# Long Baseline Neutrino Oscillation Experiments :

## Machine-Experiment Interface

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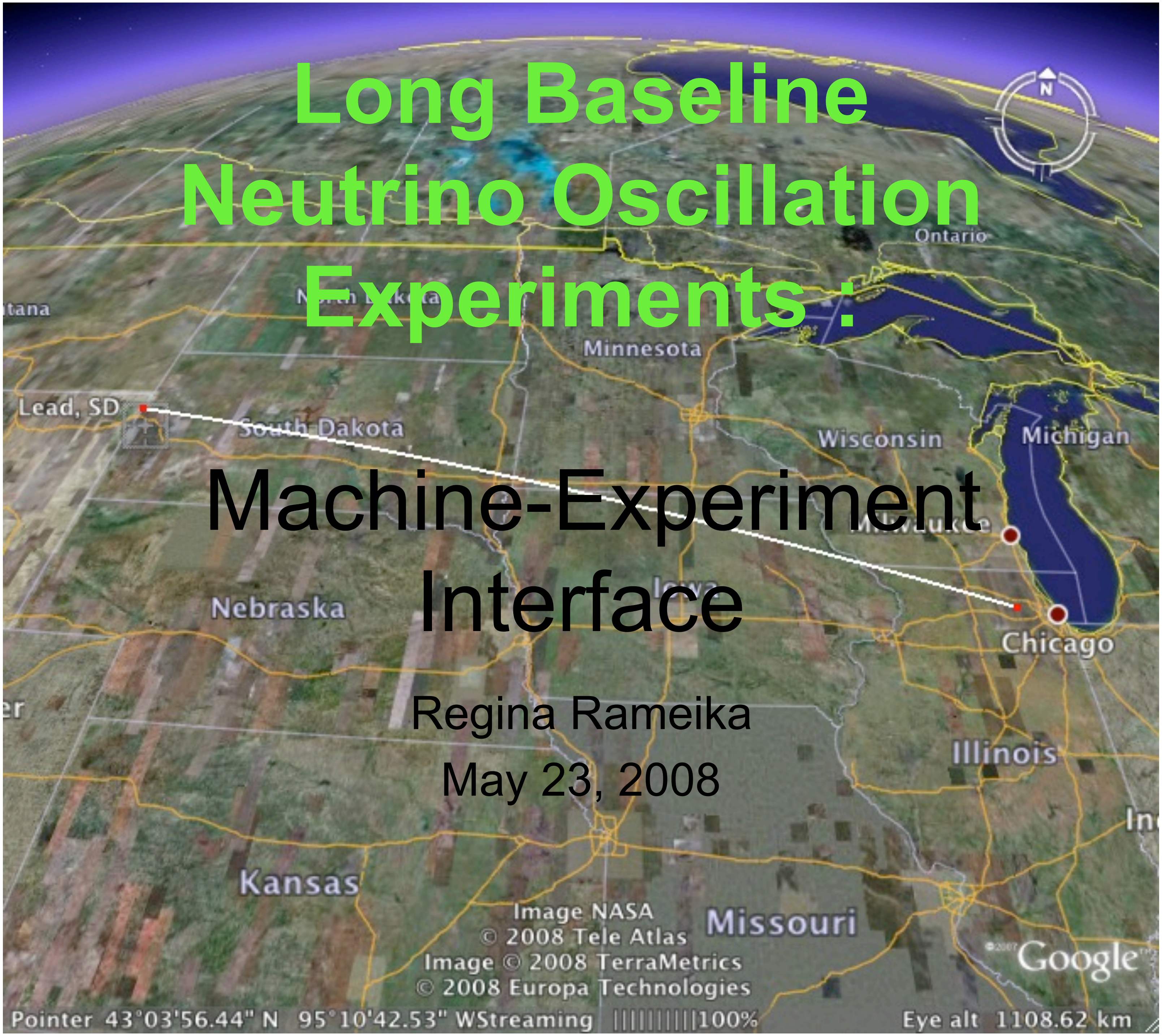
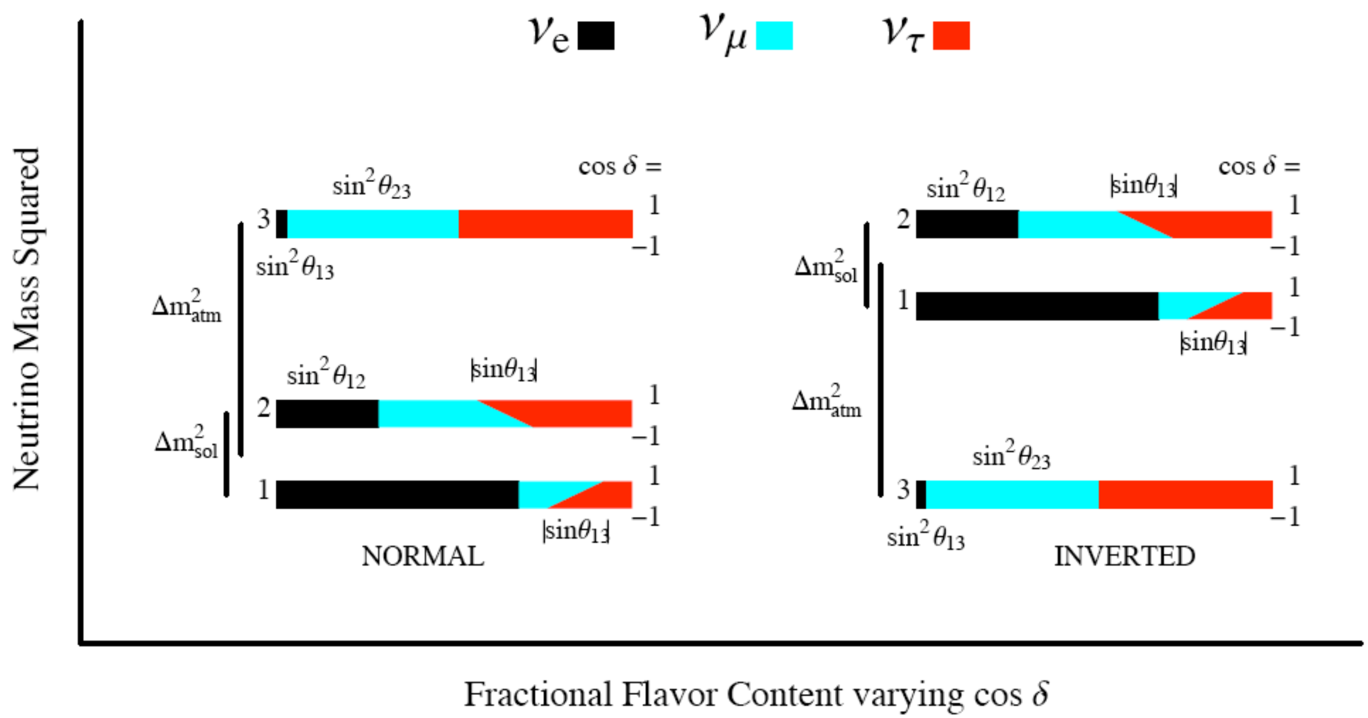


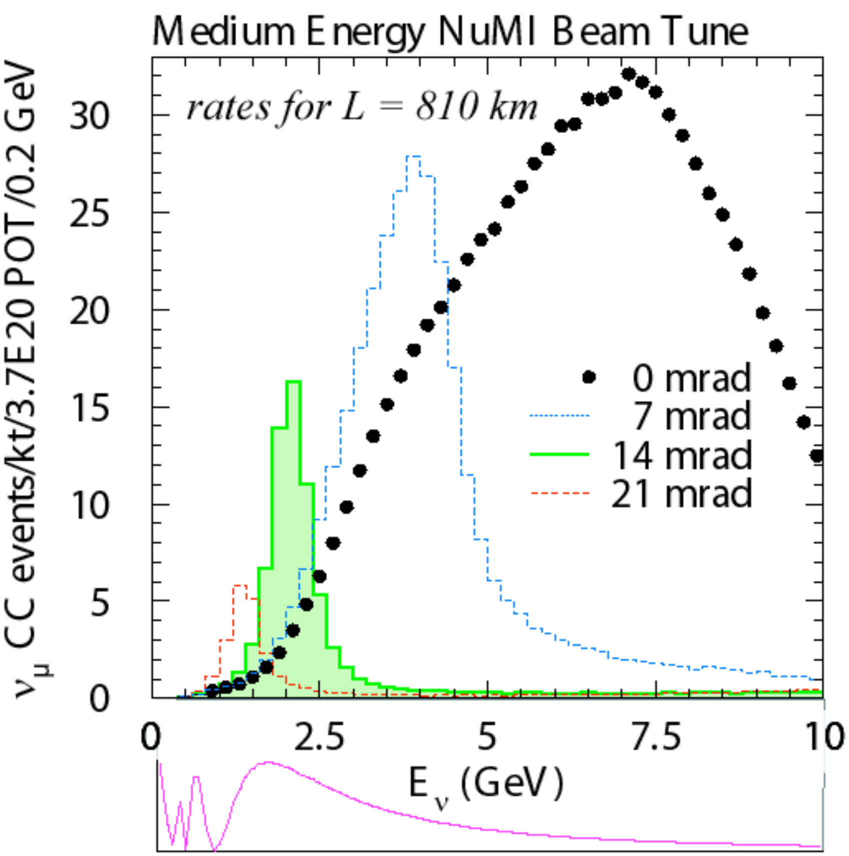
# The Questions for Long Baseline Neutrino Oscillation Experiments



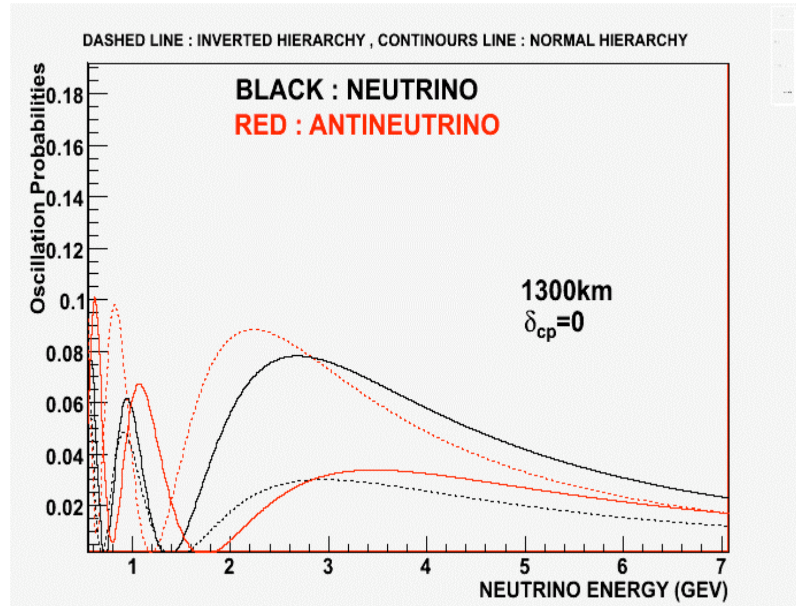

- What is the size of $\theta_{13}$?
- Is the hierarch normal or inverted?
- What is the value of $\delta_{CP}$?

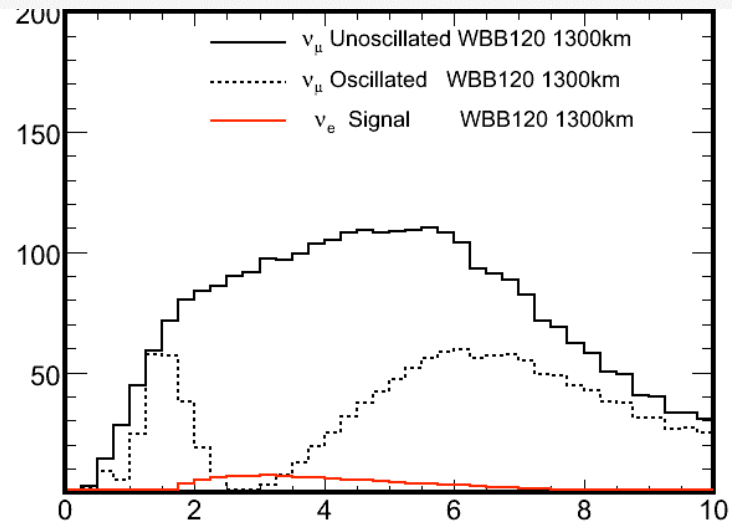
# Experimental Techniques

Off-axis/narrow band beam



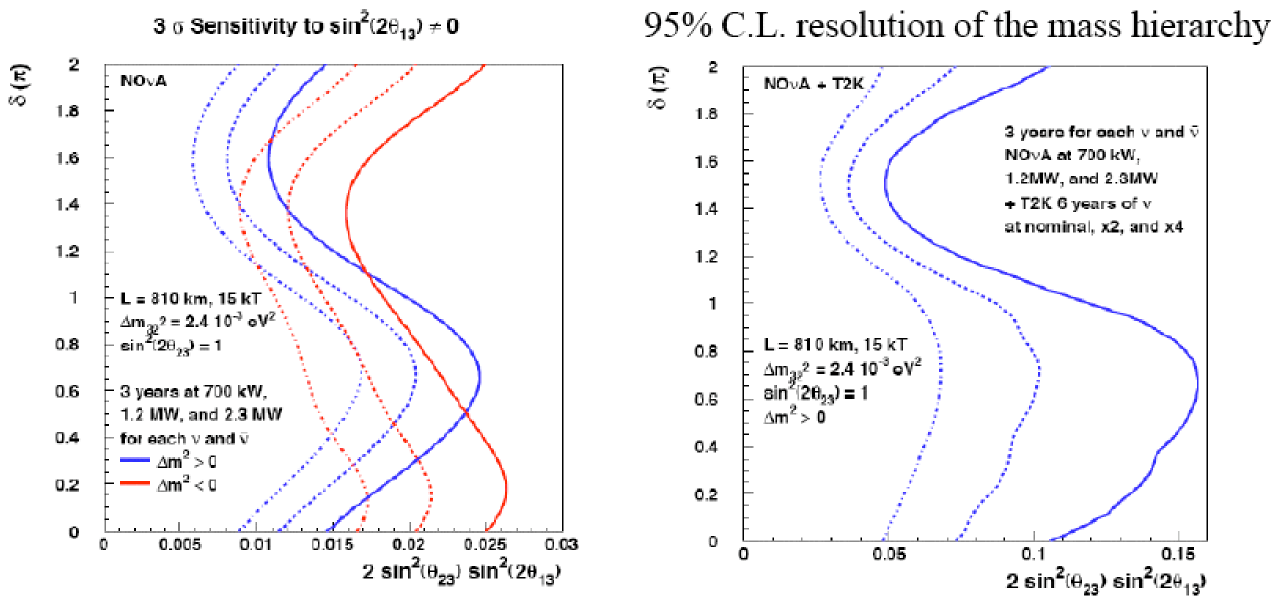

On-axis/wide band beam



An experiment’s sensitivity is measured in $\sin^2 2\theta_{13}$ and $\delta_{CP}$ space

## NOvA Experiment Sensitivities (shown by G.Feldman at P5 2008 SLAC meeting)




Normal Ordering

Lines ~represent equal numbers

Of signal events for a given set of $\sin^2 2\theta_{13}, \delta_{CP}$



More neutrinos or more mass;

more neutrinos → instantaneous intensity+ time

| | | Neutrino Rates | | | | Anti Neutrino Rates | | | |
|---|---|---|---|---|---|---|---|---|---|
| Beam (mass ordering) | $\sin^2 2\theta_{13}$ | $\delta_{CP}$ deg. | | | | | | | |
| | | 0° | -90° | 180° | +90° | 0° | -90° | 180° | +90° |
| NuMI LE 12 km offaxs (+) | 0.02 | 76 | 108 | 69 | 36 | 20 | 7.7 | 17 | 30 |
| NuMI LE 12 km offaxs (-) | 0.02 | 46 | 77 | 52 | 21 | 28 | 14 | 28 | 42 |
| NuMI LE 12 km offaxs (+) | 0.1 | 336 | 408 | 320 | 248 | 86 | 57 | 78 | 106 |
| NuMI LE 12 km offaxs (-) | 0.1 | 210 | 280 | 224 | 153 | 125 | 95 | 126 | 157 |
| NuMI LE 40 km offaxs (+) | 0.02 | 5.7 | 8.8 | 5.1 | 2.2 | 2.5 | 1.6 | 0.7 | 3.3 |
| NuMI LE 40 km offaxs (-) | 0.02 | 4.2 | 8.0 | 5.7 | 2.0 | 2.3 | 2.2 | 0.8 | 3.6 |
| NuMI LE 40 km offaxs (+) | 0.1 | 17 | 24 | 15 | 9.4 | 6.7 | 2.8 | 4.6 | 8.5 |
| NuMI LE 40 km offaxs (-) | 0.1 | 12 | 21 | 16 | 7.7 | 6.6 | 3.4 | 6.4 | 9.6 |
| WBLE 1300 km (+) | 0.02 | 141 | 192 | 128 | 77 | 19 | 11 | 18 | 36 |
| WBLE 1300 km (-) | 0.02 | 58 | 111 | 88 | 35 | 45 | 25 | 45 | 64 |
| WBLE 1300 km (+) | 0.1 | 607 | 720 | 579 | 467 | 106 | 67 | 83 | 122 |
| WBLE 1300 km (-) | 0.1 | 269 | 388 | 335 | 216 | 196 | 154 | 196 | 240 |
| WBLE 2500 km (+) | 0.02 | 61 | 103 | 88 | 46 | 11 | 4.6 | 4.7 | 11 |
| WBLE 2500 km (-) | 0.02 | 16 | 36 | 33 | 13 | 28 | 15 | 18 | 31 |
| WBLE 2500 km (+) | 0.1 | 270 | 361 | 328 | 238 | 27 | 13 | 13 | 28 |
| WBLE 2500 km (-) | 0.1 | 47 | 92 | 85 | 39 | 103 | 74 | 80 | 109 |

Charge current events per **100kT mass per 1 MW per $10^7$ sec**

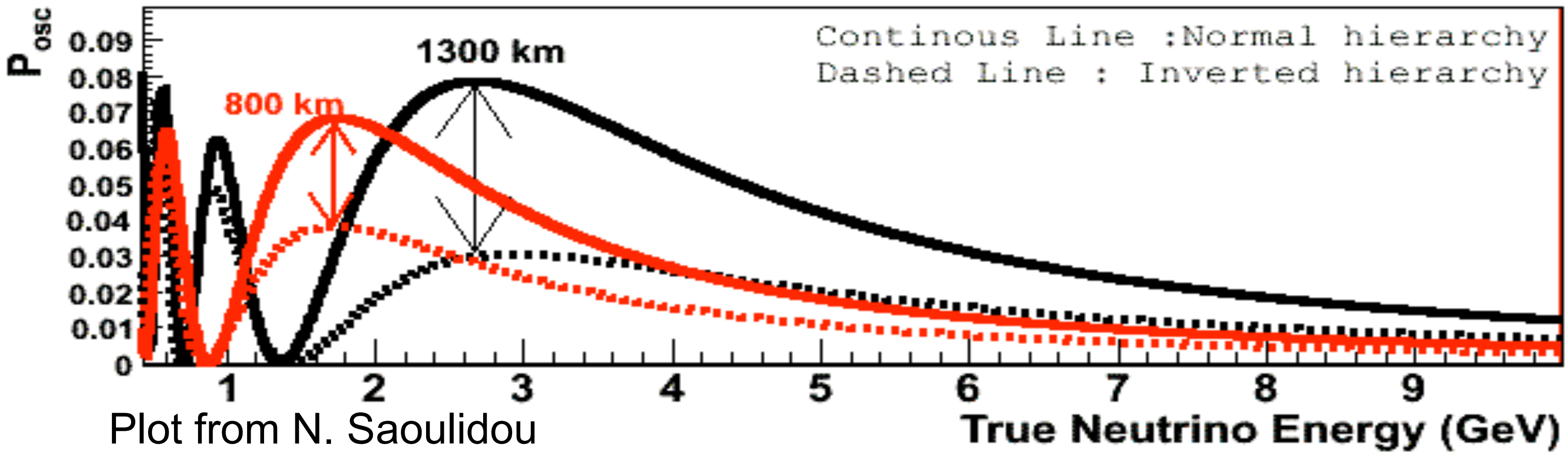
No detector model or backgrounds

(NuMI - 120 GeV
WBLE - 60 GeV)

DUSEL rates

~10-1000 evts

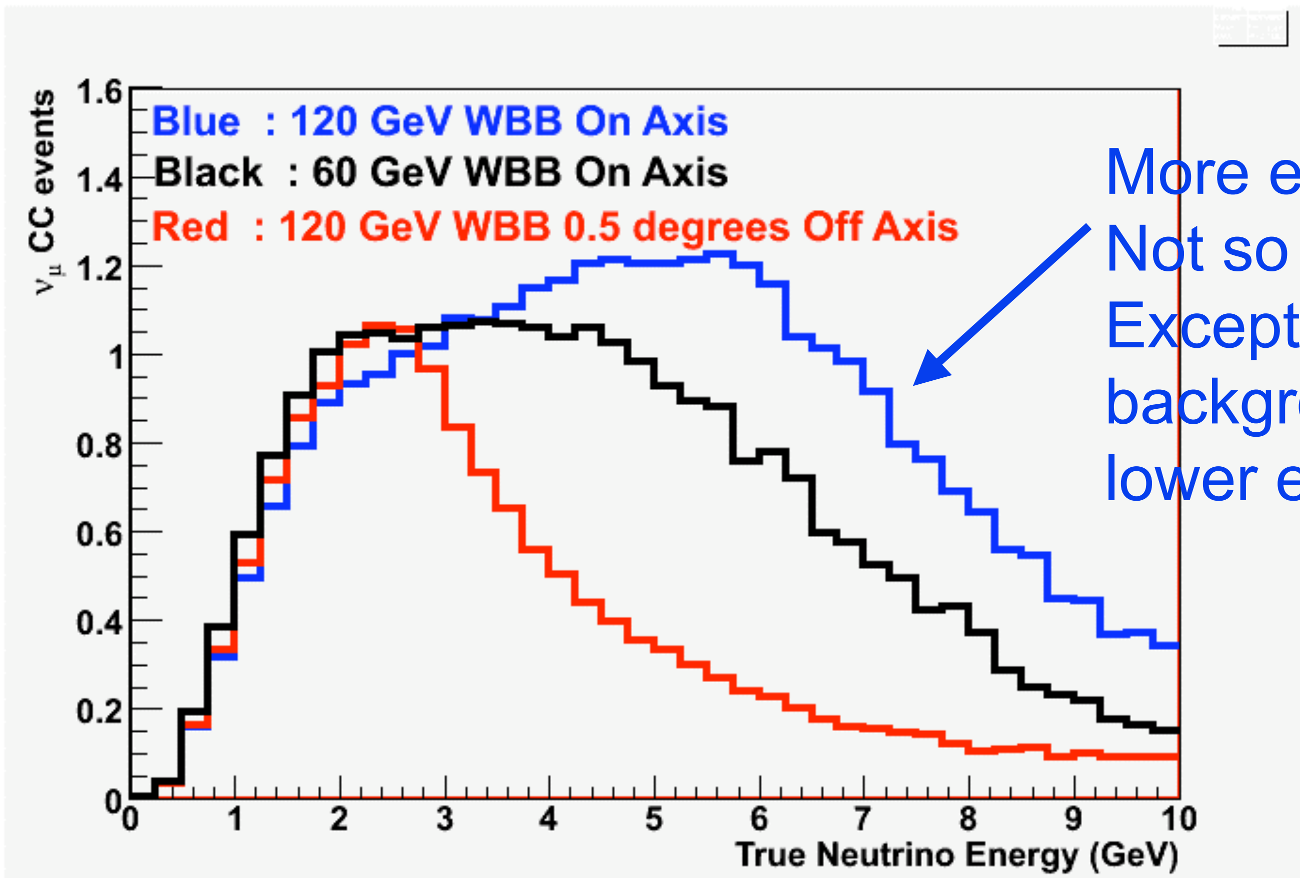
# Why is the longer baseline so much better?




Plot from N. Saoulidou

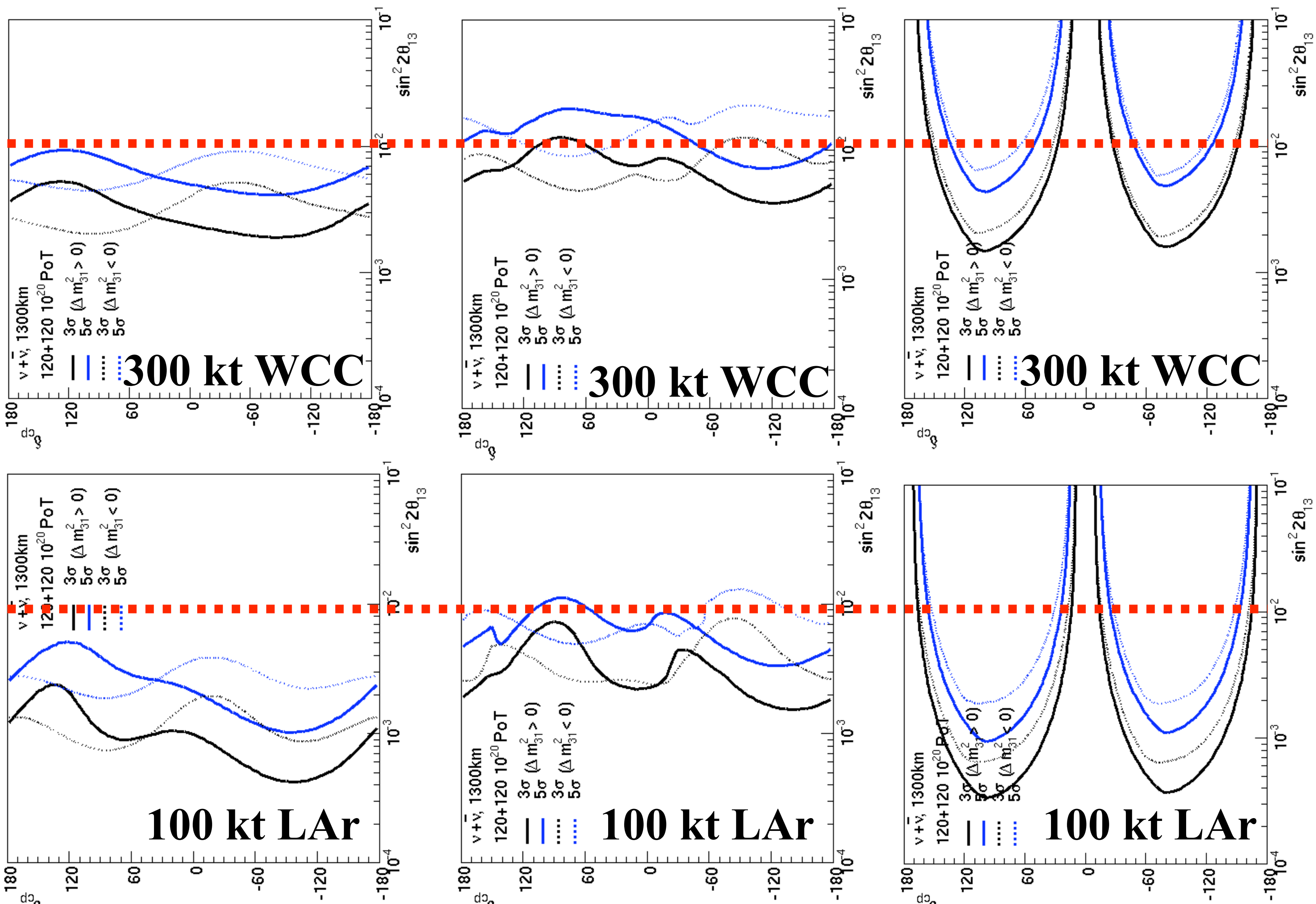
- Oscillation maxima are moved to higher energy
- Matter effects are significantly larger

# Options and optimizations

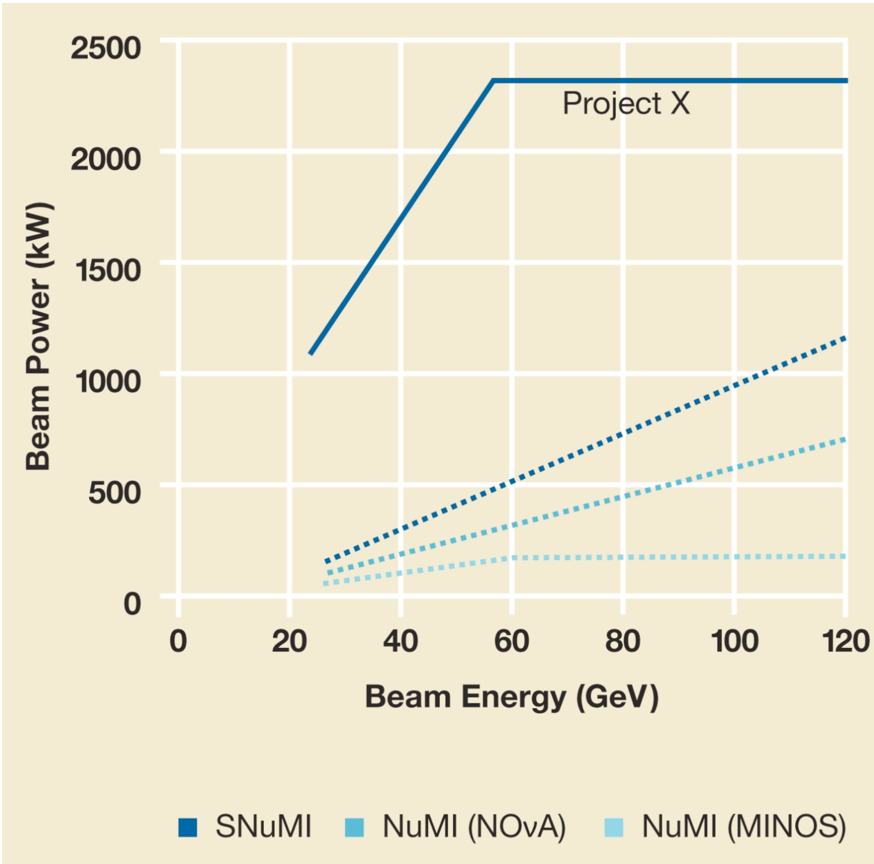



More events, but Not so interesting, Except for creating backgrounds at lower energy

# 100 kt LAr vs 300 kt of WCC



- 60 -120 GeV protons from the Main Injector fed by Project X




$20\text{-}40 \times 10^{20}$ POT/yr

$10 \times 10^{20}$ POT/yr

$6 \times 10^{20}$ POT/yr

$3 \times 10^{20}$ POT/yr

Recent sensitivity studies are being done for $120 \times 10^{20}$ POT each $\nu$ and $\bar{\nu}$ (120 GeV)

$$POT(10^{20}) = \frac{1000 \times BeamPower(MW) \times T(10^{7}s)}{1.602 \times E_p(GeV)}$$

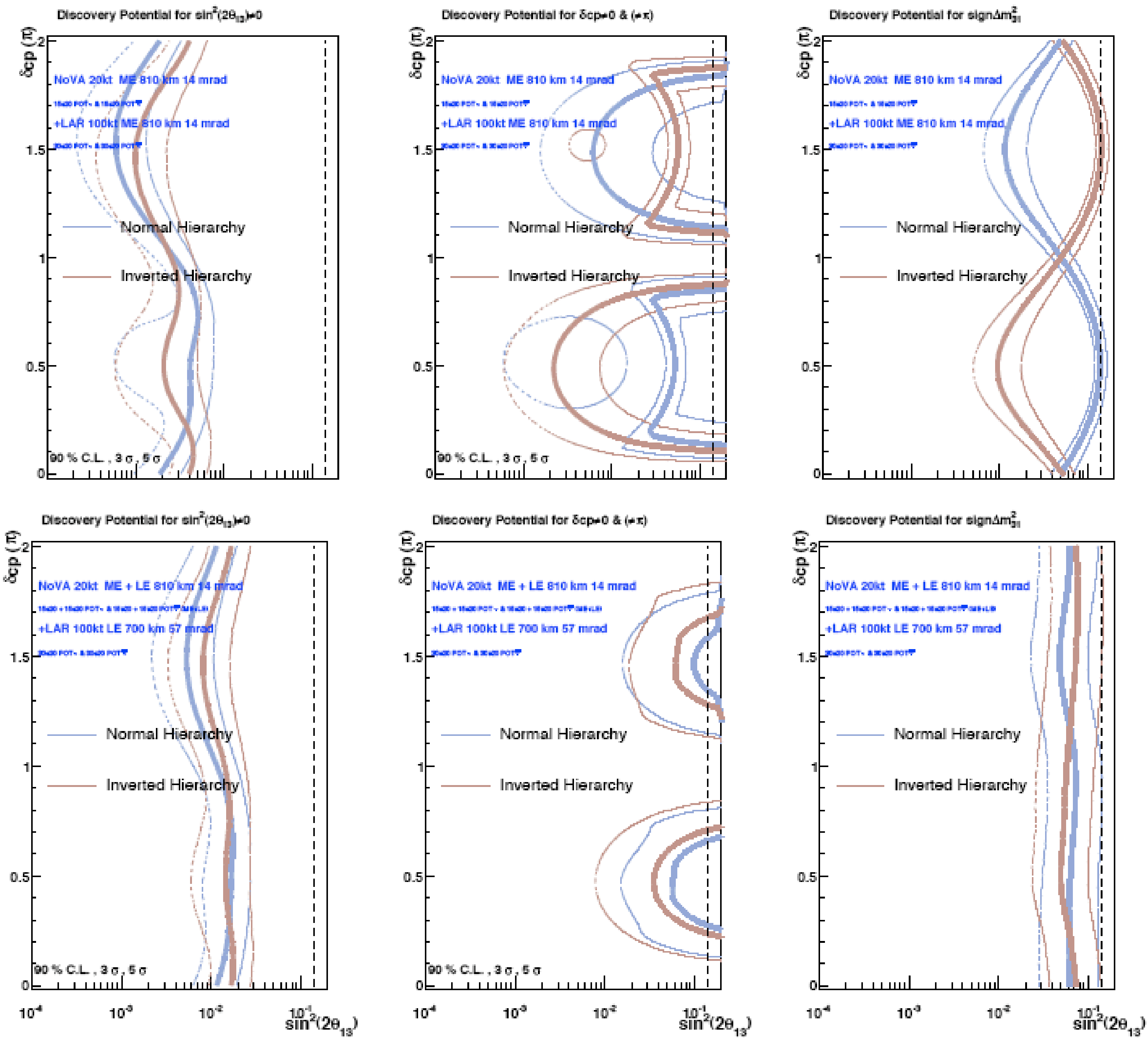
# Summary

- Flexibility to choose energy at the same power is a real plus
  - Lower proton energy may have real advantages
- Integrated intensity goal
  - 240 (480) x $10^{20}$ POT @ 120 (60) GeV
- Annual intensity goal
  - 20 (40) x $10^{20}$ POT @ 120 (60) GeV
- Instantaneous intensity
  - Single turn extraction (10$\mu$s every 1.4 sec)
    - No rate effects at far detector
  - $15 \times 10^{14}$ per spill $\rightarrow$ 2 MW at 120 GeV

# Summary

- Experiments are statistics limited for values of $\sin^2 2\theta_{13}$ well below 0.01
- For far detector operation, fast extraction (10$\mu$s every 1.4 sec) of 15x$10^{14}$ per spill yields ~40 < interactions per year < 4000
- Sensitivities achievable at the statistics/systematics limit can use up to 120x$10^{20}$ protons in each the neutrino and anti-neutrino running mode -> 5 years each mode
- For near detector operation at this intensity, event overlap could be significant; detector configuration will need to take this into account

NuMI
1st max




NuMI
2nd max