Early Neutrino Data in the NOvA Near Detector

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For the NOvA Collaboration

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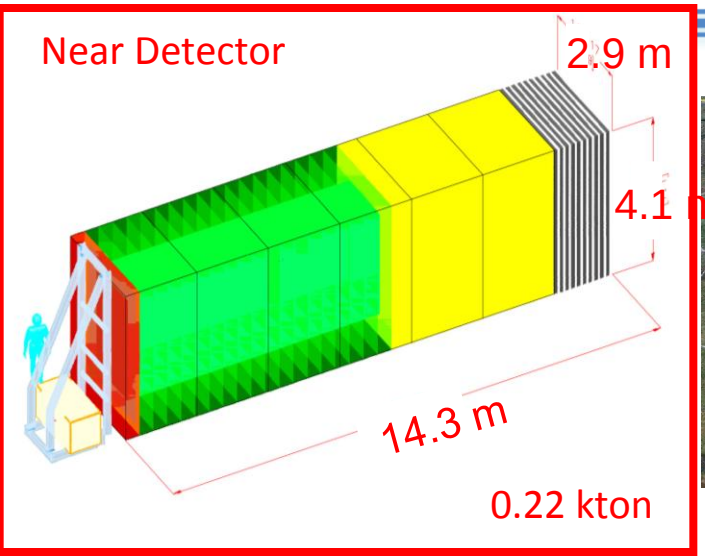
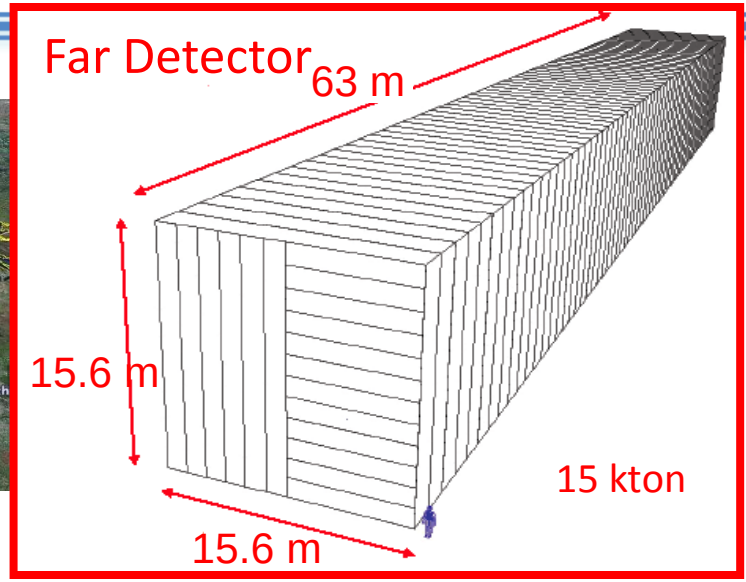
NOνA Experiment





Physics Goals for NOνA

- NOνA will study ν_e appearance in ν_μ and anti-ν_μ neutrino beam
- Measure of θ_{13} and search for the mass ordering
- Search for the CP violation phase δ
- Precise measurement of θ_{23} and Δm^2_{32}
- Cross section measurements for charged current (CC) quasi elastic (QE) and pion production

Near Detector On the Surface (NDOS)

NOνA Near Detector prototype

located on the surface at Fermilab

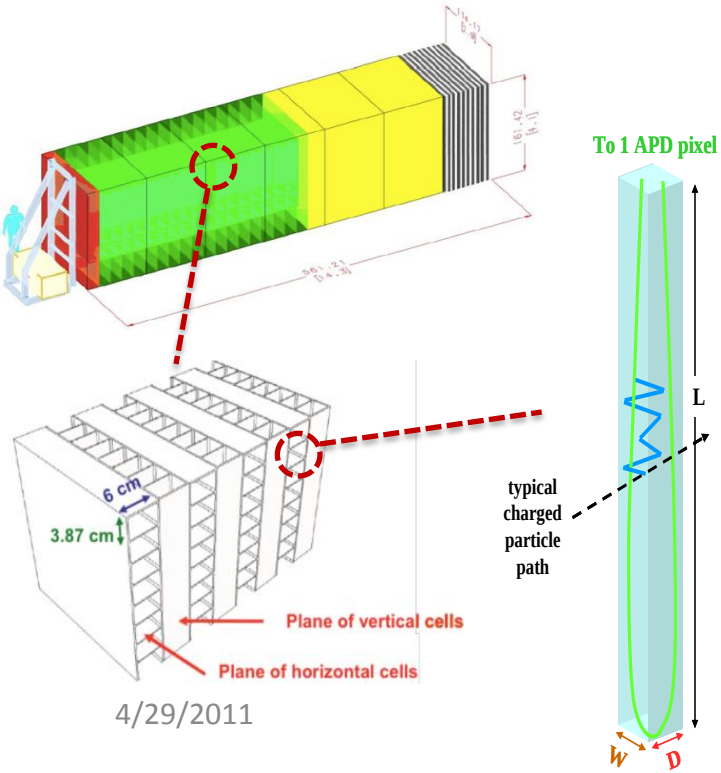
Detector made of rigid plastic(PVC)modules

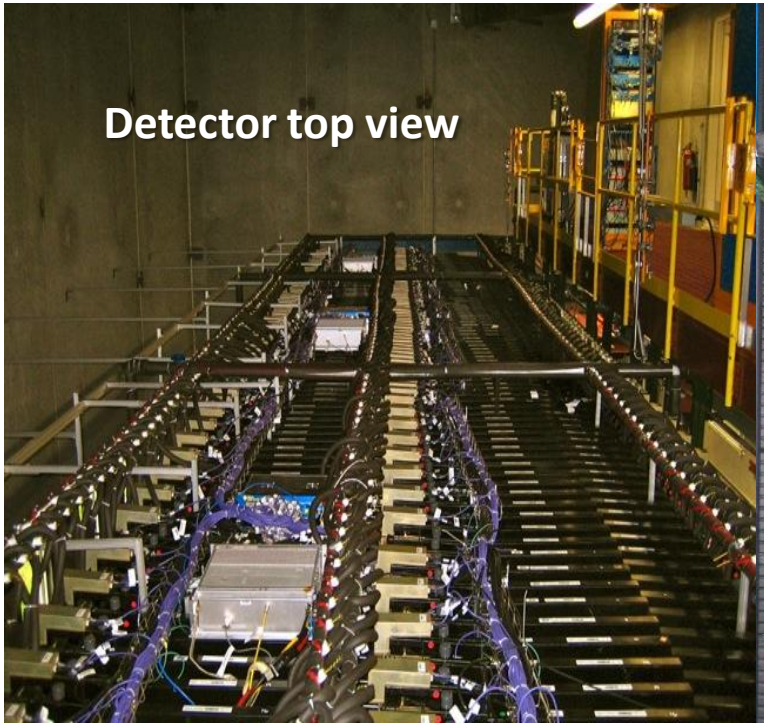
Filled with liquid scintillator

Uses Avalanche photodiode (APD)

Prototype accomplishes:

- Assembly technique
- Scintillator filling
- Light yield
- APD installation and functioning
- Electronics installation and functioning
- DAQ functioning

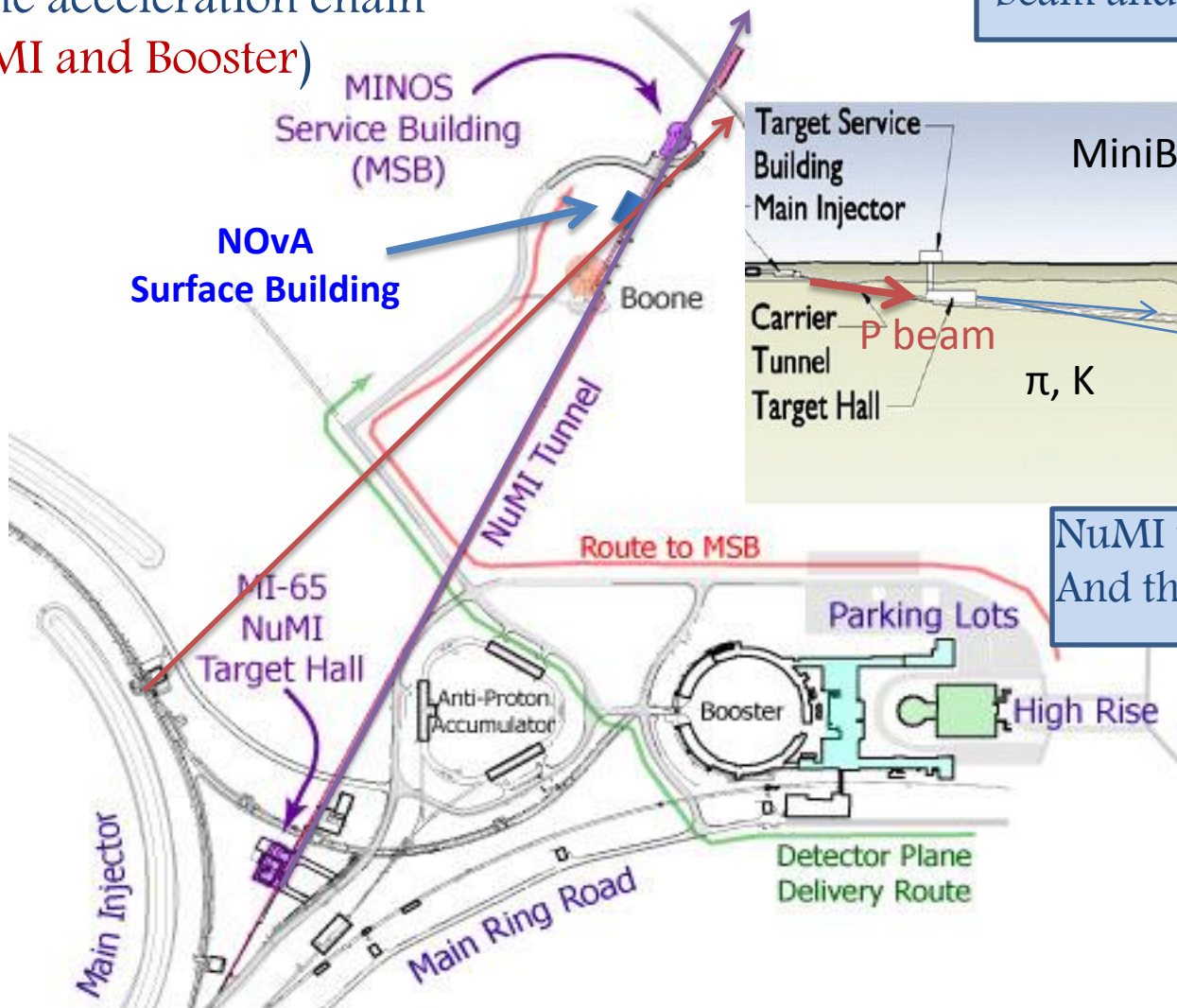


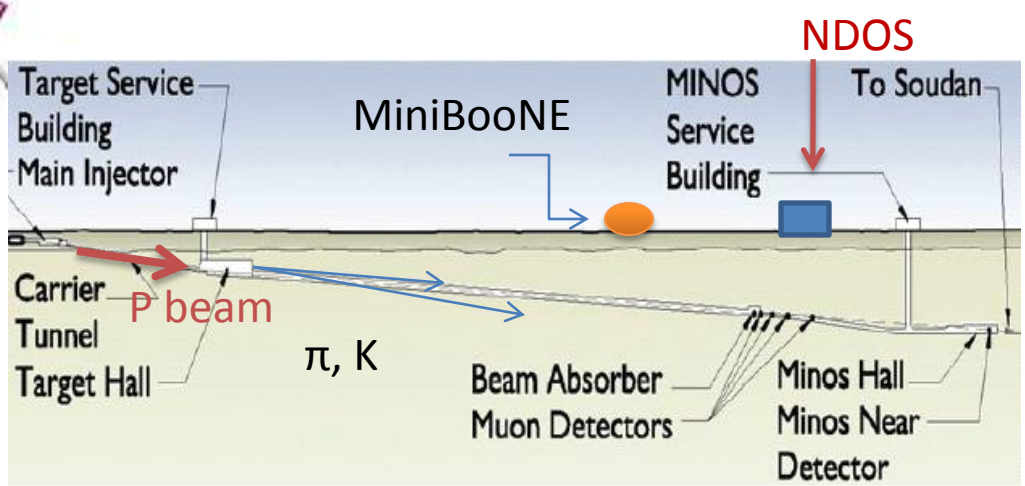


NDOS is taking data from two Neutrino beams

Beams are produced at two different stages on the acceleration chain (NuMI and Booster)

NDOS is ~6.1° off axis of the NuMI beam and on axis of the Booster

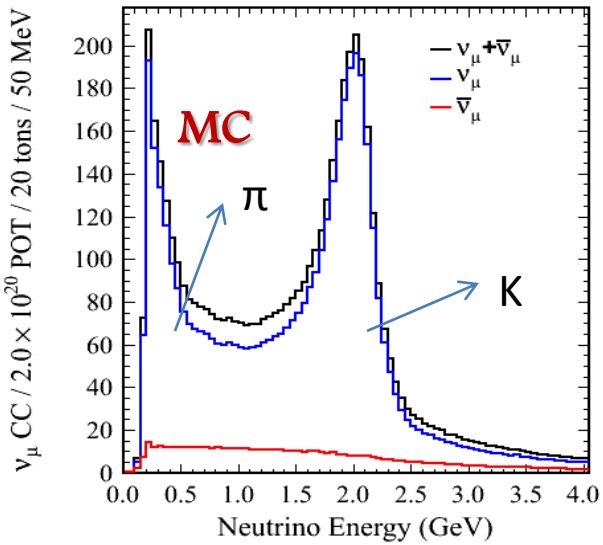




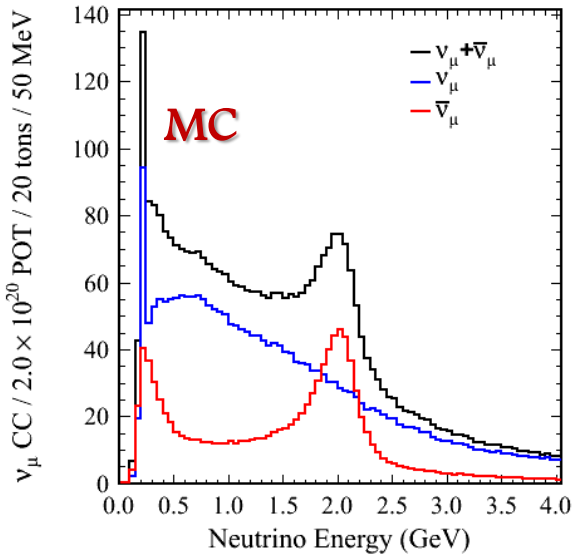
NuMI uses 120 GeV protons
And the Booster uses 8GeV protons

Physics goals for NDOS

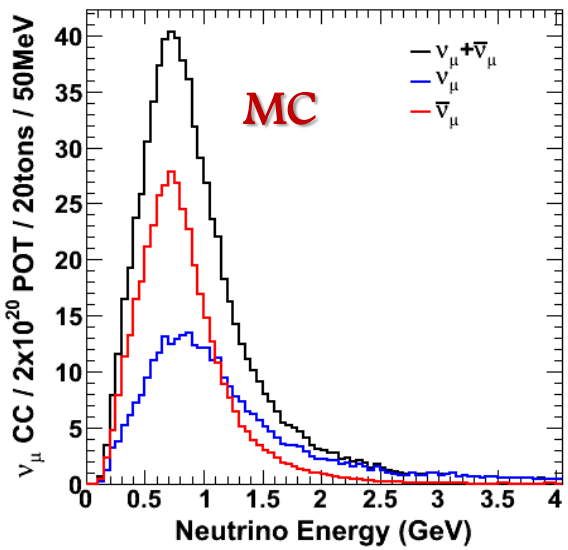
Neutrino run from NuMI



Antineutrino run from NuMI



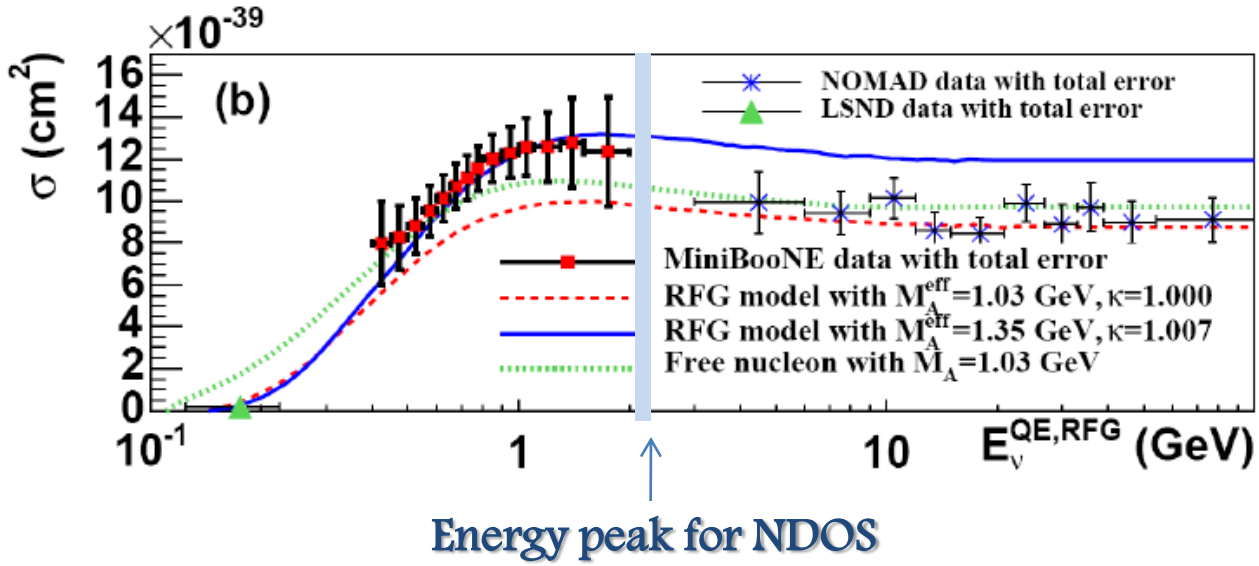
Antineutrino run from Booster



- Calibrate the detector and determine composition of the beam
- Investigate the detector sensitivity to cosmic ray background
- Study response of the detector to electron neutrinos
- Measure the rate of neutrino interactions for the quasi-elastic (QE) interactions

QE Studies in NDOS

- NDOS energy spectrum has a peak around 2GeV, an ideal energy to disentangle current cross section measurements



- Measure ν_μ QE cross section at 2GeV
- QE studies in NDOS will help to develop the analysis for the θ_{23} and Δm^2_{32} NOνA measurements

Event Rates in NDOS

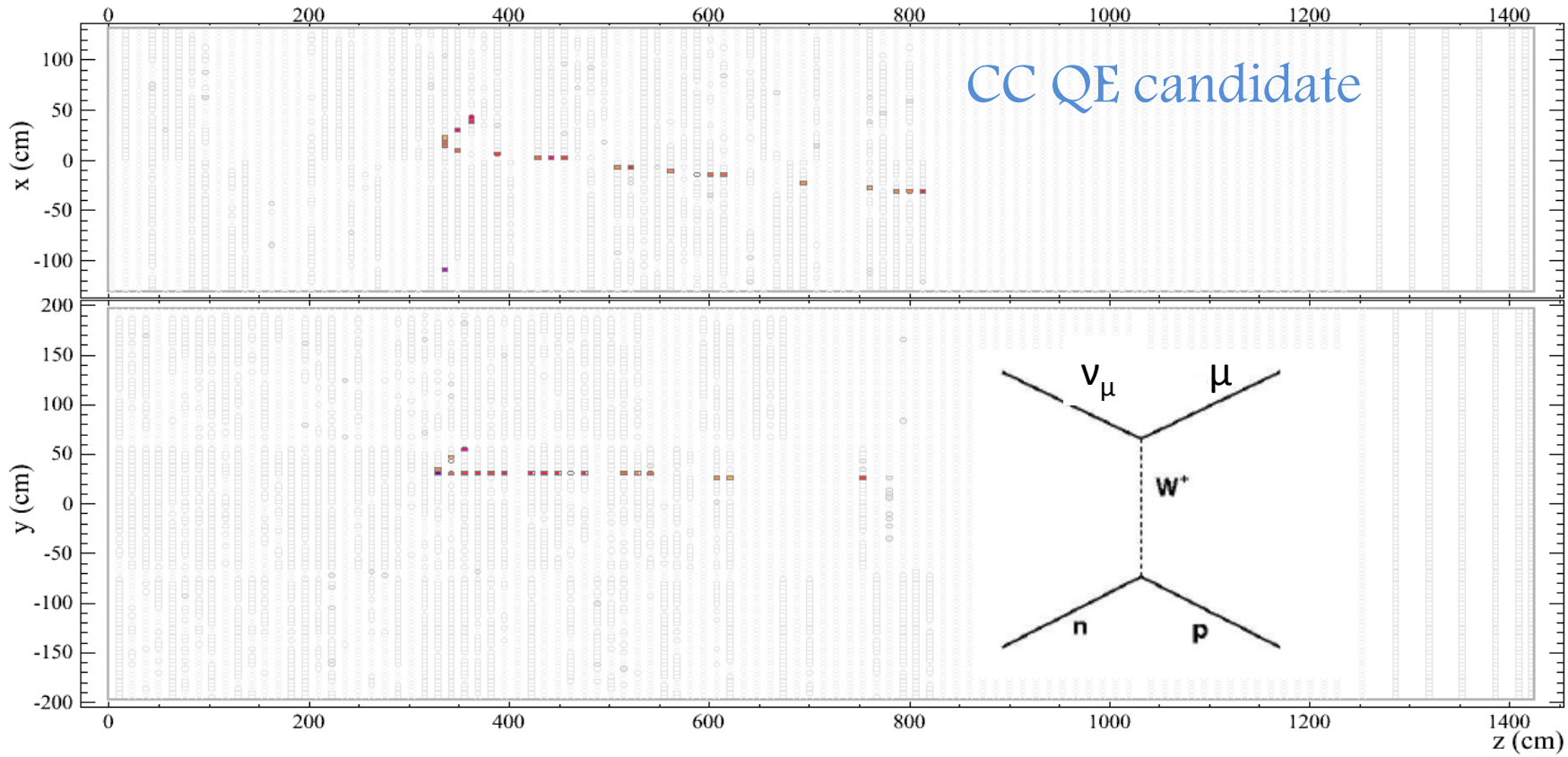
- NDOS will collect data for a year

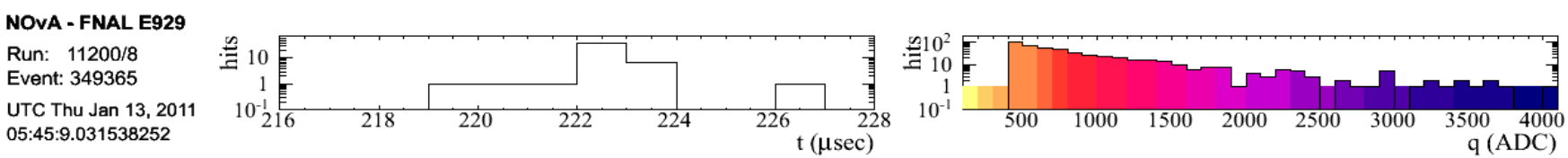
$2x10^{20}$POT 20 tons	NuMI Neutrino	NuMI Anti-Neutrino	Booster Anti-Neutrino
ν_μ+anti-ν_μ CC	4500	3300	735
In 2GeV peak	1500	800	
ν_e+anti-ν_e CC	200	160	10
NC	2000	1600	392

- We will have a significant sample of ν_μ CC QE

Detector during commissioning

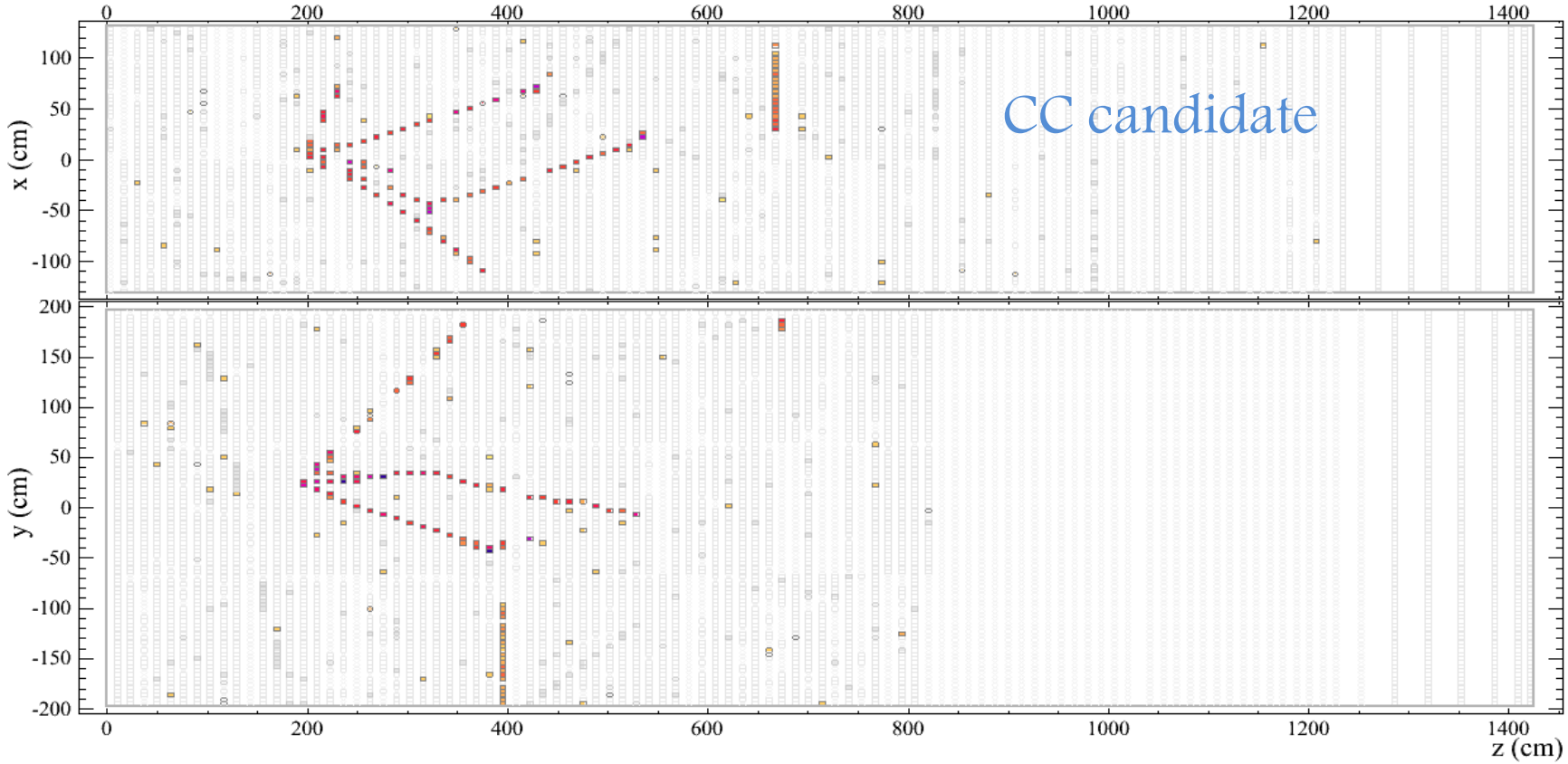
Beam direction



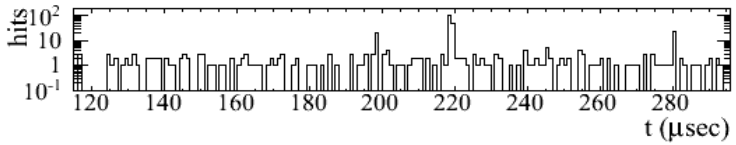


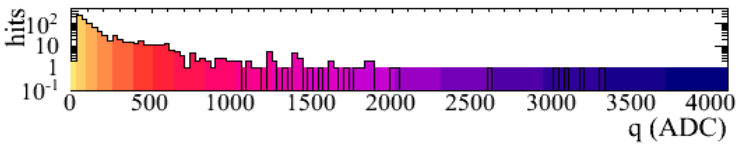
Detector during commissioning

Beam direction



NOvA - FNAL E929
Run: 11945/20
Event: 1043748
UTC Sat Apr 9, 2011
19:08:36.717589440

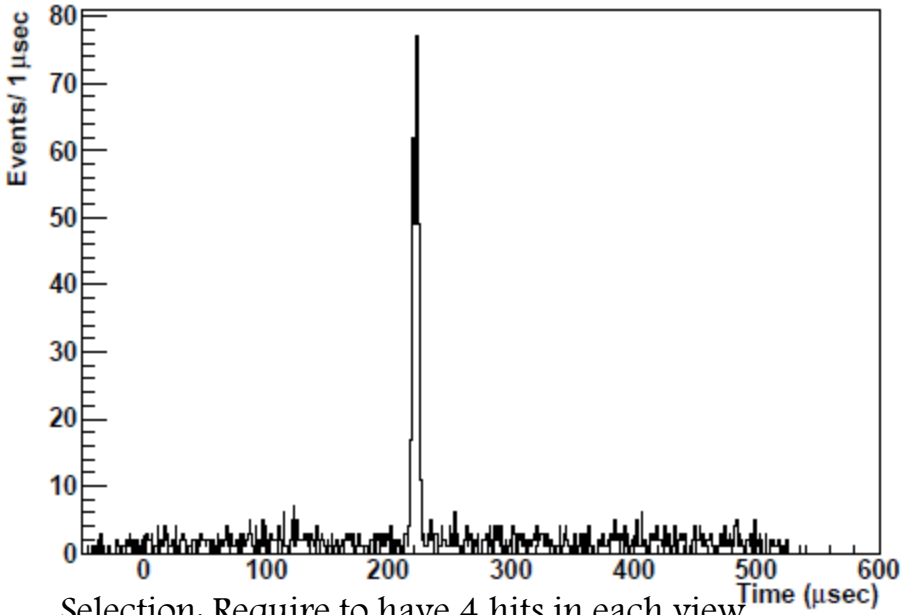




Neutrino signal in NDOS

Time distribution for NuMI neutrinos

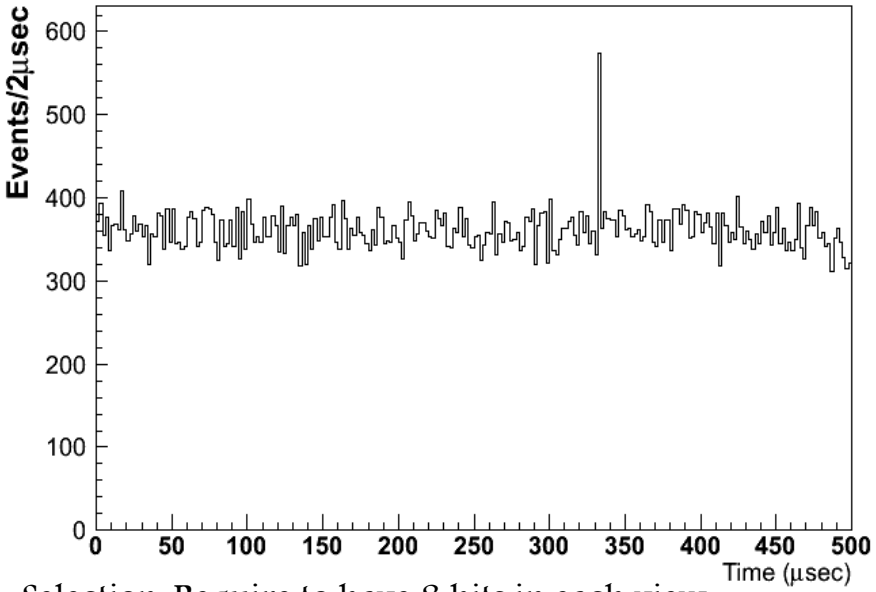
We have collected Antineutrino run ($6x10^{19}$protons on target)



Selection: Require to have 4 hits in each view
Fiducials |x|<110cm, y<140cm and z>50cm and z<770 cm

Time distribution for Booster neutrinos

We have collected Antineutrino run ($2.7x10^{19}$ protons on target)

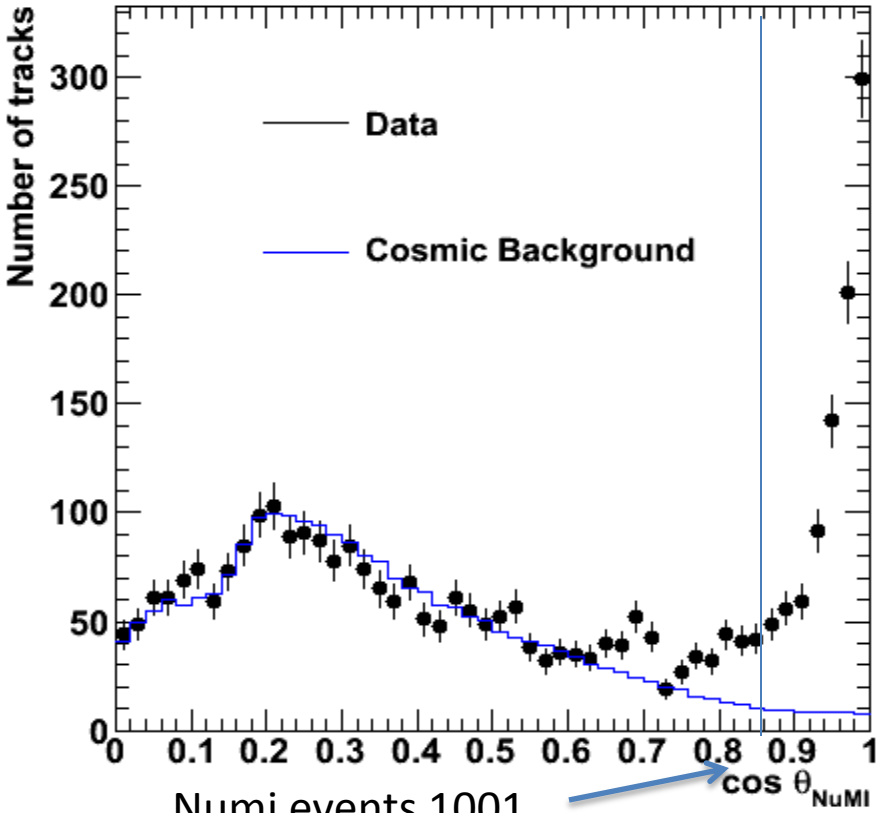


Selection: Require to have 8 hits in each view
Fiducials |x|<110cm, y<140cm and z>50cm and z<770cm

Beam Neutrino Interactions

Reconstructed muon angle with respect to the beam direction

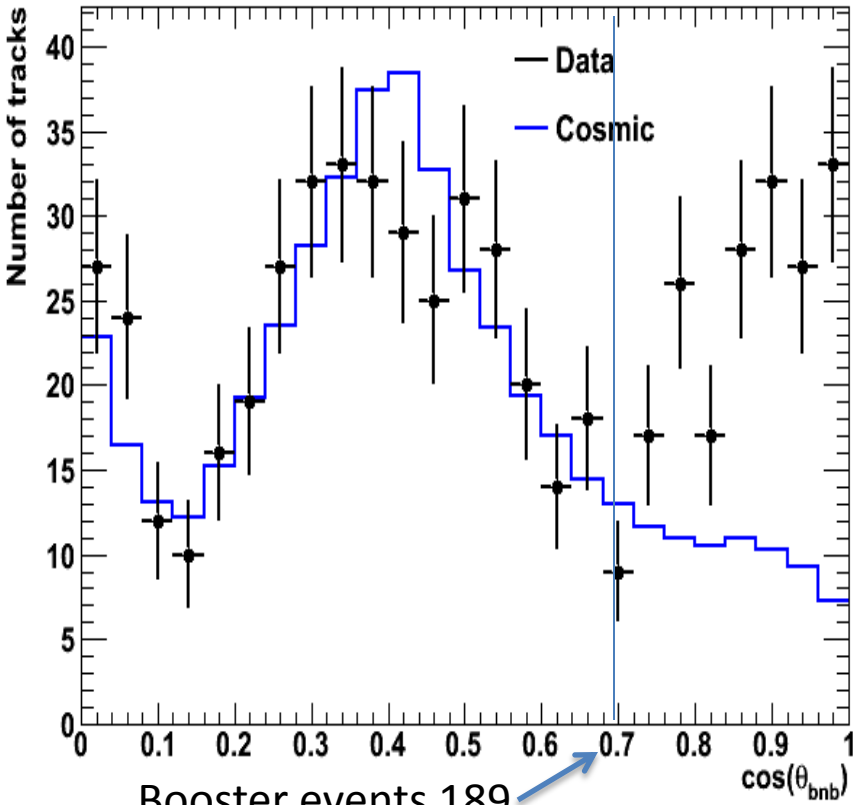
NuMI



Numi events 1001

Cosmic background 69

Booster



Booster events 189

Cosmic background 84

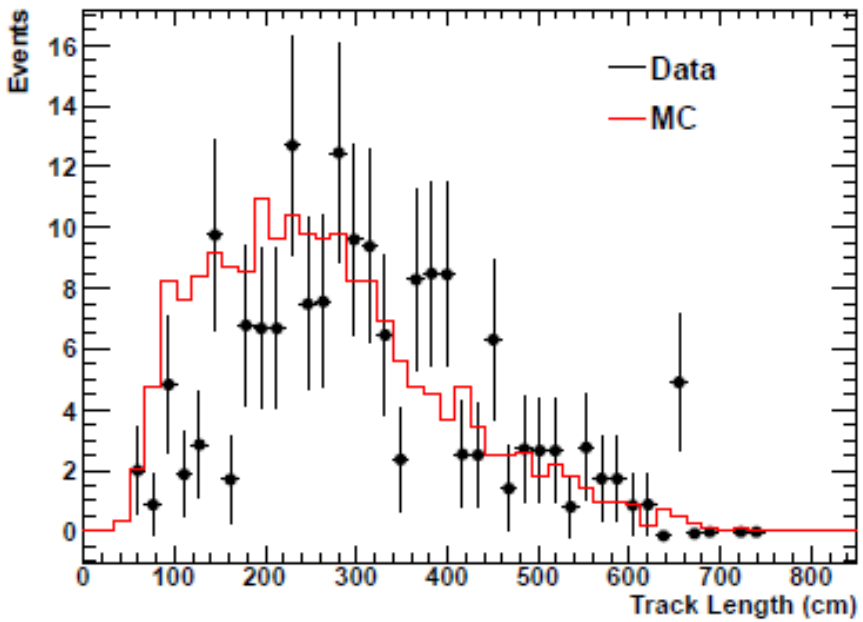
Track Length for NuMI signal events

- Track length for the fully contained events

Fully contained: Events with vertex and end of the track inside of fiducial region

	NuMI	Cosmic	MC
Fiducial	1001	2362	861
Fully contained	184	12	187

Events in the fiducial region contain events from the interaction of neutrinos with the rock which are not simulated in the MC



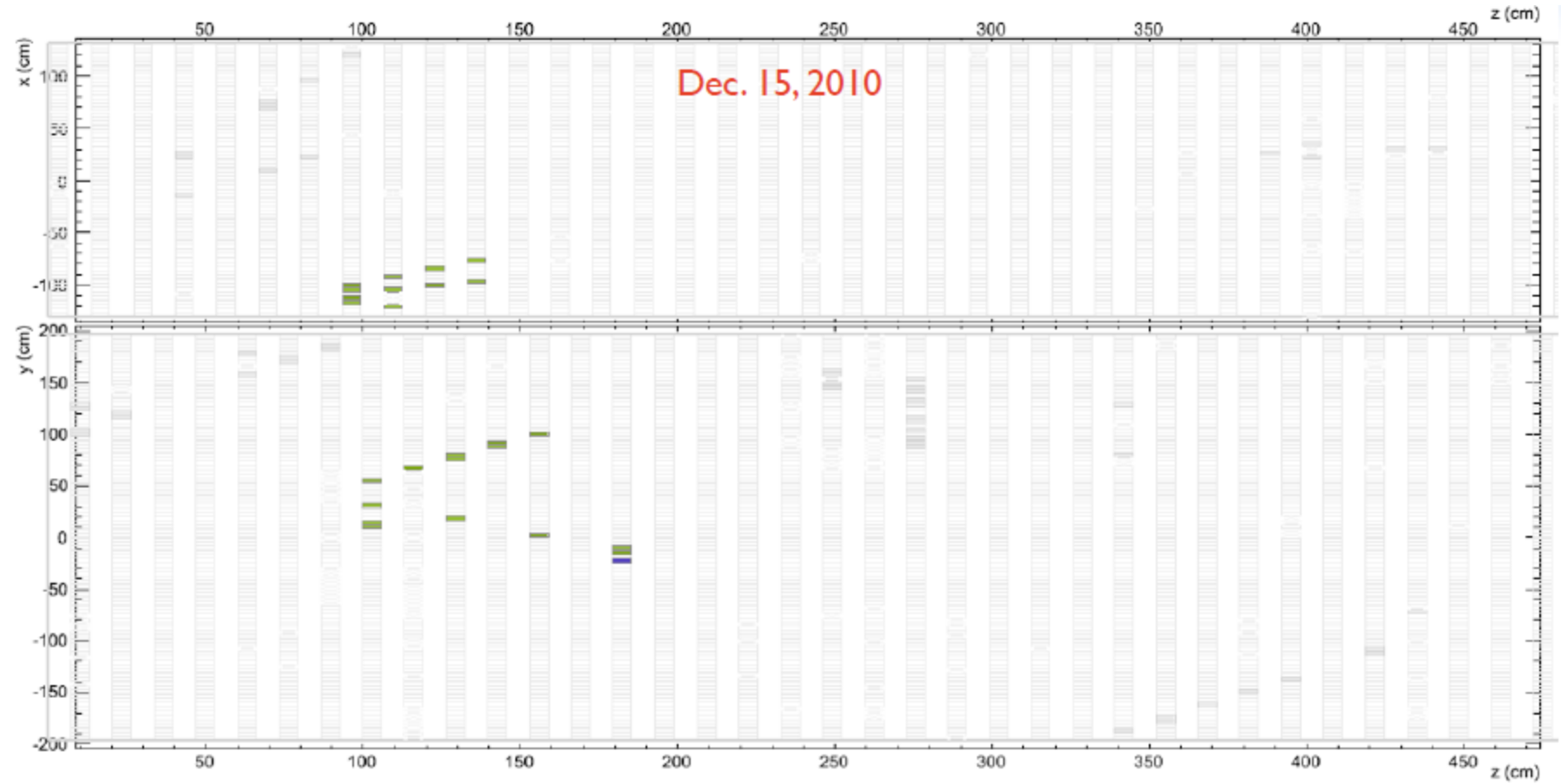
MC : fully contained antineutrino events normalized to Data Exposure

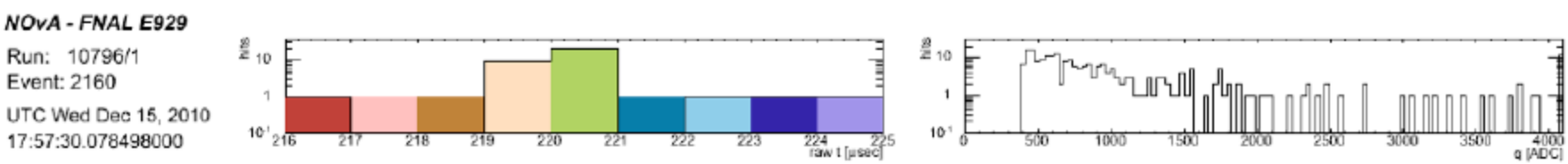
Difference between MC and Data at short track length because early data was collected with very high threshold

Conclusions

- NOνA has a working detector, taking neutrino and cosmic data
- We are taking data for NuMI and Booster neutrino beams
- Measure ν_μ QE cross section
- QE studies are important for θ_{23} and Δm^2_{32} and cross section measurements of NOνA
- Starting construction of the NOνA Far Detector in early 2012

First Neutrino event



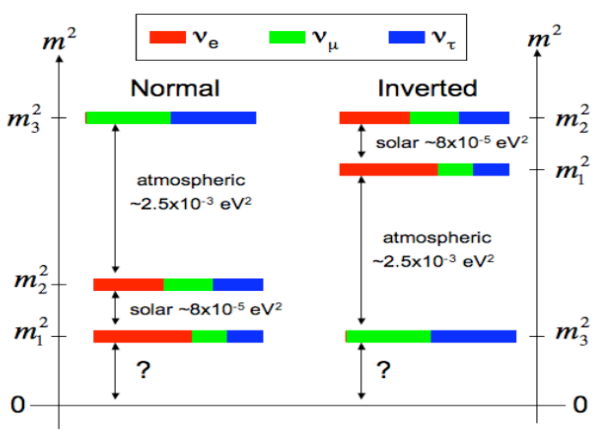


Neutrino Mixing

Neutrinos have mass states and week states

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13} e^{-i\delta_{CP}} \\ 0 & 1 & 0 \\ -s_{13} e^{i\delta_{CP}} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

Atmospheric terms **Unknown terms** **Solar terms**



Remaining questions:

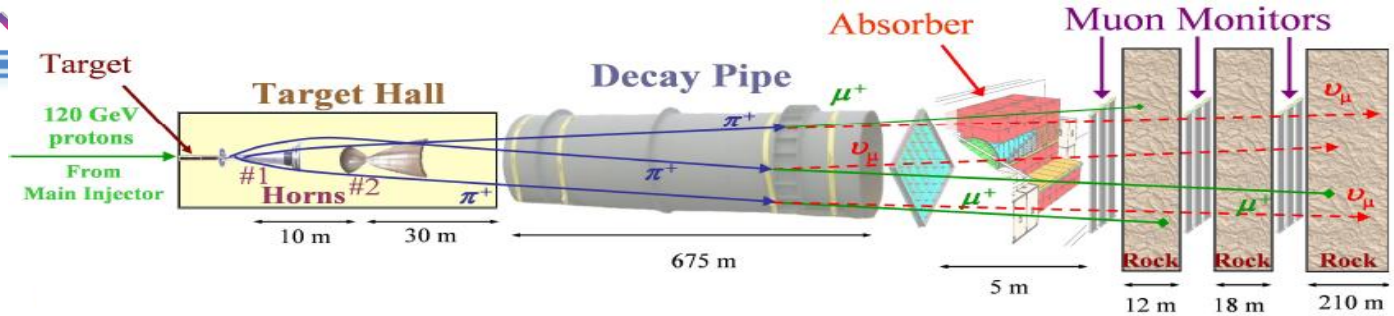
Is $\theta_{13} \neq 0$?

Is there CP violation in the lepton sector $\delta \neq 0$?

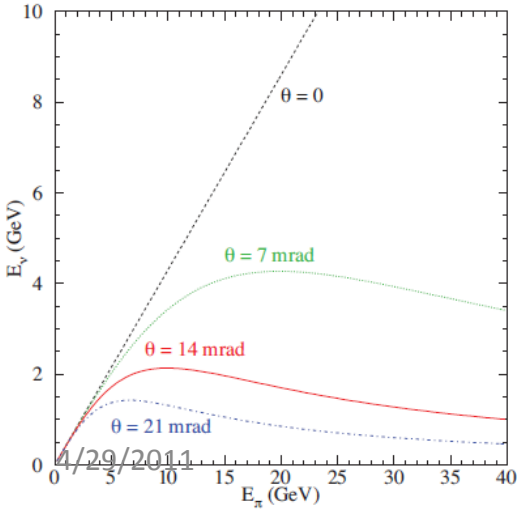
What is the mass hierarchy?

Is $\theta_{23} \neq 45$?

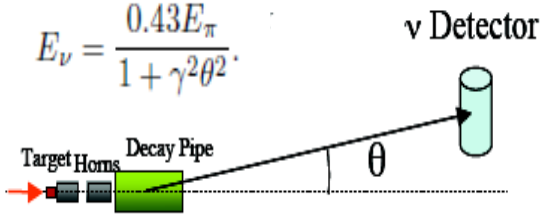
Neutrino production

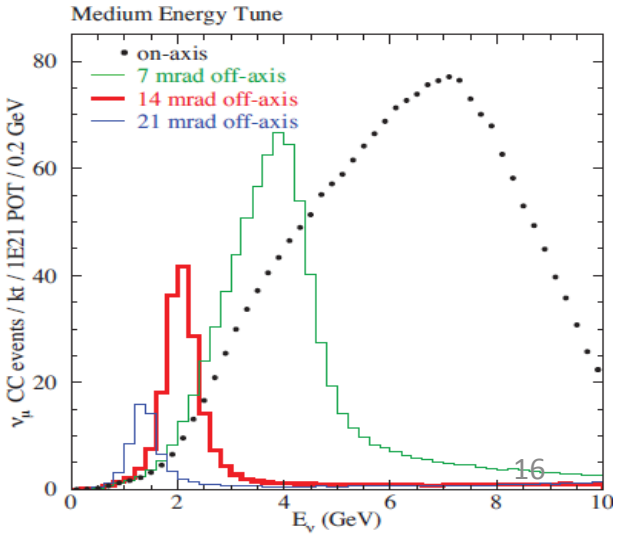


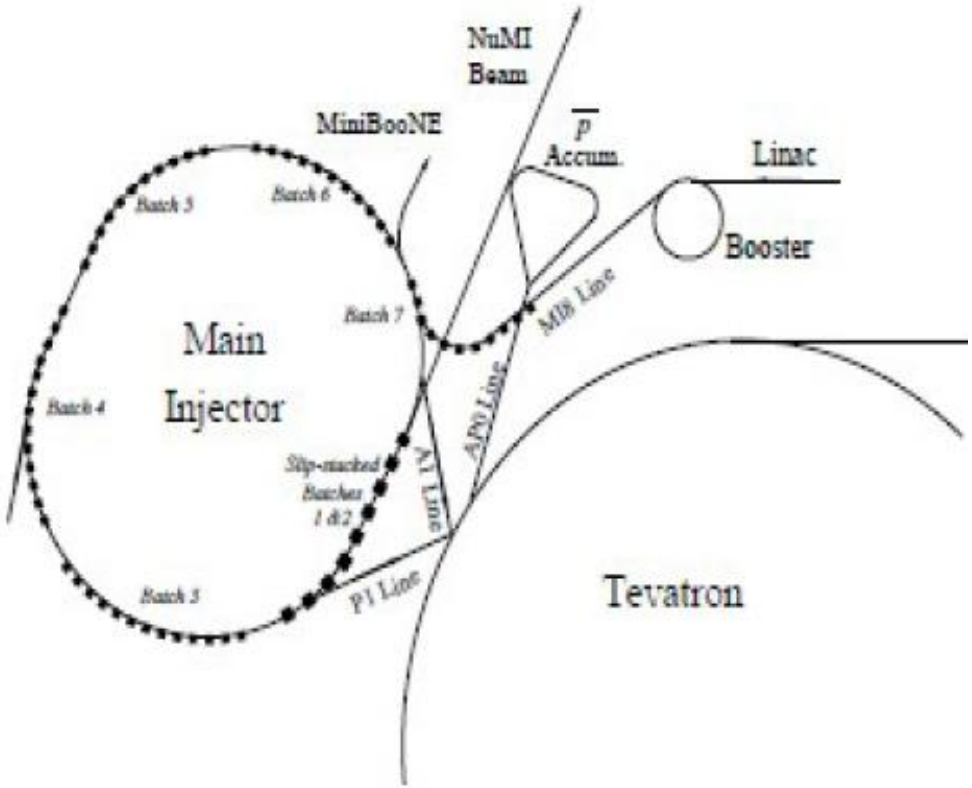
- 120 GeV protons from the Fermilab Main Injector hit a 1 m graphite target, producing pions (π) and kaons (K)
- Magnetic horns to focus charged π and K
- Nova experiment uses off-axis design (14mrad off-axis angle) and medium energy

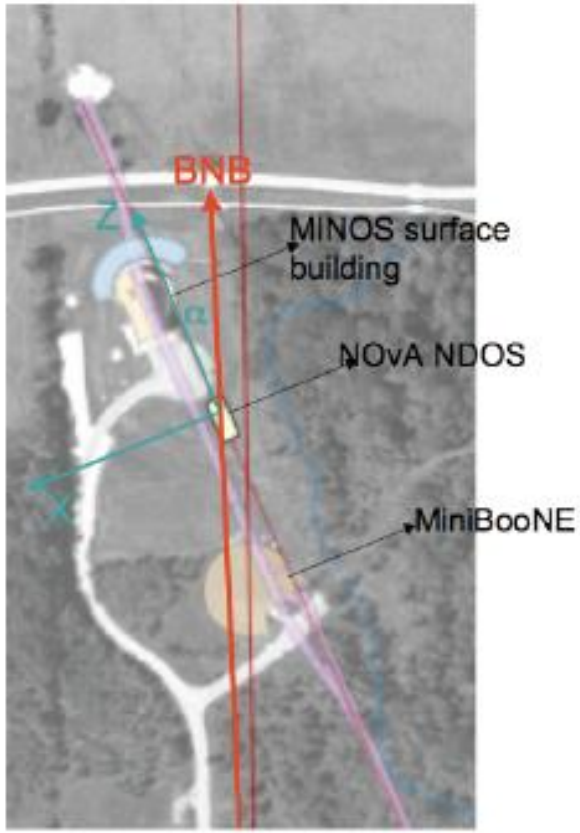


$$E_\nu = \frac{0.43E_\pi}{1+\gamma^2\theta^2}.$$






NuMI
Beam
MiniBooNE
$\overline{p}$
Accum.
Linac
Booster
Batch 5
Batch 6
Batch 7
Main
Injector
Batch 4
Slip-stacked
Batches
1 & 2
Batch 3
MI8 Line
AP0 Line
A1 Line
P1 Line
Tevatron


BNB
MINOS surface
building
NOvA NDOS
MiniBooNE