Neutrino interactions in the NOvA detectors

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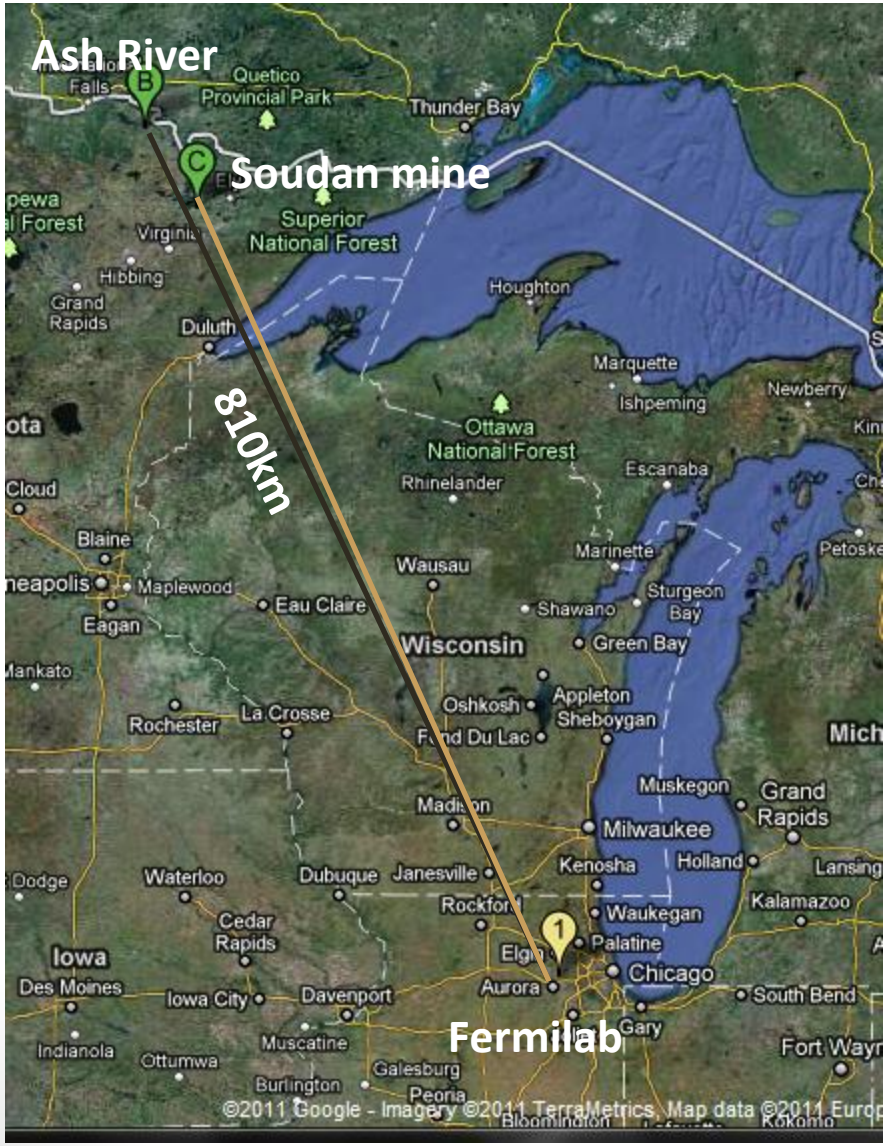
University of Minnesota
For NOvA Collaboration

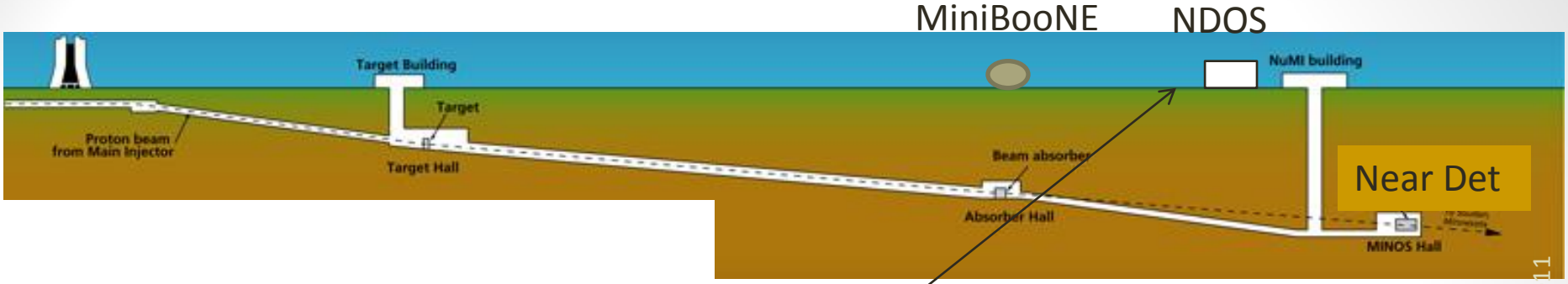
Meeting of the Division of Particles and Fields of the American Physical Society

NuMI Off-axis ν_e Appearance Experiment

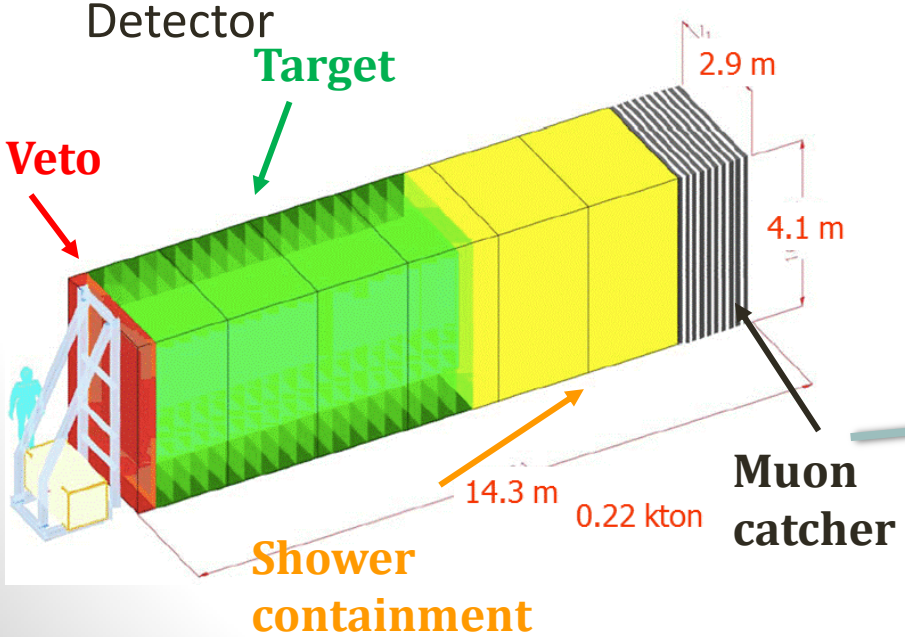


- Search for ν_e appearance in ν_μ beam:
  - θ_{13}
  - **Mass hierarchy**
  - **Constrain CP violation phase**
  - Θ_{23}, Δm^2_{32}
- Project
  - 810 km long baseline.
  - Two detectors 14 mrad off the beam axis.
  - Near detector at fermilab 1 km from target.
  - Far detector in Ash River, MN.
  - NuMI beam upgraded to 700kW.

NOνA Near Detector Prototype (NDOS)

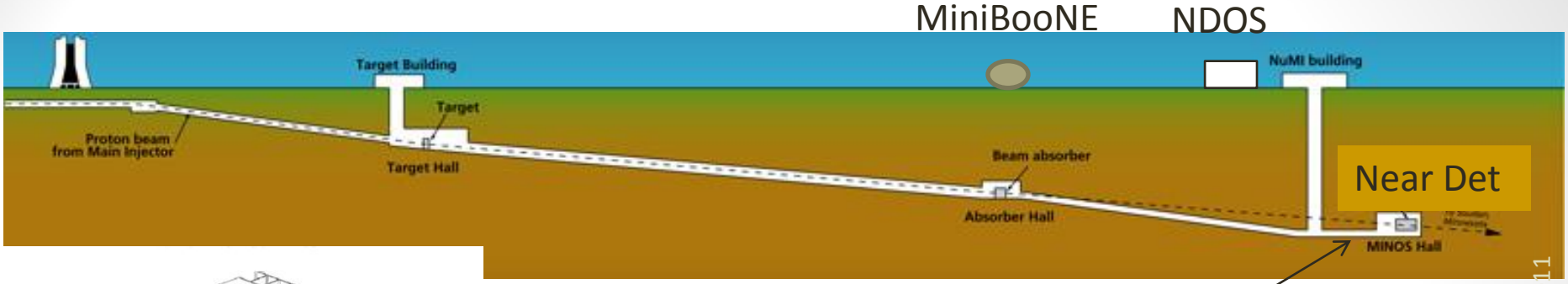


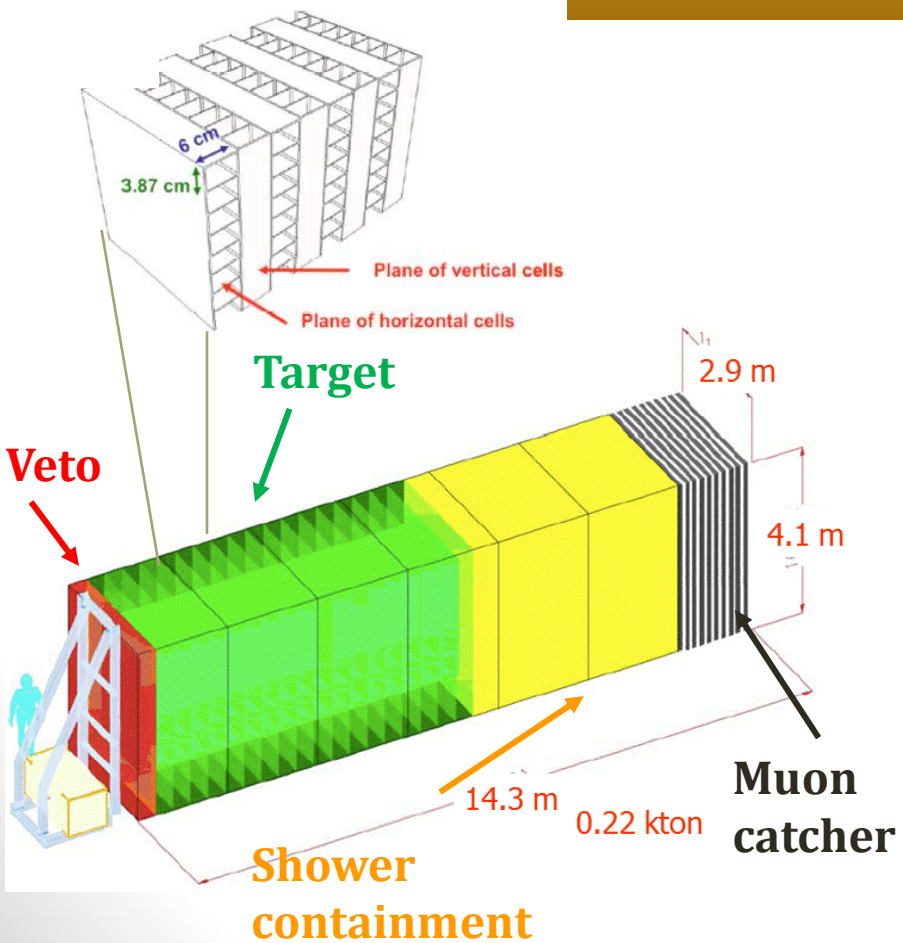
- Prototype **N**ear **D**etector **o**n **S**urface (NDOS) –
- Taking data since November 2010
- Prototype of the future Near Detector



See S. Lein talk on Friday

NOνA Near Detector

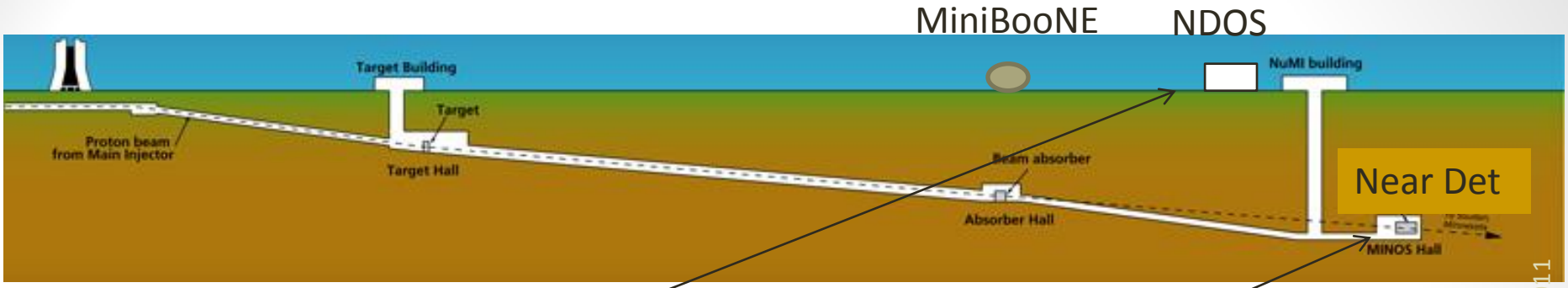




Near Detector

- 196 Planes (3m x 4m)
  + 10 Steel Planes ("Muon Catcher")
- 220 Ton
- 16000 cells
- Cosmic Ray Muon Rate:
  - ~50 Hz (105 m overburden)
- In-Spill Rate:
  - 10 μs duration every 1.33 s
  - **30 neutrino events/spill**

NOνA Near Detector Prototype (NDOS)



Prototype (NDOS)

- 196 Planes (3m x 4m)
  + 10 Steel Planes ("Muon Catcher")
- 220 Ton
- 16000 cells
- Cosmic Ray Muon Rate:
  - ~ 4 kHz (on surface)
- In-Spill Rate:
  - 10 μs duration every 2.2 s
  - 16 neutrino events/day (NuMI + BNB)
  - Partially instrumented

Near Detector

- 196 Planes (3m x 4m)
  + 10 Steel Planes ("Muon Catcher")
- 220 Ton
- 16000 cells
- Cosmic Ray Muon Rate:
  - ~50 Hz (105 m overburden)
- In-Spill Rate:
  - 10 μs duration every 1.33 s
  - **30 neutrino events/spill**

Prototype detector

Main goals are:

- Test detector design and prepare for far detector production.
- Develop DAQ system on custom design hardware
- Tune calibration procedures.
- Show electron neutrino selection and $e\backslash\pi^0$ separation.
- Verify cosmic background suppression.

Prototype detector

- NDOS collects data from NuMI and BNB beams

NuMI off-axis 110 mrad

- $<E_\nu> \sim 2$ GeV
- L ~ 850 m
- L/E~0.43 km/GeV

Booster (BNB) on axis but rotated wrt to the beam

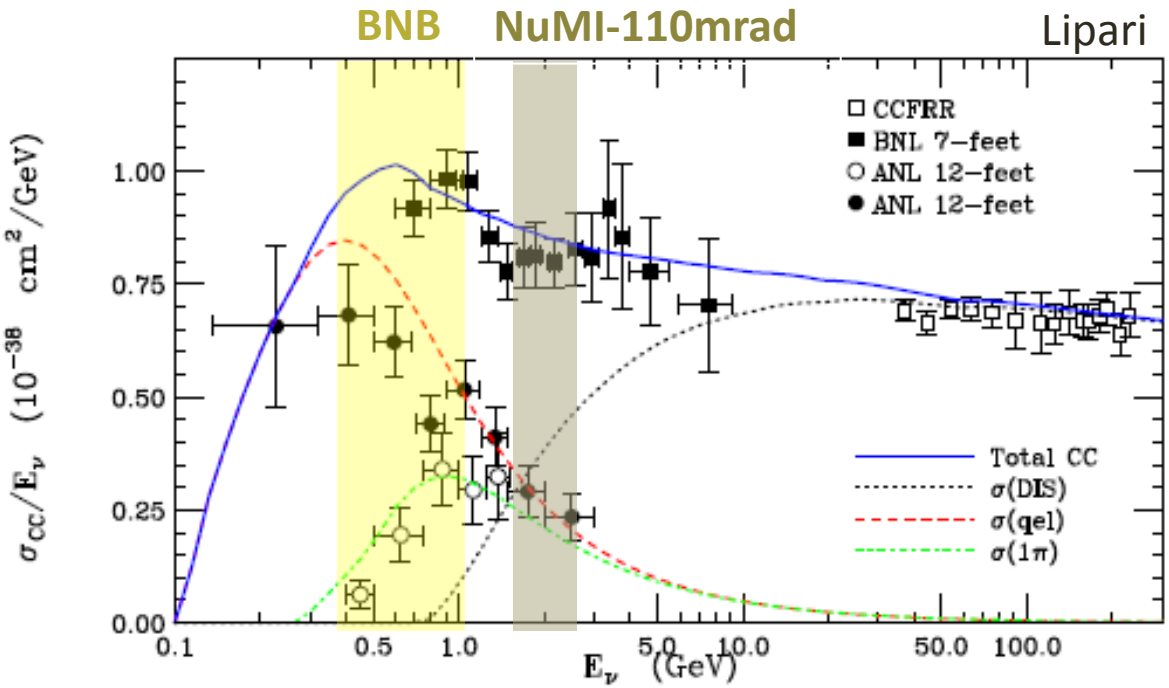
- $<E_\nu> \sim 0.8$ GeV
- L ~ 650 m
- L/E~0.8 km/GeV

- Quasi-elastic cross section at 1 and 2 GeV.
- Study nuclear hadronization models and multinucleon production.

	PoT	NuMI	Cosmic Bg
Neutrino	5.6e18	253	39
Antineutrino	8.4e19	1001	69

	PoT	BNB	Cosmic Bg
Antineutrino	3e19	222	92

Neutrino Cross section data



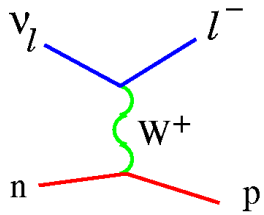
- Complicated situation in the few-GeV neutrino energy range
- Recent high statistic results from BooNEs, K2K, NOMAD and MINOS reported new features in the neutrino interaction which should be independently confirm.
- Soon new results from T2K, Minerva
- **NDOS can look at rates from both BNB and NuMI beams (different backgrounds and systematics).**

NOvA x-section measurements

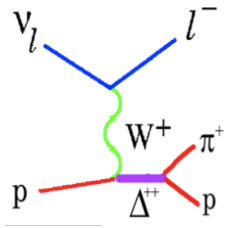
- Possible channels to be measured in the NOvA detectors

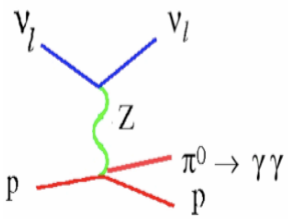
NDOS

- CCQE
  - (ν_μ + n -> μ + p)

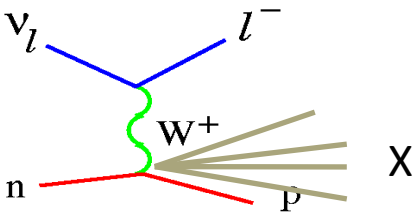


- CC 1pi
  - ν_μ + n -> μ + p + π^0
  - ν_μ + n -> μ + n + π^+
  - ν_μ + p -> μ + p + π^+ (largest channel)



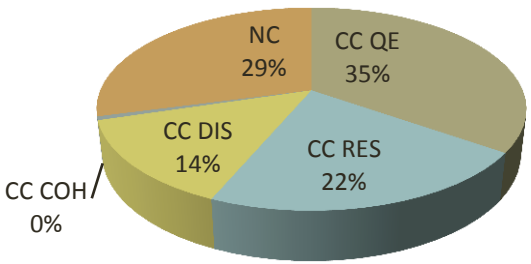


- Deep Inelastic scattering
  - ν_μ + N -> μ + X

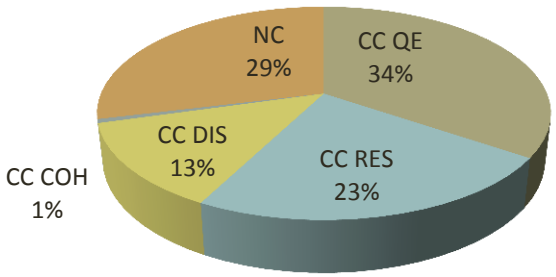


Neutrino interaction in the NDOS

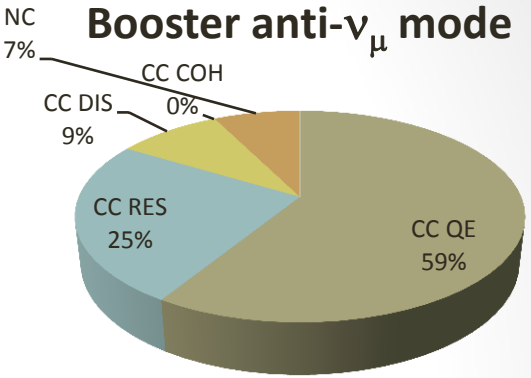
NuMI anti-ν_μ mode

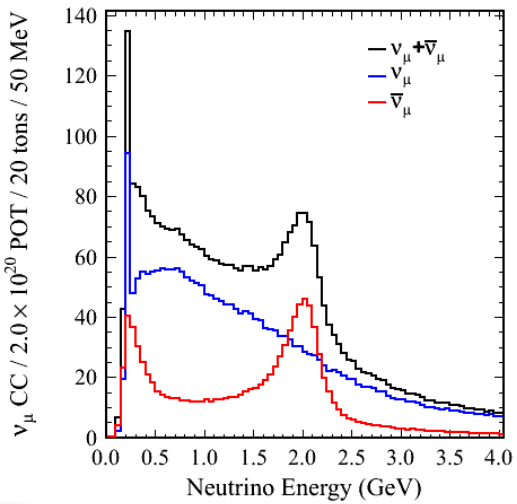


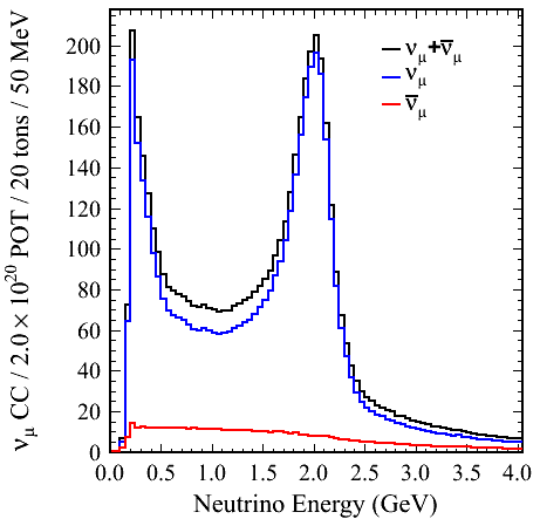
NuMI ν_μ mode

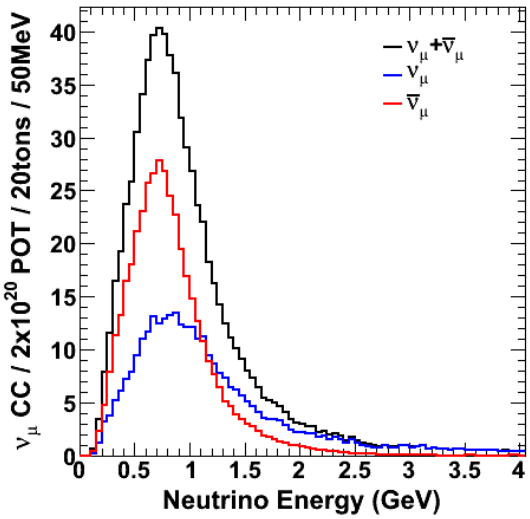


Booster anti-ν_μ mode



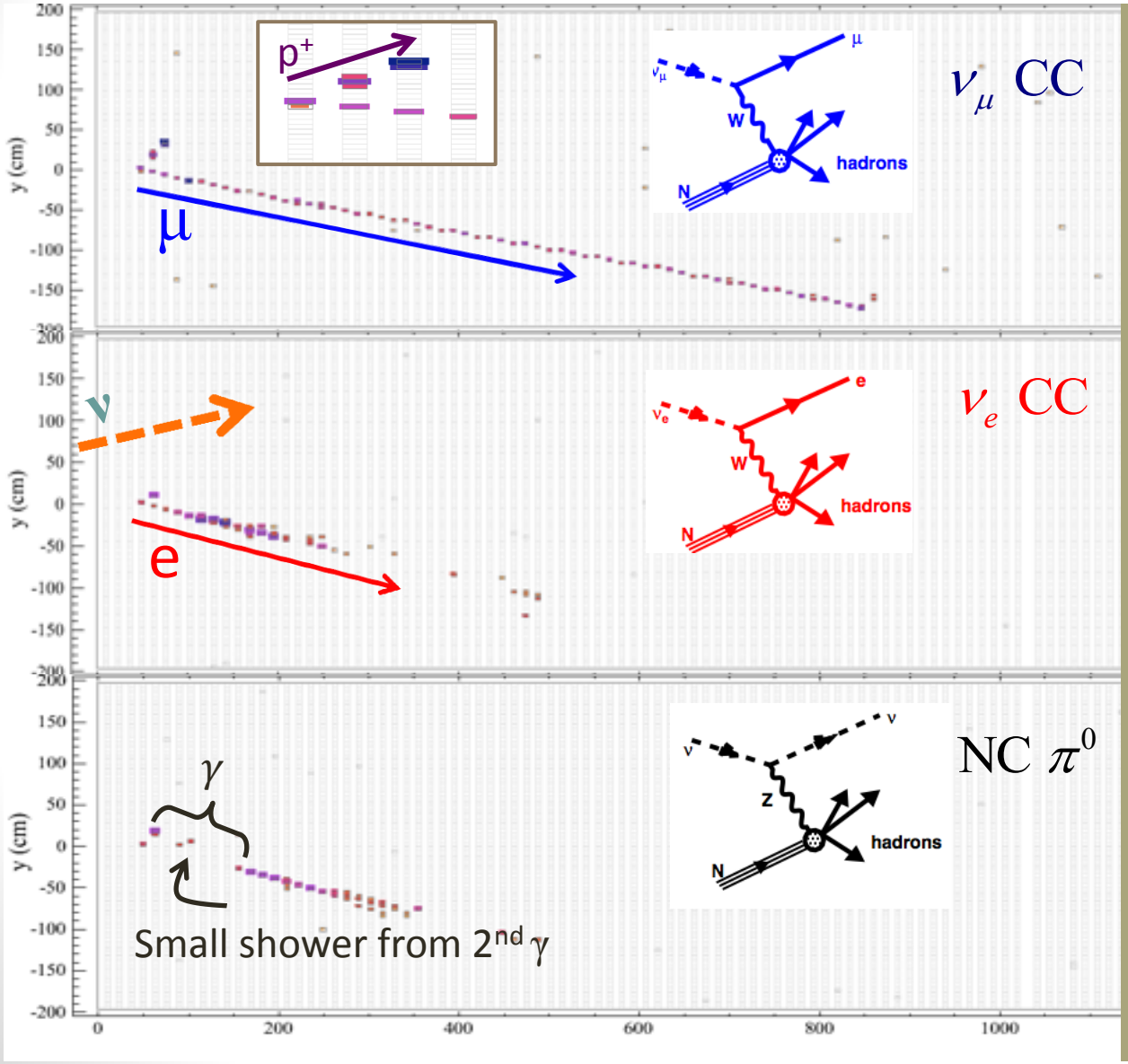






Monte Carlo Events in NDOS

MC



V_μ Charged-current

Long well-defined muon track, proton is a short track with large energy deposition at the track end.

V_e Charged –current

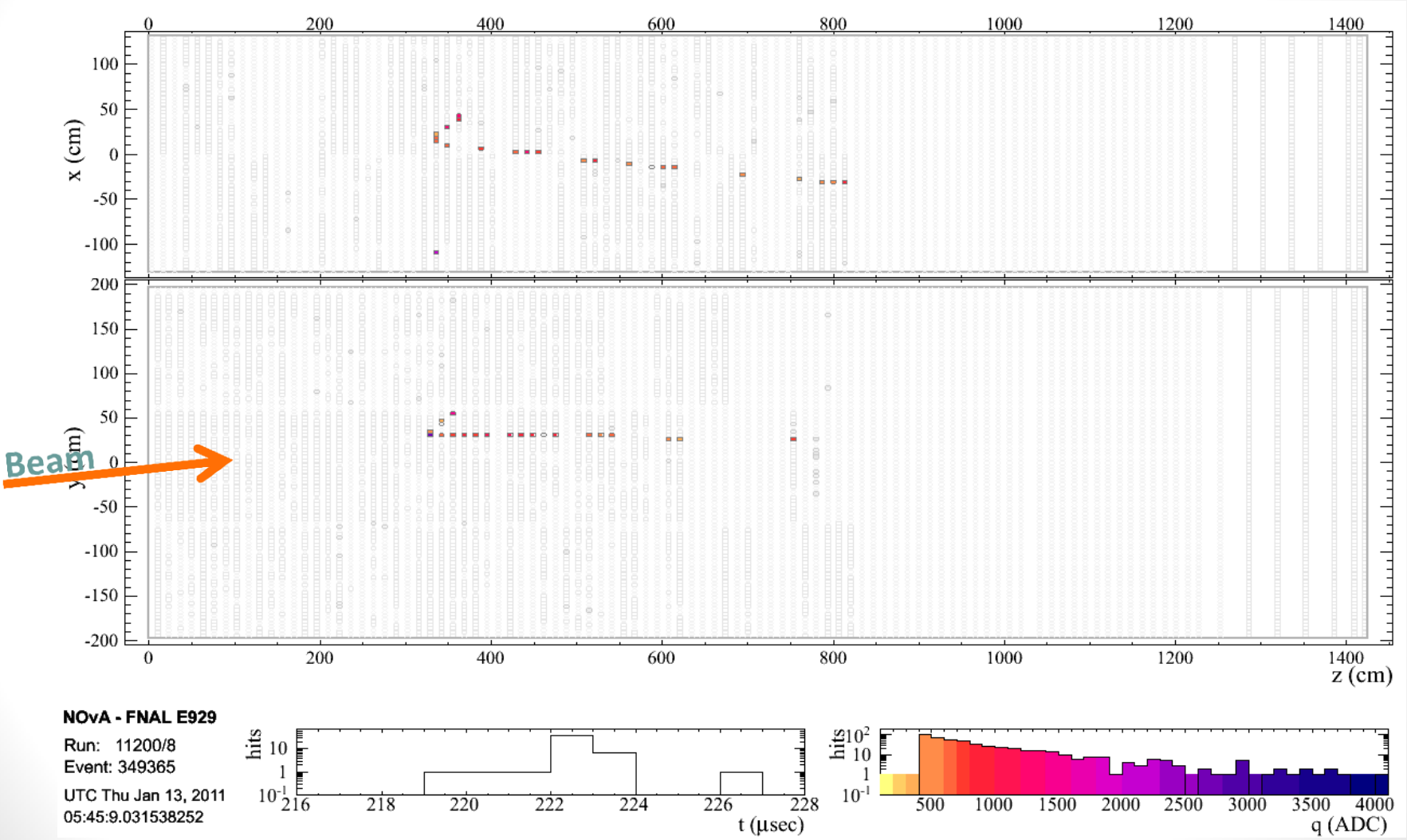
Single shower with characteristic e-m shower development.

NC with π^0 in final state

Possible gaps near event vertex, multiple displaced e-m showers.

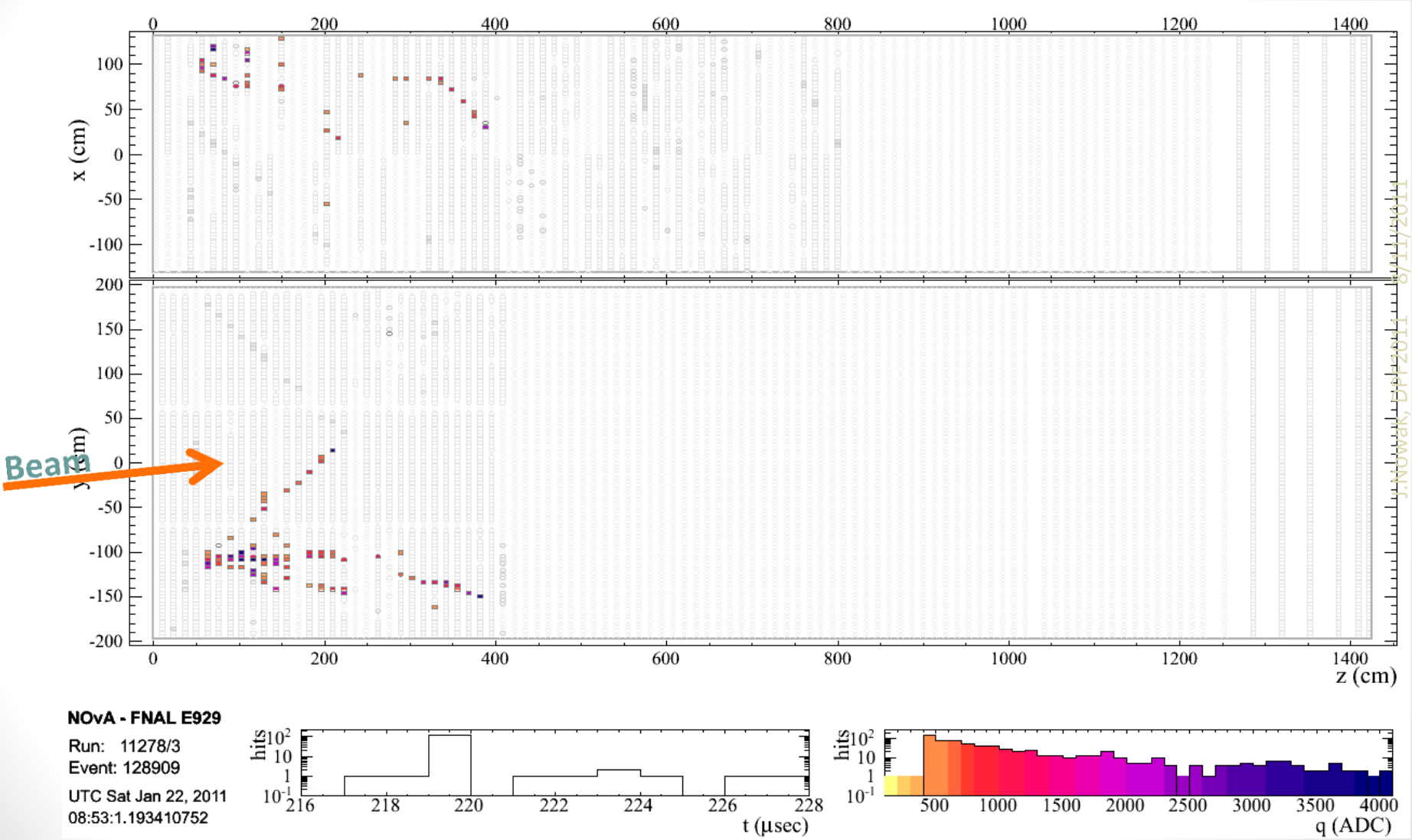
Neutrinos

DATA

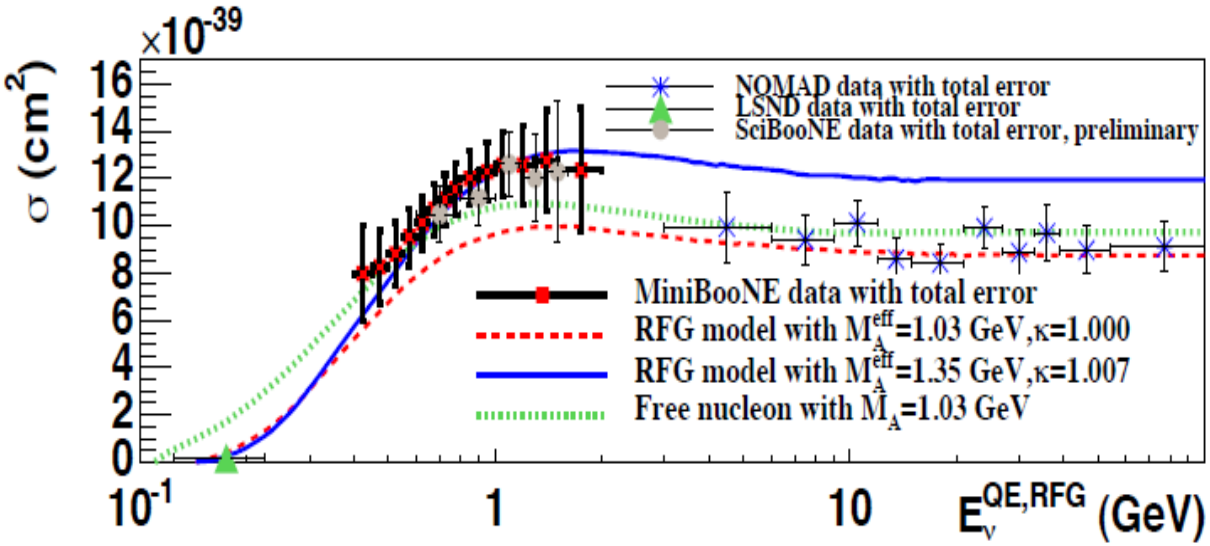


Neutrinos

DATA



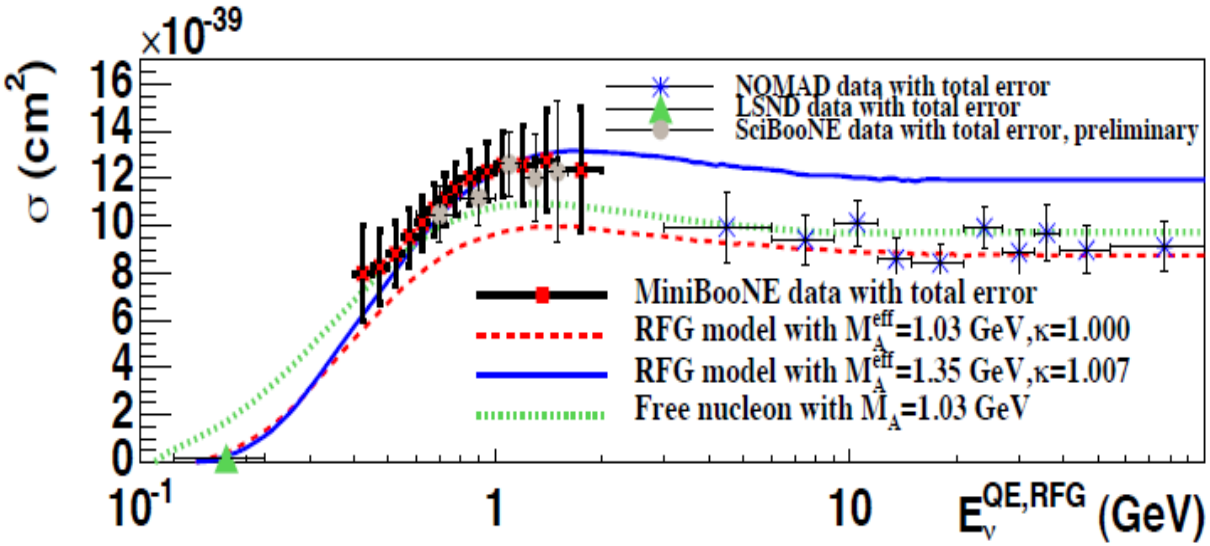
Quasielastic scattering



- Unable to describe results for NOMAD and MiniBooNE with the same prediction
- Possible explanation is neutrino scattering on correlated nucleons.
- No simple way to distinguish final state interactions (FSI) from multi nucleon interactions.

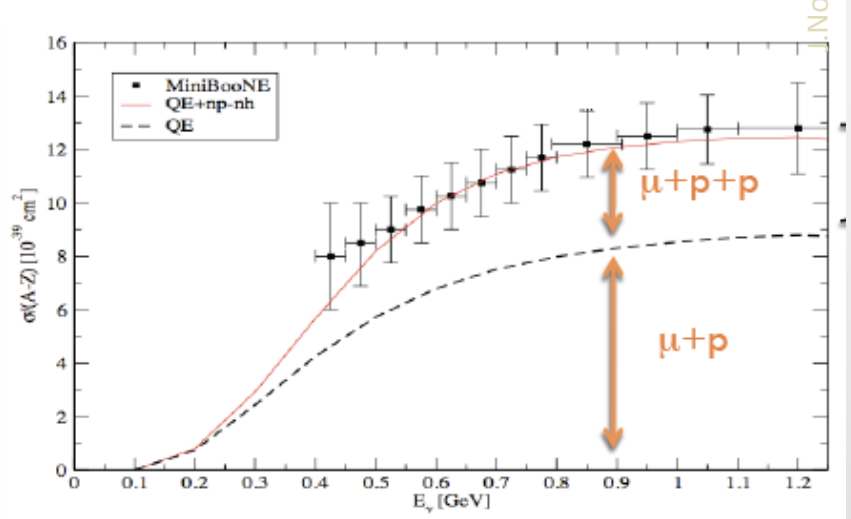
Main CCQE analysis see M. Betancourt talk

Quasielastic scattering



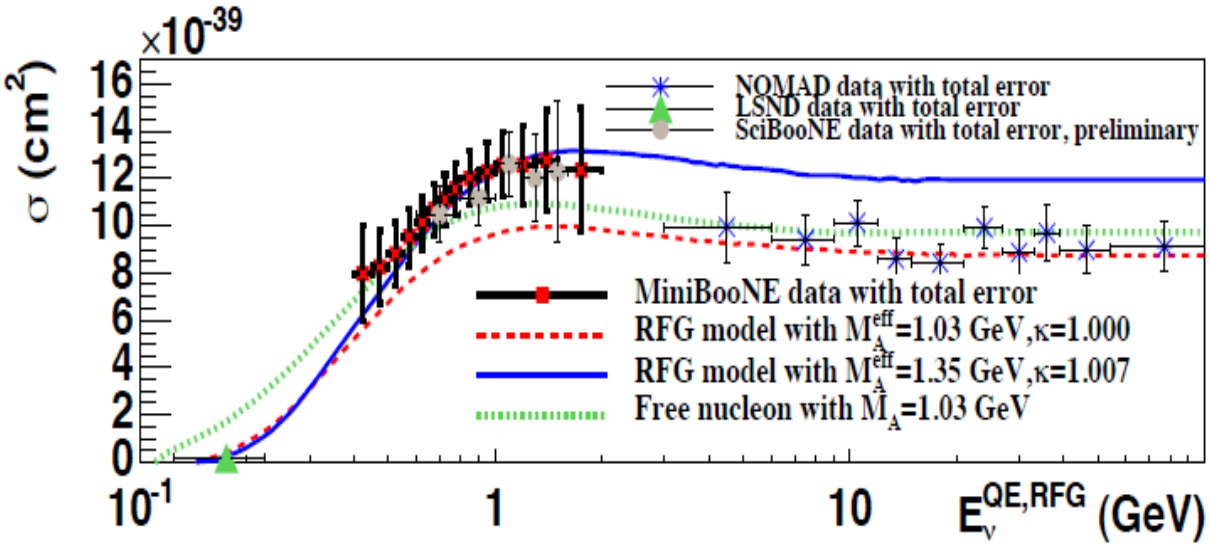
Different definitions of the CCQE interactions

- **MiniBooNE: μ+p and μ+p+p**
- **NOMAD: μ+p**



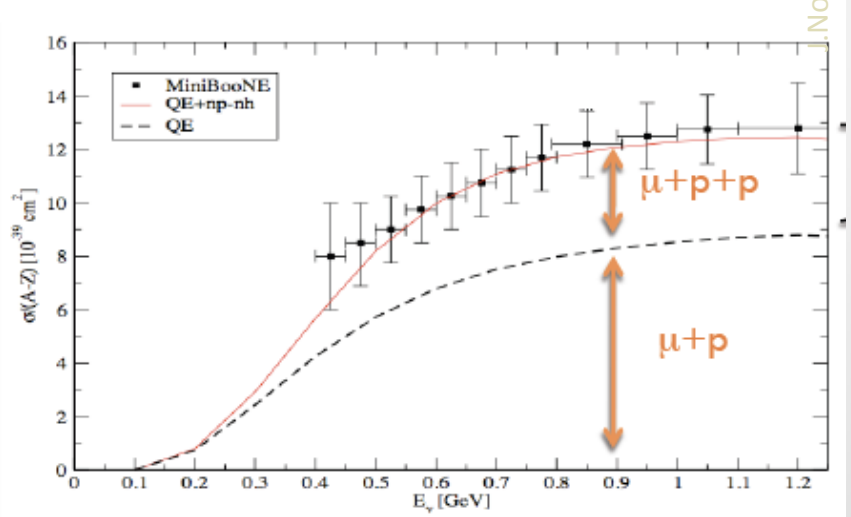
Martini *et al.*, PRC **80**, 065001 (2009)

Quasielastic scattering



Different definitions of the CCQE interactions

- **MiniBooNE: μ+~~π~~ and μ+~~π~~+~~π~~**
- **NOMAD: μ+p**



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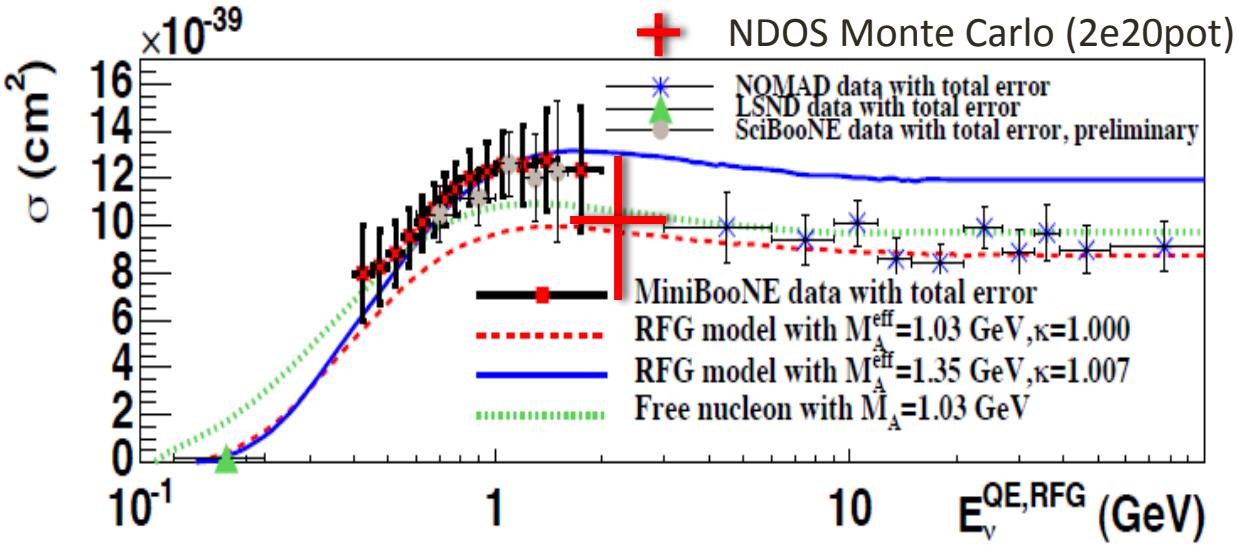
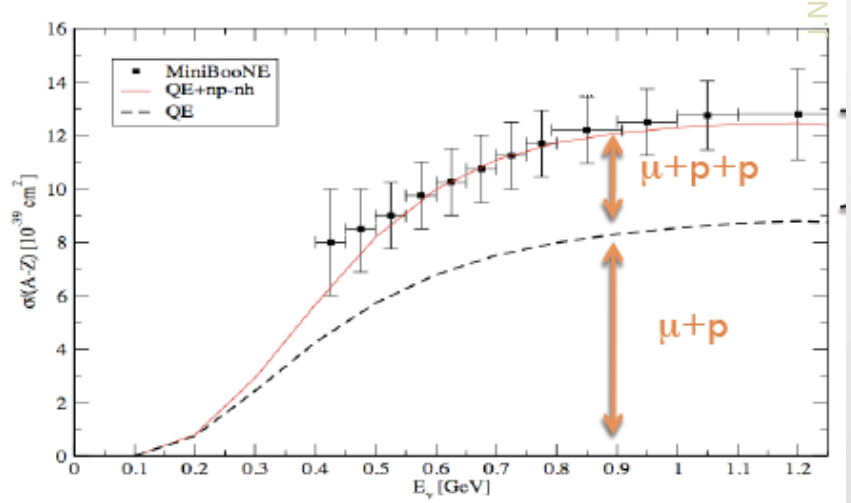
Quasielastic scattering



NDOS prediction.
Statistically limited
ND will be systematically limited.
NovA will be able to measure protons in final state.

Different definitions of the CCQE interactions

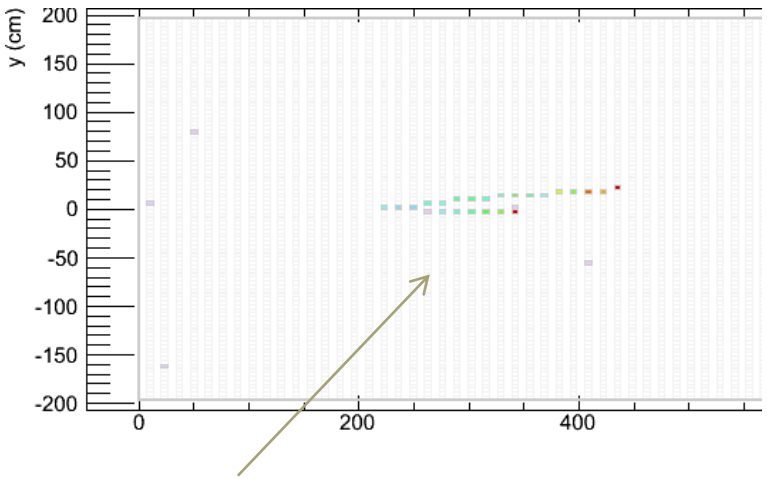
- **MiniBooNE: μ+~~π~~ and μ+~~π~~+~~π~~**
- **NOMAD: μ+p**
- **NOvA: μ+p and μ+p+p**

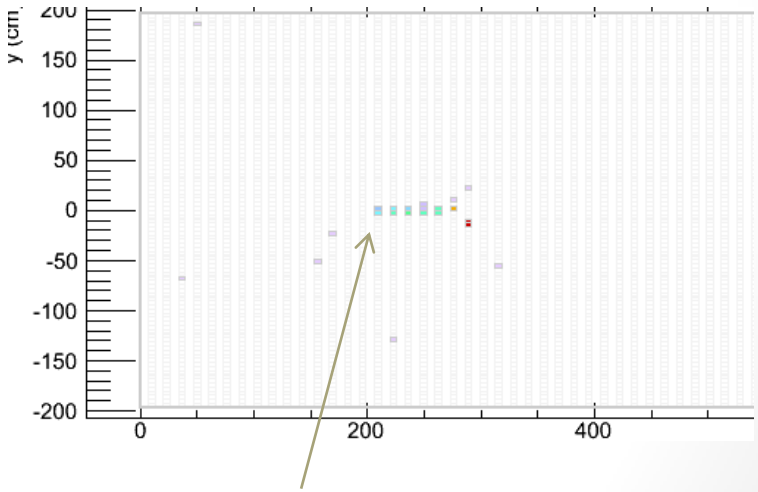


Martini *et al.*, PRC **80**, 065001 (2009)

Two proton events

- Example of event displays for two 1GeV/c protons
- For many such events tracks are easily separable
- Events with small opening angle will require additional separation method (dE/dx, Bragg peak, etc…).





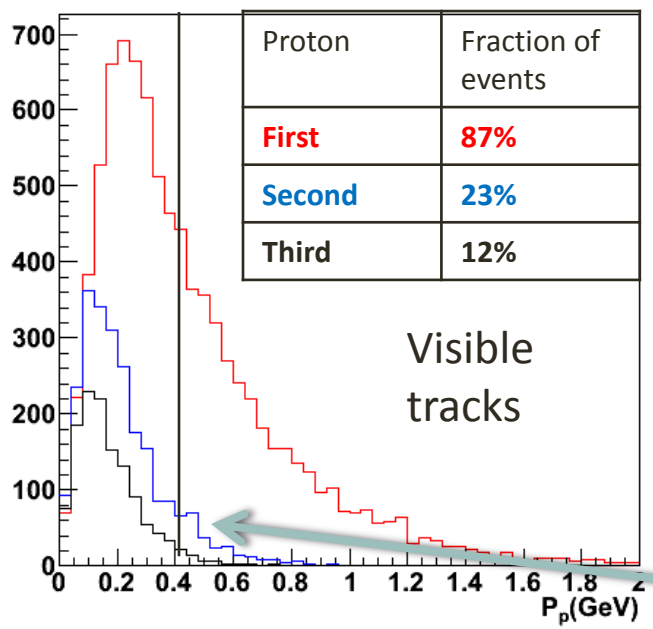
- Two clear tracks

small opening angle

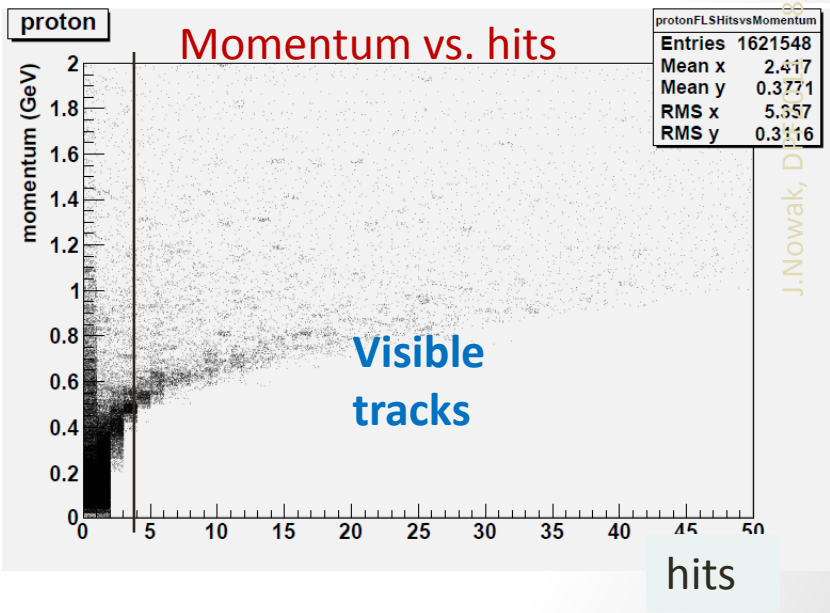
Momentum of the leading protons

- **Background for scattering on correlated nucleon pairs.**
- Our Monte Carlo doesn't include any interaction beyond the impulse approximation (scattering on separate nucleons inside the nucleus)
- Multinucleons final states are produced due to rescattering inside nucleus
- Momenta of the 1st , 2nd and 3rd protons from FSI after QE interactions

ONLY FSI



Proton	Fraction of events
First	87%
Second	23%
Third	12%

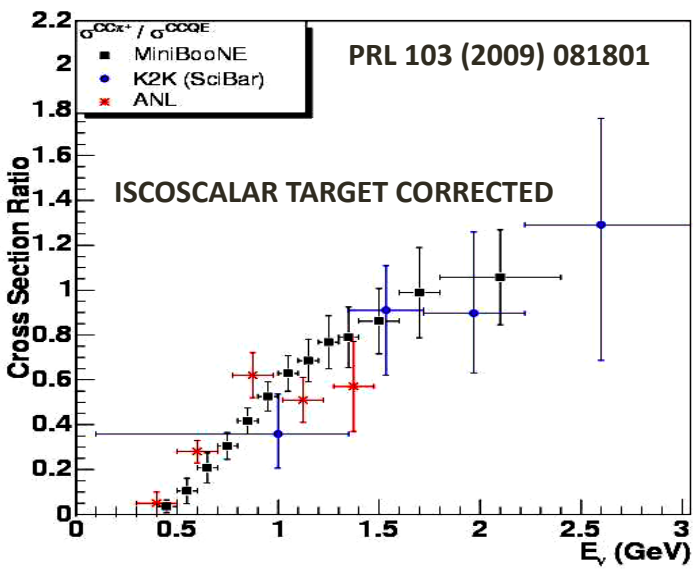


In case of scattering on correlated pairs there should be ~30% excess of second highest momentum protons

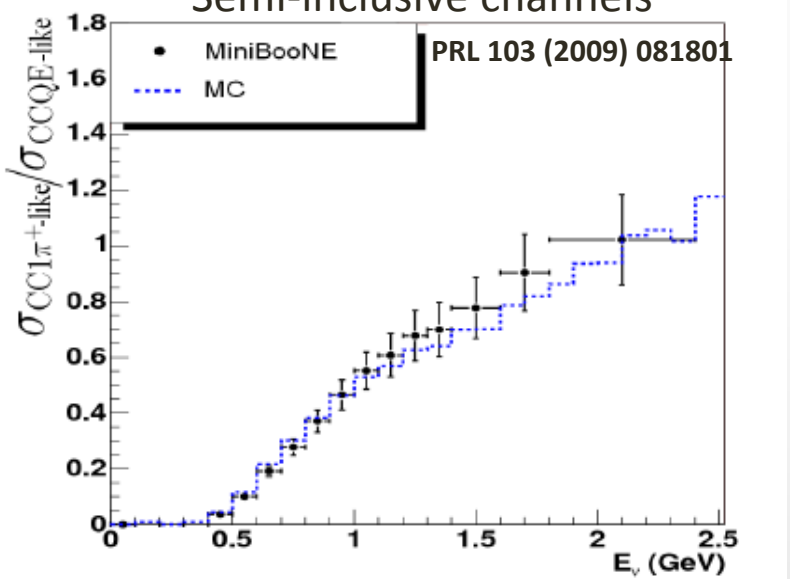
J.Nowak, D 8/11/2011

CC π^+/CCQE ratio

- In recent high statistics results discrepancy between data and MC were seen for various interaction channels.
- However, there is a good agreement for cross section ratio CCπ^+/CCQE
- In the cross section ratio most of the flux uncertainties cancel out.
- The most precise measurement from MiniBooNE – direct measurement of 'semi-inclusive' CCQE and CCπ^+ channels.

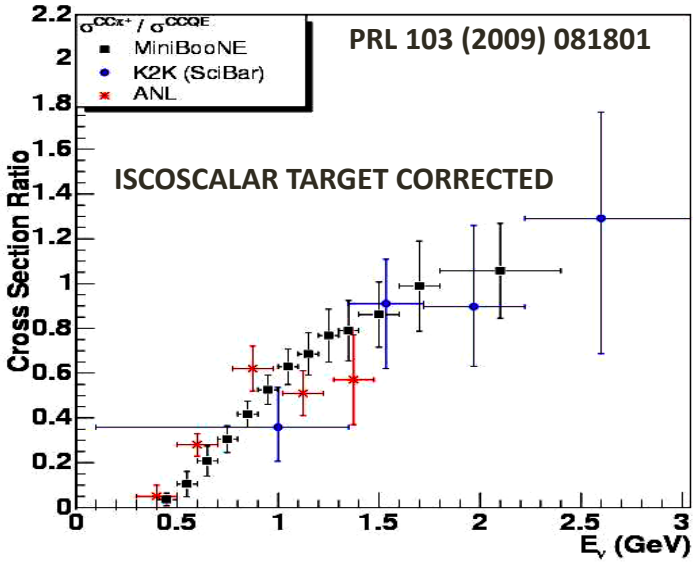


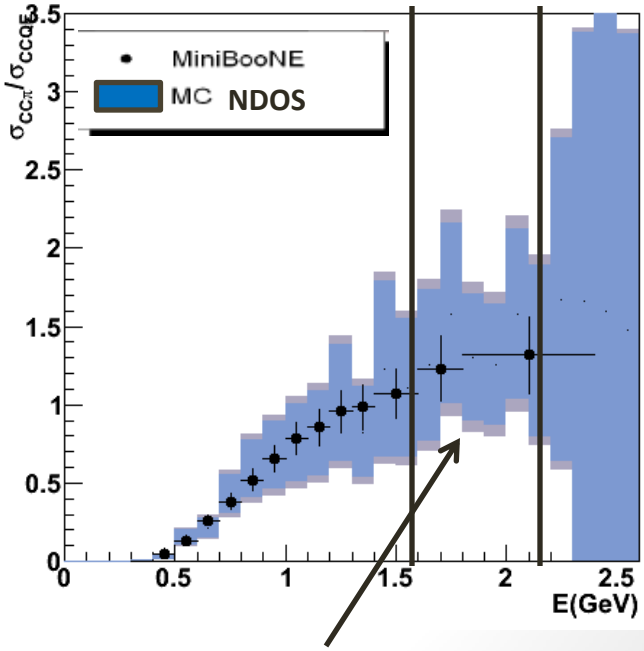
Semi-inclusive channels



CC π^+/CCQE ratio

- NOvA will be able to measure directly the inclusive channels.
- Measure interactions from NuMI neutrino beam.
- For antineutrino similar ratio may be measure and compare two beams using the same detector.





Most of NDOS events

Summary

- The near detector prototype was extremely useful in testing future production and installation procedures of near and far detectors.

- Near detector will be able to precisely measure cross sections for neutrino scattering on Carbon.
- Near detector on the surface is taking neutrino data now (statistically limited)

- We take data from NuMI and BNB
  - Charged current quasielastic cross section
  - Excess of high momentum protons from scattering on correlated nucleon pairs