The Short Baseline Thrust

Sam Zeller, Fermilab

DOE Laboratory Intensity Frontier Research Review

May 21, 2013

Short-Baseline Physics at Fermilab

- Fermilab is host to a vital SBL program that makes use of two neutrino beams

- Booster (8 GeV protons)
  - SciBooNE *(2007-2008)*
  - MiniBooNE *(2002-2012)*
  - MicroBooNE *(2014+)*

- NuMI (120 GeV protons)
  - ArgoNeuT *(2009-2010)*
  - MINERνA *(2010+)*
  - MINOS & NOνA NDs

Fermilab

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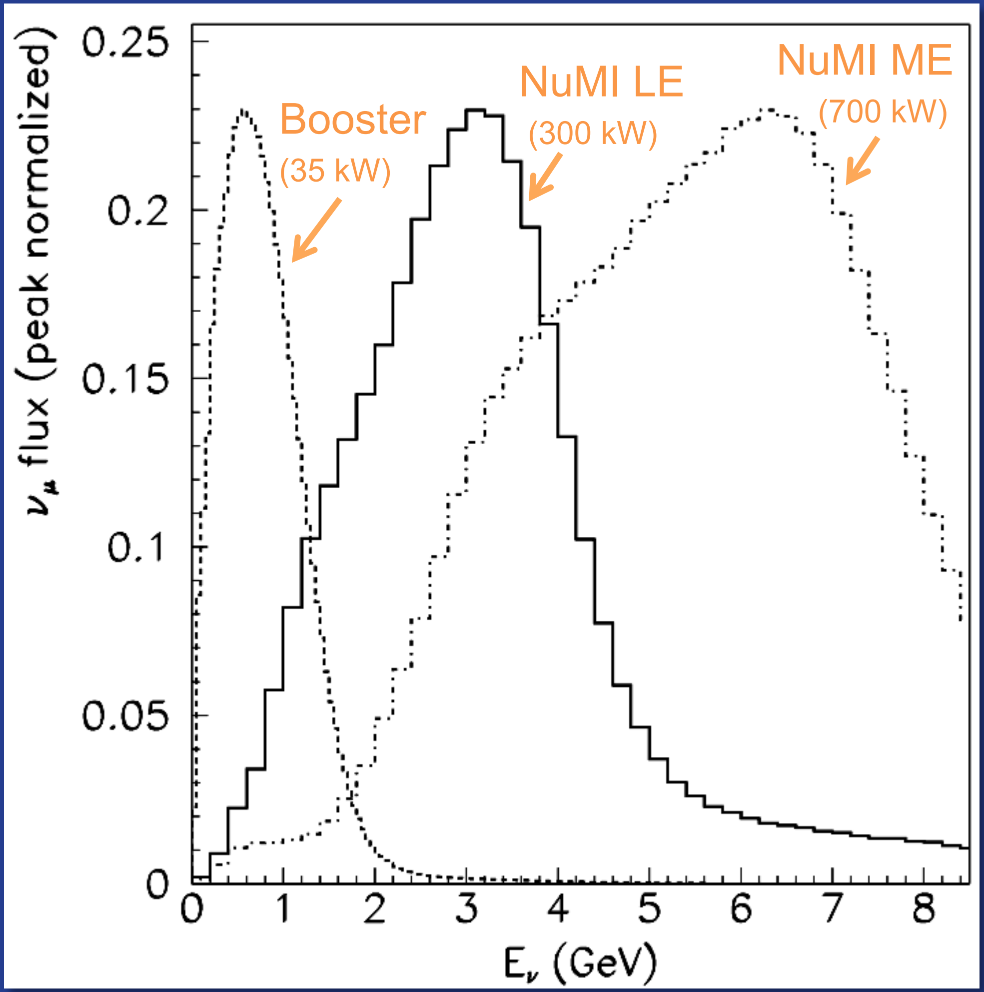

- experiments are at a variety of stages

Fermilab

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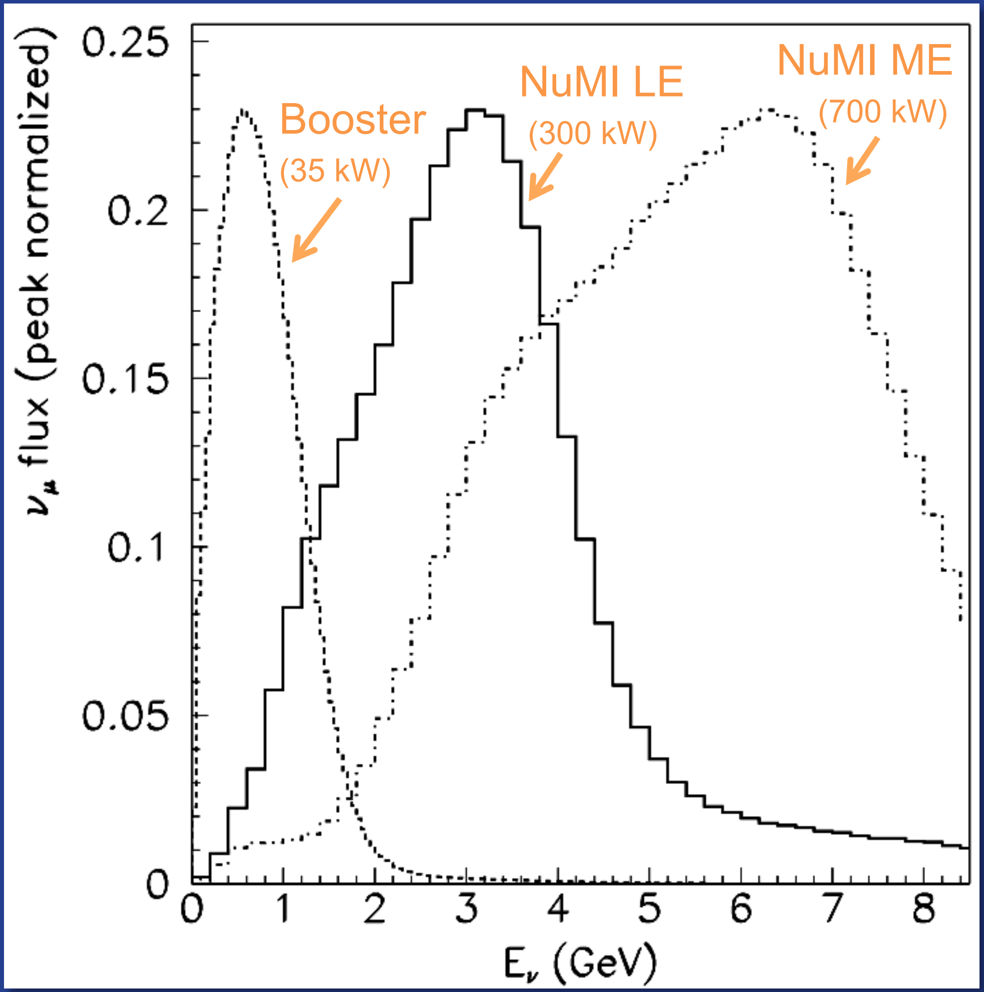

Brian will cover the long-baseline efforts (MINOS, NOvA, LBNE + LAr R&D)

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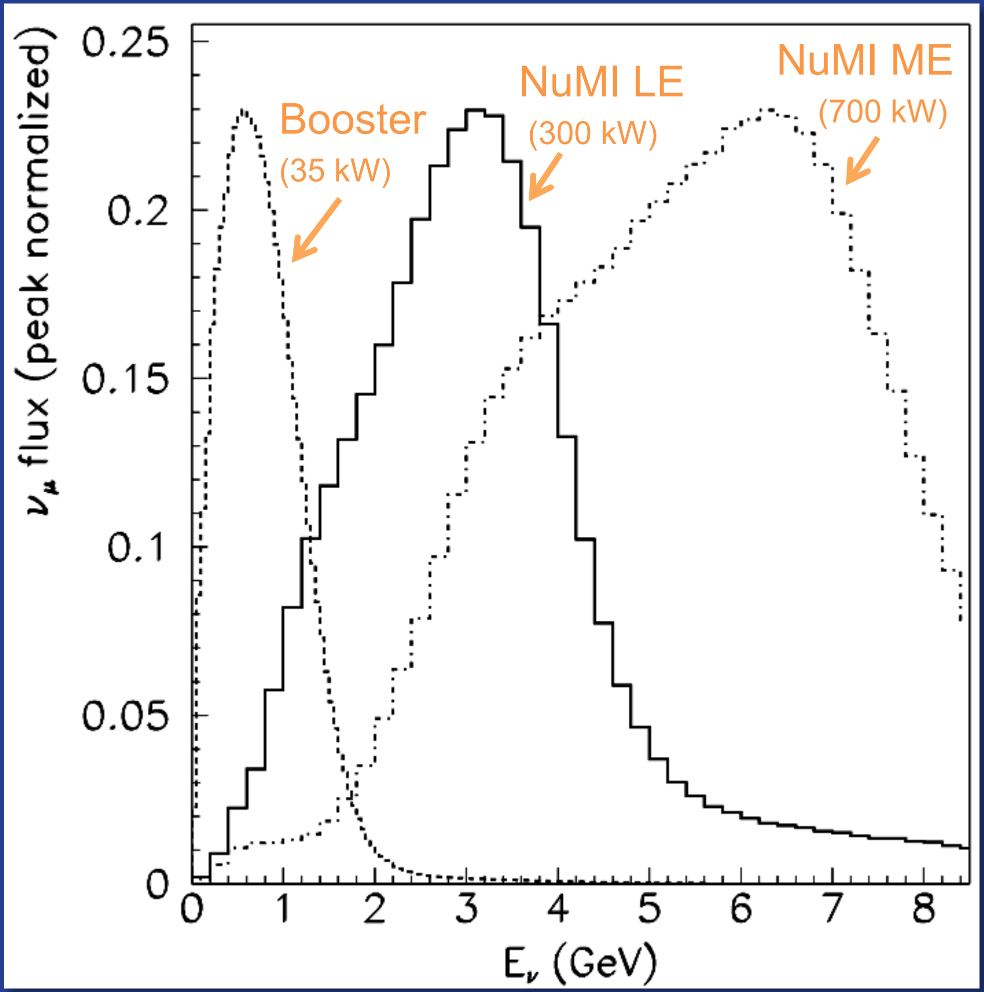
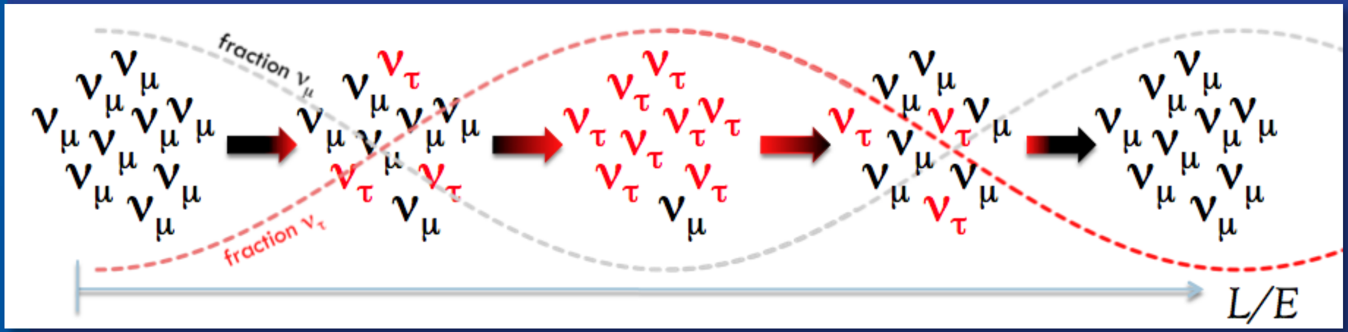


- total of 27 scientists including 7 postdocs

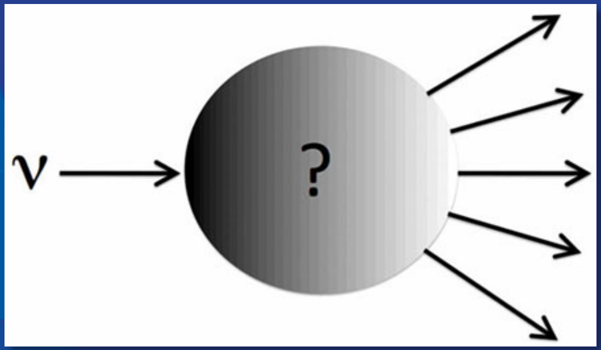
Outline

I will discuss what these 3 experiments and Fermilab scientists contribute to the understanding of:

- short-baseline neutrino oscillations



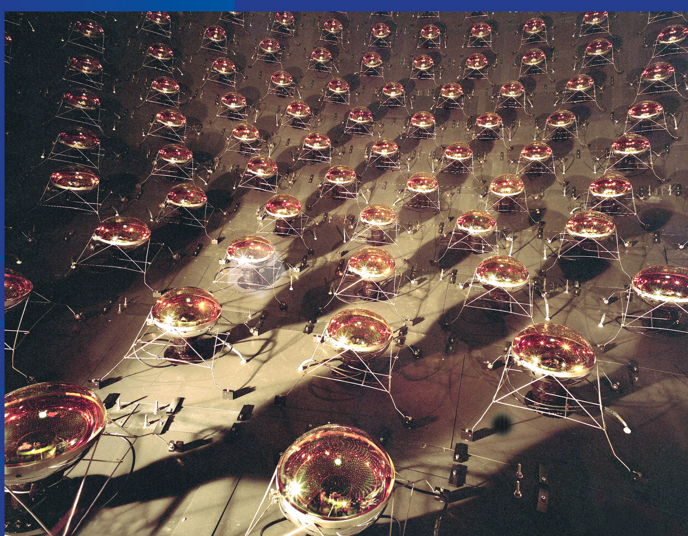
- neutrino interaction physics



MiniBooNE

2002 - 2012

- mature, single detector experiment
- ν oscillations (LSND $\rightarrow \nu_S$)
- ν interaction program



(86 collaborators, 19 institutions, 2 countries)

Fermilab Scientific Effort on MiniBooNE

- the # of Fermilab scientists on MiniBooNE has been small in recent years, but impact has been disproportionately large

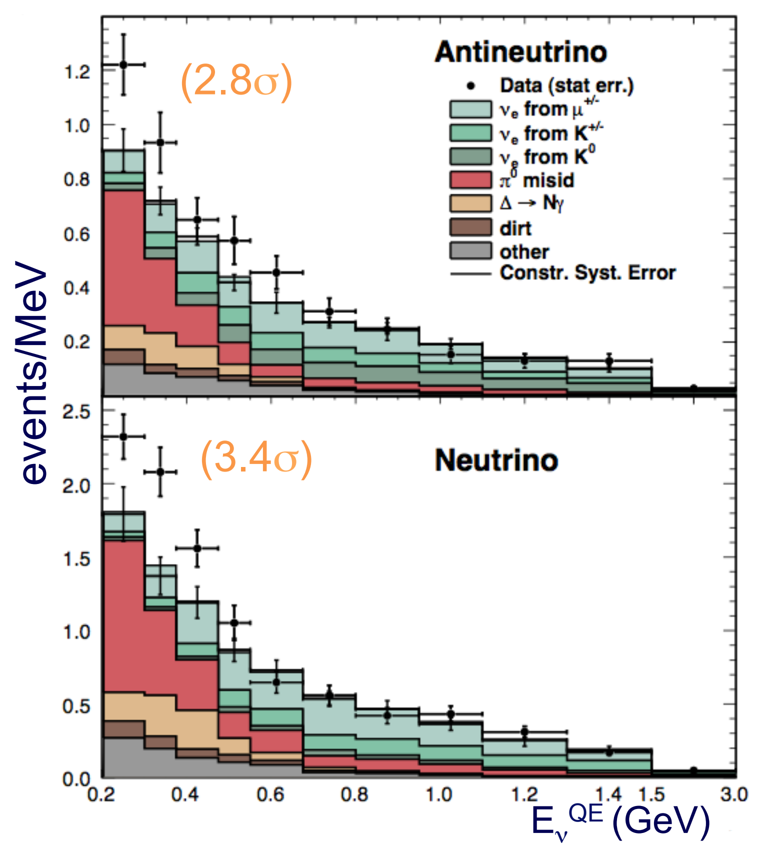
MiniBooNE	
Steve Brice	Co-Spokesperson
Chris Polly, Sam Zeller	Analysis Co-Coordinators

- 23 publications in period from 2008-2012
  - *9 neutrino oscillations* (under Polly)
  - *10 neutrino interactions* (under Zeller)
  - *4 assorted topics (detector, flux, Lorentz violation, supernova)*

- finishing up final analyses with this data set
  (3 more papers expected: $\overline{\nu}$ NC elastic, CC inclusive, oscillation PRD)

MiniBooNE Oscillations

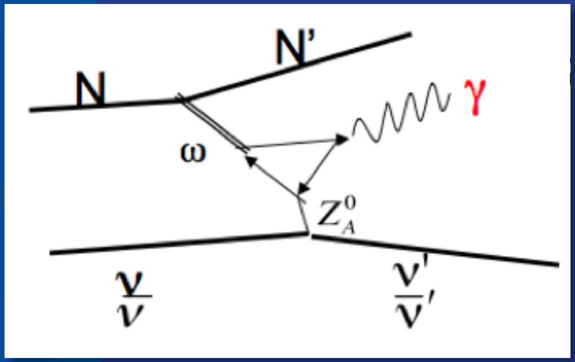
- analyses of ν_e, $\overline{\nu}_e$ appearance and ν_μ, $\overline{\nu}_\mu$ disappearance resulting in a total of 9 publications *(work closely with LANL, Univs)*
- published ν_e and $\overline{\nu}_e$ results with the entire data set this year *(Phys. Rev, Lett. 110, 161801 (2013))*



- Polly drove these analyses in his role as analysis co-coordinator
- see an excess of low energy events in both running modes
- source of the excess is unknown (MicroBooNE) — γ (bkg) / e^- (signal)

Input from Fermilab Theory Department

- background interpretation:



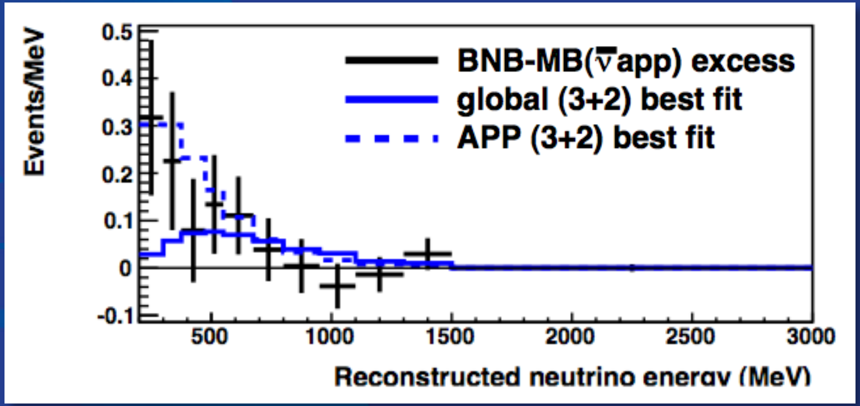
R. Hill, C. Hill, J. Harvey, PRL 99, 261601 (2007)
R. Hill, PRD 84, 017501 (2011)

- example: ν_μ-induced photon production (C. Hill)

the jury is still out on this

(this is where MicroBooNE comes in)

- signal interpretation:



J. Conrad et al., Adv. HEP 2013, 163897 (2013)

- example: 3+n global fits (Kayser)

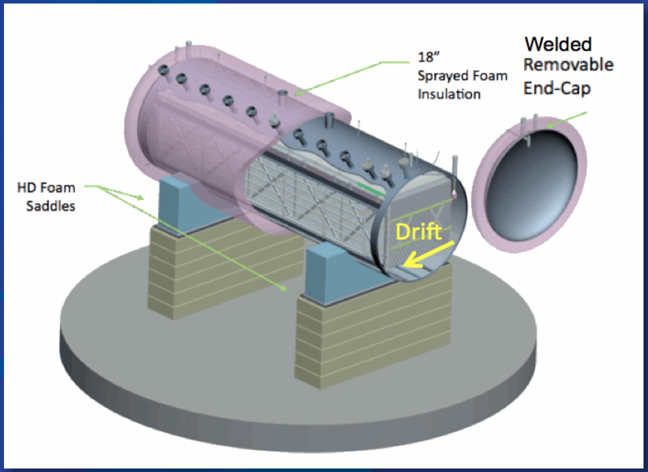
Fermilab has also been host to theorists specializing in σ_ν
Paschos, Mosel, Sobczyk

MicroBooNE

2014+

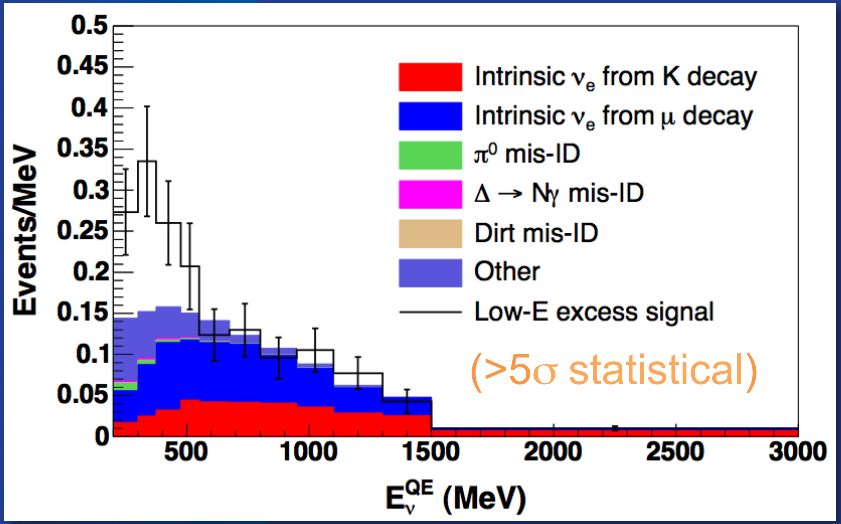
- 170 ton LAr TPC just upstream of MiniBooNE

- MiniBooNE excess events
- σ_ν measurements in Ar
- R&D for LAr TPCs



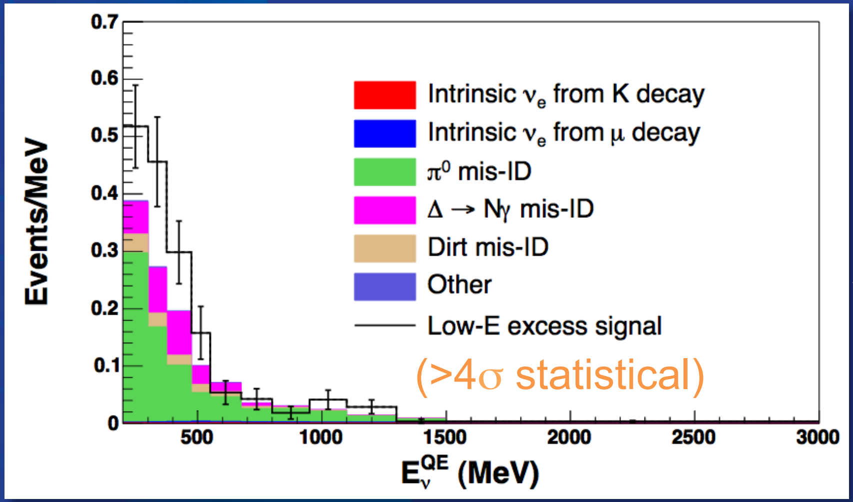
(108 collaborators, 19 institutions, 3 countries)

MicroBooNE Oscillation Physics



unlike MiniBooNE, MicroBooNE can distinguish e^-'s from γ's

if assume an electron signal and have analyzed for an e^-

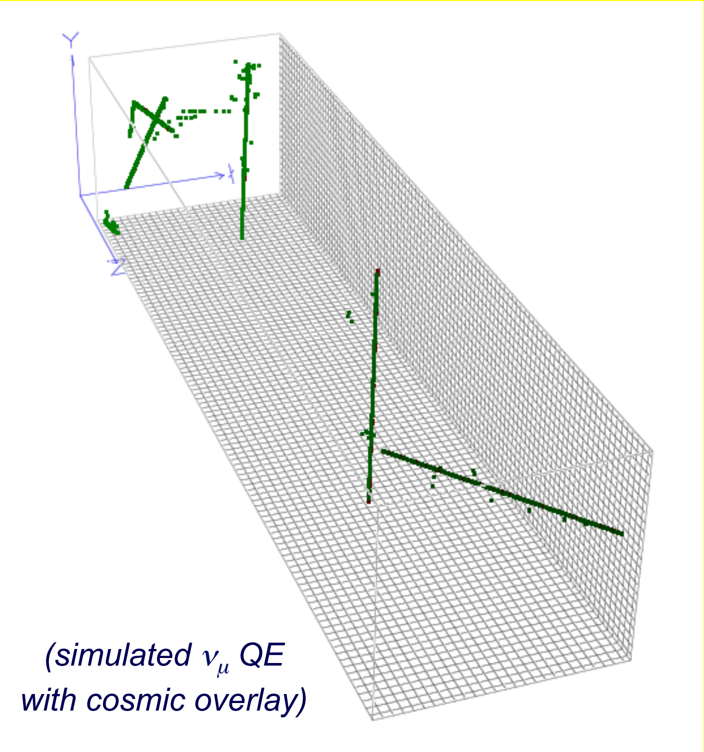


if assume a photon background and have analyzed for a γ

(projections for 6.6×10^{20} POT)

MicroBooNE Oscillation Physics

- Lockwitz (RA): leader of cosmic ray study group

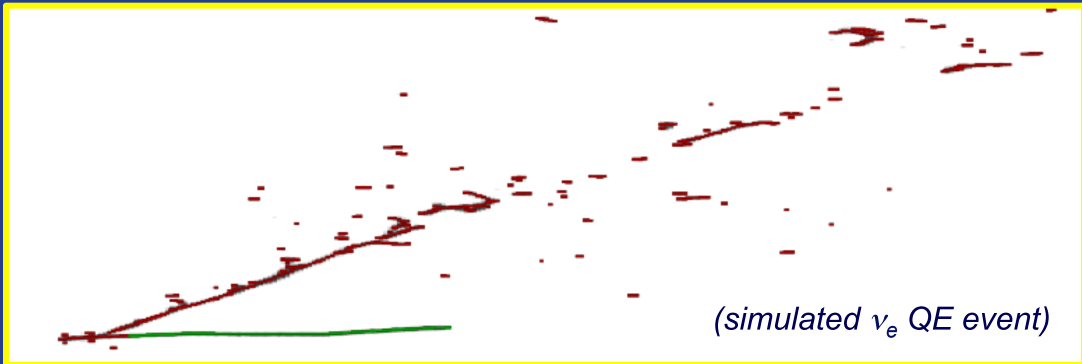


(simulated ν_μ QE with cosmic overlay)

- Fermilab scientists are taking lead roles in preparing for these flagship measurements

- Greenlee: Analysis Tools co-convener for MicroBooNE

- Carls (RA): fundamental pattern recognition



(simulated ν_e QE event)

Fermilab Scientific Effort on MicroBooNE

- FNAL is currently the largest group on MicroBooNE

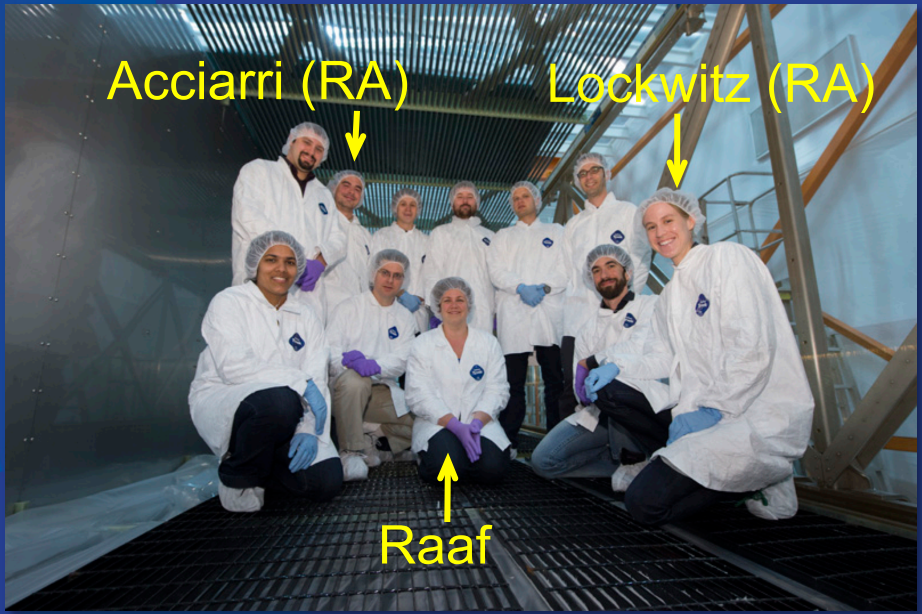
MicroBooNE	
Sam Zeller	Co-Spokesperson
Gina Rameika, Cat James	Project Manager, Deputy Project Manager
Bruce Baller, Dixon Bogert, Brian Rebel, Jen Raaf	Level-2 Managers
Herb Greenlee	Analysis Tools Co-Convener
Roberto Acciarri (RA)	TPC Construction, Calibrations, Reconstruction
Ben Carls (RA)	Cryogenics, Monte Carlo Convener, Reconstruction
Mike Cooke (RA)	Cryogenics, ν_e Analysis Reviewer
Hans Jostlein	TPC HV Feed-Through
Mike Kirby	Scientific Computing Division Liaison, Reconstruction
Sarah Lockwitz (RA)	TPC HV Feed-Through, Cosmic Ray Study Group Leader
Byron Lundberg	Signal Efficiency & Background Estimates for ν_e Analysis
Alberto Marchionni	Neutrino Beam Modeling
Stephen Pordes	Materials Test Stand
Steve Wolbers	Scientific Computing Division Liaison
Tingjun Yang (RA)	LAPD, Reconstruction

(19 total including 5 postdocs)

Fermilab scientists are integral to every part of the experiment

MicroBooNE Construction

- entire Fermilab group on MicroBooNE is involved in building MicroBooNE; we work closely with BNL, Universities
- has provided an important training ground for students/postdocs working side-by-side with Fermilab scientists



- data taking in 2014!

Planning Next Steps with Sterile Neutrino Searches

- Fermilab (chair: Geer) organized a short-baseline focus group and community workshop to review the current situation on sterile neutrinos and possible future directions

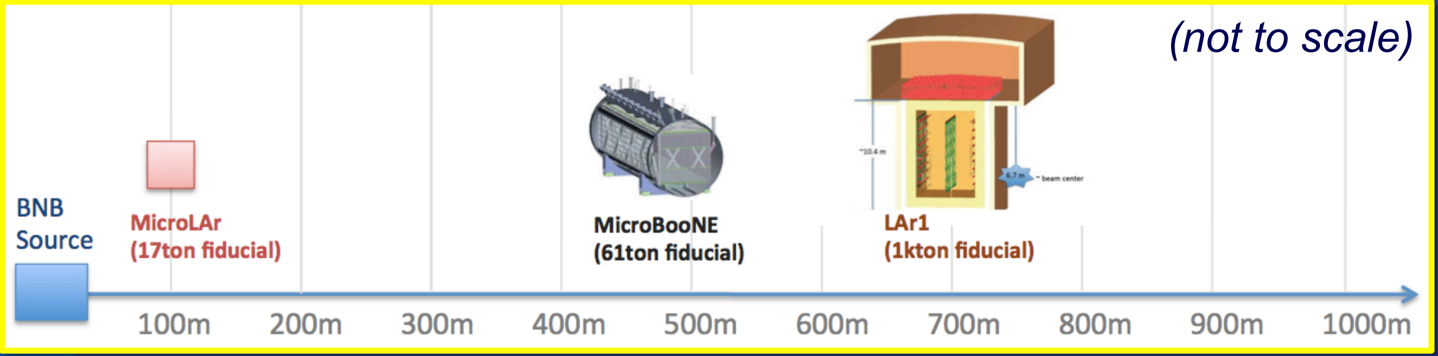
(9 Fermilab scientists on 15 member focus group, 111 workshop participants, report issued in June 2012: Fermilab-FN-0947)

- proposals for two next generation short-baseline neutrino experiments at Fermilab
  - LAr1
  - νSTORM

- Fermilab scientists are playing key roles in helping our colleagues develop these proposed follow-on experiments

LAr1

- addition of LAr detectors at both near and far sites along the Booster neutrino beamline (along with MicroBooNE)
- builds off existing beam and uses LAr TPC technology



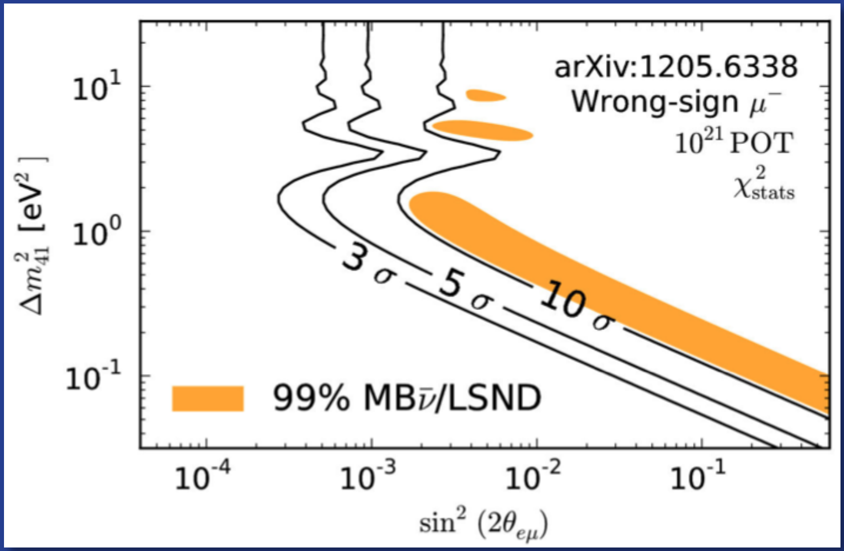
(LOI: 50 collaborators, 13 institutions)
http://lss.fnal.gov/archive/test-proposal/1000/fermilab-proposal-1030.pdf

- Fermilab scientists working with LAr1 collaborators to advance this into a full proposal; they bring considerable costing and design expertise from MicroBooNE, LBNE (Baller, Rameika)

νSTORM

- ν' s from a few-GeV muon storage ring aimed at near & far magnetized iron detectors

(Bross*, Brice, Morfin, Neuffer, Popovic) *spokesperson



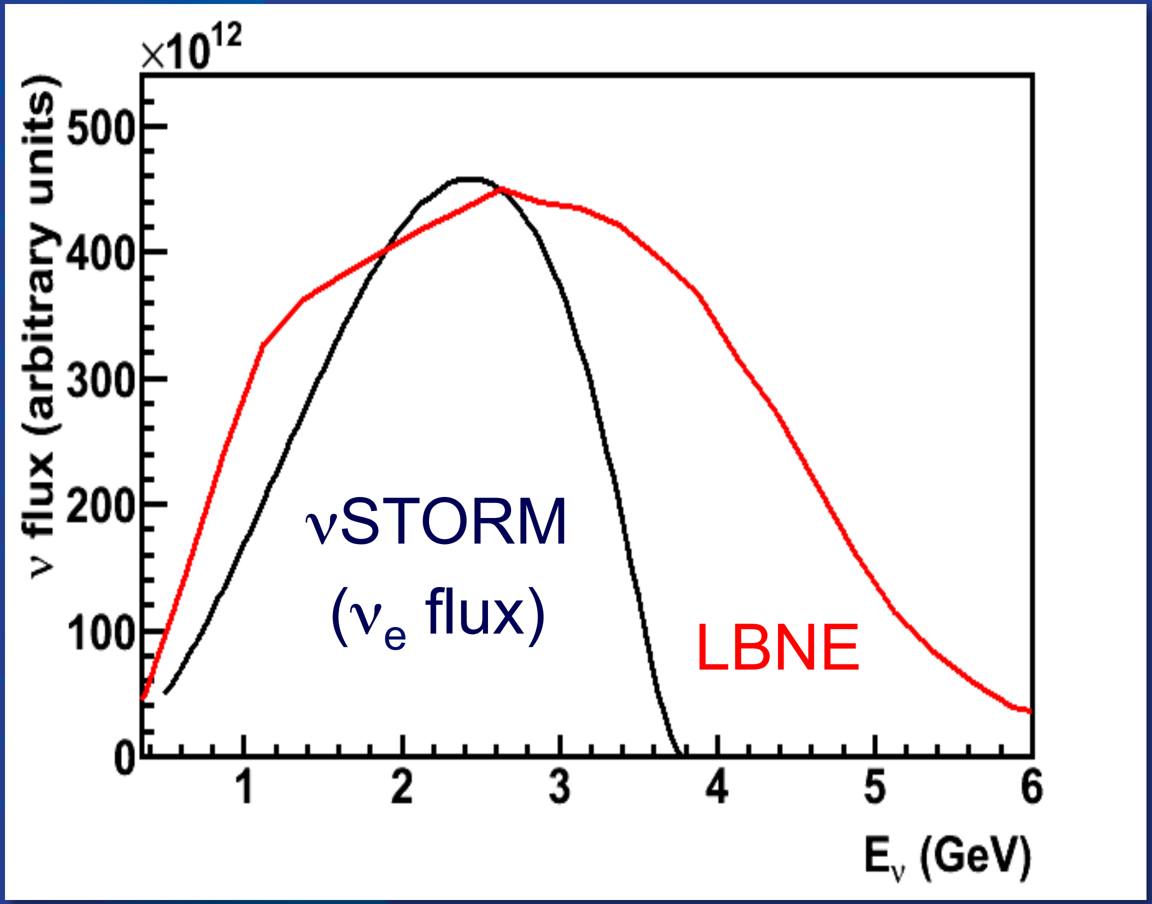
(C. Tunnell, Oxford)

- $\nu_e \rightarrow \nu_\mu$ appearance
  (CPT conjugate to MiniBooNE)
- testbed for future μ storage rings

(110 collaborators, 37 institutions)

https://indico.fnal.gov/conferenceDisplay.py?confId=6794

νSTORM



plot from S. Zeller (FNAL), Chris Tunnell (Oxford)

- unique in two ways:
  - large source of ν_e, $\overline{\nu}_e$
  - very well-known flux

- νSTORM can make precise measurements of individual ν_e and $\overline{\nu}_e$ cross sections in an important energy range (Morfin, Zeller)

example: 1 ton ND at 50m would collect about 40,000 CC ν_e events in 10^{21} POT

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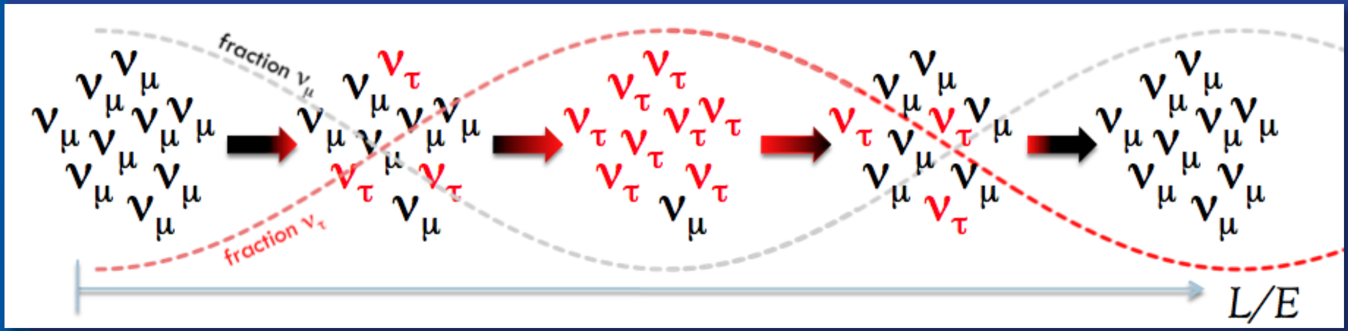
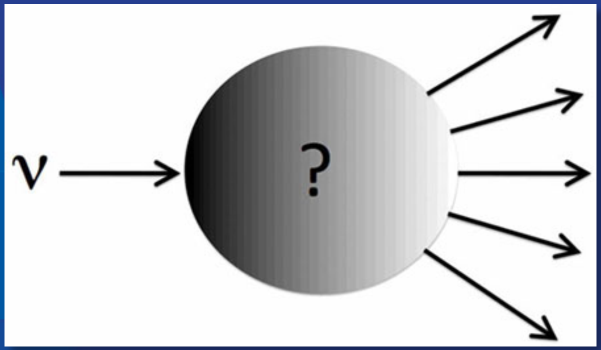
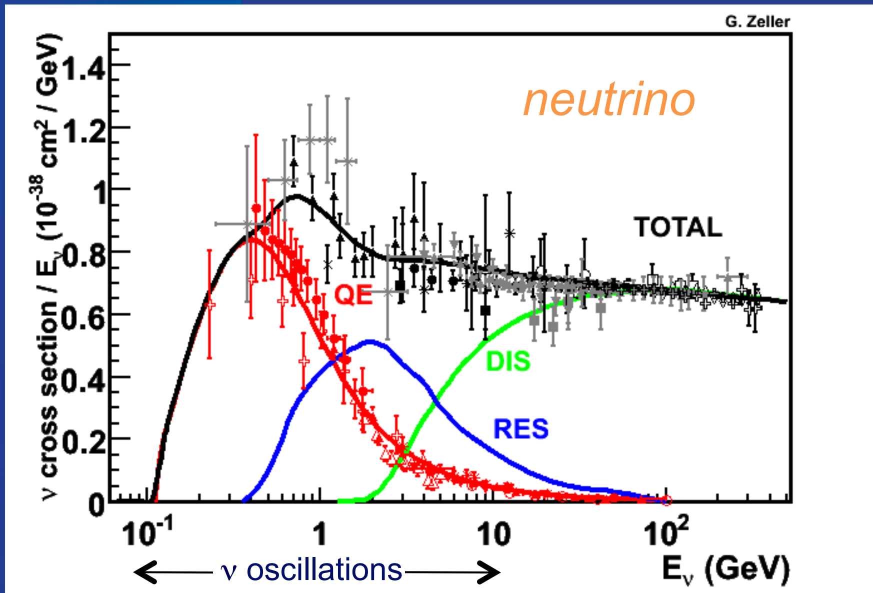


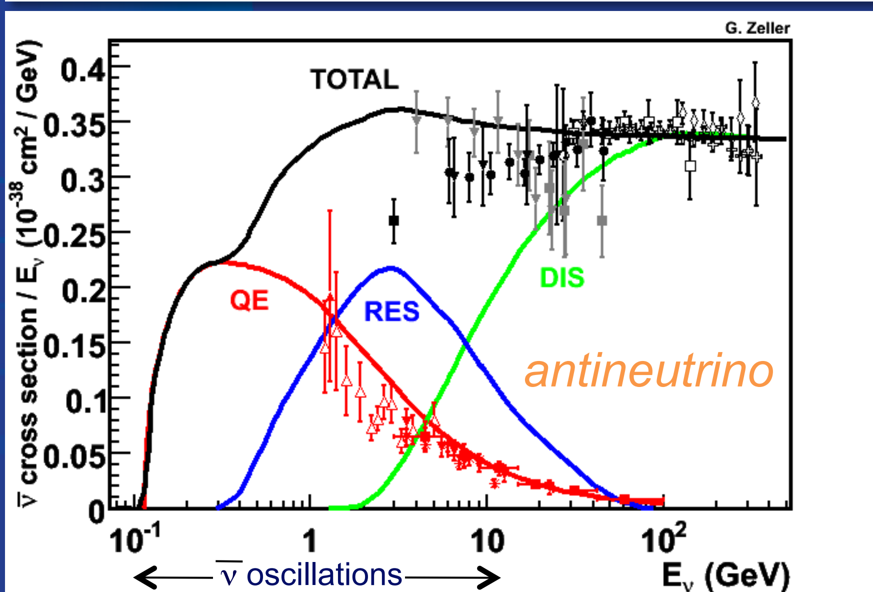
- neutrino interaction physics



Fermilab

Neutrino Cross Sections

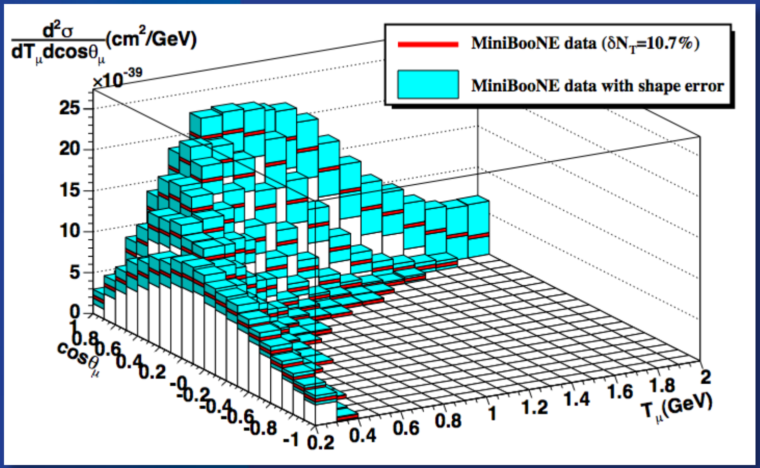




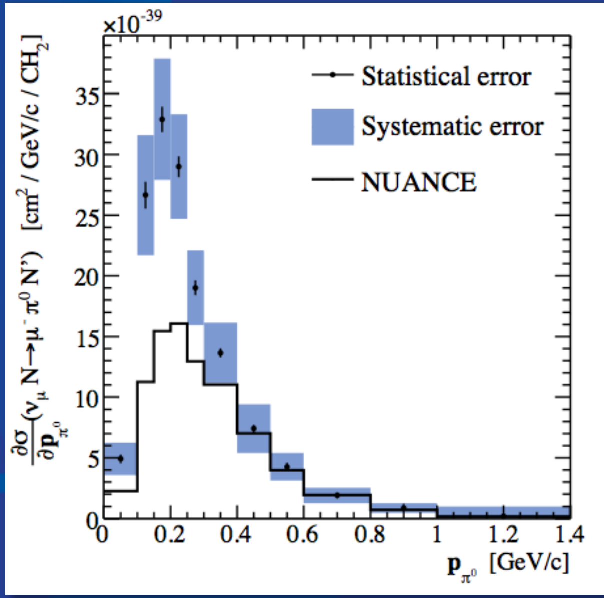
- this topic has received a lot of attention recently
  - *- interesting on their own*
  - *- crucial for ν oscillations*
- ν cross sections historically not well-known in the energy range we care about
- nuclear effects are far more complex than we thought
  - *- has forced a dramatic shift in our thinking*

in large part, driven by results coming out of MiniBooNE

MiniBooNE ν Cross Section Program



T. Katori (Indiana, now MIT)

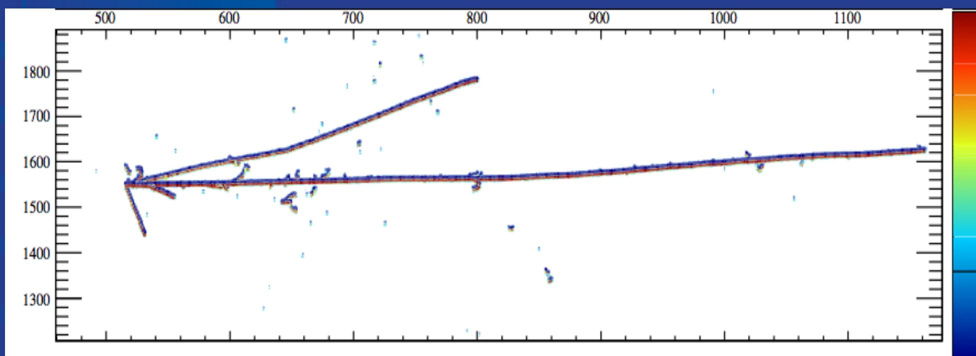


B. Nelson (Colorado, now Caltech)

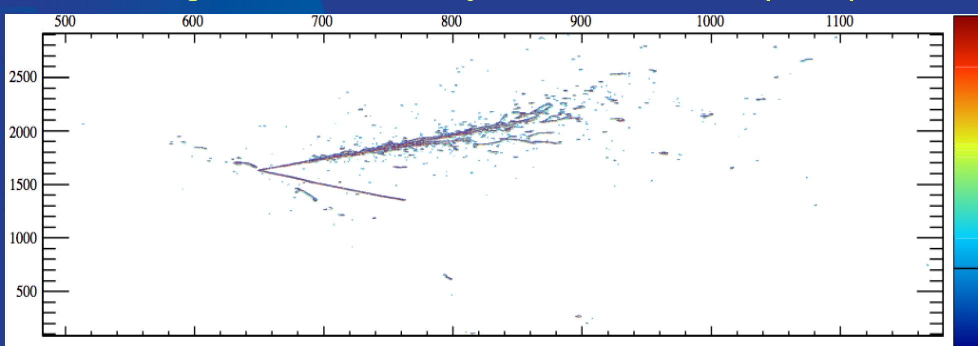
- Zeller co-mentored 10 Ph.D. students working on cross section measurements using ν, $\bar{\nu}$ data
- resulted in 10 publications and over 650 citations
- has set a new bar in the field in terms of quality, caliber of results
  - *- differential cross sections*
  - *- reduced model dependence*
- result of a coordinated effort of Fermilab scientists working with students/PDs from other institutions

MicroBooNE

- will more precisely examine final states produced in these neutrino interactions by exploiting LAr TPC capabilities and building off of MiniBooNE & ArgoNeuT



(simulated ν events in MicroBooNE)
generated by Ben Carls (RA)



- MicroBooNE will make the first σ_ν measurements in argon at low energy (1 GeV)
- Fermilab will be major contributors to 1st analyses
- they bring expertise from ArgoNeuT, MiniBooNE, NuMI

(Baller, Yang (RA)) (Raaf, Zeller) (James, Lundberg, Rameika, Rebel)

MINERνA

(80 collaborators, 23 institutions, 9 countries)

2010 - present

- precision ν cross section measurements on a variety of nuclear targets over a broad E_ν range

- uses the MINOS ND for CC ν analyses

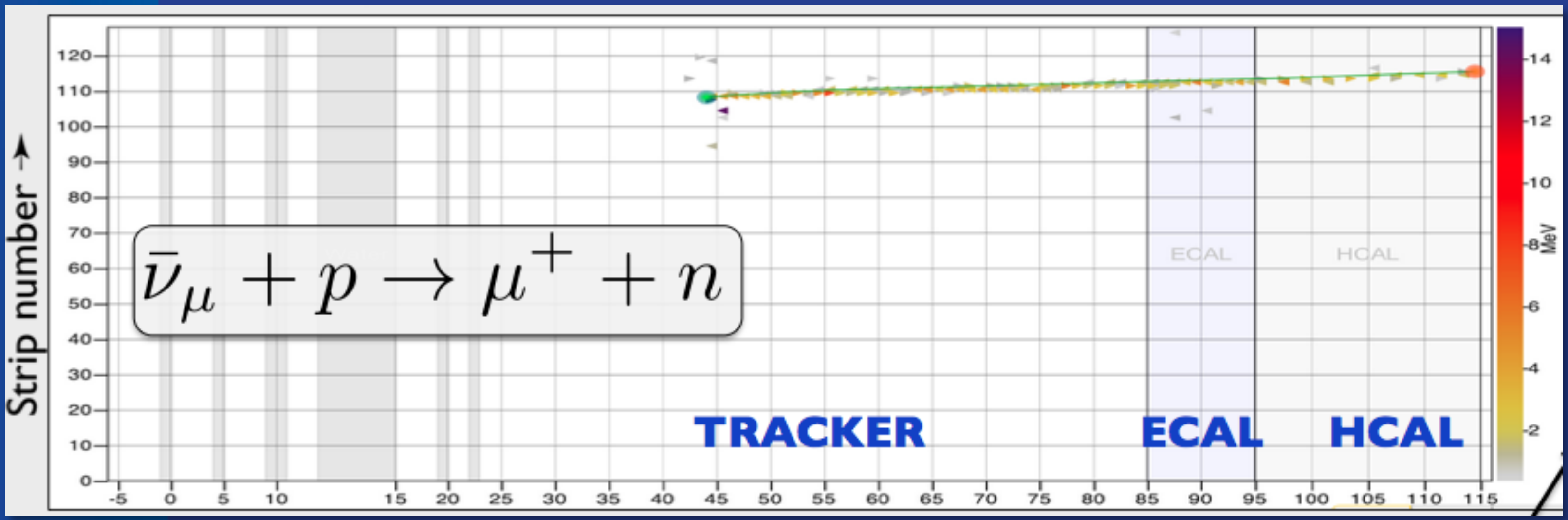
Fermilab Scientific Effort on MINERνA

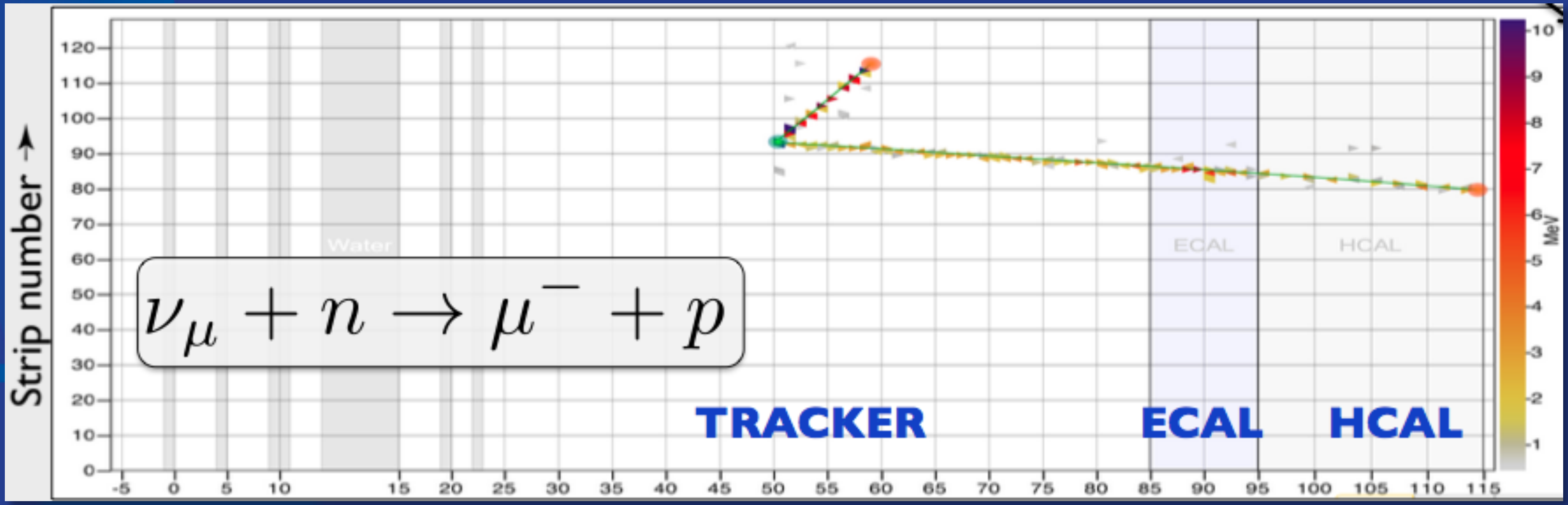
MINERνA	
Debbie Harris	Project Manager → Co-Spokesperson
Dave Schmitz (LF)+ *(+Lederman Fellow now at University of Chicago)*	Run Coordinator, Reconstruction Coordinator → Analysis Coordinator
Jorge Morfin	Founding Co-Spokesperson, DIS subgroup, South American Guest & Visitor Program
Jyotsna Osta (RA)	Testbeam Detector Comissioning/Operations, Hadronic and Electromagnetic Reconstruction, Muon Monitor Expert
Rick Snider	Scientific Computing Division Liaison

- they play crucial roles on the experiment
- each person actively mentors MINERvA students; Fermilab is a hub of activity for MINERvA *(just like MiniBooNE, MicroBooNE)*

First MINERνA Physics Publications!

arXiv:1305.2234 and 1305.2243





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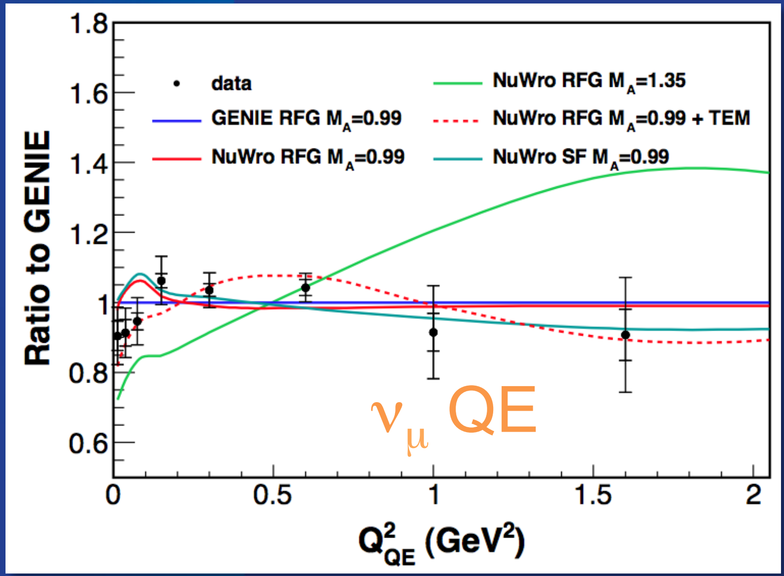
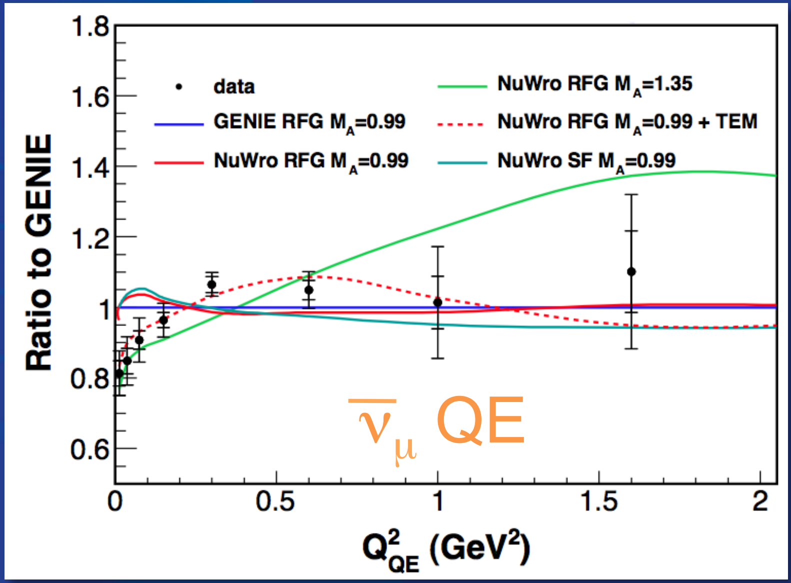
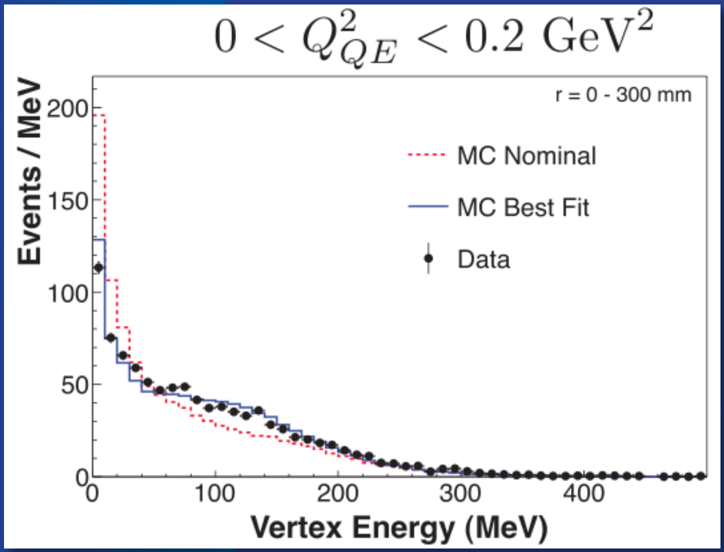
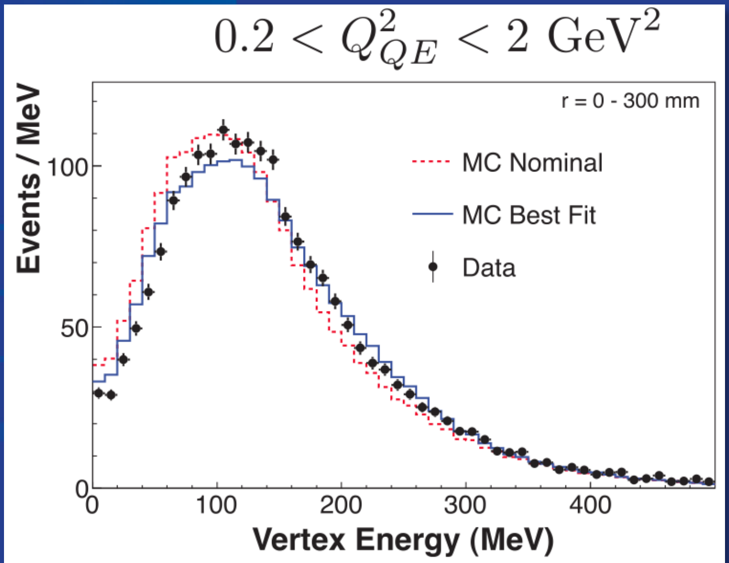




- Schmitz led the neutrino analysis which is the thesis work of Arturo Fiorentino *(a South American student who has been based at Fermilab)*
- curves from Jan Sobczyk; Morfin orchestrated this year-long visit
- Harris co-edited of publications working with Kevin McFarland (Rochester) and Mike Kordosky (William & Mary)

Taking This a Step Further …





- Jyostna Osta (RA) developed the energy deposition routines that made these analyses possible & is now working on a 2-track analysis

We find that adding an additional low-energy proton (KE < 225 MeV) to **(25 ± 9)% of QE events** improves agreements with data

- getting this physics right and into our simulations is crucial for future precision long-baseline ν physics

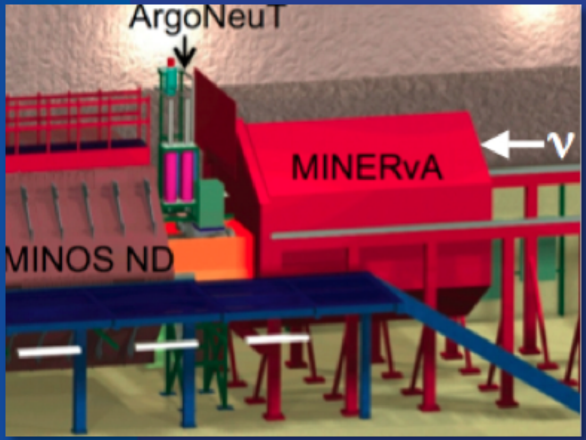
Next for MINERνA …

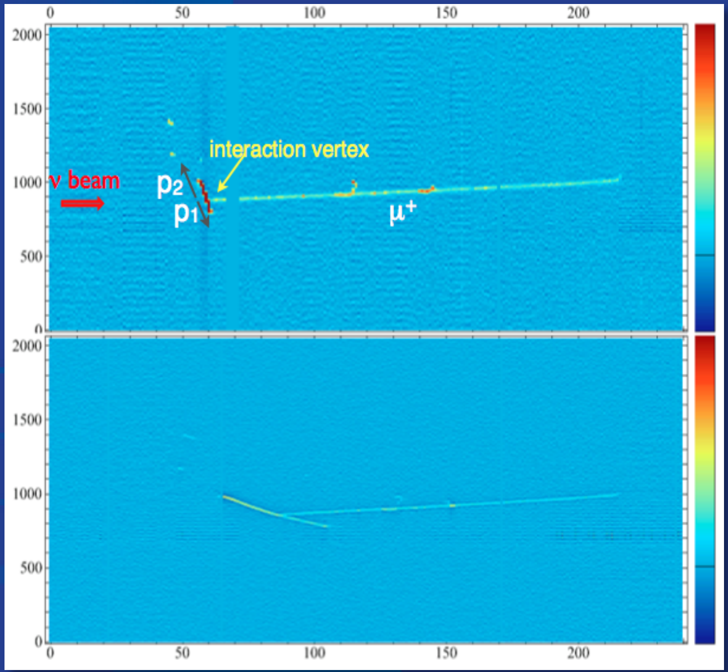
- data-taking in ME beam starting this summer
  - *increased physics reach*
- plan is to keep churning out physics
  - *much more to come!*
- in the process of hiring another Fermilab postdoc
- 90+ paper on the MINERνA detector and calibrations
  - *Debbie Harris is leading this effort with Dave Schmitz, Donna Naples (U Pittsburgh)*

>20 Ph.D. students working on their dissertations using MINERνA data

1) "Differential Cross Sections vs Q2 in Muon Anti-Neutrino Quasi-Elastic Interactions"
2) "Differential Cross Sections vs Q2 in Muon Neutrino Quasi-Elastic Interactions"
3) "Differential Cross Sections vs Q2 in Electron Neutrino Quasi-Elastic Interactions"
4) "Activity near the interaction vertex in Neutrino and Anti-neutrino Quasi-Elastic Interaction vertices"
5) "Comparisons of Neutrino Quasi-Elastic scattering on carbon, lead, iron and scintillator"
6) "Absolute Cross Sections vs neutrino Energy, muon momentum and angle in Muon Anti-Neutrino Quasi-Elastic Interactions"
7) "Absolute Cross Sections vs neutrino Energy, muon momentum and angle in Muon Neutrino Quasi-Elastic Interactions"
8) "Measurement of the Total Neutrino Charged Current Cross Section on Scintillator"
9) "Measurement of the Total Anti-Neutrino Charged Current Cross Section on Scintillator"
10) "Ratios of Neutrino and Anti-Neutrino Total Charged Current Cross-sections on carbon, lead, iron and scintillator"
11) "Kinematics of Inclusive Charged Current Scattering by neutrinos on Scintillator from 2-8GeV"
12) "Kinematics of Inclusive Charged Current Scattering by anti-neutrinos on Scintillator from 2-8GeV"
13) "Charged Pion production in Neutrino Charged Current scattering"
14) "Charged Pion production in Anti-Neutrino Charged Current scattering"
15) "Neutral Pion production in Neutrino Charged Current scattering"
16) "Neutral Pion production in Anti-Neutrino Charged Current scattering"
17) "Coherent Charged Pion production by Muon Neutrinos at 2-20GeV"
18) "Coherent Neutral Pion production by Muon Neutrinos at 2-20GeV"
19) "Coherent Charged Pion production by Muon Anti-Neutrinos at 2-20GeV"
20) "Strange Particle Production in 2-10GeV neutrinos and anti-neutrinos
21) "Nuclear Dependence of Coherent Charged Pion production from 2-10GeV"
22) "Absolute Neutrino Cross Sections on Helium vs Neutrino Energy"
23) "Ratios of Inclusive Neutrino and Anti-Neutrino Charged Current Cross-sections on helium, carbon, iron, lead and scintillator"
24) "Structure Functions on Scintillator from 2-20GeV"

ArgoNeuT (2009 – 2010)





(O. Palamara, SLAC March 2013)

- ArgoNeuT data also playing a very important role here
- Baller working on PID, studies of e^- recombination using protons
- Yang (RA) is leader of the CC inclusive group, MINOS liaison
- Zeller lends expertise from her experience on MiniBooNE
- Acciarri (RA) will be contributing to ν_e analyses

Conclusions

- Fermilab is a primary contributor to our understanding of:

  - short-baseline neutrino oscillations
  - neutrino interaction physics

- Fermilab scientists drive the realization, leadership, & physics output of three crucial experiments:

  - MiniBooNE, MicroBooNE, MINERνA

- Fermilab is also involved in the design and hosting of possible future short-baseline ν oscillation experiments:

  - LAr1, νSTORM

- Fermilab scientists play a unique role in enabling the community to perform world-class short-baseline ν physics

Backup

What Are The Specific Detector R&D Objectives of MicroBooNE And How Will They Inform LBNE?

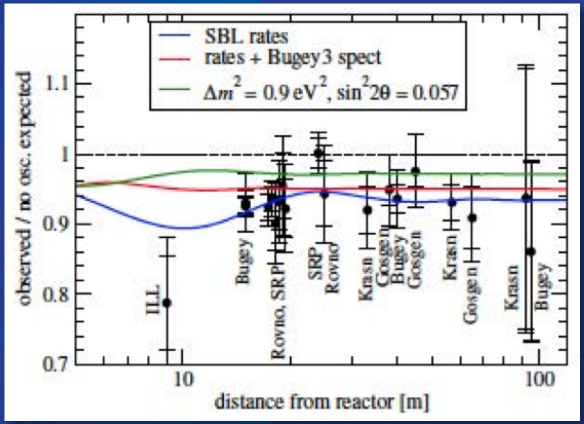
The MicroBooNE detector is not a pure prototype for LBNE. The construction techniques for LBNE will be quite different due to its much larger size. However, the MicroBooNE detector incorporates several major advances over the (larger, 1st generation) ICARUS detector, which are important "proofs of principle" that will be incorporated into next generation large detectors. These are:

- *non-evacuated cryostat*
- *passive insulation of the cryostat and cryogenics*
- *cold (in liquid) electronics*
- *2.5 meter drift*

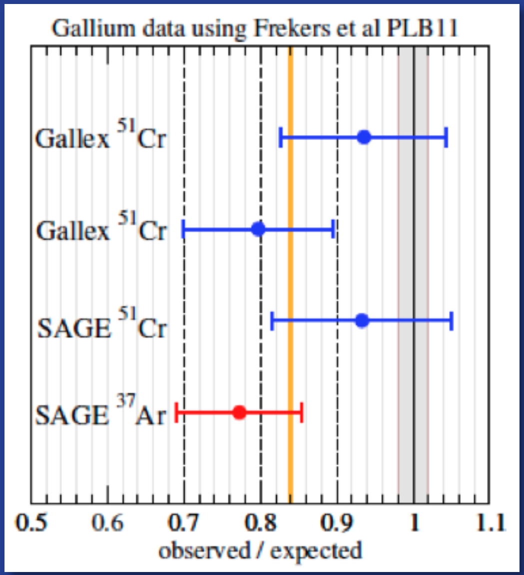
Additionally, MicroBooNE will collect a large data set of neutrino interactions which will be used to fully develop automated event reconstruction. Being located on the surface, the MicroBooNE data set will also measure non-beam backgrounds which are relevant to determining the reach of additional physics which can or cannot be done with a surface detector.

More Than 3 Neutrinos?

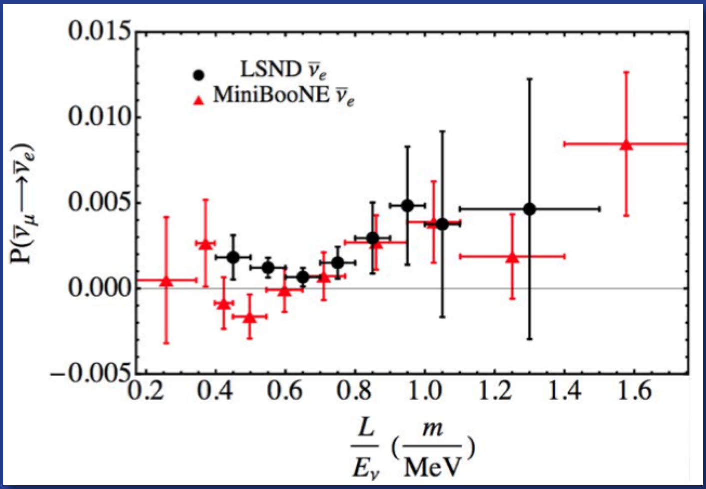
Reactor Anomaly



Gallium Anomaly



LSND & MiniBooNE



what comes next?

Interests in MicroBooNE Physics

MicroBooNE	
Roberto Acciarri (RA)	ν_e Interactions, LArIAT Calibrations in MicroBooNE
Bruce Baller	Charged Pion Production, Detector Backgrounds (Cosmics, Neutrons)
Ben Carls (RA)	Neutrino Cross Sections
Mike Cooke (RA)	ν_e Interactions, PID
Herb Greenlee	ν_μ CC Total Cross Section
Cat James	NuMI Events in MicroBooNE
Mike Kirby	ν_e Interactions
Sarah Lockwitz (RA)	Cosmics, Neutrino Cross Sections
Byron Lundberg	NuMI Events in MicroBooNE
Alberto Marchionni	Neutrino Flux, Backgrounds for Proton Decay and Supernova Burst Neutrinos
Stephen Pordes	ν_μ CC Total cross section, Cosmics
Jen Raaf	Cosmic-Induced Proton Decay Backgrounds, NC π^0 Production
Gina Rameika	NuMI Events in MicroBooNE
Brian Rebel	NuMI Events in MicroBooNE, Cosmics
Steve Wolbers	Neutrino Cross Sections
Tingjun Yang (RA)	Neutrino Oscillations and Nuclear Effects
Sam Zeller	Neutrino Cross Sections

Promoting Collaboration on ν Interaction Physics

- Fermilab scientists on ArgoNeuT, MiniBooNE, MicroBooNE, and MINERνA are co-organizing a variety of workshops on neutrino interactions with our colleagues: (Harris, Morfin, Zeller)

  - *NuInt workshop series*
  - *workshop on neutrino event generators at University of Pittsburgh, June 9-11, 2013*
  - *workshop on neutrino scattering at INT in Seattle, December 3-13, 2013*

- CTEQ, INSS summer schools (Brice, Harris, Morfin)

- Fermilab has been host to a number of theorists *(Manny Paschos, Ulrich Mosel, Jan Sobczyk)*

J. Morfin, J. Nieves, J. Sobczyk , Adv. HEP 2012, 934597 (2012)

Neutrino Cross Section Reviews

From eV to EeV: Neutrino Cross-Sections Across Energy Scales

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(Dated: July 2, 2012)

Since its original postulation by Wolfgang Pauli in 1930, the neutrino has played a prominent role in our understanding of nuclear and particle physics. In the intervening 80 years, scientists have detected and measured neutrinos from a variety of sources, both man-made and natural. Underlying all of these observations, and any inferences we may have made from them, is an understanding of how neutrinos interact with matter. Knowledge of neutrino interaction cross-sections is an important and necessary ingredient in any neutrino measurement. With the advent of new precision experiments, the demands on our understanding of neutrino interactions is becoming even greater. The purpose of this article is to survey our current knowledge of neutrino cross-sections across all known energy scales: from the very lowest energies to the highest that we hope to observe. The article covers a wide range of neutrino interactions including coherent scattering, neutrino capture, inverse beta decay, low energy nuclear interactions, quasi-elastic scattering, resonant pion production, kaon production, deep inelastic scattering and ultra-high energy interactions. Strong emphasis is placed on experimental data whenever such measurements are available.

CONTENTS

I. INTRODUCTION

The investigation into the basic properties of the particle known as the neutrino has been a particularly strong and active area of research within nuclear and particle physics. Research conducted over the latter half of the 20th century has revealed, for example, that neutrinos can no longer be considered as massless particles in the Standard Model, representing perhaps the first significant alteration to the theory. Moving into the 21st century, neutrino research continues to expand in new directions. Researchers further investigate the nature of the neutrino mass or explore whether neutrinos can help explain the matter-antimatter asymmetry of the universe. At the heart of many of these experiments is the need

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J. Formaggio (MIT), S. Zeller (FNAL), Rev. Mod. Phys. 84, 1307 (2012)

H. Gallagher (Tufts), G. Garvey (LANL), S. Zeller (FNAL), Ann. Rev. Nucl. Part. Sci. 61, 355 (2011)

Neutrino-Nucleus Interactions

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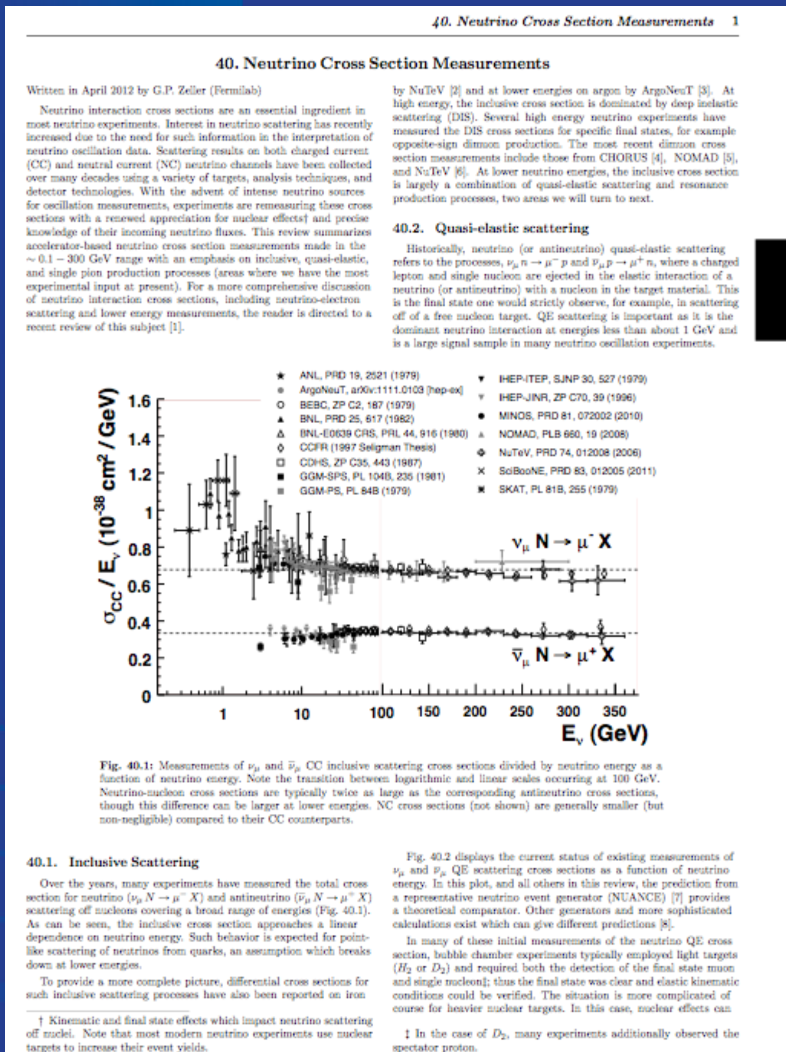
0163-8998/11/1123-0355$20.00

Keywords
neutrino, quasi-elastic

Abstract
The study of neutrino oscillations has necessitated a new generation of neutrino experiments that are exploring neutrino-nuclear scattering processes. We focus in particular on charged-current quasi-elastic scattering, a particularly important channel that has been extensively investigated both in the bubble-chamber era and by current experiments. Recent results have led to theoretical reexamination of this process. We review the standard picture of quasi-elastic scattering as developed in electron scattering, review and discuss experimental results, and discuss additional nuclear effects such as exchange currents and short-range correlations that may play a significant role in neutrino-nucleus scattering.

Particle Data Book



40. Neutrino Cross Section Measurements

Written in April 2012 by G.P. Zeller (Fermilab)

Neutrino interaction cross sections are an essential ingredient in most neutrino experiments. Interest in neutrino scattering has recently increased due to the need for such information in the interpretation of neutrino oscillation data. Scattering results on both charged current (CC) and neutral current (NC) neutrino channels have been collected over many decades using a variety of targets, analysis techniques, and detector technologies. With the advent of intense neutrino sources for oscillation measurements, experiments are remeasuring these cross sections with a renewed appreciation for nuclear effects† and precise knowledge of their incoming neutrino fluxes. This review summarizes accelerator-based neutrino cross section measurements made in the $\sim 0.1 - 300$ GeV range with an emphasis on inclusive, quasi-elastic, and single pion production processes (areas where we have the most experimental input at present). For a more comprehensive discussion of neutrino interaction cross sections, including neutrino-electron scattering and lower energy measurements, the reader is directed to a recent review of this subject [1].

Fig. 40.1: Measurements of ν_μ and $\bar{\nu}_\mu$ CC inclusive scattering cross sections divided by neutrino energy as a function of neutrino energy. Note the transition between logarithmic and linear scales occurring at 100 GeV. Neutrino-nucleon cross sections are typically twice as large as the corresponding antineutrino cross sections, though this difference can be larger at lower energies. NC cross sections (not shown) are generally smaller (but non-negligible) compared to their CC counterparts.

40.1. Inclusive Scattering

Over the years, many experiments have measured the total cross section for neutrino ($\nu_\mu N \rightarrow \mu^- X$) and antineutrino ($\bar{\nu}_\mu N \rightarrow \mu^+ X$) scattering off nucleons covering a broad range of energies (Fig. 40.1). As can be seen, the inclusive cross section approaches a linear dependence on neutrino energy. Such behavior is expected for point-like scattering of neutrinos from quarks, an assumption which breaks down at lower energies.

To provide a more complete picture, differential cross sections for such inclusive scattering processes have also been reported on iron by NuTeV [2] and at lower energies on argon by ArgoNeuT [3]. At high energy, the inclusive cross section is dominated by deep inelastic scattering (DIS). Several high energy neutrino experiments have measured the DIS cross sections for specific final states, for example opposite-sign dimuon production. The most recent dimuon cross section measurements include those from CHORUS [4], NOMAD [5], and NuTeV [6]. At lower neutrino energies, the inclusive cross section is largely a combination of quasi-elastic scattering and resonance production processes, two areas we will turn to next.

40.2. Quasi-elastic scattering

Historically, neutrino (or antineutrino) quasi-elastic scattering refers to the processes, $\nu_\mu n \rightarrow \mu^- p$ and $\bar{\nu}_\mu p \rightarrow \mu^+ n$, where a charged lepton and single nucleon are ejected in the elastic interaction of a neutrino (or antineutrino) with a nucleon in the target material. This is the final state one would strictly observe, for example, in scattering off of a free nucleon target. QE scattering is important as it is the dominant neutrino interaction at energies less than about 1 GeV and is a large signal sample in many neutrino oscillation experiments.

Fig. 40.2 displays the current status of existing measurements of ν_μ and $\bar{\nu}_\mu$ QE scattering cross sections as a function of neutrino energy. In this plot, and all others in this review, the prediction from a representative neutrino event generator (NUANCE) [7] provides a theoretical comparator. Other generators and more sophisticated calculations exist which can give different predictions [8].

In many of these initial measurements of the neutrino QE cross section, bubble chamber experiments typically employed light targets (H_2 or D_2) and required both the detection of the final state muon and single nucleon‡; thus the final state was clear and elastic kinematic conditions could be verified. The situation is more complicated of course for heavier nuclear targets. In this case, nuclear effects can

† Kinematic and final state effects which impact neutrino scattering off nuclei. Note that most modern neutrino experiments use nuclear targets to increase their event yields.

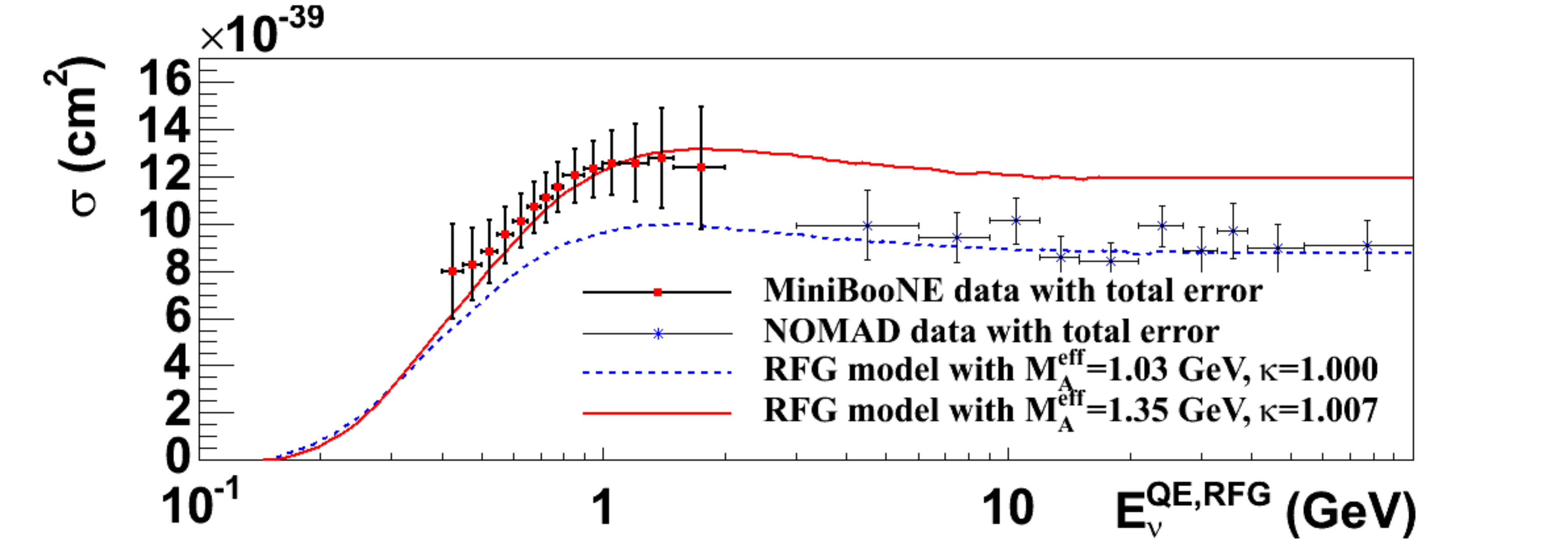
‡ In the case of D_2, many experiments additionally observed the spectator proton.

Review of Particle Properties (2012)

- review of neutrino cross section measurements is a new permanent fixture in the PDG, another update planned in Fall

- Fermilab scientists largely responsible for this development
  - PDG advisory group (Harris)
  - author of review (Zeller)

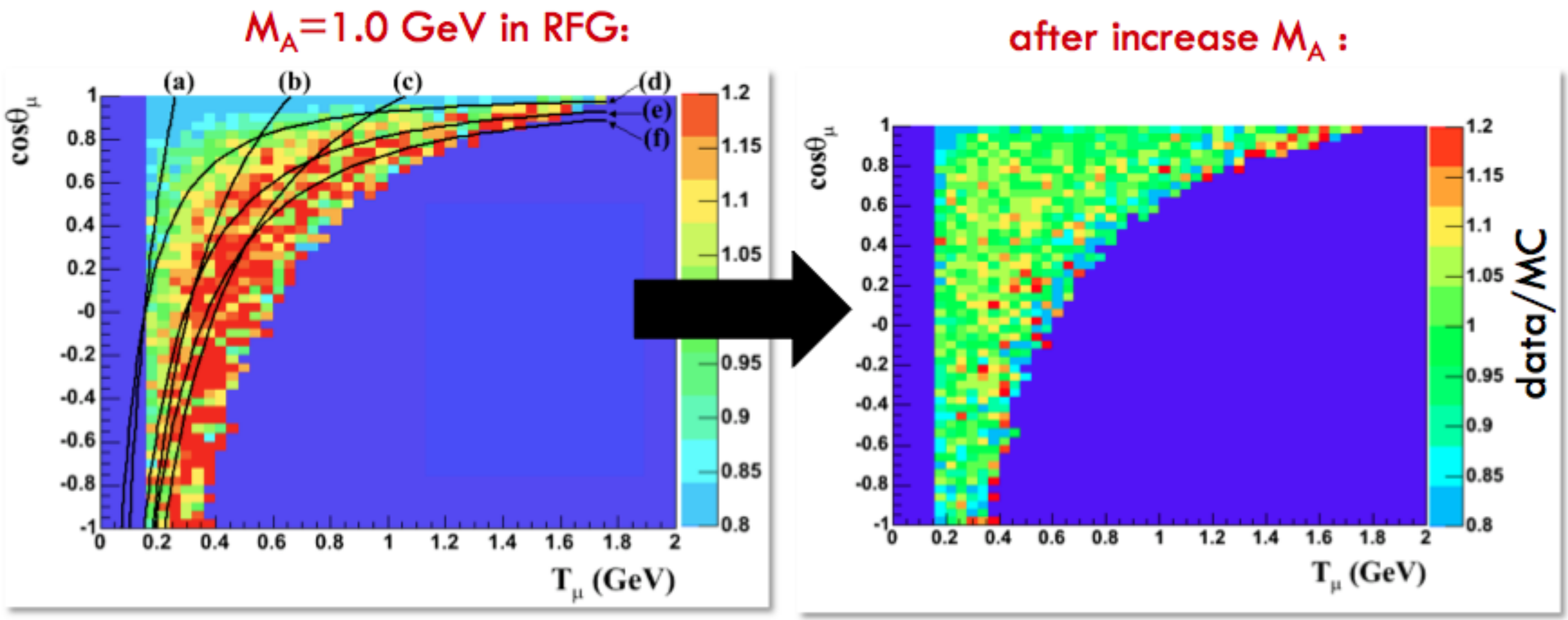
MiniBooNE and NOMAD Results



Phys. Rev. D81, 092005 (2010)

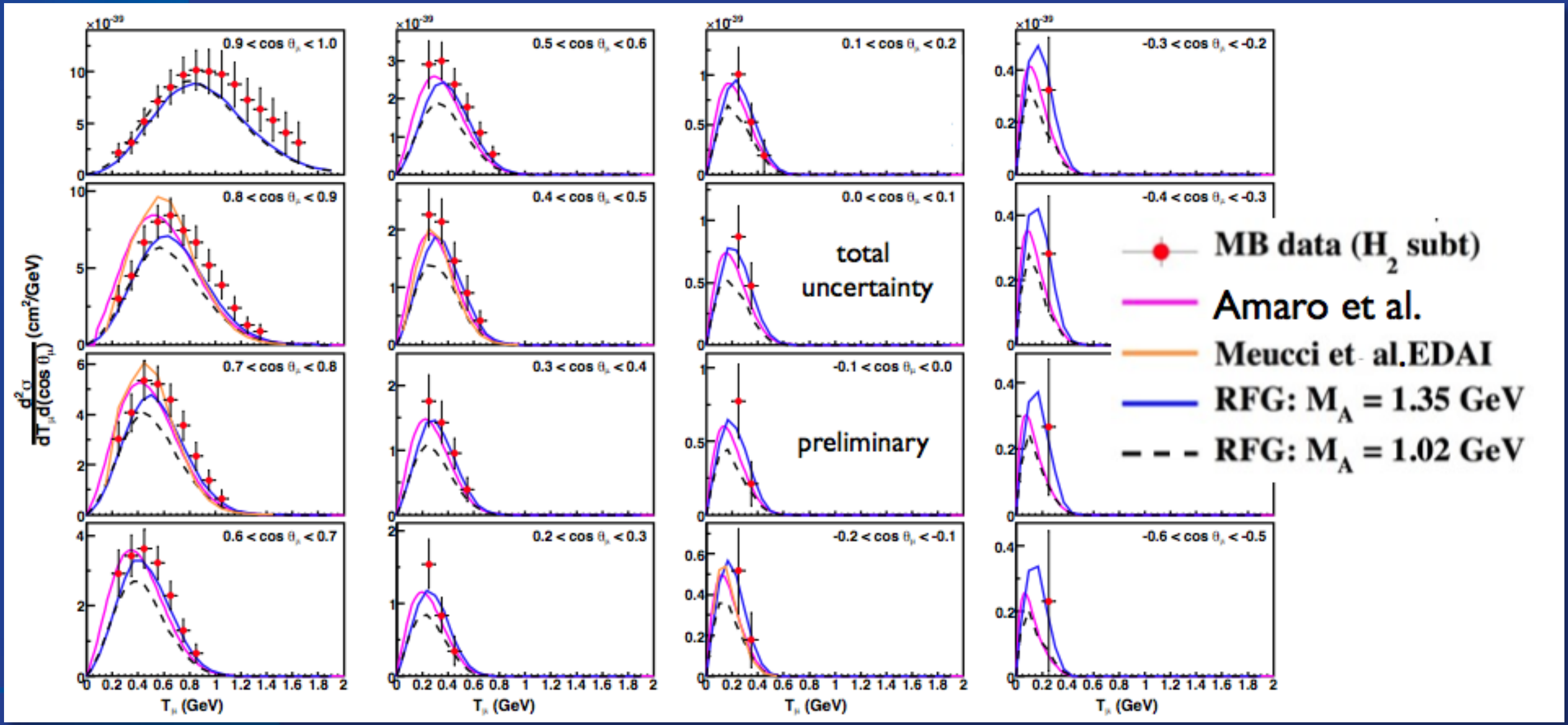
MiniBooNE Neutrino Double Differential Data

- data/MC disagreement in MiniBooNE ν_μ QE sample follows lines of constant Q^2 not E_ν … cross section not a flux problem



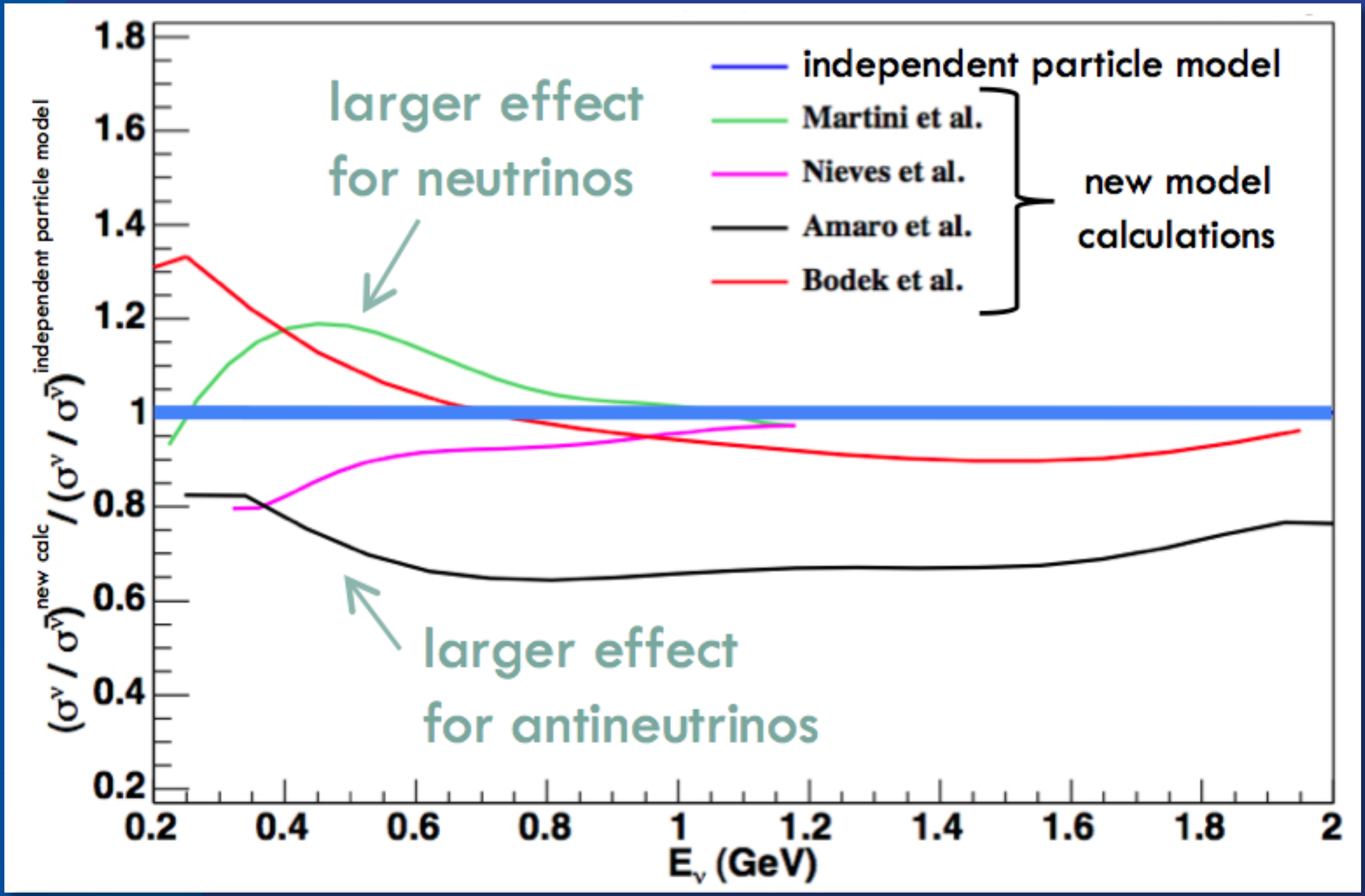
(both relatively normalized)

MiniBooNE Antineutrino Double Differential Data



(J. Grange)

Antineutrino/Neutrino Predictions



(J. Grange, S. Zeller)