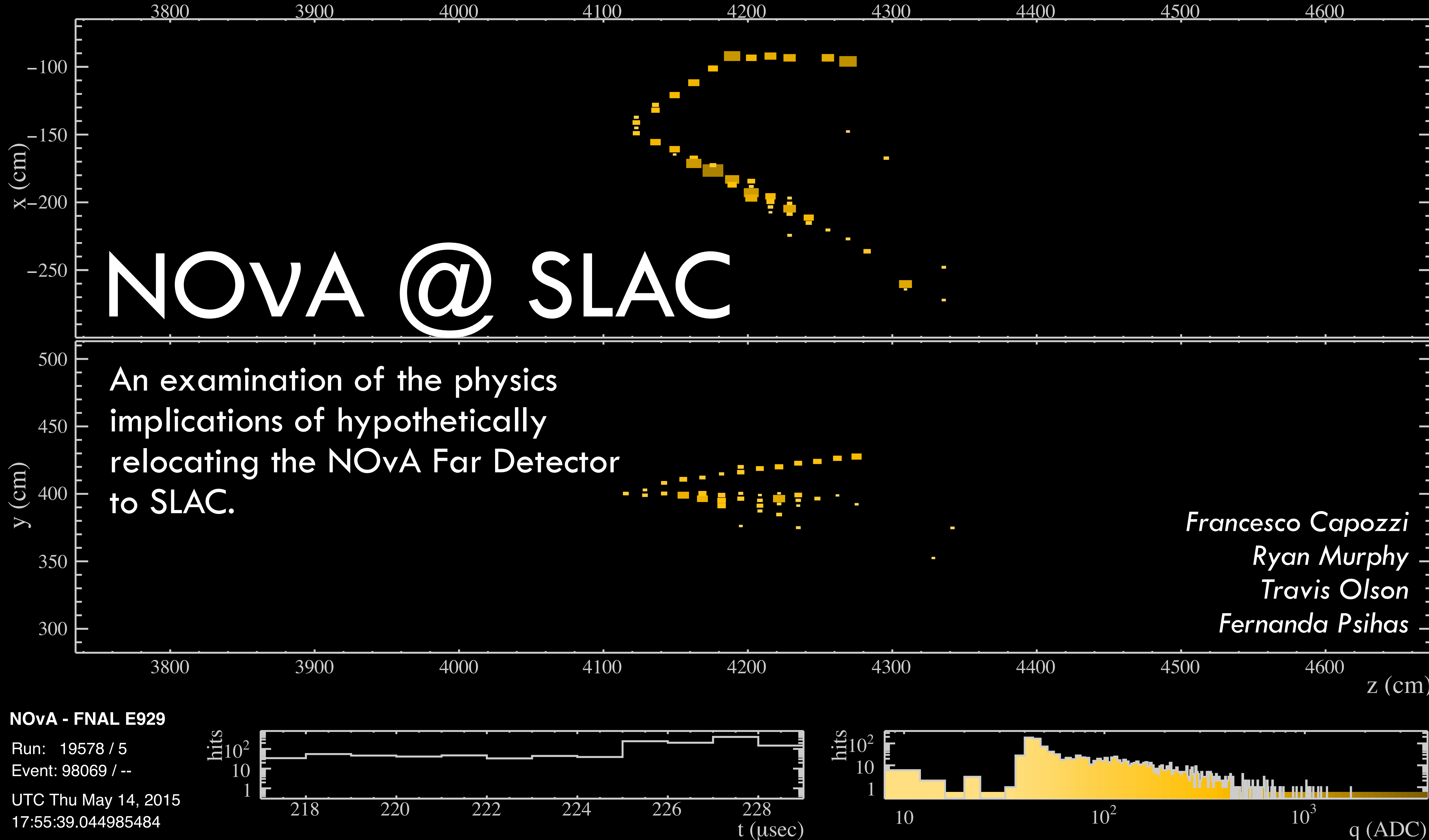
NOvA @ SLAC

An examination of the physics implications of hypothetically relocating the NOvA Far Detector to SLAC.

Francesco Capozzi
Ryan Murphy
Travis Olson
Fernanda Psihas



SLAC Summer Institute 2015 - The Universe of neutrinos.

NOνA @ SLAC

Basic Assumptions:

The NOνA far detector is placed at a new location (at SLAC) with identical characteristics.

The NuMI beam and the near detector rotate accordingly, without changing their current characteristics or relative positions.

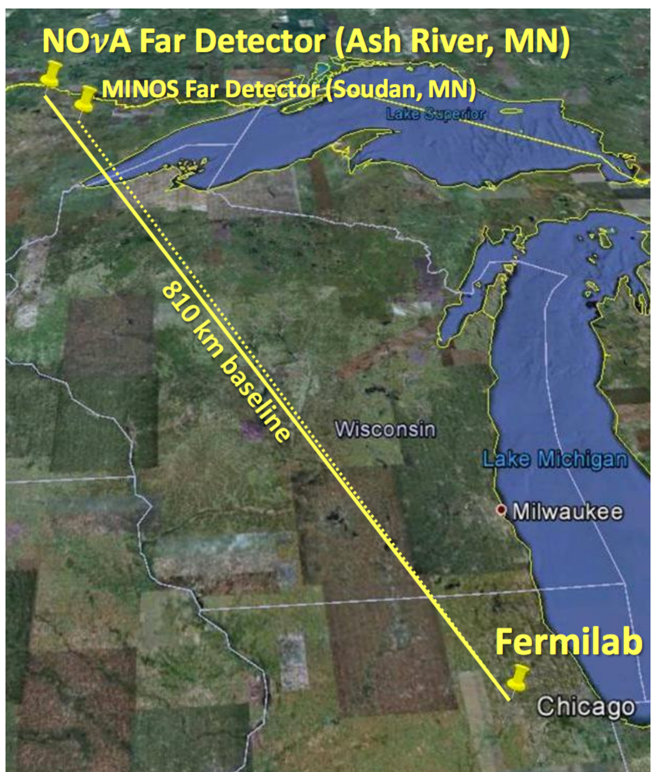
What happens with the physics?

SuperNOVA?

Basic Assumptions:

The NOVA detector is placed at a new location (at SLAC) with identical characteristics.

The NuMI beam and the near detector rotate accordingly, without changing their current characteristics or relative positions.



NOvA official

The main consideration to be examined is the effect of changing the baseline:

What effects does L have in the design and physics reach of neutrino oscillation experiments?

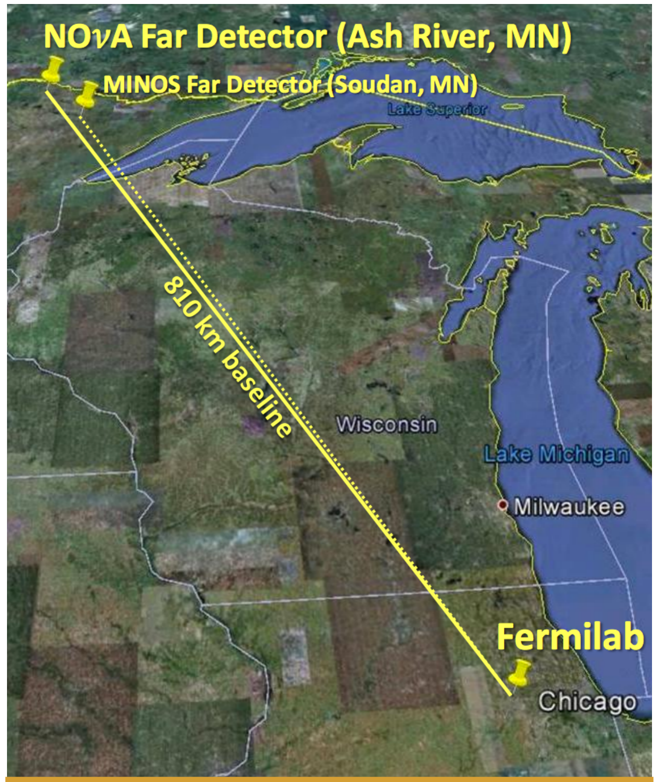
Super NOνA

SuperNOVA?

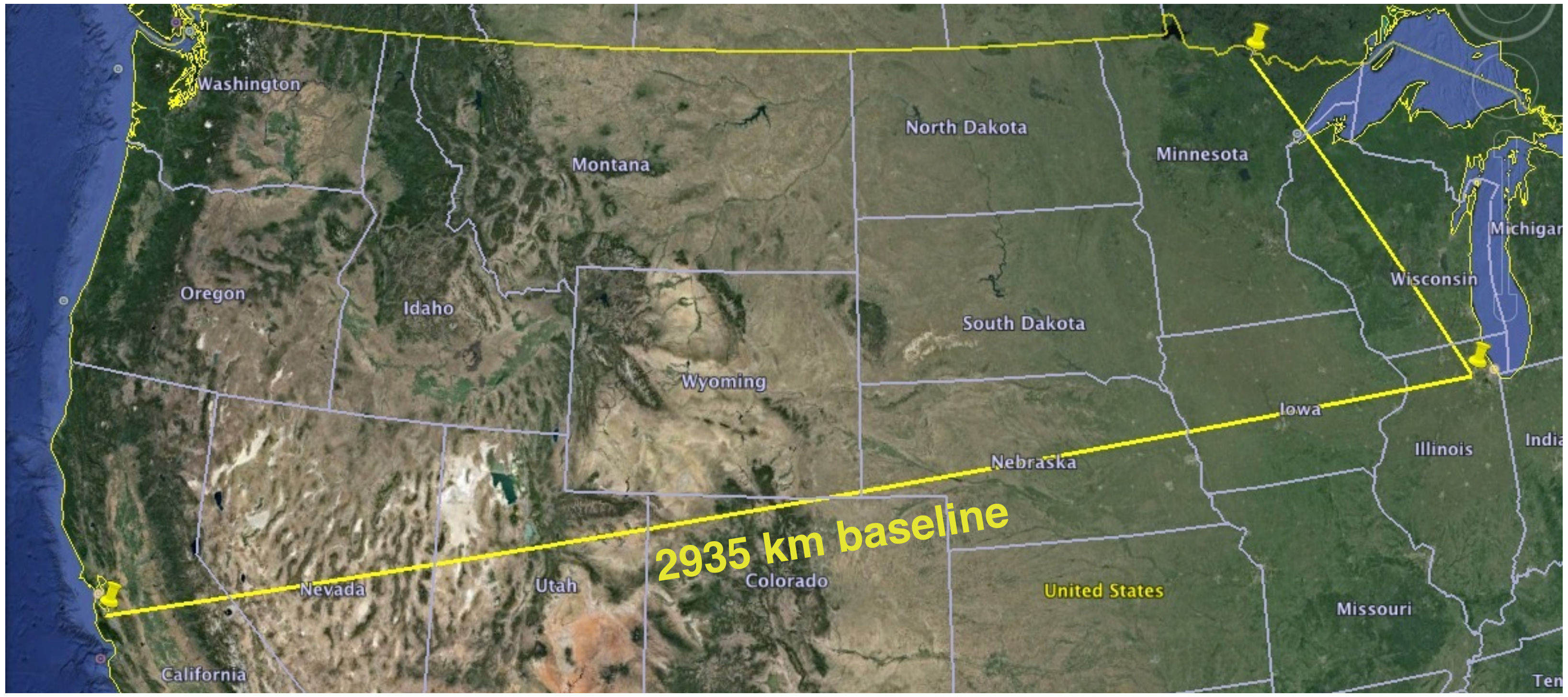
Basic Assumptions:

The NOVA detector is placed at a new location (at SLAC) with identical characteristics.

The NuMI beam and the near detector rotate accordingly, without changing their current characteristics or relative positions.



NOvA official



What effects does L have in the design and physics reach of neutrino oscillation experiments?

Changing the Baseline

$$P_{\mu e} \simeq P_{e\mu} \simeq \sin^2\theta_{23}\sin^2 2\theta_{13}^{\rm eff}\sin^2\left(\frac{\Delta_{13}^{\rm eff}L}{2}\right),$$

$$\sin^2 2\theta_{13}^{\rm eff} = \frac{\Delta_{13}^2\sin^2 2\theta_{13}}{(\Delta_{13}^{\rm eff})^2},$$

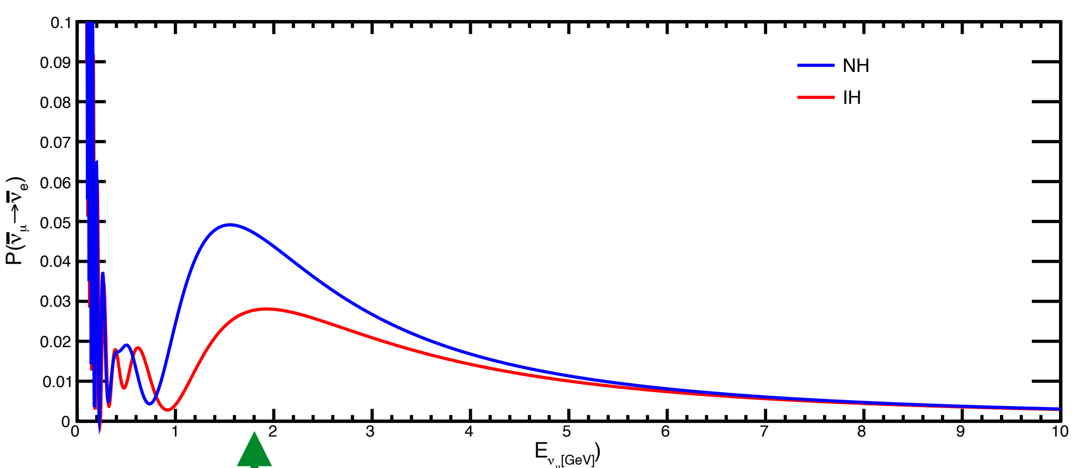
$$\Delta_{13}^{\rm eff} = \sqrt{(\Delta_{13}\cos 2\theta_{13} - A)^2 + \Delta_{13}^2\sin^2 2\theta_{13}},$$

$$\Delta_{13} = \frac{\Delta m_{13}^2}{2E},$$

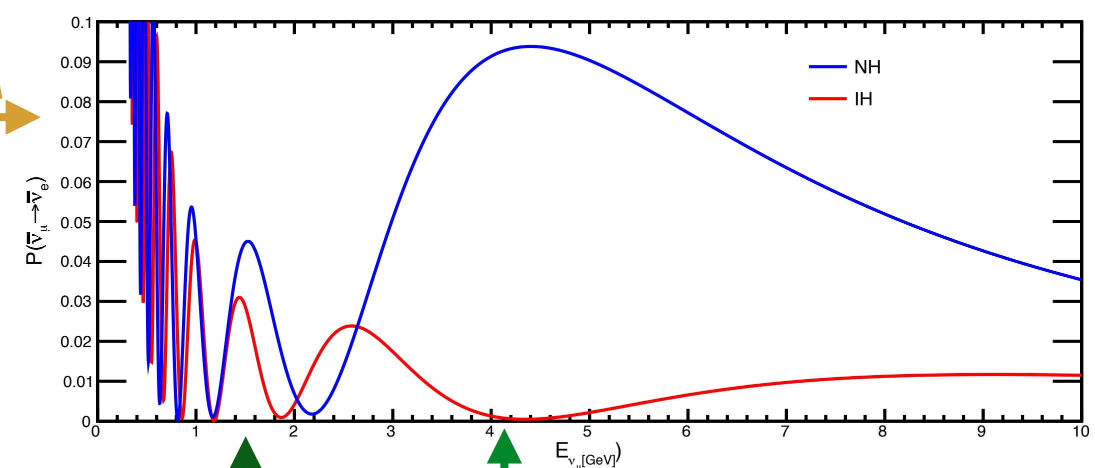
From Neutrino Basics II

The matter effect becomes more important at longer baselines. $A \equiv \pm\sqrt{2}G_F N_e$

Thus, this affects the normal and inverted hierarchy cases differently.



SuperNOvA



From GLoBES
$\sin^2 2\theta_{13} = 0.1,$
$\sin^2\theta_{23} = 0.5,$
$\Delta m_{31}^2 = 2.4 \times 10^{-3}\ \mathrm{eV}^2,$
$\delta = 1.5\pi$

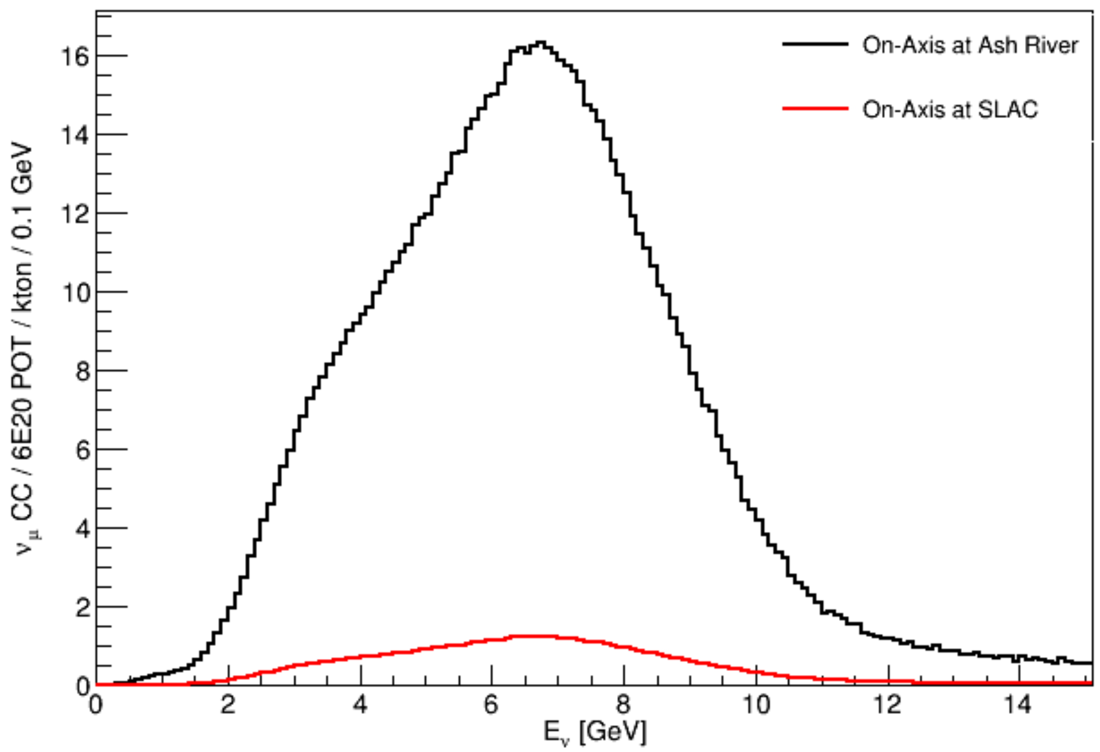
Oscillation maximum for NOvA original baseline

New oscillation maximum (minimum for NH). Higher than for NOvA original baseline

New second oscillation maximum is comparable to the first maximum for NOvA original baseline

What is the optimal L/E for best physics reach?

Flux changes



The most adverse effect of increasing L is in the neutrino flux.

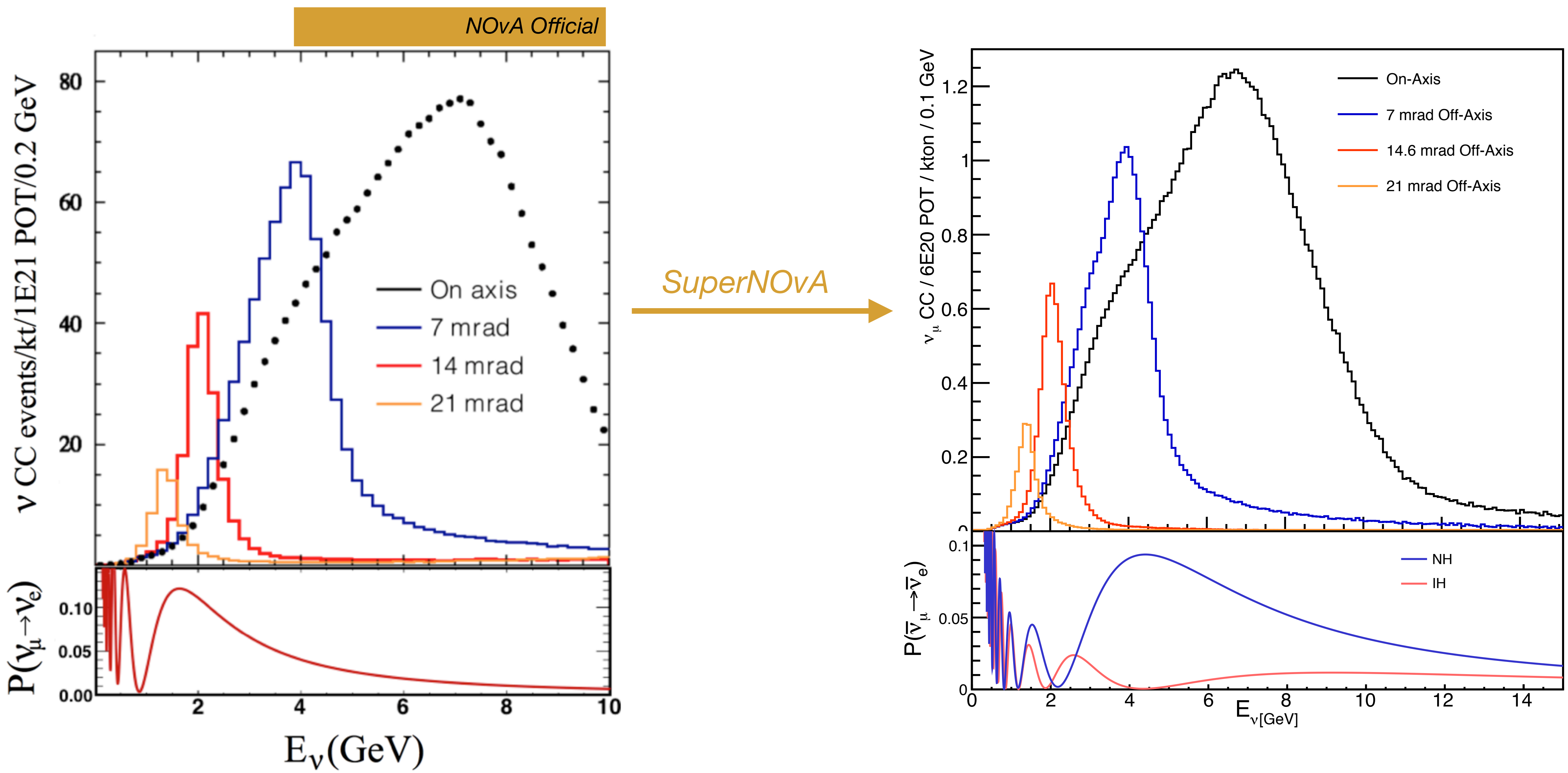
At 2935km from the NuMI beam, the flux would be ~an order of magnitude smaller than that at 810km!

What is the optimal L/E for best physics reach?

-Maximize the flux and the oscillation probability.

Super NuMI **Off-Axis** νe Appearance

The Off-Axis technique exploits π decay kinematics to get a narrower spectrum at a higher flux!



We can pick an off axis angle to maximize either oscillation maximum.

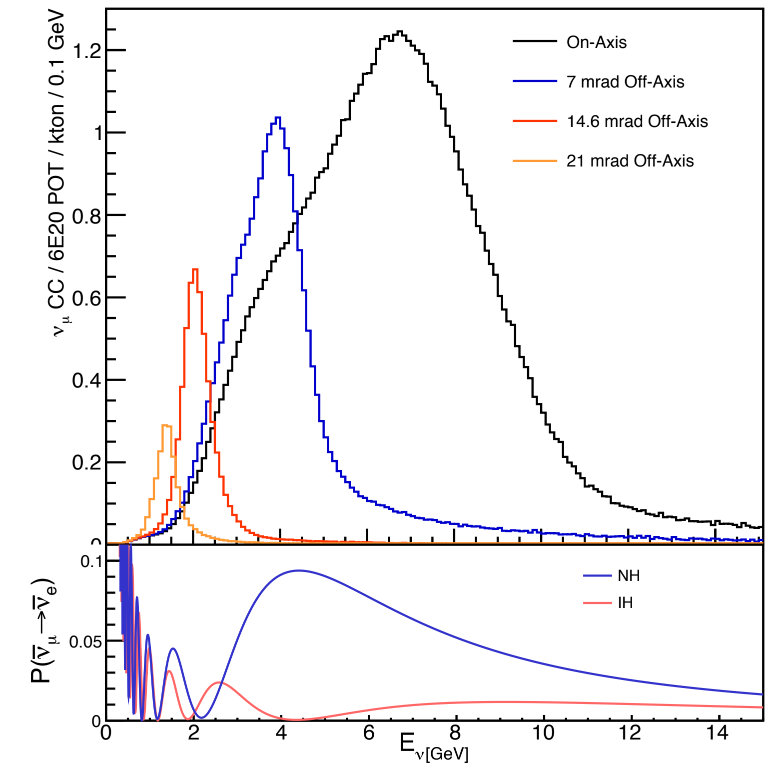
How are our measurements and sensitivities affected by this choice?

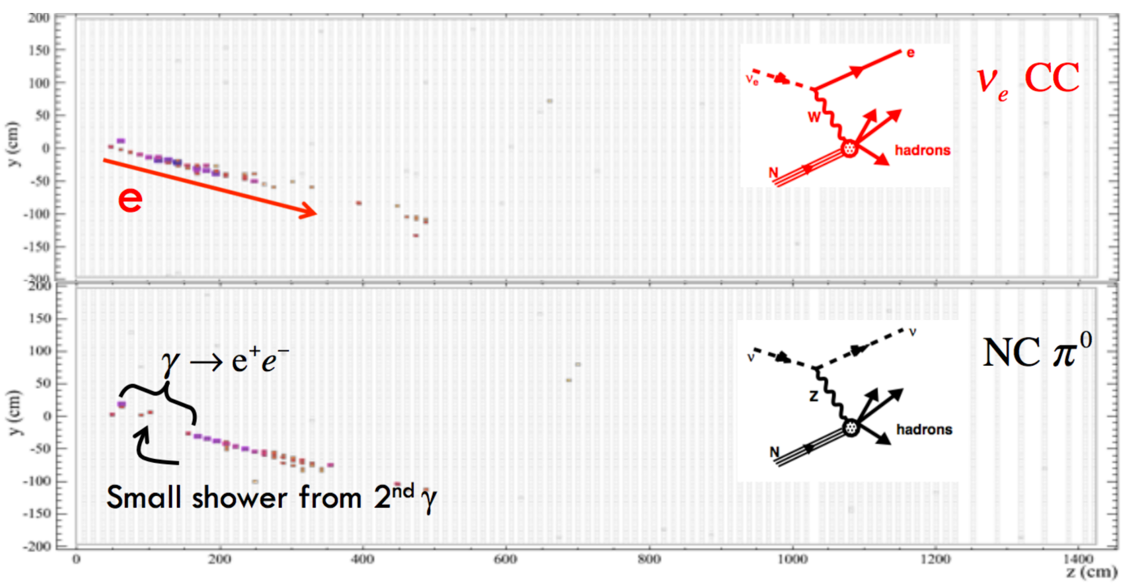
Signal to Background

The broader energy spectrum also means more background events.

	Total Bkg	Beam ν_e	NC	ν_μ CC	ν_τ CC	Cosmic
LID	**0.94 ± 0.09**	**0.47**	**0.36**	**0.05**	**0.02**	**0.06**
LEM	1.00 ± 0.11	0.46	0.40	0.07	0.02	0.06

From the NOvA Results





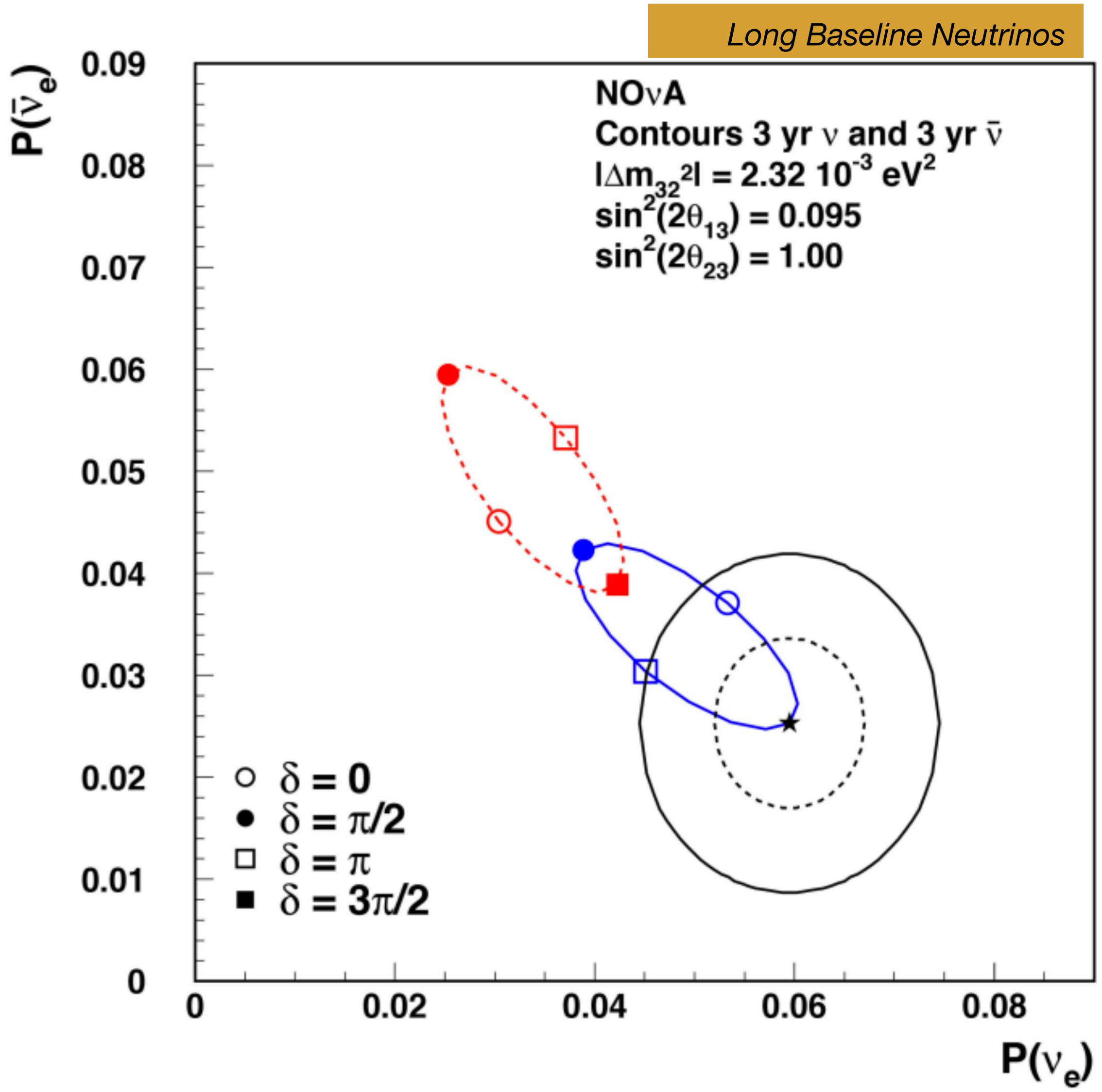
NOvA Official

Cosmic backgrounds under control, our main backgrounds come from the beam composition.

The broader spectrum at 7mrad would significantly increase the amount of beam background events per signal ν_e events.

Super NuMI **Off-Axis** νe Appearance

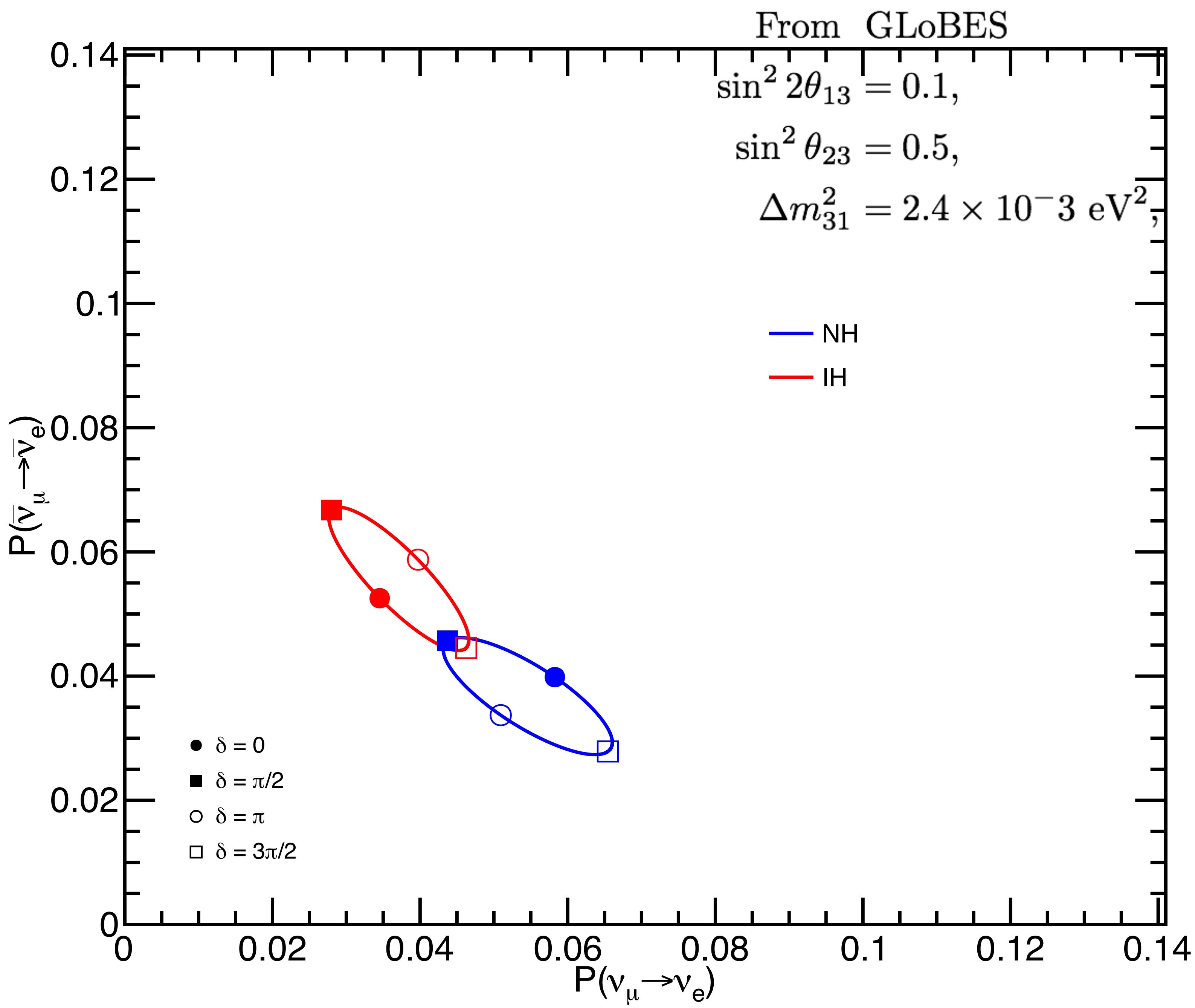
Ultimately, we want to measure the mass ordering and the value of δcp.



NOvA case:
Good resolution for mass hierarchy and most values of δcp.

Super NuMI **Off-Axis** νe Appearance

Ultimately, we want to measure the mass ordering and the value of δcp.

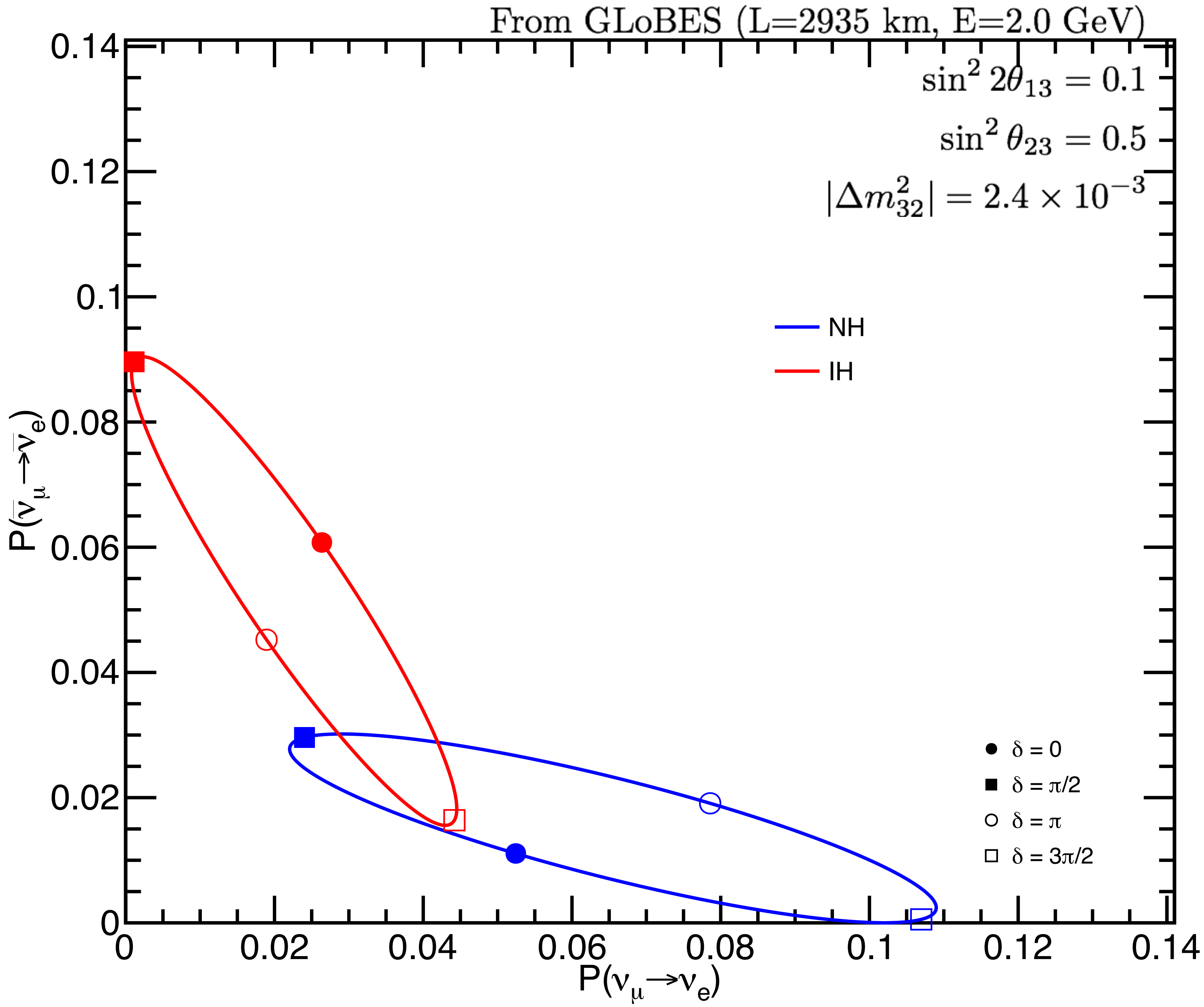


NOvA case:

Good resolution for mass hierarchy and most values of δcp.

Super NuMI **Off-Axis** νe Appearance

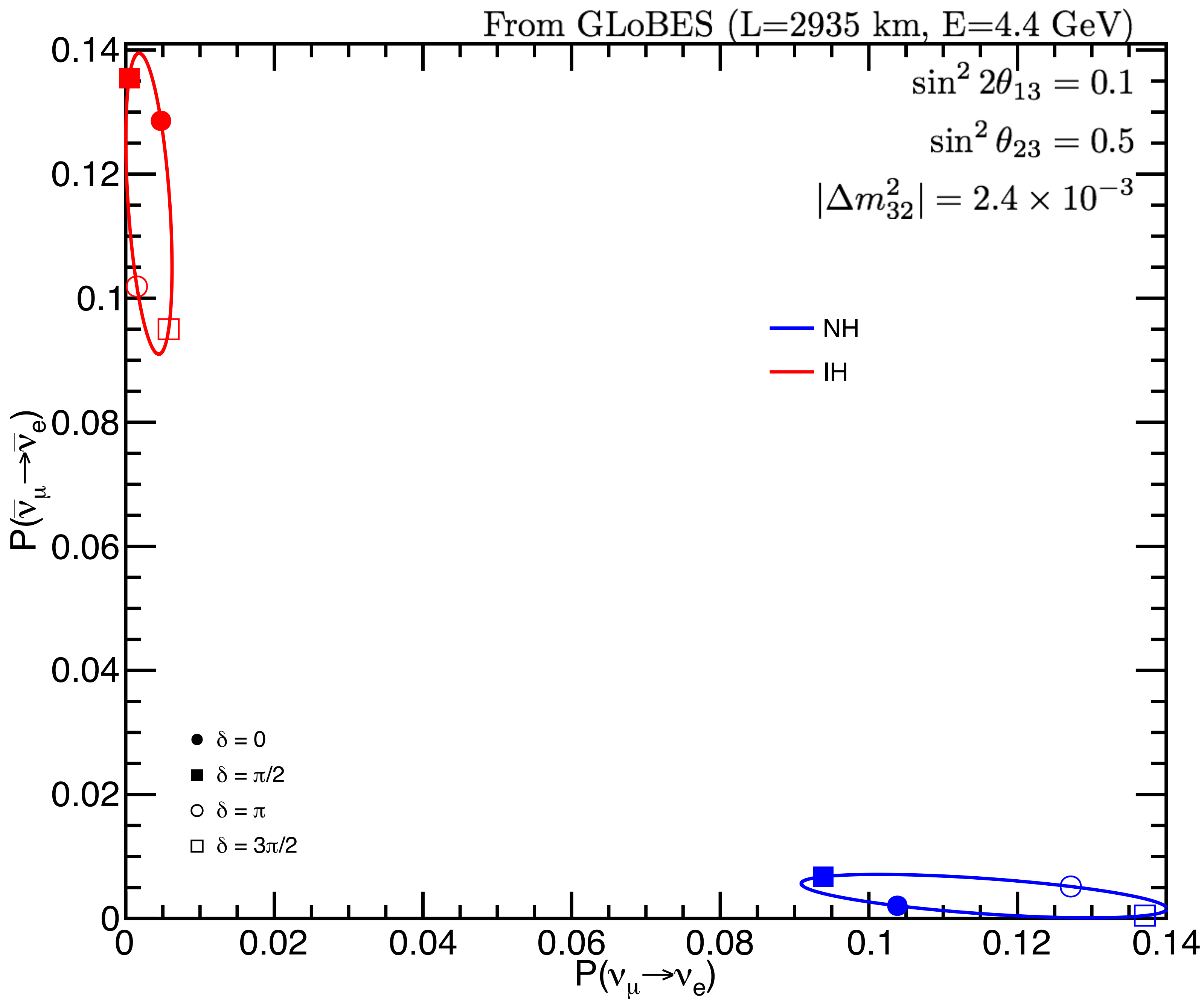
Ultimately, we want to measure the mass ordering and the value of δcp.



SuperNOvA second max:
Very poor resolving power for the mass ordering. Improved sensitivity to δcp, provided that the hierarchy is known.

Super NuMI **Off-Axis** νe Appearance

Ultimately, we want to measure the mass ordering and the value of δcp.



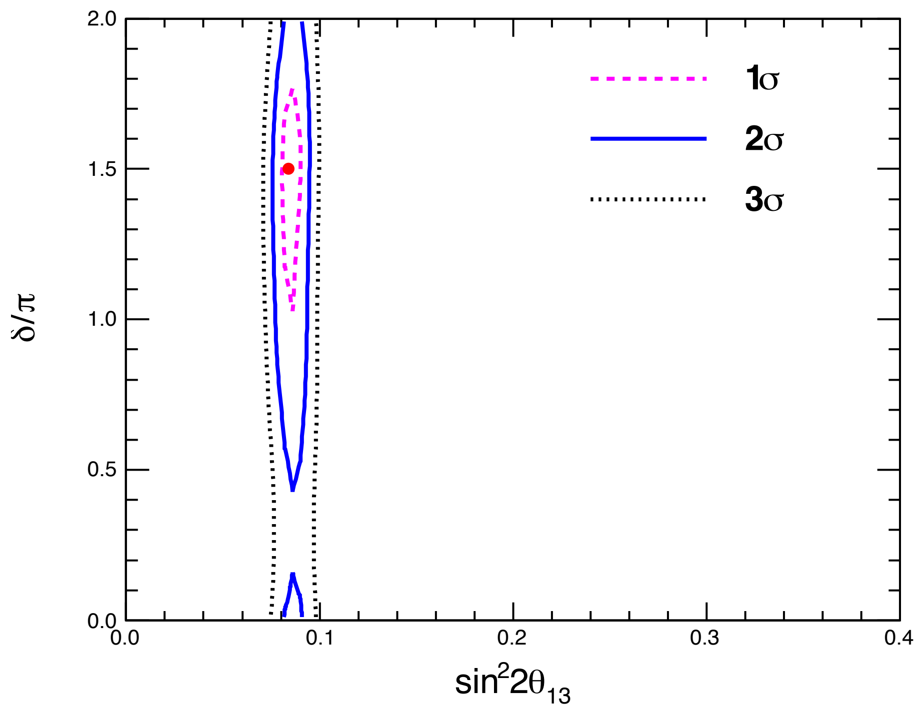
SuperNOvA first max:
Very good resolving power for mass ordering.
Poor δcp resolution.

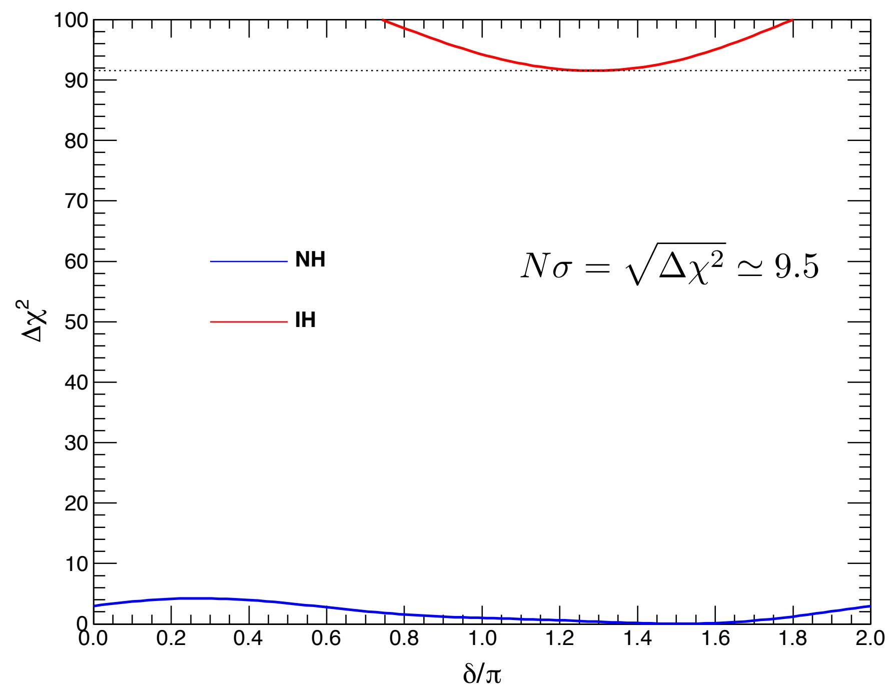
SuperNOVA Sensitivity Analysis

To further compare our two options for L/E we ran simulations to estimate the hierarchy and δcp sensitivities for the first and second oscillation maxima.

- We used GLoBES for producing the events spectra and the statistical analysis.
- Assuming the same nominal exposure of NOvA
- We varied $\theta_{13}, \theta_{23}, \delta, \Delta m^2_{31}$ in their current errors given by other experiments.
- δ is free

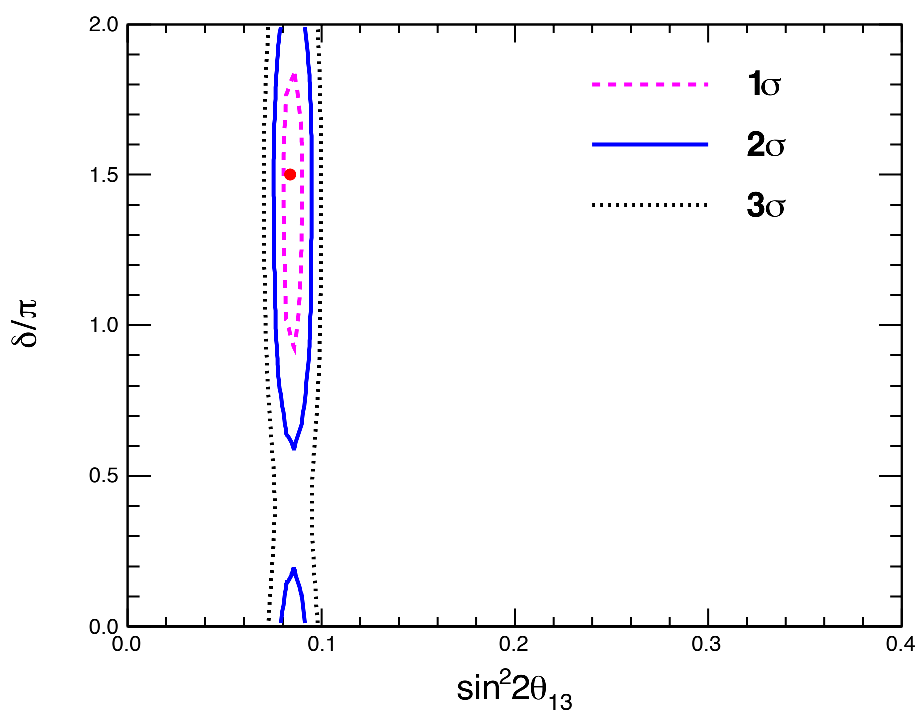
SuperNOVA Sensitivity Analysis

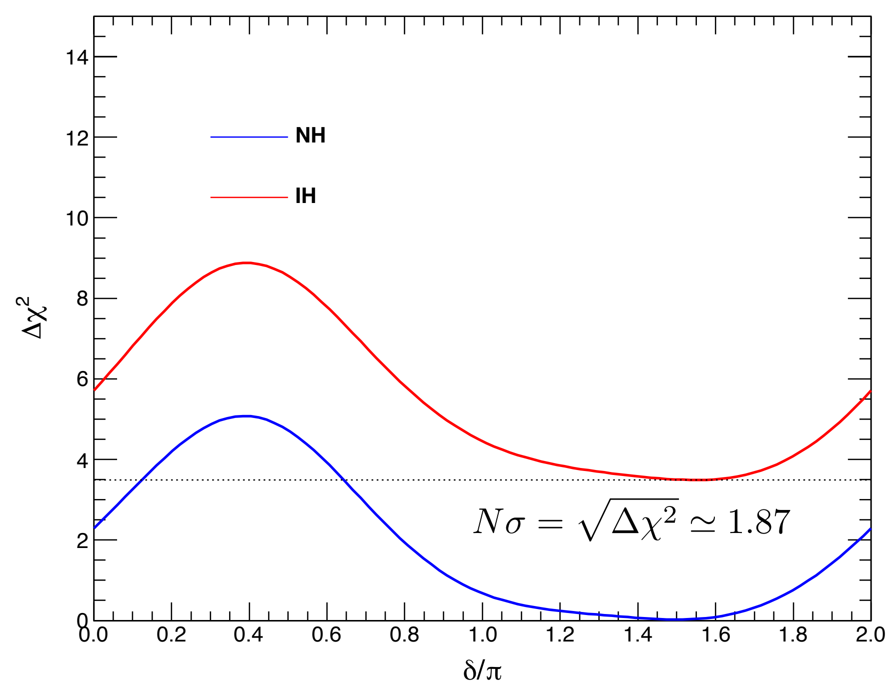




NOvA 7 mrad off-axis

Less sensitivity to δcp wrt NOvA (each value allowed at 3σ), but increased hierarchy discrimination, even with less statistics, because of the strong matter effects.





NOvA 14 mrad off-axis

Less sensitivity to δcp wrt NOvA (each value allowed at 3σ).

Less sensitivity to hierarchy discrimination.

Conclusions

Increasing L enhances the contribution of the matter effect to the measurement but decreases the flux greatly.

The first oscillation peak for SuperNOvA introduces much larger beam background contributions but has excellent resolving power for mass hierarchy. This is not the case for δcp.

In principle, the second oscillation peak has higher sensitivity to δcp than the first one but extremely low statistics at the 14mrad required.

SuperNOvA could not make a good measurement of both the hierarchy and δcp.

The precision for the second could be improved with significant increases in the beam intensity or the detector mass or by using the on-axis spectrum with careful treatment of the background.

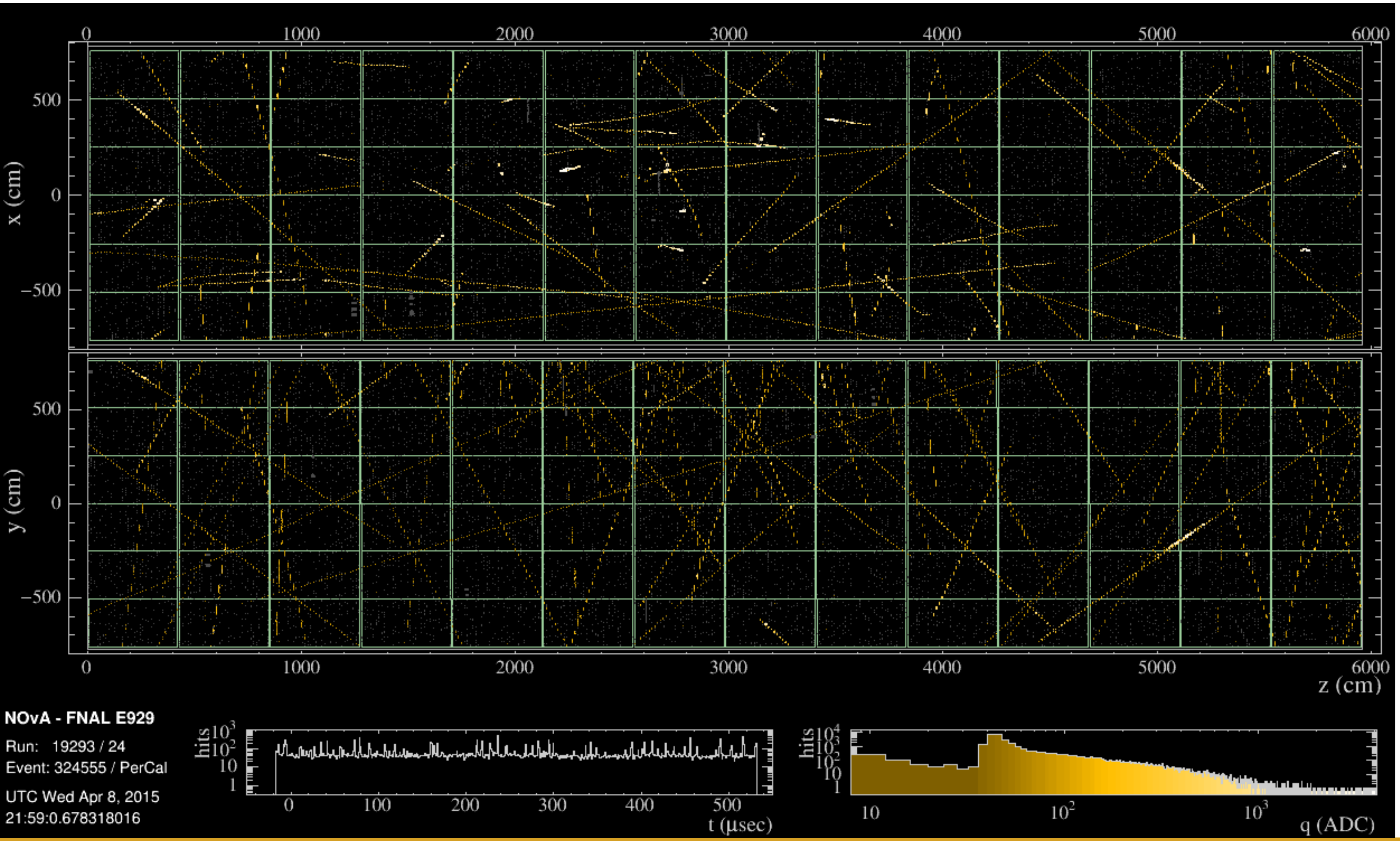
Signal to Background

No major change is expected on the cosmic background.

According to Google Earth, the altitude difference between Stanford and AshRiver, MN is negligible (~200m).

	Total Bkg	Beam ν_e	NC	ν_μ CC	ν_τ CC	Cosmic
LID	**0.94 ± 0.09**	**0.47**	**0.36**	**0.05**	**0.02**	**0.06**
LEM	1.00 ± 0.11	0.46	0.40	0.07	0.02	0.06

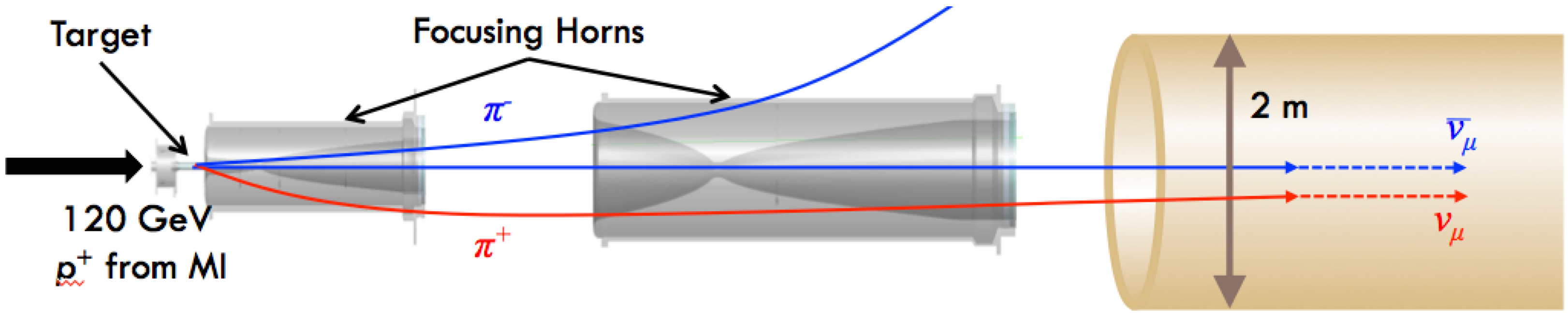
From the NOvA Results



NOvA already achieves better than 1 in 10^8 cosmic rejection with containment, timing and angle cuts alone.

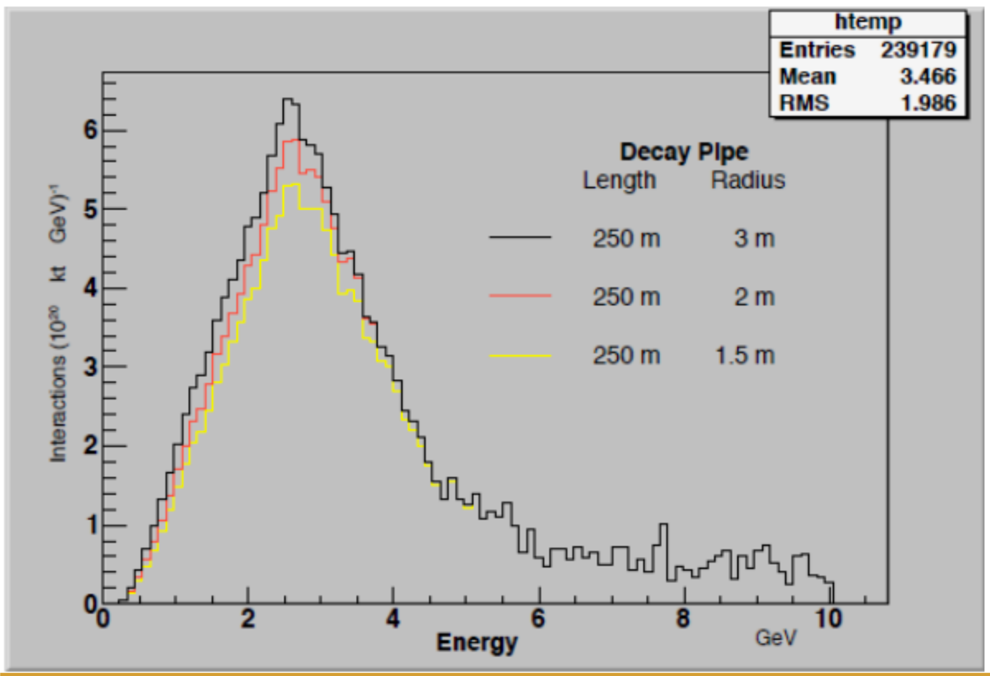
Thus, we expect any other effects on the cosmic flux on SuperNOvA (mainly from the Earth's magnetic field) to be negligible.

Beam Improvements



Studies have been done (especially for LBNE) for beam optimizations which result in higher fluxes at low energies. Based on the following:

$$E_\nu = \frac{0.427 E_\pi}{(1+\gamma^2\theta^2)} \qquad Flux = \left(\frac{2\gamma}{1+\gamma^2\theta^2}\right)^2 \frac{1}{4\pi r^2}$$



Most improvements in this study come from:

Horn focusing (radius and current)

Distance between horn and target.

From http://www.fnal.gov/directorate/lbne_reconfiguration/files/LBNE-Reconfiguration-NuMI-beam-August2012.pdf

Off-Axis Spectra comparison