Very Long Baseline Neutrino Project

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Introduction: The Current Neutrino Picture

Apparently 3 neutrinos (possibly also sterile neutrinos)

Mixing depends on three angles:

$\sin^2(2\theta_{12})$	0.86±0.04
$\sin^2(2\theta_{23})$	1.02±0.04
$\sin^2(2\theta_{13})$	?? (<0.12)

As neutrinos travel, they oscillate. The oscillation probability depends on the masses and a CP violation phase

Δm^2_{12}	8.0±0.3e-5 eV^2
$\lvert \Delta m^2_{32} \rvert$	2.5±0.3e-3 eV^2
δ_{cp}	??

Charge/Parity invariance would suggest that neutrinos and anti-neutrinos behave the same way... but (like quarks) they might not

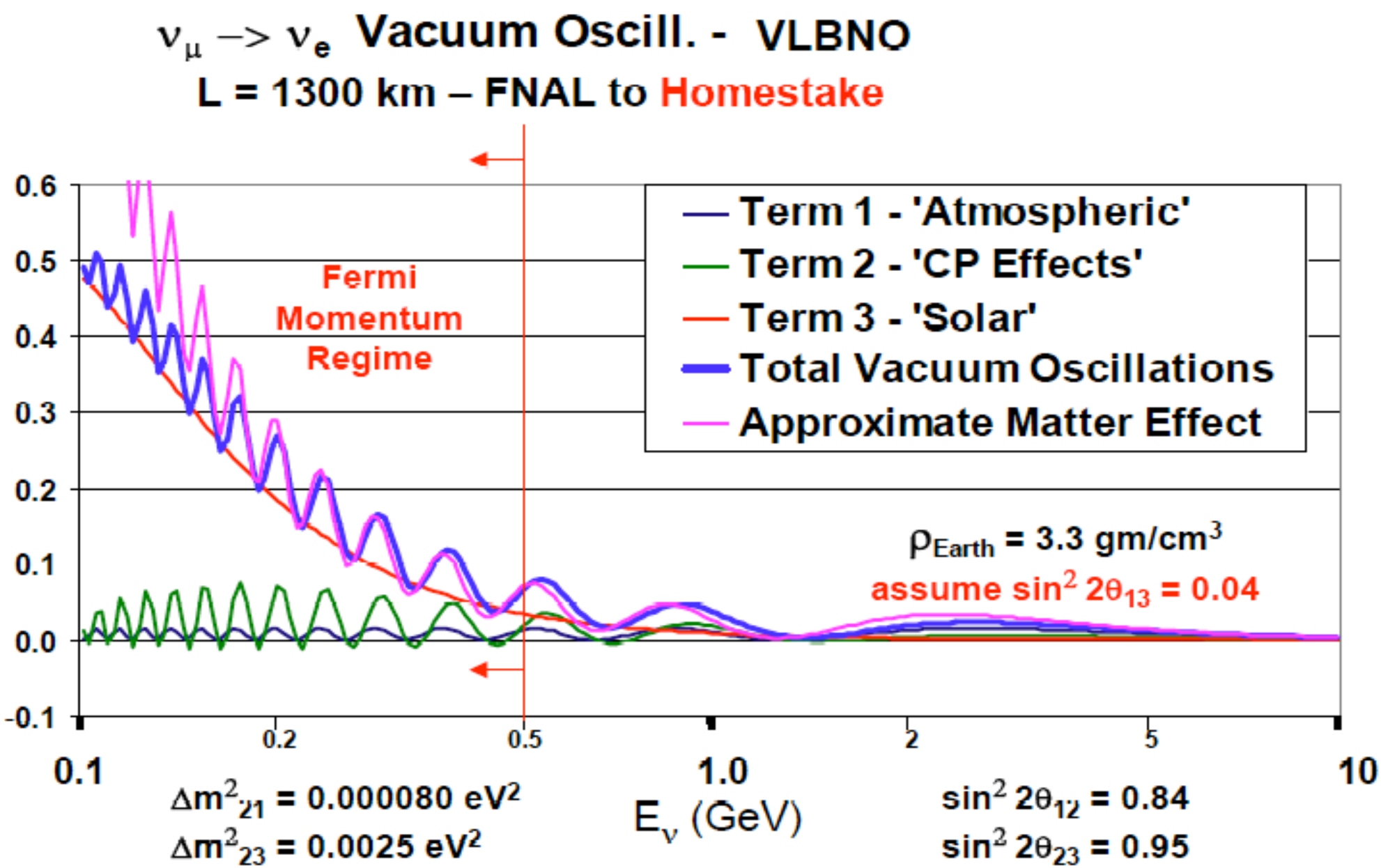
Very Long Baseline Neutrino Oscillations

- Very long baseline – i.e. >1000km
  - Examples: BNL - HS 2540km or **FNAL - HS 1300km**
- Matter effects more significant than with shorter baselines
  - ν_e has CC interaction with e^-
  - Effect on ν_e appearance rate is dependent on the mass hierarchy
- Wide band beam – neutrino energies 0 - 12 GeV
  - Gives many values of L/E, allows resolution of degeneracies

Oscillation Probability (approx.)

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

where: $\alpha = \frac{\Delta m_{21}^2}{\Delta m_{31}^2}, \quad \Delta = \frac{\Delta m_{31}^2 L}{4E}, \quad A = \frac{2\mathrm{VE}}{\Delta m_{31}^2}, \quad V = \sqrt{2}\, G_F n_e$



M. Diwan: http://www.hep.net/nusag_pub/May2006/diwan-nusag-may-20.pdf

VLBNO Goals

Pin down oscillation parameters

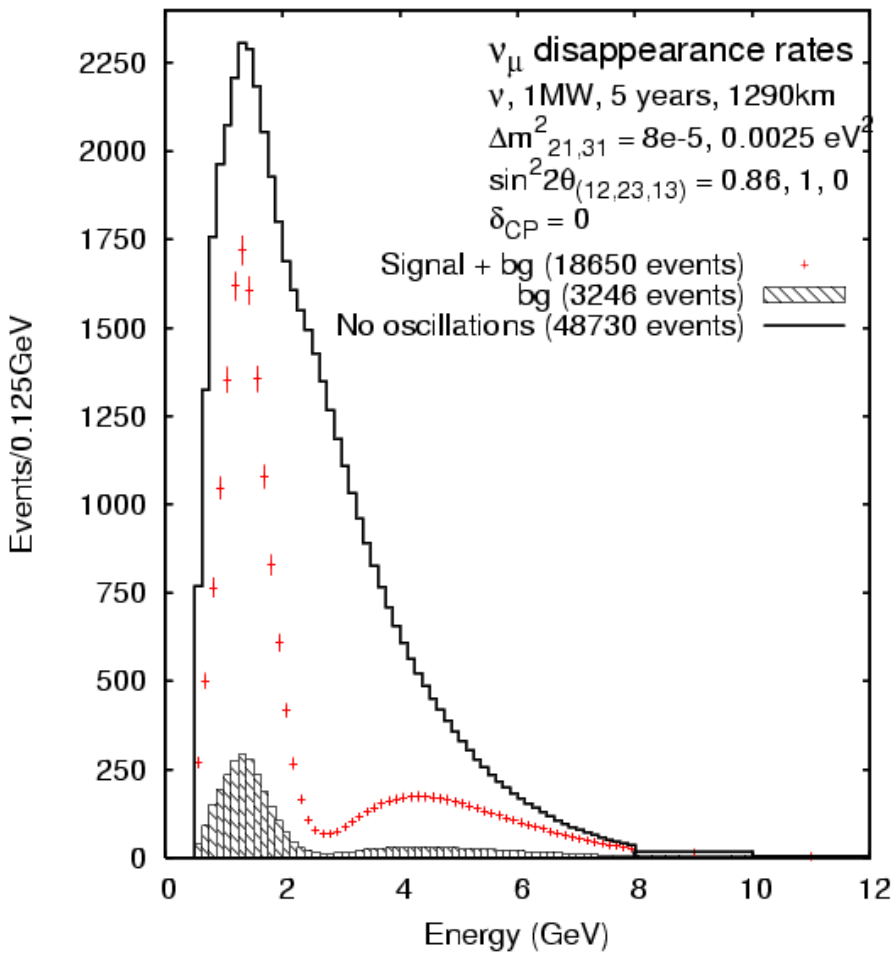
Resolve mass hierarchy

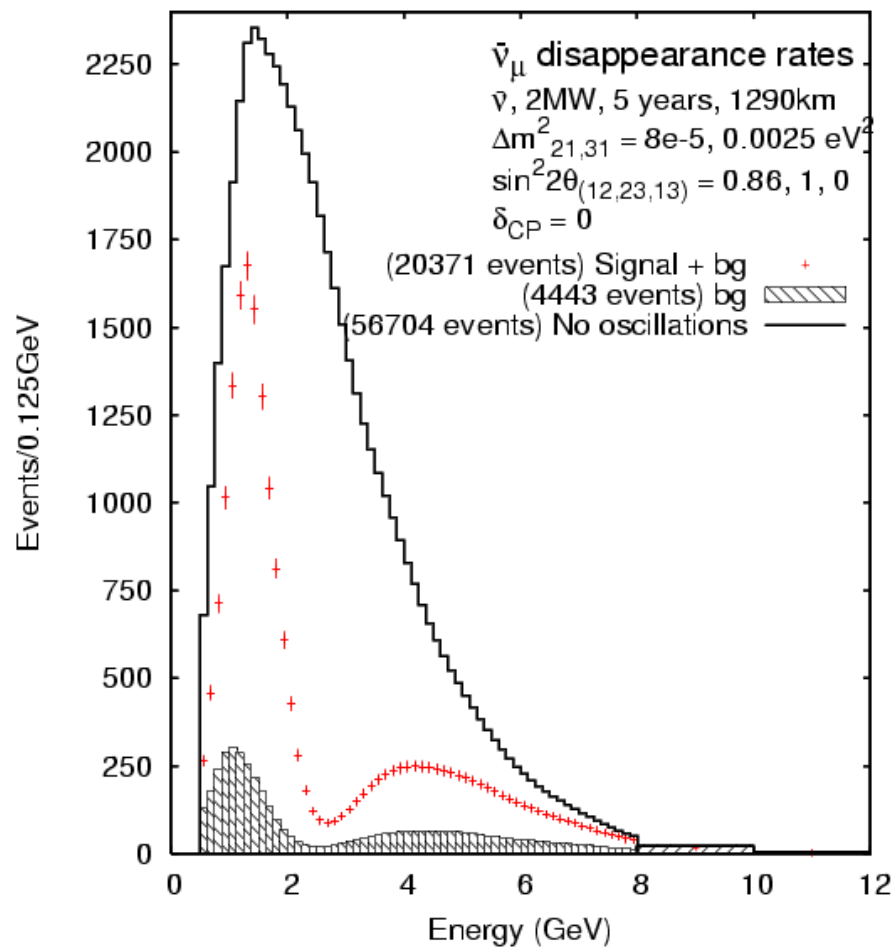
Measure θ_{13}, δ_{CP}

Possible Setup

- Want exposure of 2500 kT*MW*(10^7)s for ν running
  - Would be doubled for anti-ν running
  - This will give 15-20° resolution on δ_{CP}, independent of θ_{13} (as long as it's not too small)
- Example (used in following calculations)
  - 500 kT water Cherenkov detector
  - 1MW proton beam to produce ν_μs
  - ν energies between 0.5 and 12GeV
  - 5 years running FNAL to Homestake

ν_μ disappearance





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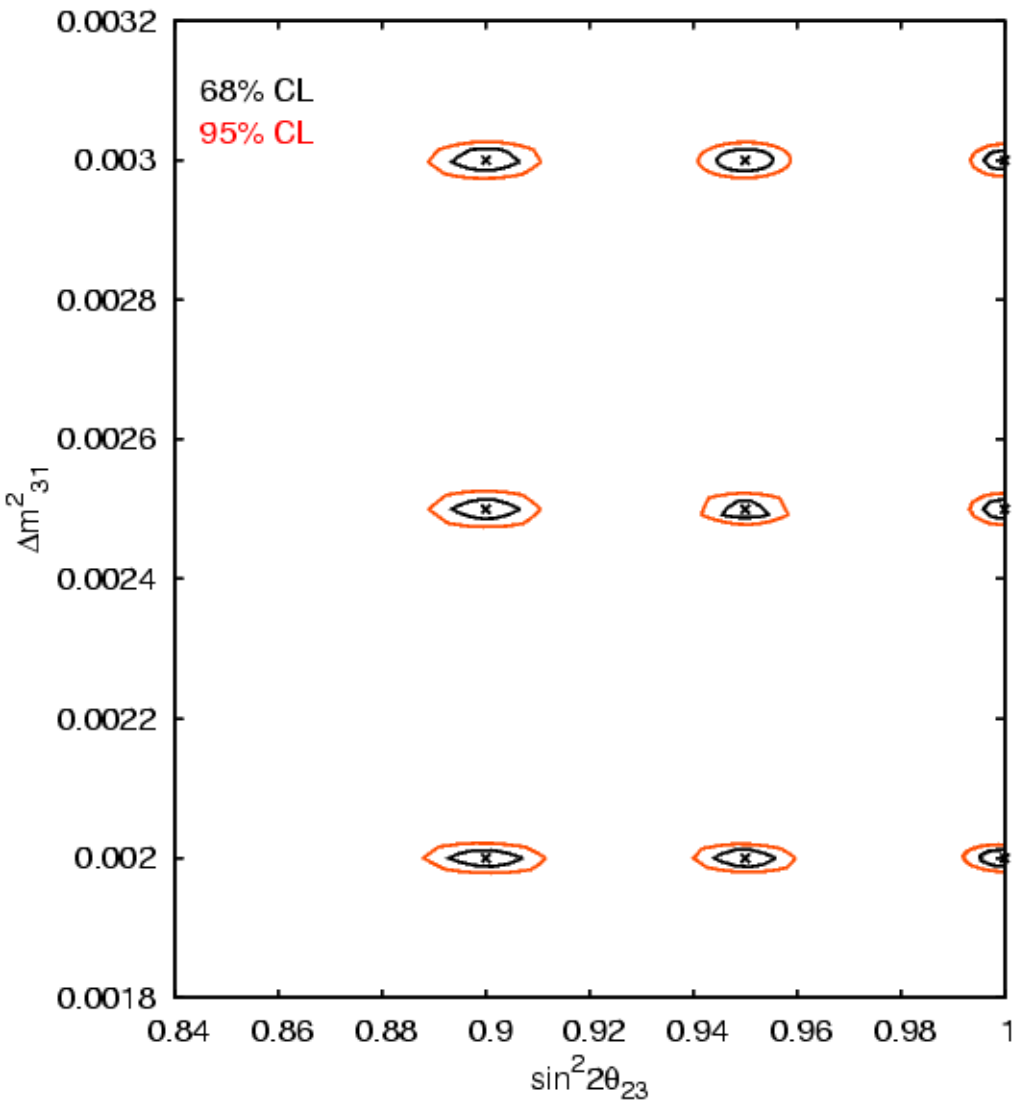
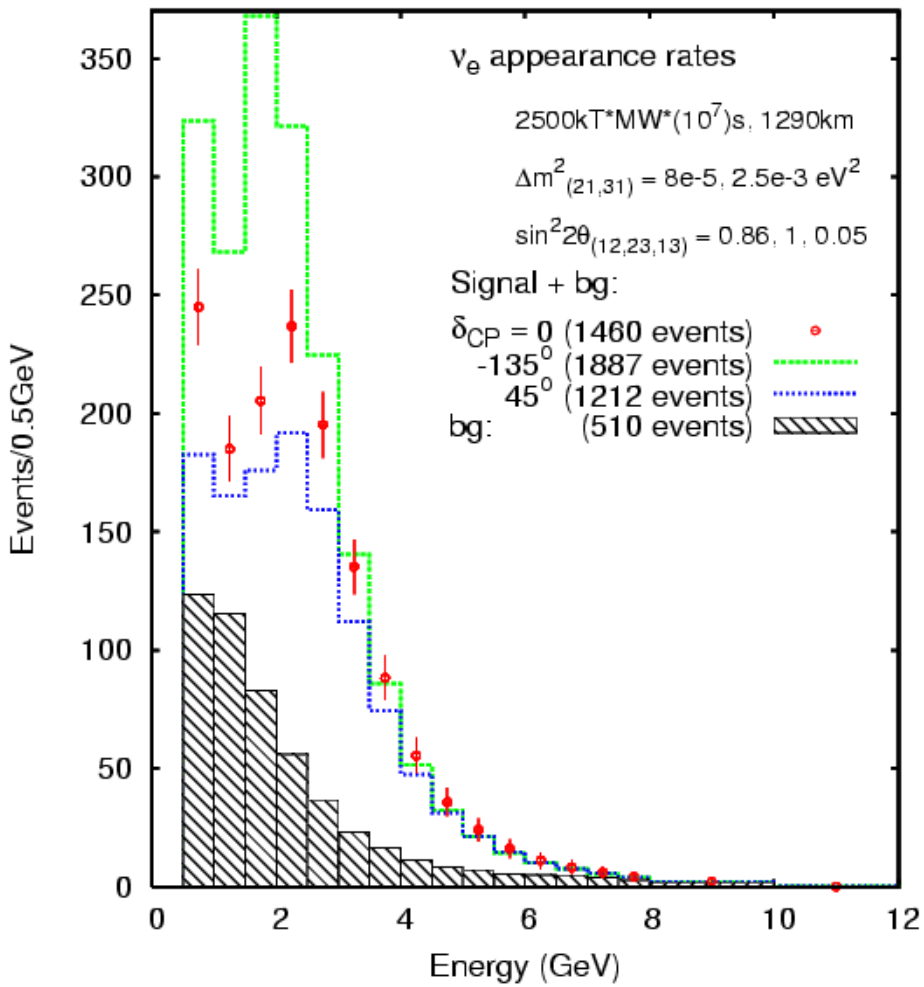
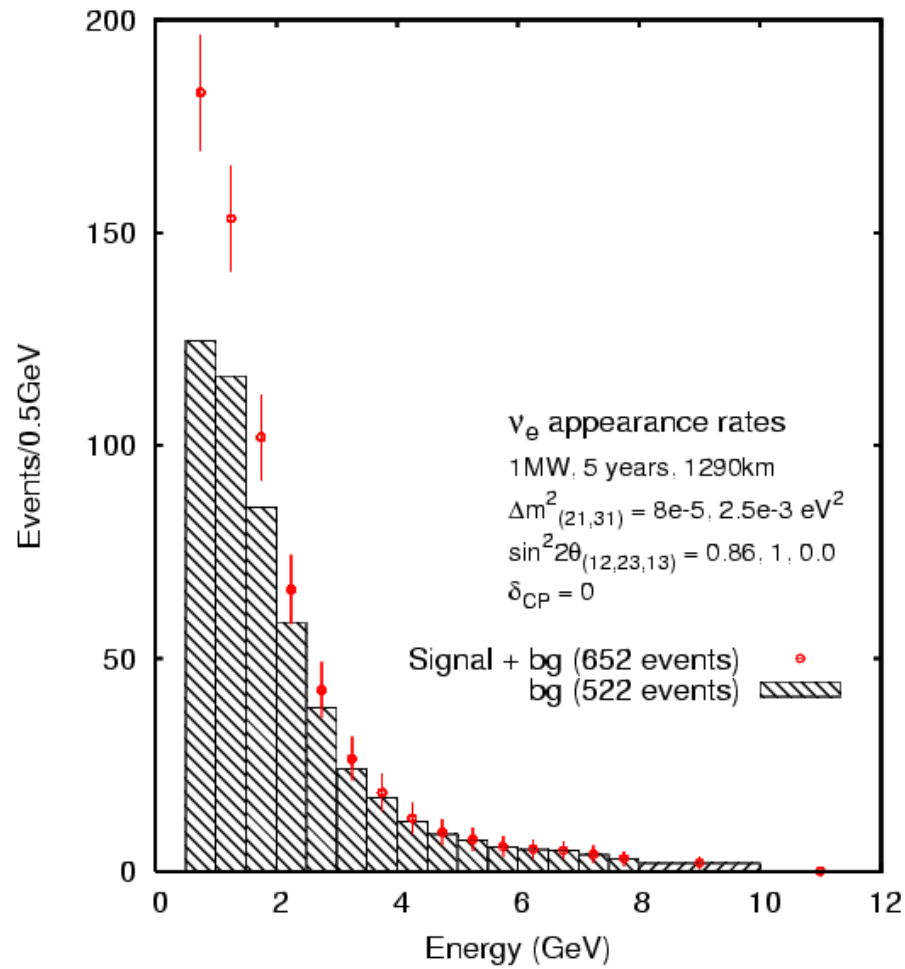
Measurement of Atmospheric Parameters

- Current values:
  - $\sin^2(2\theta_{23})$ 1.02±0.04
  - $|\Delta m^2_{32}| = 2.5\pm0.3e\text{-}3\ eV^2$
- Resolution (1 sigma) after ν running only
  - ~1.6% on $\sin^2 2\theta_{23}$
  - ~0.7% on Δm^2_{32}
- This resolution is improved with additional anti-ν running
- Systematics are limiting, but measurement to ~1% should be possible



ν_e appearance



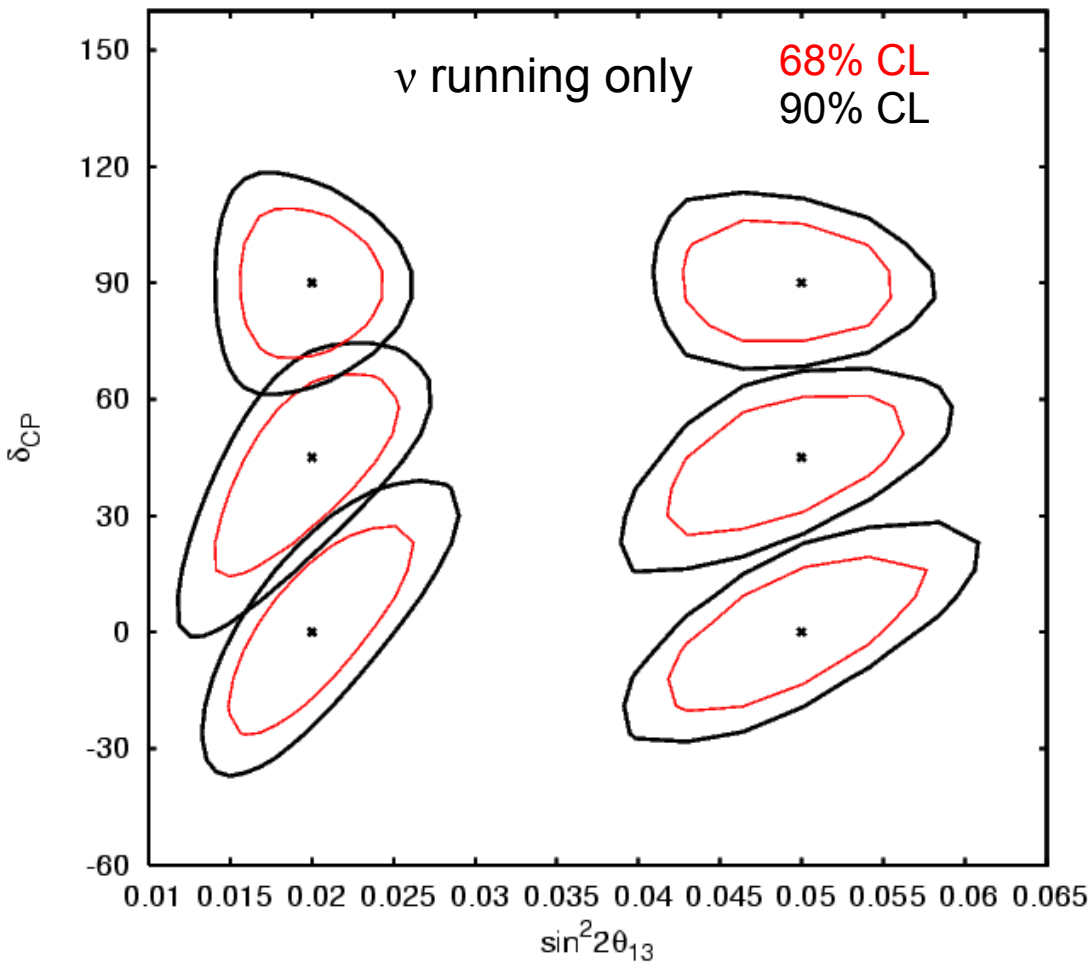


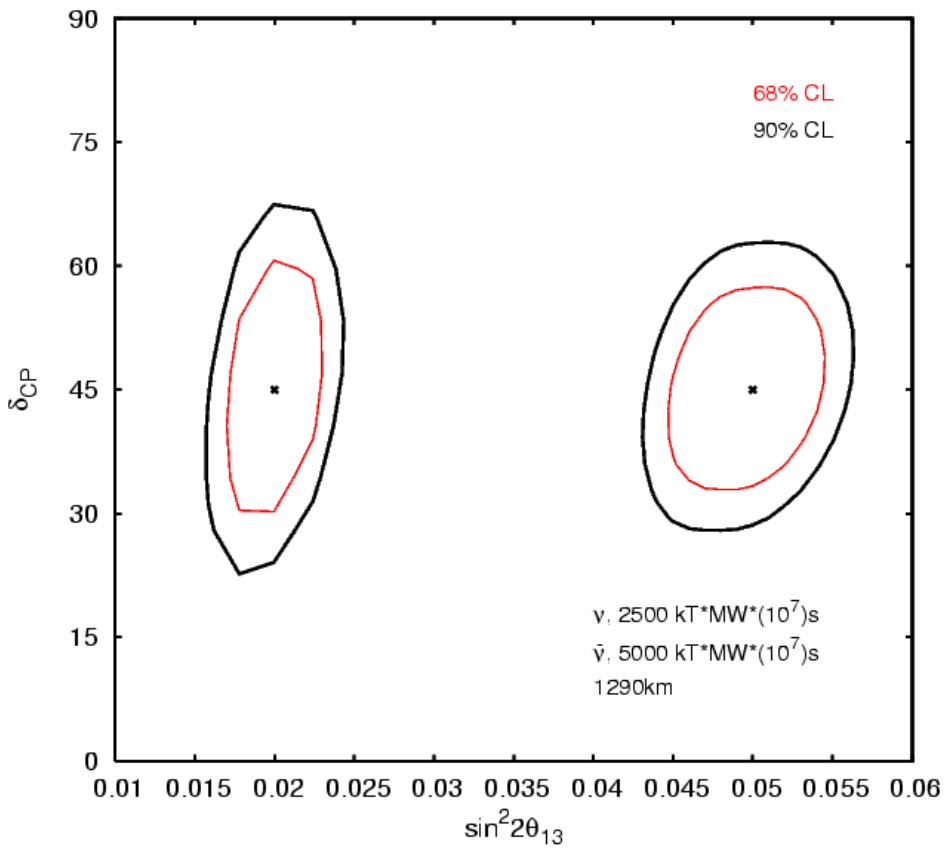
Signal is dependent on δ_{cp} and θ_{13}

As θ_{13} gets smaller, rates become indistinguishable for different values of δ_{cp}

θ_{13} and δ_{cp}

- $\sin^2 2\theta_{13}$ is currently known to be less than 0.12 (CHOOZ)
- δ_{cp} unknown





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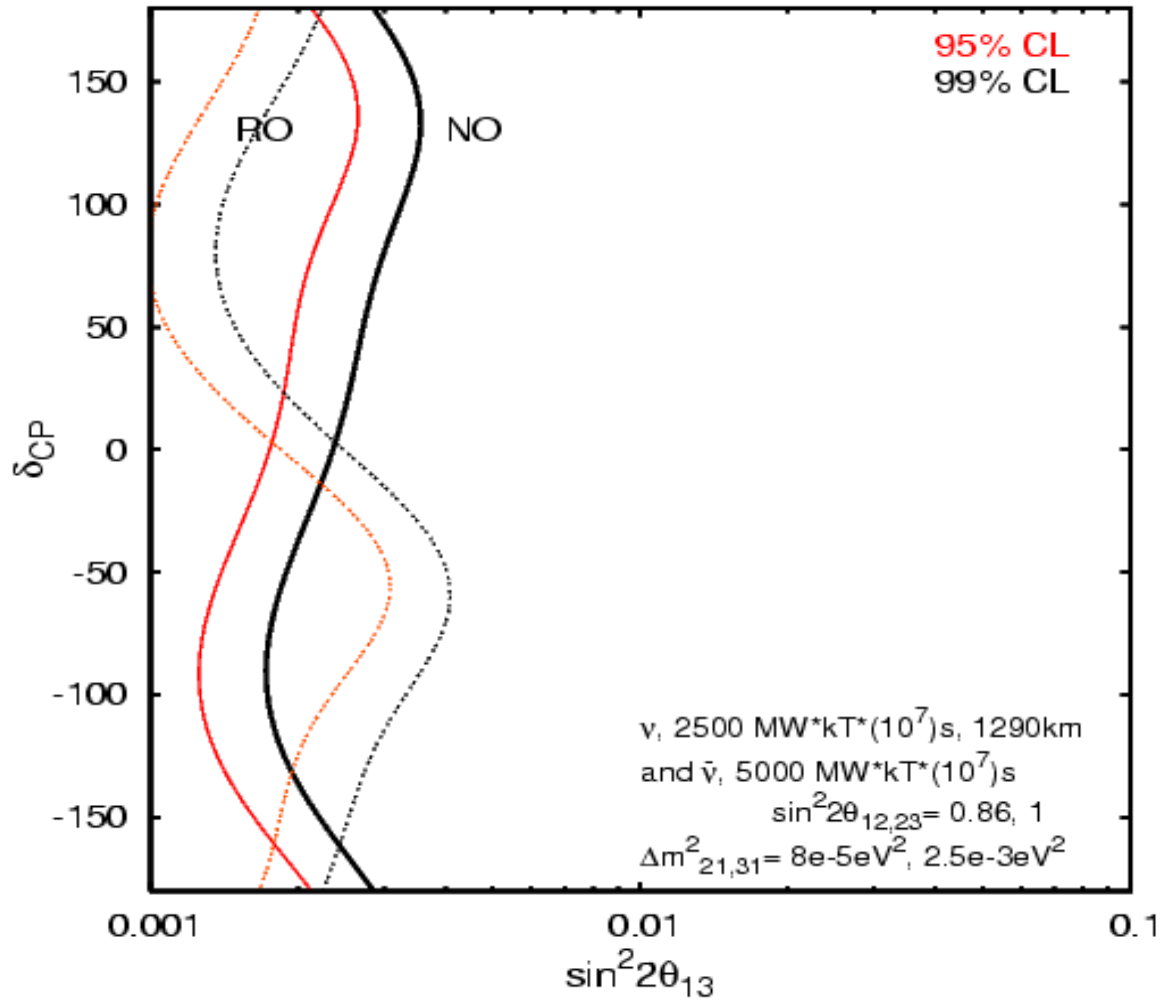
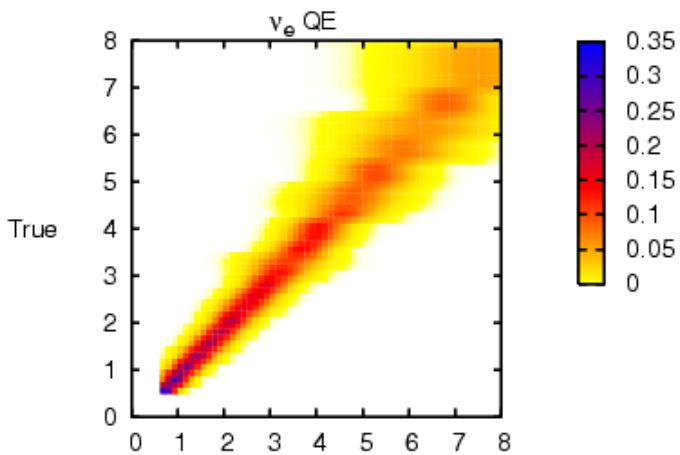
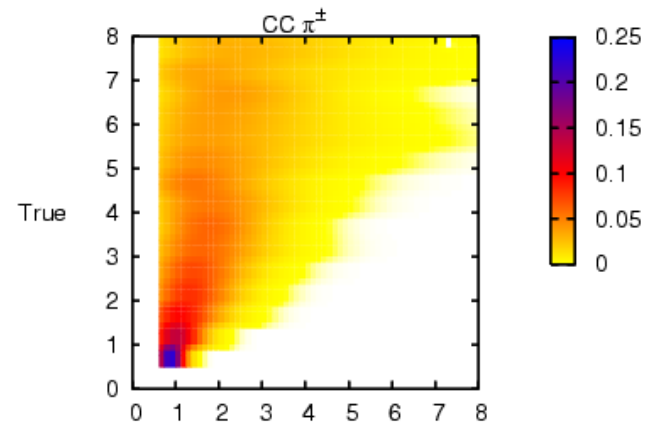
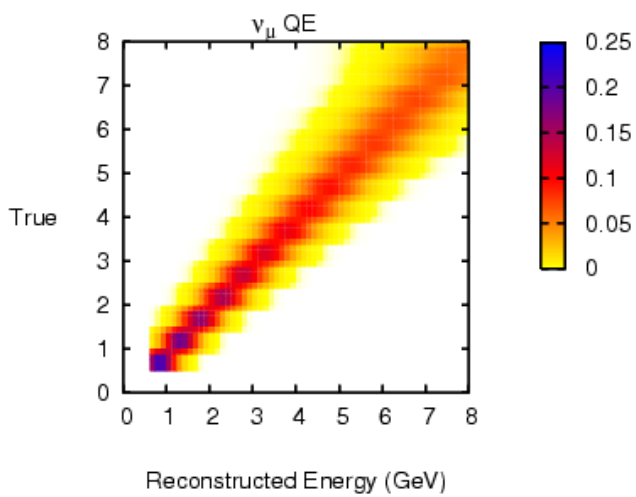
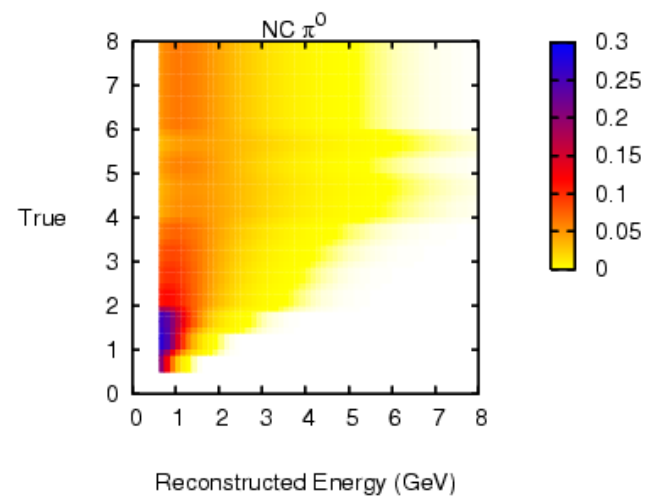
θ_{13} Exclusion

If θ_{13} is zero, region to the right of the curves would be excluded after ν and anti-ν running



Conclusion

- A very long baseline experiment would be really cool
  - Improve measurements of known parameters
  - Good chance to measure unknowns
- More information is available at
  - http://www.fnal.gov/directorate/DirReviews/Neutrino_Wrkshp.html
- There are other possible experiment setups being considered
  - Liquid Argon detector, Off-axis detector, etc.
- Anyone interested in participating in this study should talk to Gina Rameika: rameika@fnal.gov

Detector Stuff