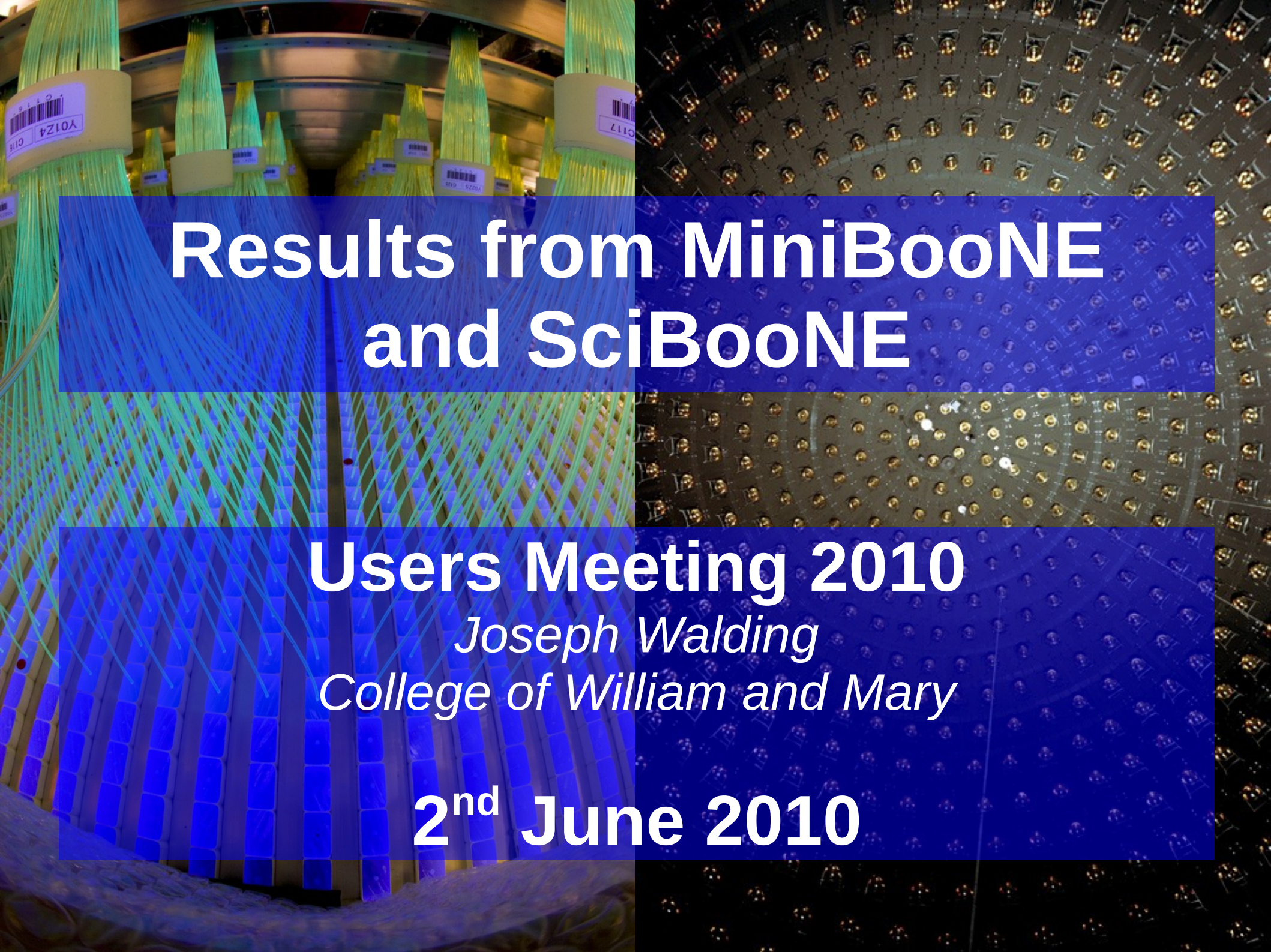


Results from MiniBooNE and SciBooNE

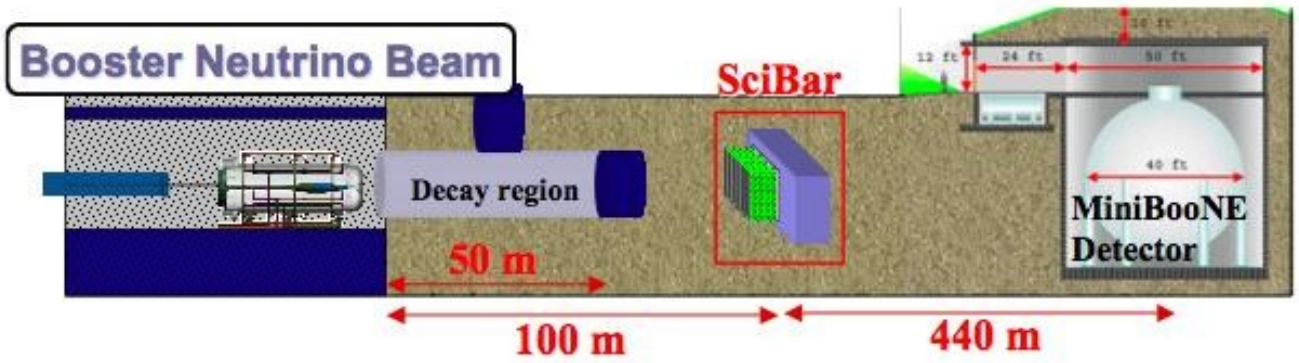
Users Meeting 2010

Joseph Walding
College of William and Mary

2nd June 2010

Outline

- MiniBooNE and SciBooNE Refresher Course
- Physics Results From The Last Year...
  - Neutrino Cross-sections
  - Neutrino Oscillations
- Summary



MiniBooNE Collaboration

SciBooNE

Joseph Walding Fermilab Users Meeting 2nd June 2010

- University of Alabama
- Bucknell University
- University of Cincinnati
- University of Colorado, Boulder
- Columbia University
- Embry-Riddle Aeronautical University
- Fermi National Accelerator Laboratory
- University of Florida
- University of Illinois
- Indiana University
- Los Alamos National Laboratory
- Louisiana State University
- MIT
- University of Michigan
- Princeton University
- Saint Mary's University of Minnesota
- Virginia Tech.
- Western Illinois University
- Yale University

SciBooNE Collaboration

Users Meeting 2010

- Universitat Autonoma de Barcelona
- University of Cincinnati
- University of Colorado, Boulder
- Columbia University
- Fermi National Accelerator Laboratory
- High Energy Accelerator Research Organization (KEK)
- Imperial College London
- Indiana University
- Institute for Cosmic Ray Research (ICRR)
- Kyoto University
- Kamioka Observatory
- Los Alamos National Laboratory
- Louisiana State University
- MIT
- Purdue University Calumet
- Universita degli Studi di Roma "La Sapienza" & INFN
- Saint Mary's University of Minnesota
- Tokyo Institute of Technology
- Unversitat de Valencia

A selection of SciBooNE collaborators at the London Collaboration Meeting. March 2008

Outline

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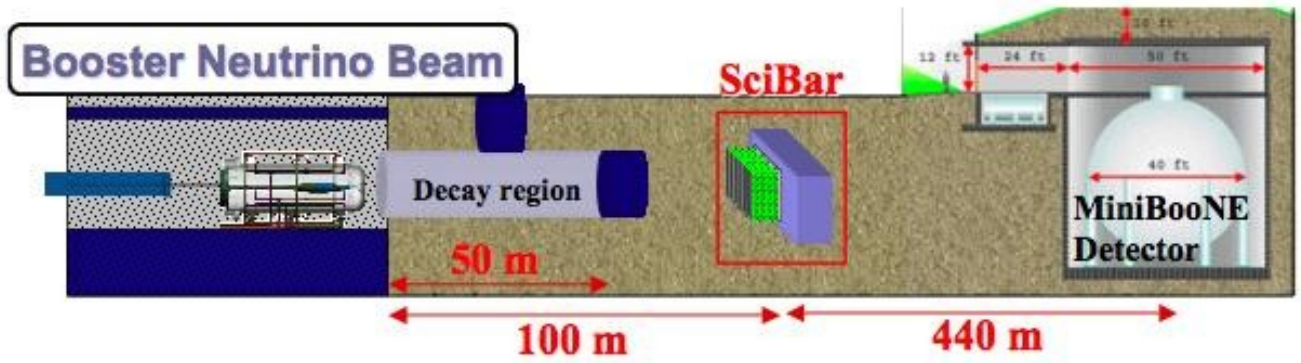

The Booster ν Experiments

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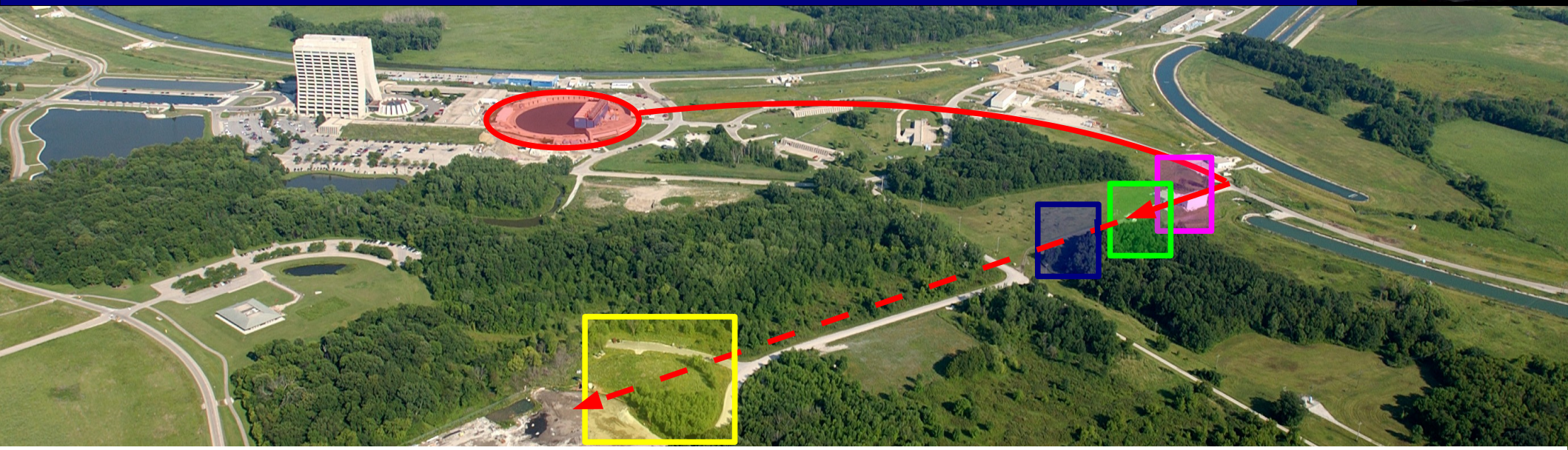
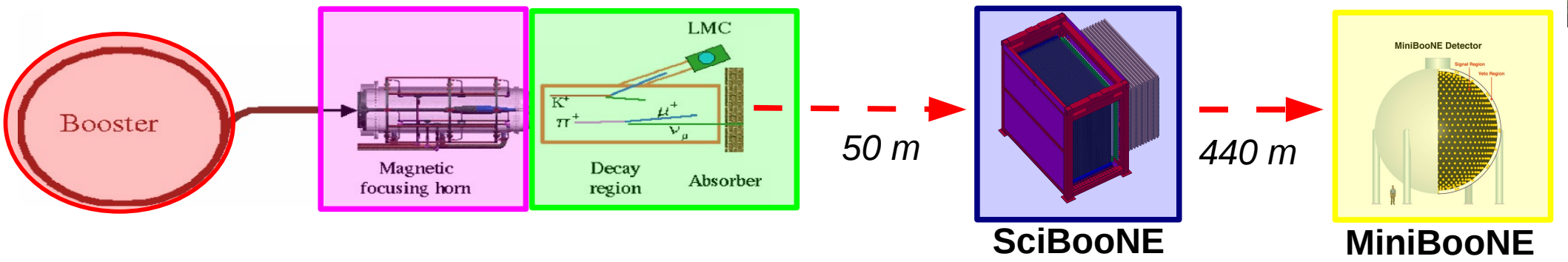
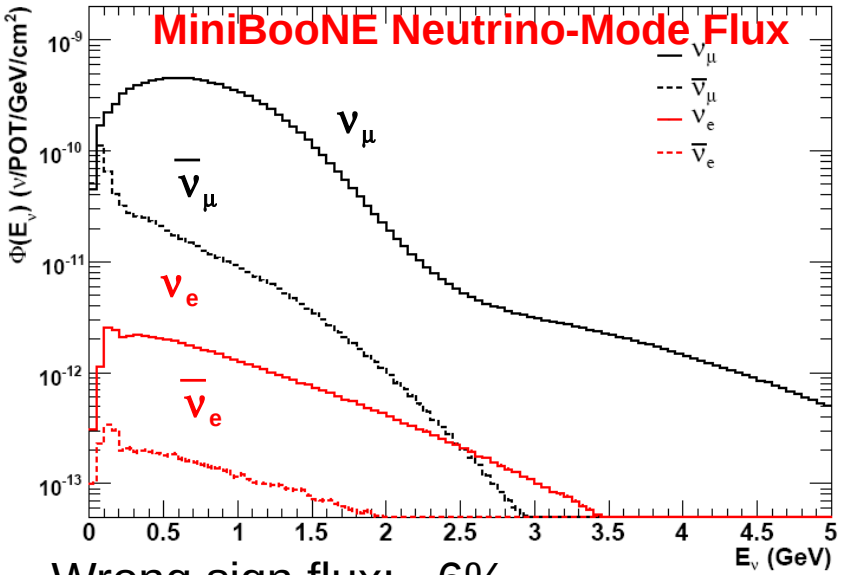


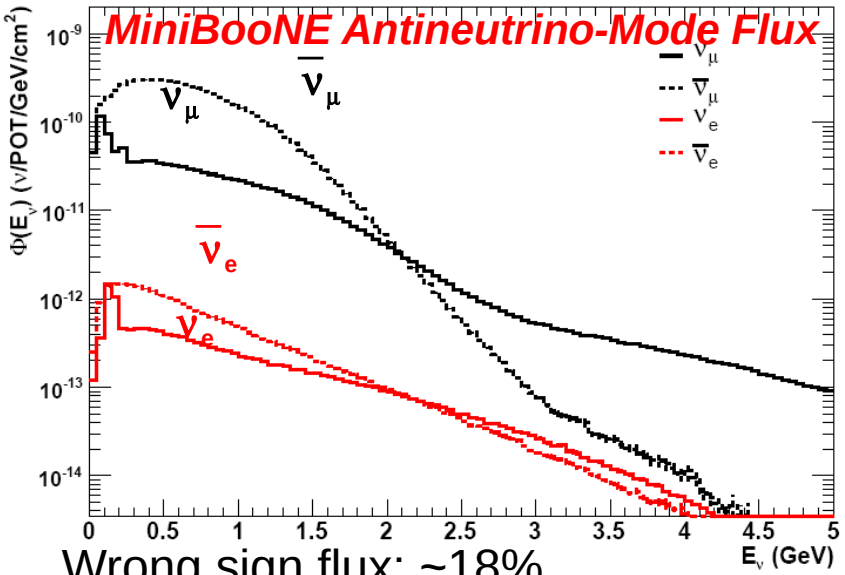


- Booster Proton accelerator: 8 GeV protons sent to target
- Target Hall: Beryllium target. 174kA magnetic horn with reversible horn polarity
- 50m decay volume: Mesons decay to μ & ν_μ. Short decay pipe minimises $\mu \rightarrow \nu_e$ decay
- SciBooNE: 100m baseline; MiniBooNE: 540m baseline

- Use HARP experiment pBe$\rightarrow\pi^{\pm}$ production data to predict our neutrino flux
  - $\pi^{+} \rightarrow \mu^{+} \nu_{\mu}$
- Kaon production: Primary source of ν_e's
- Reversible horn polarity used to sign select mesons
  - Run in neutrino or anti-neutrino mode



Wrong sign flux: ~6%
Intrinsic ν_e flux: ~0.5%



Wrong sign flux: ~18%
Intrinsic ν_e flux: ~0.5%

SciBar

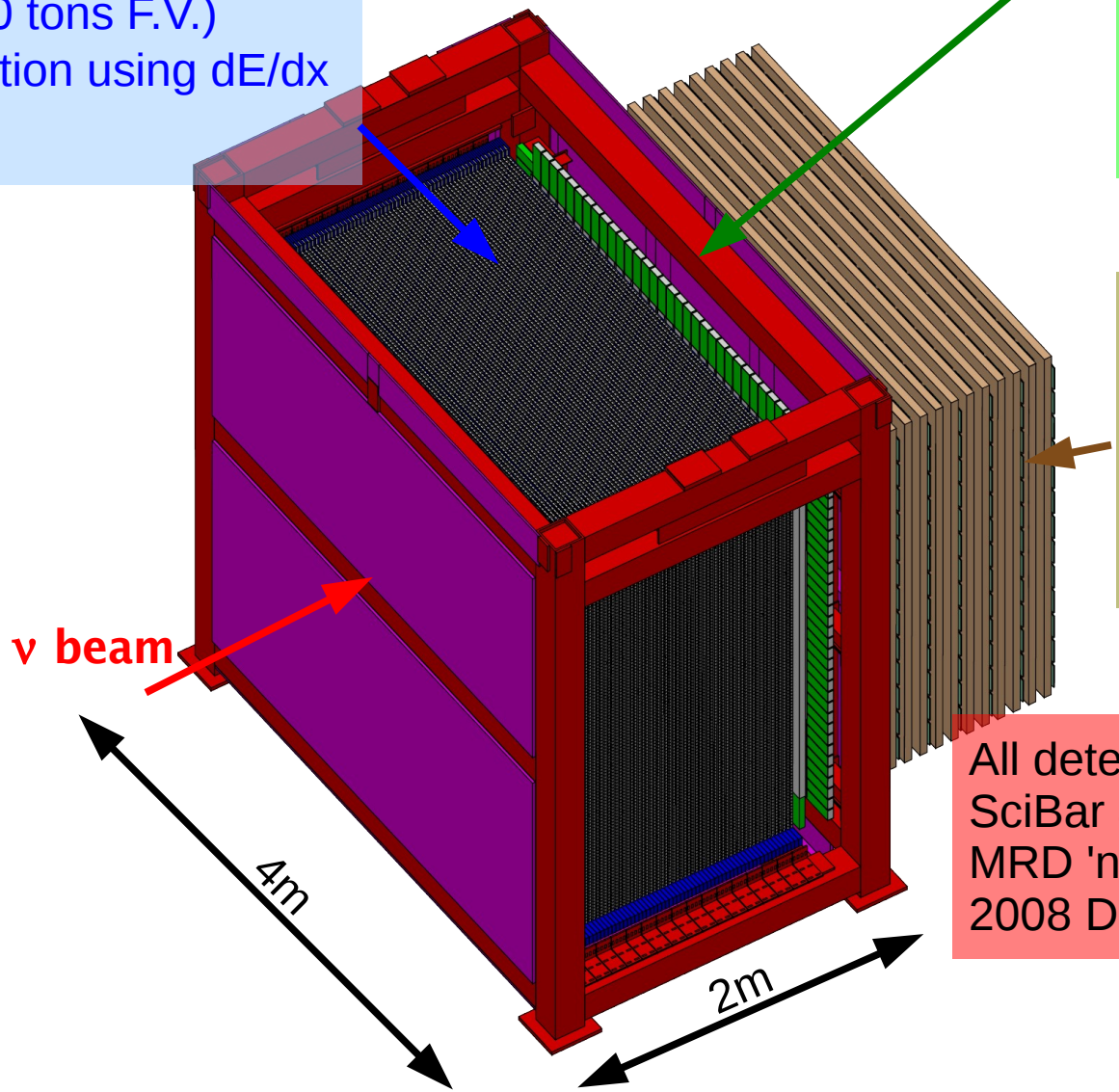
14,336 Scintillator bars
15 tons (10 tons F.V.)
p/π separation using dE/dx

Electron-Catcher (EC)

'Spaghetti' Calorimeter
2 planes (x&y)
$11X_0$
identify π^0 & ν_e

Muon Range Detector (MRD)

12 2" iron planes
362 scintillator panels
stop μ's with p < 1.2 GeV/c

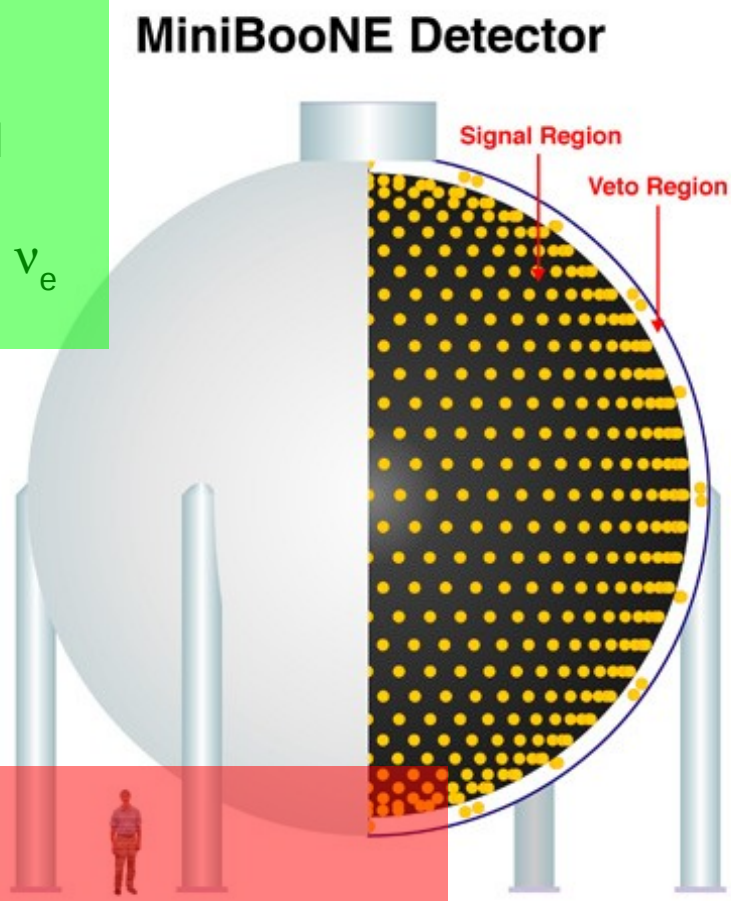


All detectors have X&Y views
SciBar & EC used at K2K
MRD 'new' detector built at FNAL
2008 DOE P2* Environmental Award

Cherenkov Detector

Events identified using:
- Ring topology
- μ-decay Michel signal
- Scintillation light

Able to distinguish ν_μ from ν_e



Specification

12 m diameter tank
900 tons mineral oil (CH_2)
1280 inner PMTs (signal region)
240 outer PMTs (veto region)

Physics Goals:

Principally a neutrino oscillation experiment.
Also able to measure neutrino cross-sections
Huge data-set in neutrino and antineutrino mode

Data Sets

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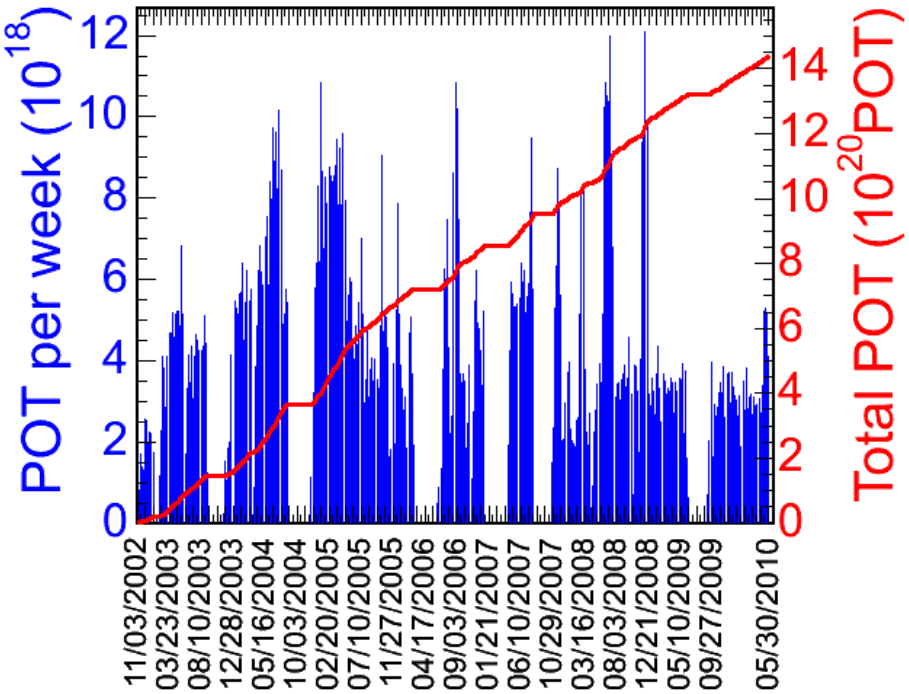
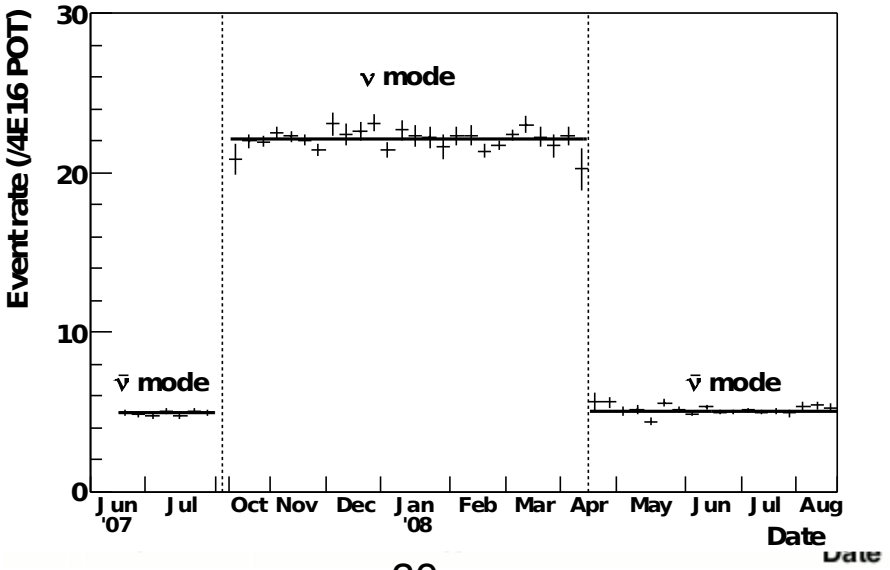
MiniBooNE



- ν: 6.5x10^{20} POT
- $\bar{\nu}$: 5.8x10^{20} POT
- Currently running in $\bar{\nu}$ mode
  - Approved for 1x10^{21} POT

SciBooNE



- ν: 0.99x10^{20} POT
- $\bar{\nu}$: 1.53x10^{20} POT
- 95% POT efficiency

Thank you to the Beams Division!

Outline

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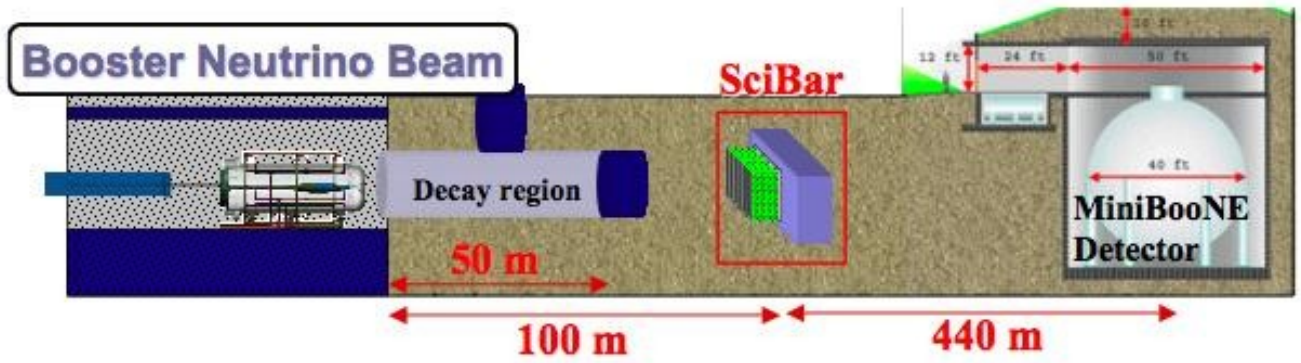

Neutrino Cross-Sections

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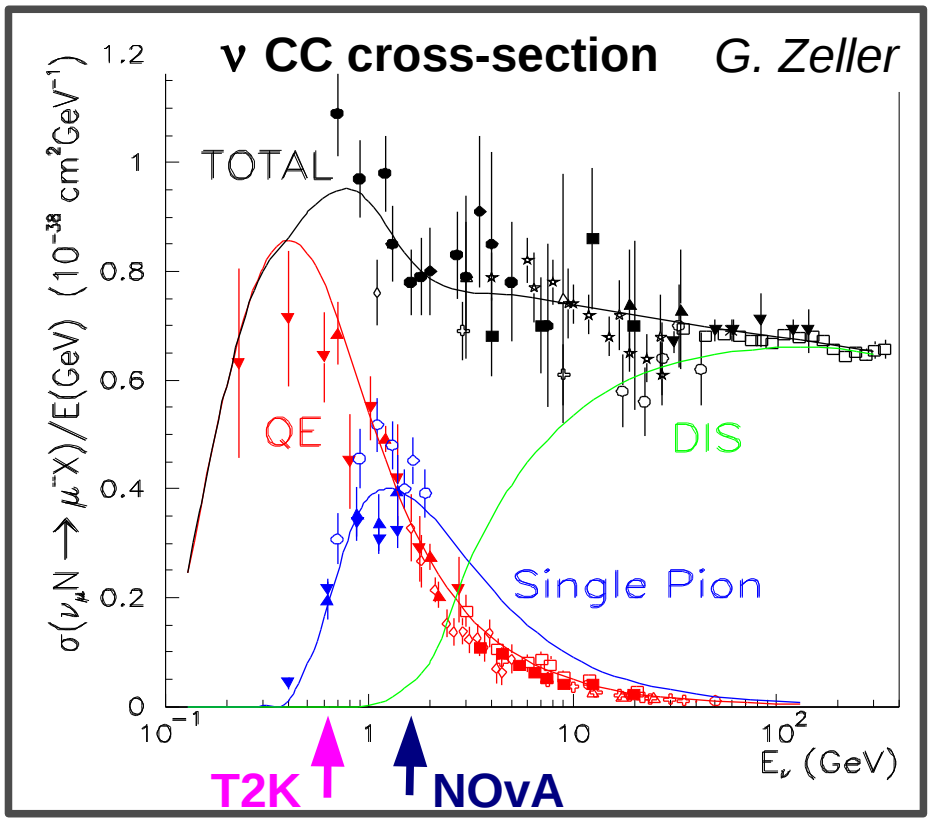
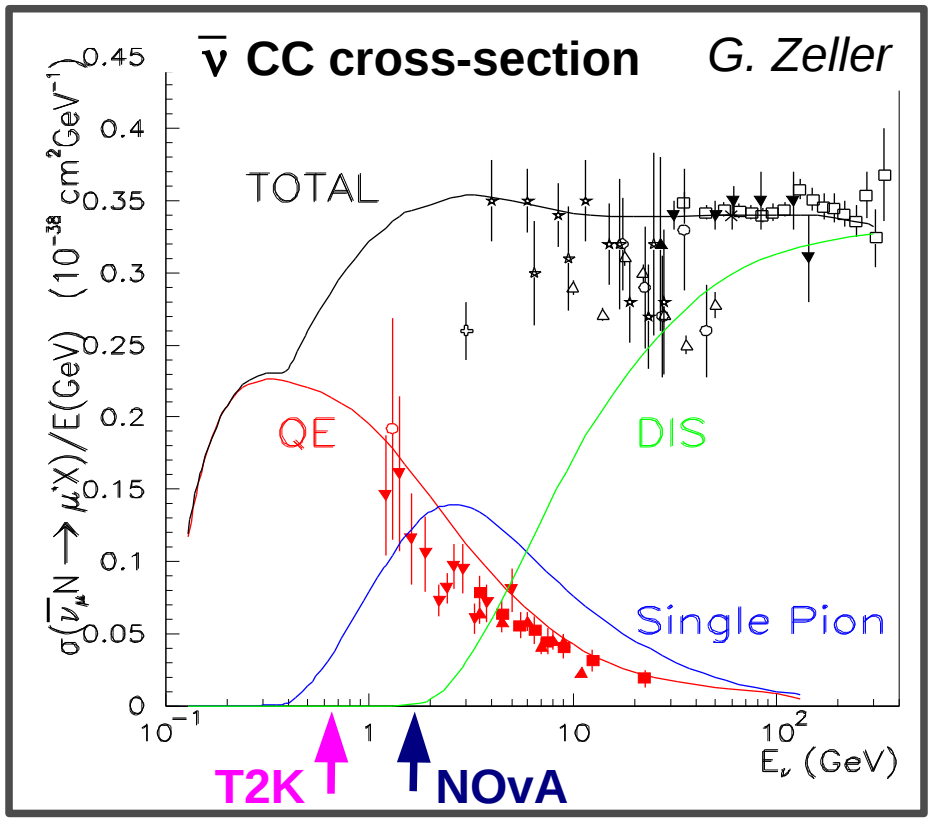
- Previous measurements from 1970's-1980's
- Mostly H_2 & D_2 targets
- Small sample sizes (100's of events)



- No measurements of sub-GeV $\bar{\nu}$ cross-sections
- Important for ~~CP~~ studies
- ν and $\bar{\nu}$ Different oscillation probabilities



Neutrino Cross-Sections

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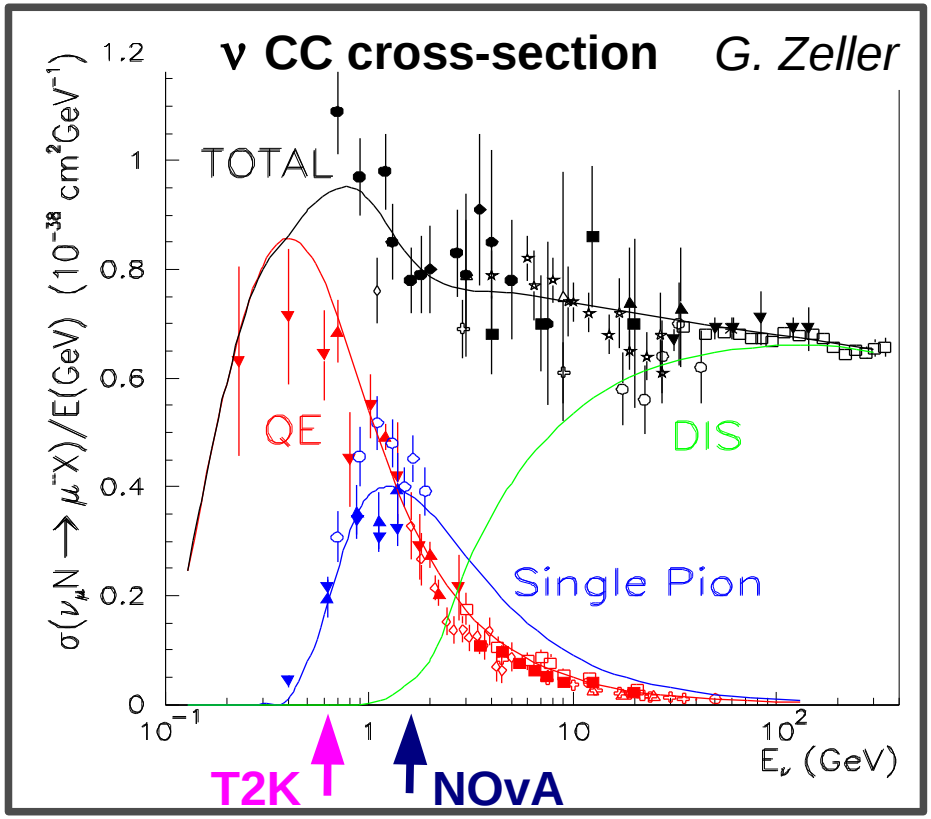
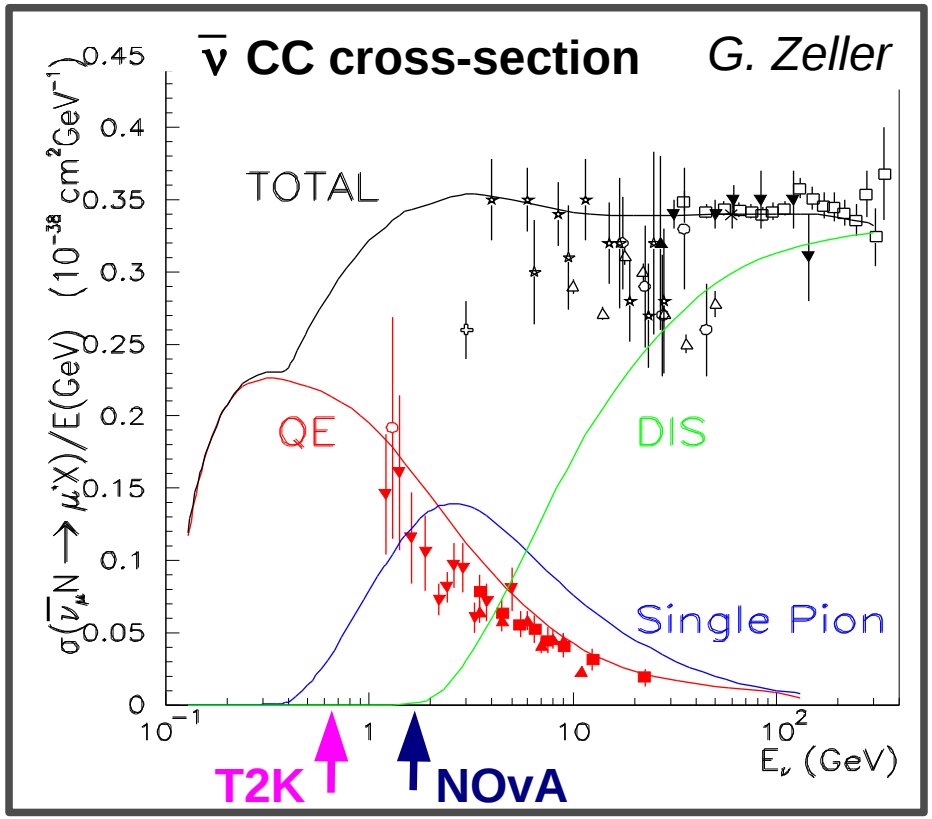
SciBooNE

Good understanding of high E cross-sections (DIS)
Low E is different regime:

Quasi-elastic (QE) and single pion (1π) events dominate

Important for future neutrino oscillation experiments





Neutrino Cross-Sections

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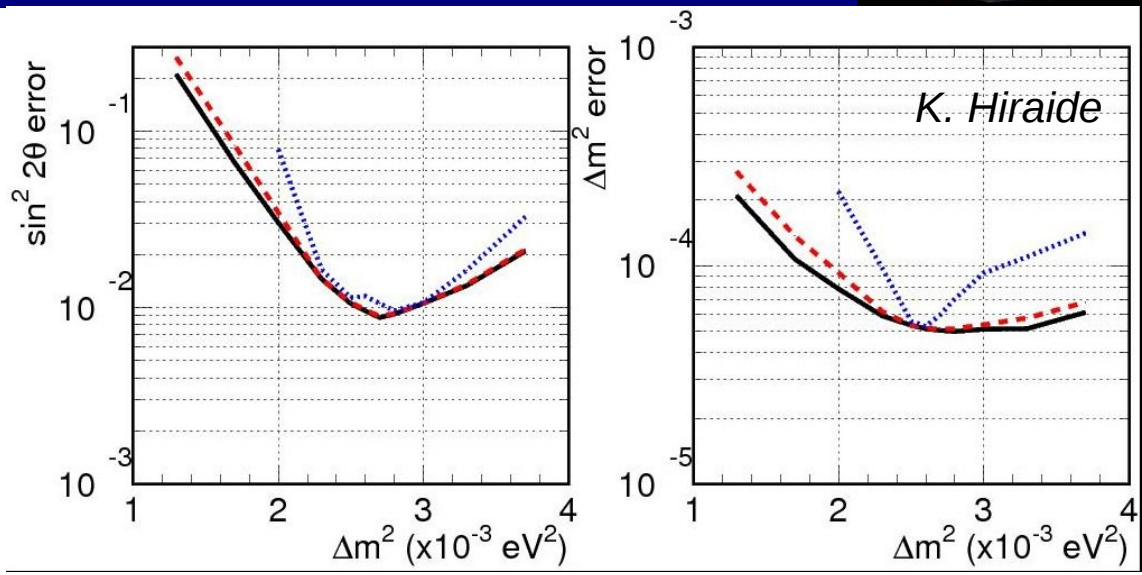
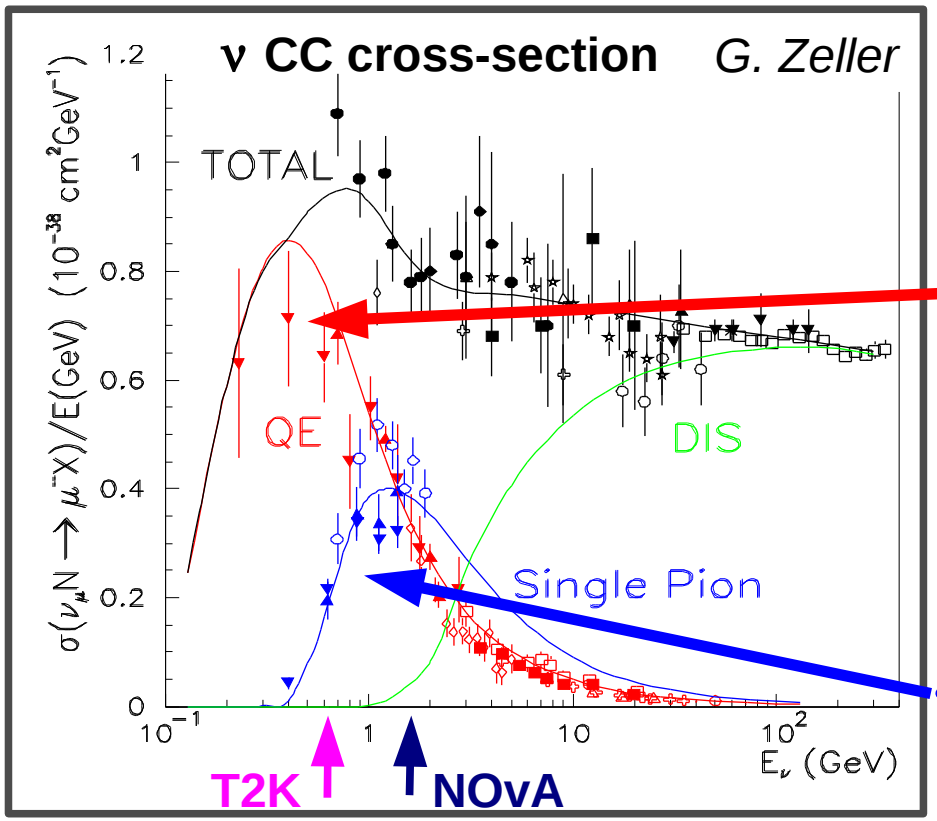
Expected statistic error (T2K)
5% systematic
20% systematic

Wish to know T2K cross-sections better than 10%



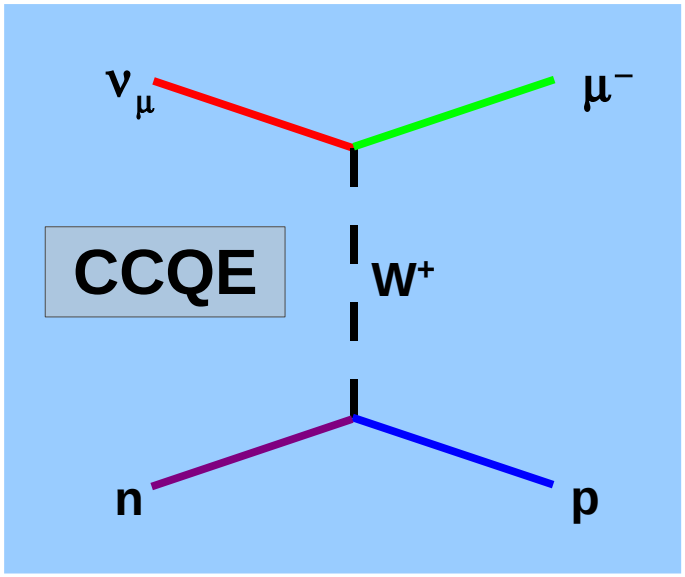


quasi-elastic (QE) signal

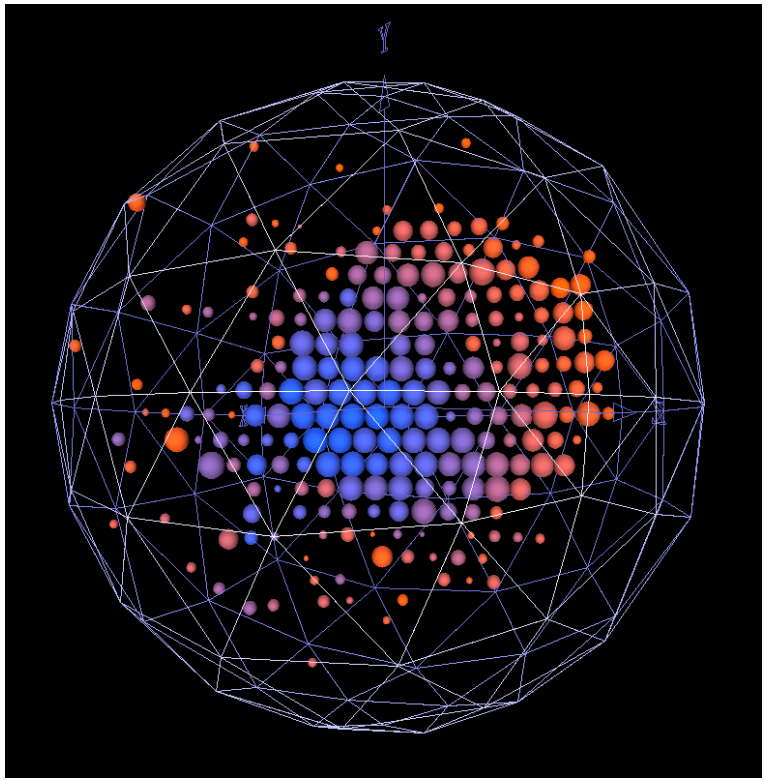
NC π^0 (background to ν_e appearance)

CC π^+ (background to ν_μ disappearance)

Quasi-Elastic Scattering



'Typical' muon ring in MiniBooNE



- MiniBooNE uses muon kinematics to describe event
- Identify muons from decay signature
- Measuring total and differential cross-sections
  - Not ratios with respect to Charged Current inclusive events

Quasi-Elastic Scattering

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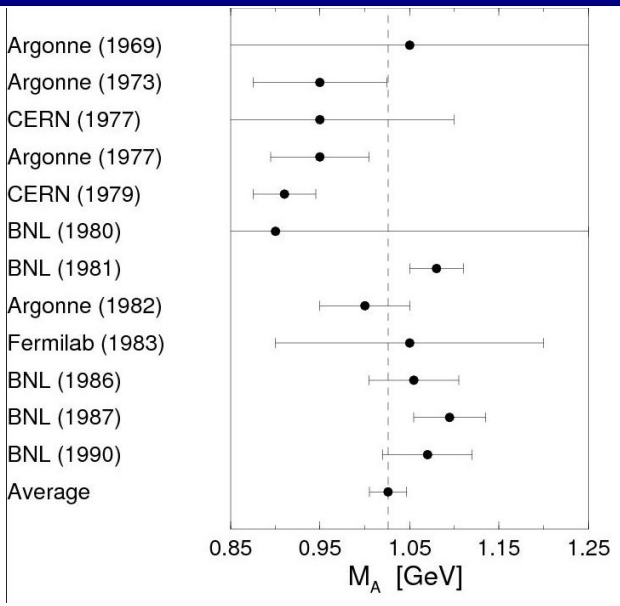
$M_A^{eff} = 1.35 \pm 0.17$ GeV/c^2

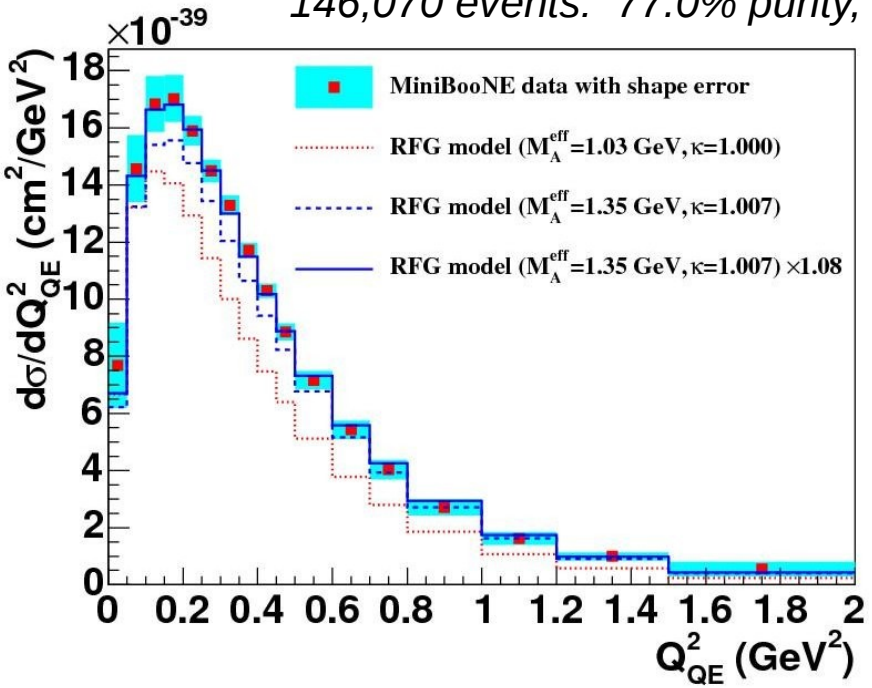
cf. K2K: $M_A = 1.20 \pm 0.12$ (SciFi)

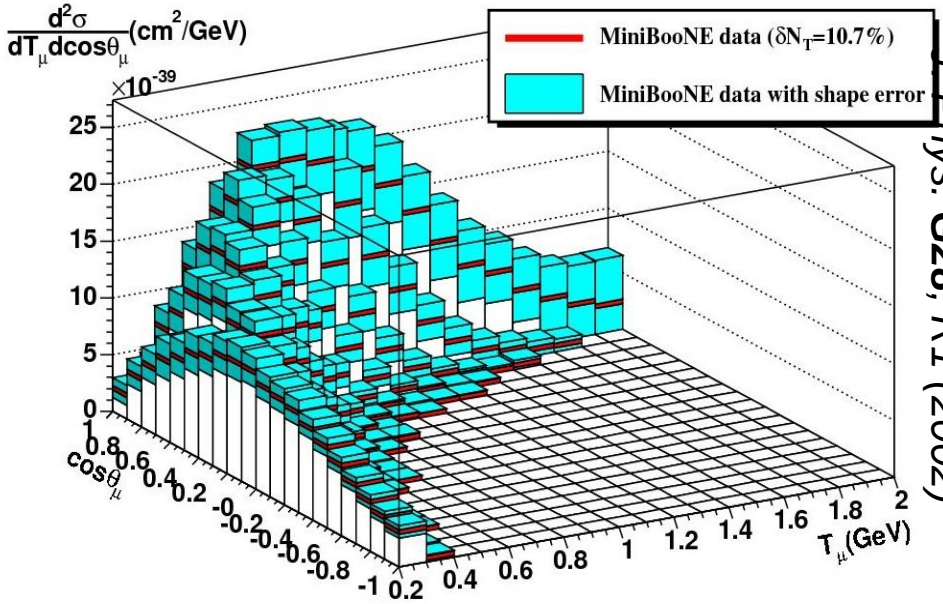
$M_A = 1.14 \pm 0.11$ (SciBar)



- Very different from light target experiments and for higher energy interactions
- First double differential CCQE cross-section
  - Model Independent

146,070 events: 77.0% purity, 26.6% efficiency





T. Katori: arXiv:1002.2680, accepted by PRD

T. Phys. G28, R1 (2002)

Quasi-Elastic Scattering

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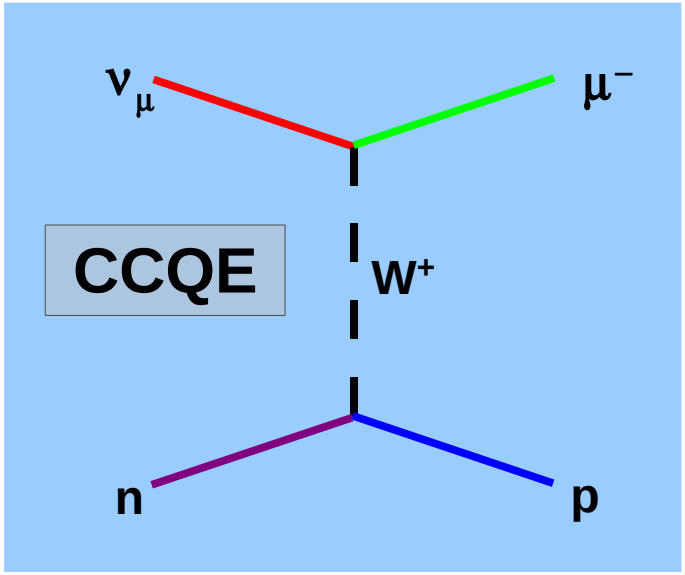
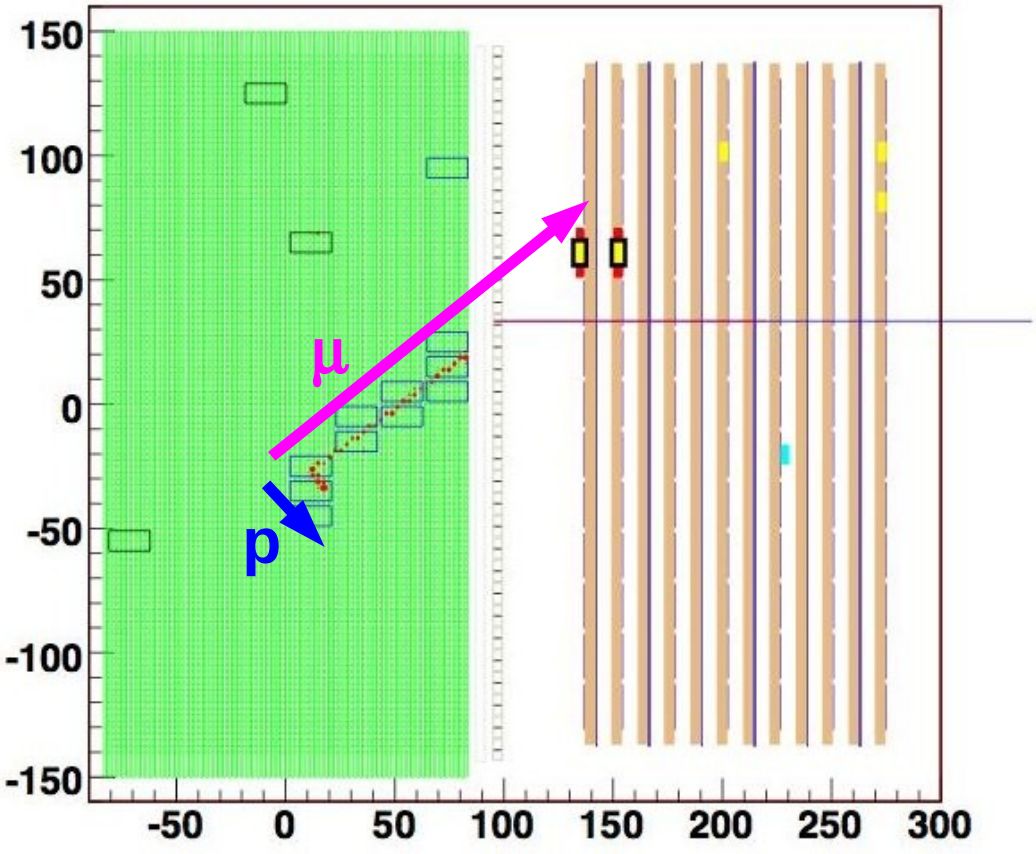


'Typical' 2-track CCQE event in SciBooNE



- SciBooNE uses muon and proton kinematics to describe event
- Identify muons using MRD or from decay signature

Quasi-Elastic Scattering

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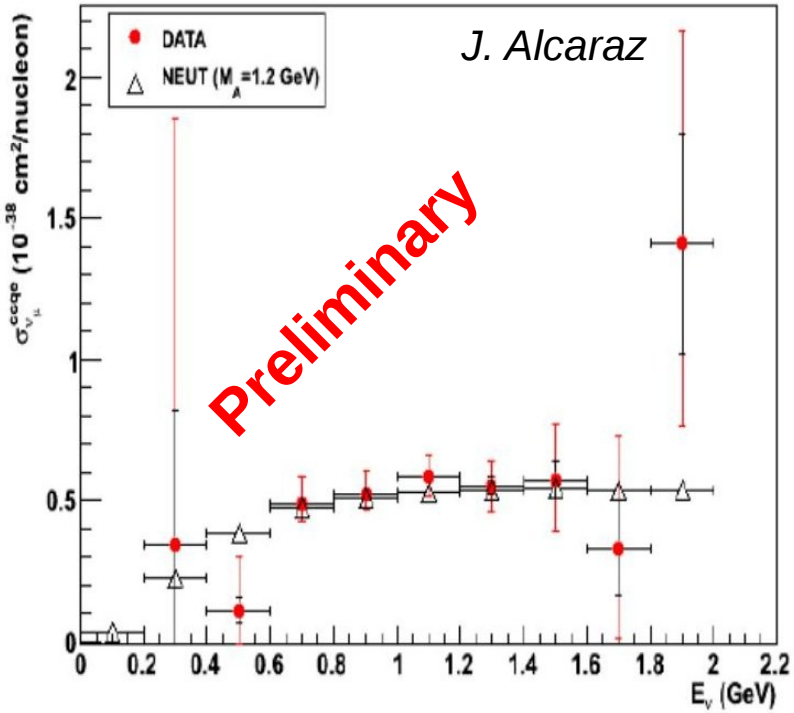
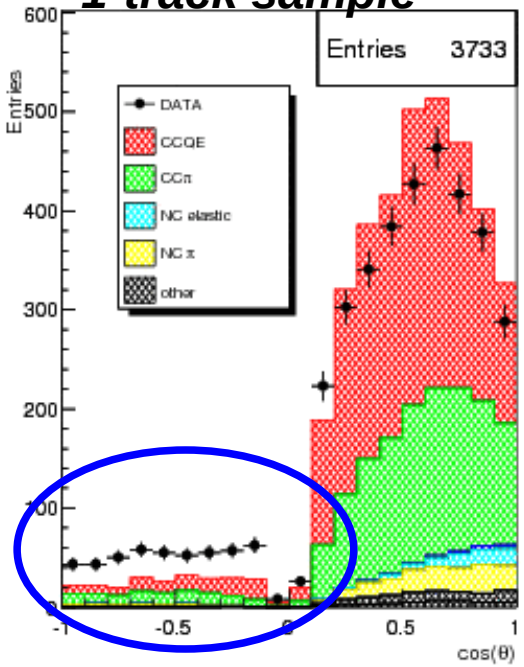
- Extraction of CCQE absolute cross-section
  - MRD-matched sample

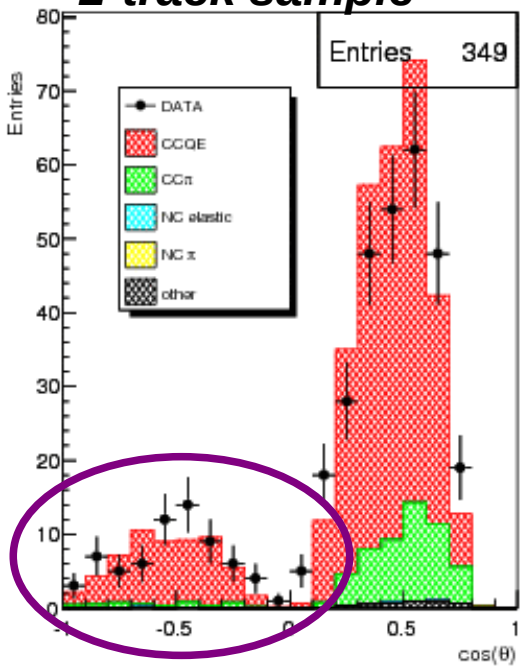
MRD-Matched Sample:
13,585 1-track events: 66.2% purity, 10.8% efficiency
2,915 2-track events: 68.5% purity, 2.3% efficiency



SciBar-Contained 1-track sample



SciBar-Contained 2-track sample



- SciBar-contained 1-track (μ) sample: Excess in backwards muon tracks
- Not seen in 2-track (μ+p) sample

J. Walding: Thesis

Quasi-Elastic Scattering

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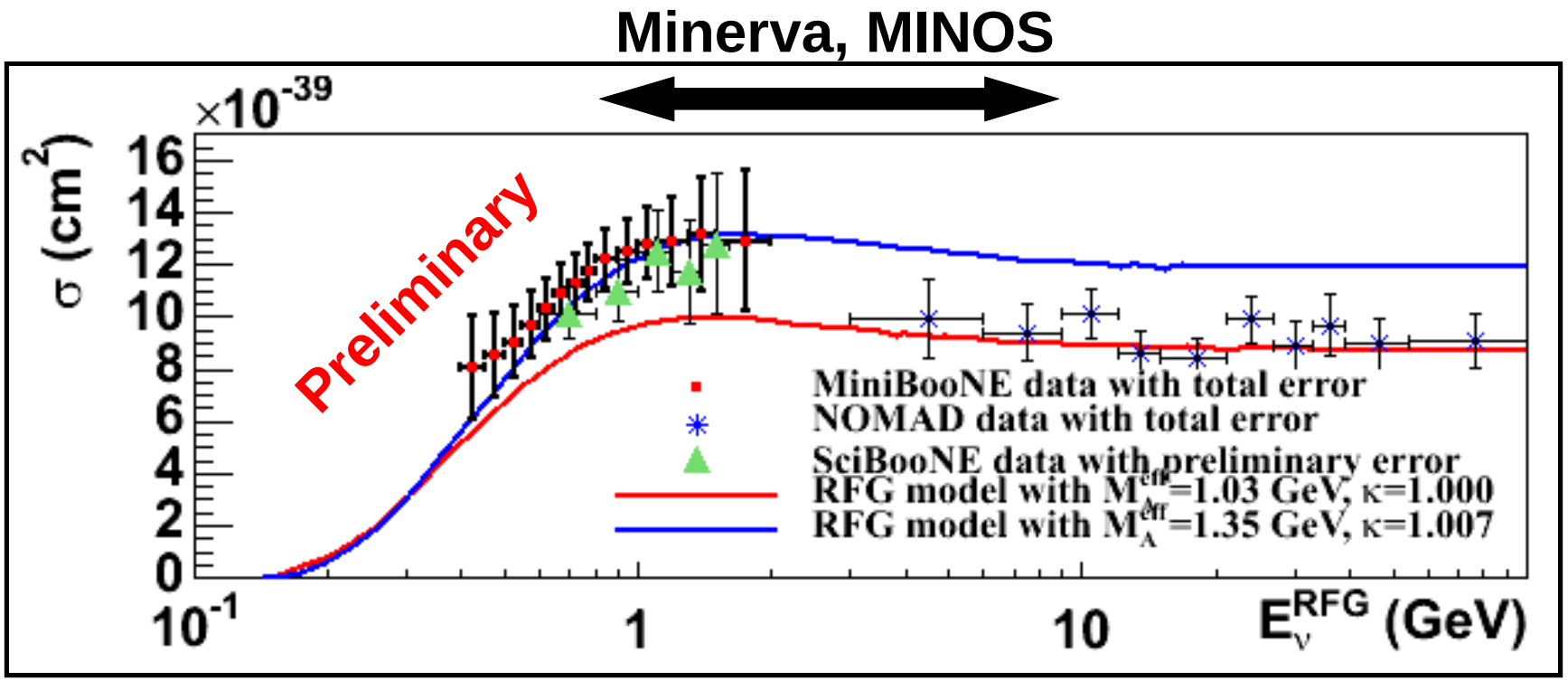
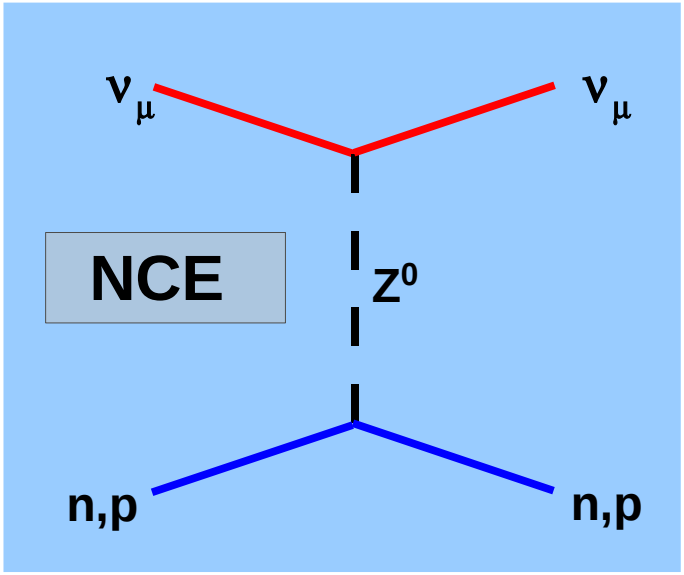
- SciBooNE and MiniBooNE data in good agreement
- Low to high energy discrepancy
  - Minerva to fill in the gaps...



NC-Elastic Scattering

Joseph Walding



- Neutral Current
  - SciBooNE: Proton track
  - MiniBooNE: Scintillation light
    - Proton typically below Cherenkov threshold

- SciBooNE:
  - NC/CCQE ratio calculation in progress – watch this space!

NC-Elastic Scattering

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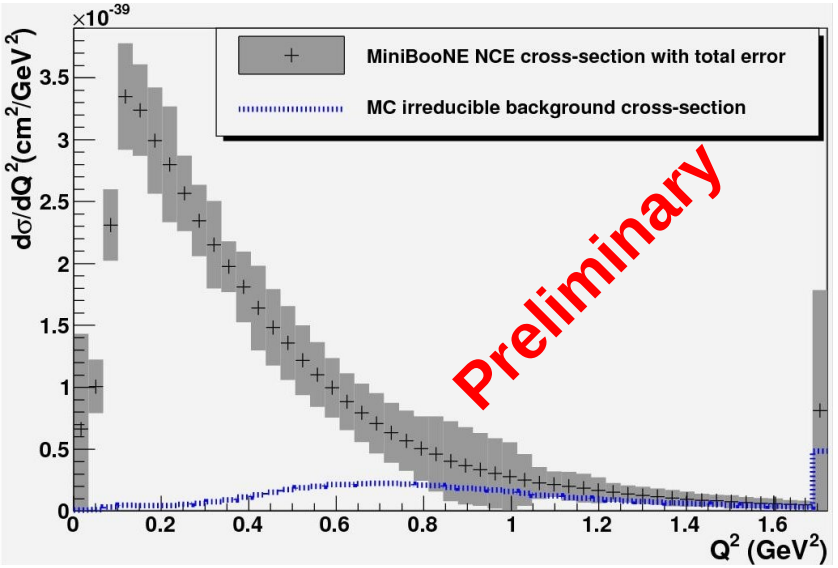
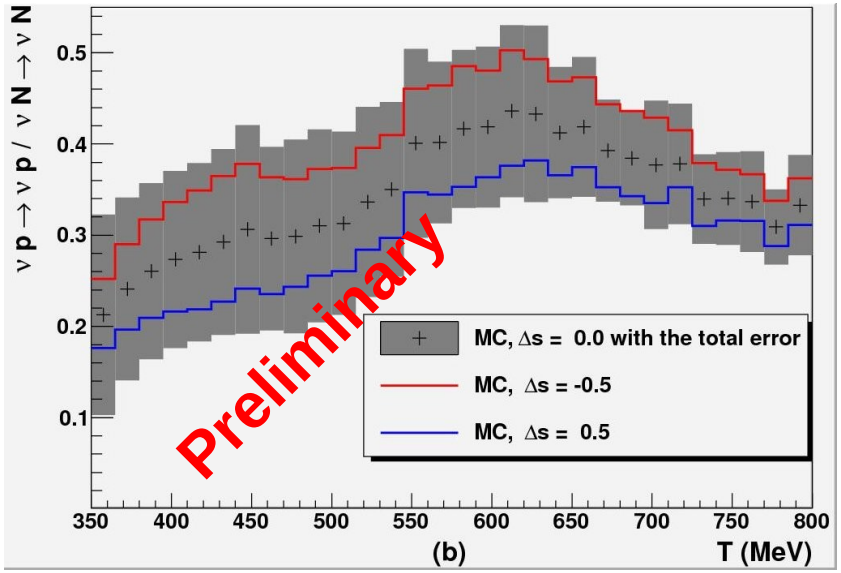
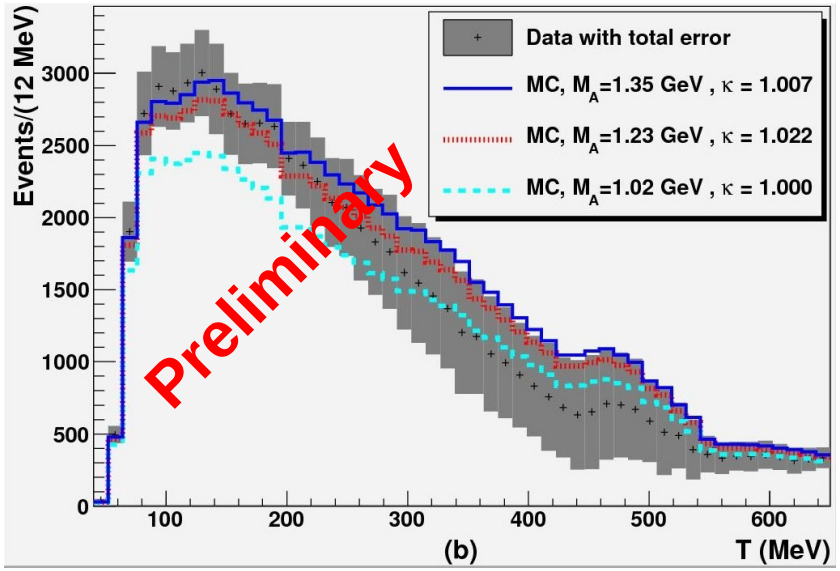
- Extracted $\frac{d\sigma}{dQ^2}$
- MiniBooNE CCQE value for M_A better description of data than world average
- Isolating a Cherenkov proton sample
  - Ratio: $\nu p \to \nu p / \nu N \to \nu N$
  - Strange spin component of the nucleon, Δs
- $\Delta s = 0.08 \pm 0.26$, systematics limited







D. Perevalov: arXiv 0909.4617

NC π^0 Production

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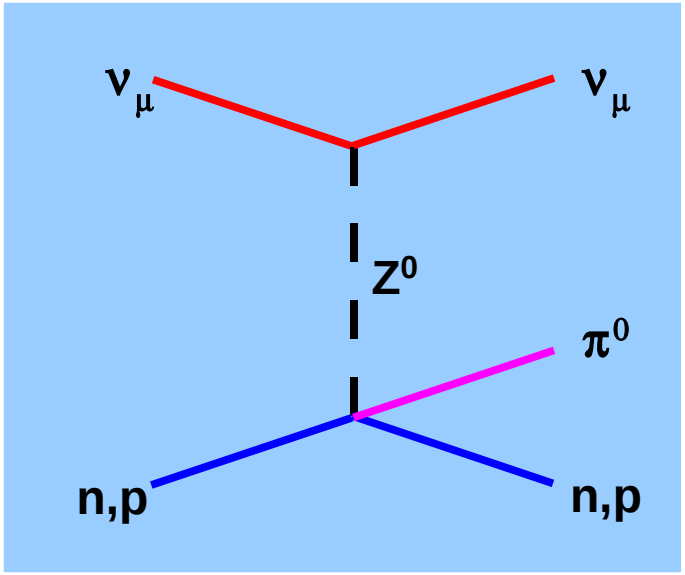

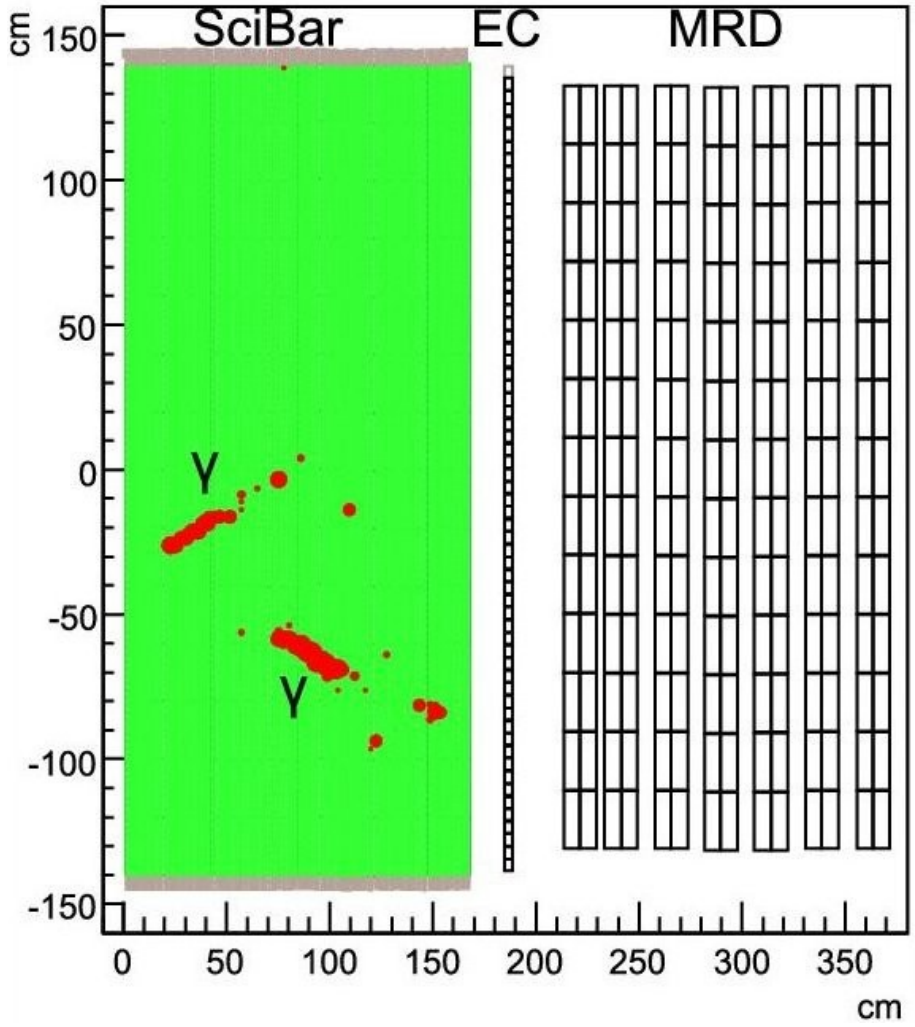

- SciBooNE: Two measurements
  - Inclusive NC π^0
  - Coherent NC π^0

Inclusive NC π^0 Production

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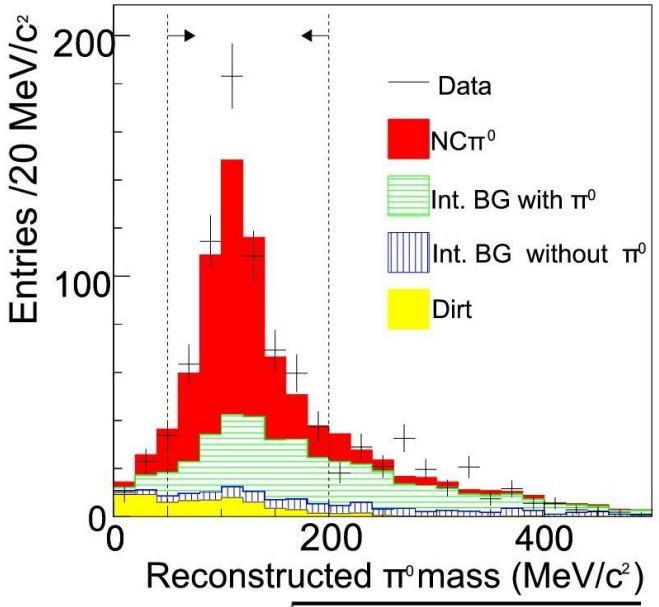
- Charged current events rejected by looking for muon decay signature
- Vertex reconstruction used to reject external neutrino events (dirt events) from sample
- Able to reconstruct the π^0 mass
- Extract model independent cross-section ratio *($\bar{E}_\nu$ = 0.8 GeV)*:

657 events selected, 240 expected background events

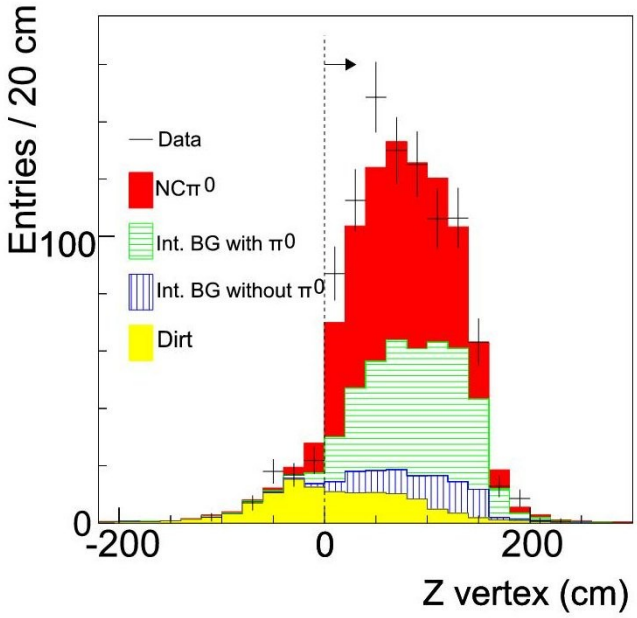
$$\frac{\sigma(NC\pi^0)}{\sigma(CC)} = \frac{(N_{obs}^{NC\pi^0} - N_{bck}^{NC\pi^0})\epsilon_{CC}}{(N_{obs}^{CC} - N_{bck}^{CC})\epsilon_{NC\pi^0}}$$

$$= 7.7 \pm 0.5^{(stat)} \pm 0.5^{(sys)} \times 10^{-2}$$

cf. MC prediction = 6.8x10^{-2}
Error < 10%



$$M_{\pi^0}^{rec} = \sqrt{2E_{\gamma 1}^{rec} E_{\gamma 2}^{rec}(1 - \cos\theta^{rec})}$$



Y. Kurimoto: Phys. Rev. D81, 033004

Coherent NC π^0 Production

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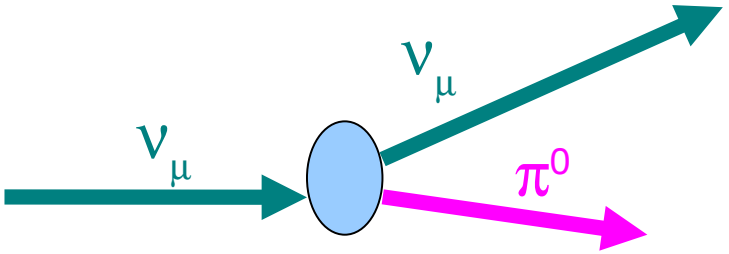
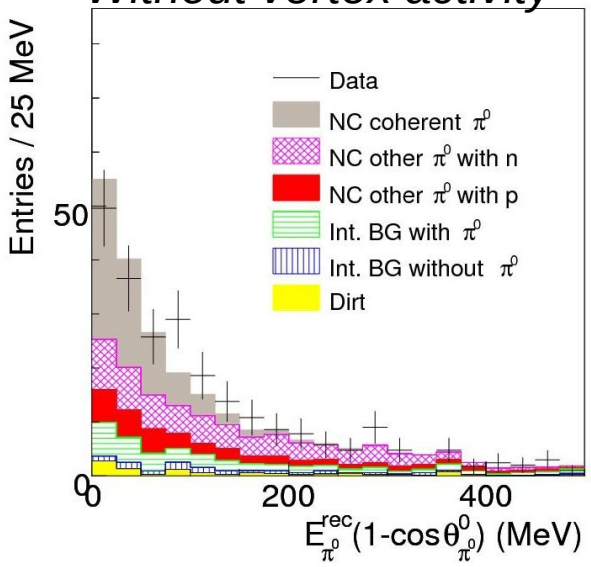


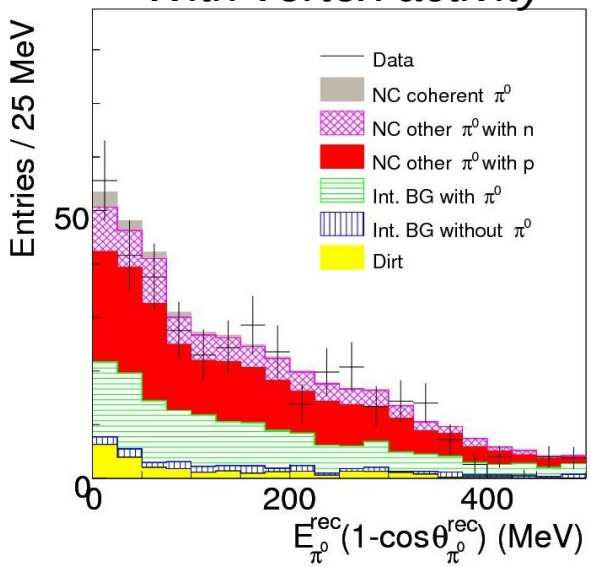
- Neutrino interacts coherently with whole nucleus
  - No nucleon recoil, forward tracks only
  - SciBar sensitive to proton recoil
    - Not possible in MiniBooNE
- Define region around reconstructed vertex to look for proton recoil activity

- Extract model-dependent coherent fraction
- Fraction of NC π^0 events from coherent channel: 17.9% (cf. MiniBooNE: 19.5%)
  - Agrees with Rein-Sehgal (RS) prediction
  - CC (K2K, SciBooNE): No evidence of coherent production - disagrees with RS prediction

Without vertex activity

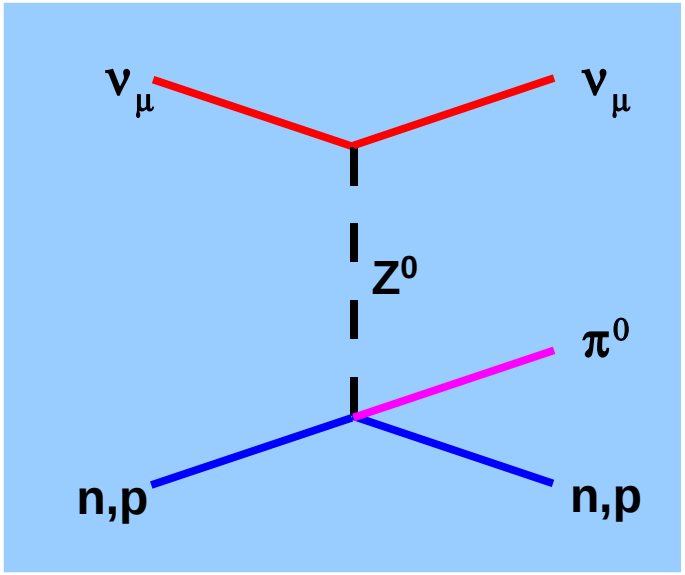


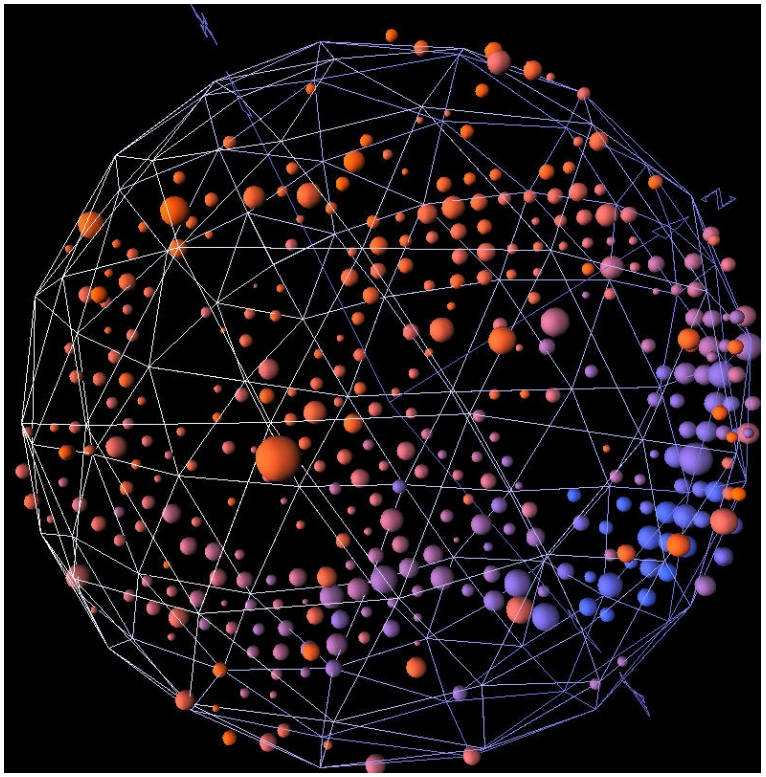
With vertex activity



Y. Kurimoto: arXiv 1005.0059, accepted by PRD

MB: NC π^0 Production

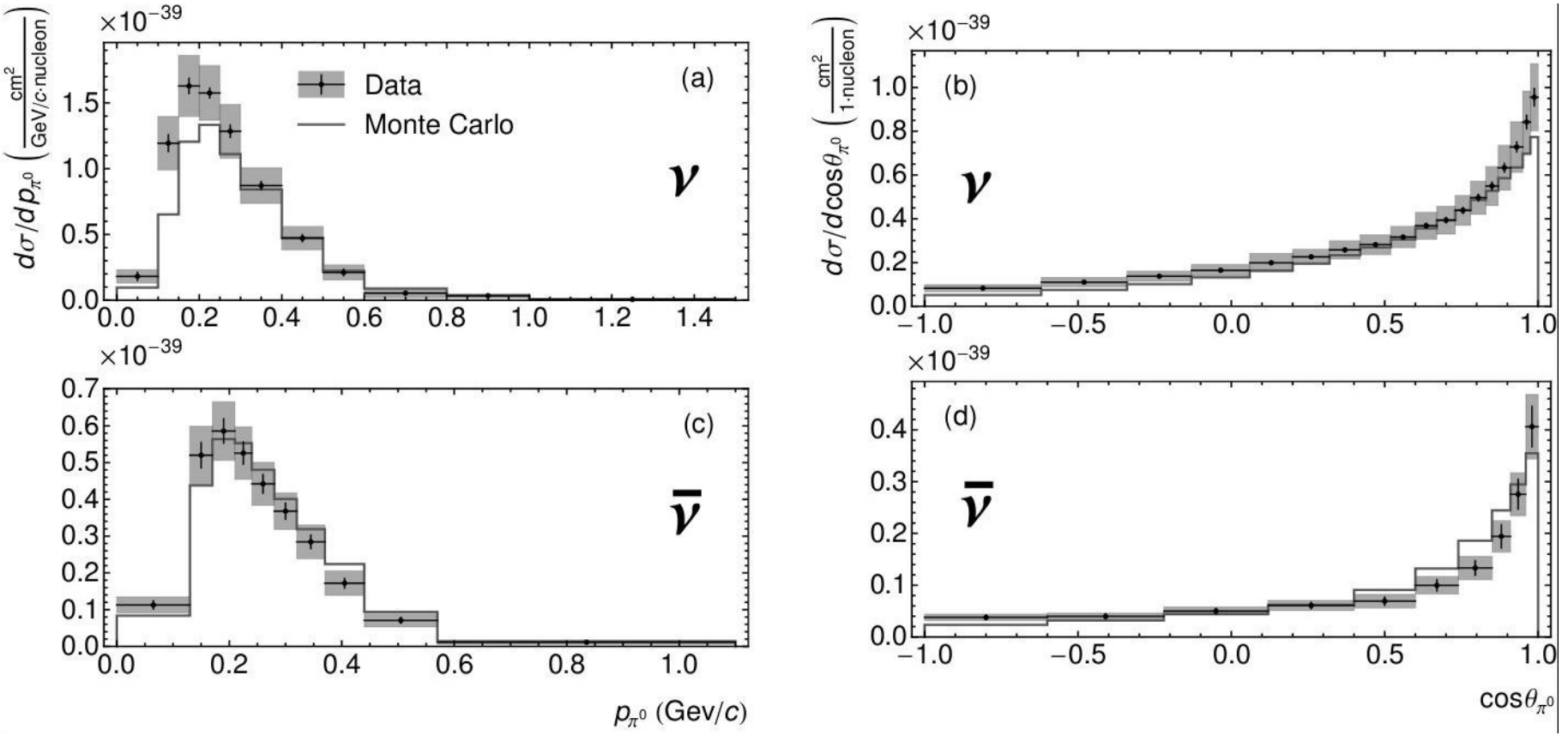




- Cross-section extraction in neutrino and antineutrino mode

MB: NC π^0 Production

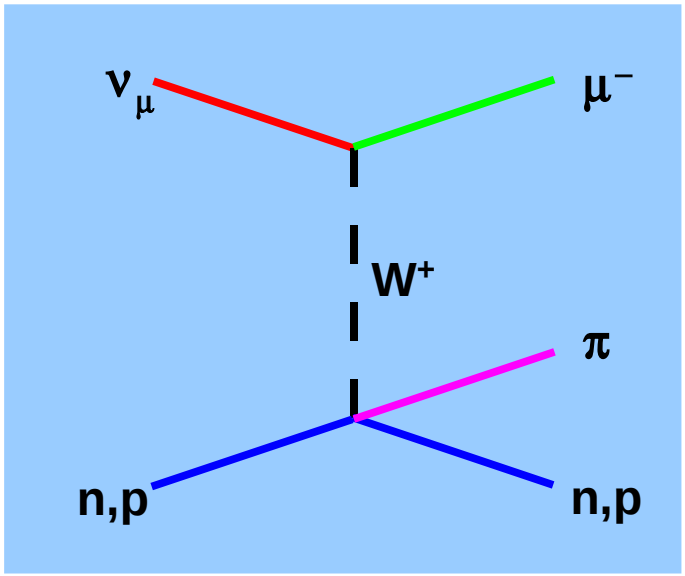
- More model-independent measurements
- Flux averaged differential cross-sections (ν and $\bar{\nu}$ mode)
  - Already being used by T2K!



C. Anderson: Phys. Rev. D81, 013005

CC π Production

Joseph Walding

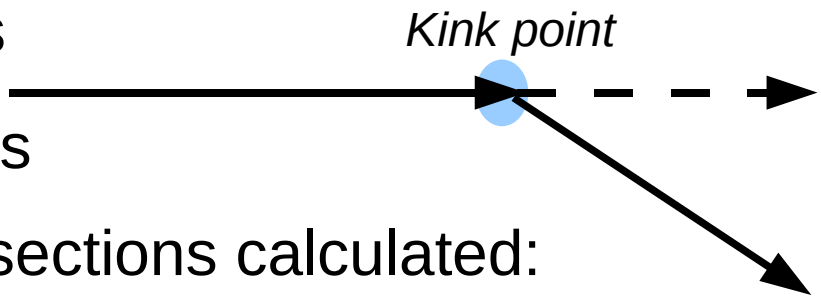


- CC-π^+: Background to ν_μ disappearance
  - If pion not identified event looks CCQE-like
  - Mis-reconstruction of neutrino energy
- For T2K need to know CC-π^+ cross-section to <10%

- CC-π^0: Not an oscillation background
  - Completes π production picture

MB: CC π^+ Production

- Ability to separate pion and muon tracks
  - Hadronic interactions → kinked tracks



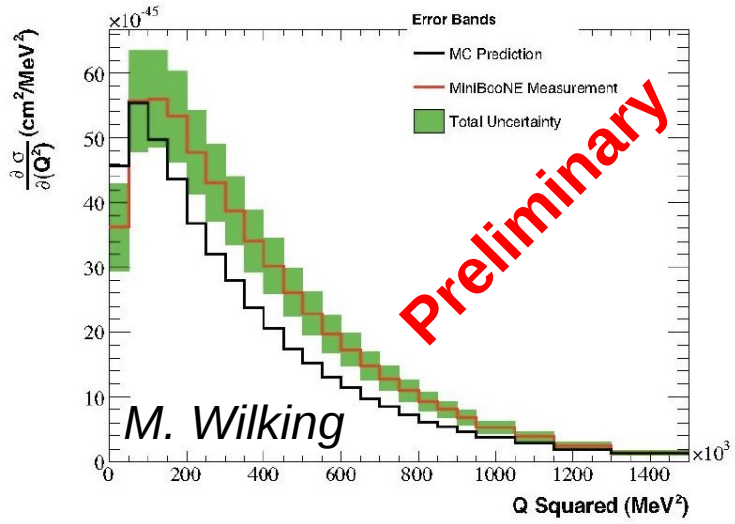
- Absolute and multiple differential cross-sections calculated:

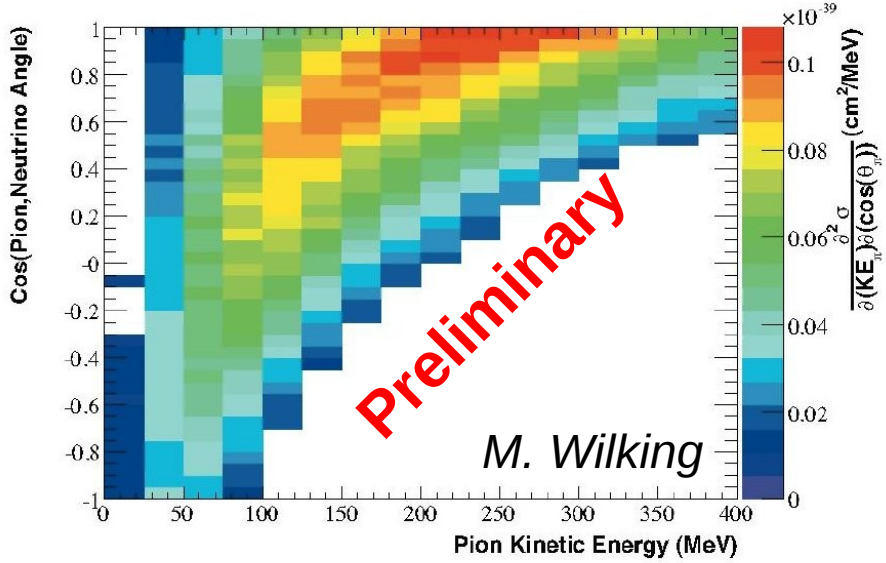
Model Independent

$$\frac{\partial\sigma}{\partial(KE_\mu)}, \frac{\partial\sigma}{\partial(\cos\theta_\mu)}, \frac{\partial\sigma}{\partial(KE_\pi)}, \frac{\partial\sigma}{\partial(\cos\theta_\pi)}, \frac{\partial^2\sigma}{\partial(KE_\mu)\partial(\cos\theta_\mu)}, \frac{\partial^2\sigma}{\partial(KE_\pi)\partial(\cos\theta_\pi)}$$

Model dependent

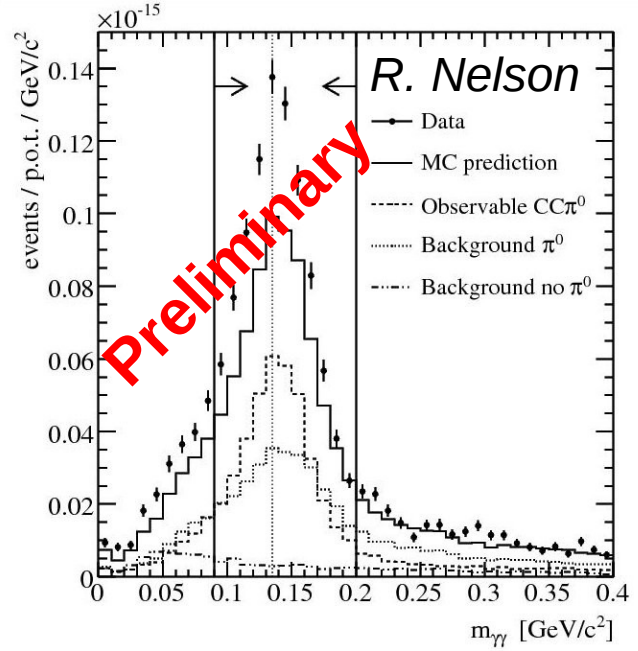
$$\sigma(E_\nu), \frac{\partial\sigma}{\partial(Q^2)}$$

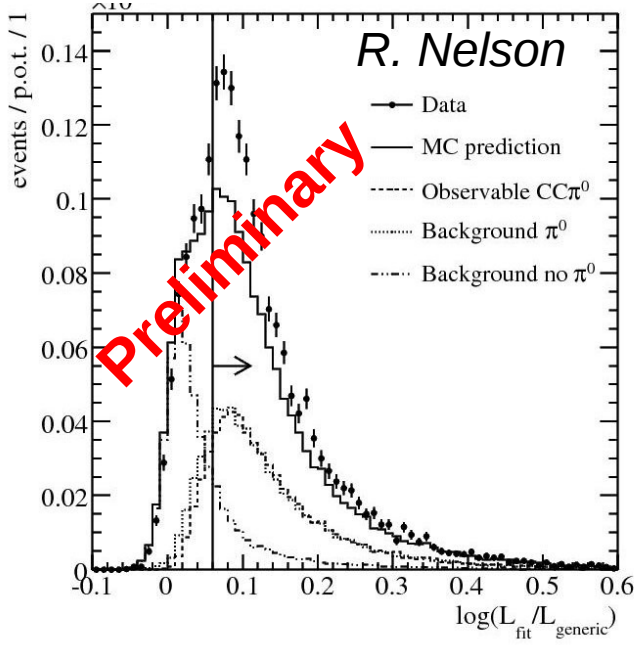




MB: CC π^0 Production

- 3-ring fitting required
  - Overlapping, difficult to distinguish
- Identify muon ring
- Reconstruct pion mass from photon rings
- Construct and cut on CCπ^0 vs. generic 3-track fit likelihood difference





Plots: Absolute normalisation

MB: CC π^0 Production

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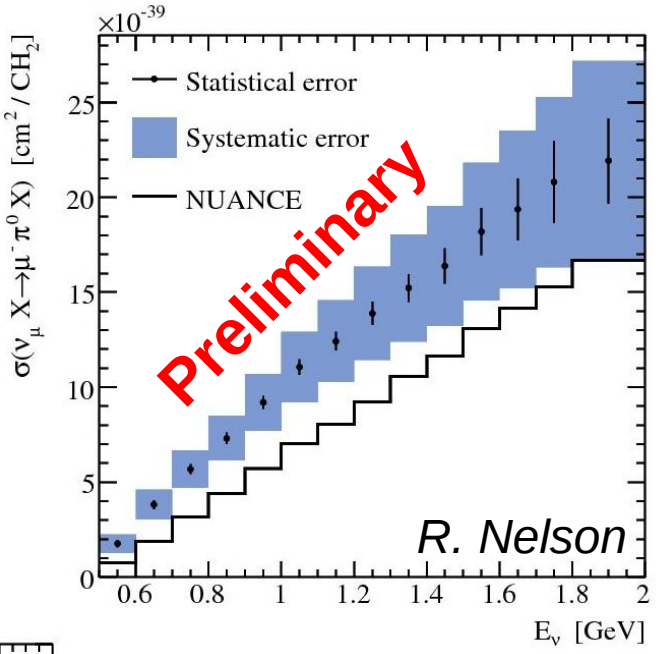
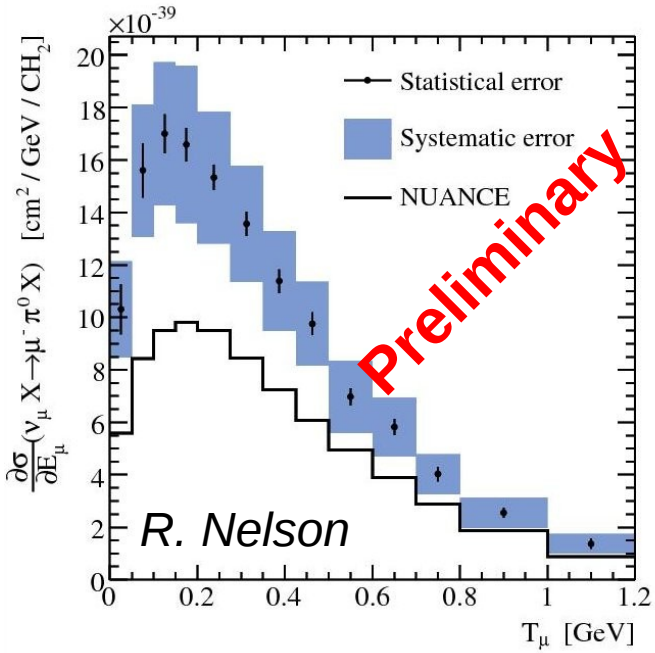
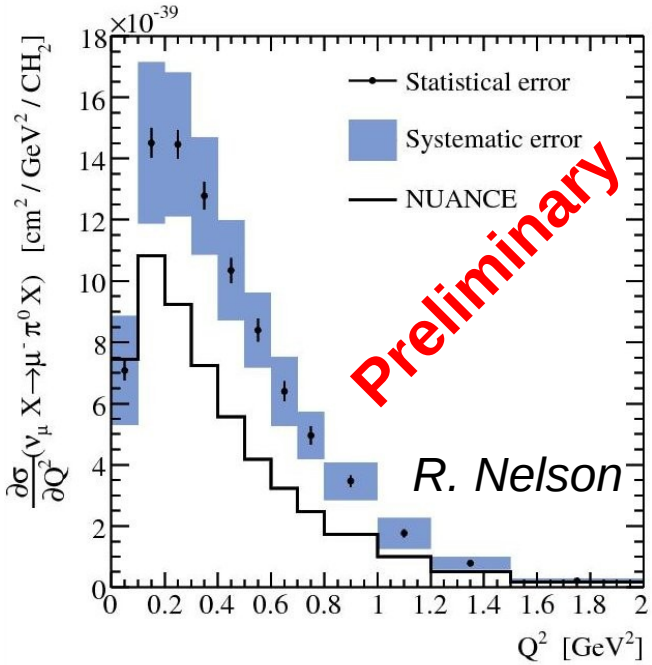
- Absolute and several differential cross-sections extracted
- MC not in agreement with measurement

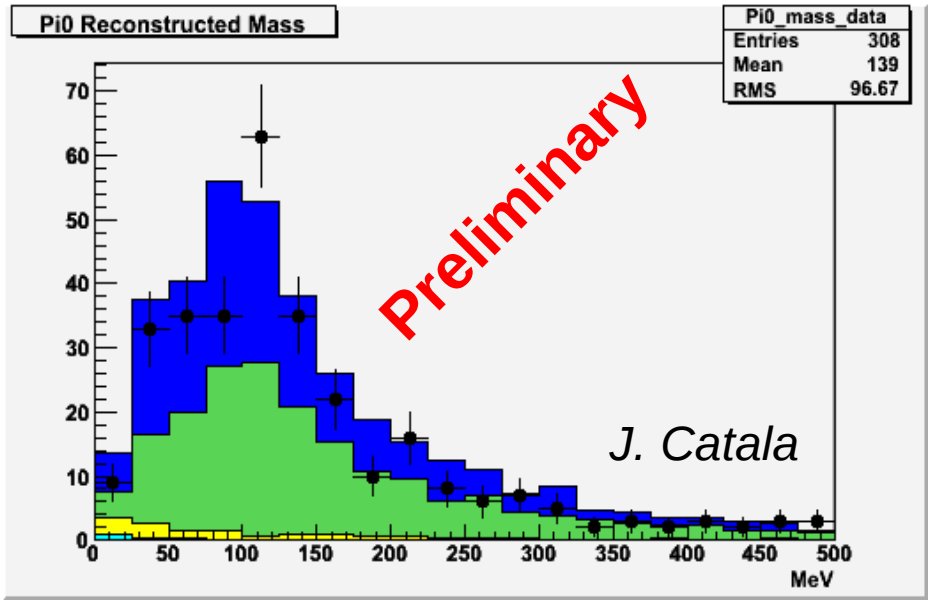






SB: CC π^0 Production

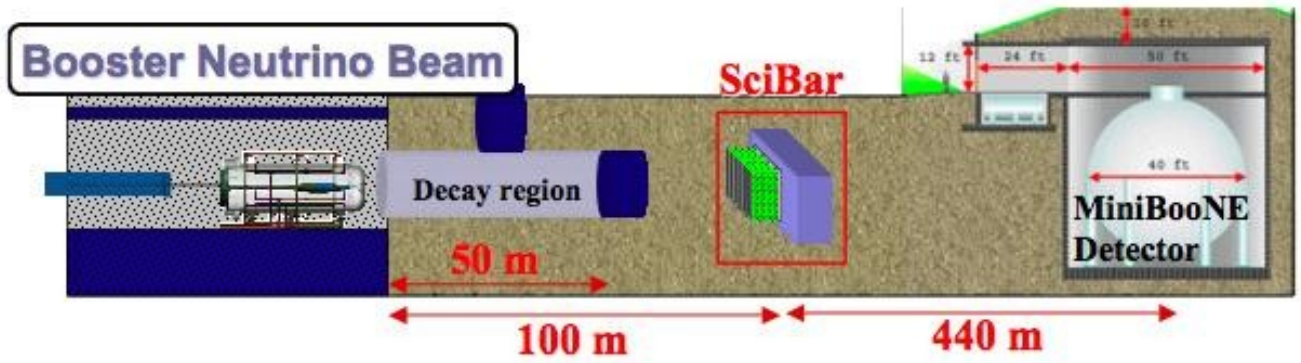
- Analysis currently in progress
  - Successfully reconstructed pion mass
- Goal: Calculate absolute cross-section



Plot: MRD-Matched Normalisation

Outline

- MiniBooNE and SciBooNE Refresher Course
- Physics Results From The Last Year...
  - Neutrino Cross-sections
  - Neutrino Oscillations
- Summary



MiniBooNE Oscillations

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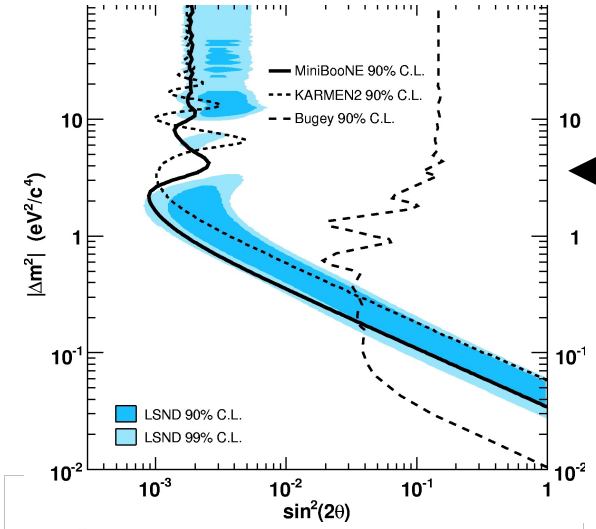
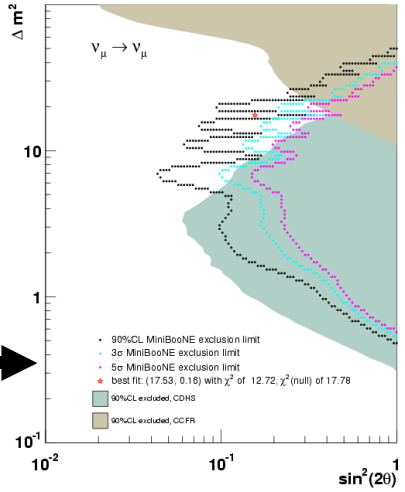


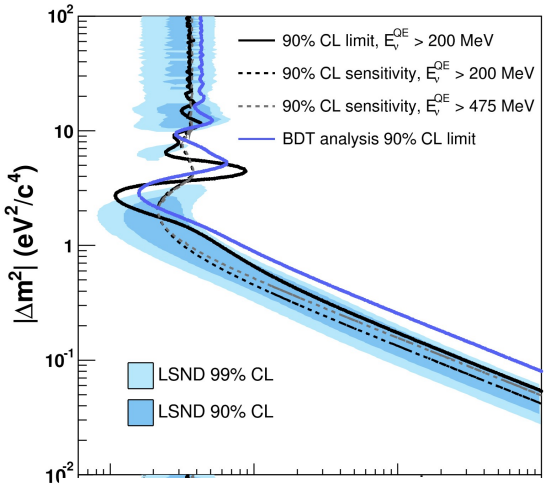
ν_e Appearance

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

ν_μ Disappearance

Phys. Rev. Lett. 103, 061802 (2009)



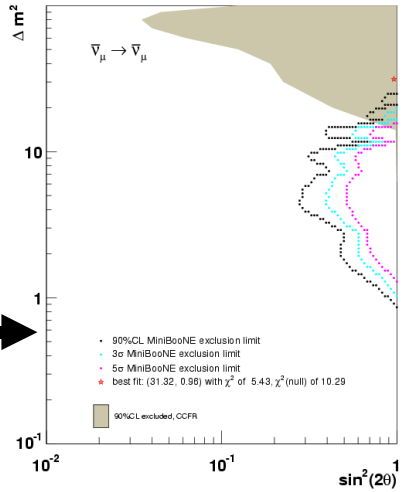


$\bar{\nu}_e$ Appearance

Phys. Rev. Lett. 103, 111801 (2009)

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

Phys. Rev. Lett. 103, 061802 (2009)



MB: $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ Appearance

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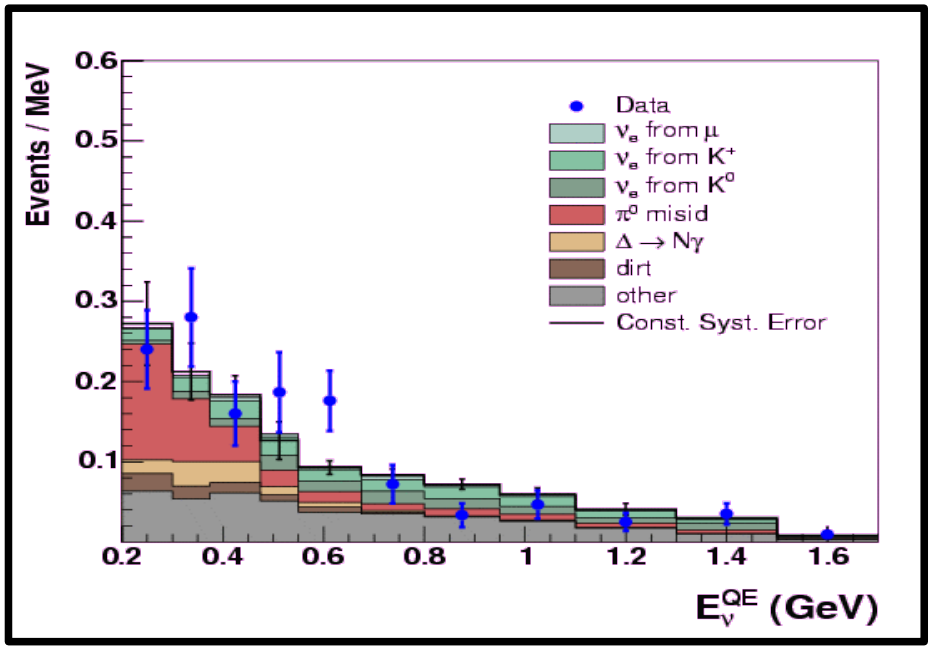

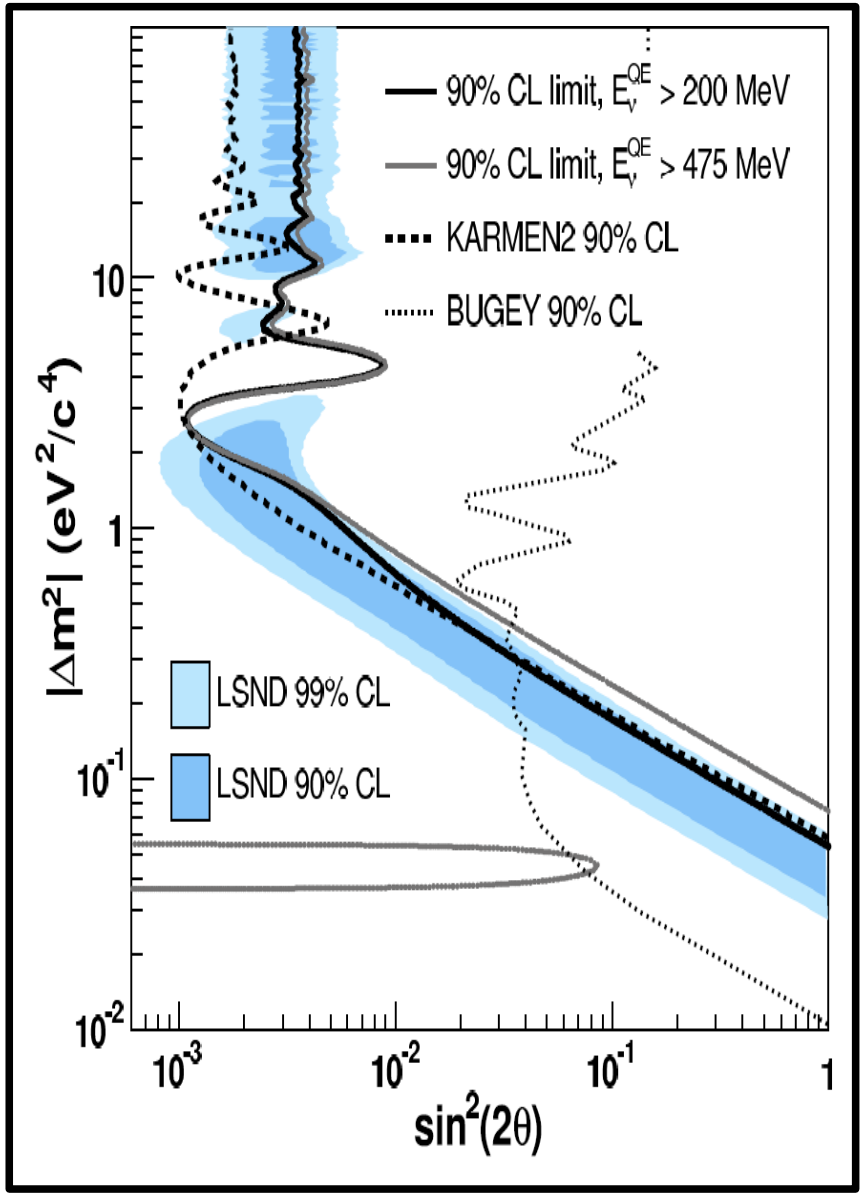

- Direct test of LSND signal
- Analysis based on 3.386×10^{20}POT
- 200-475 MeV: -0.5 ± 11.1 events
- 475-1250 MeV: 3.2 ± 10.0 events
  - No indication of data-MC excess

Result inconclusive with respect to LSND

MB: $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ Appearance

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Fermilab Users Meeting

2nd June 2010

?

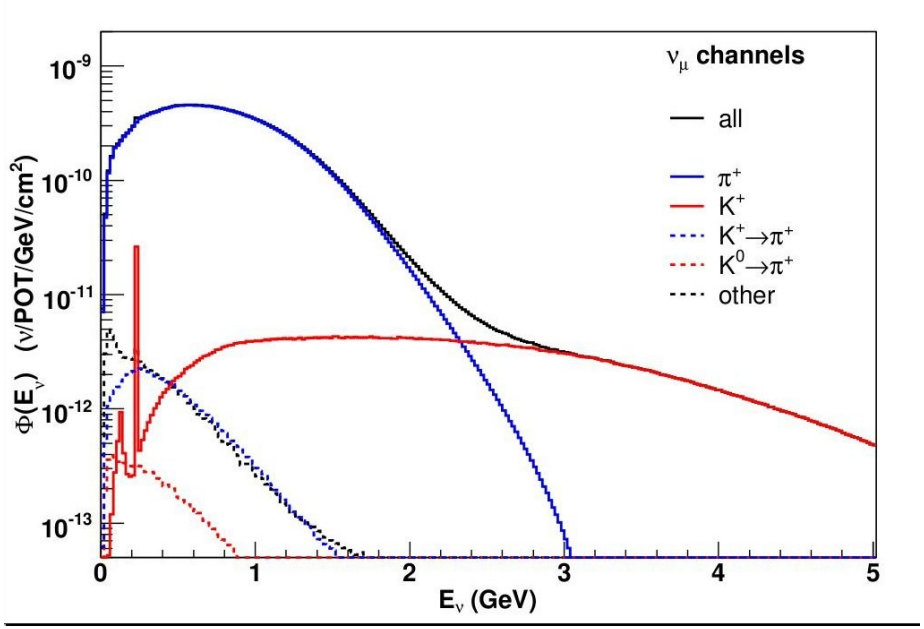
?

Updated MiniBooNE anti-neutrino result coming...
See W&C 14th June and Neutrino 2010

Kaon Production

Joseph Walding

- Kaon production in beam corresponds to intrinsic ν_e in neutrino beam
- Major source of uncertainty for the MiniBooNE ν_e appearance measurement
  - $K^+ \rightarrow \pi^0 e^+ \bar{\nu}_e$ (BR: 5%)
  - Constrain K^+ flux from high energy ν_μ events



MiniBooNE Collaboration: Phys. Rev. D79, 072002 (2009)

- Data/MC ratio:
  - 2-Track ν_μ sample: $0.74 \pm 0.06(\text{stat.}) \pm {}^{0.35}_{0.26}(\text{sys.})$ *(preliminary)*
  - 3-Track ν_μ sample: $0.77 \pm 0.08(\text{stat.}) \pm {}^{0.35}_{0.27}(\text{sys.})$ *(preliminary)*

G. Cheng analysis

SB+MB ν_μ Disappearance

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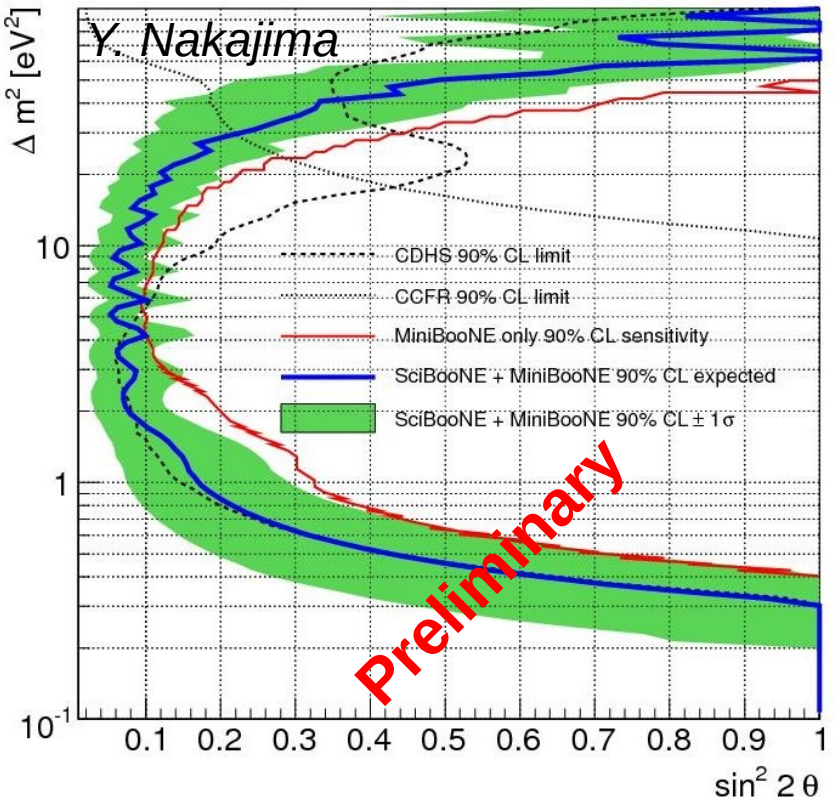
- First inter-collaboration measurement!
- Improve disappearance measurement
  - Use SciBooNE as a near detector
  - Same nuclear target (Carbon)
- Reduce uncertainties
  - Beam flux



- Improved from MiniBooNE-only sensitivity especially at low-Δm^2 region, where absolute normalisation is important.

Final data fit result will be released soon!

MB: Supernova Search

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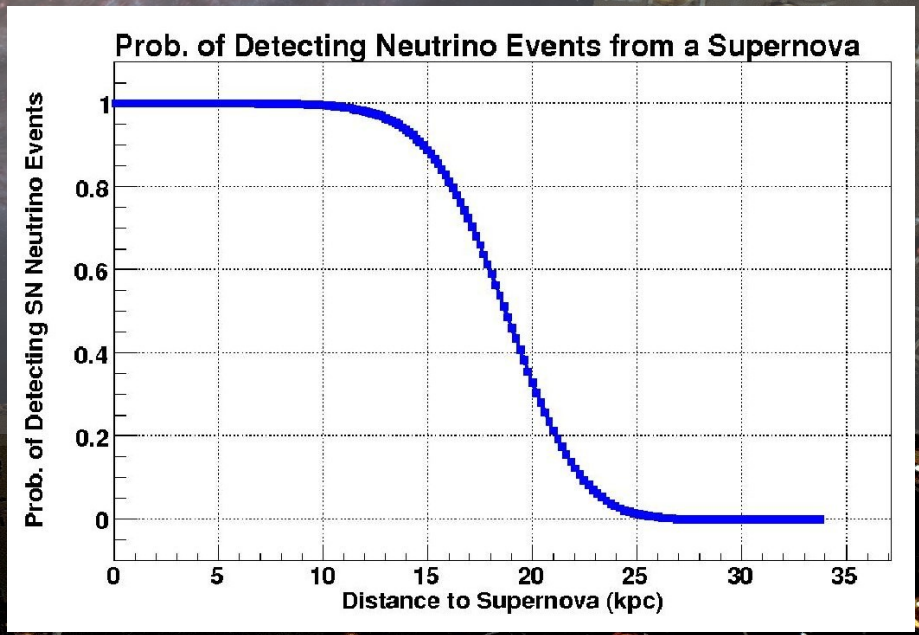
- Search for supernova from Dec. 14th 2004 – July 31st 2008
  - 98% detector live-time
- No observation of supernova within the Milky Way galaxy is observed to a distance of 13.5kpc
  - Limit set to 0.69 supernova per year inside 13.5kpc (90% CL)



M. Fisher, H. Ray: Phys. Rev. D81, 032001

Papers and Theses

- SciBooNE:
  - Papers
    - NC Inclusive π^0: Phys. Rev. D81, 033004
    - NC Coherent π^0: arXiv:1005.0059 (accepted to Phys. Rev. D)
  - Theses: Y. Kurimoto, J. Walding
- MiniBooNE:
  - Papers
    - CCQE: arXiv: 1002.2680 (accepted to Phys. Rev. D)
    - NCπ^0: Phys. Rev. D81, 013005
    - CCπ^+/QE ratio: Rev. Lett. 103, 081801
    - MiniBooNE Supernova Search: Phys. Rev. D81, 032001
  - Theses: D. Perevalov, R. Nelson

Summary

- A number of new cross-section results from both experiments published or in the pipeline
  - Many firsts!
  - Model-independent differential cross-sections
  - Interesting kinematic distributions
- First joint SB+MB Analysis: Paper in the works

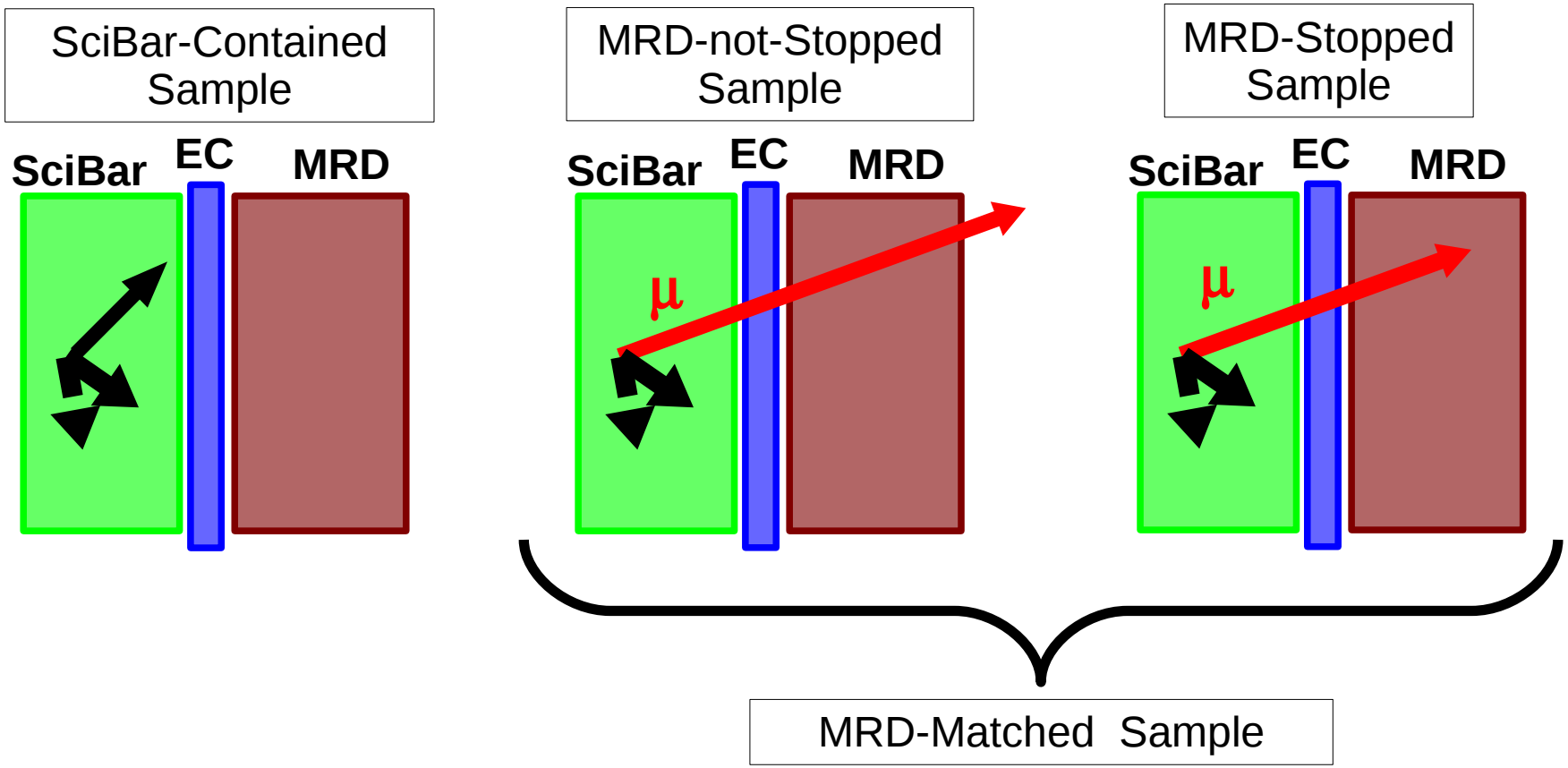

Thank you!

Backup

SciBooNE Event Definition

Joseph Walding

- Three event sub-categories



Quasi-Elastic Scattering

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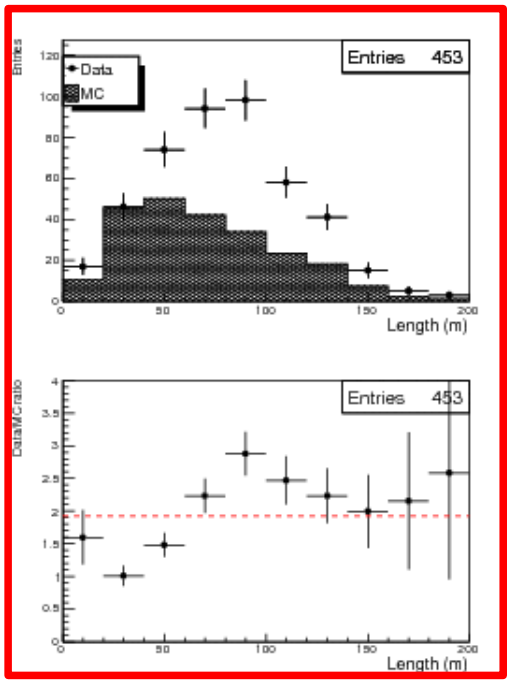
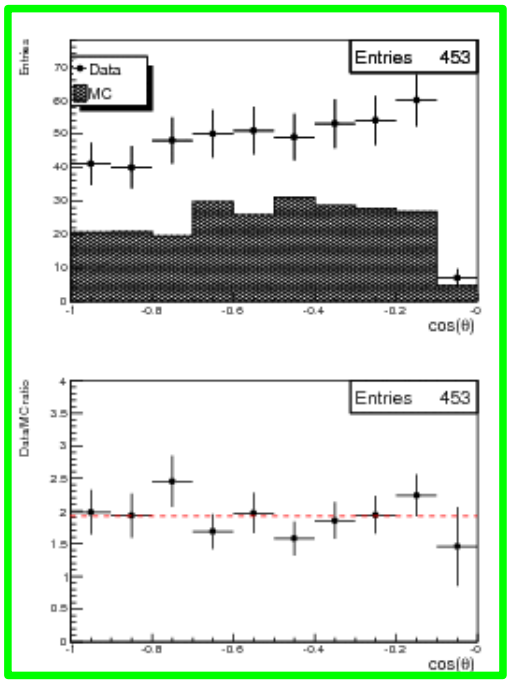
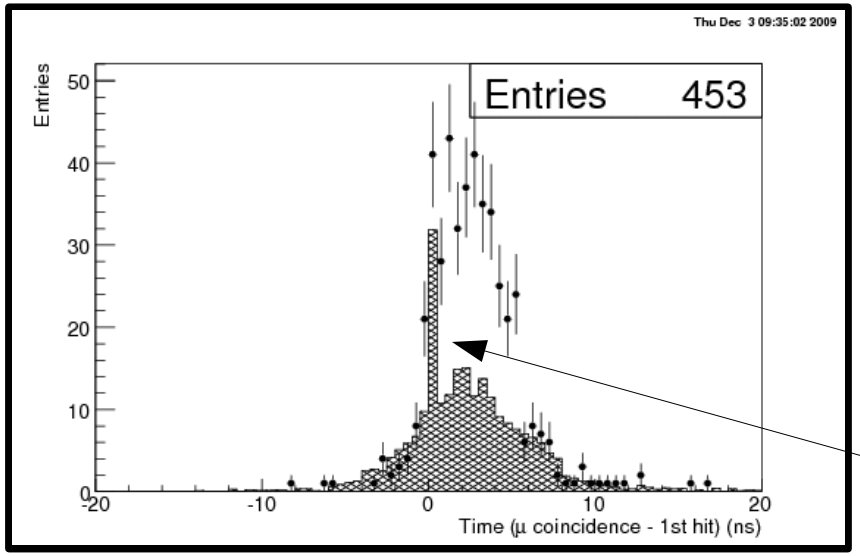
- SB-contained 1-track (μ) sample: Excess in backwards muon tracks
- Not seen in 2-track (μ+p) sample
- Mis-reconstruction
  - Short tracks
  - High angle tracks
- Not the case, looks to be real physics
  - Under further investigation





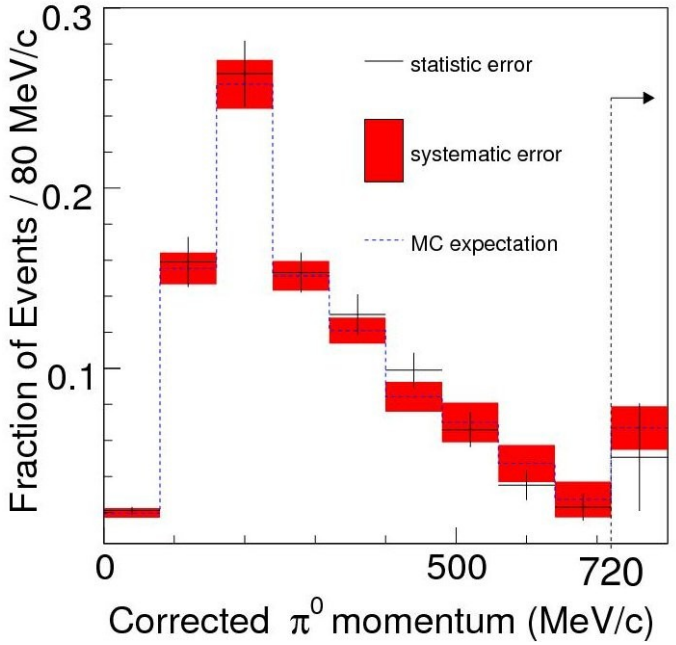


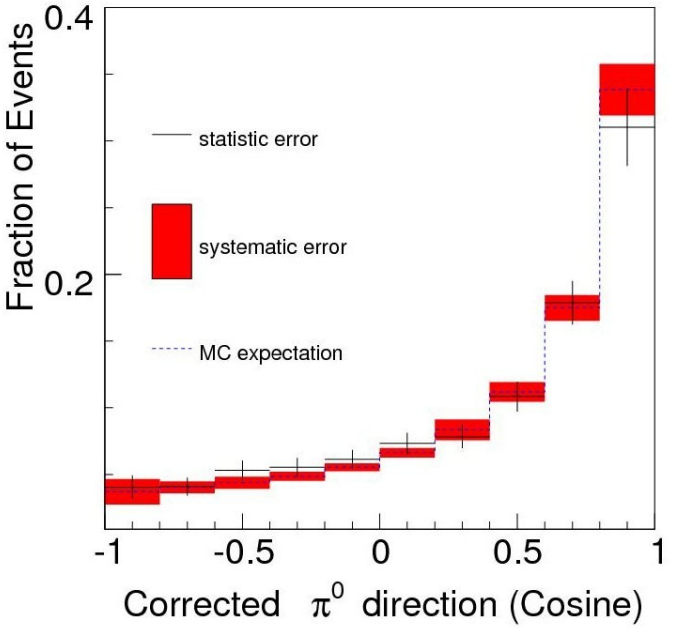
- Timing comparison between track ends supports case for physics effect

Instrumental effect

Inclusive NC π^0 Production

N_{obs}	657
N_{BG}	240
$\varepsilon_{NC\pi0}$	0.05
$N^{CC}{}_{obs}$	21702
$N^{CC}{}_{BG}$	2348
ε_{CC}	0.19


Fraction of Events / 80 MeV/c
0.3
0.2
0.1
0
500
720
statistic error
systematic error
MC expectation
Corrected π^0 momentum (MeV/c)


Fraction of Events
0.4
0.2
-1
-0.5
0
0.5
1
statistic error
systematic error
MC expectation
Corrected π^0 direction (Cosine)

MB: NC π^0 Production

Joseph Walding

- Data in agreement with MC including coherent production for both ν and $\bar{\nu}$ mode
  - Angular distribution
  - Total cross-section
- Consistent with SciBooNE result