NOνA

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On behalf of the NOνA Collaboration

College of William and Mary

APS April Meeting

April 30, 2011

Neutrinos

- Neutrinos can be described in one of two bases, the weak (ν_e ν_μ ν_τ) eigenstates when they are created and detected and the mass (ν_1 ν_2 ν_3) eigenstates when they travel through space
- Neutrinos can oscillate between the three flavor states

flavor eigenstates → $$|\nu_\alpha\rangle = \sum_{i=1}^{3} U^*_{\alpha i} \, |\nu_i\rangle$$ ← mass eigenstates

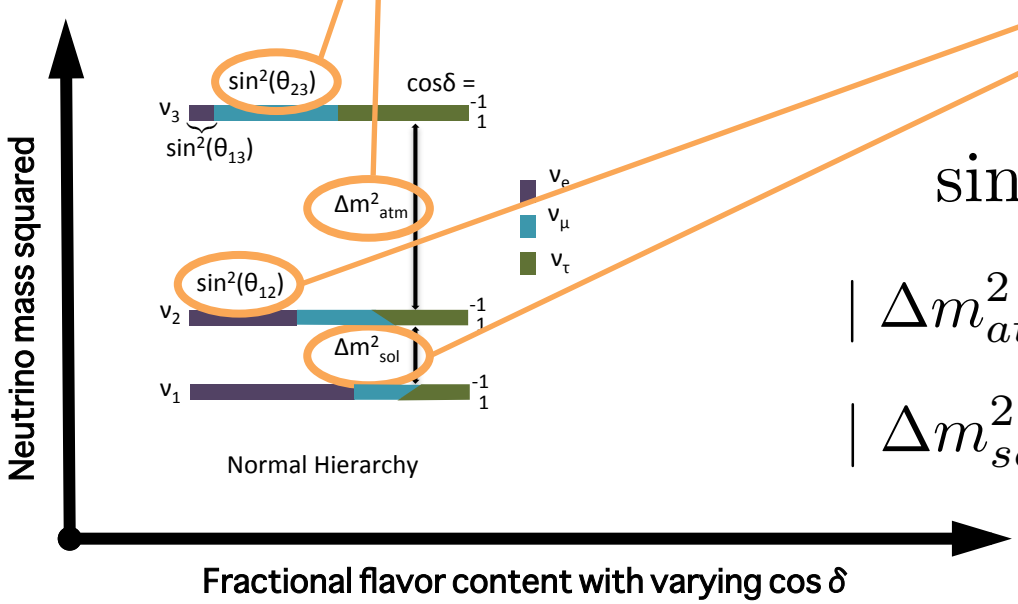
$$U = \overbrace{\underbrace{\begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix}}_{\substack{\text{atmospheric} \\ \nu_\mu \to \nu_\tau}} \underbrace{\begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{pmatrix}}_{\substack{\text{atmospheric} \\ \nu_\mu \to \nu_e}} \underbrace{\begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}}_{\substack{\text{solar} \\ \nu_e \to \nu_{\tau,\mu}}}}^{\text{unitary mixing matrix}}$$

$c_{ij} = cos\theta_{ij}$ $\quad$ $s_{ij} = sin\theta_{ij}$

- Oscillation probabilities depend on the mass splittings
- Sensitivity to a mass splitting depends on L/E of the experiment

Neutrinos: What we know

$$U = \underbrace{\begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix}}_{\substack{\text{atmospheric, L/E ~ 500km/GeV} \\ \nu_\mu \to \nu_\tau}} \underbrace{\begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{pmatrix}}_{\substack{\text{atmospheric, L/E ~ 500km/GeV} \\ \nu_\mu \to \nu_e}} \underbrace{\begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}}_{\substack{\text{solar, L/E ~ 15,000km/GeV} \\ \nu_e \to \nu_{\tau,\mu}}}$$



$$\tan^2\theta_{12} = 0.452^{+0.035}_{-0.033}{}^{\blacklozenge}$$

$$\sin^2(2\theta_{23}) > 0.96 \text{ (at 90\% C.L.)}^{*}$$

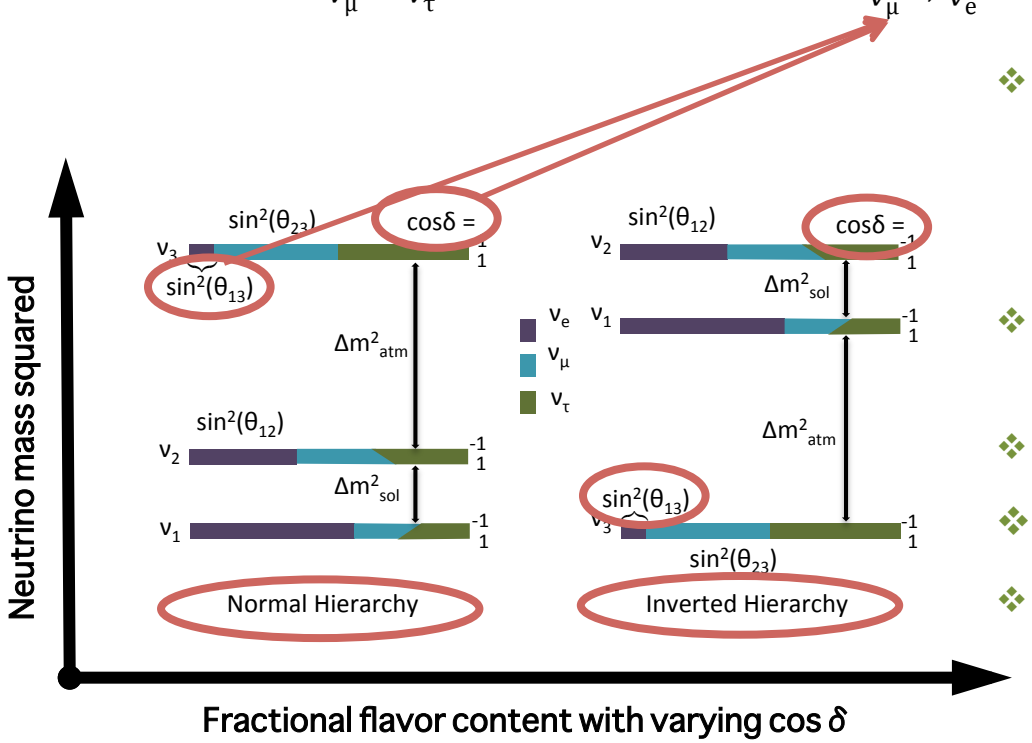
$$|\Delta m^2_{atm}| = 2.32^{+0.12}_{-0.08} \times 10^{-3}\text{eV}^{2\,\dagger}$$

$$|\Delta m^2_{sol}| = 7.50^{+0.19}_{-0.20} \times 10^{-5}\text{eV}^{2\,\blacklozenge}$$

† arXiv:1103.0340v1 [hep-ex] 2 Mar 2011
✦ Phys.Rev.D.83.052002 (2011)
*Preliminary results from SuperK at Neutrino 2010

Neutrinos: What we don't know

$$U = \underbrace{\begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix}}_{\substack{\text{atmospheric, L/E ~ 500km/GeV} \\ \nu_\mu \to \nu_\tau}} \underbrace{\begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{pmatrix}}_{\substack{\text{atmospheric, L/E ~ 500km/GeV} \\ \nu_\mu \to \nu_e}} \underbrace{\begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}}_{\substack{\text{solar, L/E ~ 15,000km/GeV} \\ \nu_e \to \nu_{\tau,\mu}}}$$



- Oscillations between ν_μ and ν_e at the atmospheric oscillation length have not yet been observed
- Neutrino mass hierarchy unknown
- Individual masses are unknown
- δ_{CP} is unconstrained
- Limits have been set on θ_{13}:

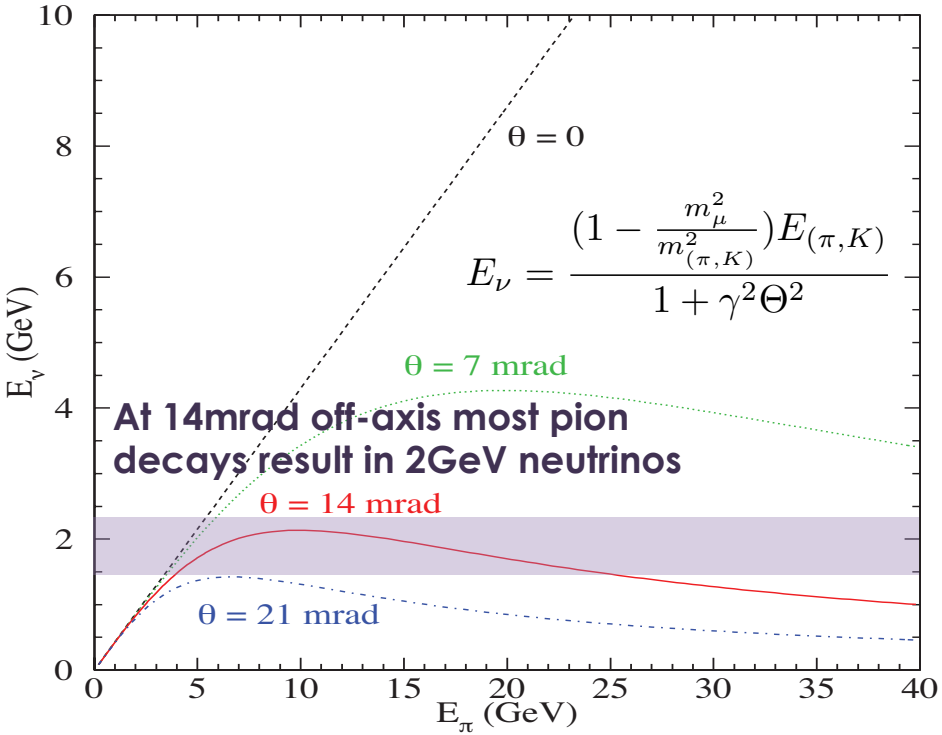
$$2\sin^2(2\theta_{13})\sin^2\theta_{23} < 0.12(0.20)^*$$

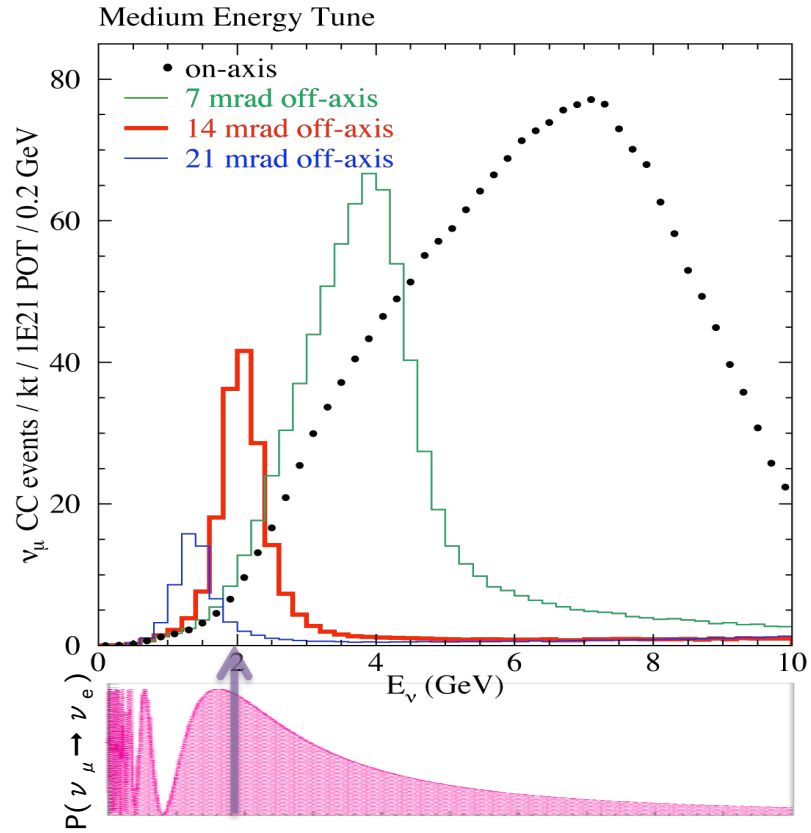
*arXiv:1006.0996v1 [hep-ex] 4 Jun 2010

NOνA

- NOνA is a second generation neutrino oscillation experiment in the NuMI beam
- Consists of two mostly active detectors filled with liquid scintillator. Near detector will be used to understand the beam at its source, and the far detector to measure oscillations.
- Optimized for the detection of $\nu_\mu \rightarrow \nu_e$ and $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ oscillations

Off-Axis





- 14mrad off-axis produces a narrow beam band peaked at ~2GeV to maximize oscillation probability
- ν_μ CC events which are a major background in MINOS are absent

- No high energy tail → reduces high energy neutral current interactions that could be background

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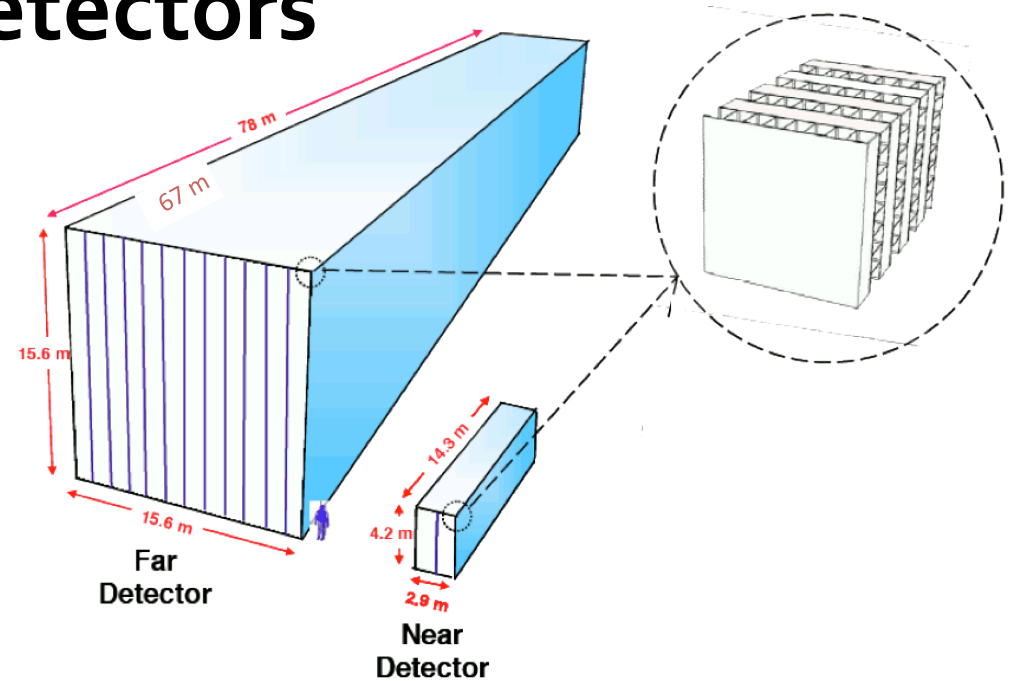
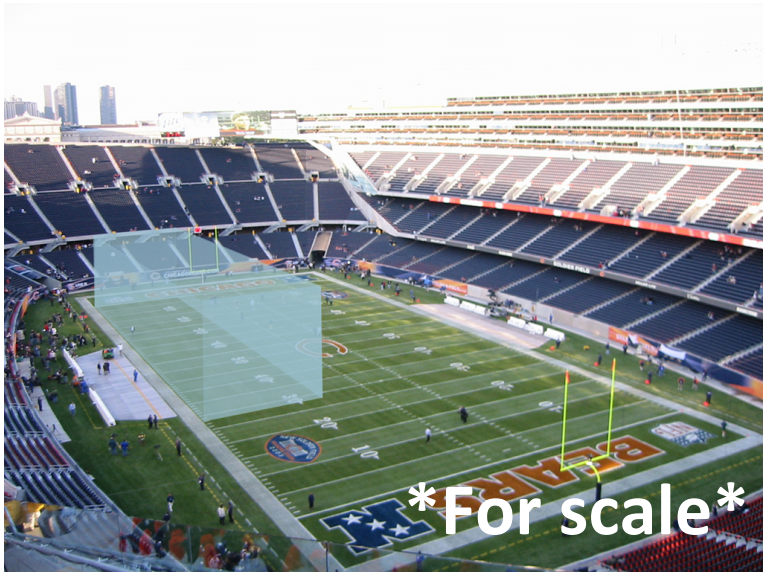
Detectors

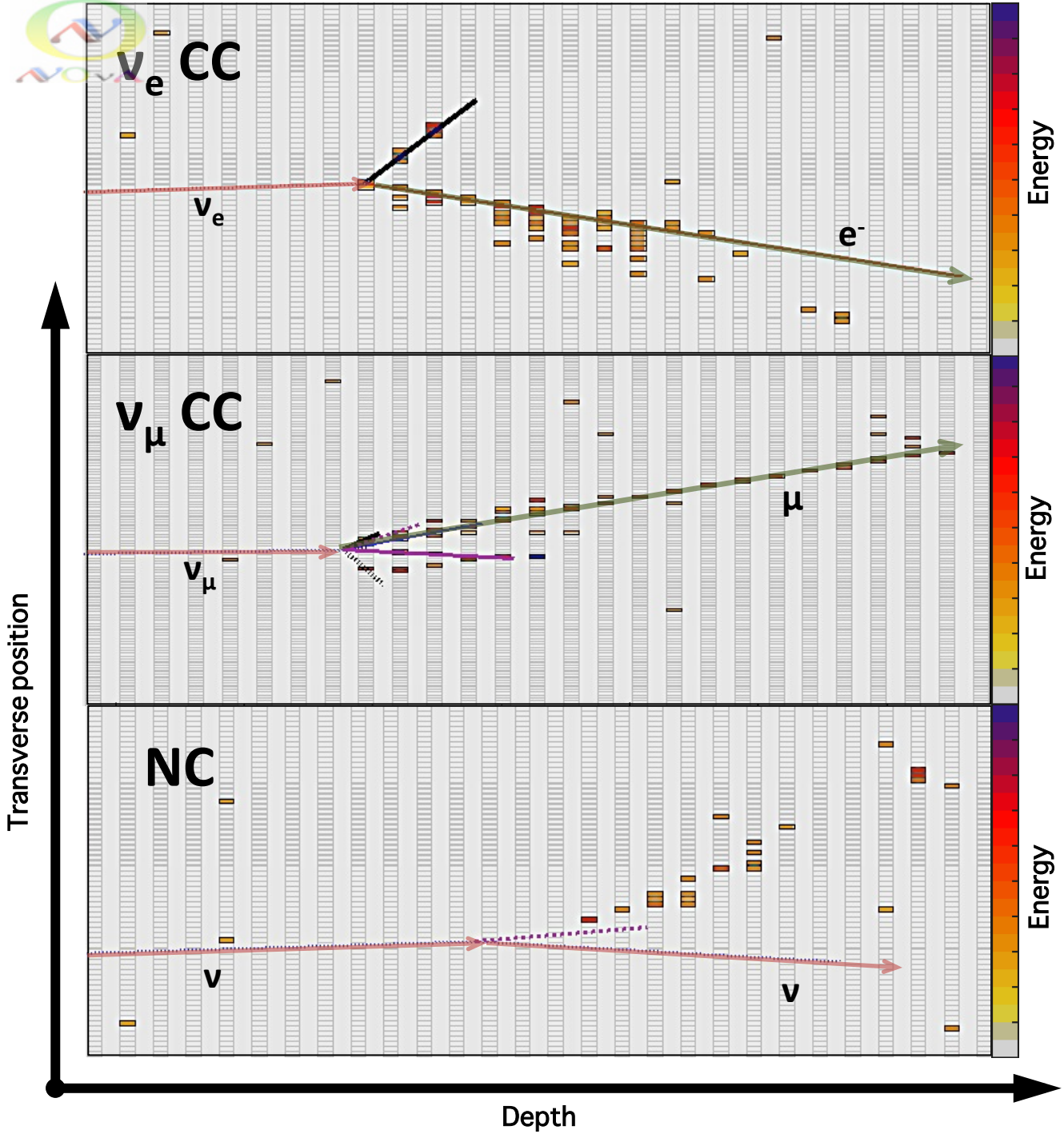
- A large detector and powerful beam are required to observe $\nu_\mu \rightarrow \nu_e$ oscillations because it is a subdominant mode
- Far detector will have 15kT total mass and 70% scintillator

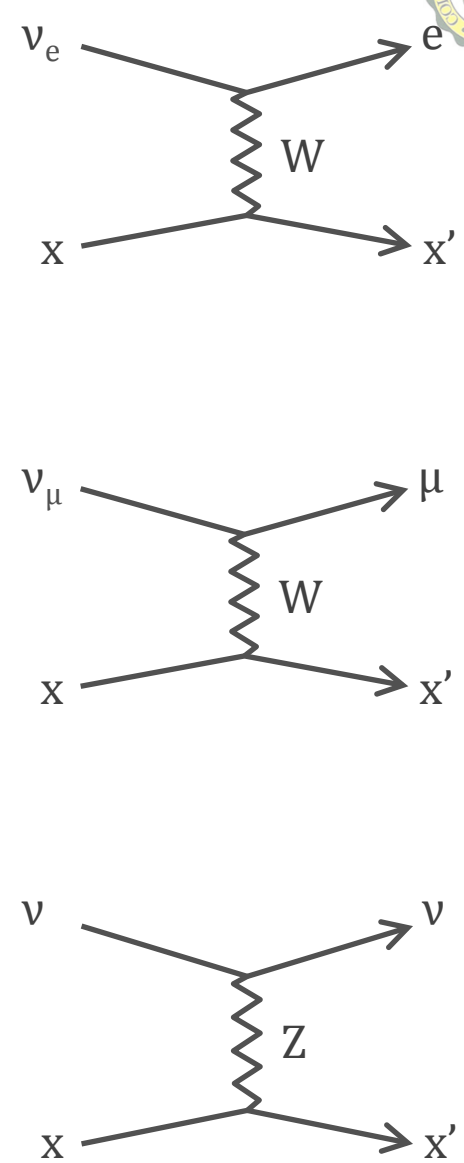




- Near detector will have 200 ton total mass
- Made up of the same extrusions and scintillator as the far detector → events look the same in both detectors, systematics cancel
- 6 samples per radiation length in NOvA corresponds to < 1samples per radiation length in MINOS

Event Topology





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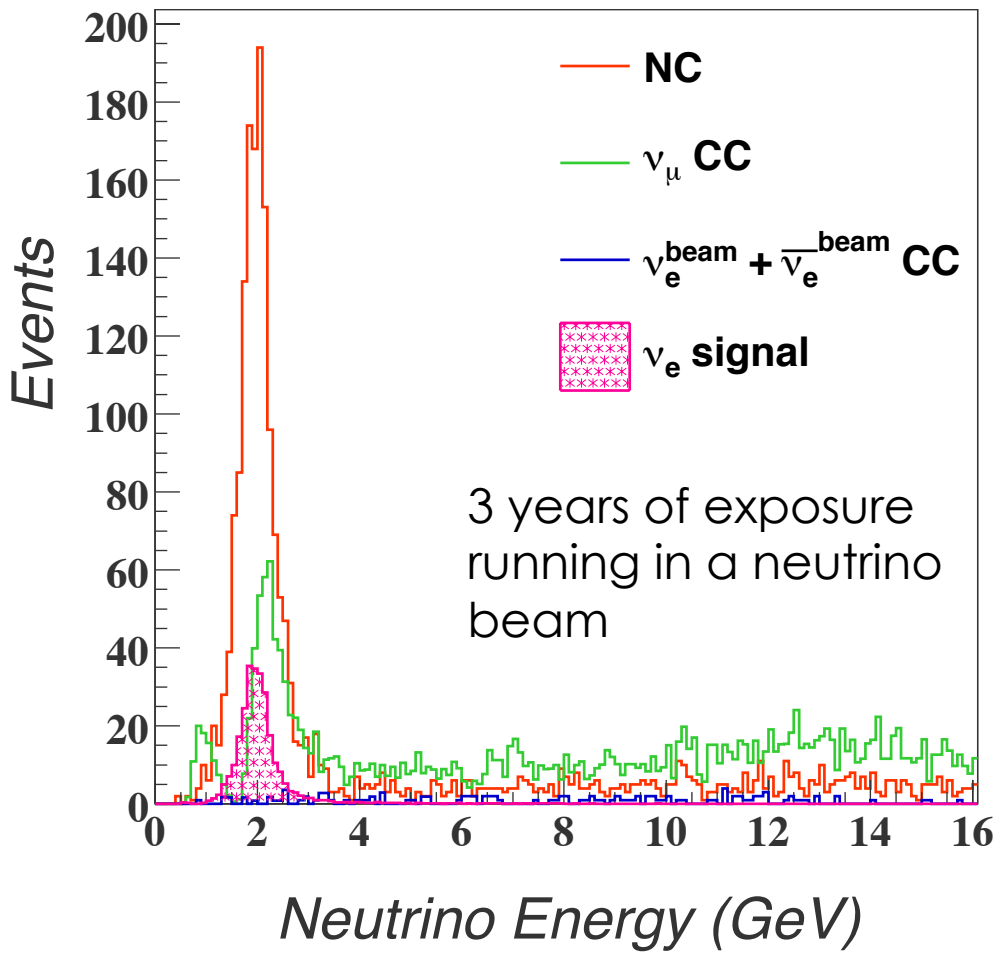
Far Detector Monte Carlo

Expected Event Rate



- Remove obvious background by making cuts on certain variables. Optimize cuts by calculating a figure of merit (FoM)

$$FoM = \frac{signal}{\sqrt{background}}$$

Type of Interaction	No. of Events
ν_μ CC	2500
NC	2200
$\nu_e^{beam} + \nu_e^{beam}$ CC	120
ν_e signal	270
FoM	**3.9**

MINOS Comparison (at CHOOZ limit):

FoM	**≈ 4**

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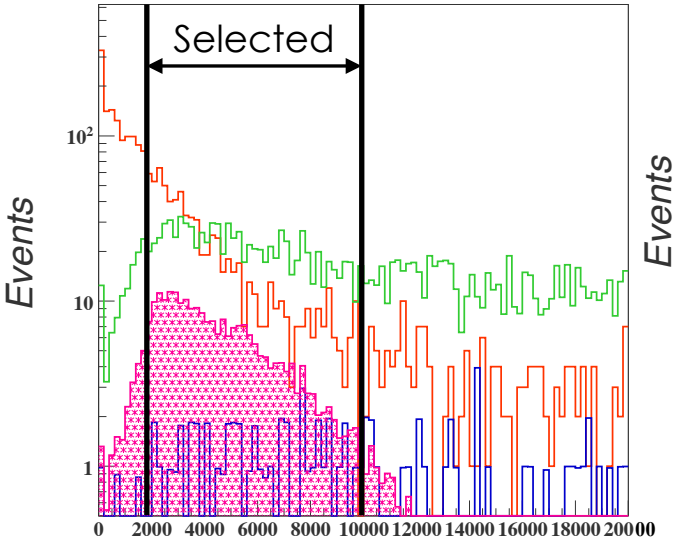
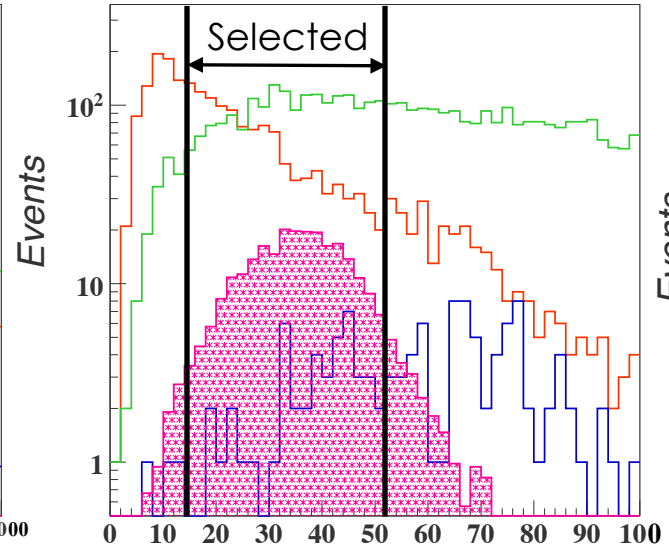
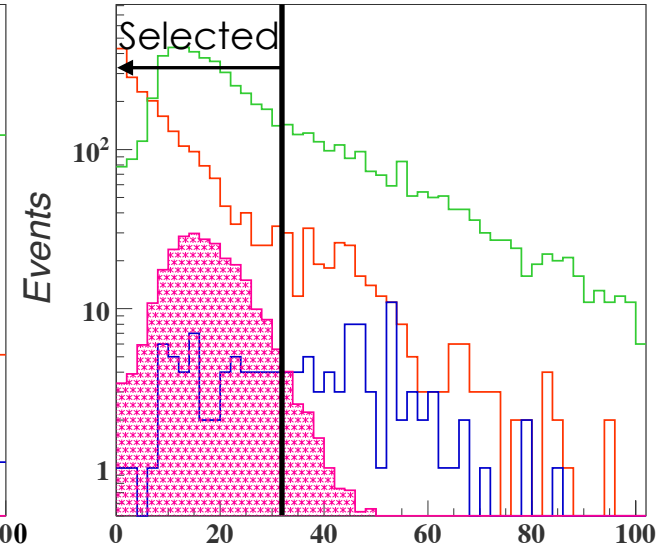
Variables To Cut On



Visible Energy



No. of Planes



Continuous No. of Planes

Visible Energy → unit of energy based on summed photoelectrons seen in the detector

No. of Planes → length of an event

Continuous No. of Planes → the length of a set of consecutive planes with hits in them

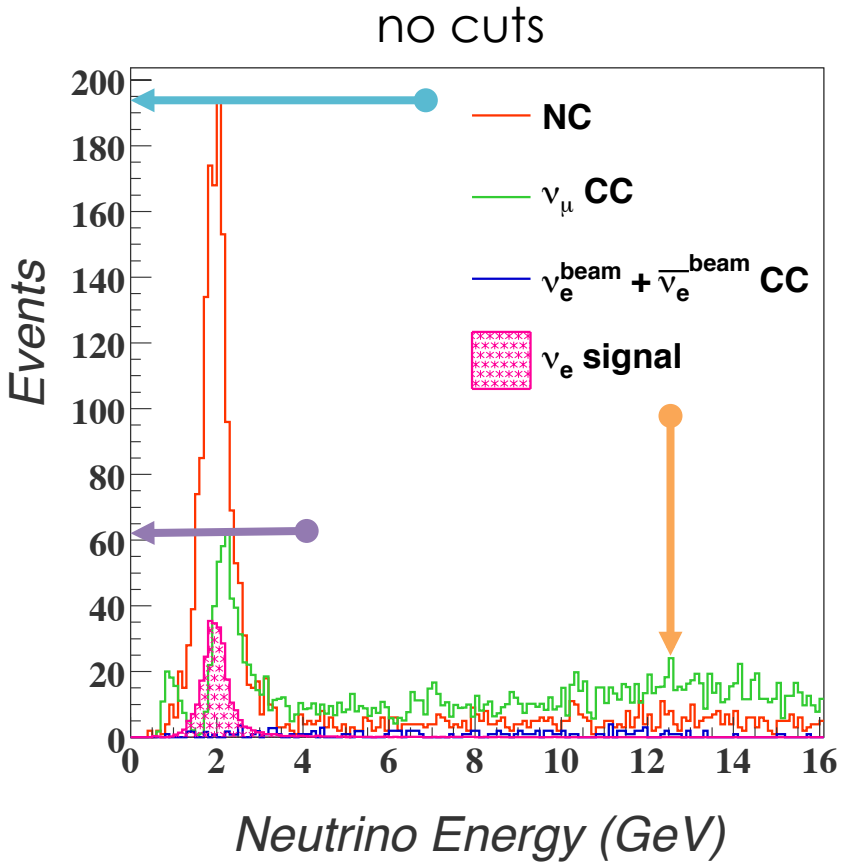
NC

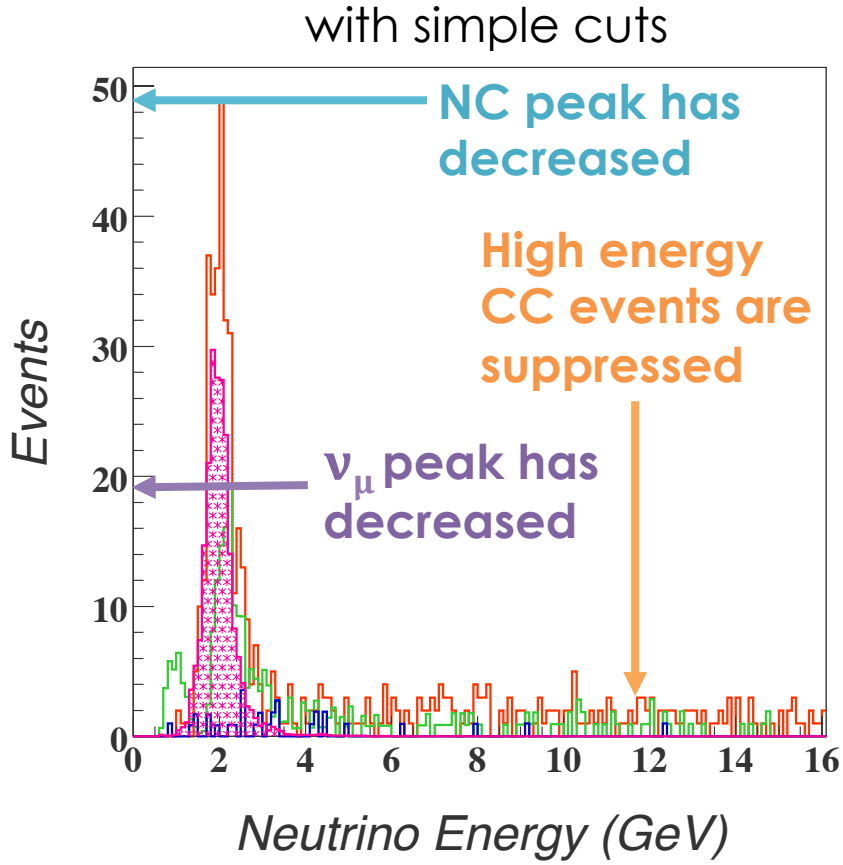
ν_μ CC

$\nu_e^{beam} + \bar{\nu}_e^{beam}$ CC

ν_e signal

Applying Simple Cuts





	No Cuts	Simple Cuts
FoM	3.9	7.1

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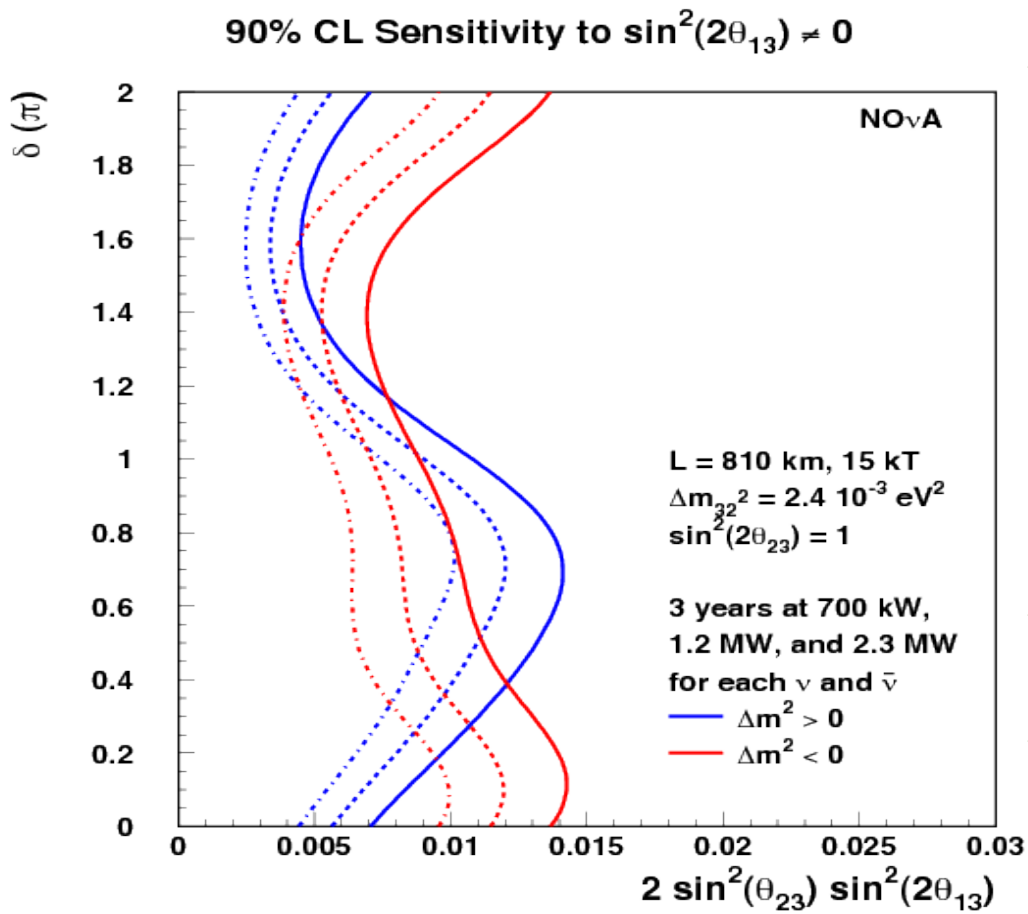
Sensitivity



90% C.L for NO ν A seeing $\nu_\mu \rightarrow \nu_e$ oscillations

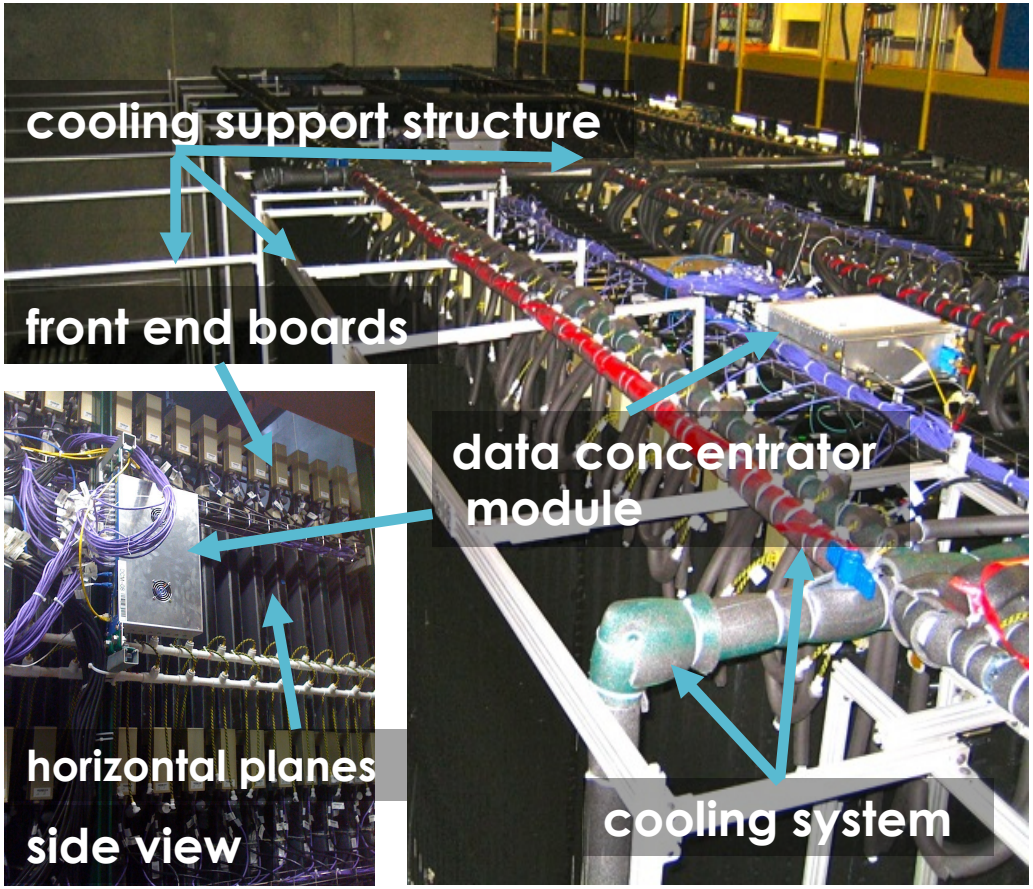
- A full PID will take into account detailed features of shower shape and energy deposition profiles

	No Cuts	Simple Cuts	Full PID
FoM	3.9	7.1	18

- Development has been done on MC
- To verify the ability to achieve the desired level of signal/ background separation, real data is needed

Near Detector On the Surface (NDOS)

- Near detector constructed on the surface in Fall 2010
- Currently taking data from the NuMI beam and the Booster beam ~107mrad off-axis

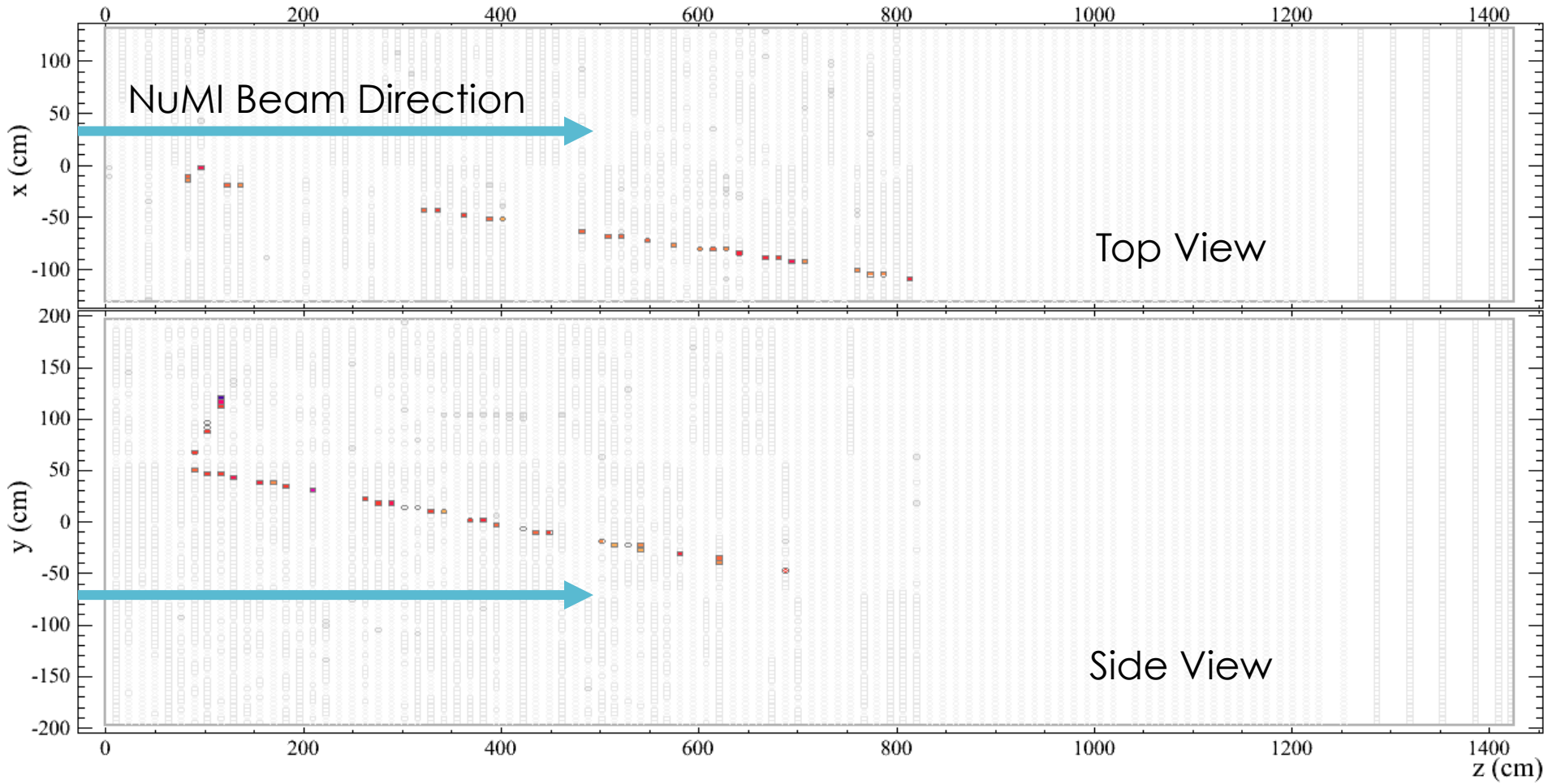


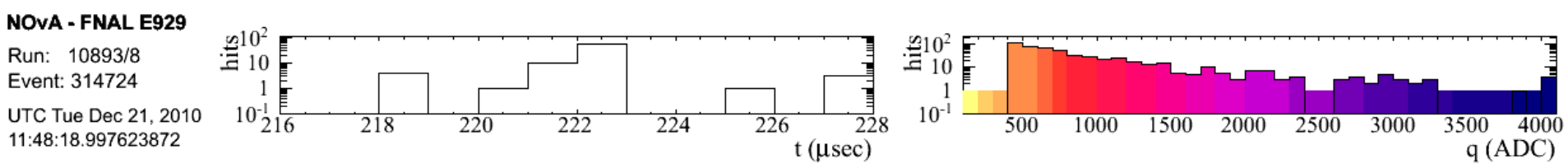
- Expected event rates for the NDOS for 2×10^{20} POT in the low-energy (LE) configuration and assuming a 20 ton fiducial mass

ν Beam	$\nu_\mu + \bar{\nu}_\mu$	$\nu_e + \bar{\nu}_e$
CC Events	4500	200
NC Events	2000	

$\bar{\nu}$ Beam	$\nu_\mu + \bar{\nu}_\mu$	$\nu_e + \bar{\nu}_e$
CC Events	3300	160
NC Events	1600	

First Look at NDOS Data





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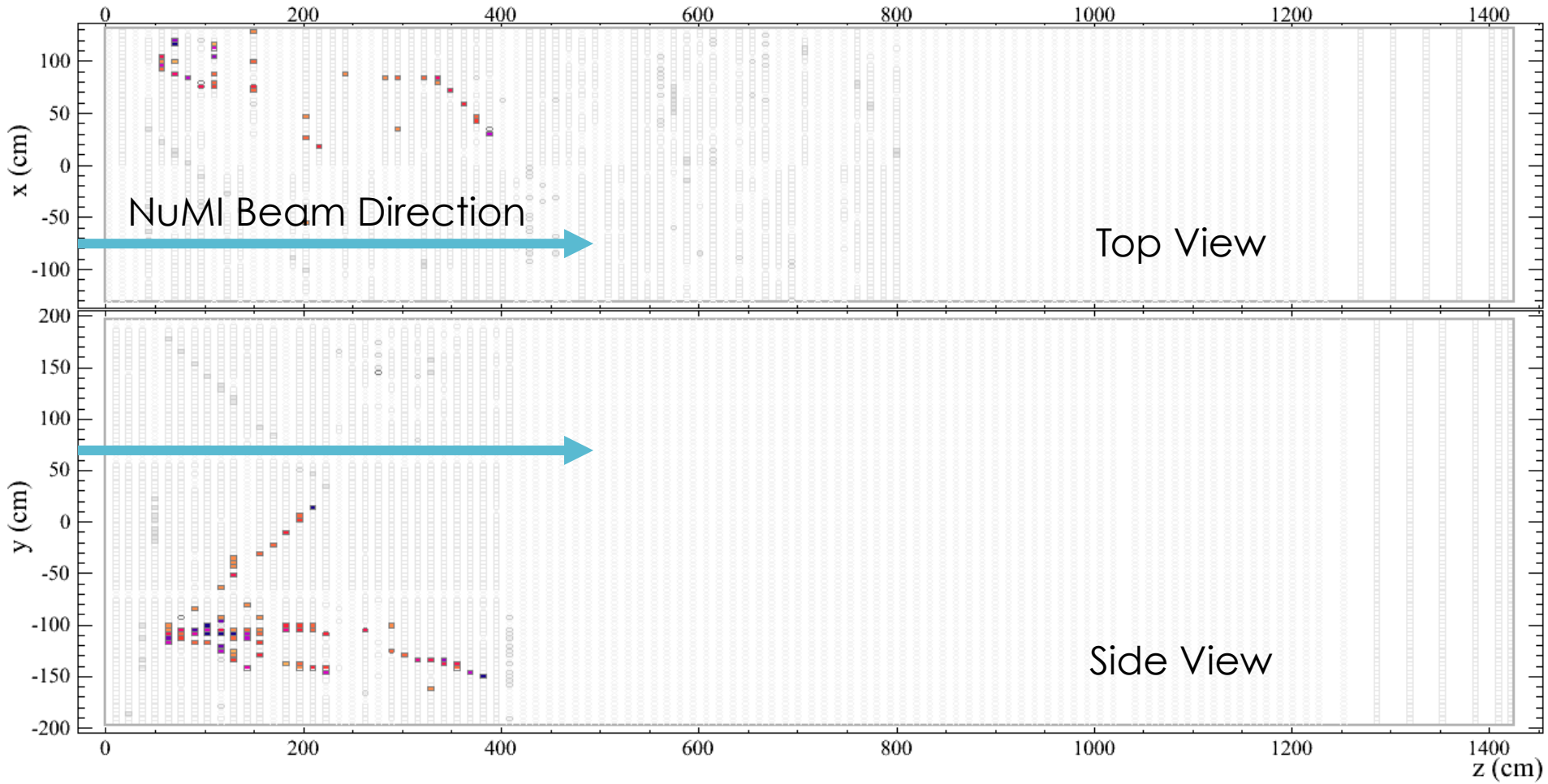

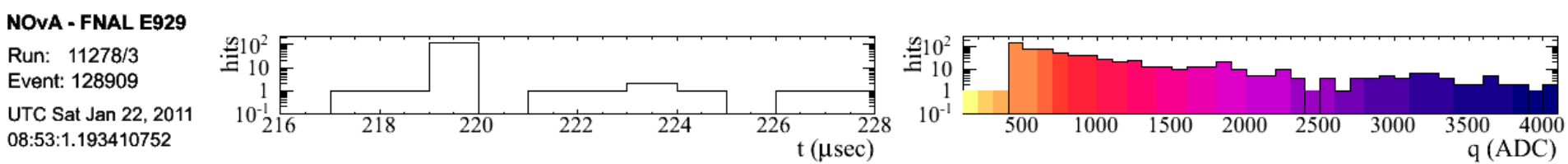

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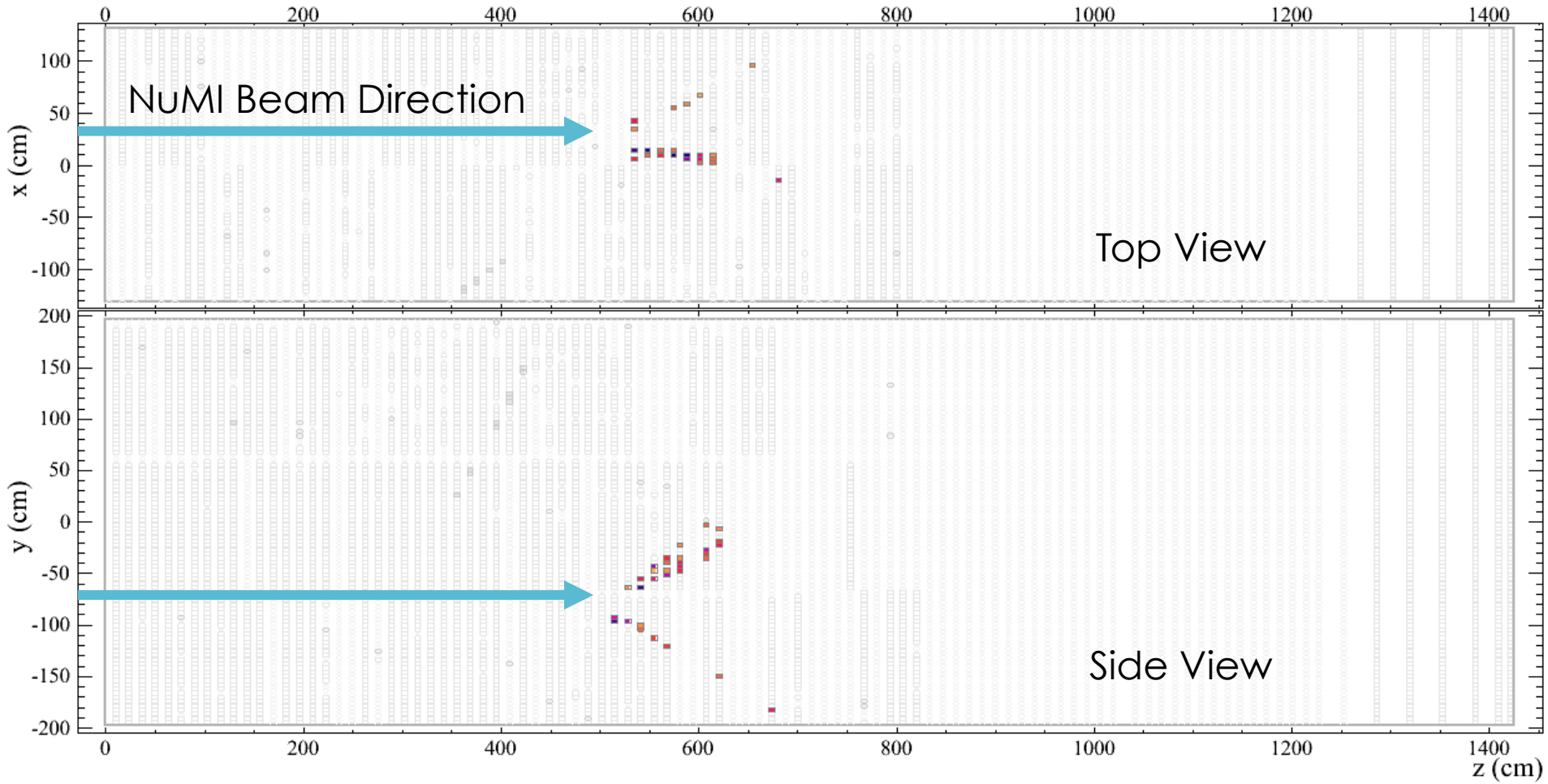

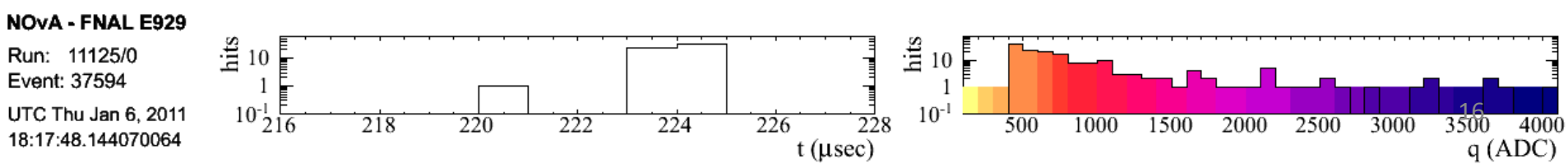

Conclusion

- NOvA has the ability to observe oscillations between ν_μ and ν_e , an oscillation that has not yet been observed at the atmospheric oscillation length
- NOvA will have an order of magnitude better sensitivity to θ_{13} than MINOS, will be able to make initial measurements on the still unconstrained δ_{CP} , and will be able to make a first estimate at the mass hierarchy
- NDOS is currently taking data from the NuMI beam and Booster beam
- NDOS will be used to verify the ability to separate signal/background