Neutrino Oscillations: Fermilab to Homestake

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Scenario:

- Conventional ν_μ beam generated at Fermilab.
- Target: Large Water Cerenkov detector at Homestake (*eg* UNO)
- Baseline: 1290 km.

Experimental goals:

- Sensitivity to small ν_e appearance signal.
- If observed: Matter effects $\rightarrow$ sign of ΔM^2.
- In LMA scenario: Sensitivity to CP violation for a broad range of parameters.
- Sensitivity to small $\nu_\mu \rightarrow \nu_\mu$ at oscillation maximum.

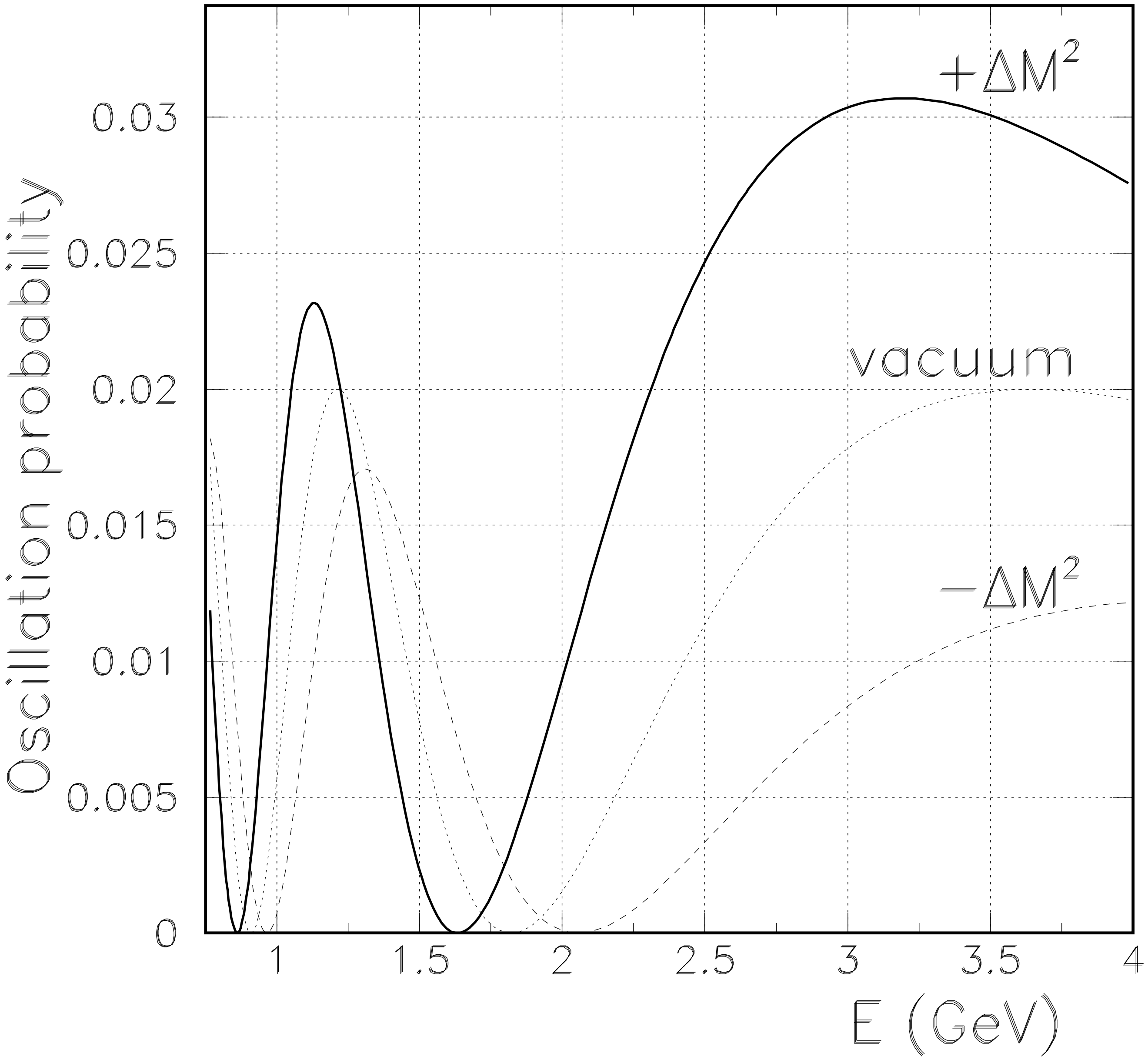
$\nu_\mu \rightarrow \nu_e$ oscillations: Leading effects

Baseline: 1290 km

Atmospheric ΔM^2: 3.5×10^{-3} eV^2

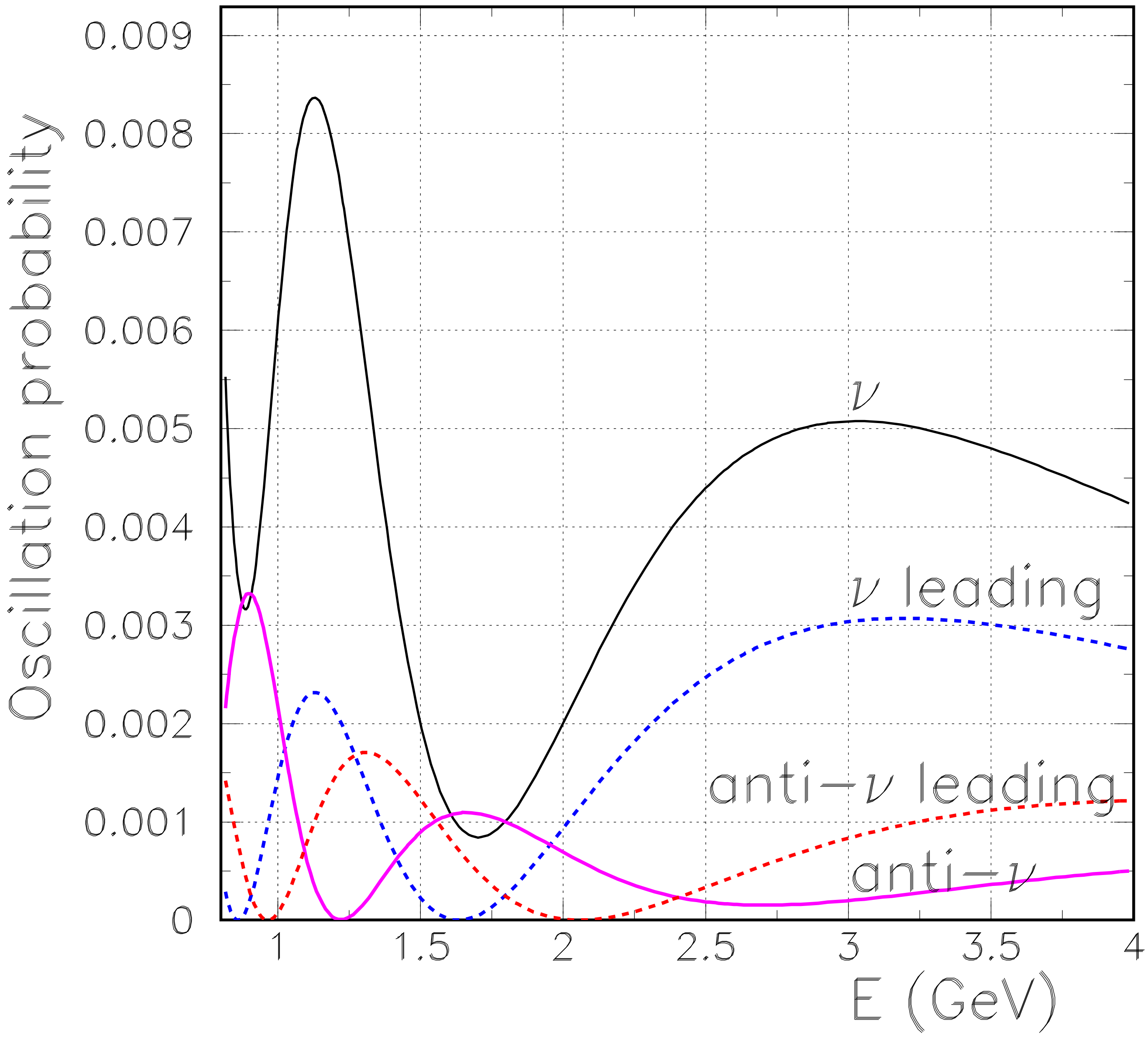
Solar oscillations: leave out for now.

Matter effects are smaller at 2nd max.



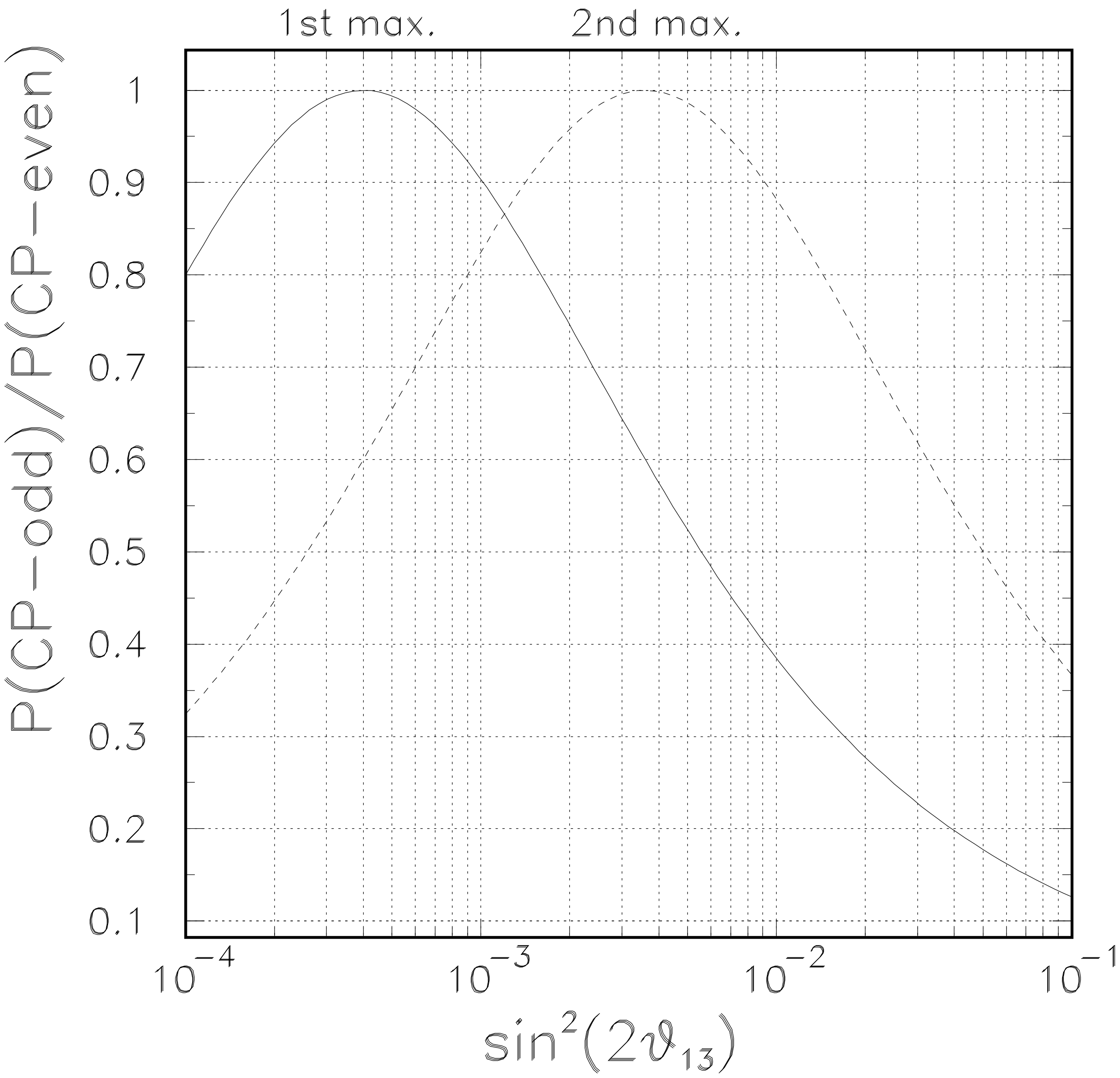
$\nu_\mu \to \nu_e$ oscillations: Sub-leading effects

Add solar oscillations (parameters typical of LMA solution):
$\Delta M^2 = 5.0 \times 10^{-5}$ eV^2, $\sin^2 2\theta_{12} = 0.8$, $\sin^2 2\theta_{23} = 1.0$
$\sin^2 2\theta_{13} = 0.004$
$\delta = \pi/2$ (maximal CP violation)
Sub-leading effects larger at 2nd max.



Maximal CP violation

Small $\sin^2 2\theta_{13} \Longleftrightarrow$ Large CP asymmetry
For a large range of parameters
CP violation potentially observable!



Signal and Background

Signal is ν_e CC event:
An electron ring with a large fraction of the energy.

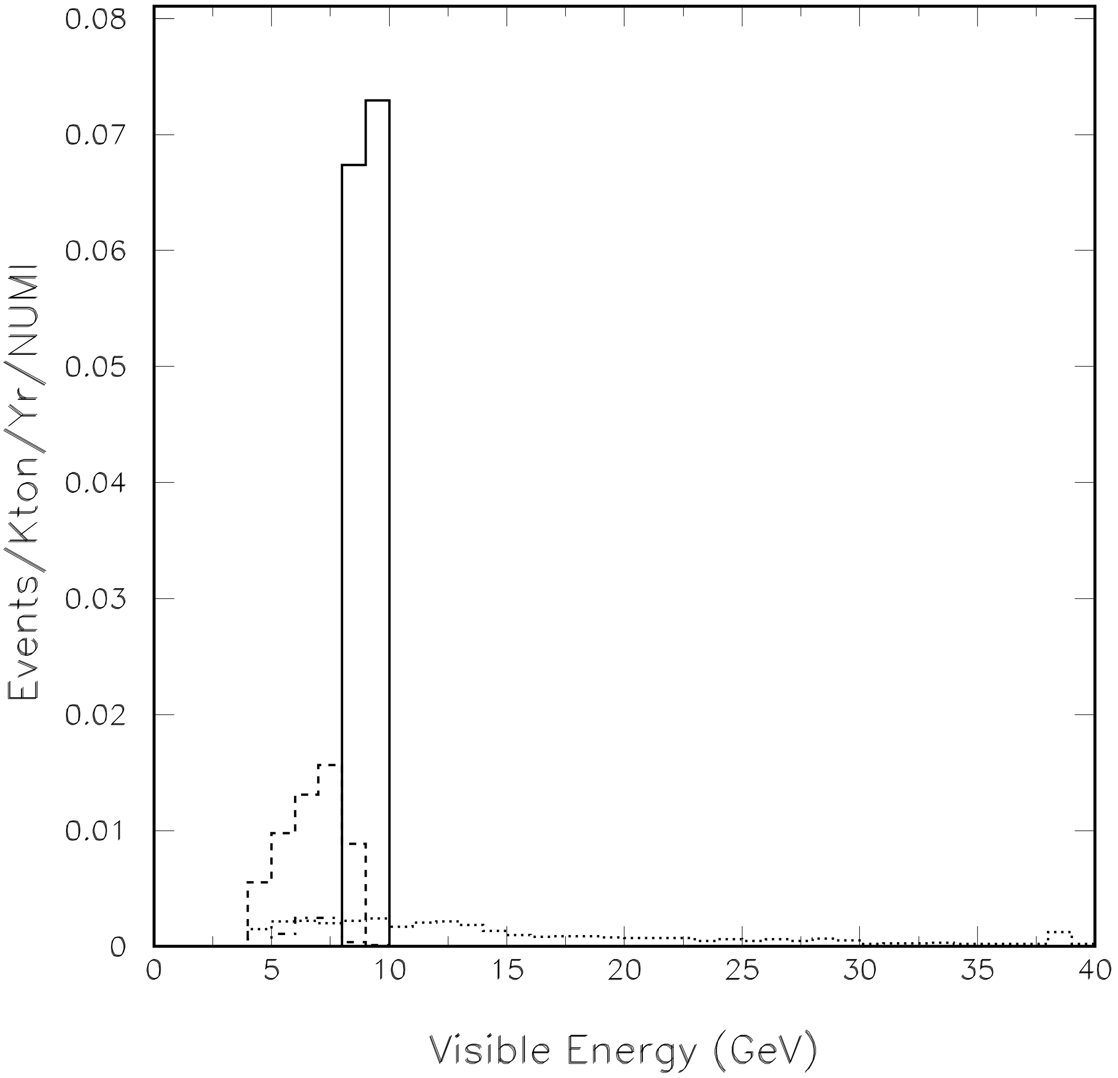
Major background:
π^0 in NC events, producing a single ring.
Other backgrounds:
Beam ν_e, $\nu_\tau \to \tau \to e$

Strategy: Use a narrow band beam.
CC events: Full neutrino energy is visible.
NC events: Escaping neutrino carries away energy.

We do not yet understand the detector response to the signal and background. I am here partly to try to organize a detector simulation effort! The remainder of this talk assumes we can achieve adequate detector performance.

Narrow band beams

Sharp cut-off at high-E side is important.

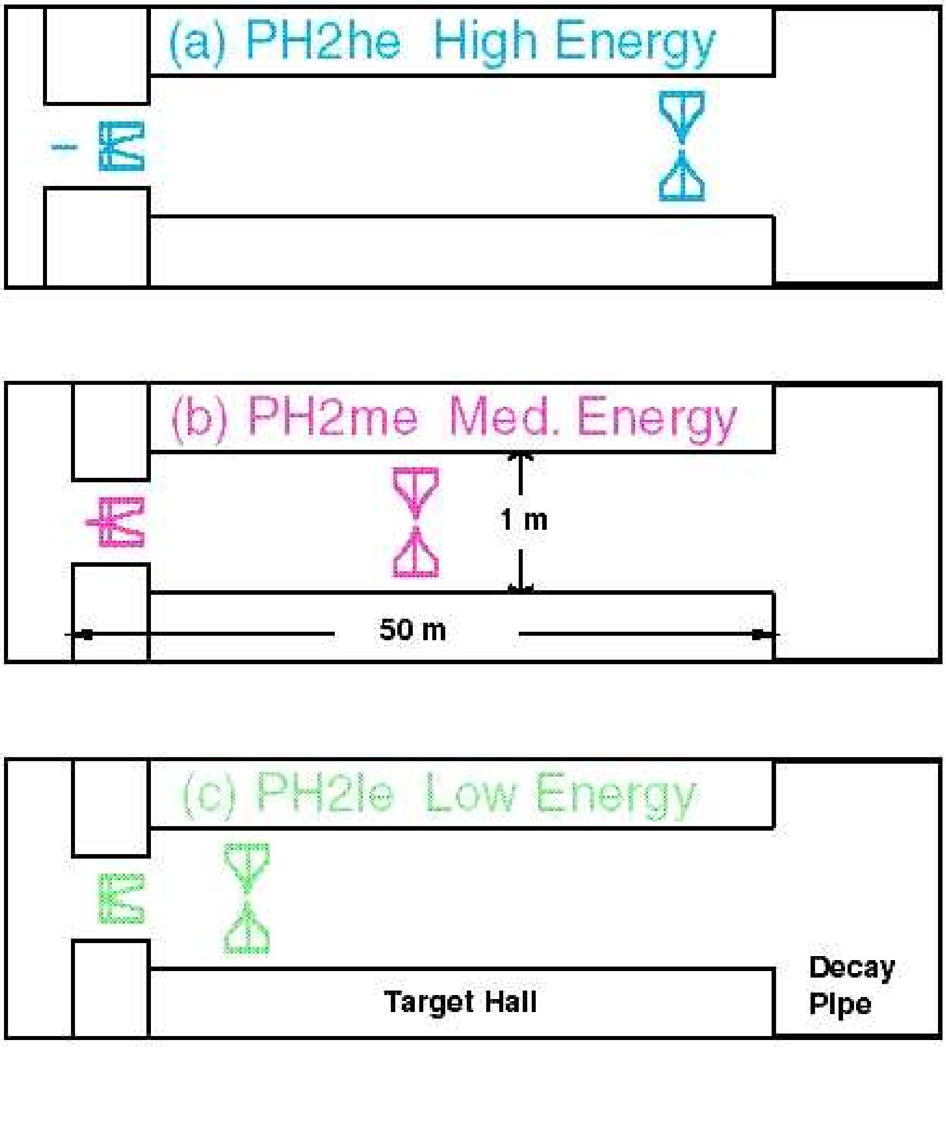


NuMI Beamline

NuMI beamline is under construction.
120 GeV protons on target, designed for 0.4 MW
Pointed to MINOS detector in Soudan mine, 732 km away.

Fast simulation of Low E option is our starting point.

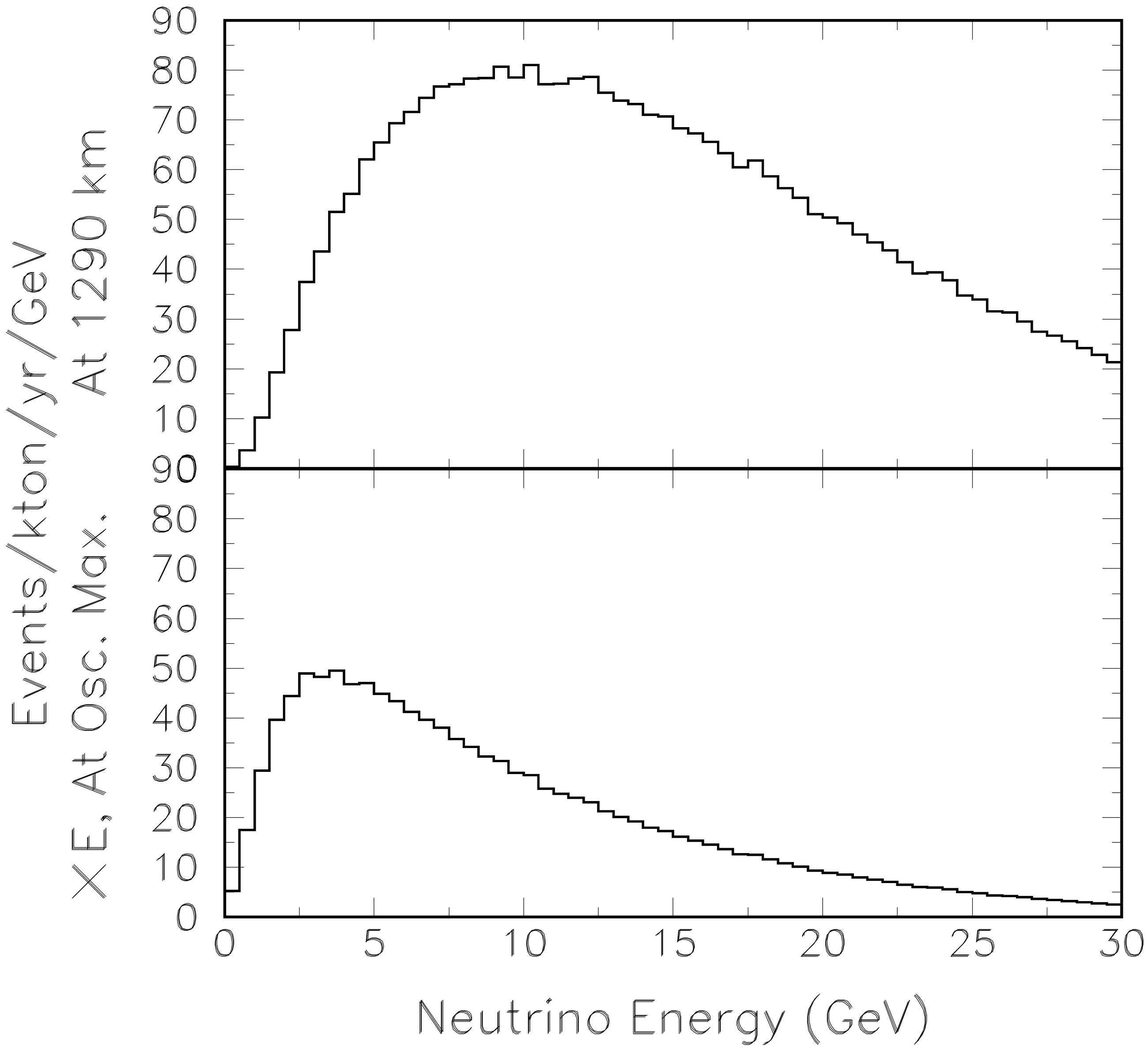
With new proton driver, 1.6 MW possible for new beamline.



E_ν spectrum from 120 GeV protons

Is 1290 km a good baseline for NuMI design?

E_ν spectrum for hypothetical "perfect focus" at NuMI
Bottom plot: scales distance with E_ν to be at osc. max.
scales with E_ν to reflect constant $\Delta E/E$

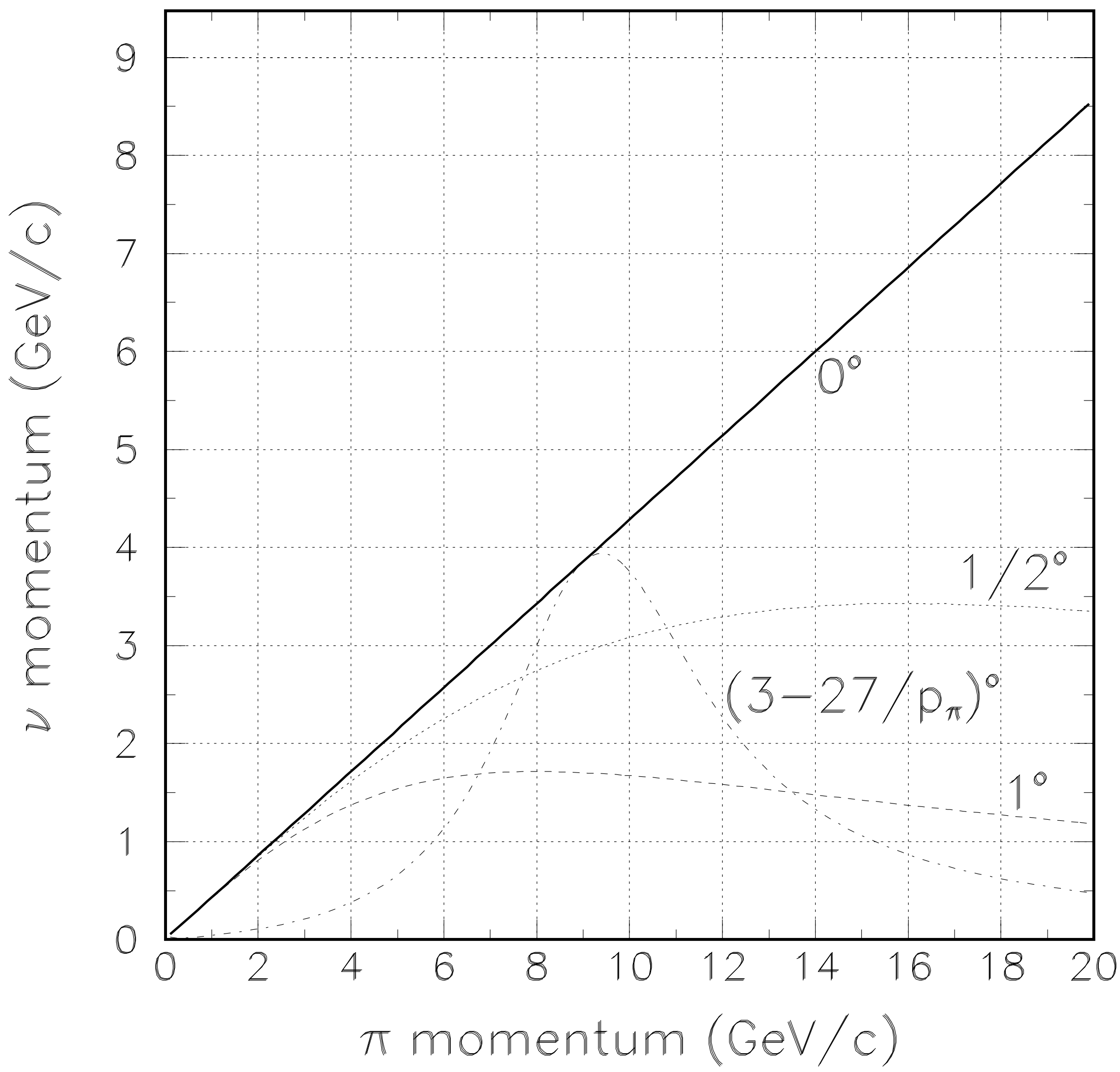


3.6 GeV is near optimal for generating a narrow band beam

Generating a narrow band beam

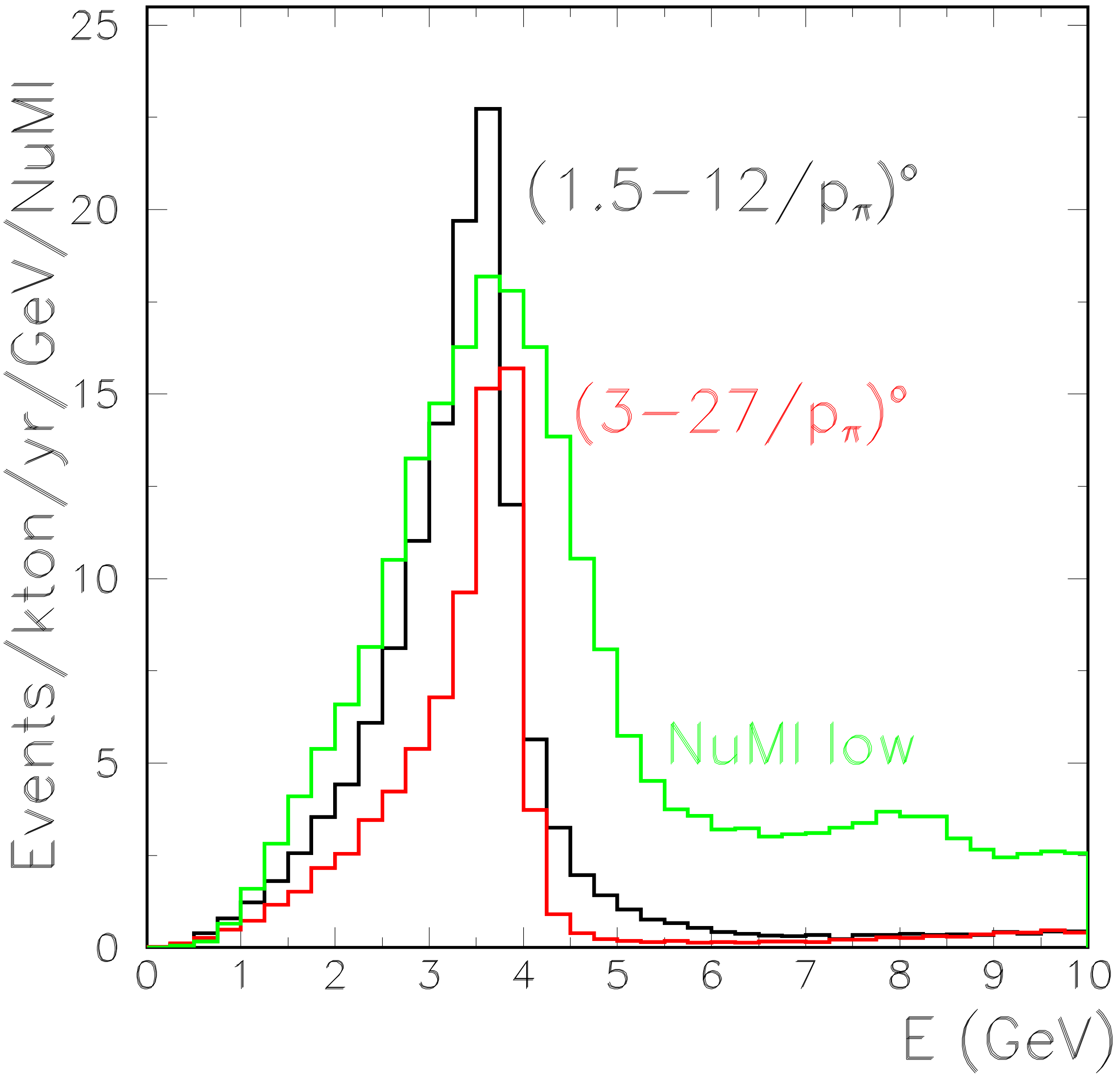
Two techniques:

1. Place detector at an angle off beam axis
2. Pass π beam through dipole bend after 2nd horn.



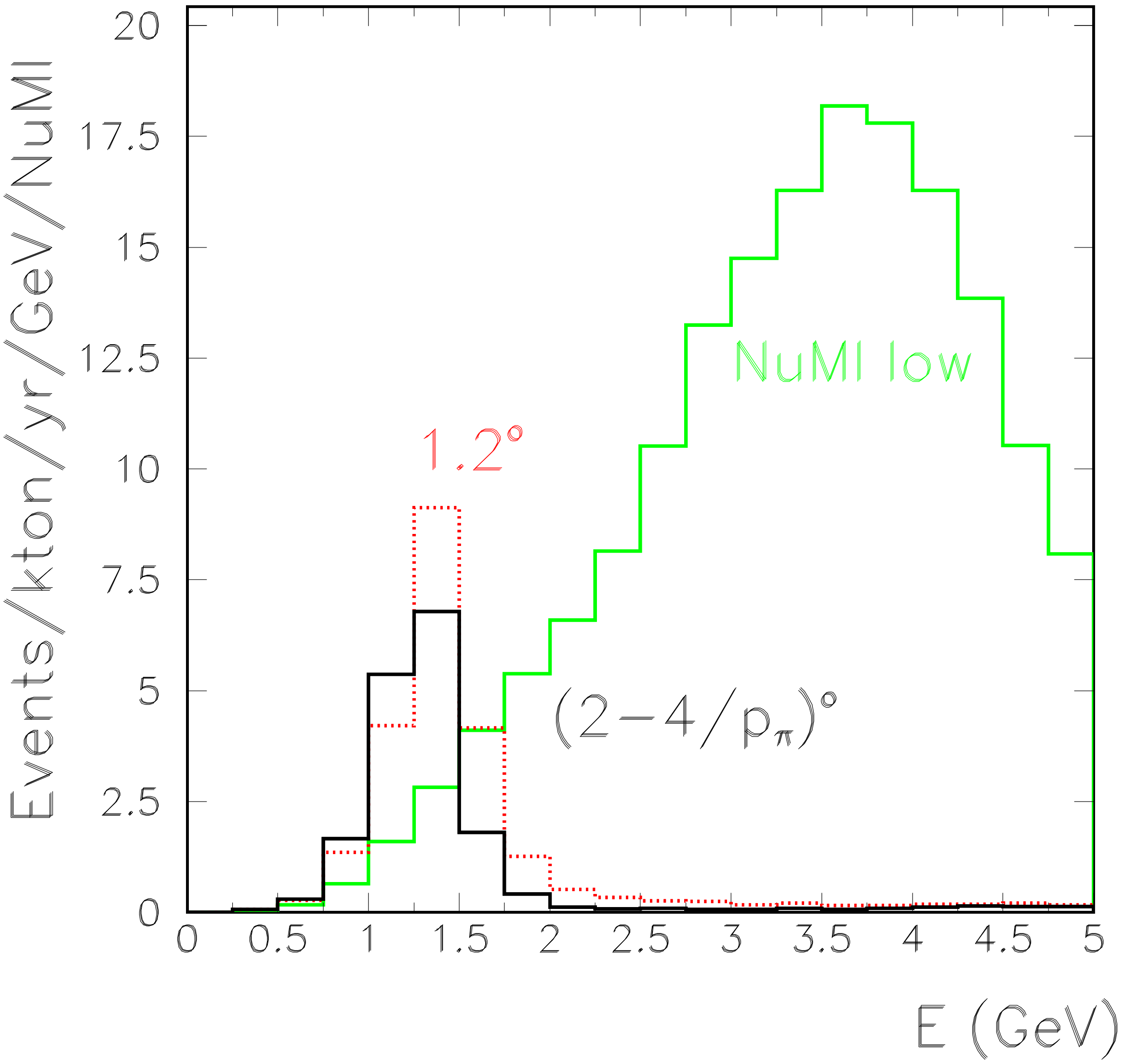
Spectra for 1st max.

NuMI intensity
1290 km



Spectra for 2nd max.

NuMI intensity
1290 km

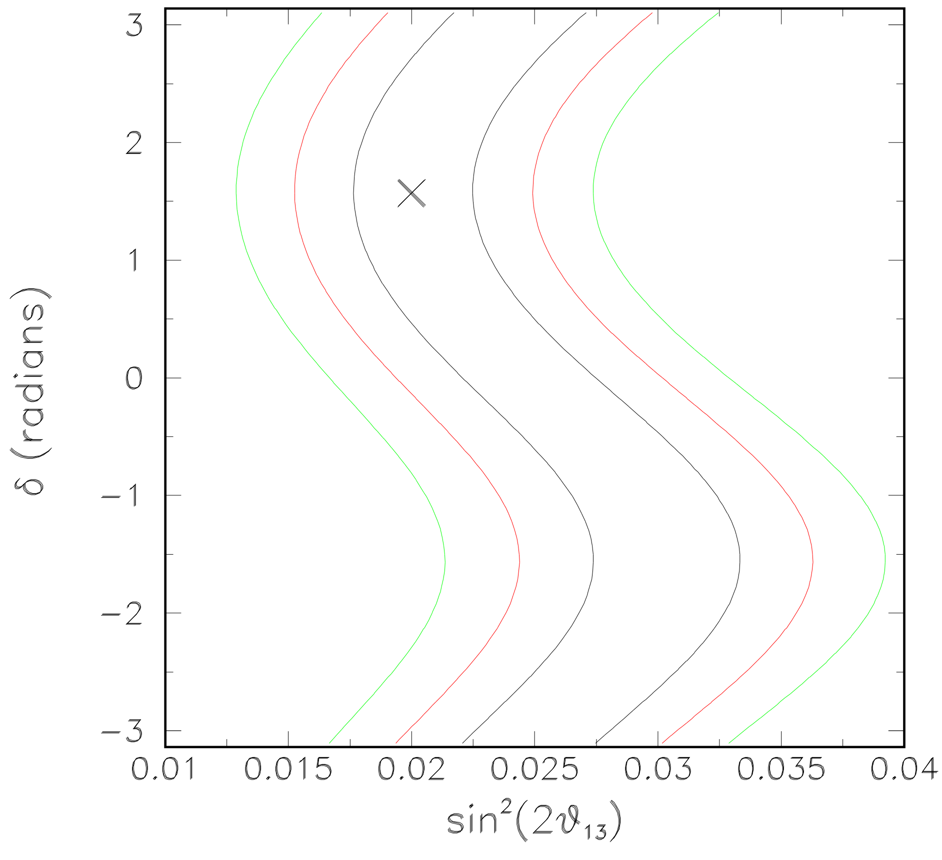


Extracting θ_{13} and δ

Assume: $\sin^2 2\theta_{13} = 0.02$ and $\delta = \pi/2$

Assume the following probability has been measured:
$P = 0.019 \pm 0.002$ for 3.6 GeV neutrinos

χ^2 analysis showing 1, 2, and 3σ contours:



Extracting θ_{13} and δ

Assume: $\sin^2 2\theta_{13} = 0.02$ and $\delta = \pi/2$

Assume the following probabilities have been measured:
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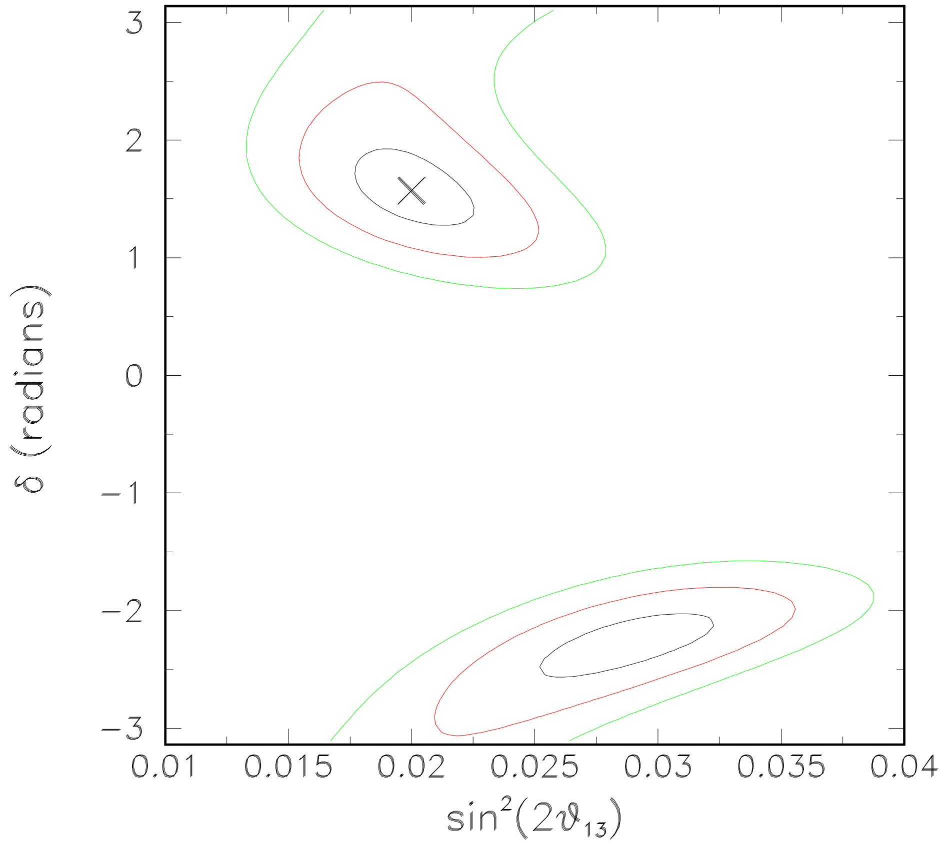
$P = 0.014 \pm 0.002$ for 1.0 GeV neutrinos

χ^2 analysis showing 1, 2, and 3σ contours:



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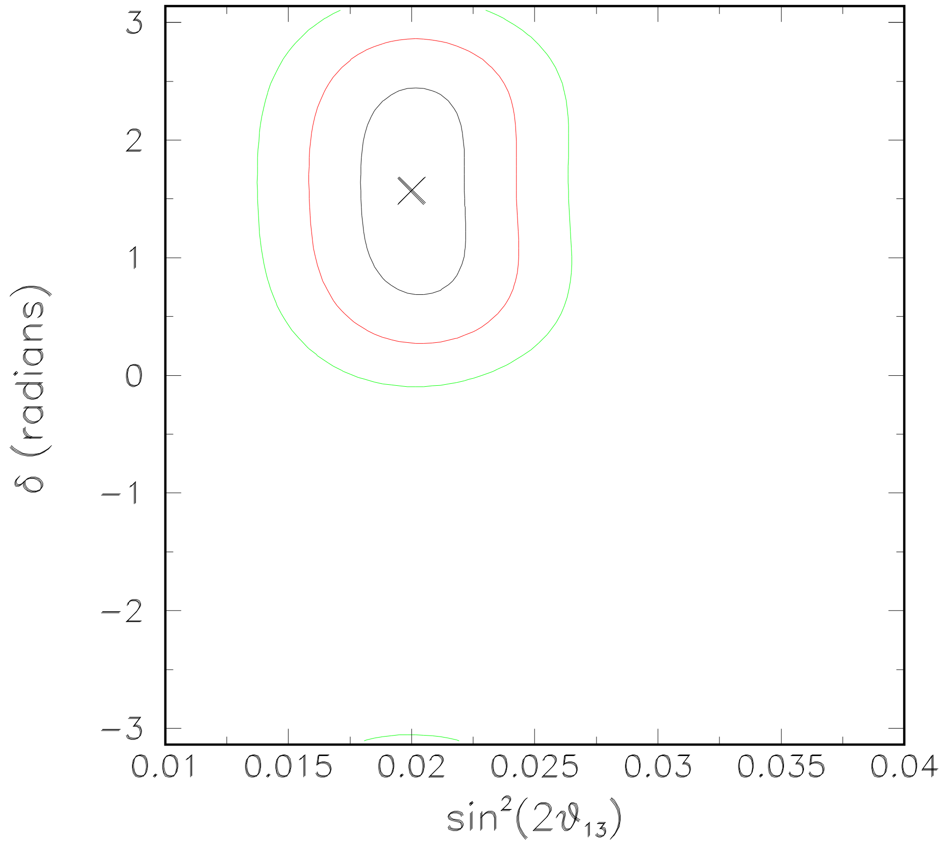
$P = 0.004 \pm 0.001$ for 3.6 GeV anti-neutrinos

χ^2 analysis showing 1, 2, and 3σ contours:



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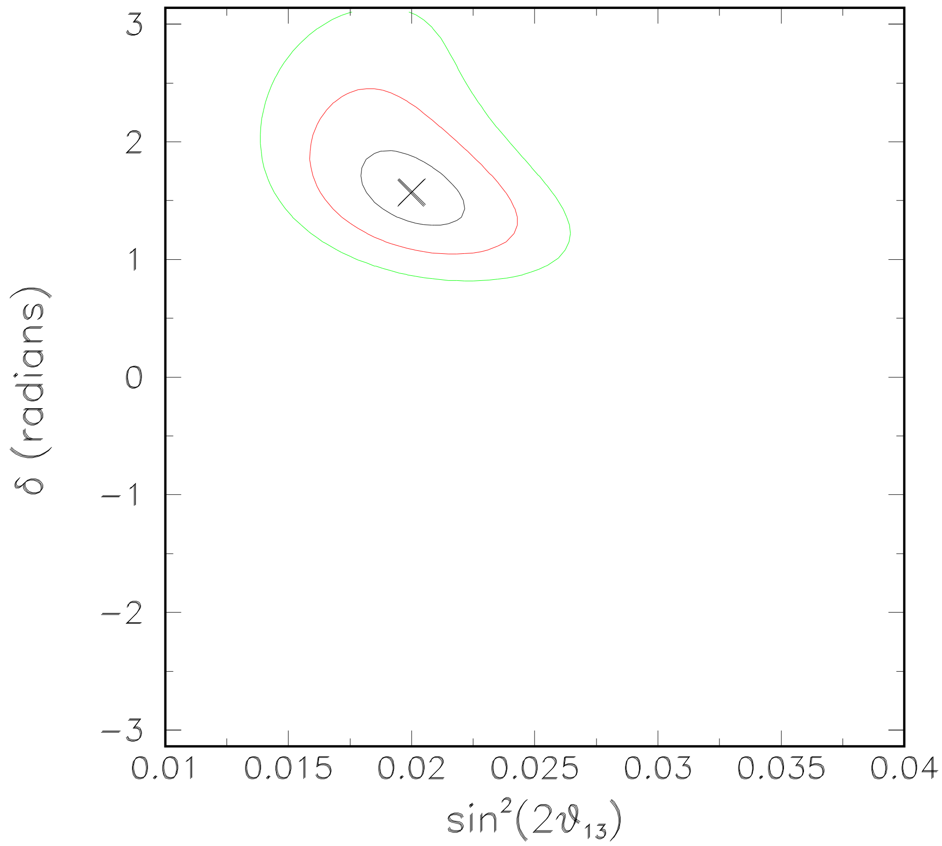

Conclusions

Preliminary results are promising:
It may be possible to observe CP violation in the LMA scenario.

More detailed studies are needed to convincingly establish the capabilities of such an experiment:

- A project at Fermilab has been initiated to do the full beam-line simulation.
- We need help from the proponents of large water cerenkov detectors to carry out a detailed detector simulation.