

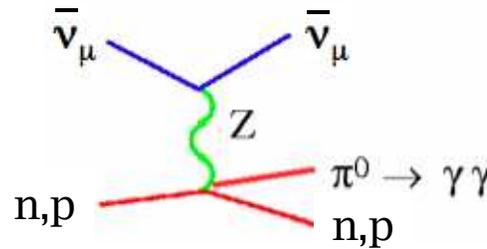
# The Angular Dependence of $\pi^0$ Production in the MiniBooNE Antineutrino Data

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# Motivation for Studying NC $\pi^0$ Production

- To date, there is only one published measurement of the absolute rate of antineutrino NC  $\pi^0$  production, the **single largest** background to future  $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$  oscillation searches; this measurement was reported with 25% uncertainty at 2 GeV.
- Current theoretical models on coherent  $\pi^0$  cross sections can vary by up to an order of magnitude in their predictions at low energy, the region most relevant for  $\nu$  oscillation experiments.



# Oscillation Search Backgrounds: NC $\pi^0$ Production

NC  $\pi^0$ 's can be created through resonant and coherent production:

- Resonant NC  $\pi^0$  production:  $\bar{\nu} N \rightarrow \bar{\nu} \Delta$   
 $\downarrow$   
 $\pi^0 N$
- **Coherent NC  $\pi^0$**  production:  $\bar{\nu} A \rightarrow \bar{\nu} A \pi^0$   
(Signature:  $\pi^0$  which is distinctly forward-scattered)

# Oscillation Search Backgrounds Cont'd

A  $\pi^0$  decays promptly into two photons.

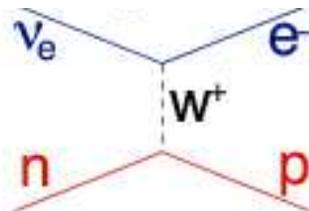
$$\pi^0 \rightarrow \gamma \gamma$$

$\pi^0$



This event can be misidentified if there are not two resolvable tracks.

misID

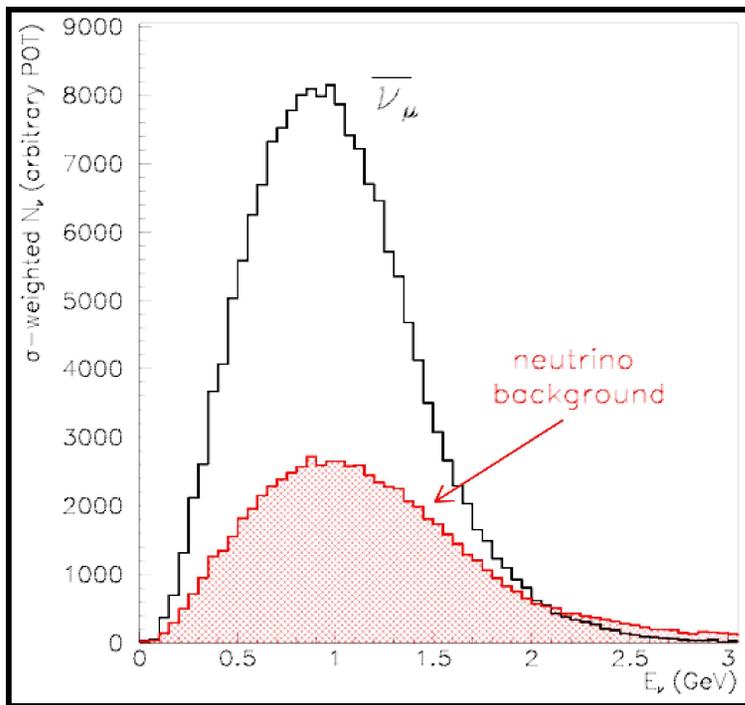


$\nu_e$

Understanding of these events is crucial!

# MiniBooNE Antineutrino Running

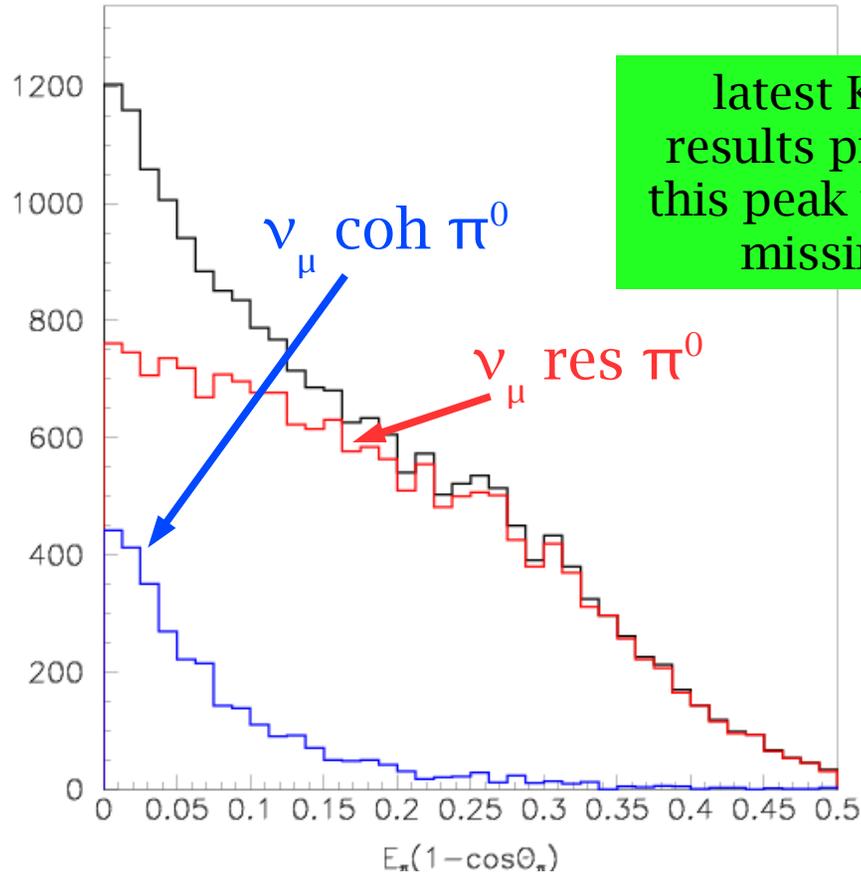
- Started antineutrino running in January 2006
- Has the world's largest sample of  $\pi^0$ 's produced by antineutrinos ( $\sim 900$  events)!
- Need to contend with neutrino aka “wrong-sign” (WS) background



- In **antineutrino mode**, neutrinos are  $\sim 30\%$  of the total events (as opposed to neutrino mode where antineutrinos are  $\sim 2\%$  of the total events)

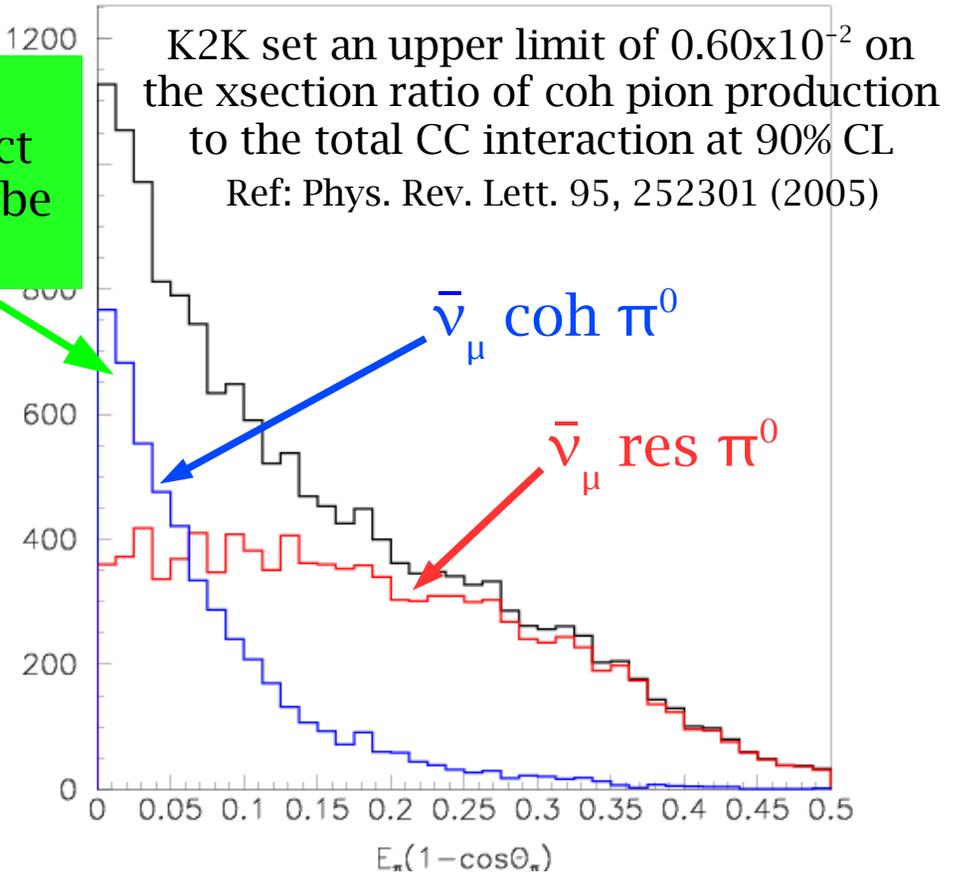
# Coherent NC $\pi^0$ 's in $\nu$ vs. $\bar{\nu}$ Running

Neutrino Mode Monte Carlo



- 20% is coherent production

Antineutrino Mode Monte Carlo



- 40% is coherent production
- “enhanced” coherent sample

Generated  $\pi^0$  angular distribution for NC  $\nu$  (left) and  $\bar{\nu}$  (right) scattering. Here  $\theta_\pi$  is the angle of the outgoing  $\pi^0$  in the lab wrt to the  $\nu$  ( $\bar{\nu}$ ) direction.

# MiniBooNE NC $\pi^0$ Selection

## pre-cuts:

event in beam time window ( $\nu$  event)

# veto hits  $< 6$  (eliminates cosmic rays)

# tank hits  $> 200$  (above Michel endpoint)

event radius  $< 500$  cm (fiducial cut)

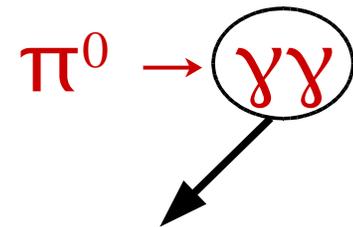
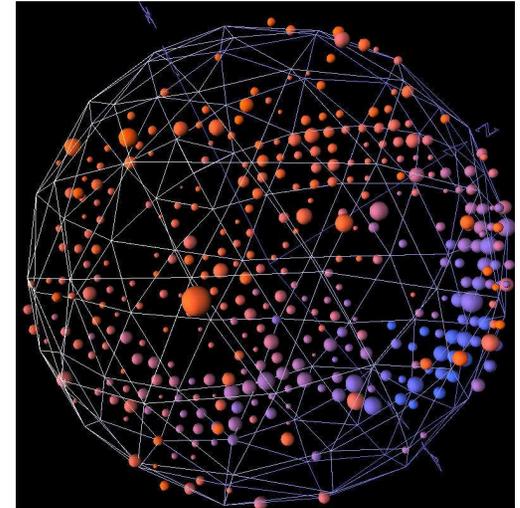
## NC $\pi^0$ analysis cuts:

one sub-event (no decaying  $\mu$ , NC)

e  $\mu$  likelihood prefers e hypothesis (EM-like)

e  $\pi$  likelihood prefers  $\pi^0$  hypothesis (2 ring)

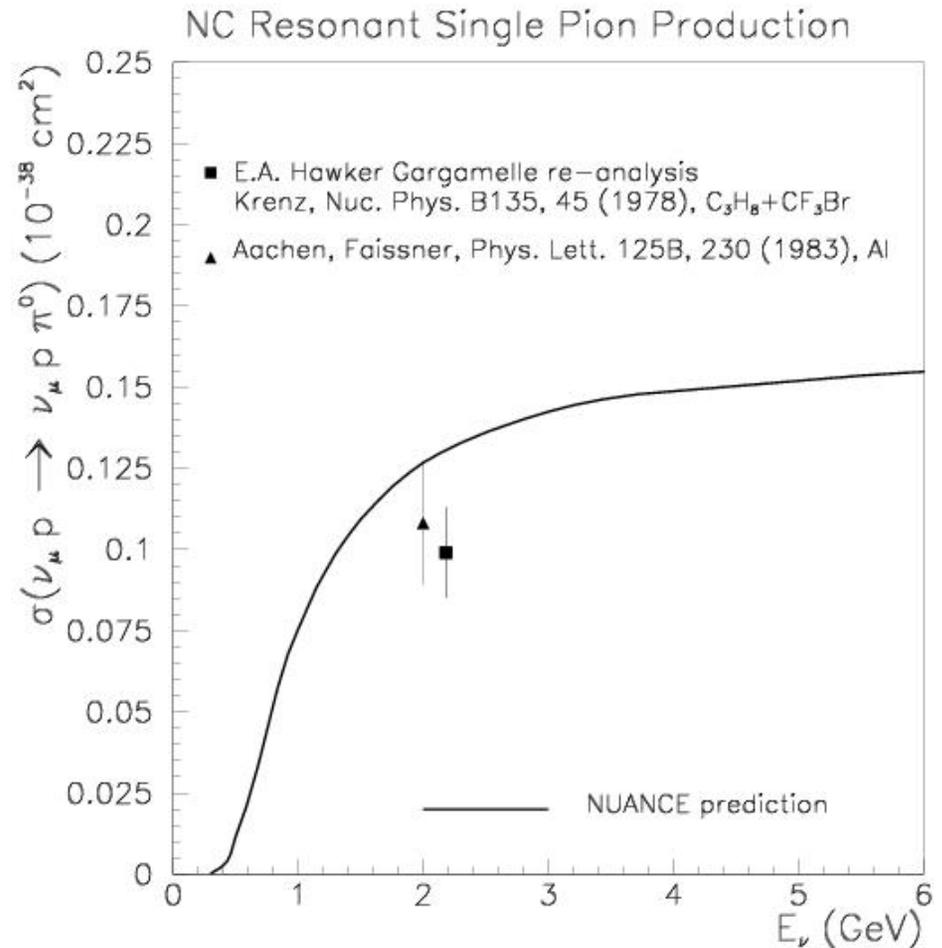
$$m_{\pi}^2 = 2E_{\gamma 1}E_{\gamma 2}(1 - \cos\theta_{12})$$



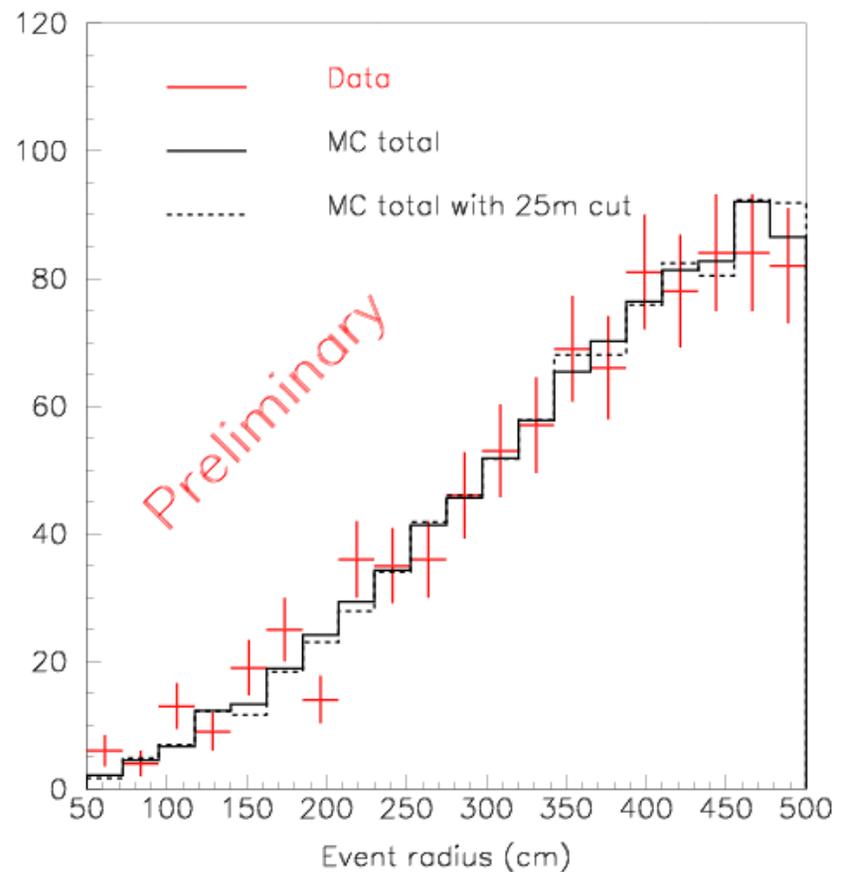
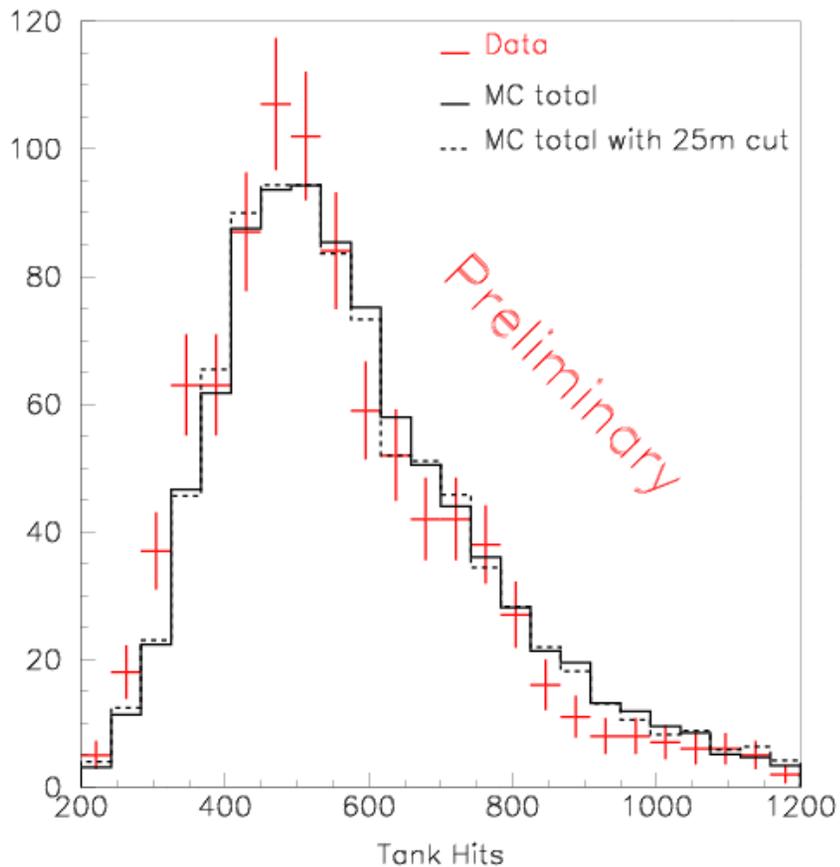
2 ring fit:  
determine E, direction  
of each Cherenkov ring  
→ decay kinematics

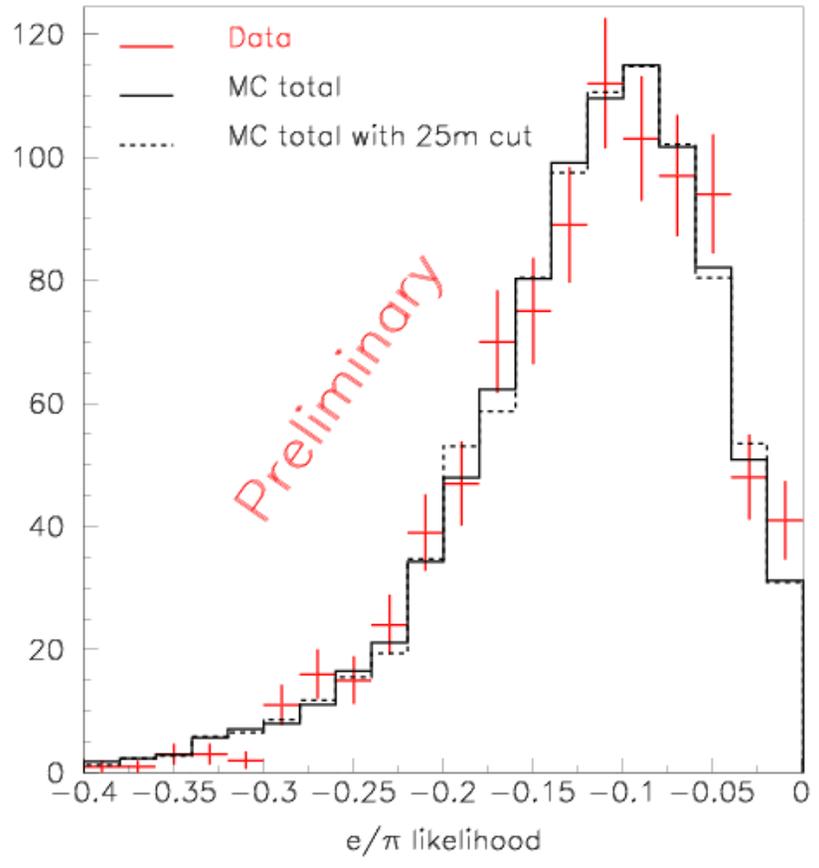
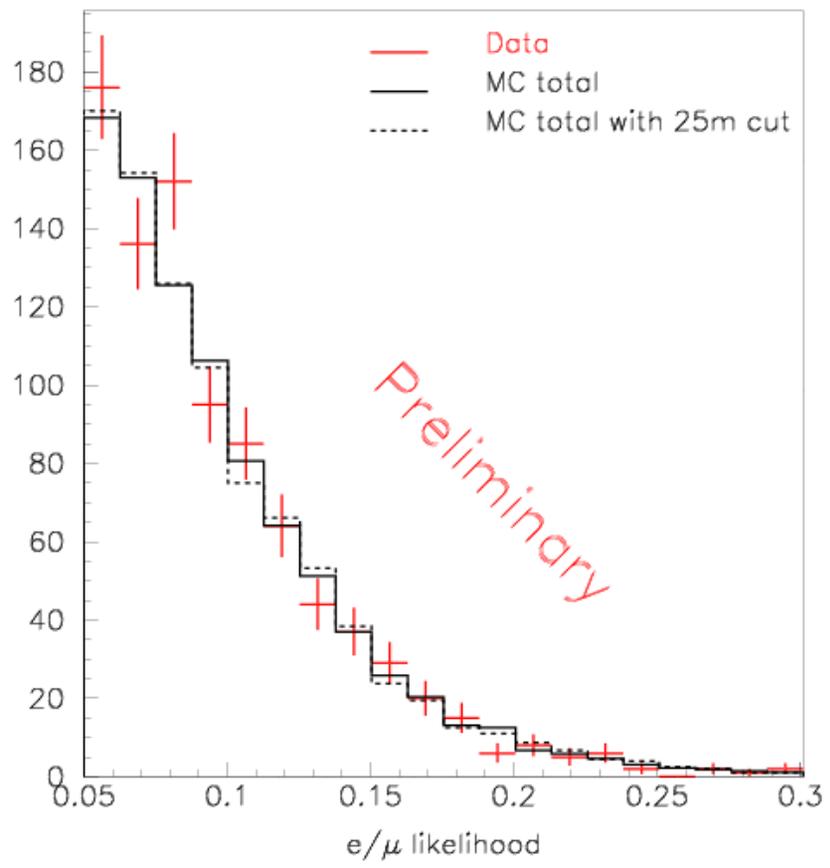
# Notes

- The data used is **ALL** of the antineutrino data
- The MC (May 06 Baseline) does not have absorber effects explicitly simulated
- We perform a 25m cut test, in which all neutrinos downstream of the 25m absorber have been eliminated
- Besides overall normalization, absorber effects produce more neutrinos at lower energies, which do not affect  $\pi^0$  kinematics (higher energy production threshold)
- The following plots have been relatively normalized

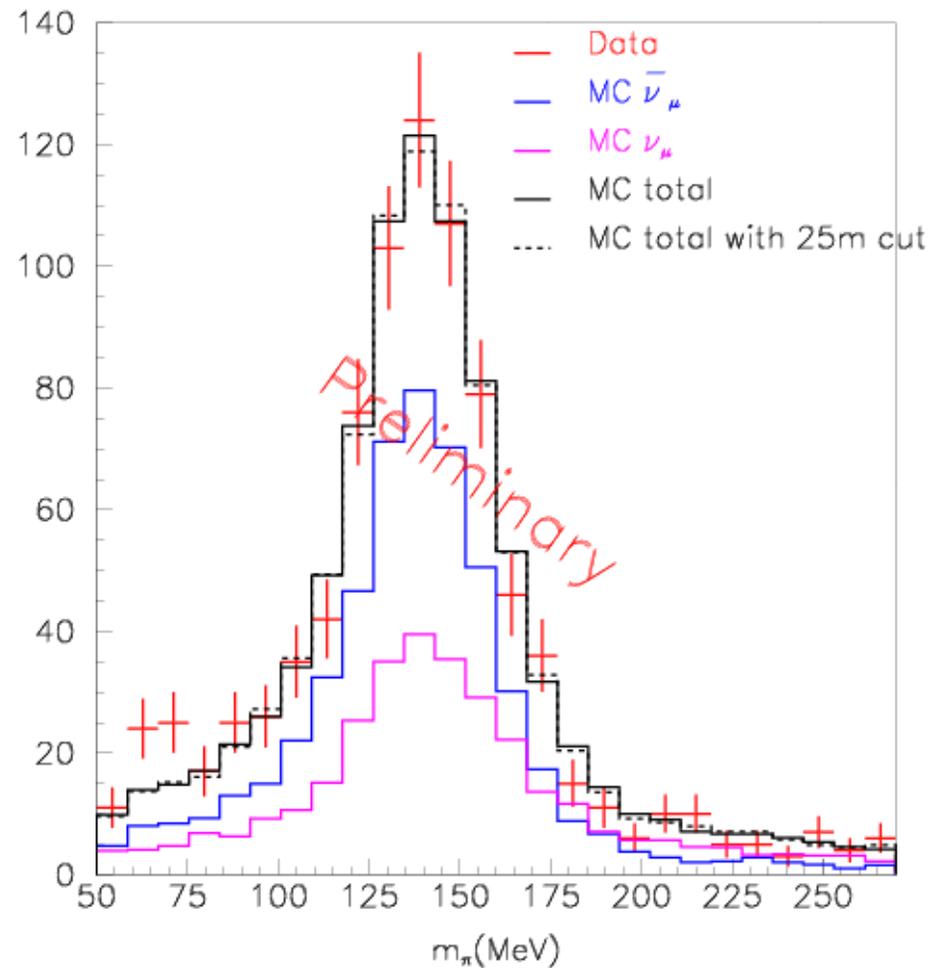


# Data/MC Comparison for Variables We Cut On

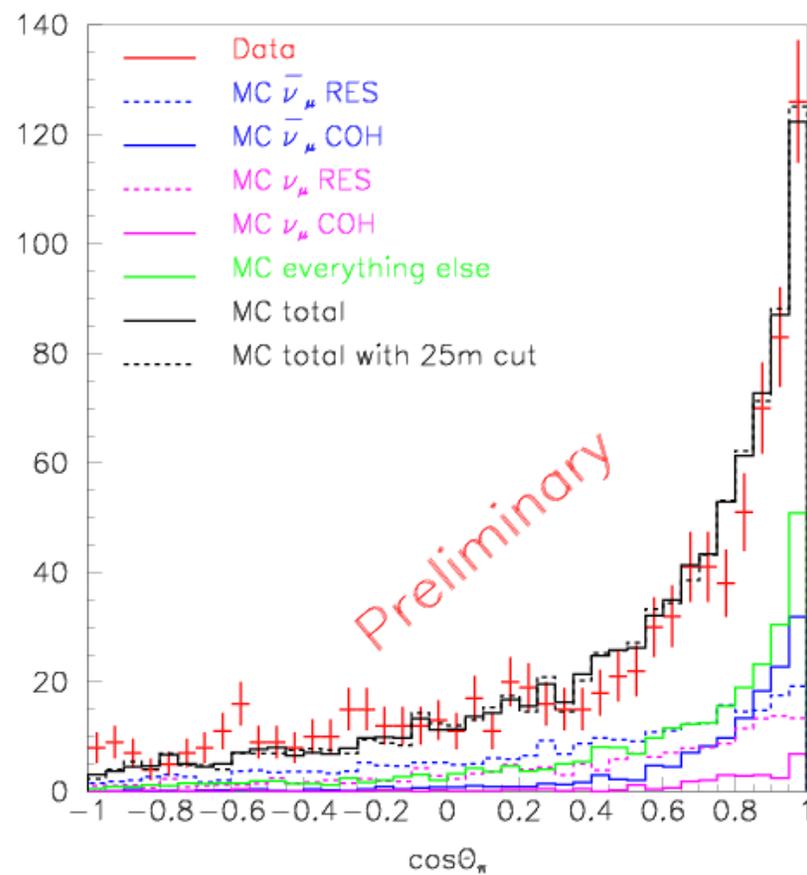
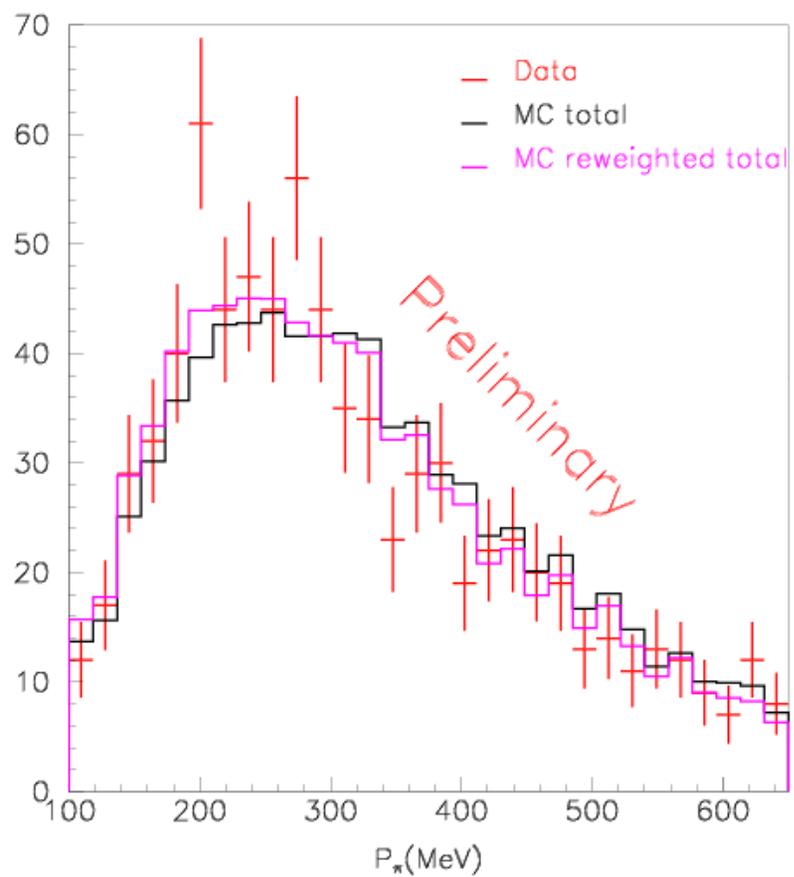




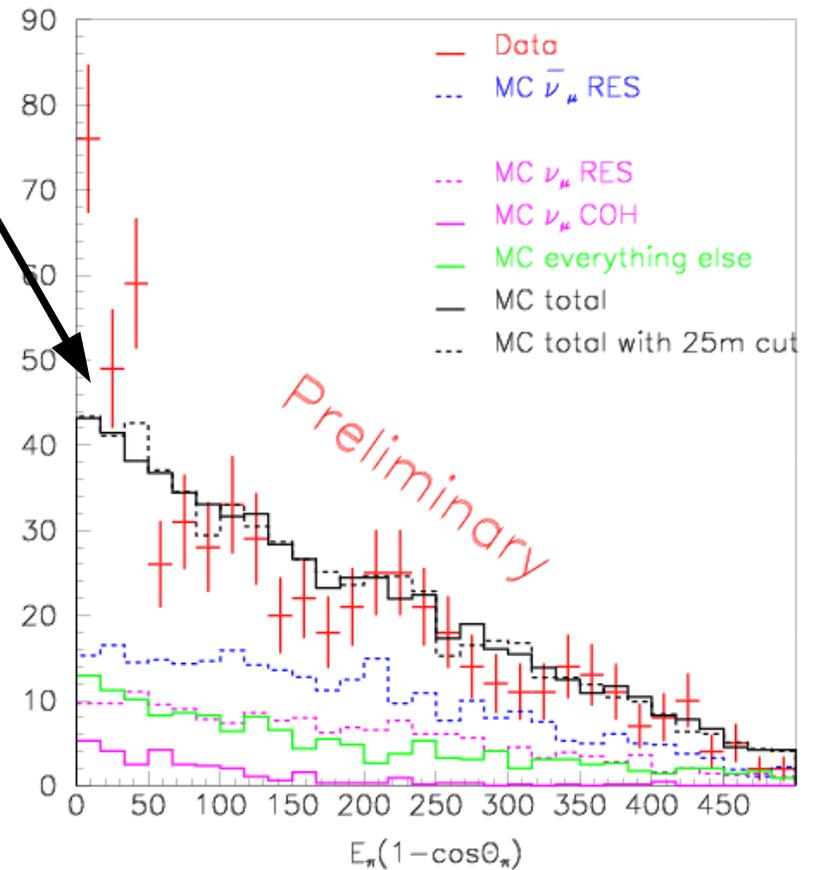
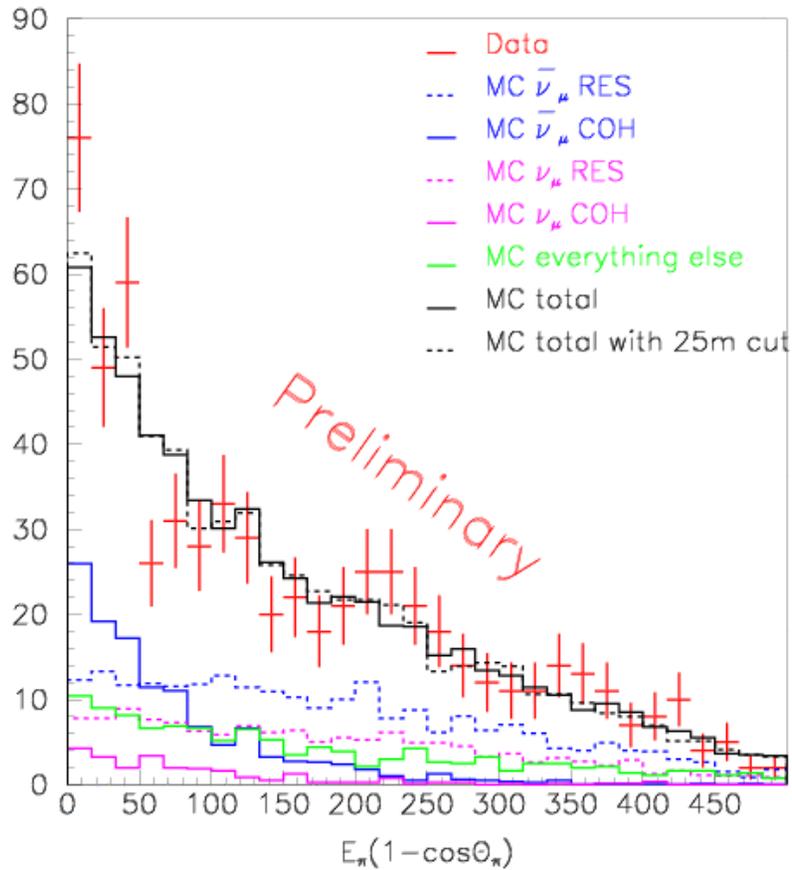
# $\pi^0$ Kinematics



MiniBooNE's resolution on the  $\pi^0$  mass peak ( $\Delta m \sim 22$  MeV) is comparable to K2K's ( $\Delta m \sim 20$  MeV) at 10% photocathode coverage compared to 40% for K2K



Suggestive of antineutrino  
NC coherent  $\pi^0$  production



No  $\bar{\nu}_\mu$  COH contribution

# Summary

- There are indeed  $\pi^0$ 's produced in our antineutrino data!
- There is good agreement between data and uncorrected MC for  $\pi^0$ 's; new updated MC expected within a few weeks
- Kinematic distributions are what we expect
- The data suggests antineutrino NC coherent  $\pi^0$  production
- Next step: fit for an exact coherent fraction in the nubar data (been done for the neutrino sample)
- Will be taking more data ~mid April.

# Acknowledgments

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