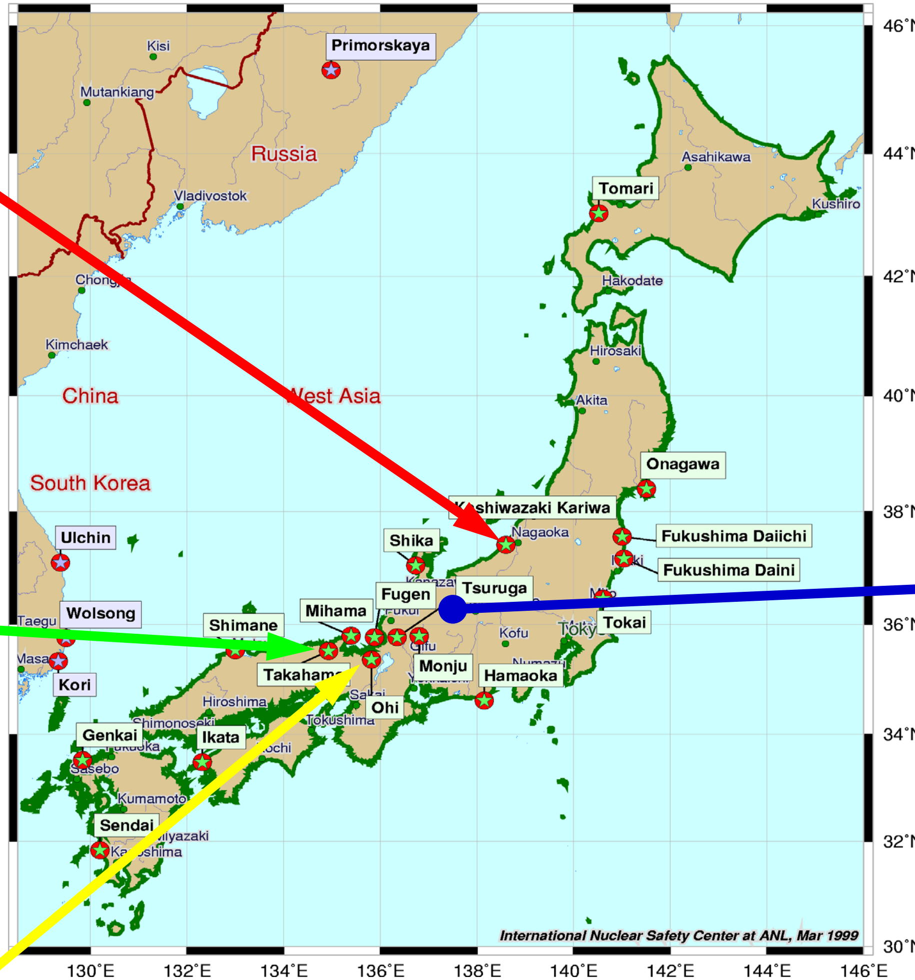
- Prompt: e^+ annihilation → $E_\nu = E_{prompt} + \overline{E}_n + 0.8$ MeV
- Delayed: **n** capture 180 μs capture time

The $\bar{\nu}_e$ energy spectrum



Neutrinos with E<1.8 MeV are not detected

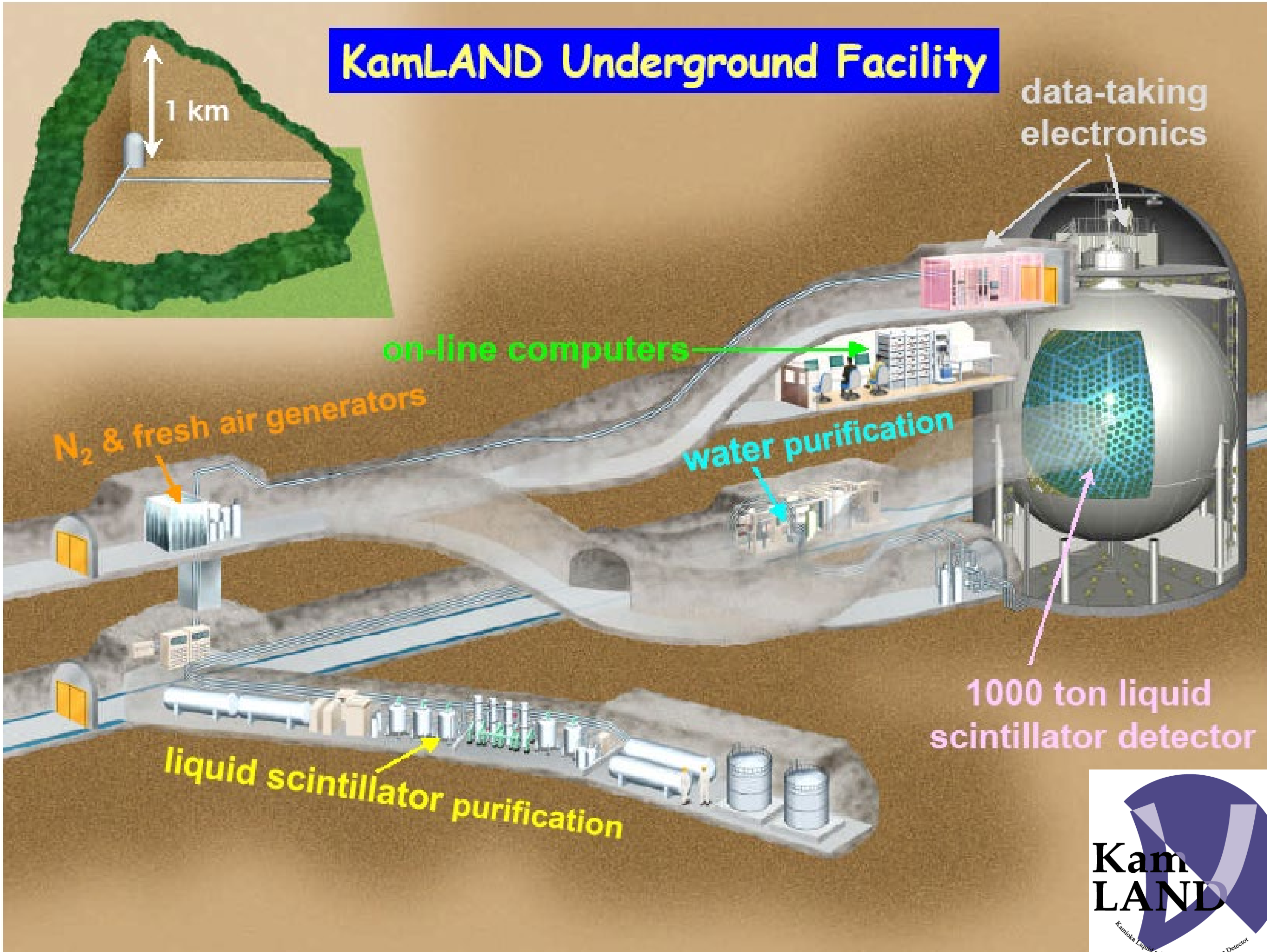




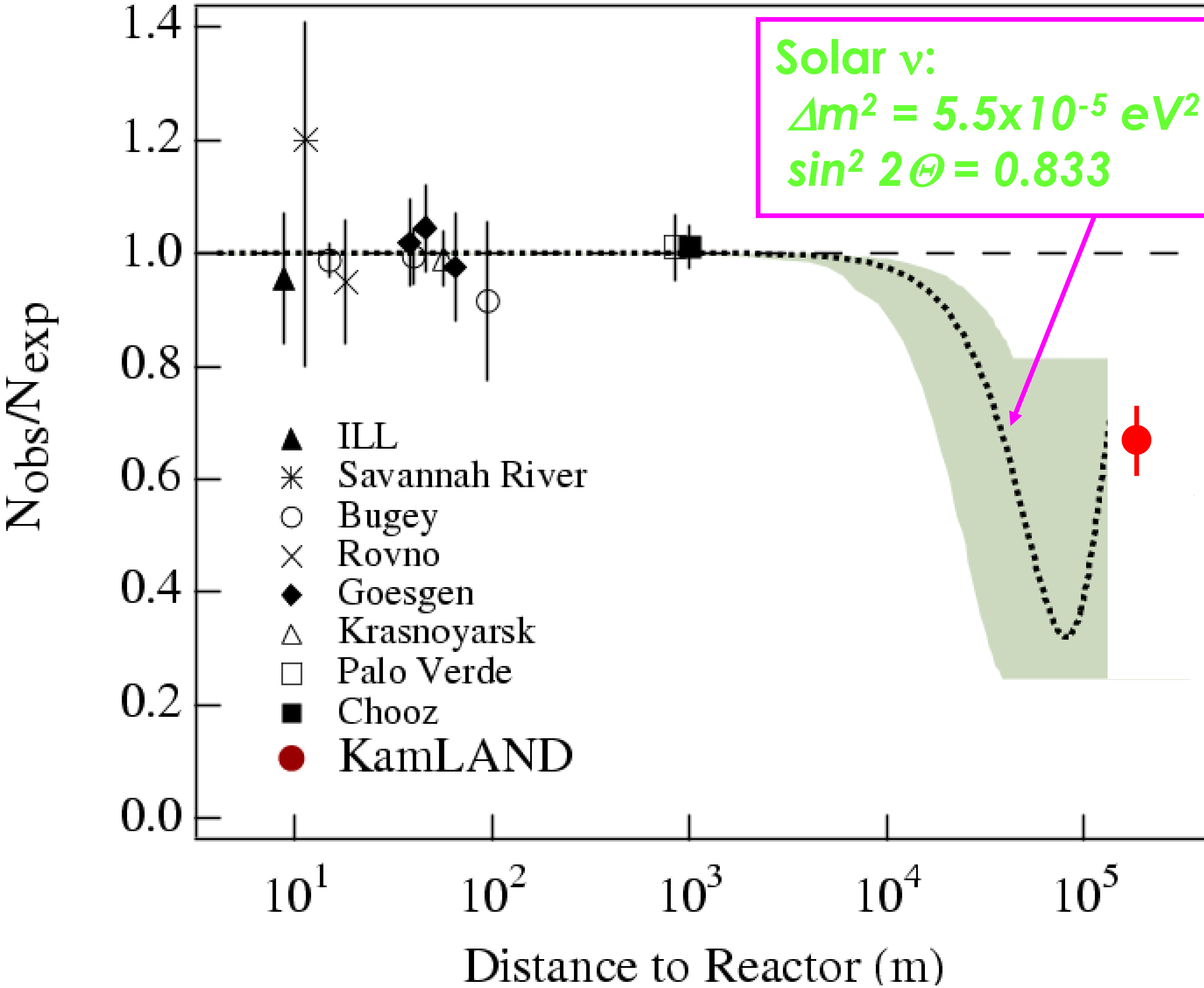
KamLAND uses the entire Japanese nuclear power industry as a longbaseline source

KamLAND

Kamioka Liquid Scintillator Anti-Neutrino Detector

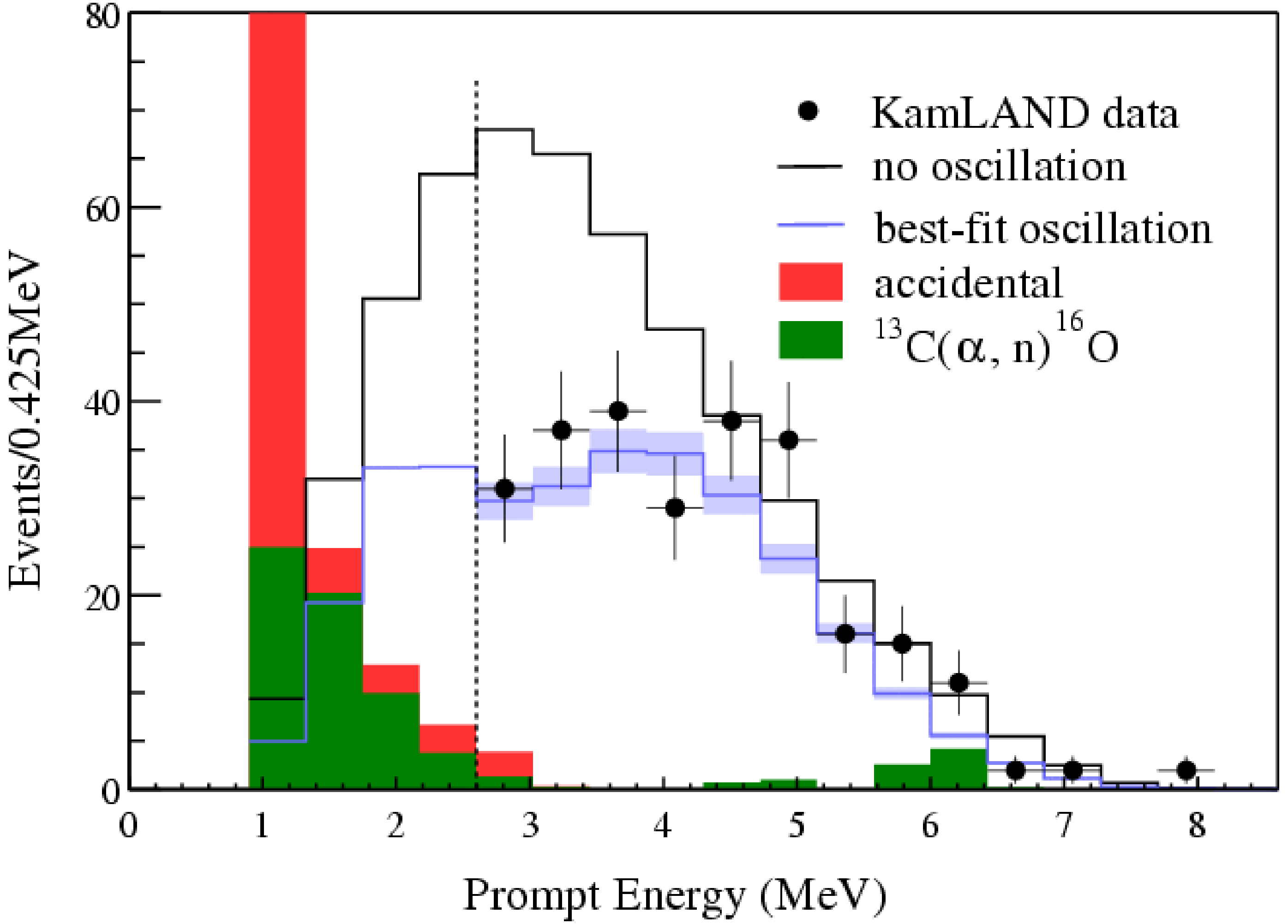

KamLAND Underground Facility
1 km
data-taking electronics
on-line computers
N_2 & fresh air generators
water purification
1000 ton liquid scintillator detector
liquid scintillator purification
Kam LAND
Kamioka Liquid scintillator Anti-Neutrino Detector

Ratio of Measured and Expected $\overline{\nu}_e$ Flux from Reactor Neutrino Experiments



G.Fogli et al., PR D66, 010001-406, (2002)

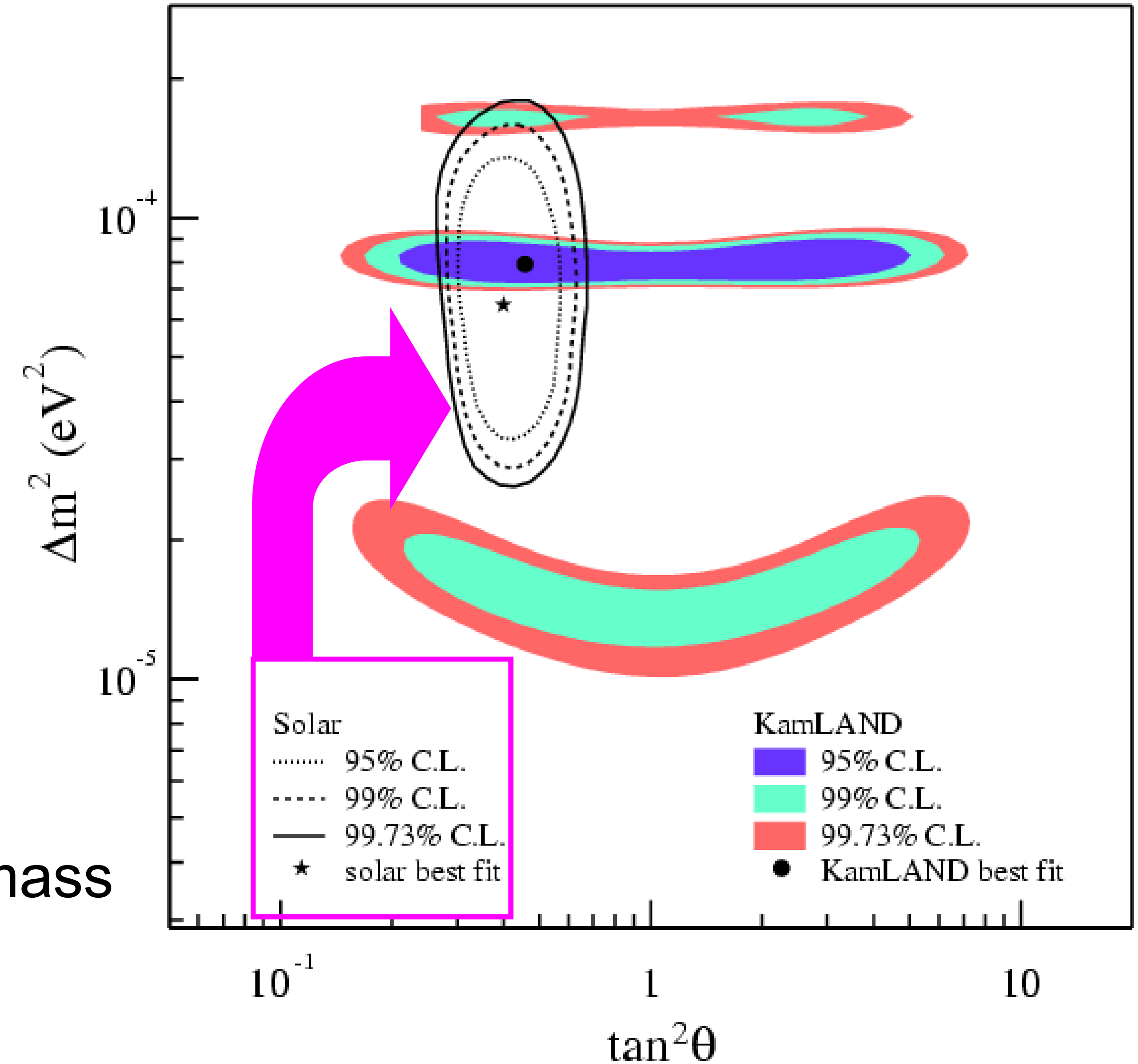
Measurement of Energy Spectrum



KamLAND best fit :

$\Delta m^2 = 7.9 \times 10^{-5}\ eV^2$

$\tan^2\theta = 0.45$

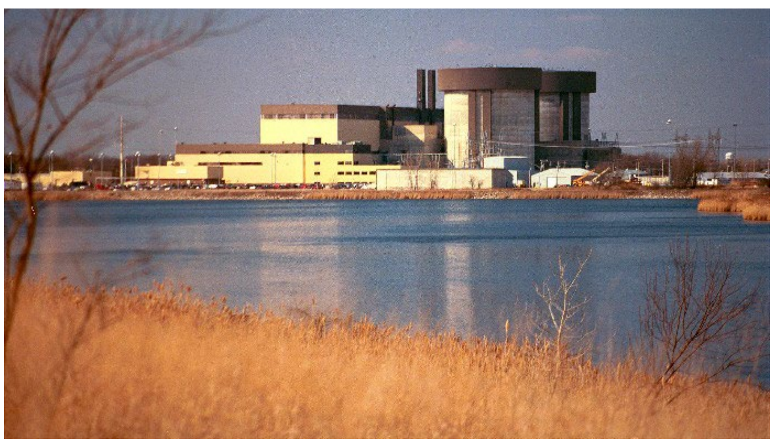


KamLAND fixes mass

Solar fixes angle

New Reactor Proposals

Daya Bay, China



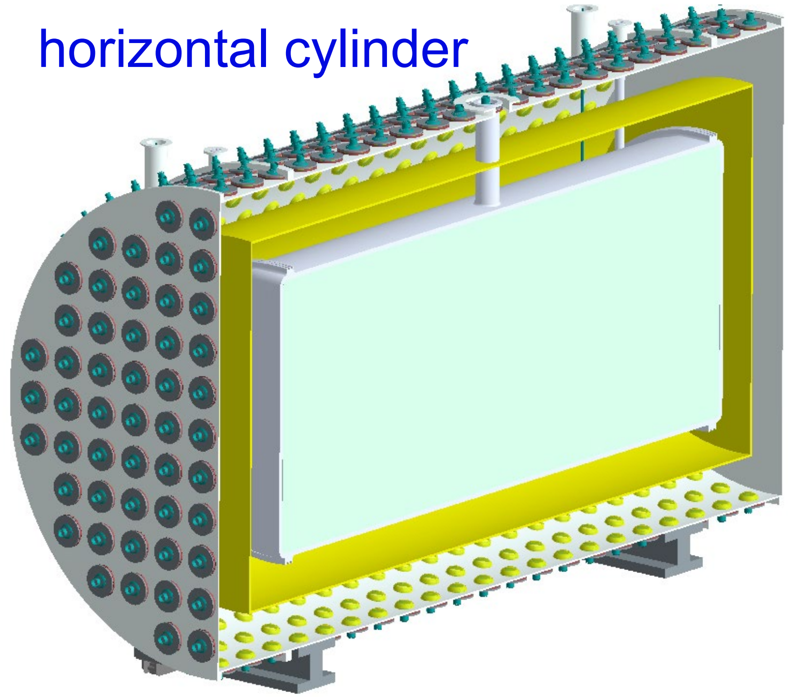
Braidwood, Il

Chooz, France

- ~1.5 km baseline
- Deeper/bigger
- Near/Far

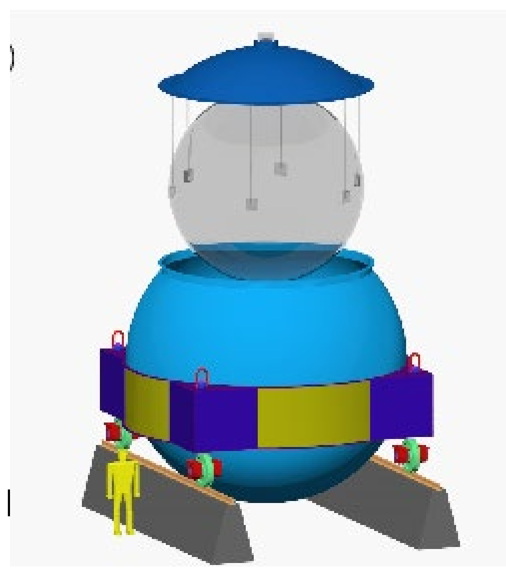
Detector Design Studies

horizontal cylinder



horizontal cylinder

spherical



Oscillation Formulae for Long-Baseline Neutrinos

$$
\begin{aligned}
P(\nu_\mu \to \nu_e) \;=\;& 4(s_{23}^2 s_{13}^2 c_{13}^2 + J_{CP}\sin\Delta_{21})\sin^2\frac{\Delta_{31}}{2} \\
&+2(s_{12}s_{23}s_{13}c_{12}c_{23}c_{13}^2\cos\delta - s_{12}^2 s_{23}^2 s_{13}^2 c_{13}^2)\sin\Delta_{31}\sin\Delta_{21} \qquad (1)\\
&+4(s_{12}^2 c_{12}^2 c_{23}^2 c_{13}^2 + s_{12}^4 s_{23}^2 s_{13}^2 c_{13}^2 - 2s_{12}^3 s_{23}s_{13}c_{12}c_{23}c_{13}^2\cos\delta - J_{CP}\sin\Delta_{31})\sin^2\frac{\Delta_{21}}{2} \\
&+8(s_{12}s_{23}s_{13}c_{12}c_{23}c_{13}^2\cos\delta - s_{12}^2 s_{23}^2 s_{13}^2 c_{13}^2)\sin^2\frac{\Delta_{31}}{2}\sin^2\frac{\Delta_{21}}{2}
\end{aligned}
$$

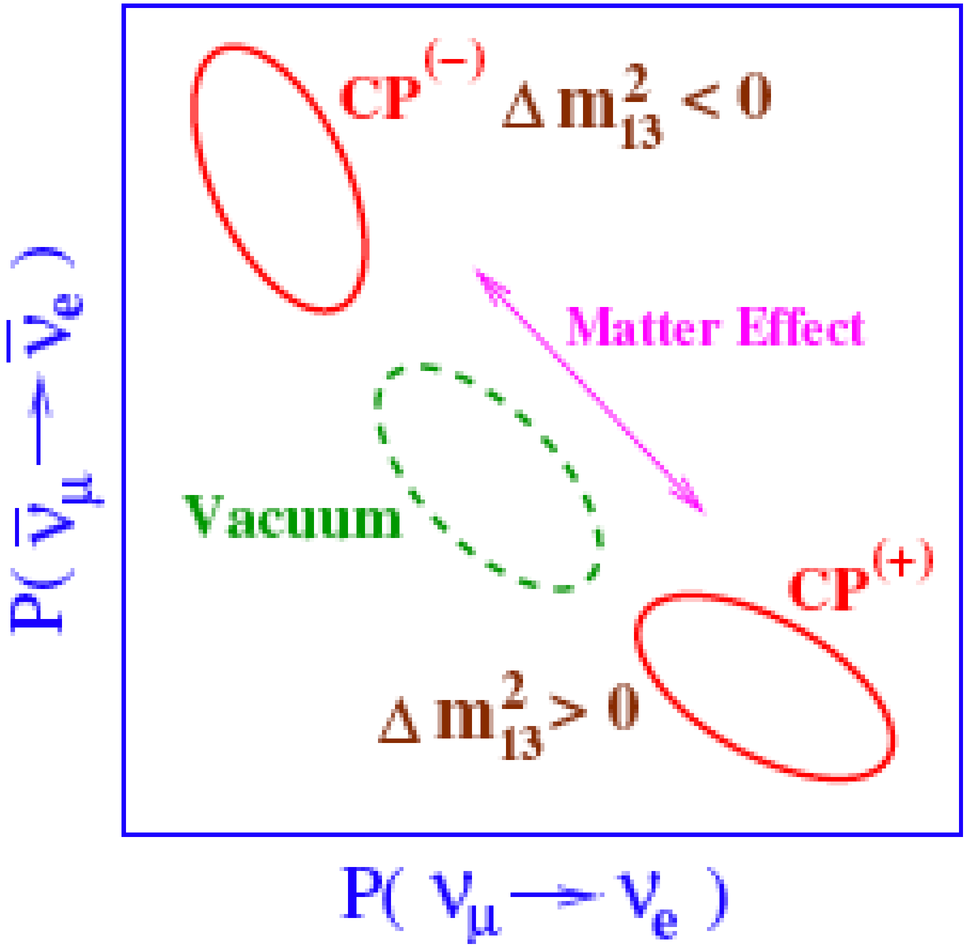
$$\Delta_{ij} \equiv \Delta m_{ij}^2 L/2E_\nu$$

For anti-neutrinos, the J_{cp} terms change sign.

Long Baseline Physics Goals

- **Definitive observation of oscillatory behavior in ν_μ disappearance mode and precise determination of δm^2_{23} and θ_{23}.**
- **Detection of oscillation $\nu_\mu - \nu_e$ in appearance mode and measurement of θ_{13}.**
- **Observe matter effects, hence sign of δm^2_{23}.**
- **Measure δ_{cp}**

CP violation and matter effects



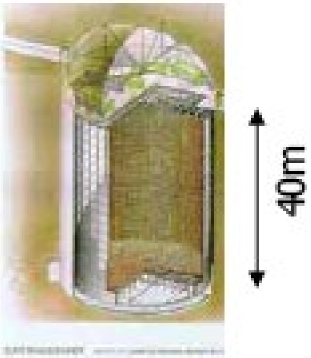
hep-ph/0306221

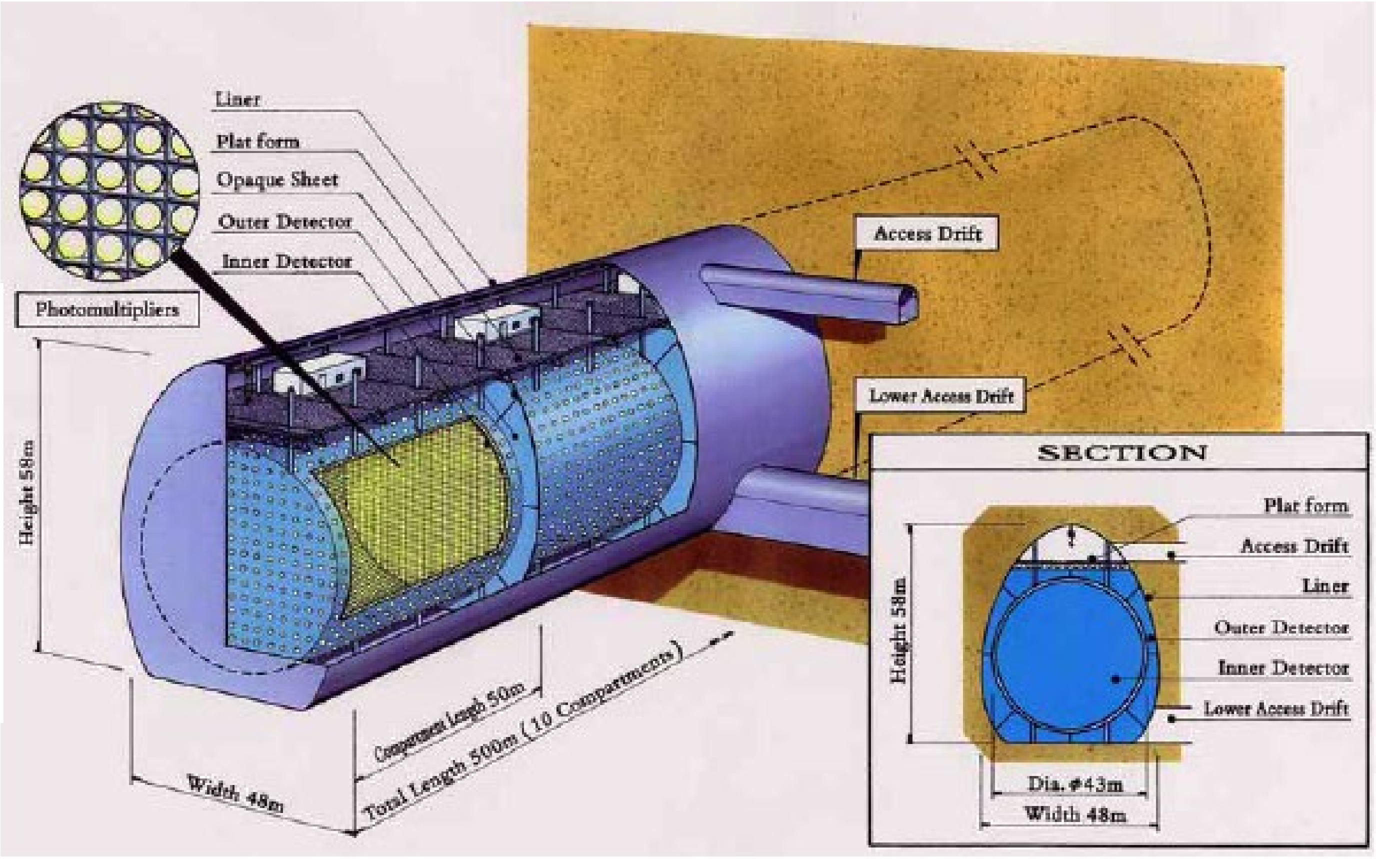
T2K

Phase I
0.75 MW +SK
Phase II
4 MW + HyperK

HyperK

Super-K





1 Mton (fiducial) volume: Total Length 400m (8 Compartments)

NOνA

Use the NUMI beam line from FermiLab.
Far detector uses alternate vertical planes of active scintillator with passive wood absorber.

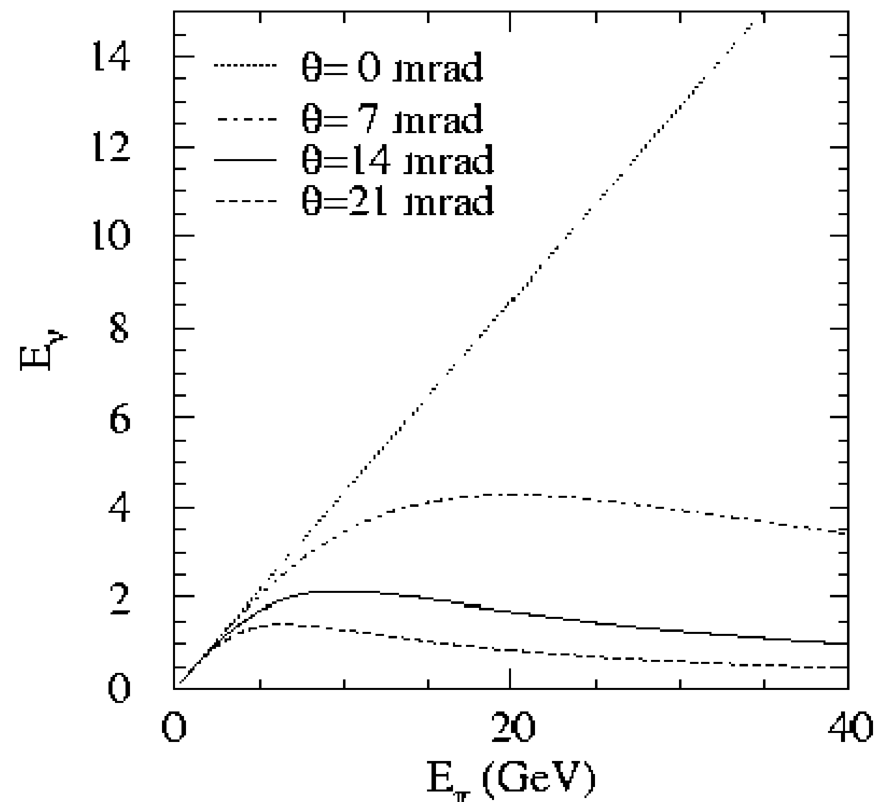
Mass (Nominal)	50,000 metric tons
Width	96 feet
Height	48 feet
Length (nominal)	562.5 feet
Number of Layers	750
Mass of Wood Particleboard (Nominal)	42,000 metric tons
Mass of Scintillator Extrusions	1,800 metric tons
Mass of Liquid Scintillator	6,900 metric tons

Table 7.1: Far Detector Parameters.

Off-Axis Beam

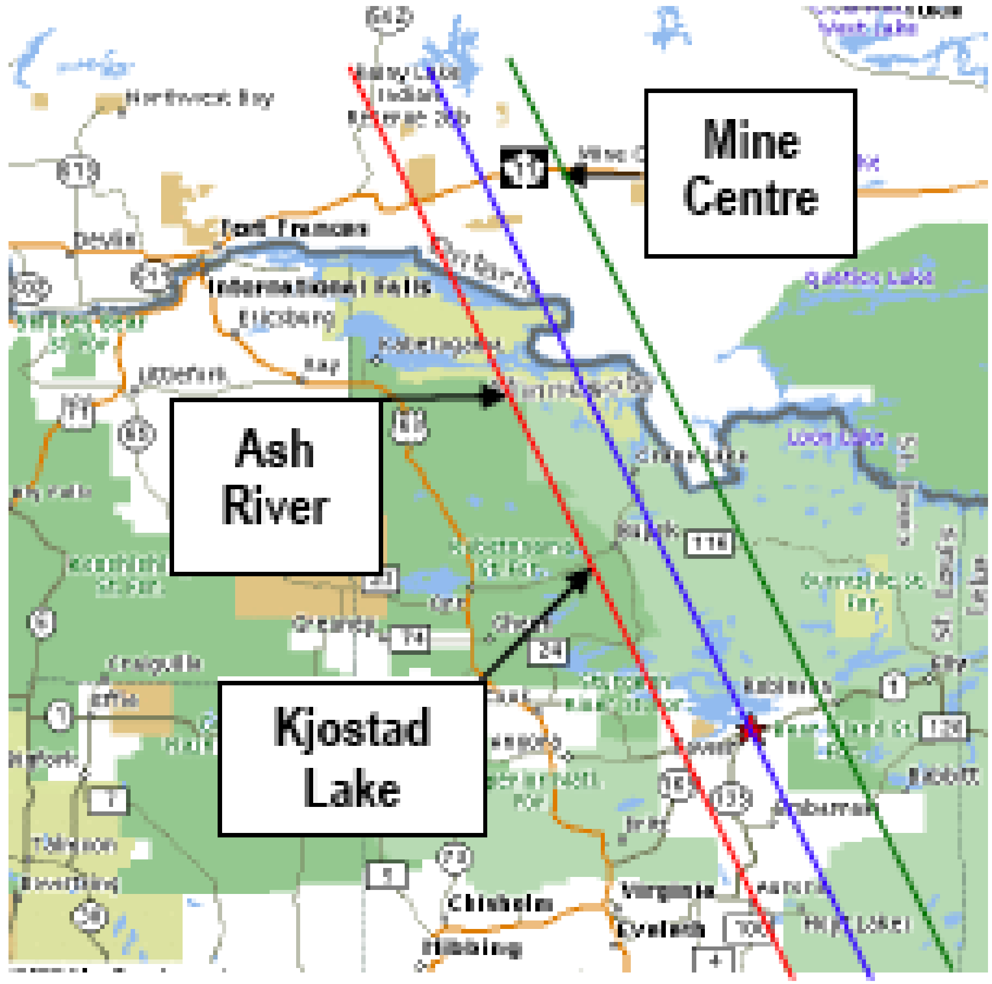
$$E_\nu = \frac{0.43 E_\pi}{1+\gamma^2\theta^2}$$

- **For pions decaying in flight, most neutrinos are forward directed**
- **Neutrino energy is proportional to E_π**
- **Neutrino energy flattens with angle, however. Allowing one to “choose” an energy by choosing the angle.**

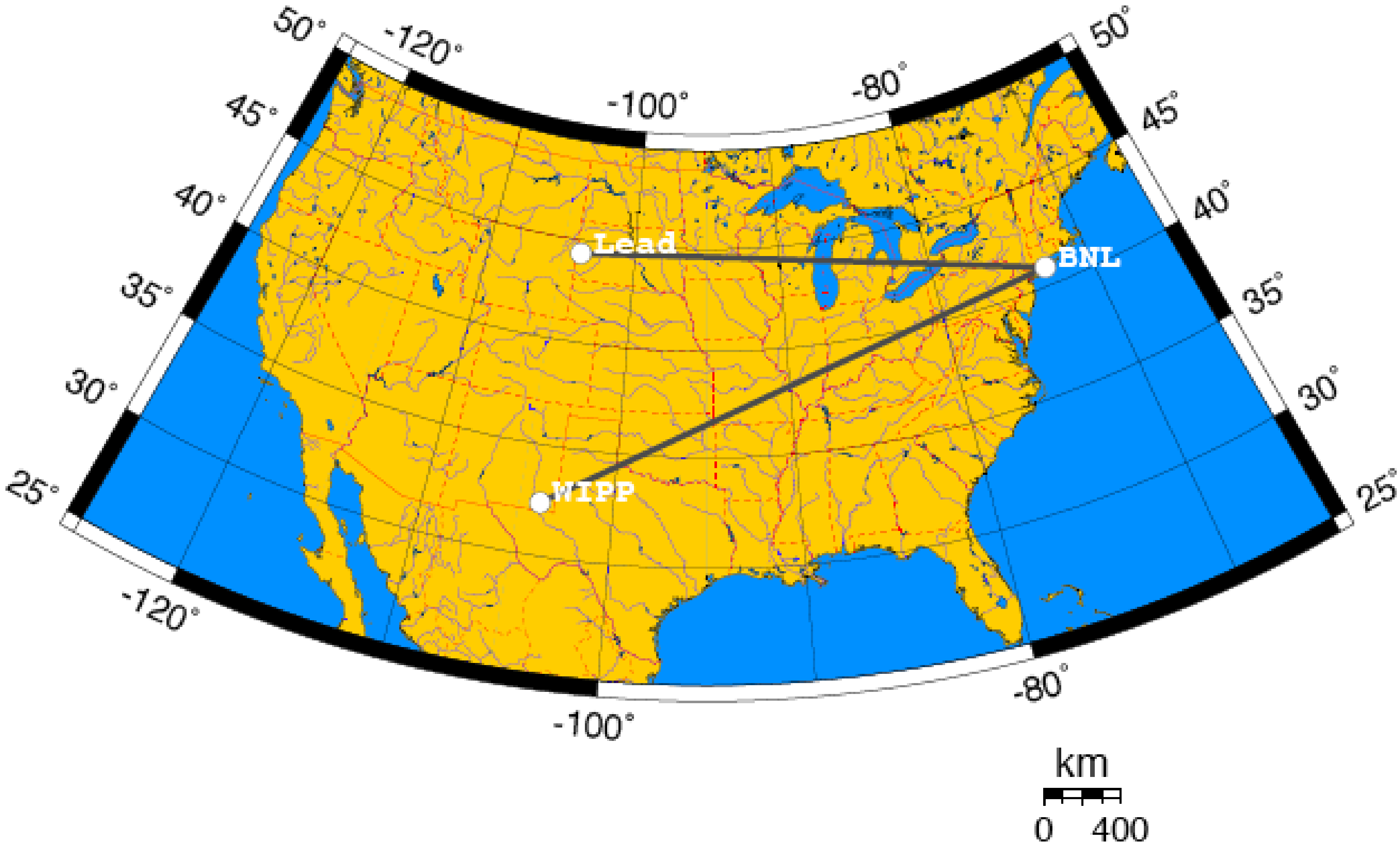


Far Detector

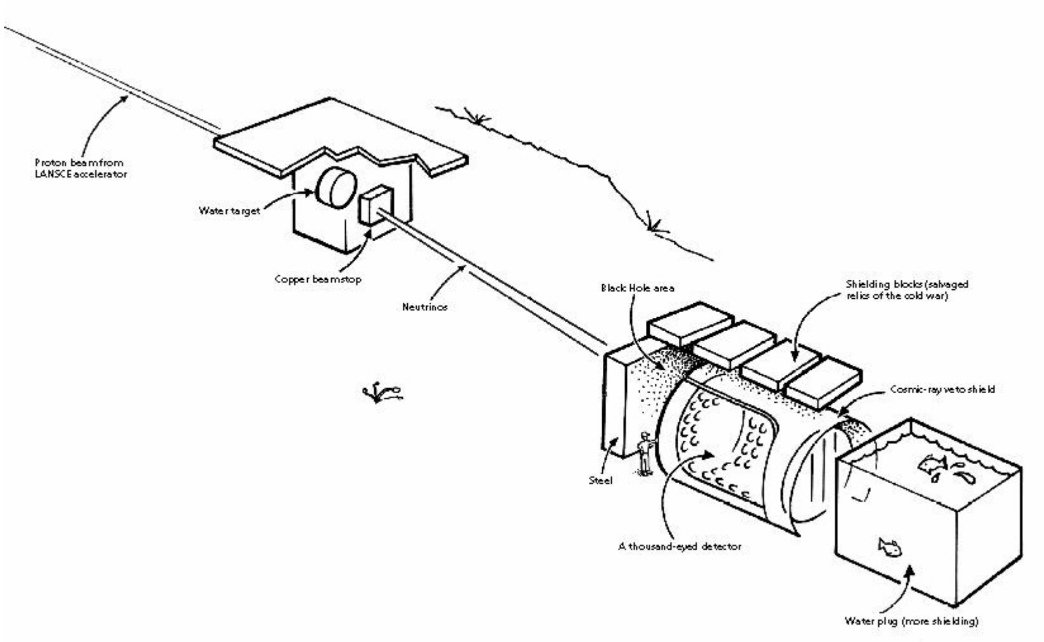
810 km from target
10-14 km off axis



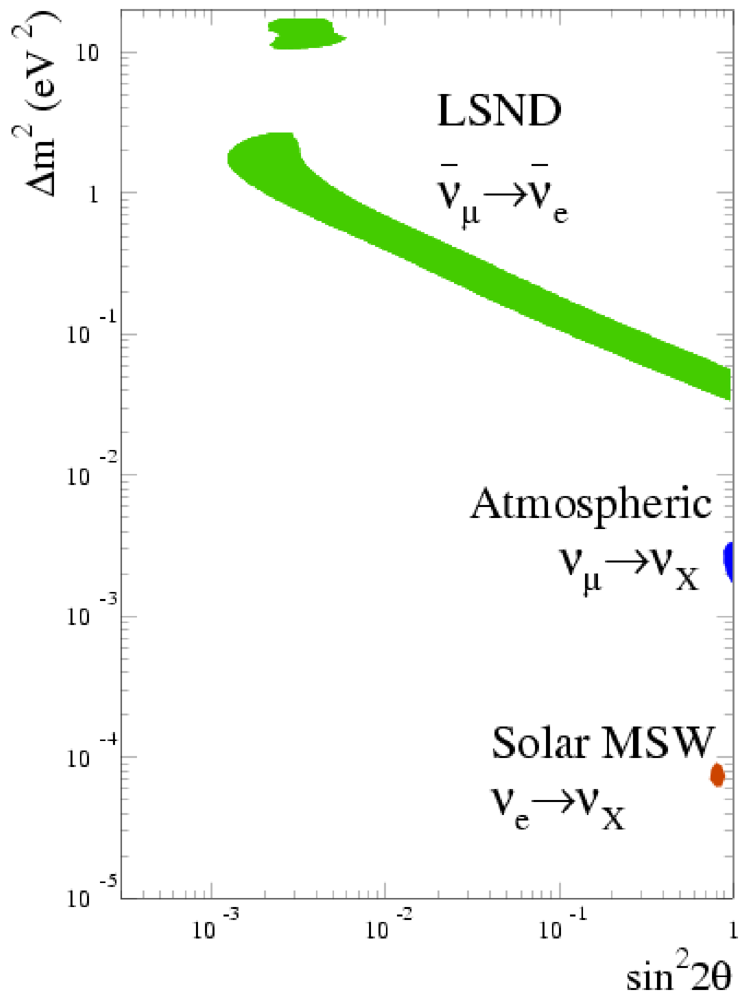
LONG baseline 2500-3000 km

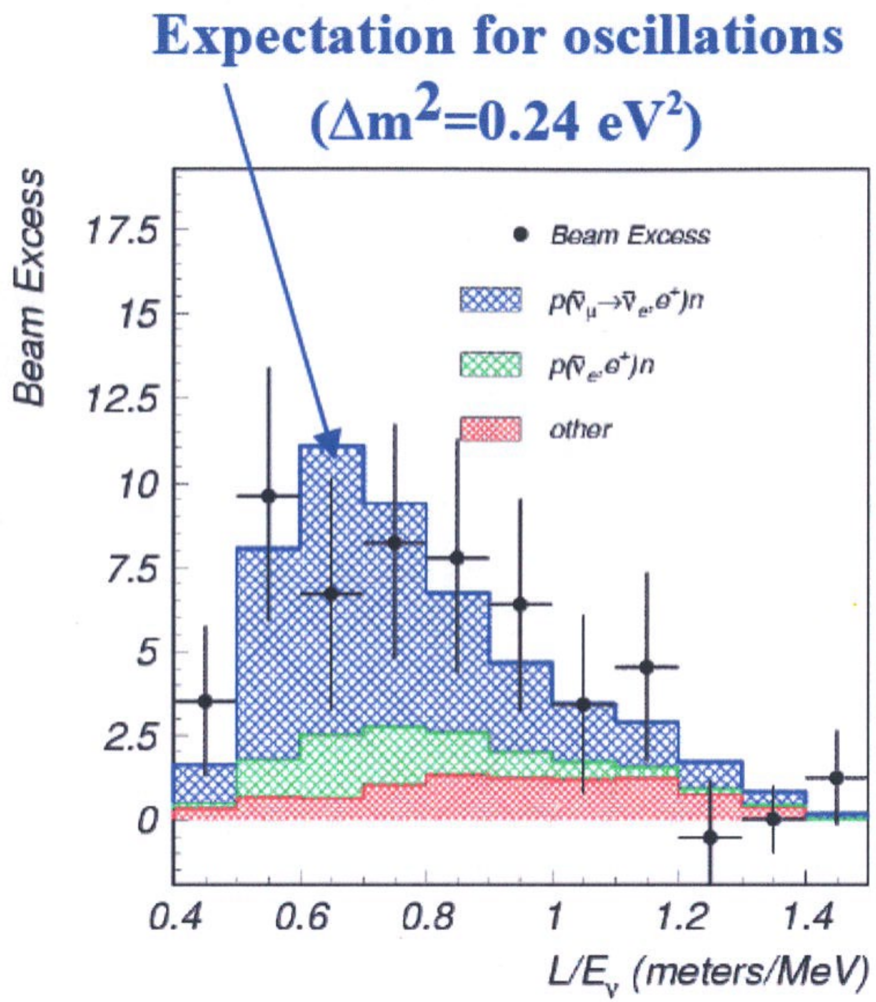


The LSND Puzzle and MiniBOONE

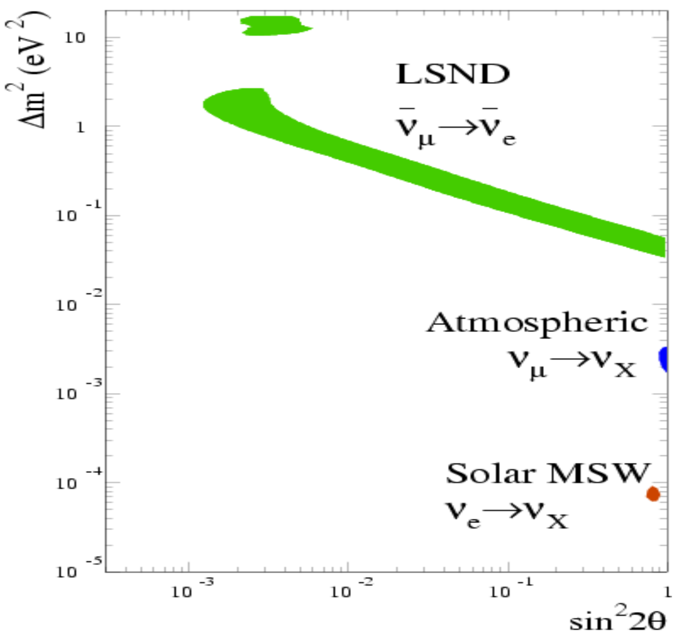


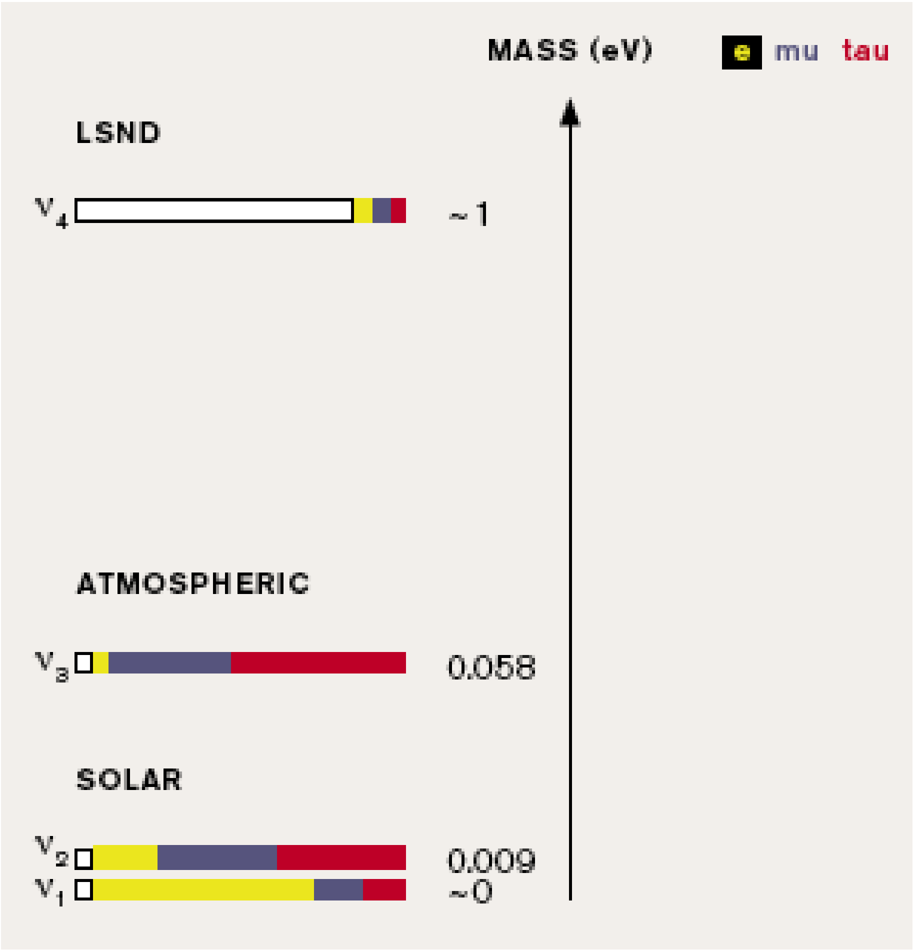
The Evidence for Neutrino Oscillations



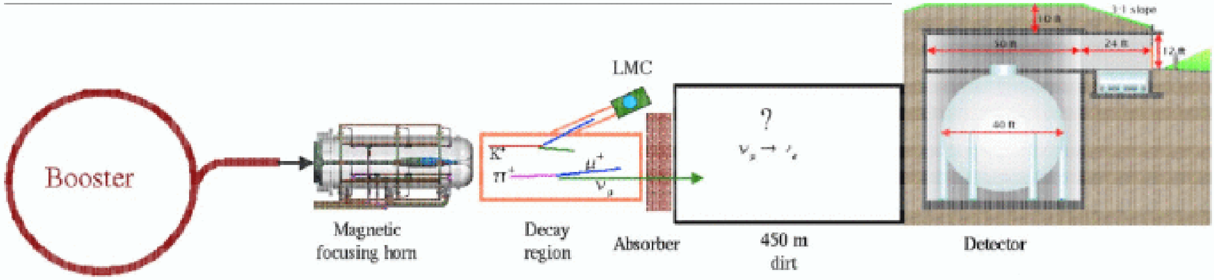


Requires a 3rd δm^2



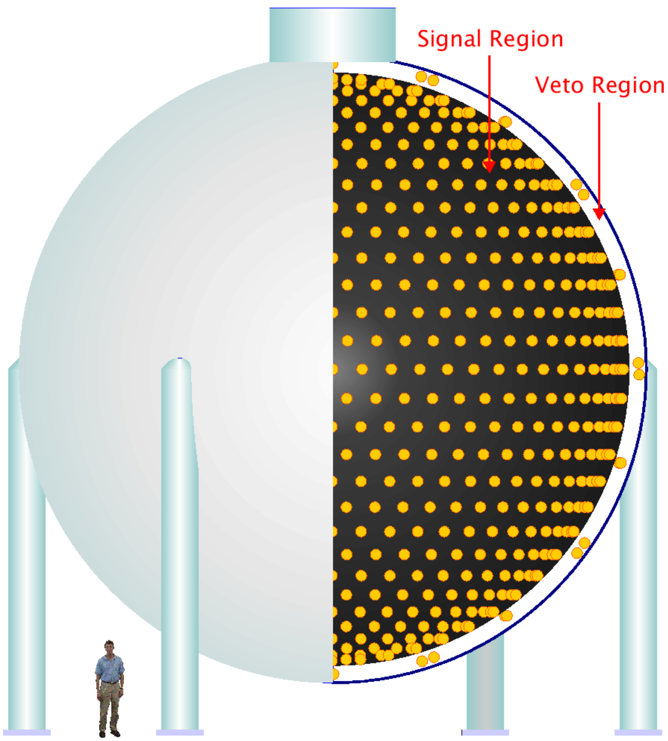


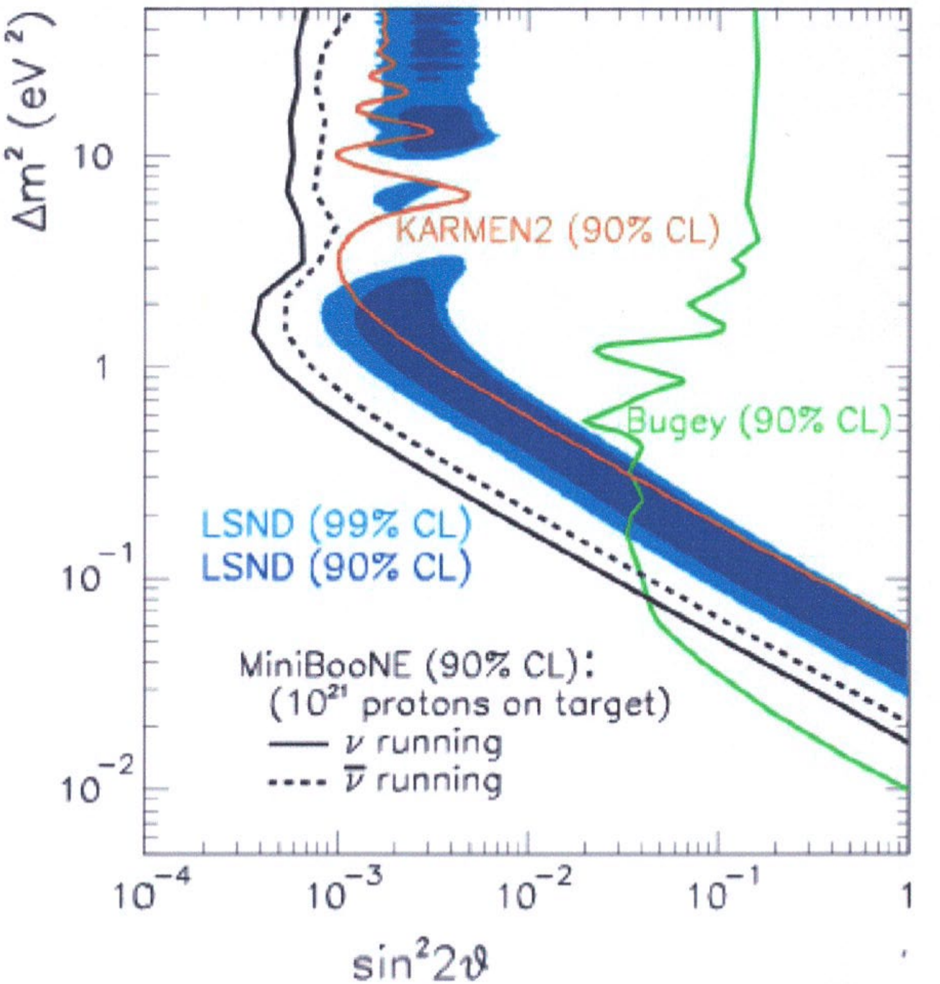
MiniBooNE - A Definitive Test of the LSND Evidence for ν Oscillations



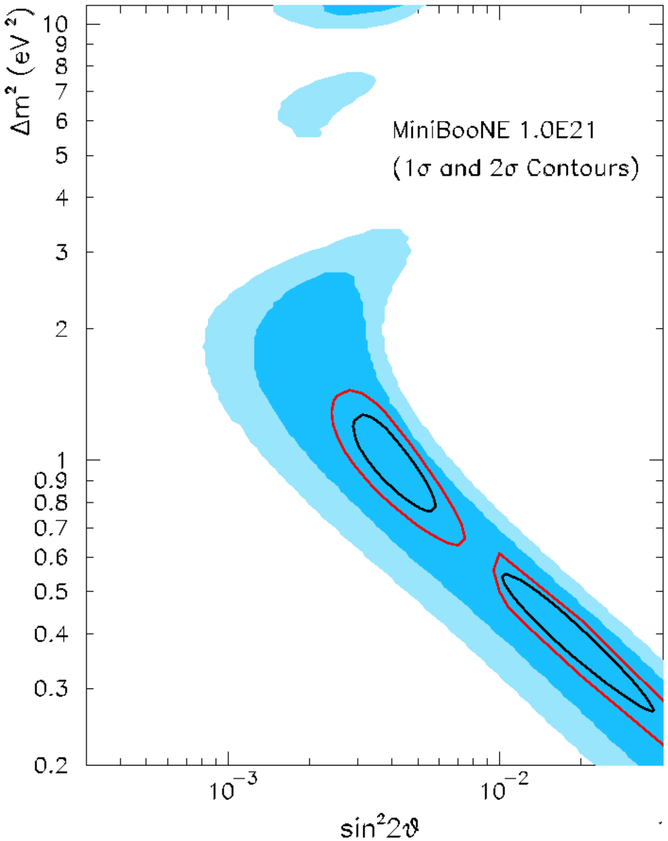
- Booster - 8 GeV proton beam (5 x 10^{20} POT/y)
- Target - 71 cm Be
- Horn - 5 Hz, 170 kA, 143 μs, 2.5 kV, 10^8 pulses/y
- Decay Pipe - 50 m (adjustable to 25 m)
- Neutrino Distance - ~ 0.5 km
- $<E_\nu>$ ~ 1 GeV
- $(\nu_e / \nu_\mu) \sim 3\text{x}10^{-3}$
- Detector - 40' diameter spherical tank
- Mass - 800 (450) tons of mineral oil
- PMTs - 1280 detector + 240 veto, 8" diameter

MiniBooNE Detector

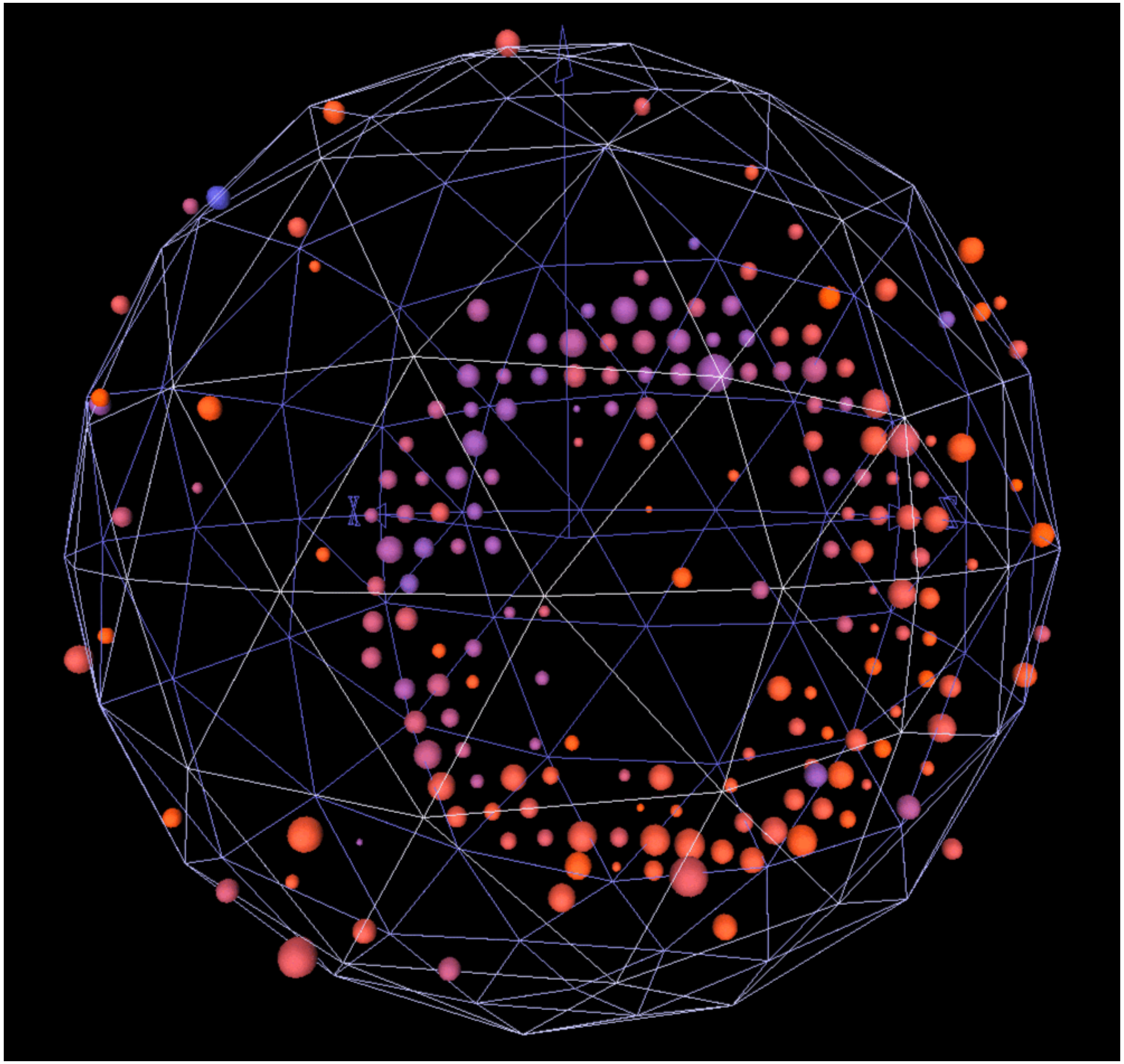




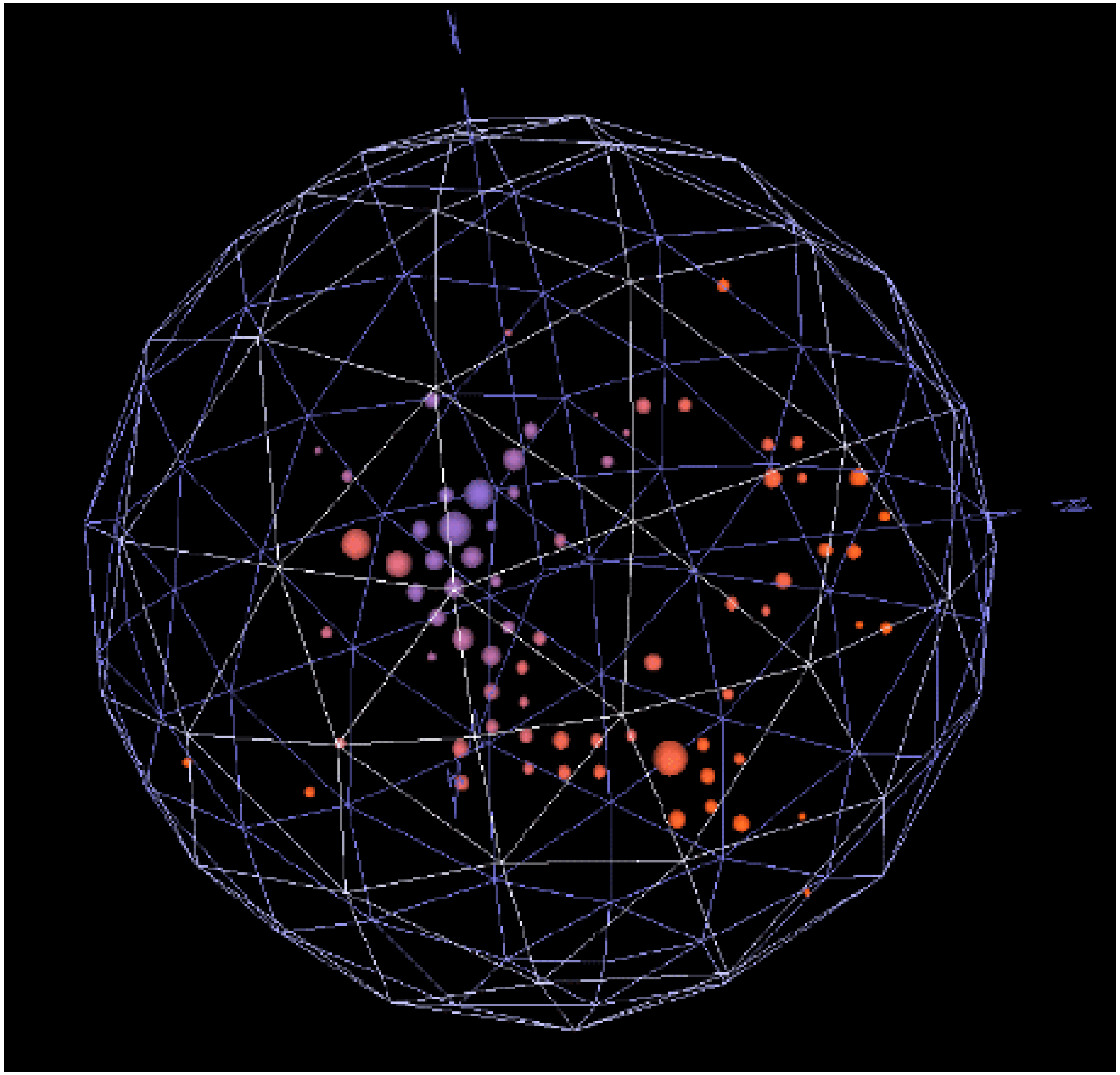
Measurement of Oscillation Parameters



Typical Muon-Neutrino Event



Typical Michel Electron Event



Resources

- Bob Mckeown APS April 2005 (Tampa)
- APS neutrino study on reactors and long baseline experiments.
- BNL, T2K and NOνA Letters of Intent
- Bill Louis Talks