Exclusive Neutrino Cross Sections From MiniBooNE

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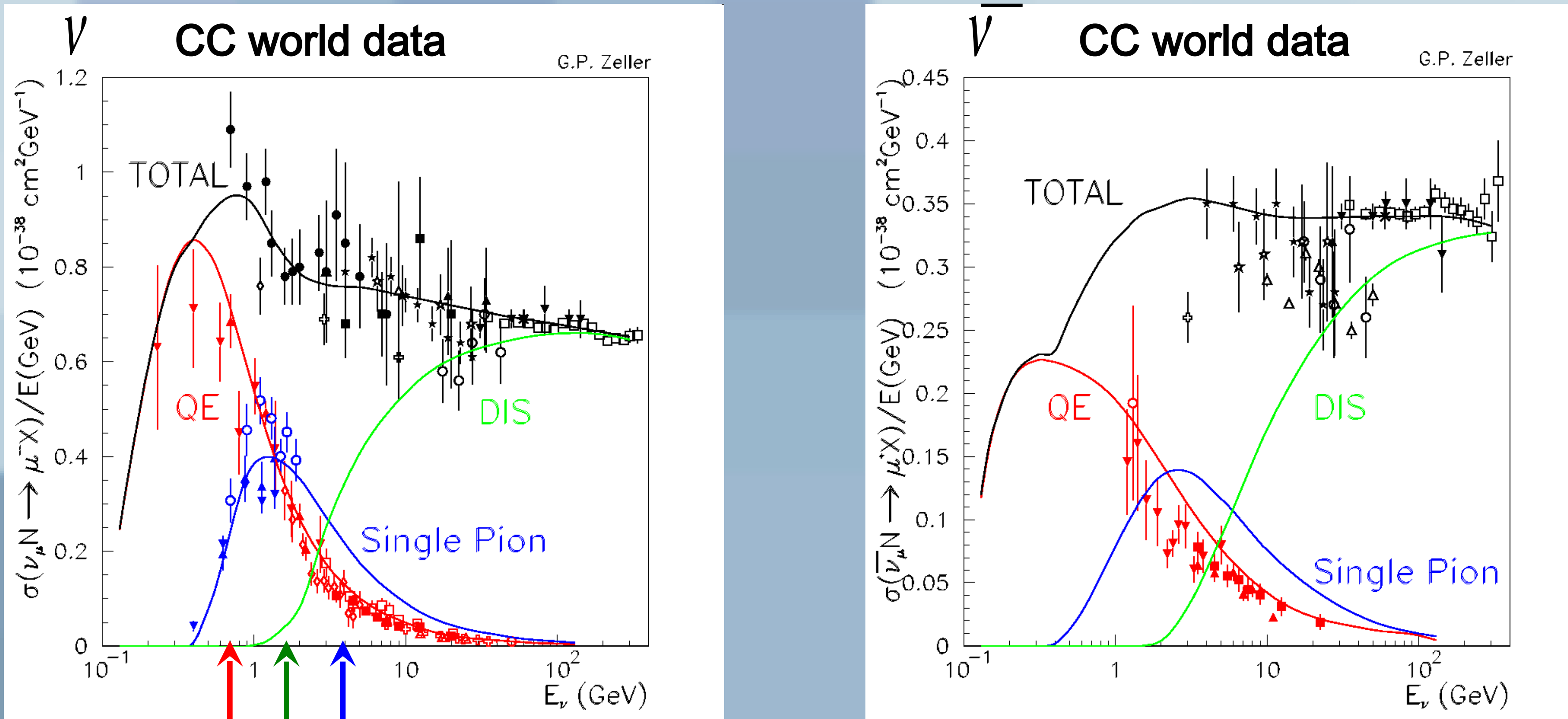
Neutrino Cross Sections Today



T2K, BooNE

K2K, NOvA

MINOS

- Precise knowledge needed for precise oscillation measurements.
- Cross section well measured above 20 GeV.
- Few measurements below 20 GeV.
- 20-30 years old bubble chamber experiments (mostly H_2, D_2).
- Neutral current cross sections are even less understood.

The MiniBooNE Experiment

BEAM:

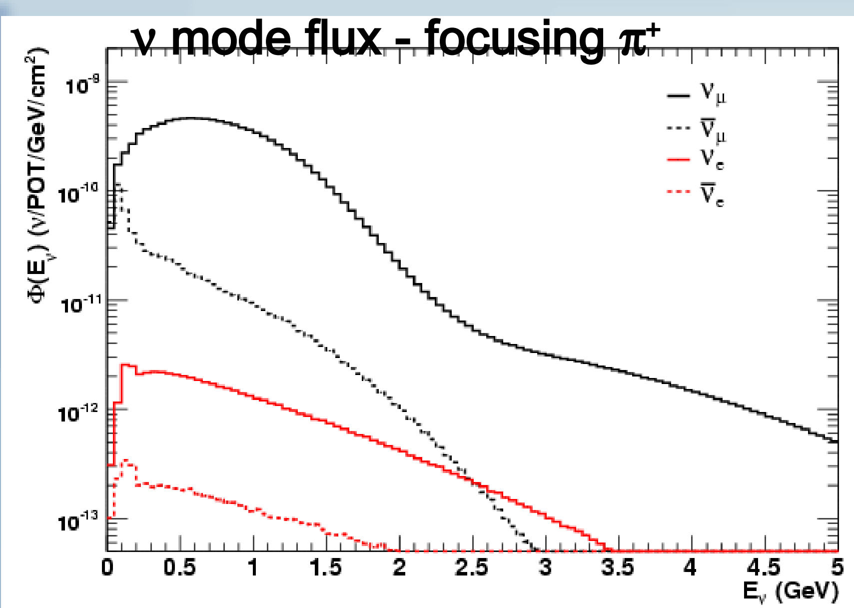
- MiniBooNE extracts protons from the 8 GeV Booster delivered to a 1.7l Be target inserted into a magnetic horn (2.5 kV, 174 kA) that (increases flux 6 times)
- ~900k interactions in fiducial volume in ν mode with small anti-ν component.
- ~90k interactions in fiducial volume in anti-ν mode with 30% ν component.

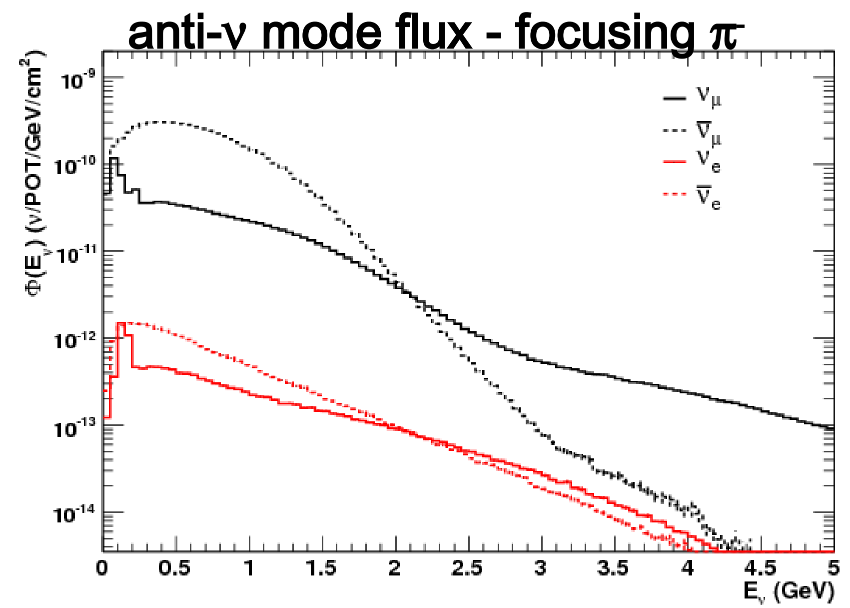
The Neutrino Flux Prediction at MiniBooNE, Submitted to PRD [arXiv:0806:1449]

DETECTOR

- 541 m downstream of target, 3 m overburden
- 12 m diameter sphere(10 m “fiducial”)
- 800 t (450 t fiducial) of pure mineral oil (CH_2)
- 1280 inner and 240 veto phototubes

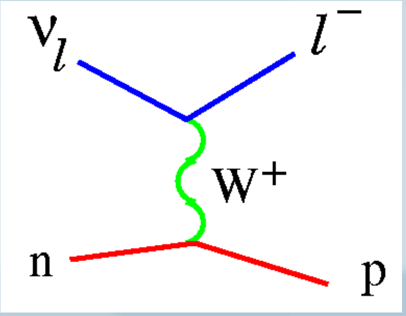
The MiniBooNE Detector, Accepted by NIM A [arXiv:0806.4201]





ν_μ CCQE

$$\nu_\mu + n \rightarrow \mu^- + p$$



Neutrino oscillations:

- dominant at this energy.
- golden channel for disappearance searches.

Neutrino cross section:

- provides information about nuclear structure.

$$F_A = \frac{g_A}{\left(1 + Q^2/M_A^2\right)^2}$$

- fits to old bubble chamber experiments (D_2).
  - M_A = 1.03 GeV.
- recent results on nuclear targets – higher M_A
  - K2K SciFi (^{16}O) M_A= (1.20 ± 0.12) GeV, PRD 74, 052002 (2006)
  - K2K Scibar (^{12}C) M_A= (1.14 ± 0.11) GeV

MiniBooNE has collected 198,000 events after cuts.

ν_μ CCQE Kinematics

- tagged by the stopped muon decay electron

- 74% purity, 35% efficiency

- measure θ_μ, $T_\mu \rightarrow E_\nu$, Q^2

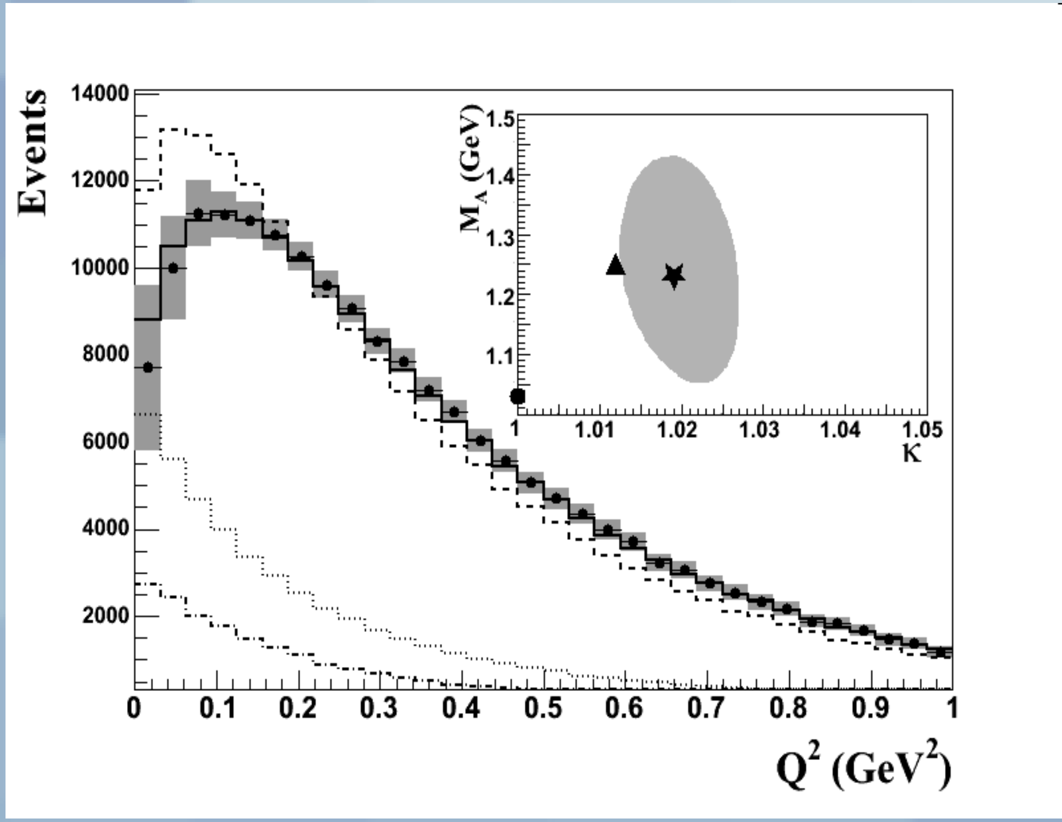
$$Q^2 = -q^2 = -m_\mu^2 + 2E_\nu(E_\mu - p_\mu \cos\theta_\mu)$$

- world M_A =1.03 GeV (dashed line) data disagree in Q^2

- fit to the Q^2 distribution using effective parameters M_A and κ (Pauli blocking parameter).

M_A = (1.23 ± 0.20) GeV, (high Q^2)
κ = 1.019 ± 0.011, (low Q^2)

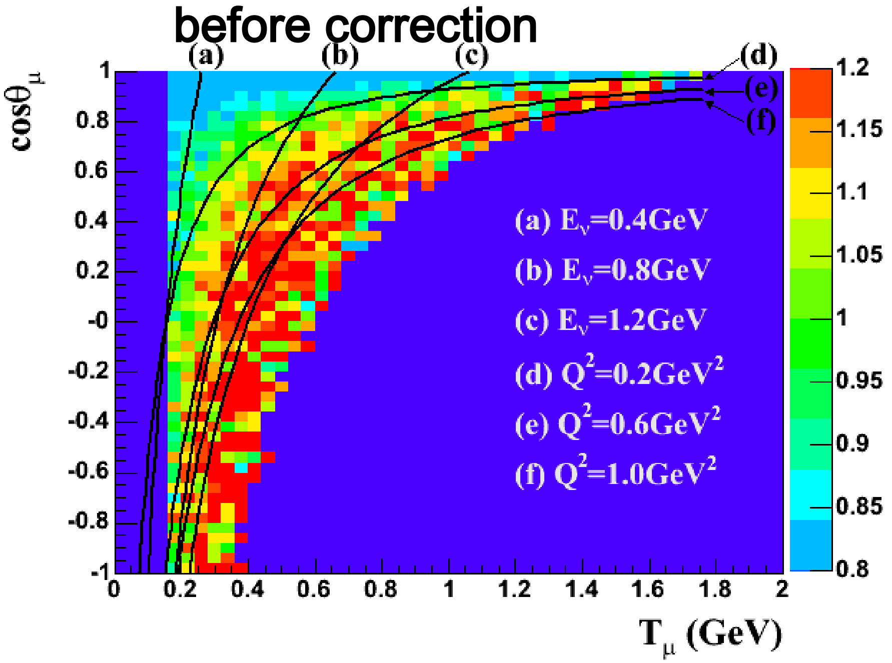
- agrees with nuclear target measurements.

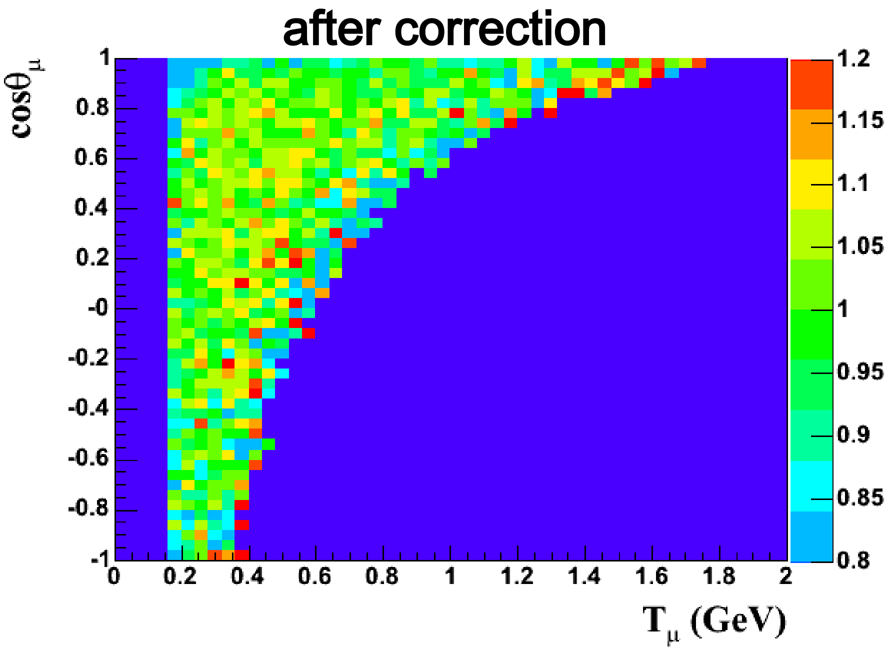


Measurement of Muon Neutrino Quasi-Elastic Scattering on Carbon, PRL 100, 032310 (2008)

ν_μ CCQE Kinematics

Data/MC ratios



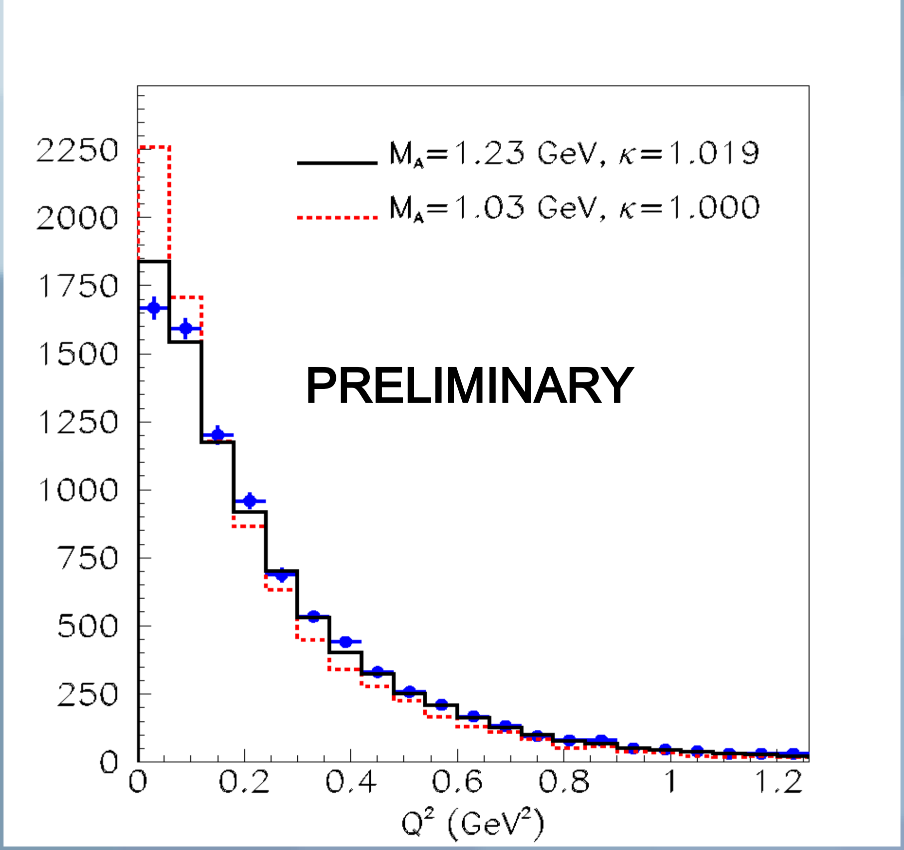


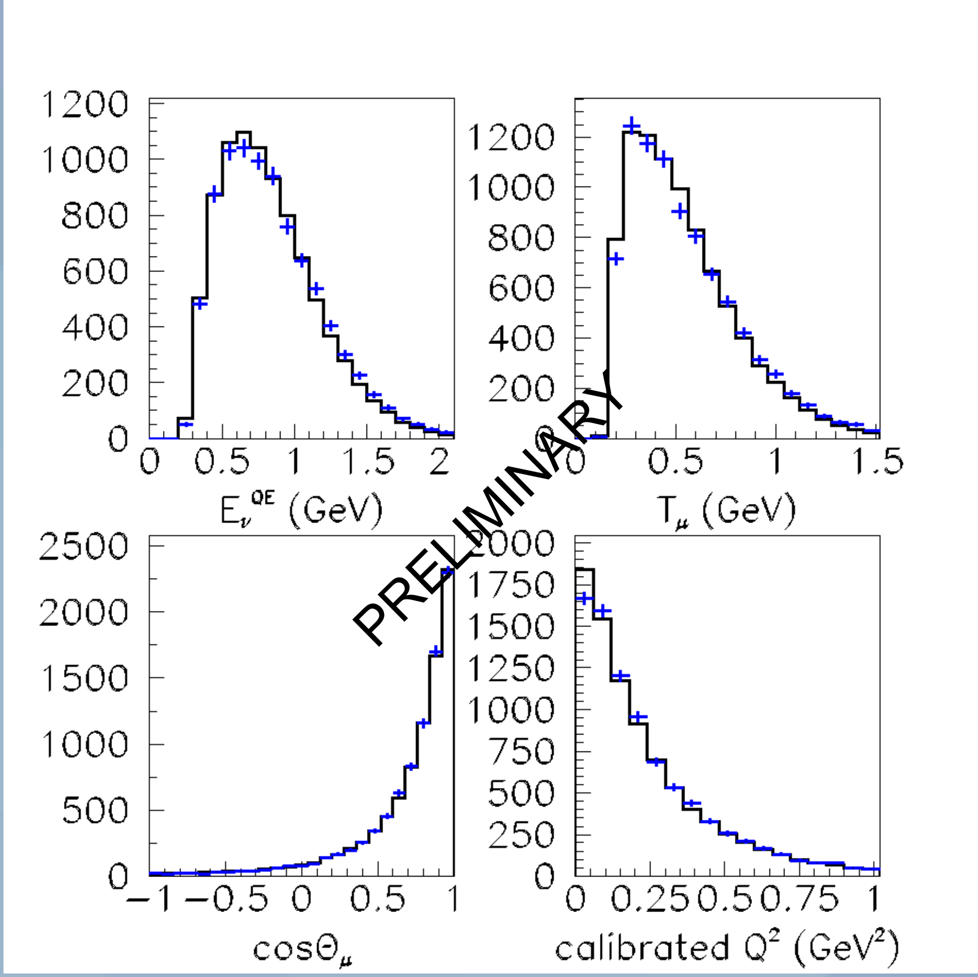
$$Q^2 = -q^2 = -m_\mu^2 + 2E_\nu (E_\mu - p_\mu \cos\theta_\mu)$$

- improves agreement with data for both $\cos\theta_\mu$ and T_μ

$\bar{\nu}_\mu$ CCQE

- $\bar{\nu}_\mu + p \rightarrow \mu^+ + n$
- apply M_A and κ from ν mode.
- good agreement with data.



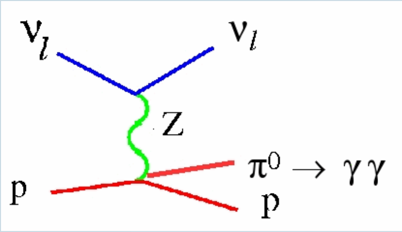


- good agreement in other kinematic variables

ν_μ NC π^0

$$\nu_\mu + N \rightarrow \nu_\mu + N + \pi^0$$ resonant

$$\nu_\mu + A \rightarrow \nu_\mu + A + \pi^0$$ coherent



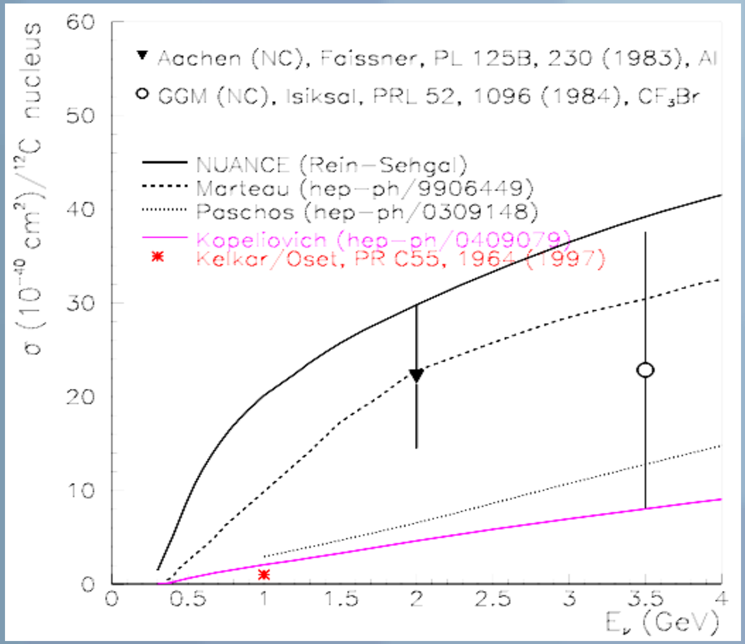
Neutrino oscillation:

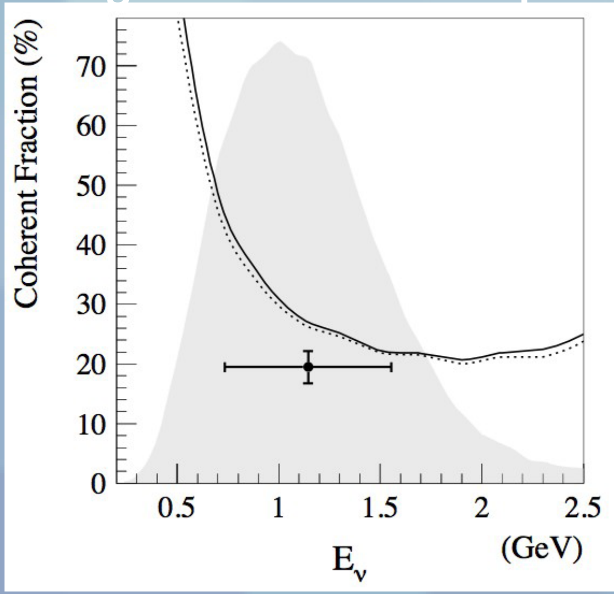
- very important for ν_e appearance searches
  - if one of the γ's is lost or below threshold

Neutrino cross section:

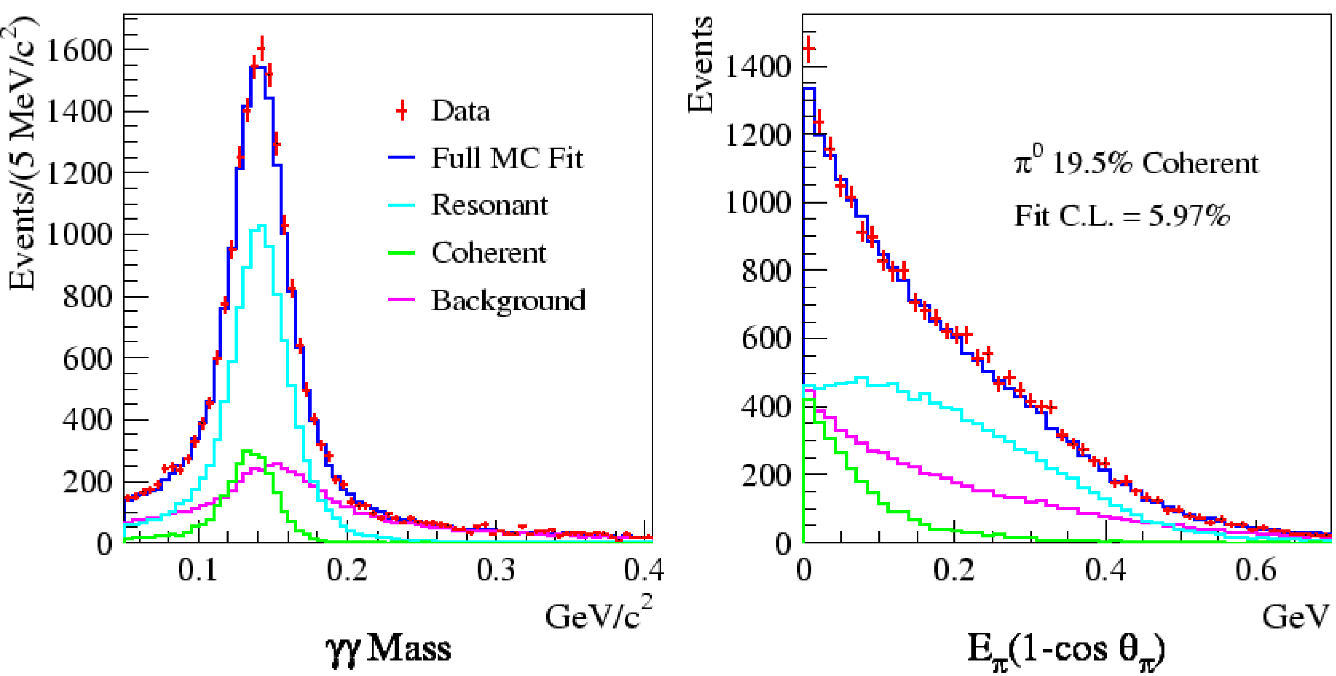
- important for understanding coherent and resonant production.
- no data below 2GeV.
- Rein – Sehgal model used for prediction.

World data on coherent production





ν_μ NC π^0



First Observation of Coherent π^0 Production in Neutrino Nucleus Interactions with E_ν<2 GeV, Phys Lett B.664, 41 (2008)

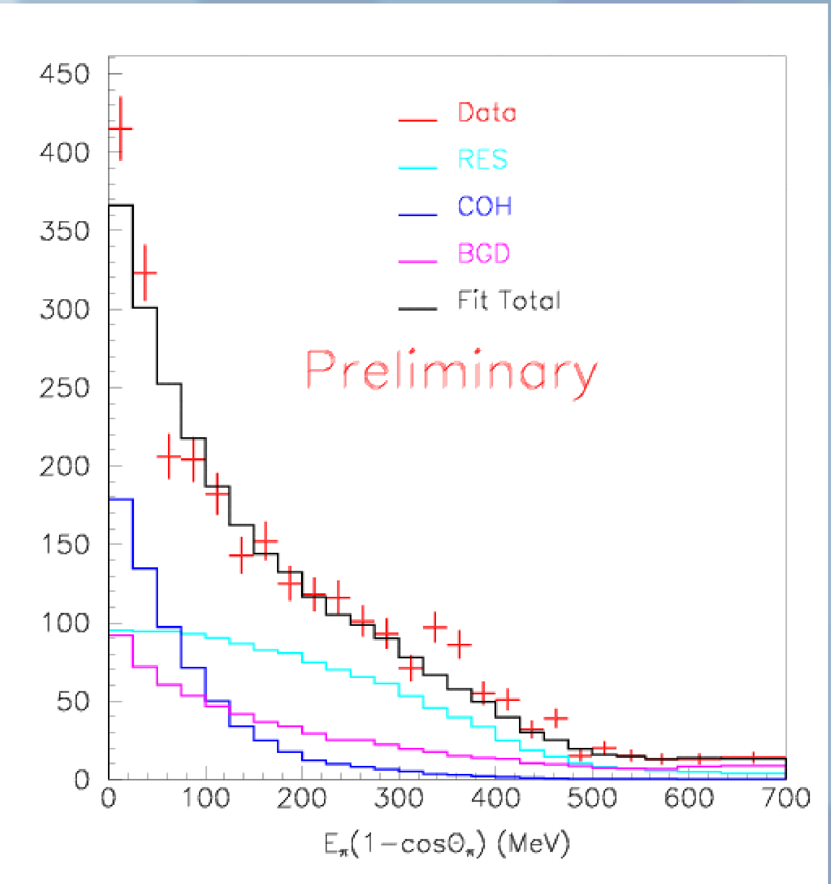
- excellent π^0 containment (4π)
- fully reconstructed π^0 sample – 28,600 events, 97% purity, 40% efficiency
- reweighting of momentum distribution gives very good agreement in other kinematic variables.

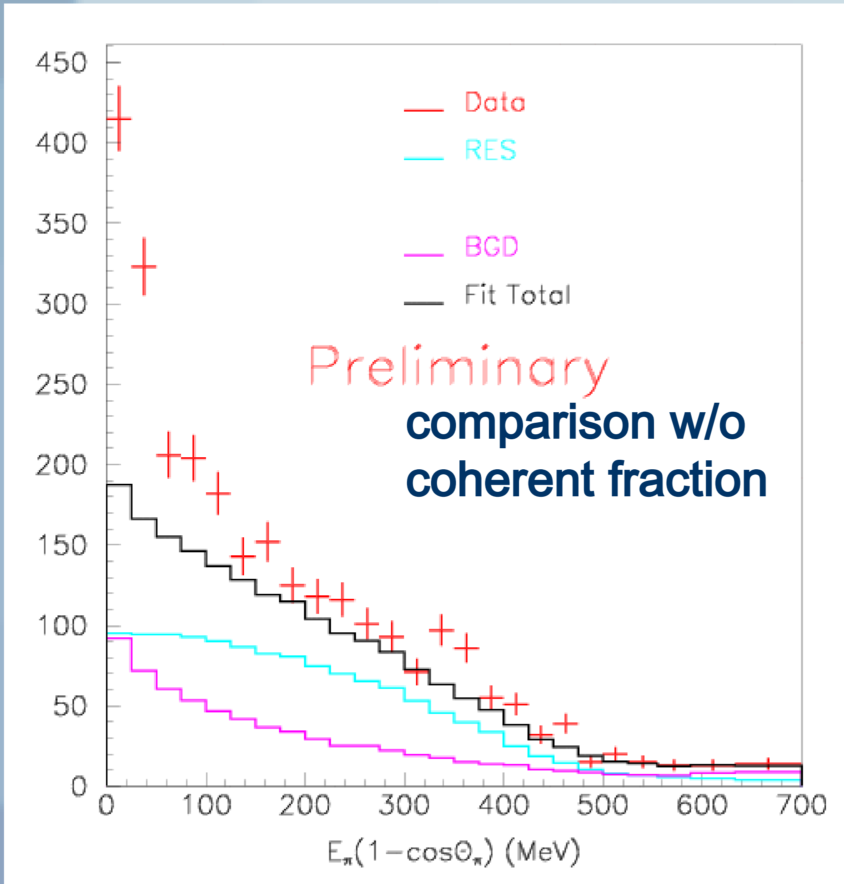
- very different angular distributions – coherent is much more forward
- fit for resonant and coherent fractions yields [19.5±1.1(stat)±2.5(syst)]% coherent fraction.

$\bar{\nu}_\mu$ NC π^0

- $\bar{\nu}_\mu + N \rightarrow \bar{\nu}_\mu + N + \pi^0$
- evidence of coherent events.
- ~2700 events after cuts
- first measurement at 1GeV

For details see poster 77 by V. Nguyen

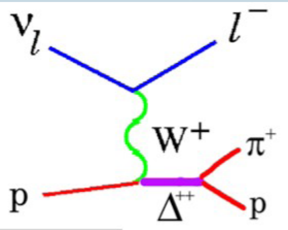




ν_μ CC π^+

$$\nu_\mu + N \rightarrow \mu^- + N + \pi^+$$ resonant

$$\nu_\mu + A \rightarrow \mu^- + A + \pi^+$$ coherent



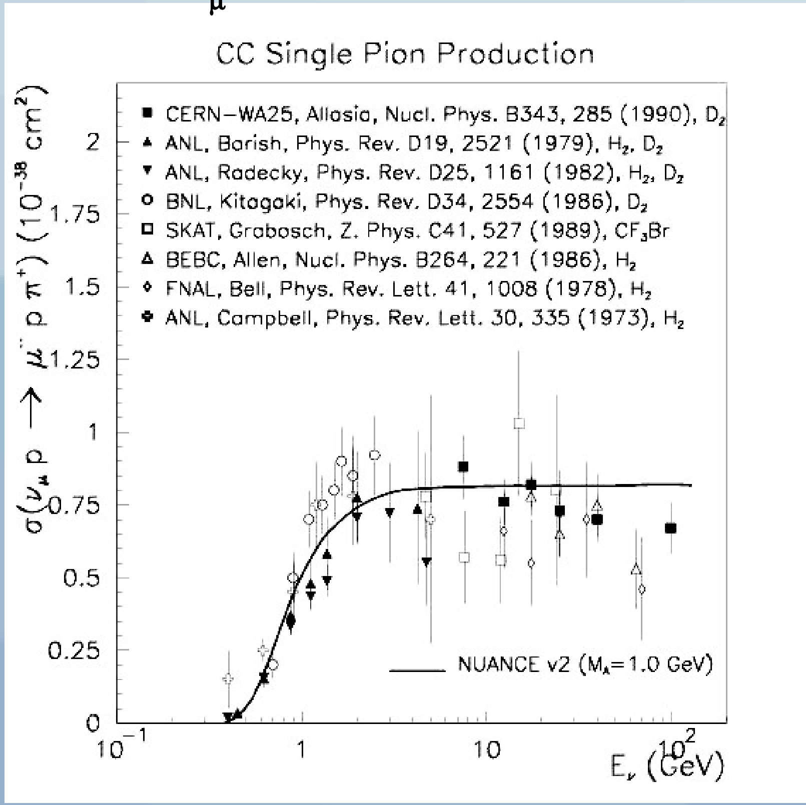
Neutrino oscillation:

- major background for ν_μ disappearance
  - if π+ is absorbed in the nucleus
- modifies ν_μQE energy spectrum
- results in larger systematic on oscillation parameters.
- need to know $\nu_\mu CC\pi+/\nu_\mu CCQE(E_\nu)$ to better than 5%.

Neutrino cross section:

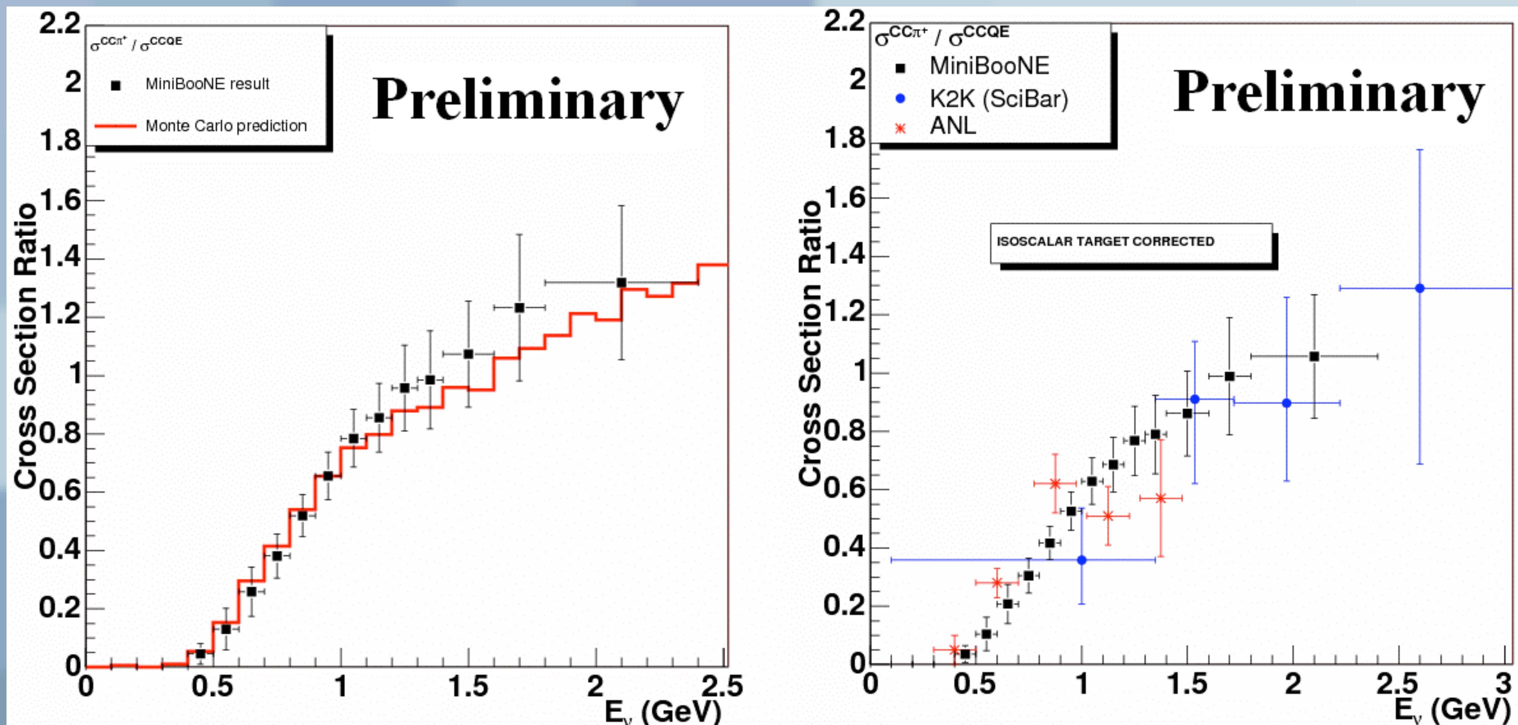
- old bubble chamber data (H_2, D_2).
- few nuclear target experiments.
- evidence of no coherent component at low energy.

ν_μ CCπ^+ world data



Also talk by SciBooNE – Y. Nakajima

$\nu_\mu CC\pi+/\nu_\mu CCQE(E_\nu)$

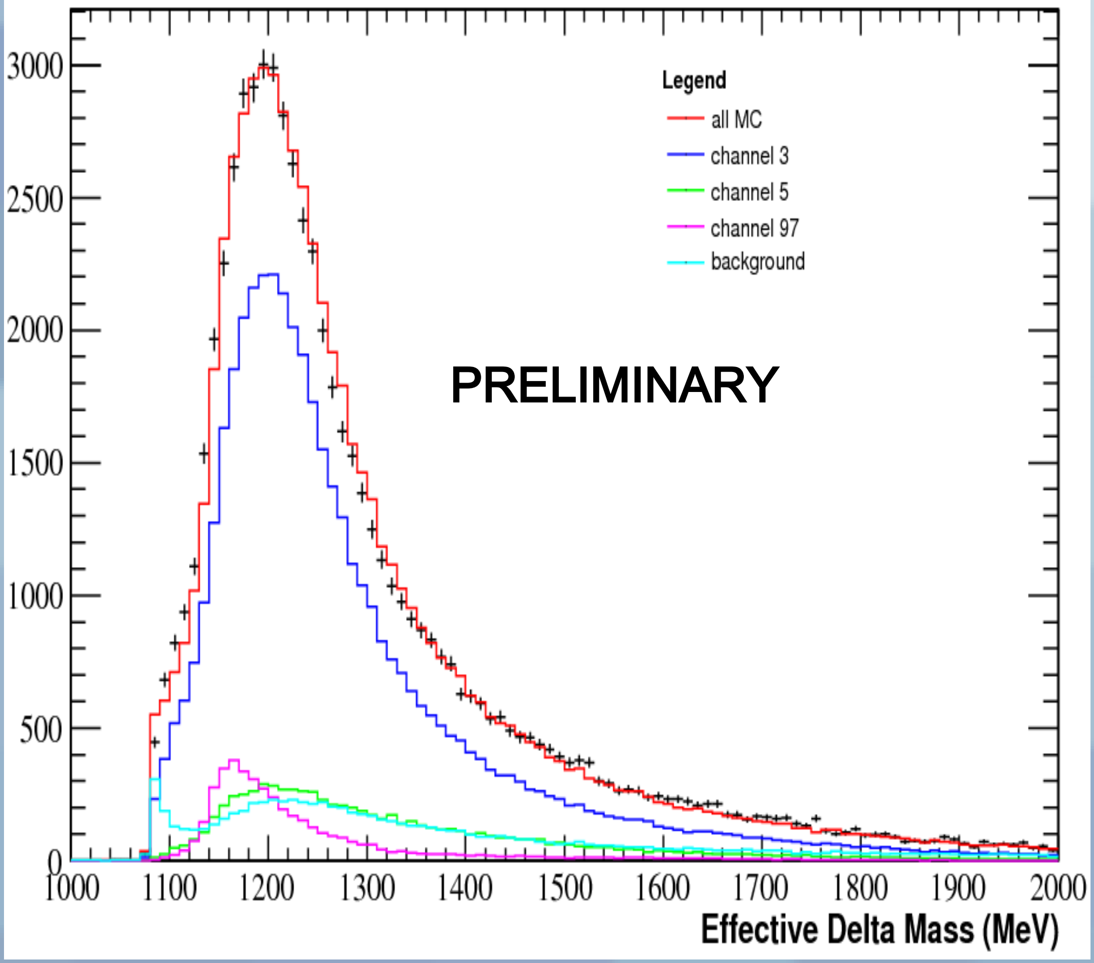


- tagged by two stopped muon decay electrons – 47,000 events 87% purity, 12% efficiency
- measure θ_μ, $T_\mu \rightarrow E_\nu$, Q^2

- MiniBooNE measurement is consistent with previous measurements and Rein-Sehgal model.
- For details see poster 79 by J. Nowak.

ν_μCC π^+ - Fully Reconstructed

- reconstructing both μ and π
- most pions undergo nuclear interactions resulting in kinked tracks.
- new fitter looks for 1 straight (muon) and one kinked (pion) track. Effectively it's a three ring fitter.
- first delta peak from neutrino experiment in more than 20 years.



More Cross Sections - $\nu_\mu CC\pi^0$ and ν_μNC elastic

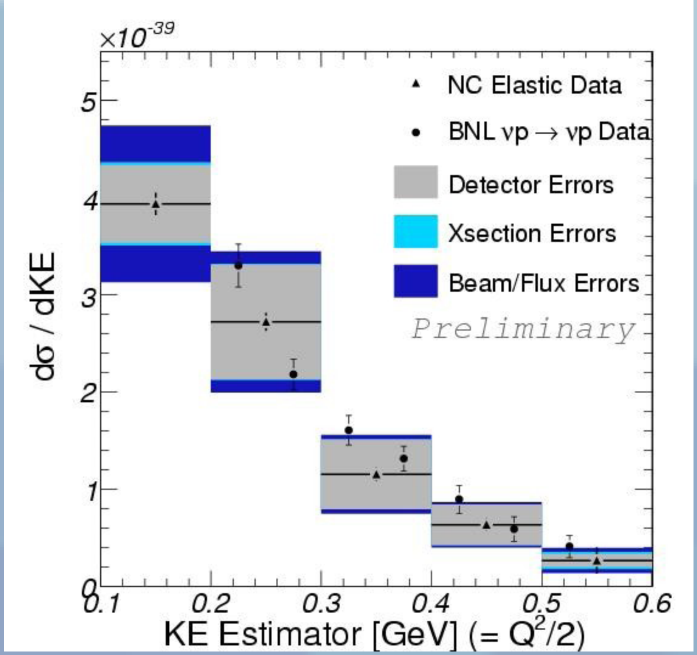
$\nu_\mu CC\pi^0$ differential cross section

$$\nu_\mu + n \rightarrow \mu^- + p + \pi^0$$

- tagged by one stopped muon decay electron.
- only resonant component.
- new three ring fitter – muon and 2 gamma tracks
- full event reconstruction.

ν_μNC elastic differential cross section

- preliminary result using prompt light for proton PID.
- new proton track fitter will provide proton PID and better reconstruction.



Published and Future Cross Section Papers

MiniBooNE cross section and other relevant papers:

- Measurement of Muon Neutrino Quasi-Elastic Scattering on Carbon, PRL 100, 032310 (2008)
- First Observation of Coherent π^0 Production in Neutrino Nucleus Interactions with E_n<2 GeV, Phys Lett B.664, 41 (2008)
- The Neutrino Flux Prediction at MiniBooNE, Submitted to PRD [arXiv:0806:1449]
- The MiniBooNE Detector, Accepted by NIM A [arXiv:0806.4201]

Papers in the immediate future:

- ν_μCCp+/ν_μCCQE(E_n) ratio measurement (S. Linden, J. Nowak)
- NC π^0 coherent/resonant fraction for anti-neutrino (V. Nguyen)

Papers to follow - Differential cross sections:

- ν_μCCQE, (T. Katori), anti- ν_μCCQE (T. Laird, J. Grange)
- ν_μCC π+ (M. Wilking)
- ν_μNC π^0 (C. Anderson)
- NC elastic (D. Perevalov)
- ν_μCC π^0 (R. Nelson)

BACKUPS

MiniBooNE Collaboration

A. A. Aguilar-Arevalo, A. O. Bazarko, S. J. Brice, B. C. Brown, L. Bugel, J. Cao, L. Coney, J. M. Conrad, D. C. Cox, A. Curioni, Z. Djurcic, D. A. Finley, B. T. Fleming, R. Ford, F. G. Garcia, G. T. Garvey, J. A. Green, C. Green, T. L. Hart, E. Hawker, R. Imlay, R. A. Johnson, P. Kasper, T. Katori, T. Kobilarcik, I. Kourbanis, S. Koutsoliotas, J. M. Link, Y. Liu, Y. Liu, W. C. Louis, K. B. M. Mahn, W. Marsh, P. S. Martin, G. McGregor, W. Metcalf, P. D. Meyers, F. Mills, G. B. Mills, J. Monroe, C. D. Moore, R. H. Nelson, P. Nienaber, S. Ouedraogo, R. B. Patterson, D. Perevalov, C. C. Polly, E. Prebys, J. L. Raaf, H. Ray, B. P. Roe, A. D. Russell, V. Sandberg, R. Schirato, D. Schmitz, M. H. Shaevitz, F. C. Shoemaker, D. Smith, M. Sorel, P. Spentzouris, I. Stancu, R. J. Stefanski, M. Sung, H. A. Tanaka, R. Tayloe, M. Tzanov, M. O. Wascko, R. Van de Water, D. H. White, M. J. Wilking, H. J. Yang, G. P. Zeller, E. D. Zimmerman

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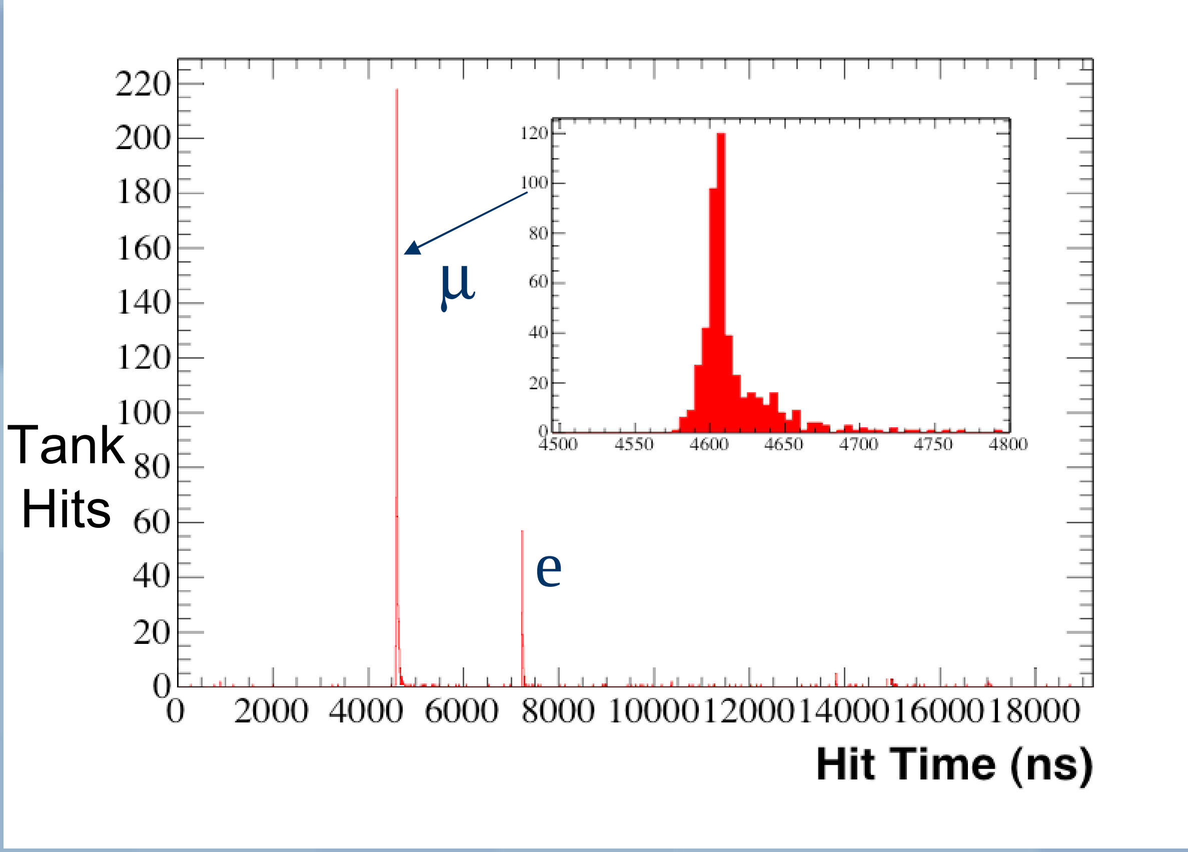
Embry Riddle University
Fermi National Accelerator Laboratory
Indiana University
Los Alamos National Laboratory
Louisiana State University
University of Michigan
Princeton University
Saint Mary's University of Minnesota
Virginia Polytechnic Institute
Western Illinois University
Yale University

Timing and Subevents

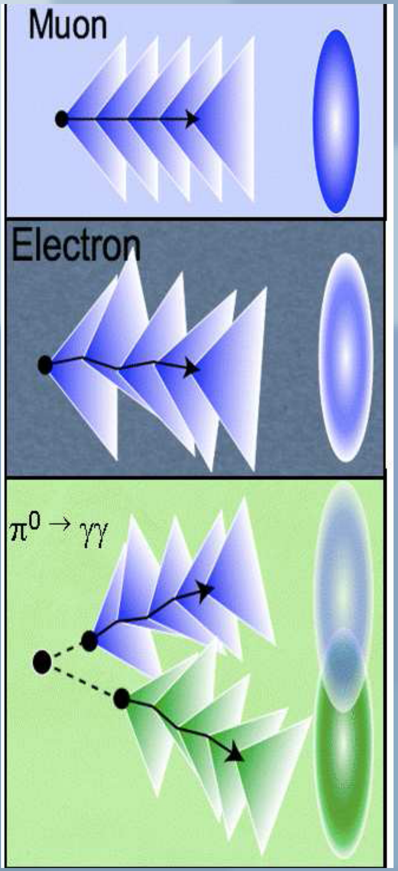
A 19.2 ms beam trigger window
- encompasses the 1.6 ms spill
- starts 4 ms before the beam

Subevent:
Multiple hits within a ~100 ns window form "subevents"

Most events are from ν_μ CC interactions ($\nu+n \rightarrow \mu+p$) with characteristic two "subevent" structure from stopped $\mu\rightarrow\nu_\mu\nu_e e$



Event Topologies in MiniBooNE Detector



Muon event

- long track, small scattering

Electron/photon event – fuzzy ring

- short track, large scattering
- g converts and looks like electrons

π^0 event – two fuzzy rings