# Recent results from SciBooNE and MiniBooNE experiments

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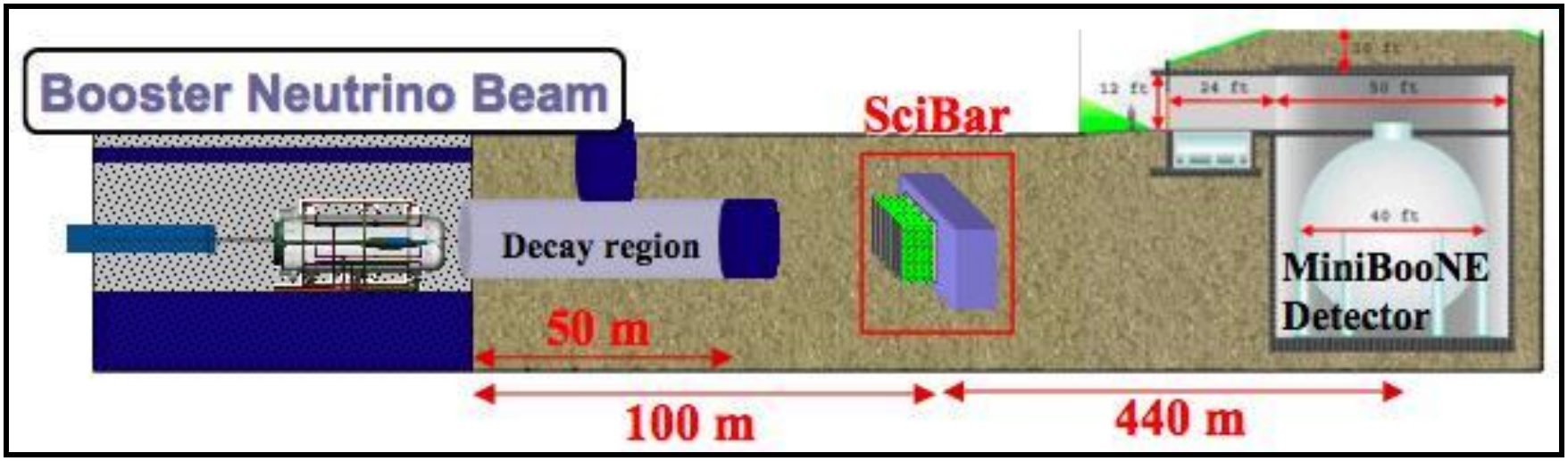
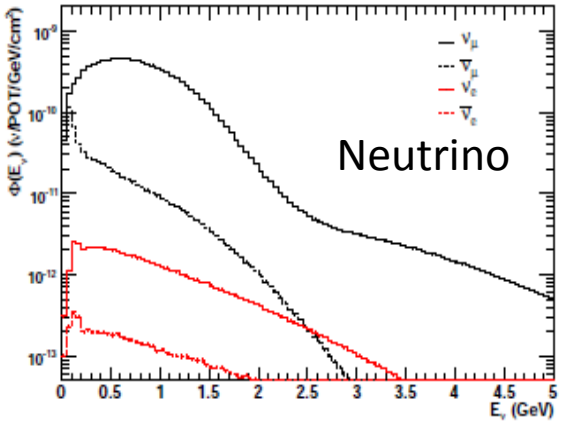
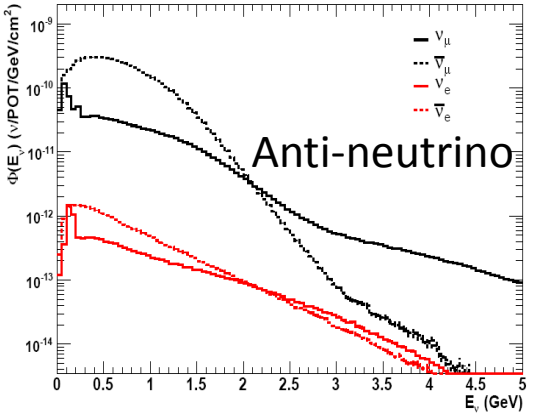
Rencontres de Moriond
18 March 2011

# Fermilab's Booster Neutrino Beam

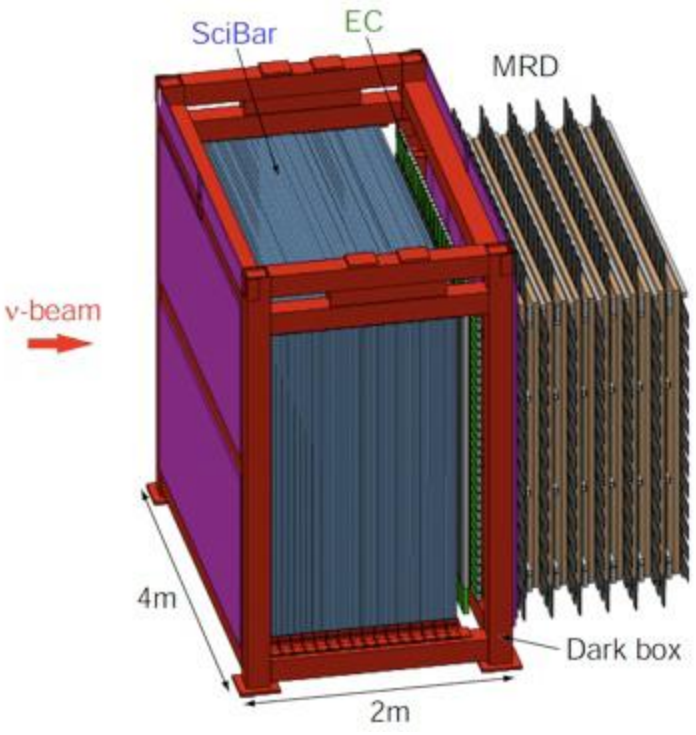



- Horn focused beam/8GeV protons from Booster
- Horn polarity -> Neutrino or Anti-neutrino mode



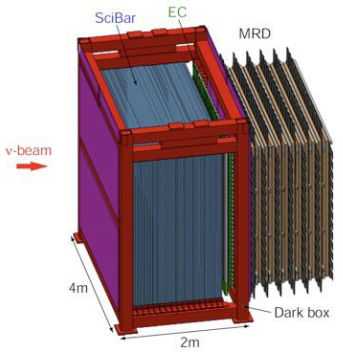



# SciBooNE experiment



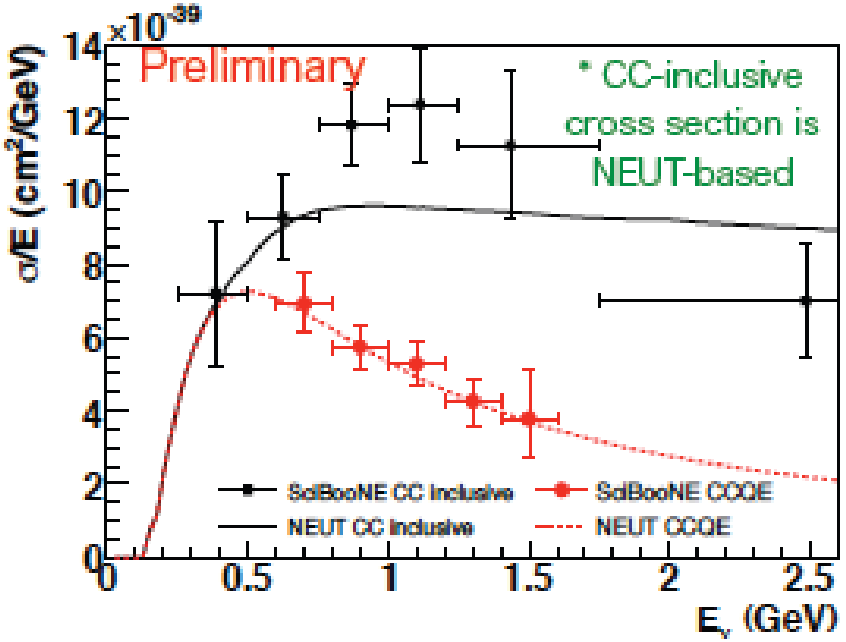

- Detector:
  - SciBar- Fully active scintillator tracker
  - Electron catcher – EM calorimeter
  - Muon Range Detector - Steel+plastic scinitillator
- Main goal to measure neutrino and anti-neutrino cross sections
- Neutrino oscillations with MiniBooNE

# CCQE



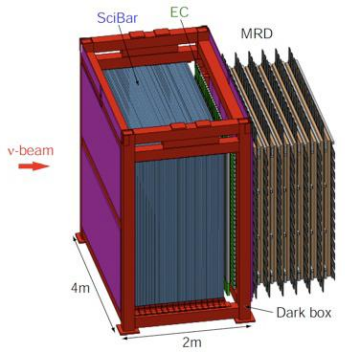

- CCQE inclusive
  - First measurement on carbon in 1 GeV region
  - Consistent with MINOS, NOMAD and old BNL bubble chamber (deuterium) measurements

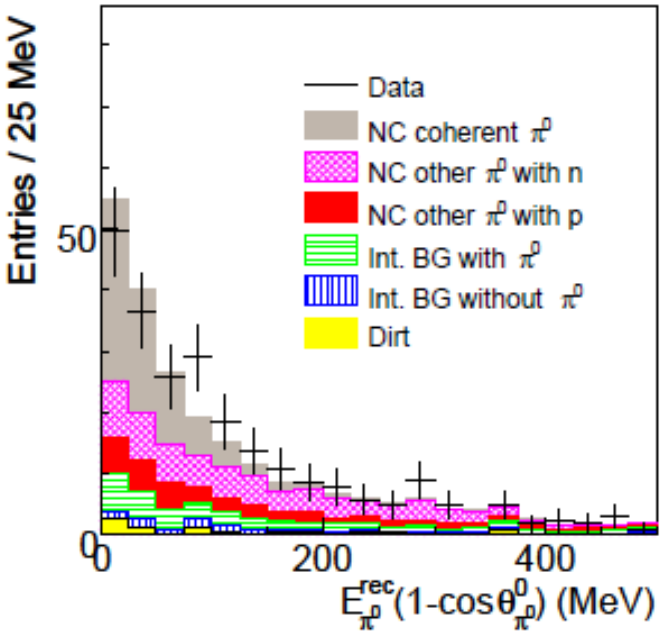
*Phys. Rev. D83, 012005 (2011)*




- CCQE (Preliminary)
  - Consistent with MiniBooNE

# NC Coherent $\pi^0$



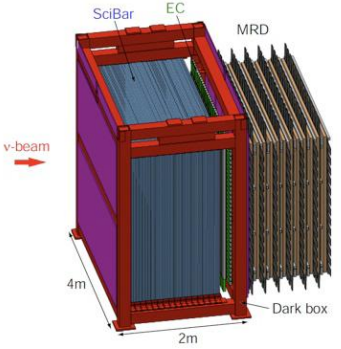

- Clear evidence of coherent production
- Cross section ratio

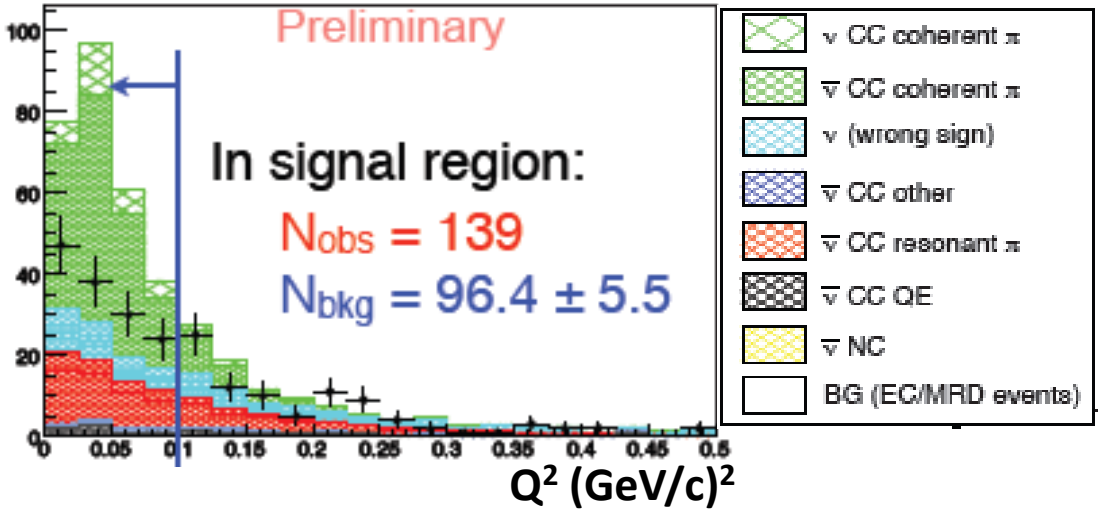
$$\frac{\sigma(\mathrm{NC\,coh}\,\pi^0)}{\sigma(\mathrm{CC})} = (1.16 \pm 0.24) \times 10^{-2}$$

consistent with Rein-Sehgal model

*Phys. Rev. D81, 111102 (2011)*

# $\bar{\nu}$ CC coherent π




$$\frac{\sigma(\bar{\nu}\ \mathrm{CC\ coh}\text{-}\pi) + r\cdot\sigma(\nu\ \mathrm{CC\ coh}\text{-}\pi)}{\sigma(\bar{\nu}\ \mathrm{CC}) + r\cdot\sigma(\nu\ \mathrm{CC})}$$

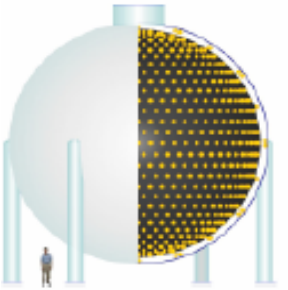
Preliminary

$$= (\ 1.13 \pm 0.34(\mathrm{stat})\ ^{+0.31}_{-0.36}(\mathrm{sys})\ ) \times 10^{-2}$$

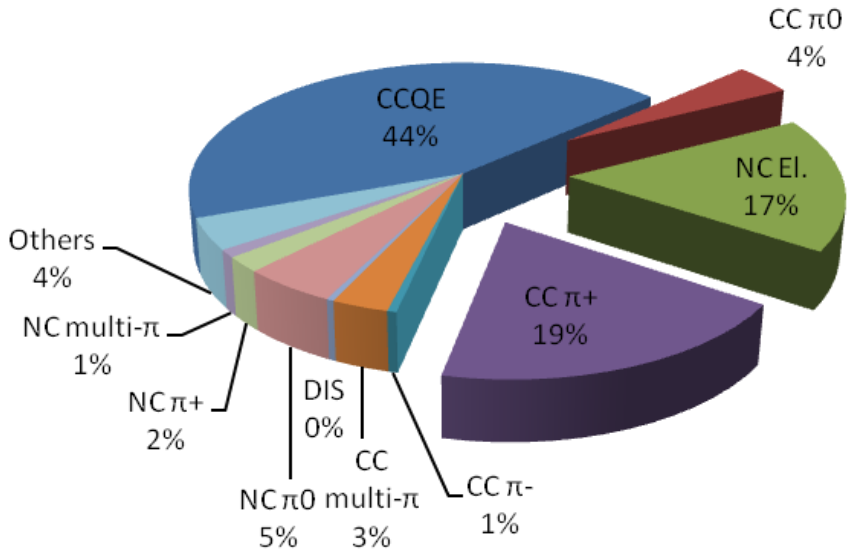
- r = ratio of ν and $\bar{\nu}$ fluxes in anti-neutrino mode = 0.19
- Previously measured cross section ratio in neutrino mode:

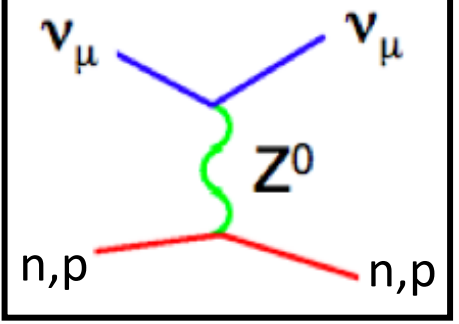
$$\frac{\sigma(\nu\ \mathrm{CC\ coh}\text{-}\pi)}{\sigma(\nu\ \mathrm{CC})} = (\ 0.16 \pm 0.17(\mathrm{stat})(\mathrm{sys})) \times 10^{-2}$$

# MiniBooNE experiment

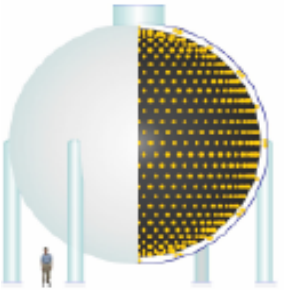


- 800t mineral oil Cerenkov detector
- Main goal to study neutrino oscillations
  - Motivated by unexplained LSND signal (observed 3.8σ excess of nuebar events in numubar beam)
- Measure neutrino cross sections (measured cross sections using ~90%  of neutrino events in detector)





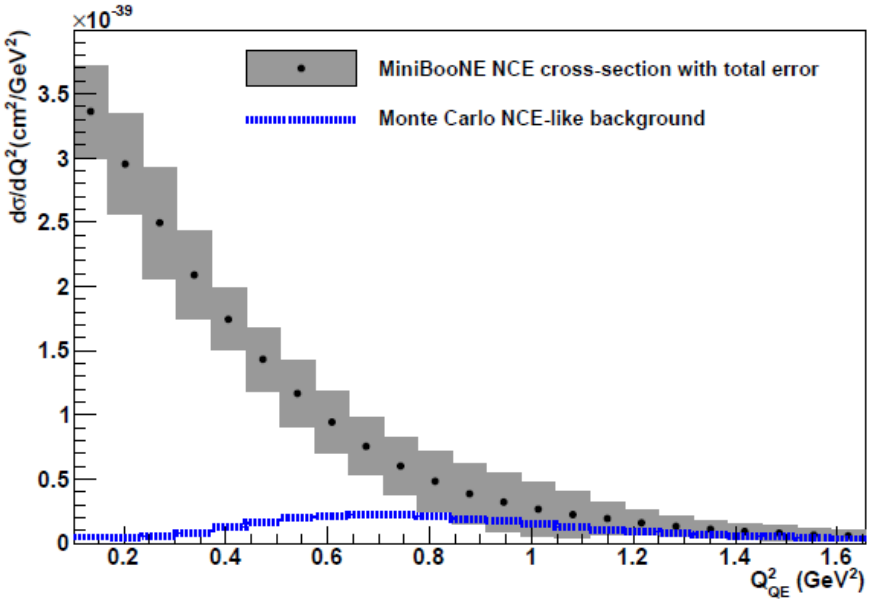

# NC elastic



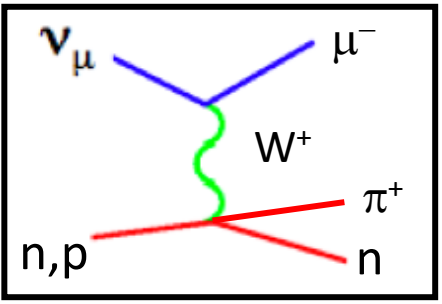
- 17% of neutrino interactions
- Flux averaged cross section
- Best match to data with $M_A$=1.39 ± 0.11 GeV (agrees with shape only fits to MiniBooNE CCQE data)

- Sensitive to strange quark component
- Protons above Cerenkov threshold distinguished from neutrons
- Strange quark component contribution to axial form factor: Δs=0.08+-0.26

  (in agreement with BNL E734)

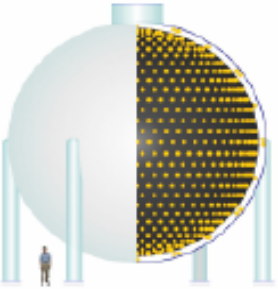


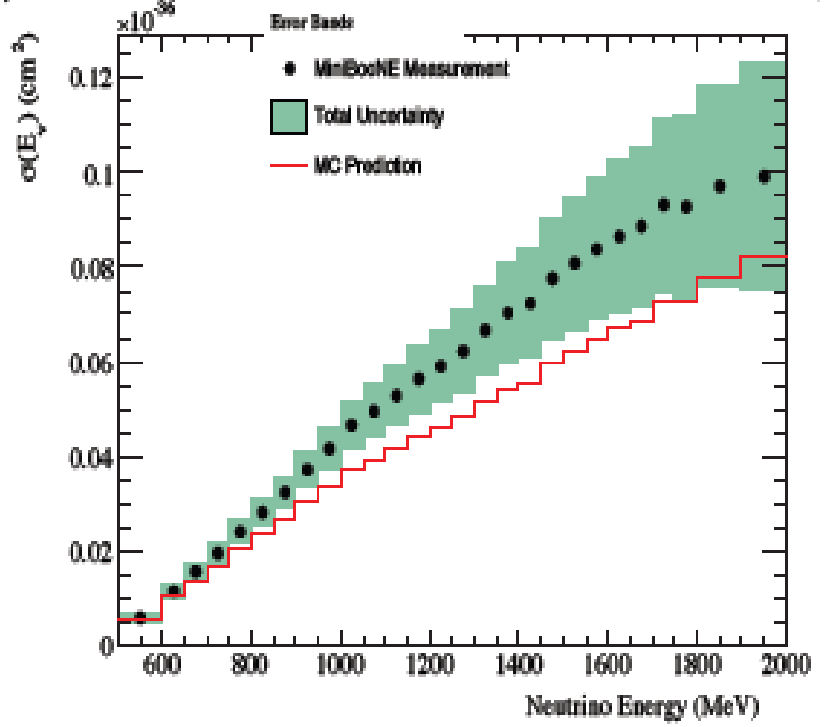

*Phys. Rev. D82, 092005 (2010)*

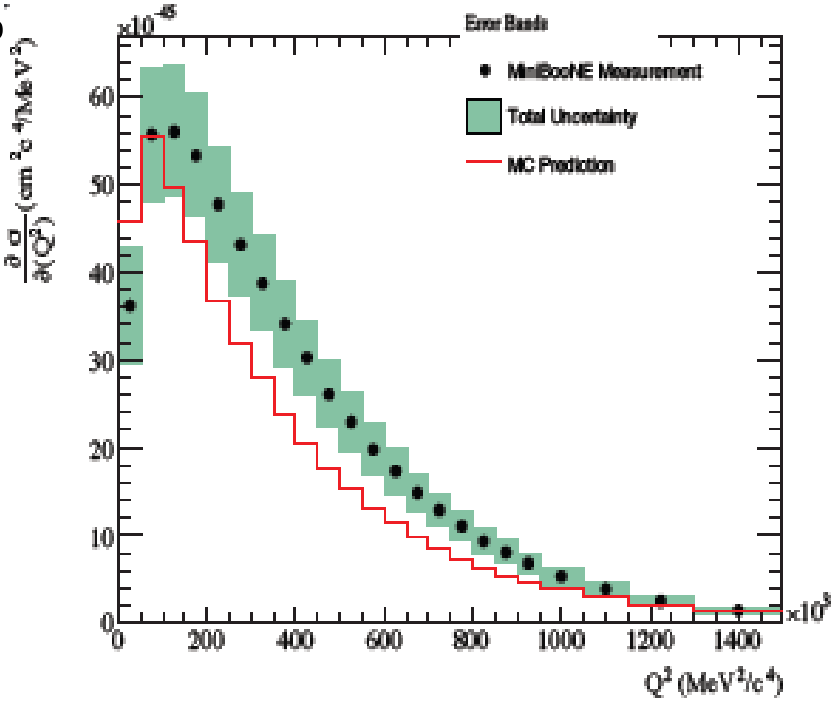



# CC $\pi^+$

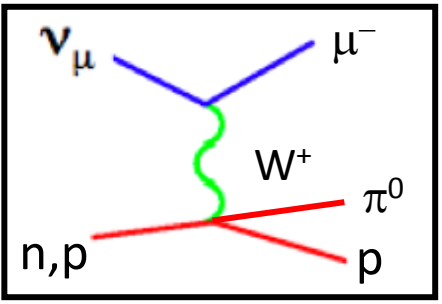
- 19% of neutrino interactions
- Important background to oscillation searches using CCQEs in few GeV range
- World largest sample of CC $\pi^+$ interactions (48322 candidates with 90% purity)
- Also measured flux averaged single and double-differential cross sections of the energy and direction of both final-state muon and pion





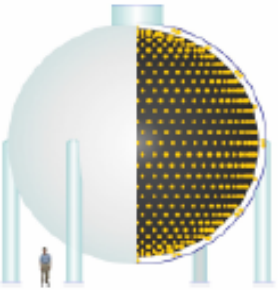



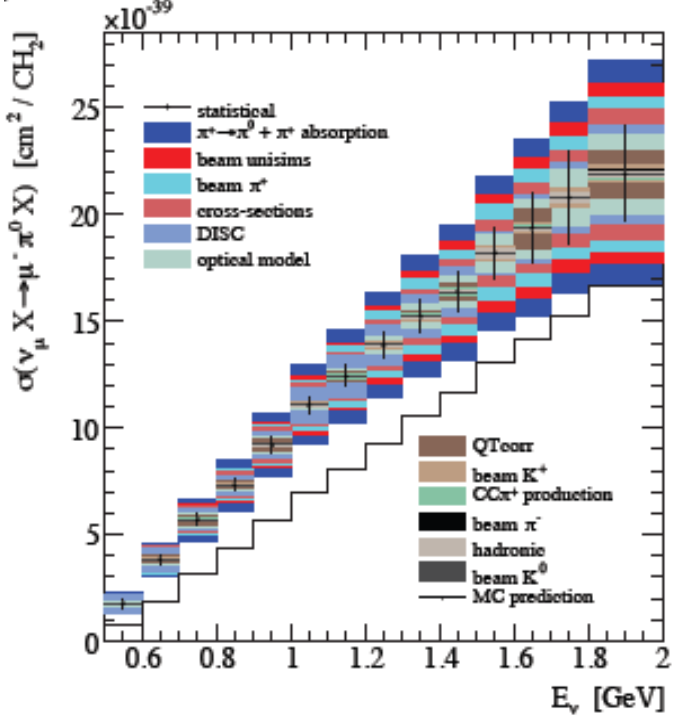

*arxiv: 1011.3572 [hep-ex]*

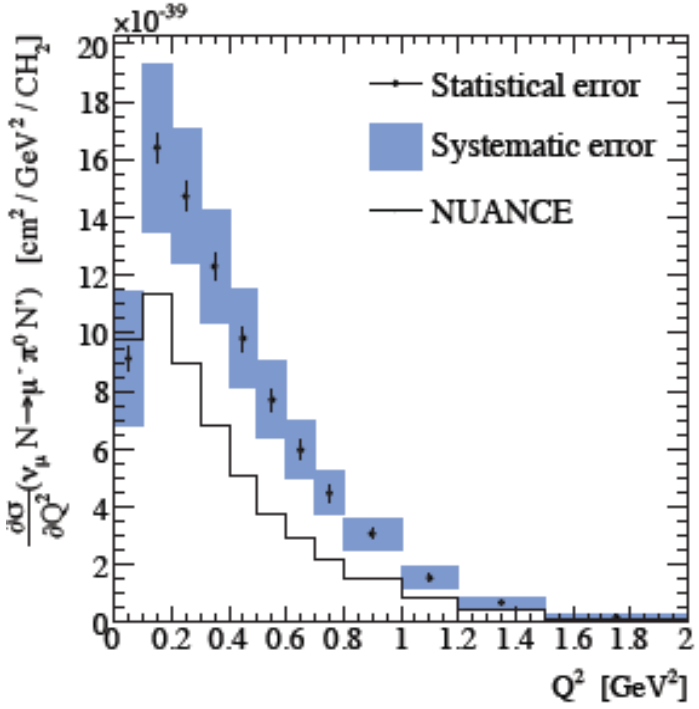



# CC $\pi^0$

- 4% of neutrino interactions
- World largest sample at energies below 2 GeV
- Larger cross section than expected
- Also measured flux-averaged differential cross sections in terms of $\mu^-$ and $\pi^0$ kinematics

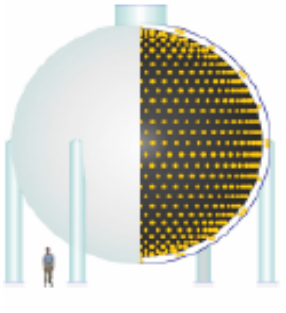




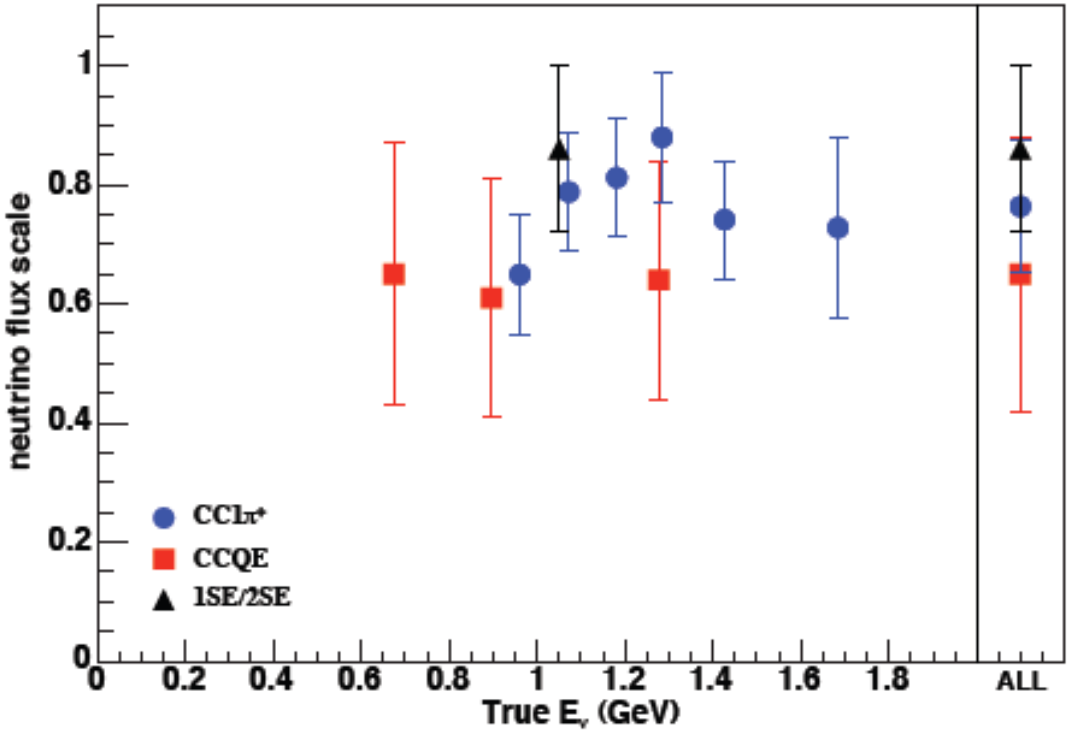




*arxiv: 1010.3264 [hep-ex]*

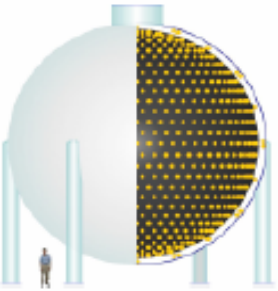
# Neutrinos in Anti-neutrino mode



- In anti-neutrino mode
  neutrinos (wrong-signs) make ~30% of events
- Important for oscillation and cross section measurements in anti-neutrino mode
- Three independent and complementary measurements of the wrong-sign backgrounc
  - Angular distribution of CCQE events
  - Using CCpi+ sample
  - Using muon decay electrons

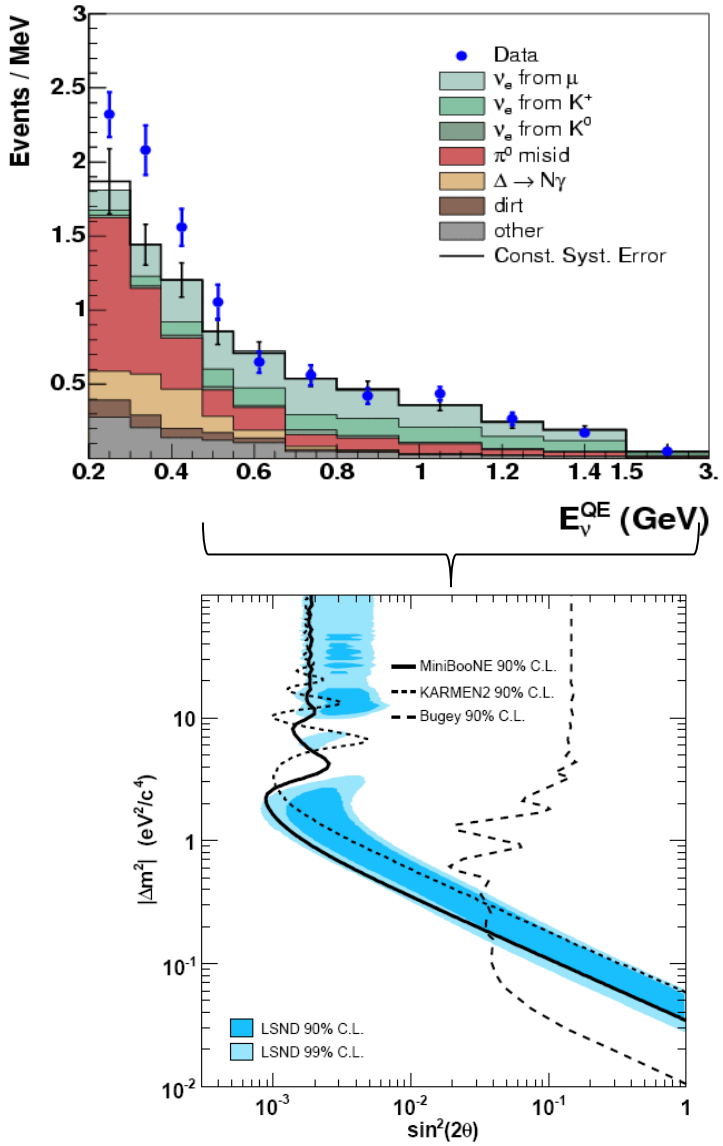



*arxiv: 1102.1964 [hep-ex]*



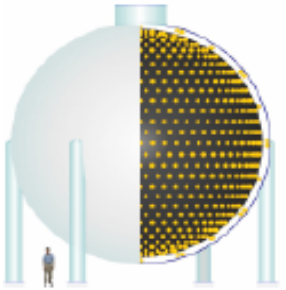
# $\nu_e$ appearance analysis

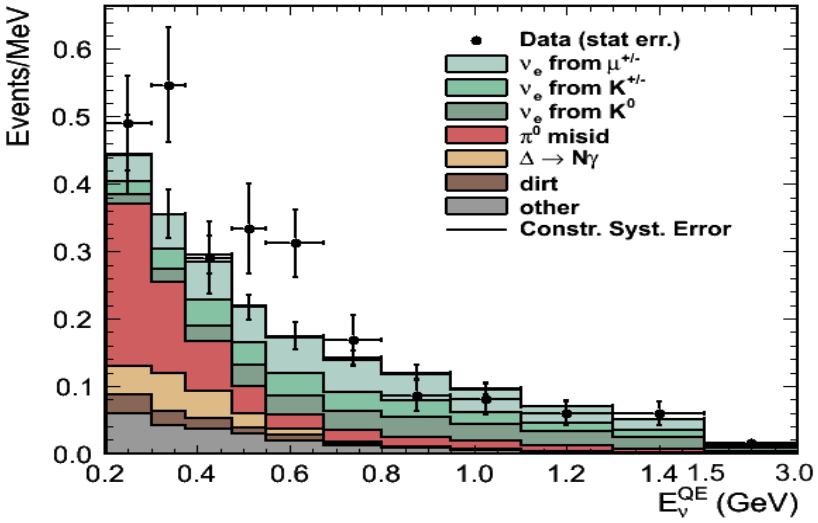
- MiniBooNE Neutrino mode:
  - no evidence of appearance in E>475MeV region (where LSND oscillation signal expected)
  - A 3σ excess of events in E<475MeV energy region (shape not consistent with 2ν oscillations)




*Phys. Rev. Lett. 102, 101802 (2009)*

# $\bar{\nu}_e$ appearance results



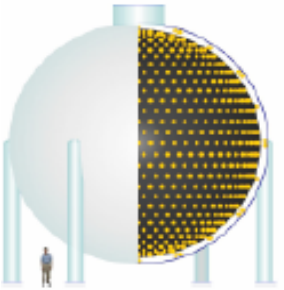



| | 200-475MeV | 475-1250MeV |
|---|---|---|
| Data | 119 | 120 |
| MC | 100.5 ± 14.3 | 99.1 ± 14.0 |
| Excess | 18.5 ± 14.3 | 20.9 ± 14.0 |
| LSND Best Fit | 7.6 | 22 |
| Expectation from v Low E excess | 11.6 | 0 |
| LSND+Low E | 19.2 | 22 |

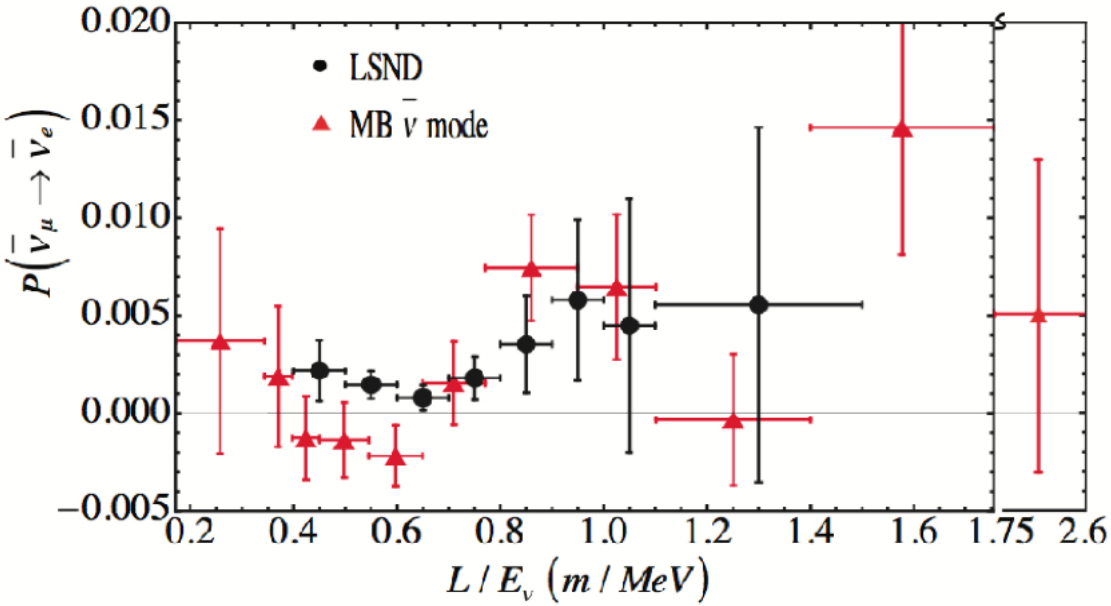
- 5.66E20 POT
- Excess of events in both 200-475MeV and 475-1250MeV region

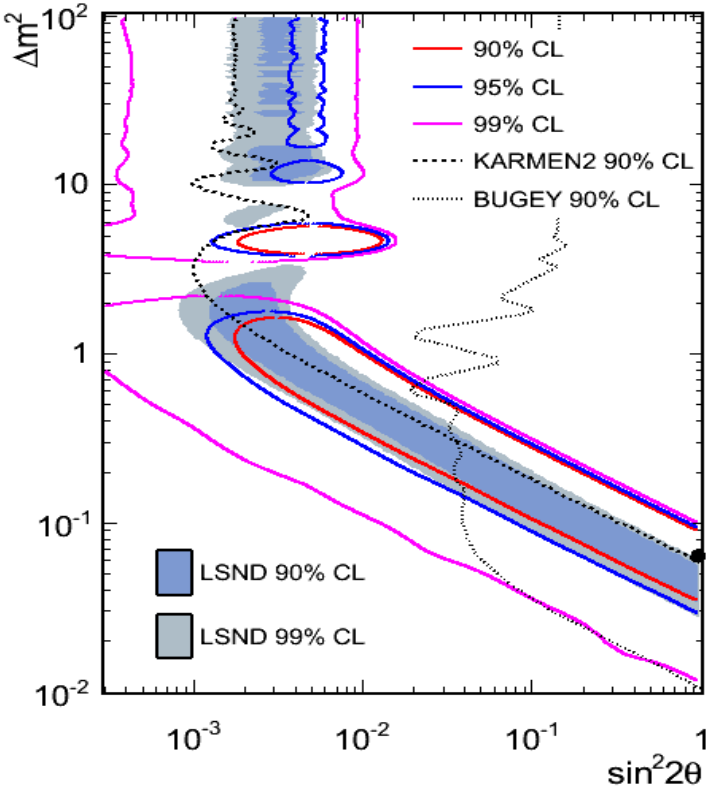
*Phys. Rev. Lett. 105, 181801 (2010)*

# $E_\nu^{QE}$>475



- 5.66E20 POT
- E>475 is signal region for LSND type osc.
- Null probability 0.5% (compared to 40% in neutrino mode)
- Oscillations favored over background only hypotheses at 99.4% CL (model dependent)
- Best fit ($\sin^2 2\theta$, $\Delta m^2$) = (0.9584, 0.064 eV$^2$)



# Conclusion

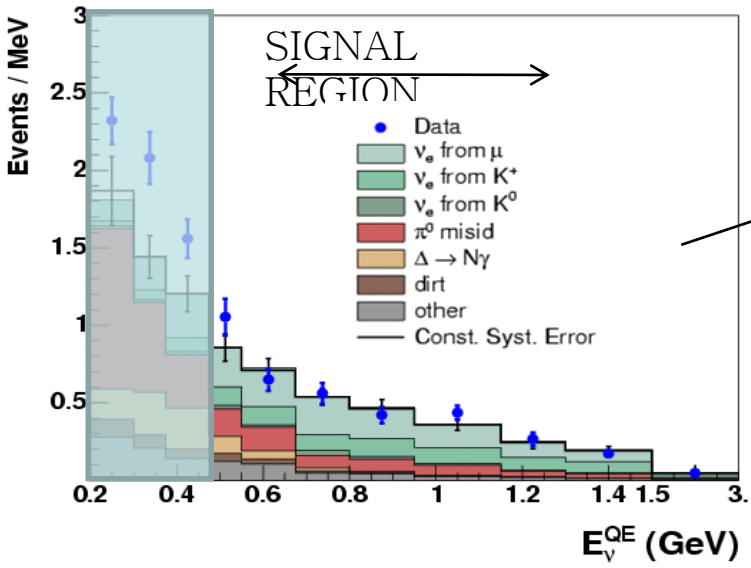
- Cross sections:
  - Important measurements from SciBooNE & MiniBooNE
  - Many 1st measurements or first time full kinematics reported
  - Measurements with anti-neutrino beam under way

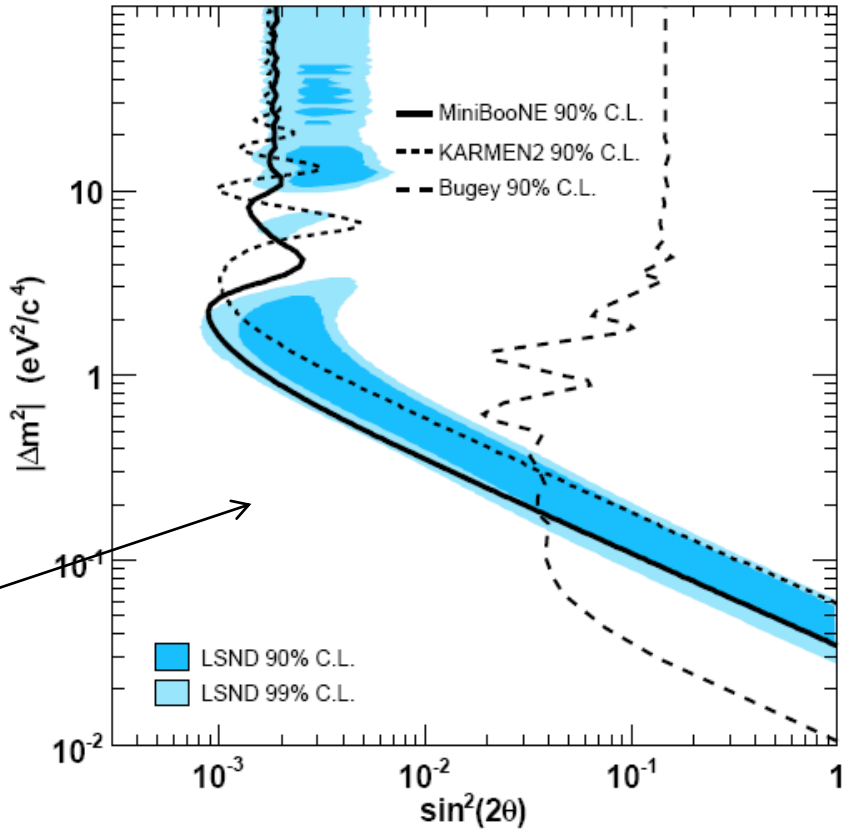
- Oscillations:
  - MiniBooNE $\bar{\nu}_e$ data prefers LSND signal over null hypothesis at 99.4%
  - Future:
    - MiniBooNE oscillation analysis with more POT and analysis improvements
    - Joint SciBooNE/MiniBooNE numu disappearance analysis

Short Baseline Neutrino Workshop at Fermilab May 12-14 ,2011. (https://indico.fnal.gov/conferenceDisplay.py?confId=4157)

# MiniBooNE neutrino result

- 6.5e20 POT
- No excess of events in signal region (E>475 MeV)
- Ruled out 2 n oscillation as LSND explanation (assuming no CP or CPT violation)



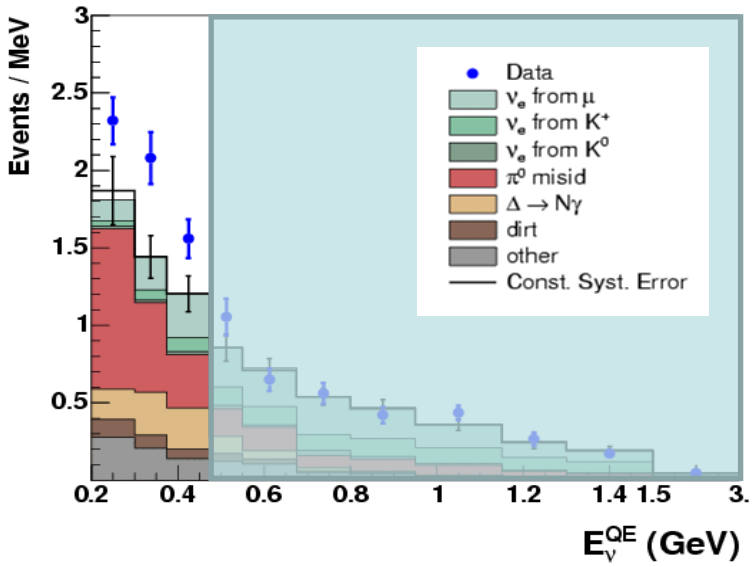

*Phys. Rev. Lett. 98, 231801 (2007)*

# MiniBooNE neutrino result

Excess of events observed at low energy:
128.8 ± 20.4 ± 38.3 (3.0σ)

Shape not consistent with 2 ν oscillations

Magnitude consistent with LSND




Anomaly Mediated Neutrino-Photon Interactions at Finite Baryon Density: Jeffrey A. Harvey, Christopher T. Hill, & Richard J. Hill, arXiv:0708.1281

CP-Violation 3+2 Model: Maltoni & Schwetz, arXiv:0705.0107; T. Goldman, G. J. Stephenson Jr., B. H. J. McKellar, Phys. Rev. D75 (2007) 091301.

Extra Dimensions 3+1 Model: Pas, Pakvasa, & Weiler, Phys. Rev. D72 (2005) 095017

Lorentz Violation: Katori, Kostelecky, & Tayloe, Phys. Rev. D74 (2006) 105009

CPT Violation 3+1 Model: Barger, Marfatia, & Whisnant, Phys. Lett. B576 (2003) 303

New Gauge Boson with Sterile Neutrinos: Ann E. Nelson & Jonathan Walsh, arXiv:0711.1363



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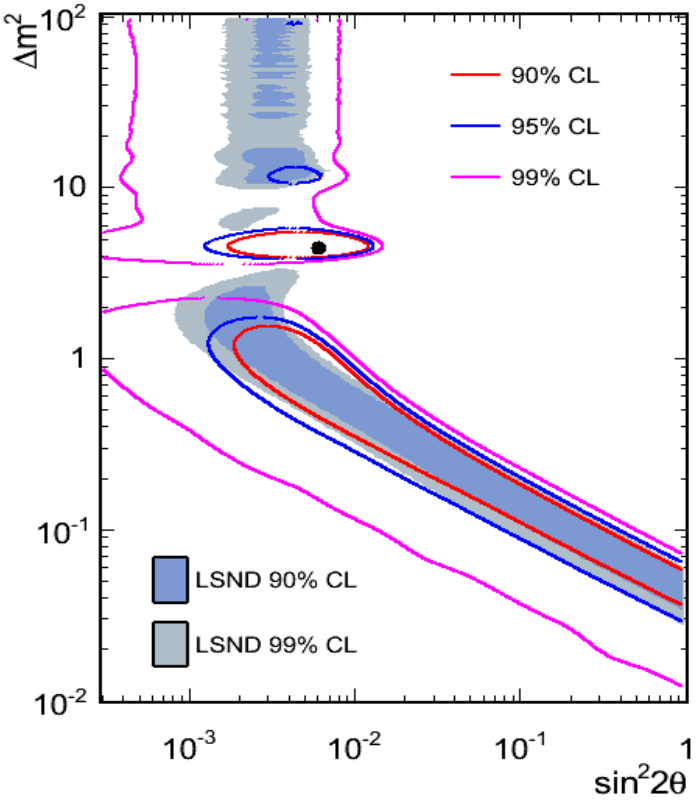
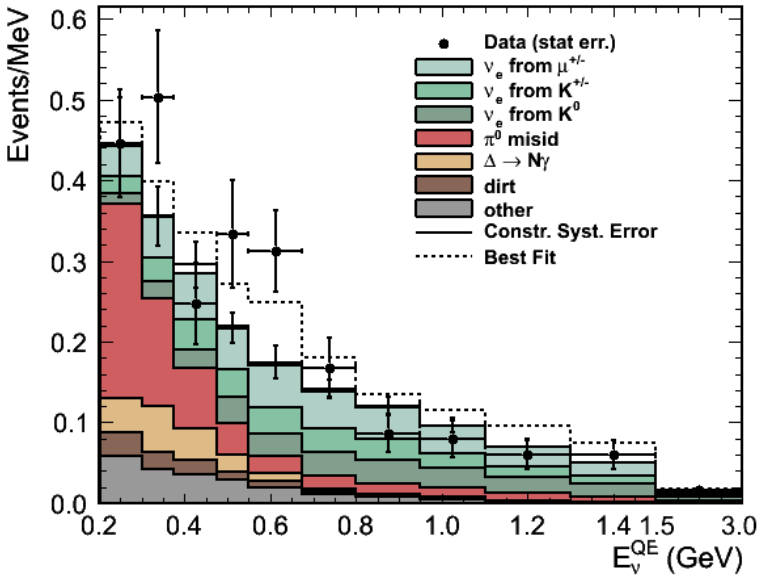
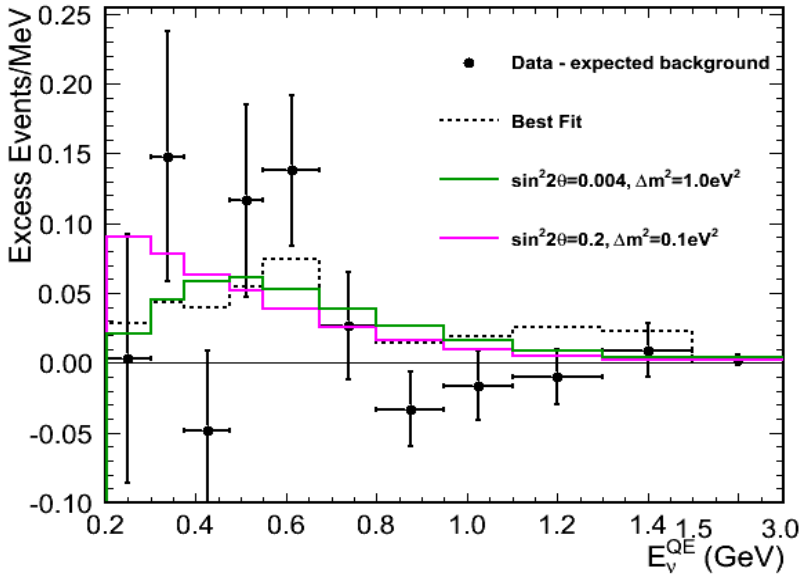
# E>200MeV

- Subtract excess produced by neutrinos in $\bar{\nu}_\mu$ mode (11.6 events)
- E<475MeV:
  - Large background
  - Not relevant for LSND type osc.
  - Big systematics
- Null $\chi^2$=32.8; p=1.7%
- Best fit ($\sin^2 2\theta$, $\Delta m^2$) = (0.0061, 4.42 eV$^2$)



# LSND $\bar{\nu}_e$ Background Estimates

| Estimate | $\bar{\nu}_e/\bar{\nu}_\mu$ | $\bar{\nu}_e$ Bkgd | LSND Excess |
|---|---|---|---|
| LSND Paper | 0.086% | 19.5+-3.9 | 87.9+-22.4+-6.0 |
| Zhemchugov Poster | 0.071% | 16.1+-3.2 | 91.3+-22.4+-5.6 |
| Dydak Seminar | 0.116% | 26.3+-5.3 | 81.1+-22.4+-7.0 |

**All $\bar{\nu}_e$ background estimates assume a 20% error. Note that the $\bar{\nu}_e/\bar{\nu}_\mu$ ratio determines the background!**

LSND Paper: A. Aguilar et al., Phys. Rev. D 64, 112007 (2001); (uses **MCNP**)

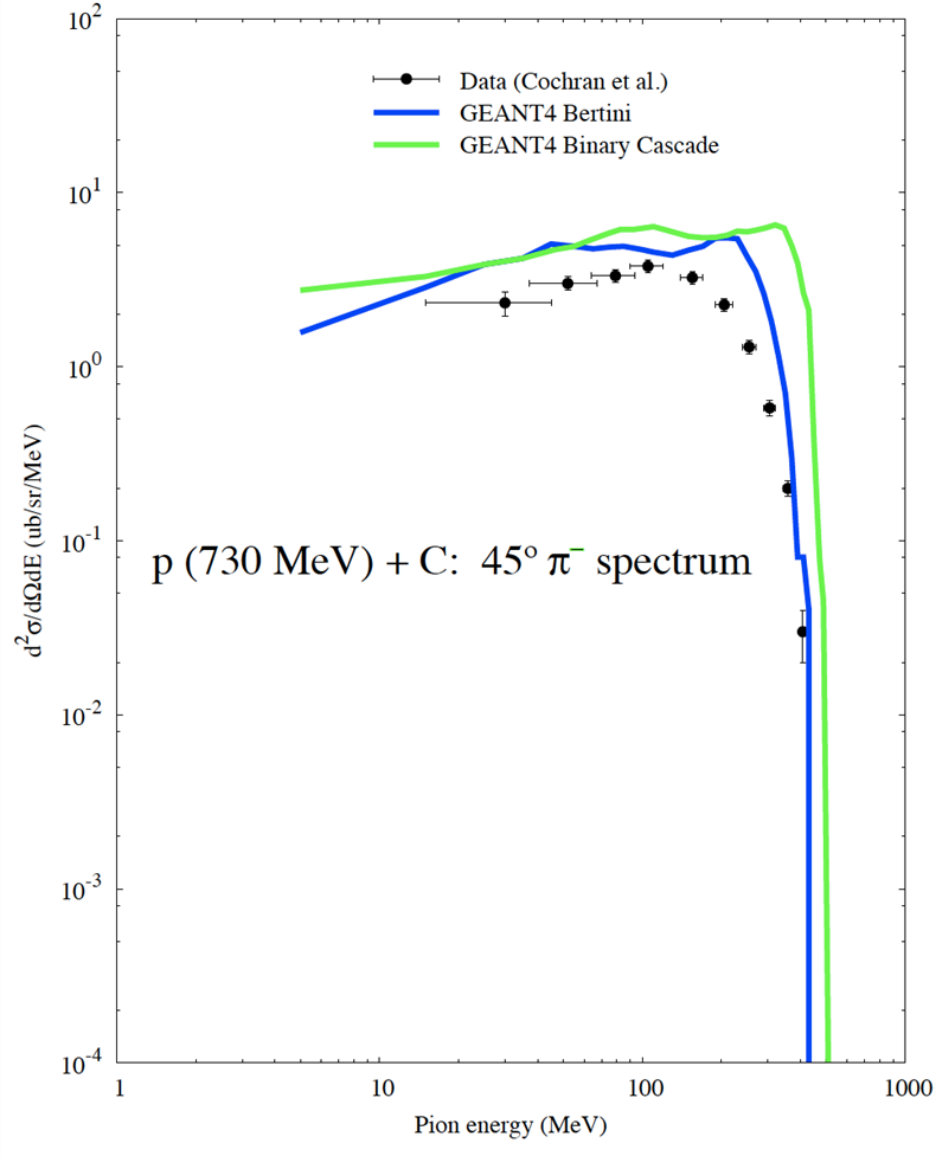
Zhemchugov Poster: **FLUKA** $\bar{\nu}_e/\bar{\nu}_\mu$ ratio presented at the ICHEP 2010 Conference, Paris

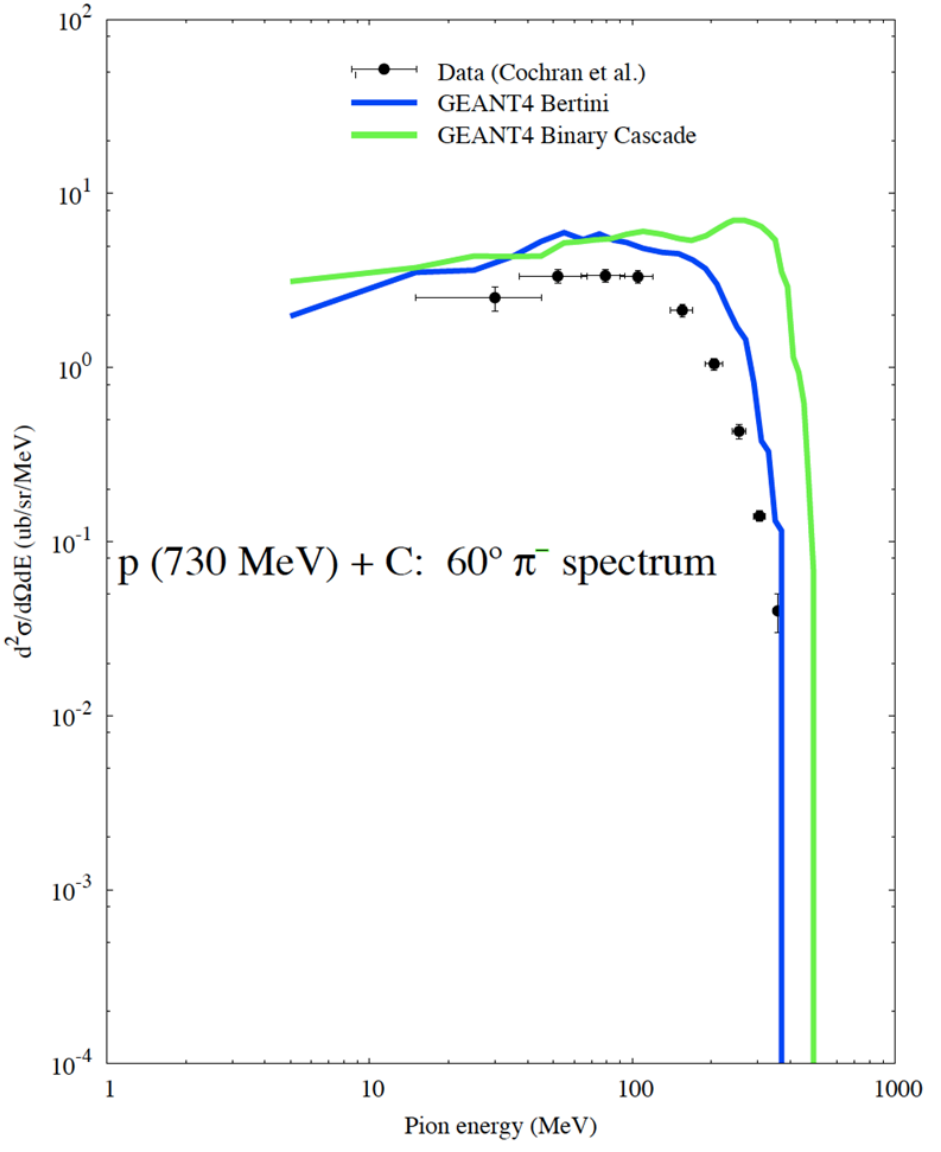
Dydak Seminar: **FLUKA** $\bar{\nu}_e/\bar{\nu}_\mu$ ratio presented at FNAL on January 14, 2011

Although the analysis of Zhemchugov, Dydak et al. is not fully understood or endorsed, their $\bar{\nu}_e/\bar{\nu}_\mu$ ratios agree reasonably well with the published LSND results.

Note that LSND measures the correct rate of $\bar{\nu}_\mu$ p -> $\mu^+$ n interactions, which confirms the $\pi^-$ production and background estimates. Note also, that FLUKA & GEANT4 overestimate $\pi^-$ production at ~800 MeV. Note that $N_{gs}$ events are included in the LSND background estimate.

# GEANT4 Overestimates $\pi^-$ Production



# $\nu_e$ C –> $e^-$ $N_{gs}$ Events Do Not Simulate $\bar{\nu}_e$ p –> $e^+$ n Events!

For $N_{gs}$ β decay to be considered a 2.2 MeV γ:
$\Delta r<2m$, $\Delta t<500\mu s$, $19<N_{hits}<51$

The number of $N_{gs}$ events with a β that satisfies this initial requirement is approximately: (600)(1)(1/31.8)(0.05) ~ 1 event.

The number of $N_{gs}$ events with $R_\gamma>10$ ~ 0.1 events.

This background is included in the LSND background estimate.