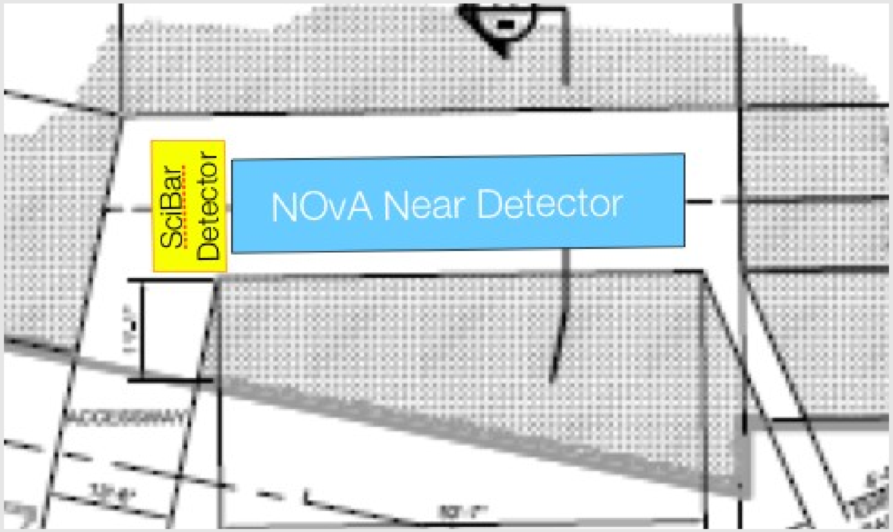
SciNOvA: A Measurement of Neutrino-Nucleus Scattering in a Narrow-Band Beam

D. Harris, R. Tesarek
FNAL
G. Feldman
Harvard
C. Bower, L. Corwin, M.D. Messier, N. Mayer, J. Musser, J. Paley, R. Tayloe, J. Urheim
Indiana U.
M. Sanchez
Iowa State U.
K. Heller
U. of Minnesota
S. Mishra, X. Tian
U. of South Carolina
H. Meyer
Wichita State U.
P. Vahle
William and Mary

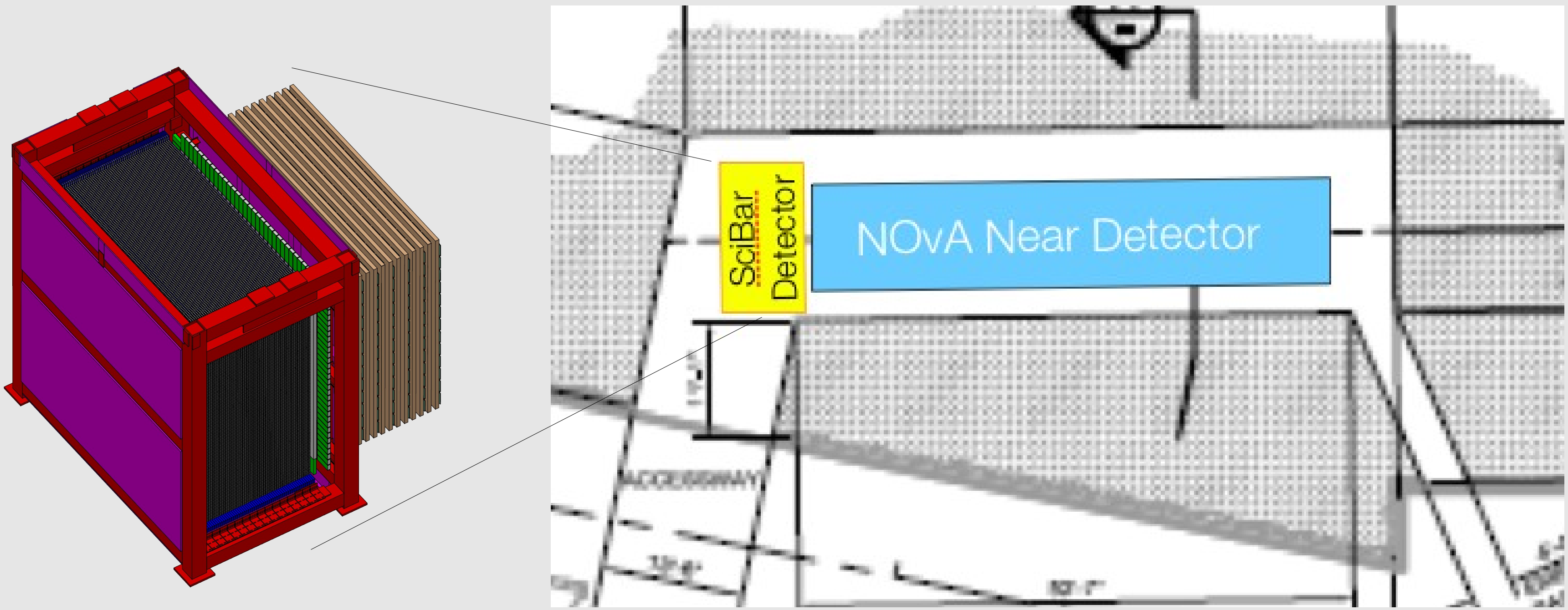
Outline of talk:
- overview
- science case:
  - ν scattering physics
  - NOvA enhancements
- project plan
- conclusions/requests



R. Tayloe,
FNAL PAC Meeting
11/09

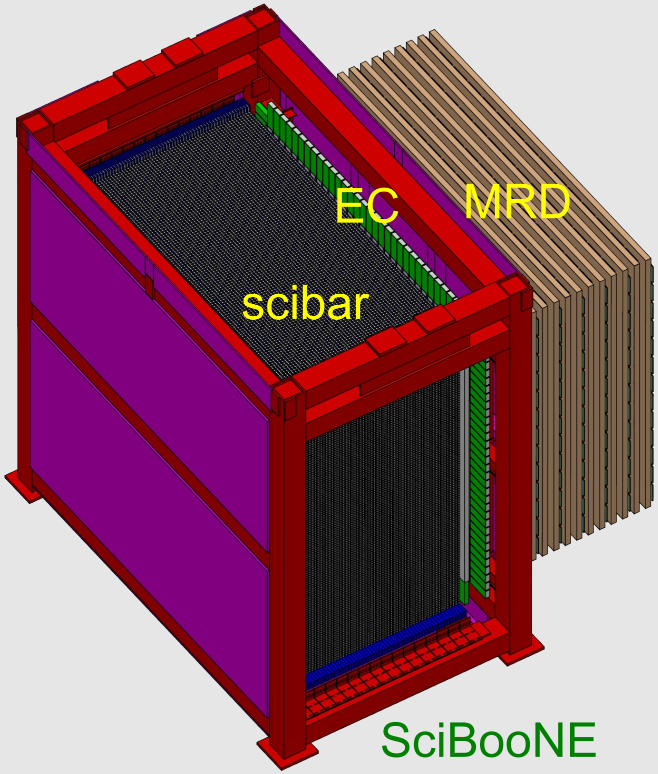
SciNOvA: Overview

We propose to reinstrument the existing SciBar detector and deploy in front of the NOvA near detector in the NuMI (off-axis) 2 GeV narrow-band beam. A fine-grained detector such as SciBar in this location enables important and unique ν scattering measurements and enhances the NOvA ν oscillation measurements.



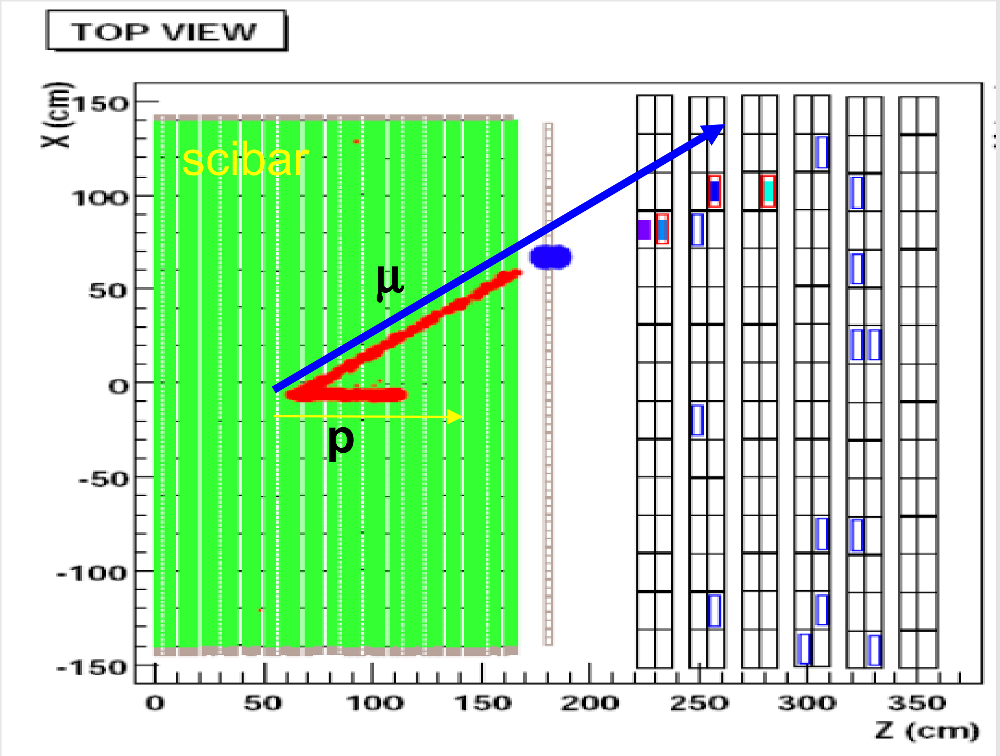
SciNOvA: overview

The SciBar detector:



- Consists of ~15k extruded $1.3 \times 2.5 \times 290 cm^3$ scintillator strips arranged in 64 (x+y) layers,
- originally built for the K2K experiment,
- then moved to FNAL for SciBooNE
- ran in booster $\nu / \bar{\nu}$ beam 6/07-8/08

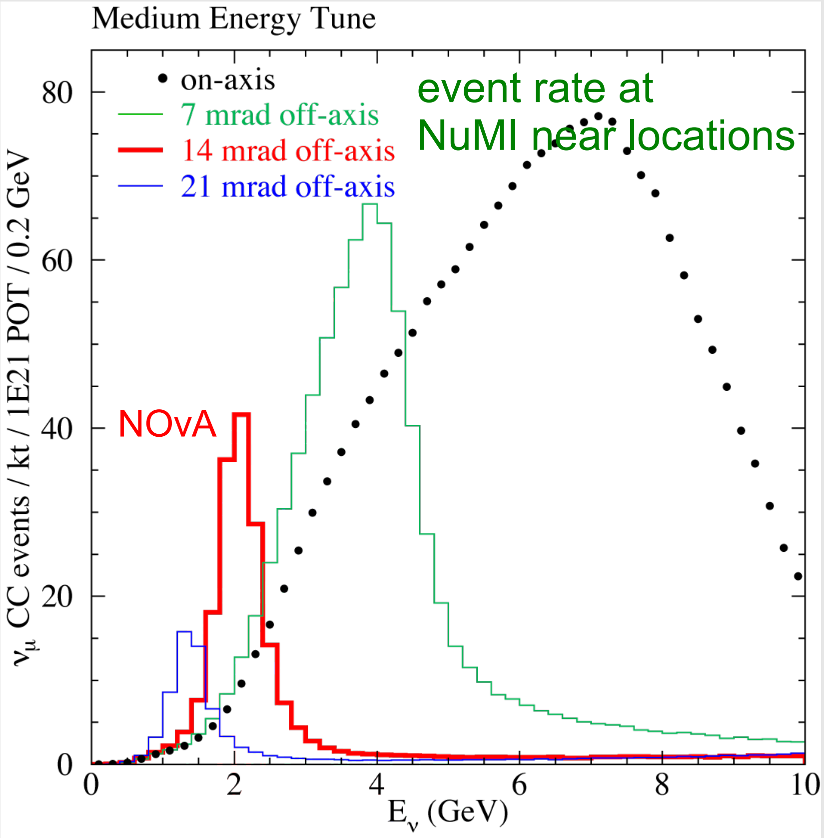
SciBooNE event display



- analyses published:
  - $CC\pi^+$, Phys. Rev. D 78, 112004 (2008),
  - $NC\pi^0$, arXiv:0910.5768[hep-ex], sub'd to PRD.
- analyses in progress:
  - CCQE, NCel, $CC\pi^0$, ν_μ disappearance, ν_e events
- PMTs and readout electronics removed and sent back to KEK, SciBar scintillators and fibers remain at FNAL (in SciBooNE enclosure).

SciNOvA: overview

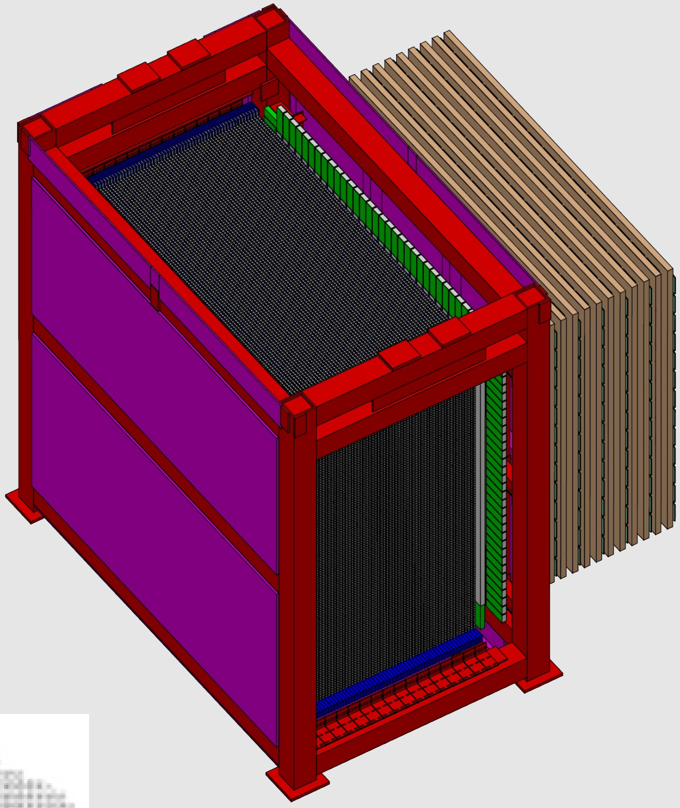
The SciBar detector at NOvA near location:
- narrow-band beam, substantial flux
- leading to large event rates



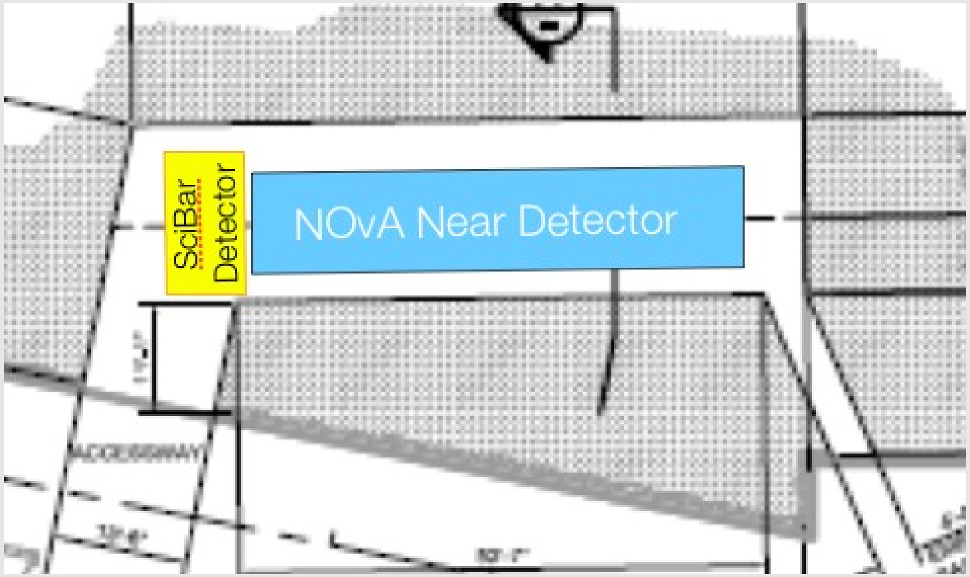
SciNOvA ν kevent/yr
(10 ton fid. vol)

	Charged-current	Neutral-current
elastic	220	86
resonant	327	115
DIS	289	96
coherent	8	5
total	845	302
$\nu + A \rightarrow \pi^0 + X$	204	106

SciNOvA: Overview



We are requesting:
- Support for science case and project strategy such that we can proceed expiditiously with:
  - further collaboration-building
  - FNAL-specific costing (moving detector, etc)
  - negotiations for detector with Kyoto U.
  - pursuit of funding (for PMTs/readout)
  - full proposal for the experiment



Science case: neutrino scattering measurements

In era of precision ν oscillation measurements, made possible at the Intensity Frontier, it is crucial to understand the detailed physics of neutrino scattering (at few-GeV)

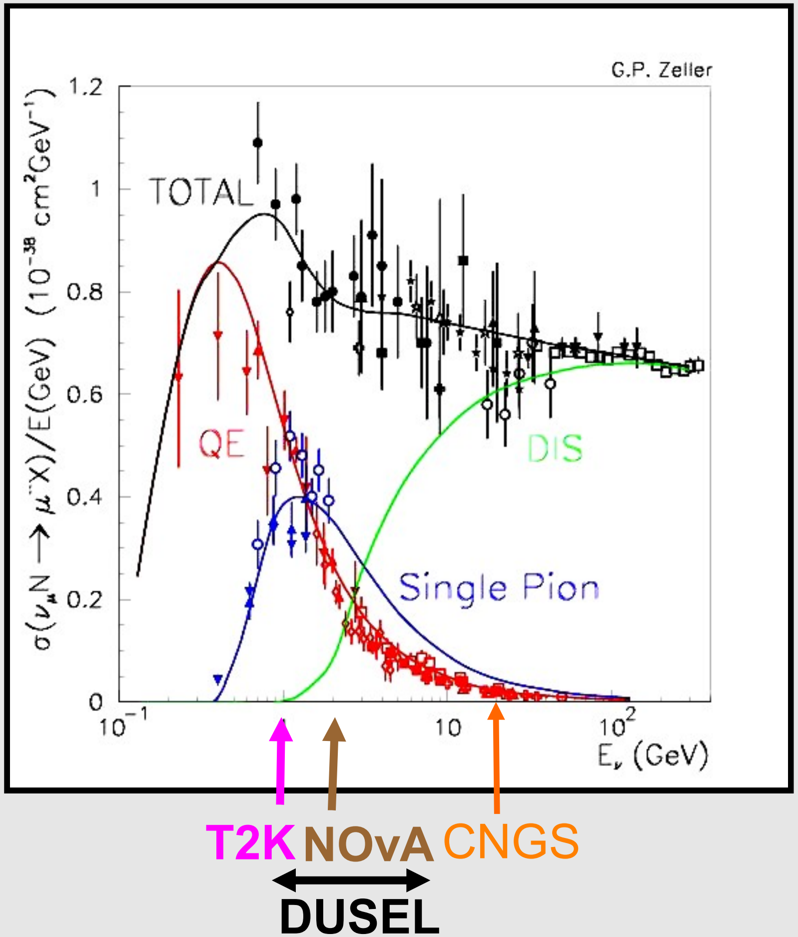
Requires: Precise measurements to enable a complete theory valid over wide range of variables (reaction channel, energy, final state kinematics, nucleus, etc)

A significant challenge:
- non-monoenergetic beams
- large backgrounds
- nuclear scattering (bound nucleons)

New measurements are forthcoming:
- MiniBooNE, SciBooNE (publications appearing)
- MINERvA, μBooNE, T2K (coming soon)

But will require even more input, especially as puzzles arise.

EG: in CCQE scattering.....



CCQE scattering

Charged-current quasielastic scattering (CCQE):

- crucial process to understand as it is...
  - detection signal for both $\nu_\mu \rightarrow \nu_e$ and $\nu_\mu \rightarrow \nu_\mu$ (in far detector),
  - normalization signal for ν_μ flux (in near detector)

- Thought to be a simple process....
  - Llewellyn-Smith formalism for diff cross section:

$$\frac{d\sigma}{dQ^2}\begin{pmatrix} \nu_l + n \rightarrow l^- + p \\ \bar{\nu}_l + p \rightarrow l^+ + n \end{pmatrix} = \frac{M^2 {G_F}^2 cos^2\theta_c}{8\pi {E_\nu}^2}\left\{ A(Q^2) \pm B(Q^2)\frac{(s-u)}{M^2} + C(Q^2)\frac{(s-u)^2}{M^4} \right\}$$

- with only one unknown parameter, M_A (via axial form factor, F_A):

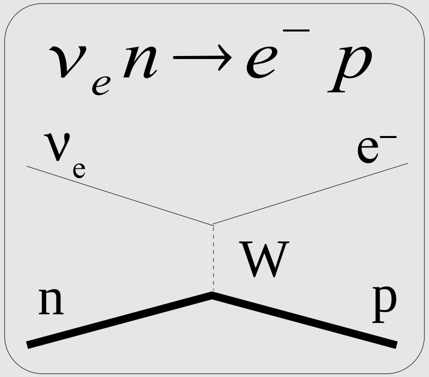
$$F_A(Q^2) = -\frac{g_A}{\left(1+\frac{Q^2}{M_A^2}\right)^2}$$

- and a CCQE measurement (has been) equiv. to M_A measurement.

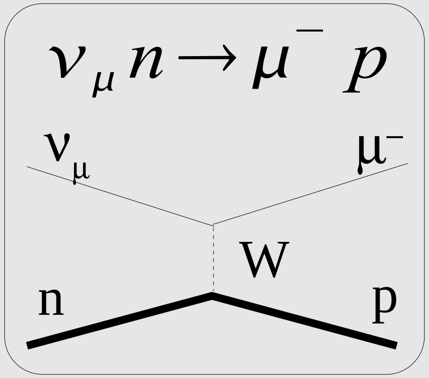
- However:
  - non-monoenergetic beams
  - different detection details between exps. (recoil nucleon detected?)
  - backgrounds (some “irreducible”, eg CCπ w/π absorption)
  - bound nucleons

- and a puzzle has emerged (with newer data)....

ν_e CCQE



ν_μ CCQE



CCQE scattering

A current puzzle in CCQE scattering:

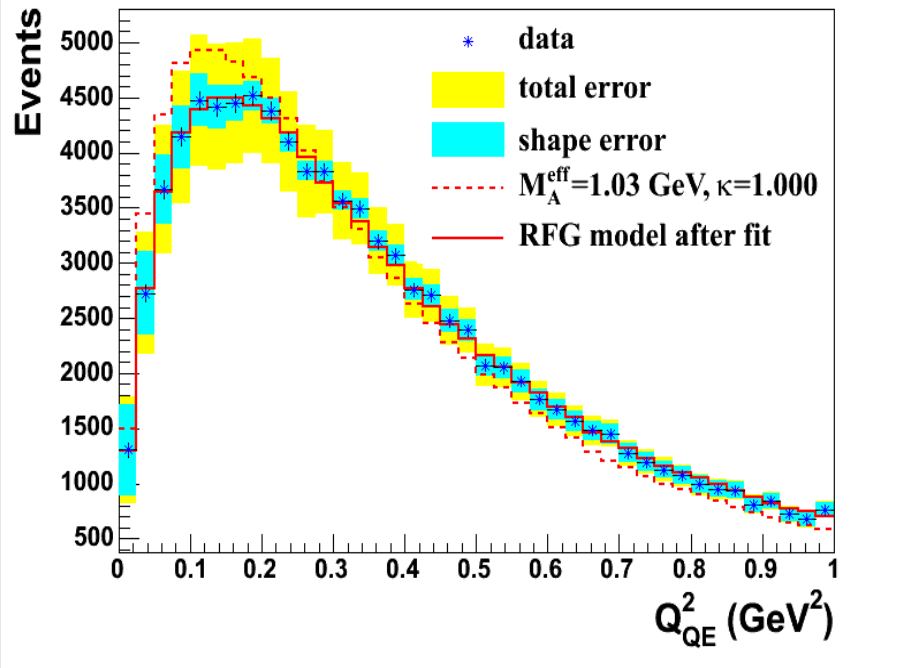
- Previous results mainly from light nuclei indicate axial mass, M_A~1.03±0.02 GeV.
- Agrees with pion electro-production data.

- recent results from heavier targets in K2K, MiniBooNE, MINOS, from Q^2-shape fits, indicate higher values (by 10-30%) (MiniBooNE result: M_A= 1.35±0.17 GeV)

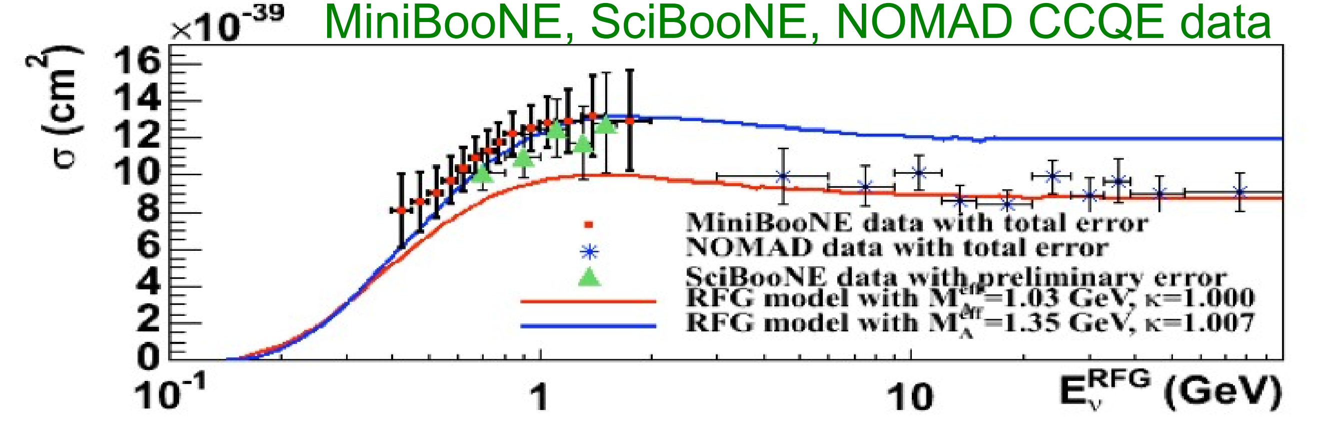
- absolute CCQE cross section (flux-normalized rate) from MiniBooNE agrees better with this larger M_A .
- Also, (preliminary) SciBooNE results show higher total cross section.

- However, recent results from NOMAD (carbon) at 3-100 GeV show expected (from world-average M_A) cross section

MiniBooNE CCQE data



MiniBooNE, SciBooNE, NOMAD CCQE data



CCQE scattering

Much recent theory work on CCQE scattering and the “high-MA” puzzle:

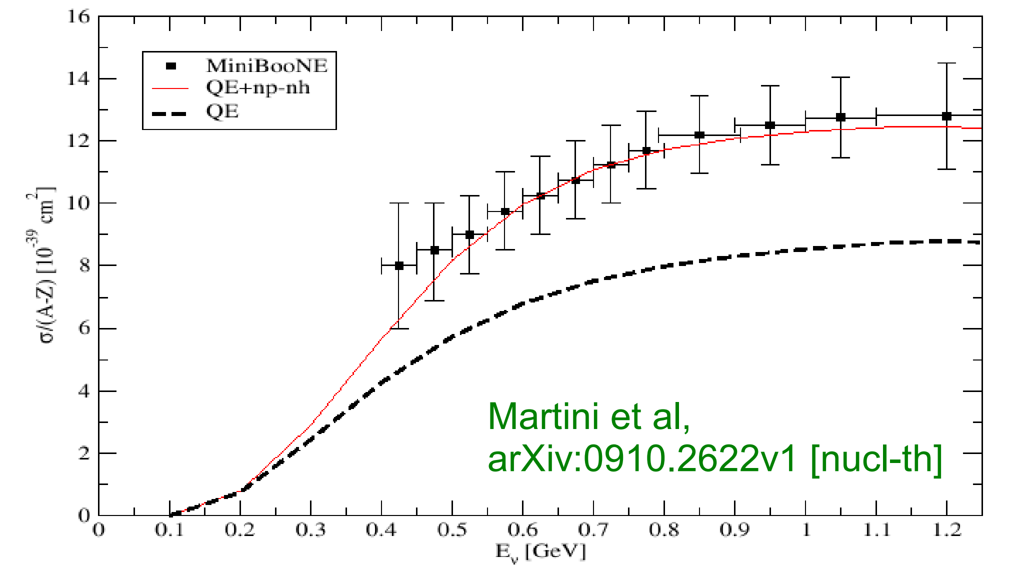
J. E. Amaro et al. ,
Phys. Rev. C 71 , 015501 (2005);
Phys. Rev. C 75 , 034613 (2007);
T. Leitner et al. ,
Phys. Rev. C 73 , 065502 (2006);
Phys. Rev. C 79 , 065502 (2006);
O. Benhar et al. ,
Phys. Rev. D 72 , 053005 (2005);
arXiv:0903.2329 [hep-ph];
A. Butkevich et al. ,
Phys. Rev. C 76 , 045502 (2007);
Phys. Rev. C 80 , 014610 (2009);
S. K. Singh et al. ,
arXiv:0808.2103 [nucl-th];
J. Nieves et al. ,
Phys. Rev. C 73 , 025504 (2006);
N. Jachowicz et al. ,
Phys. Rev. C 73 , 024607 (2006);
A. M. Ankowski et al. ,
Phys. Rev. C 77 , 044311 (2008);
A. Meucci et al. ,
Nucl. Phys. A 739 , 277 (2004).

- No solution has yet emerged.

A unified approach for nucleon knock-out, coherent and incoherent pion production in neutrino interactions with nuclei

M. Martini[1,2,3], M. Ericson[1,3], G. Chanfray[1] and J. Marteau[1]

[1] Université de Lyon, Univ. Lyon 1, CNRS/IN2P3, IPN Lyon, F-69622 Villeurbanne Cedex, France
[2] Università di Bari, I-70126 Bari, Italy
[3] Theory Group, Physics Department, CERN, CH-1211 Geneva, Switzerland

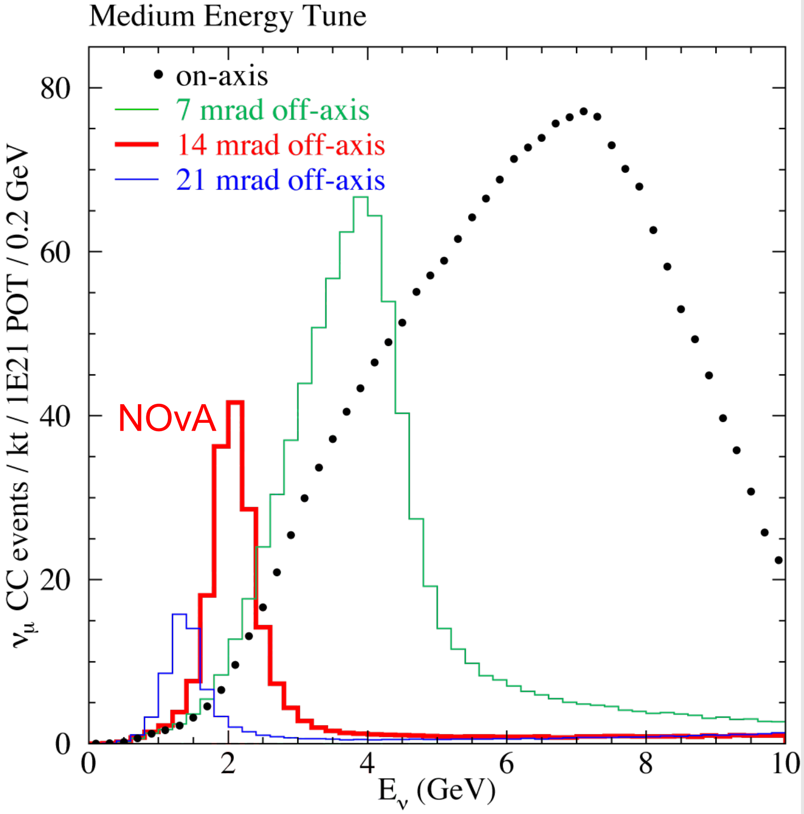


- However, a (very) recent work by Martini et al (arXiv:0910.2622v1 [nucl-th]) proposes a model that reproduces larger CCQE cross section.... needs further scrutiny

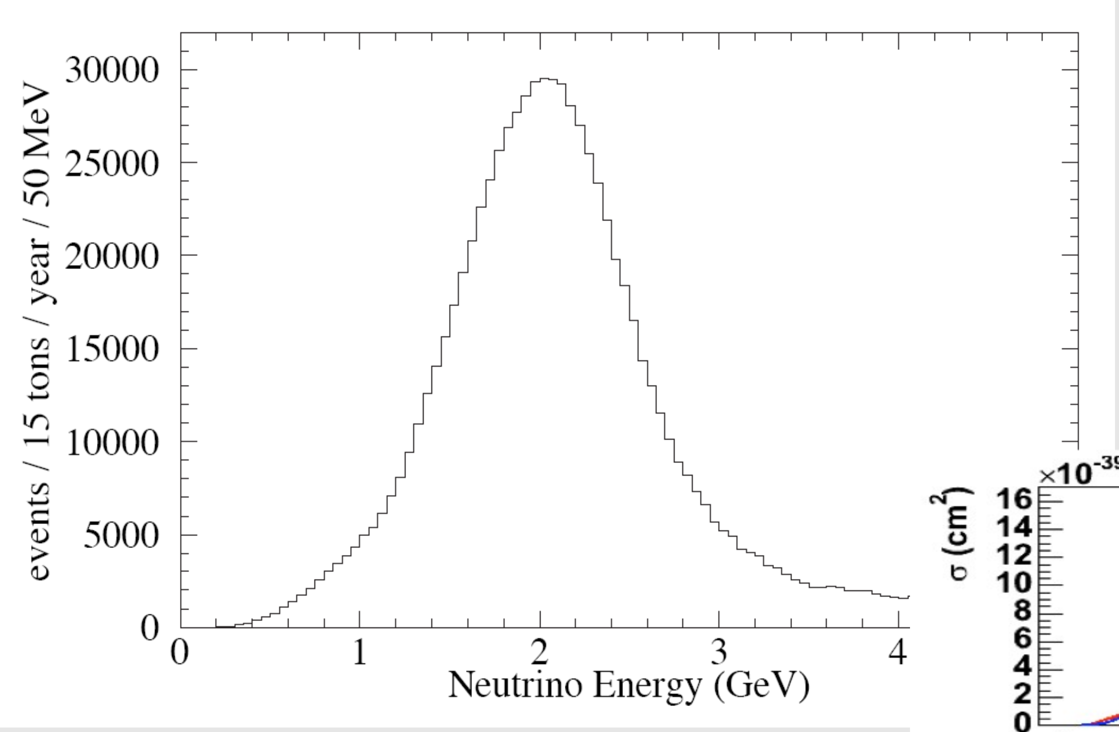
CCQE scattering

- A measurement with the SciBar detector (which has produced CCQE measurements in SciBooNE/K2K)...
- in the narrow-band 2 GeV ν, $\bar{\nu}$ beam, where CCQE vs CCpi kinematics, are more easily separated..
- will be invaluable in testing/guiding future CCQE models

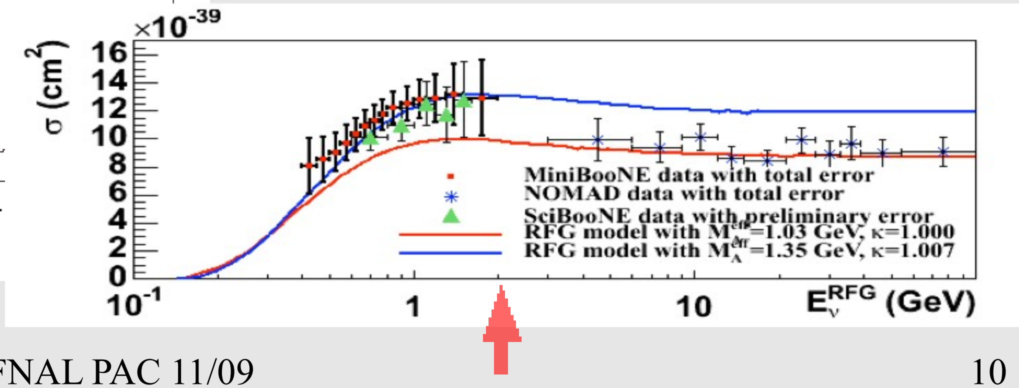
event rate from NuMI near locations



neutrino event rate at NOvA near location



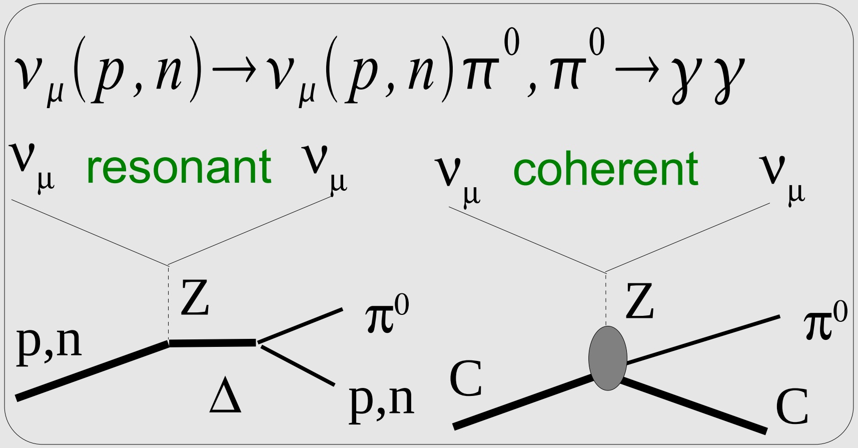
MiniBooNE & others CCQE data



additional ν scattering measurements

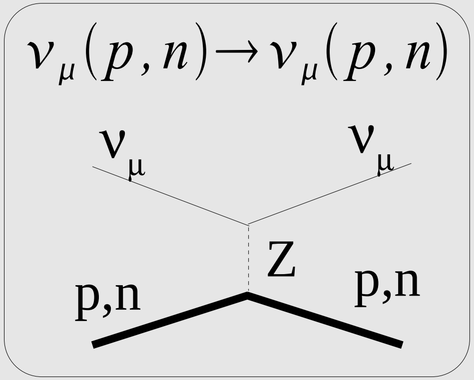
Additional measurements of interest:

- neutral-current π^0 production (NCπ^0)
  - differential cross section (rate) important to understand for oscillation measurement as background
  - current interest/debate on coherent contribution in the 1 GeV energy range



NCπ^0 production

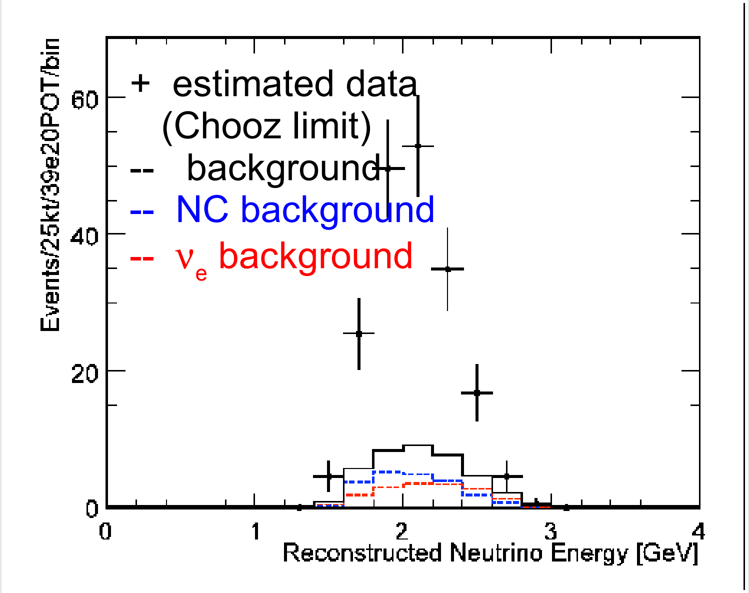
- neutral-current nucleon elastic scattering (NCel)
  - most fundamental NC probe of nucleus
  - comparison to CCQE can provide information about additional isoscalar contributions to nucleon spin (such as strange quarks)

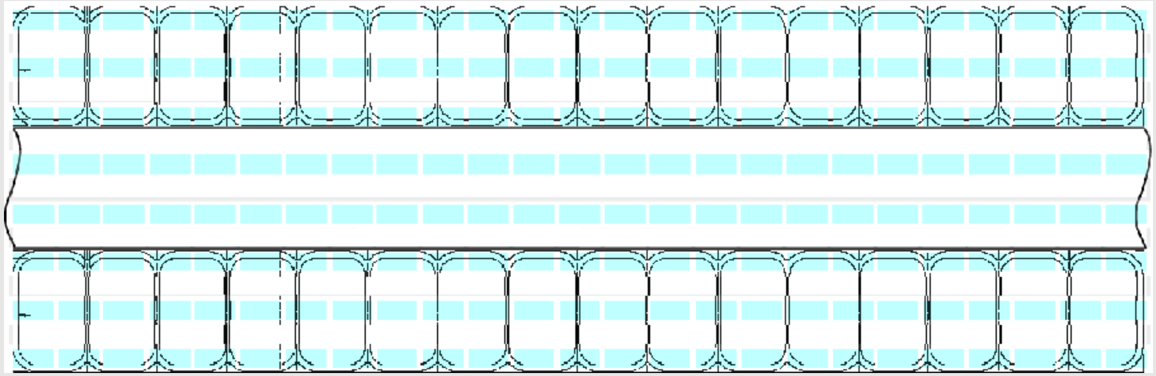


NC elastic

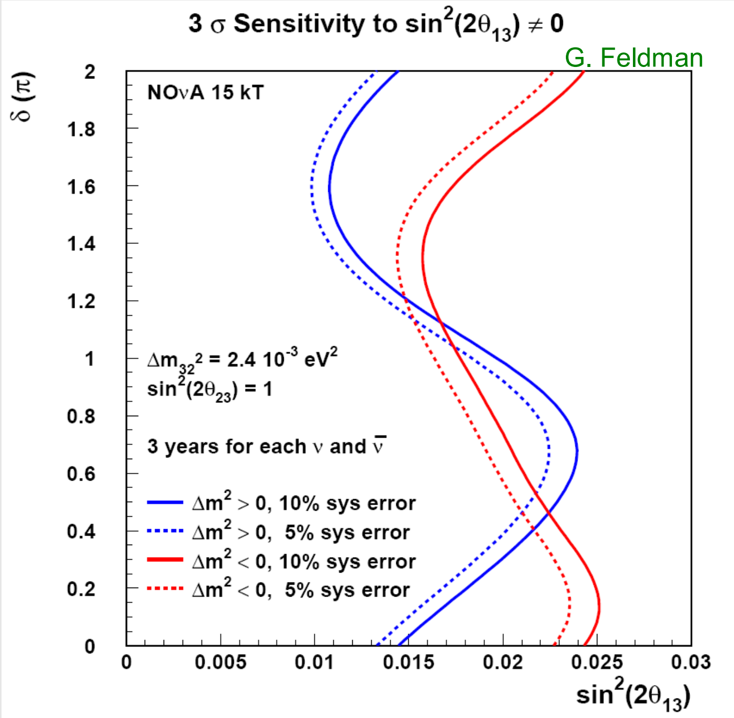
Science case: enhancements to NOvA program

- SciNOvA will enhance the NOvA program by providing a test of the background prediction with a fine-grained detector (SciBar)..
- in particular, the NCπ^0 background
- and may allow a reduction in the NCπ^0 background uncertainty (from current estimate of 10%).



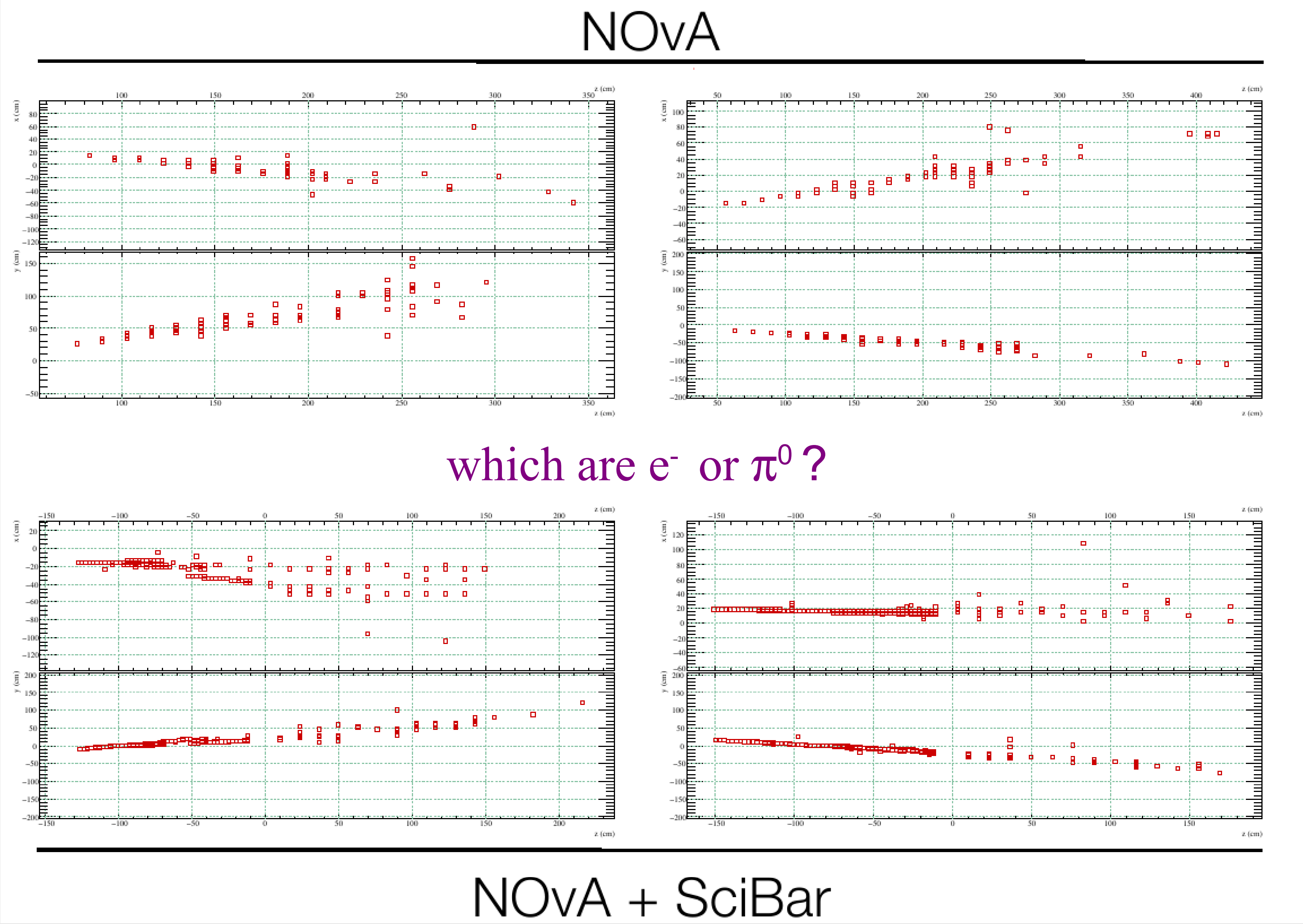


overlay of scibar and NOvA showing "pixel" sizes



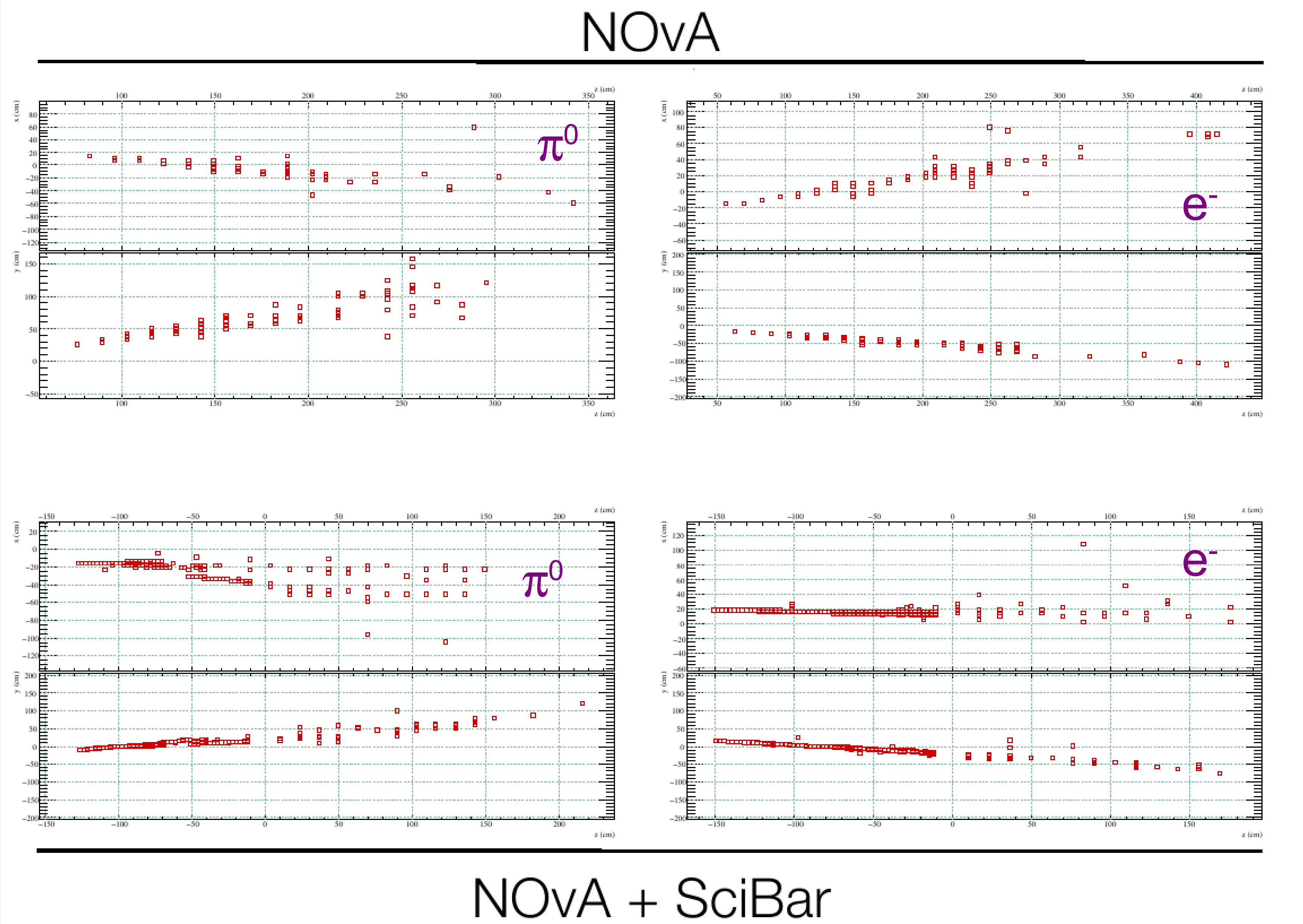
enhancements to NOvA program

- An inital event scan of π^0 vs e^- events in NOvA vs NOvA+scibar



enhancements to NOvA program

- An inital event scan of π^0 vs e^- events in NOvA vs NOvA+scibar



enhancements to NOvA program

- An inital event scan of π^0 vs e^- events in NOvA vs NOvA+SciBar
- 1/2 of π^0s not resolved by NOvA alone were resolved by NOvA+SciBar

Hand scan of 500 events
- P = 2 GeV
- pid chosen randomly 50/50 electron or pizero
- vertex location chosen 50/50 in SciBar or in NOvA
- vertex location and angles randomized to avoid scanning bias

event scan of π^0 vs e^- events in NOvA vs NOvA+SciBar

Raw data: #'s are event counts

NOvA Alone		
scan=electron	108	32
scan=pizero	16	91
	true=electron	true=pizero

NOvA + SciBar		
scan=electron	118	17
scan=pizero	14	104
	true=electron	true=pizero

Scaled so that "perfect" performance would have 100% on diagonal

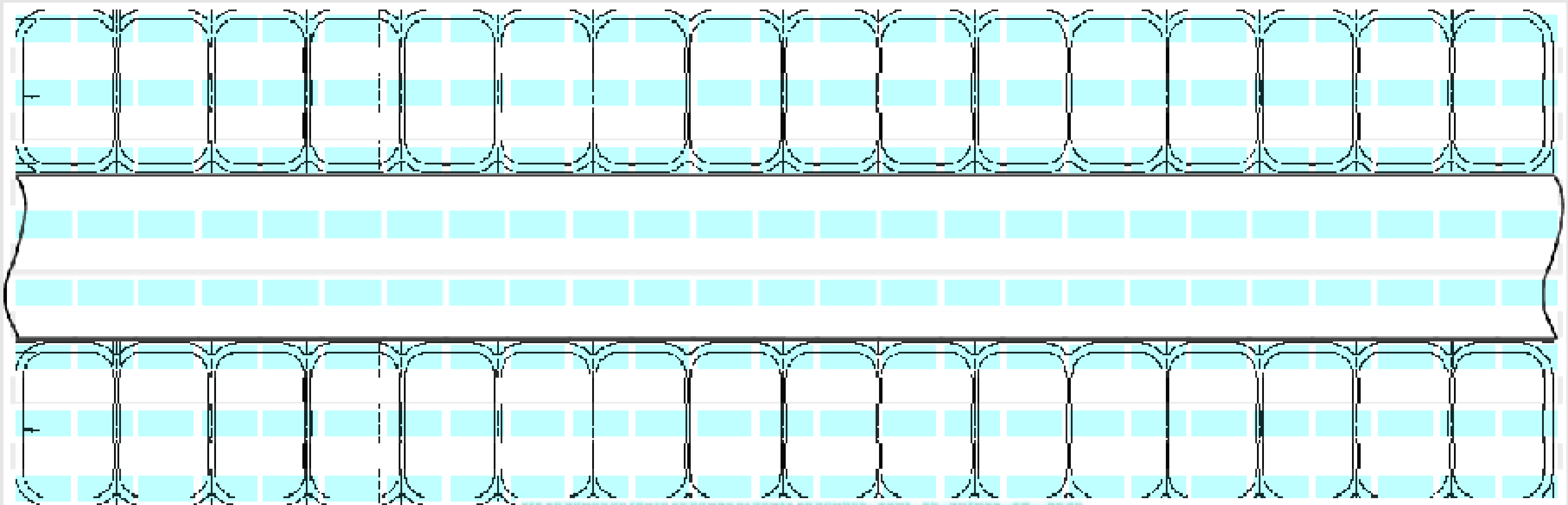
NOvA Alone		
scan=electron	88	26
scan=pizero	12	74
	true=electron	true=pizero

NOvA + SciBar		
scan=electron	93	13
scan=pizero	11	82
	true=electron	true=pizero

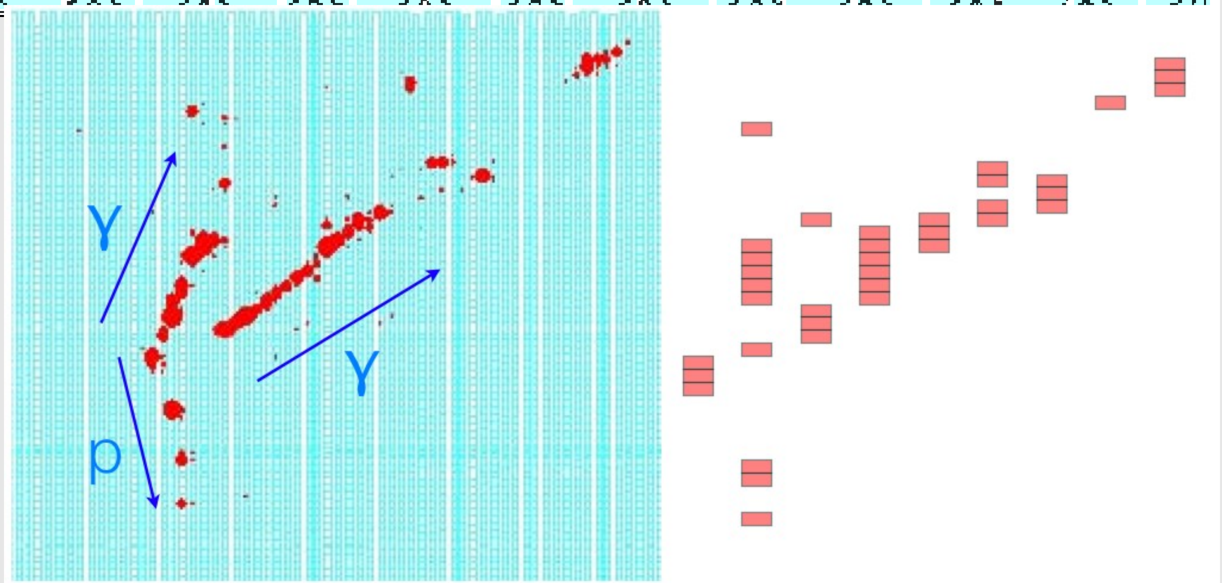
Overall: 199/247 = 81% correct assignments w/ NOvA
222/253 = 88% correct assignments w/ NOvA + SciBar
Probability to correctly identify an electron: 108/124 = 87% NOvA, 118/132 = 89% w/ SciBar
Probability to correctly identify a pizero: 91/123 = 74% NOvA, 104/121 = 86% w/ SciBar
Purity of electron sample = 108/140 = 77% NOvA, 118/135 = 87% w/ SciBar
Purity of pizero sample = 91/107 = 85% NOvA, 104/118 = 88% w/ SciBar

enhancements to NOvA program

overlay of scibar and NOvA showing “pixel” sizes



The more fine-grained SciBar detector would enable a data-driven calculation and a double-check of the NCπ^0 background in NOvA.



$p + \pi^0$ in SciBar   Same event resampled in NOvA

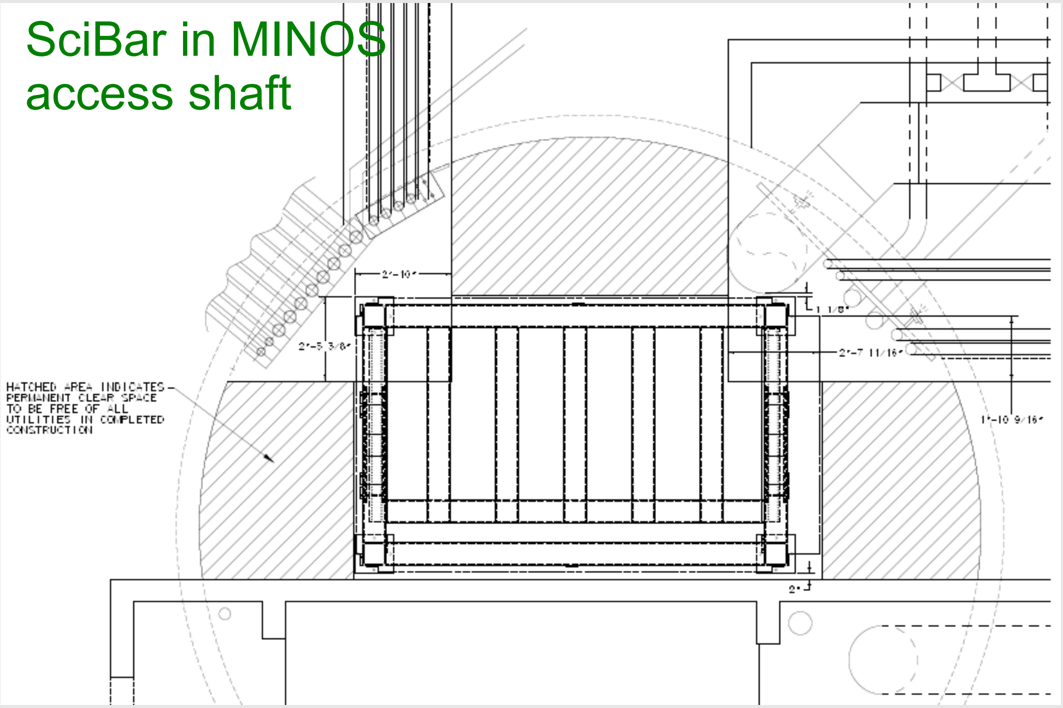
experimental plan

Moving the SciBar detector at NOvA near location:

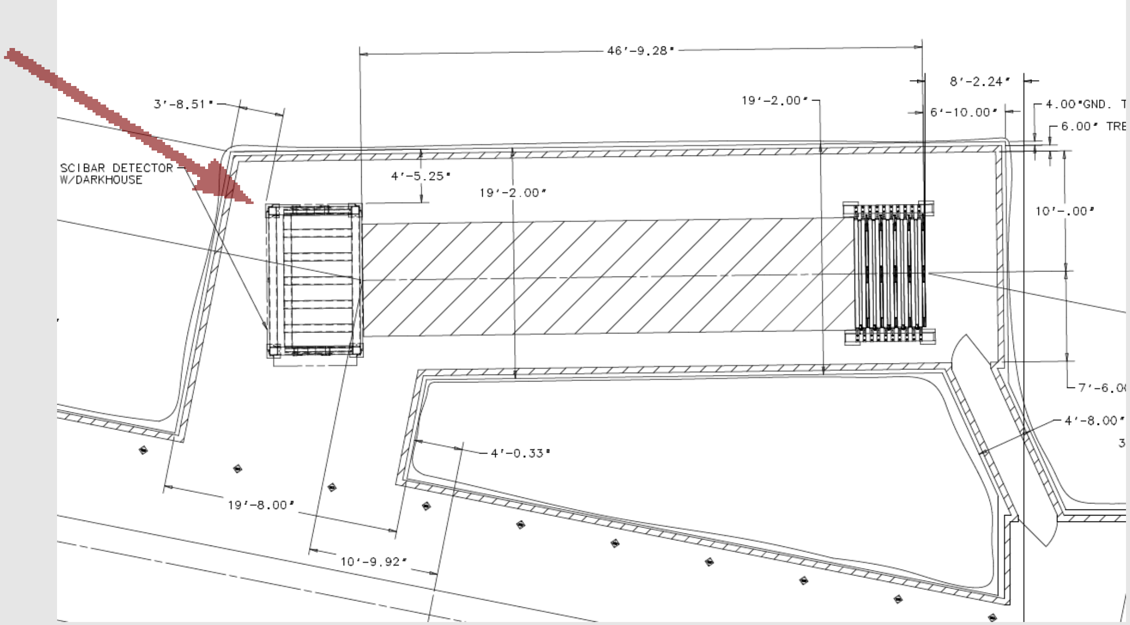
- (short) study by FNAL PPD engineering indicated no show-stoppers, but some challenges:

  - access shaft clearance is tight
  - MINOS crane not adequate for fully assembled SciBar

SciBar in MINOS access shaft



SciBar in NOvA near location



experimental plan

Reinstrumenting the SciBar detector for SciNOvA:

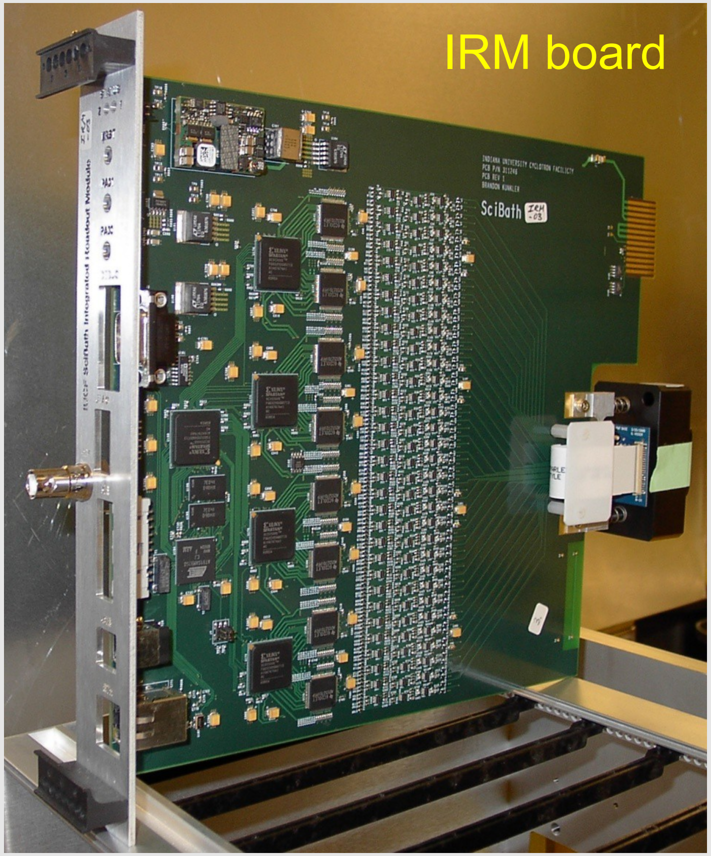
- PMTs/readout electronics removed from SciBar after SciBooNE completed

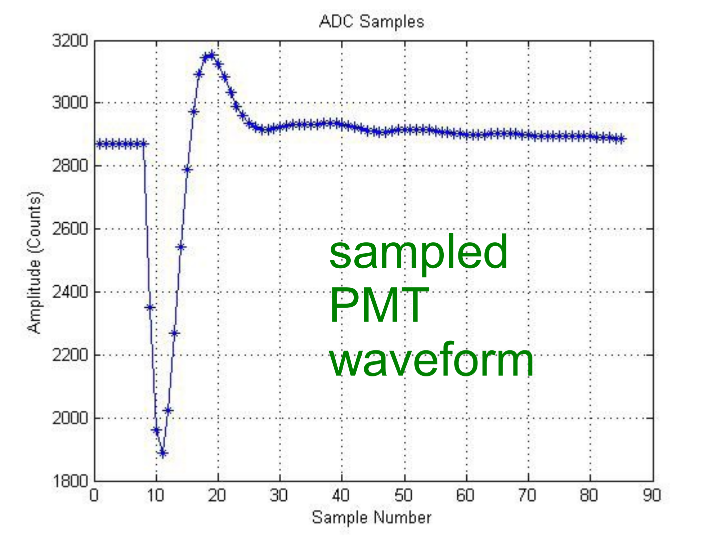
- At Indiana U. , a system has been developed (with support from Indiana U. and NSF) for WLS-fiber readout of "scibath" detector

- 15 "IRM" boards built and running!

- Integrated readout of (64-channel) PMT with flash ADC of "ringing integrator" front-end circuit for charge, time info with one-ADC channel.

- Cost:
  - $50/channel for readout (including mechanical)
  - $25/channel for PMT



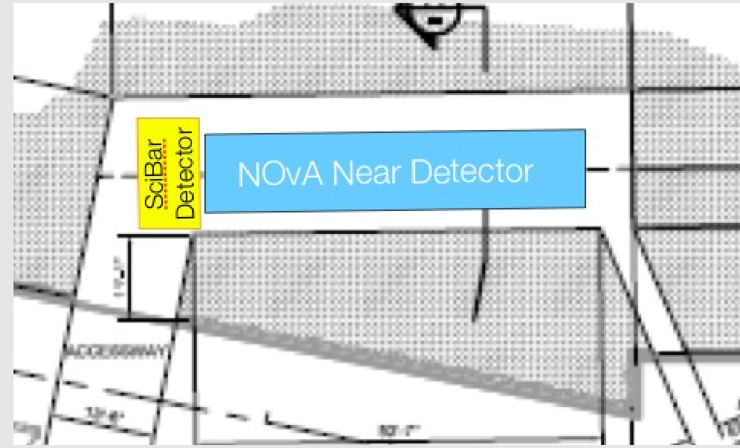


costs and schedule

Estimated costs:

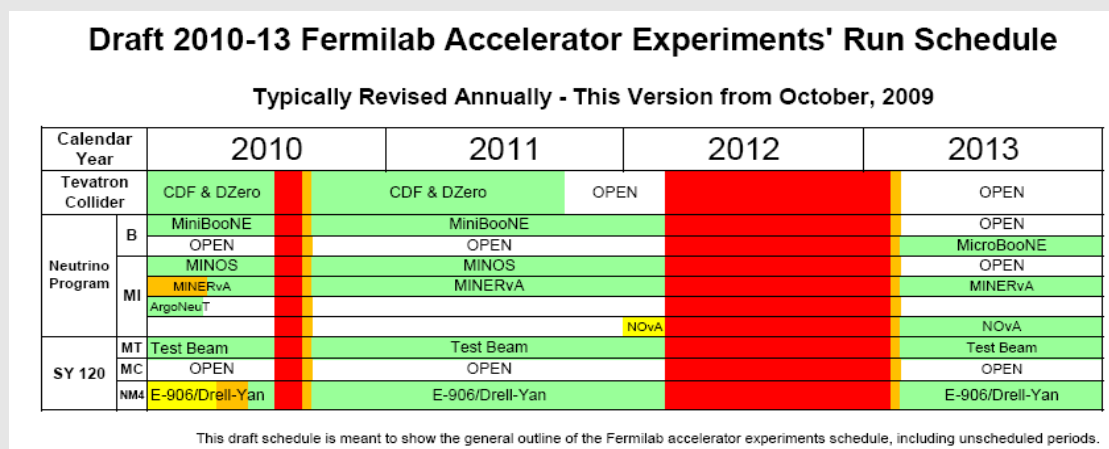
- readout system, equipment: $1.255M
  - boards: $775k
  - PMTs: 400k
  - misc: 80k
- readout system, personnel: $290k
- readout total (w/overhead) $1.75M

- costs of moving detector and associated, TBD.



Schedule:

- 11/09 FNAL support agreed (details TBD)
- 01/10 NSF MRI submission
- 08/10-12/11 PMT/readout procurement/fabrication
- 08/10-12/11 scibar detector move planning, support fabrication
- 01/12-06/12 commissioning, substructure assembly
- 07/12 ready for installation at NOvA near location



Using the SciBar detector

Using the SciBar detector:

- Detector is owned by Kyoto U.
  Would need to negotiate usage for SciNOvA.

- There is another idea for use of SciBar detector:

- If SciNOvA is encouraged, this would be negotiated further.

Proposal to use the SciBar detector as a solar energetic particle detector at a high altitude mountain in Mexico

The SciCR Collaboration

Yoshitaka Itow, Yutaka Matsubara, Yuya Nagai, Takashi Sako
(Solar-Terrestrial Environment Laboratory, Nagoya University, Japan)

Yasushi Muraki
(Department of Physics, Konan University, Japan)

Kazuoki Munakata
(Department of Physics, Shinshu University, Japan)

Shoichi Shibata
(College of Engineering, Chubu Universty, Japan)

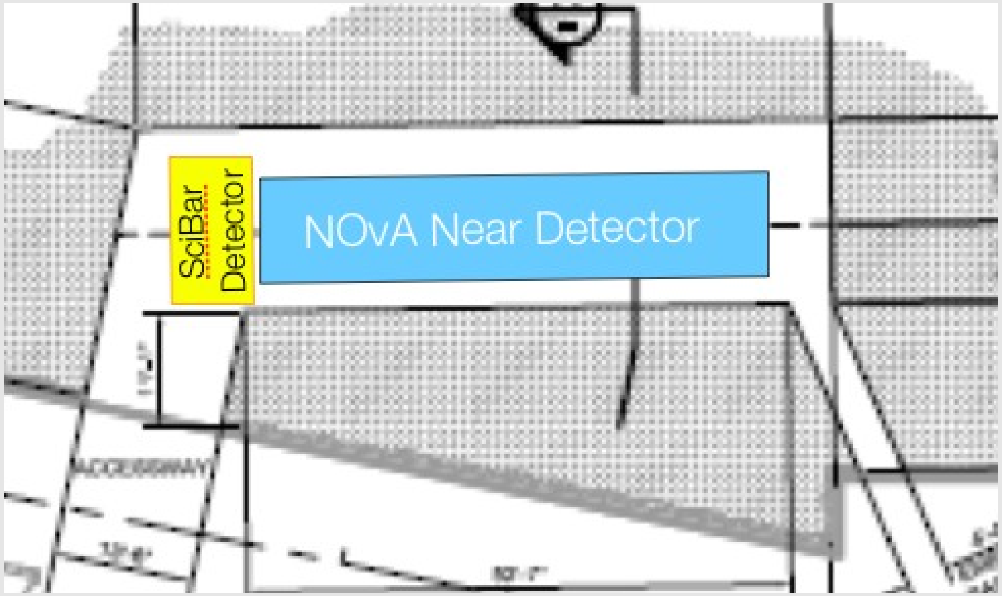
Harufumi Tsuchiya
(Institute of Physical and Chemical Research, Japan)
Kyoko Watanabe
(JAXA/ISAS)

Jose Valdés-Galicia
(Instityto de Geofísica, Universidad Nacional Autóma de México, Mexico)

Conclusions/Request:

- There is currently a window of opportunity to add to the NOvA program with the reuse of the SciBar detector in the NOvA narrow-band beam.
- This will allow new insight into neutrino scattering processes and
- enhance the NOvA ν oscillation program.

We are requesting:
- Support for science case and project strategy such that we can proceed expiditiously with:
  - further collaboration-building
  - FNAL-specific costing (moving detector, etc)
  - negotiations for detector with Kyoto U.
  - pursuit of funding (for PMTs/readout)
  - full proposal for the experiment



backups etc

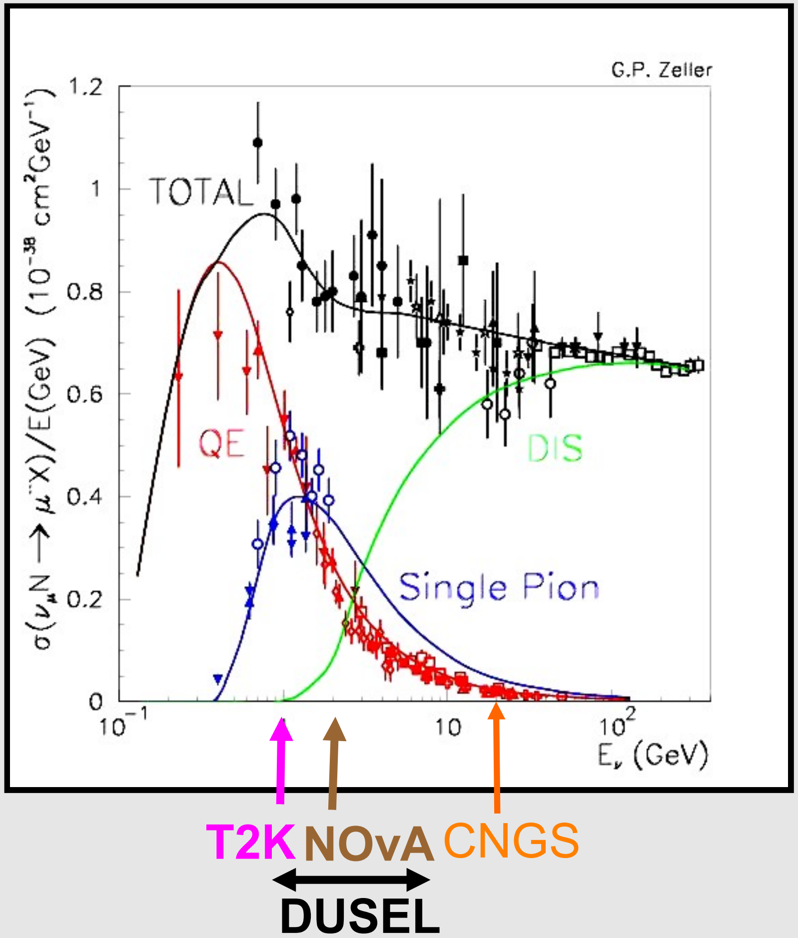
SciNOvA: science case

In era of precision ν oscillation measurements, made possible at the Intensity Frontier, it is crucial to understand the detailed physics of neutrino scattering.
Requires: Precise measurements as input to accurate, complete models (and vice versa)

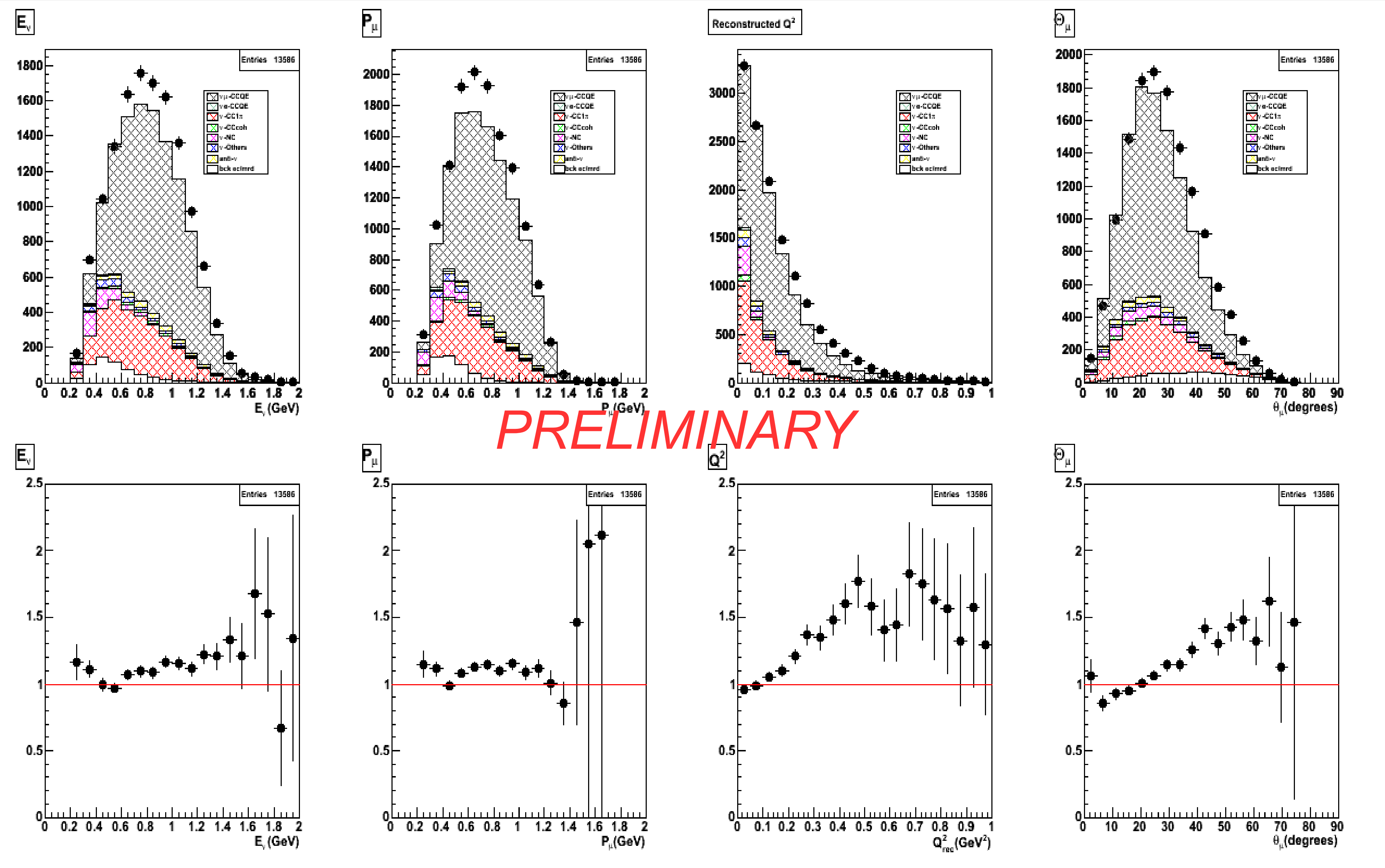
ν–scattering models currently implemented (e.g. within NUANCE) are dated and looking to be inadequate, for example:

- CCQE, rel. Fermi Gas:
  Smith and Moniz, Nucl. Phys. B43, 605 (1972).
- resonant/coherent pion production:
  Rein and Sehgal, Annals Phys. 133, 79 (1981),
  Nucl. Phys. B 223, 29 (1983).

New event generators are improving (eg GENIE),
but underlying models are not very different (at least not yet).

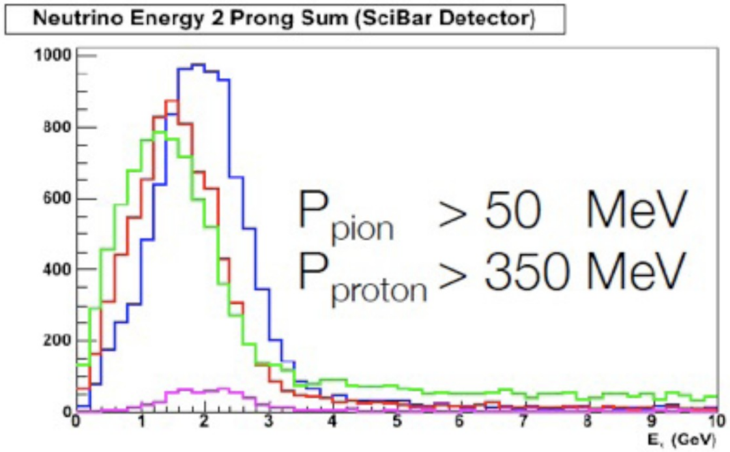


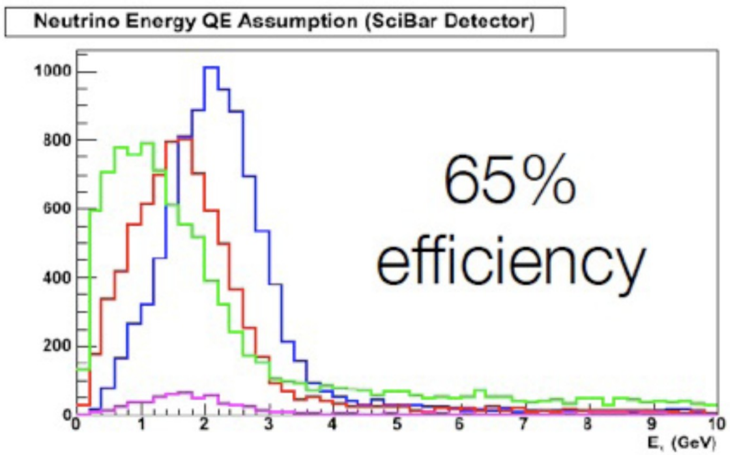
SciBooNE CCQE



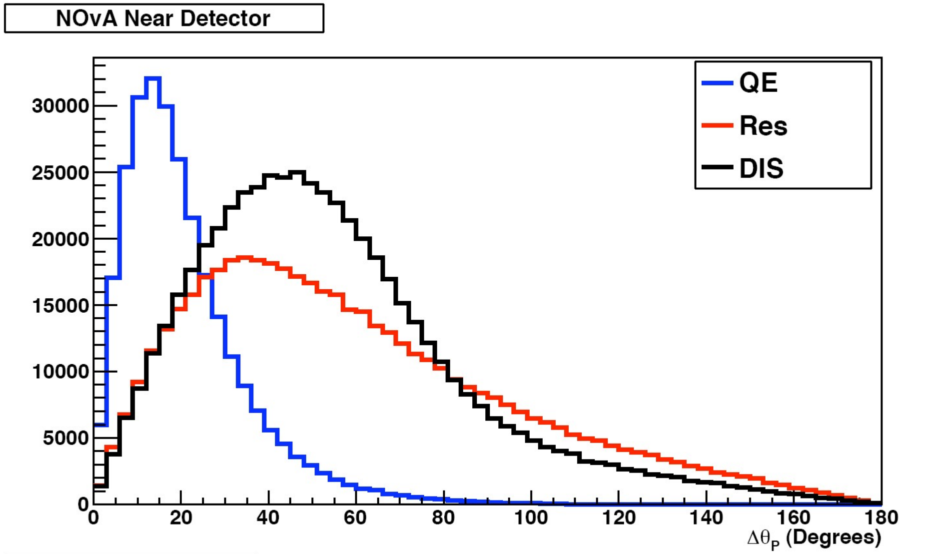
SciNOvA: enhancements to NOvA program

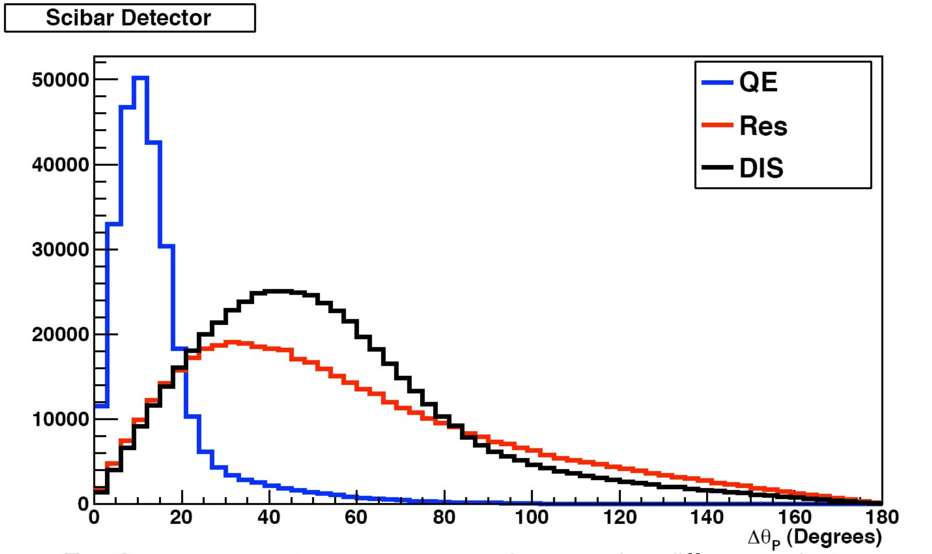
- improvement to NOvA near detector ν_μ rate measurement





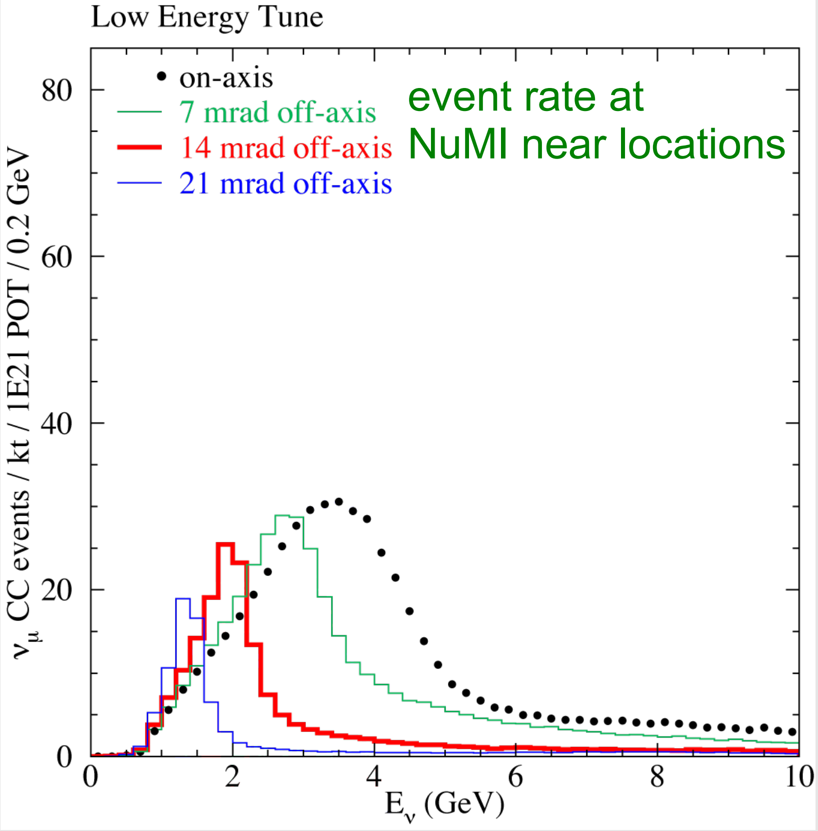
Reconstructed angle for 2 and 1 prong events. In 2 prong events, the energy is reconstructed assuming a muon and proton track; in the case of 1-prong QE kinematics are assumed. The accumulation at E<2 GeV give some sense of the feed down from RES and DIS into the QE sample. NBB helps with this.

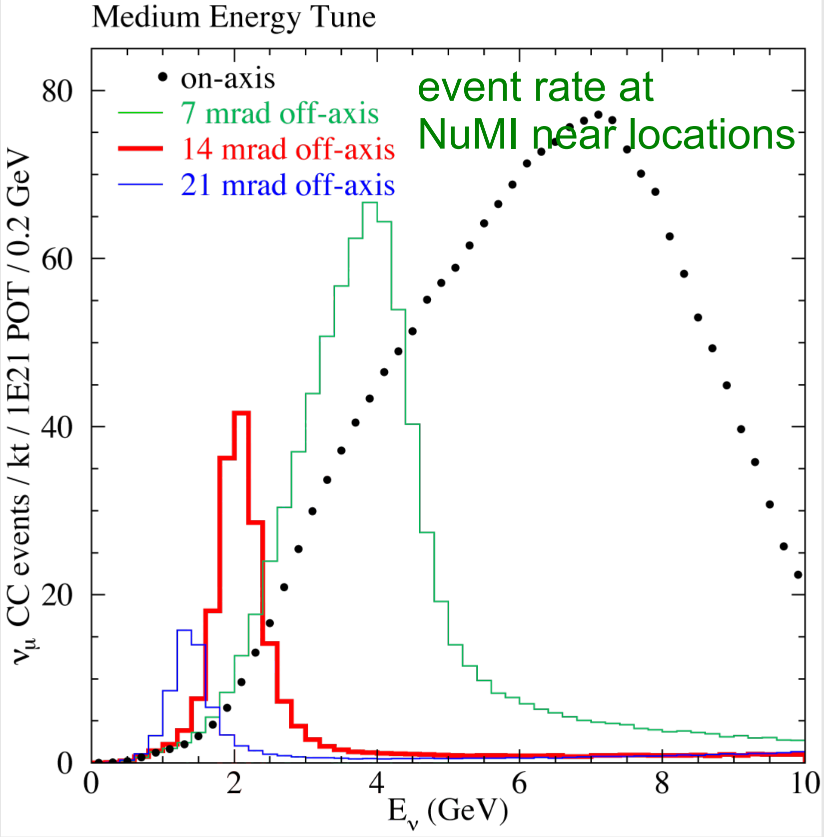




For 2-prong events we measure the angular difference between the 2nd prong and its calculated trajectory assuming QE kinematics. This is the most useful selection for removing non-QE events. Top: NOvA, Bottom: SciBar. The QE efficiency/purity is much improved in SciBar compared to NOvA.

SciNOvA: on-axis compared to off-axis





M_A from CCQE

- M_A measurments, from Lyubushkin, etal (NOMAD collab, arXiv:0812.4543)

- different targets/energies

- world average from Bernard, etal, JPhysG28, 2002: M_A=1.026±0.021 (also, M_A from π photo-production similar)

- However, recent data from some high-stats experiments not well-described with this M_A and/or the simple model described on previous page

summary of ν, $\bar{\nu}$ measurements of M_A

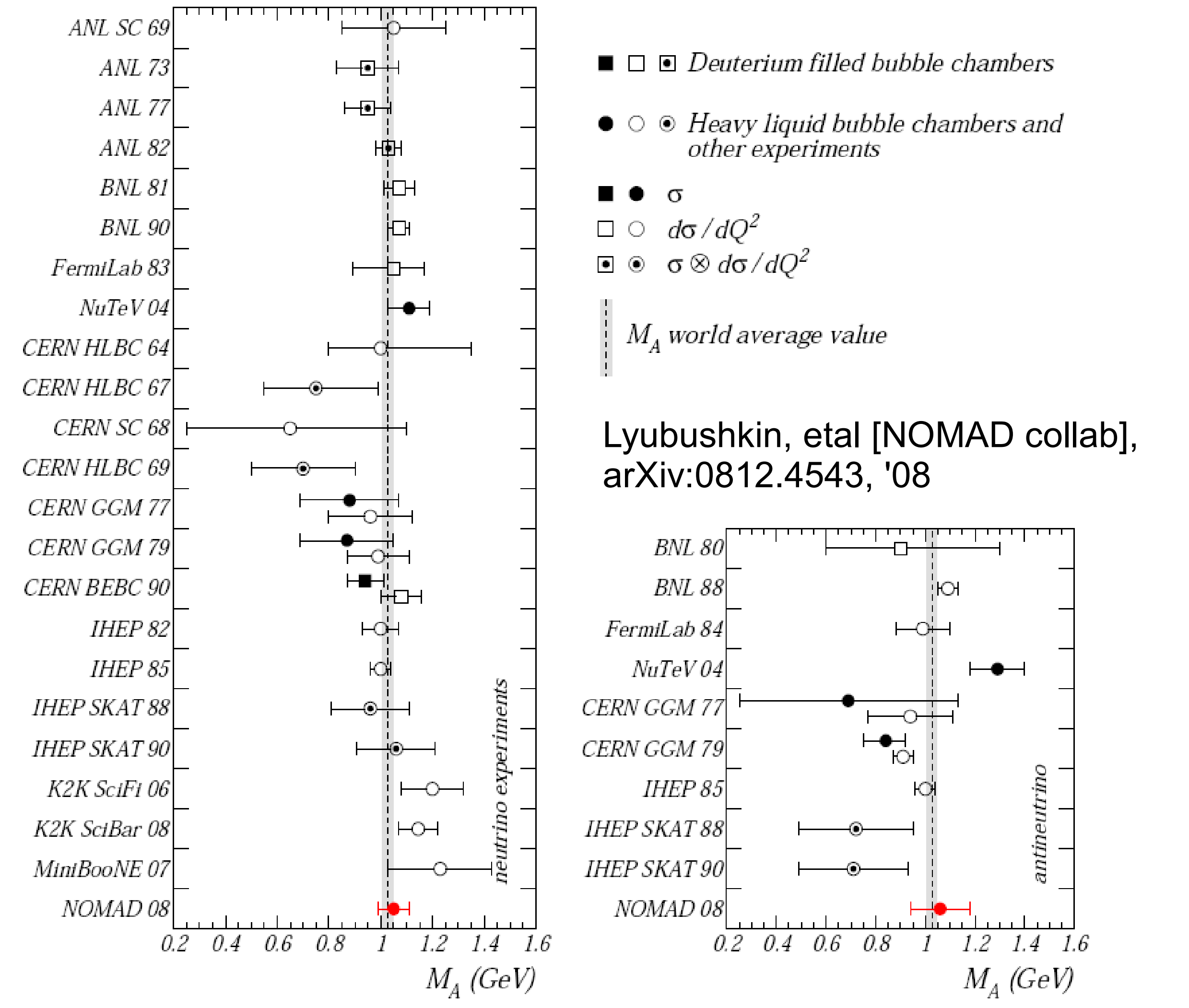


Fig. 18. A summary of existing experimental data: the axial mass M_A as measured in neutrino (left) and antineutrino (right) experiments. Points show results obtained both from deuterium filled BC (squares) and from heavy liquid BC and other experiments (circles). Dashed line corresponds to the so-called world average value $M_A = 1.026 \pm 0.021$ GeV (see review [33]).

Previous CCQE results

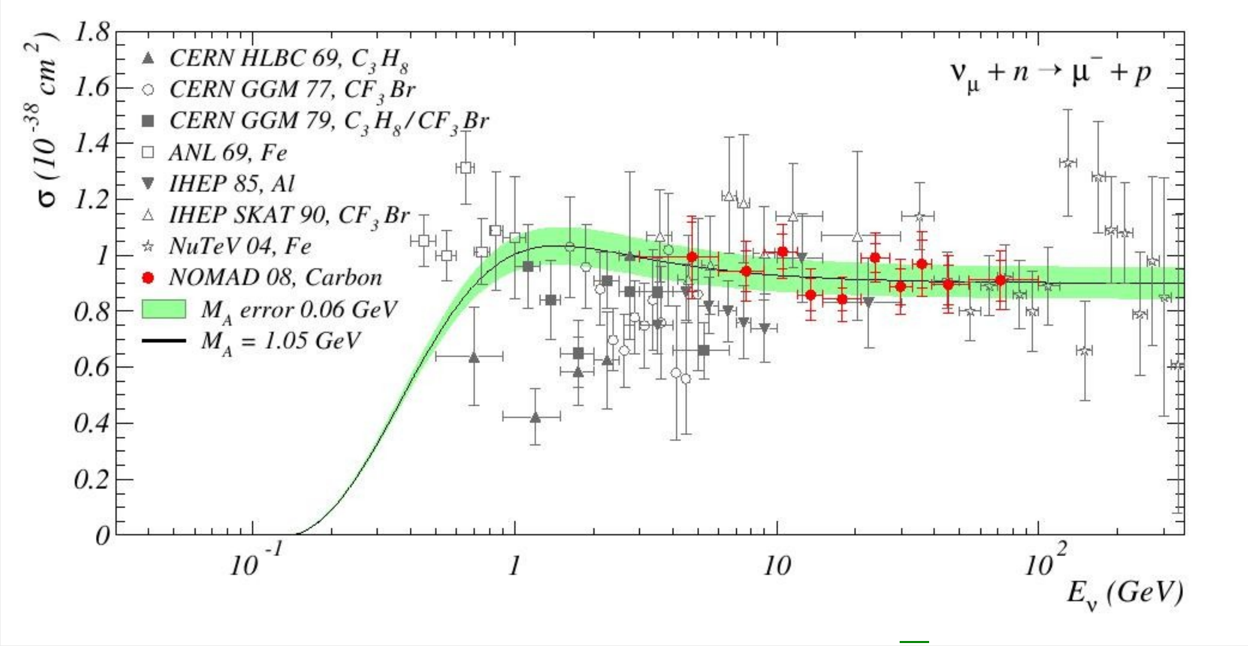
- total cross section measurements as func of E_ν

- from Lyubushkin, etal (NOMAD collab, arXiv:0812.4543)

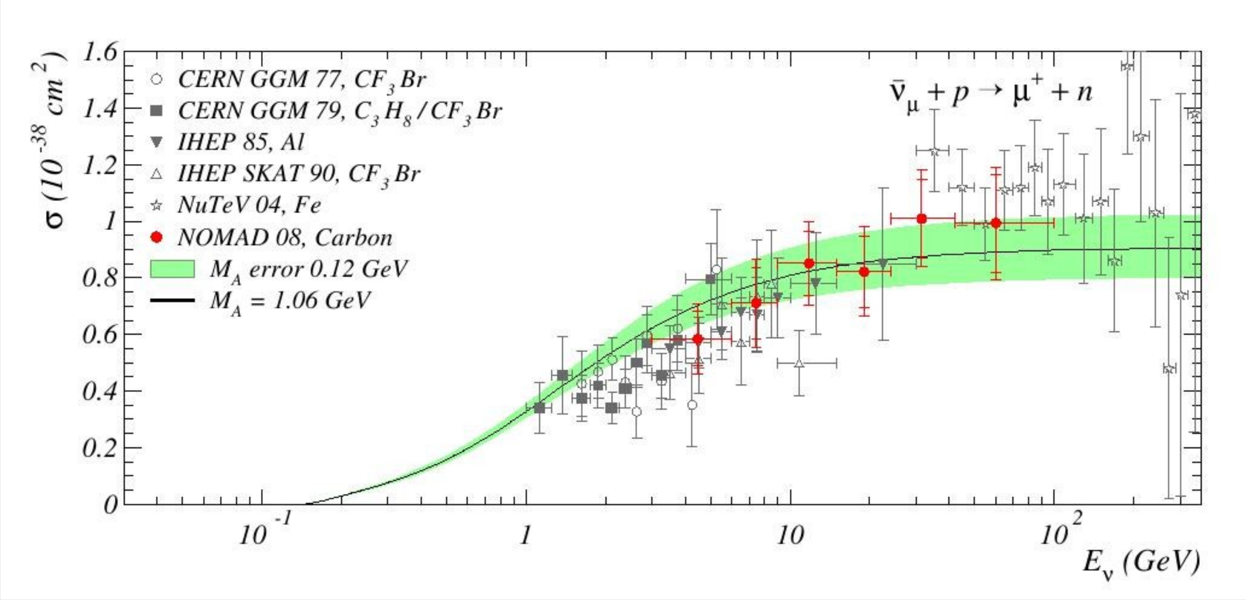
- different targets, different energies

- curve is that predicted with M_A of this NOMAD measurement

ν cross section



$\bar{\nu}$ cross section

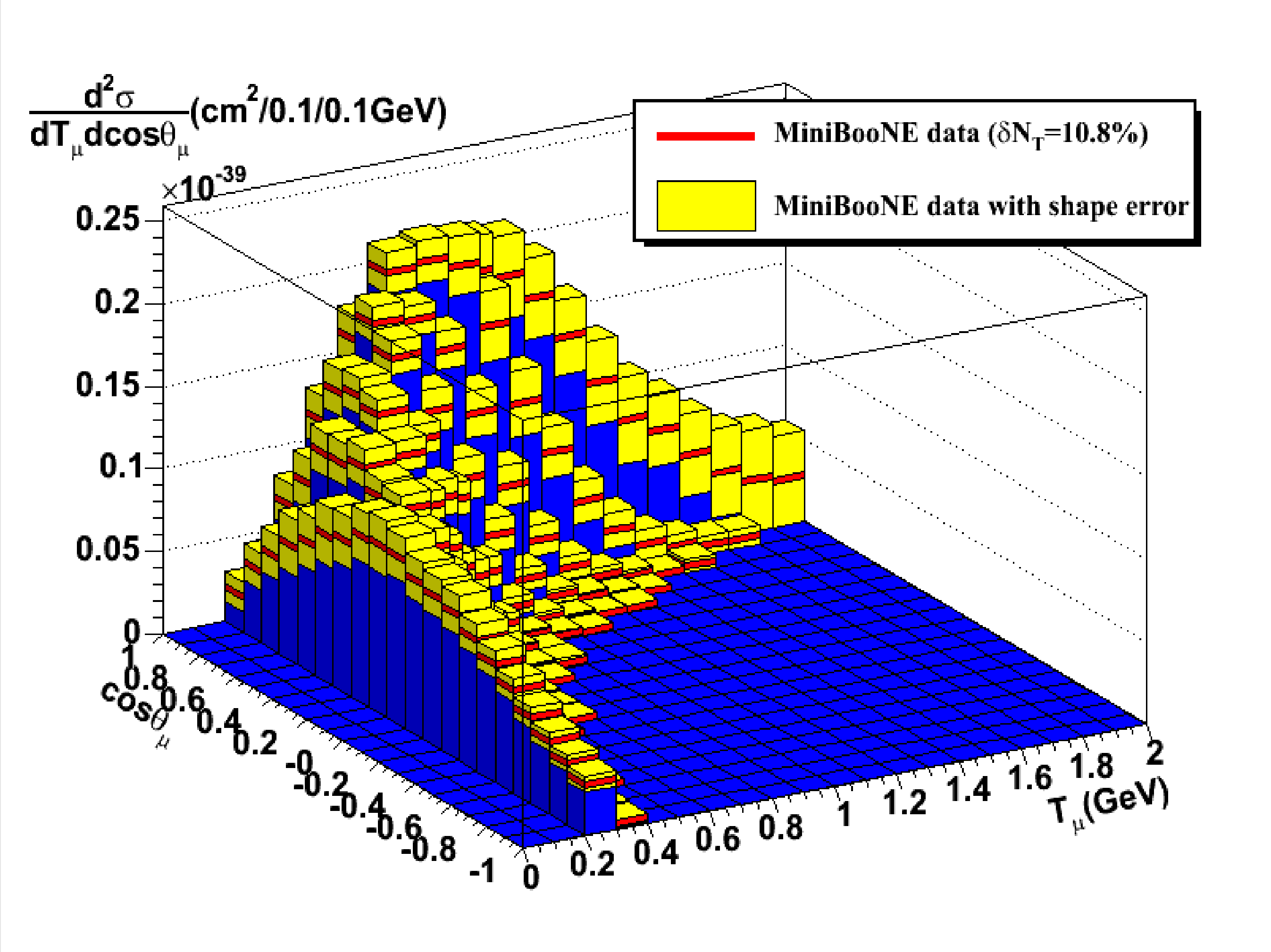


MiniBooNE CCQE results

- most complete and most model independent specification of CCQE reaction (from μ kinematics)

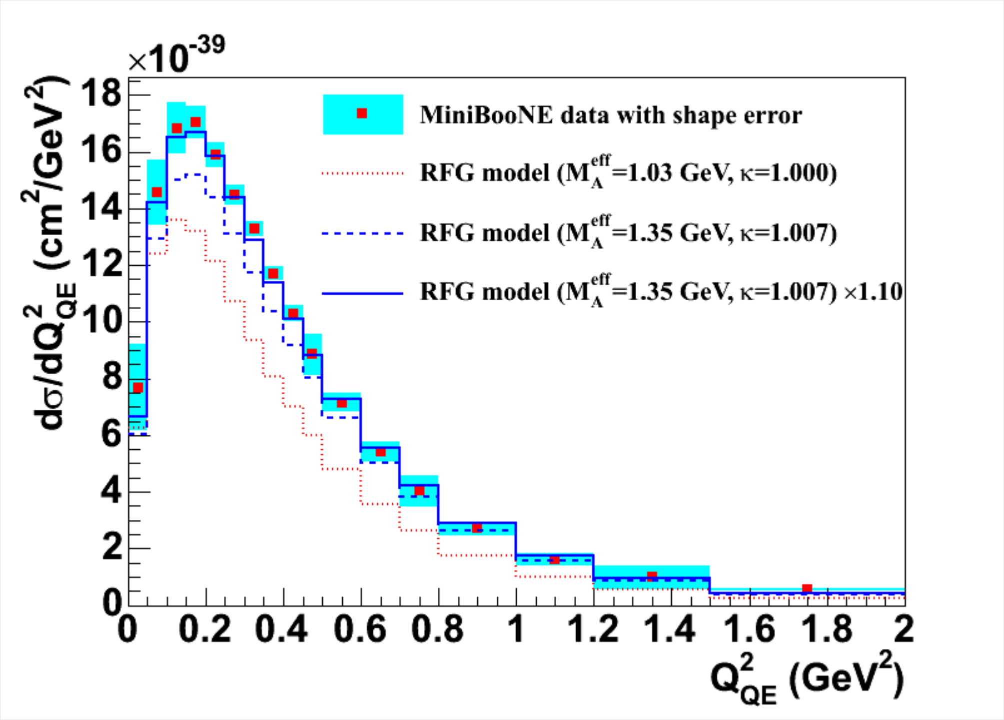
This is result best used to compare to models

flux-average double differential cross section



MiniBooNE CCQE results

flux-average differential cross section

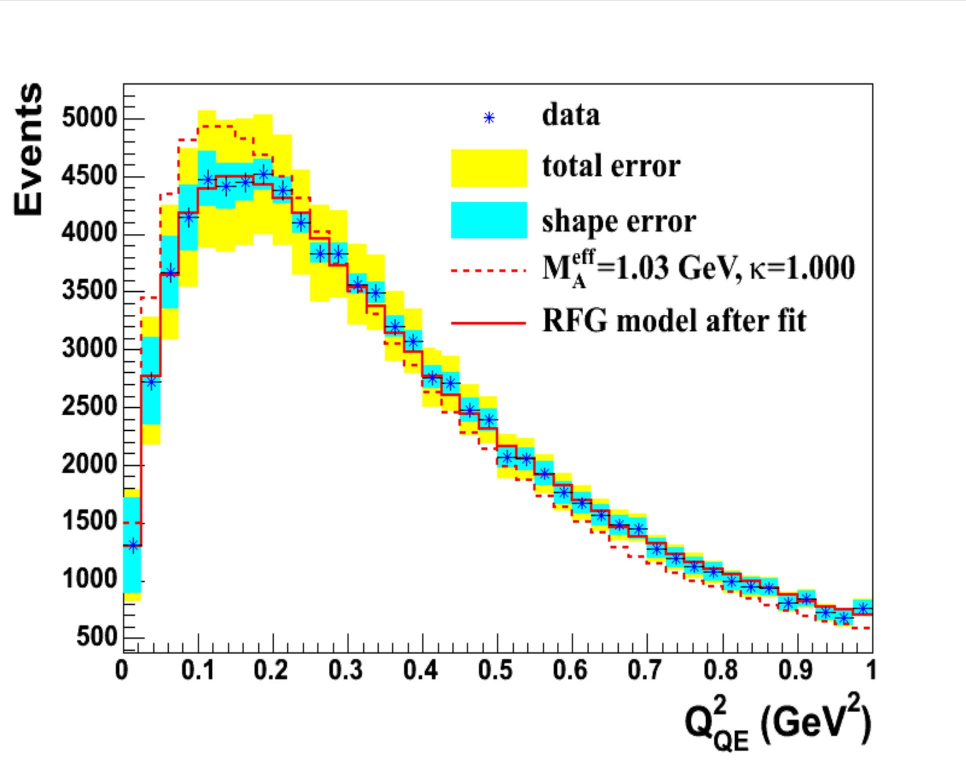


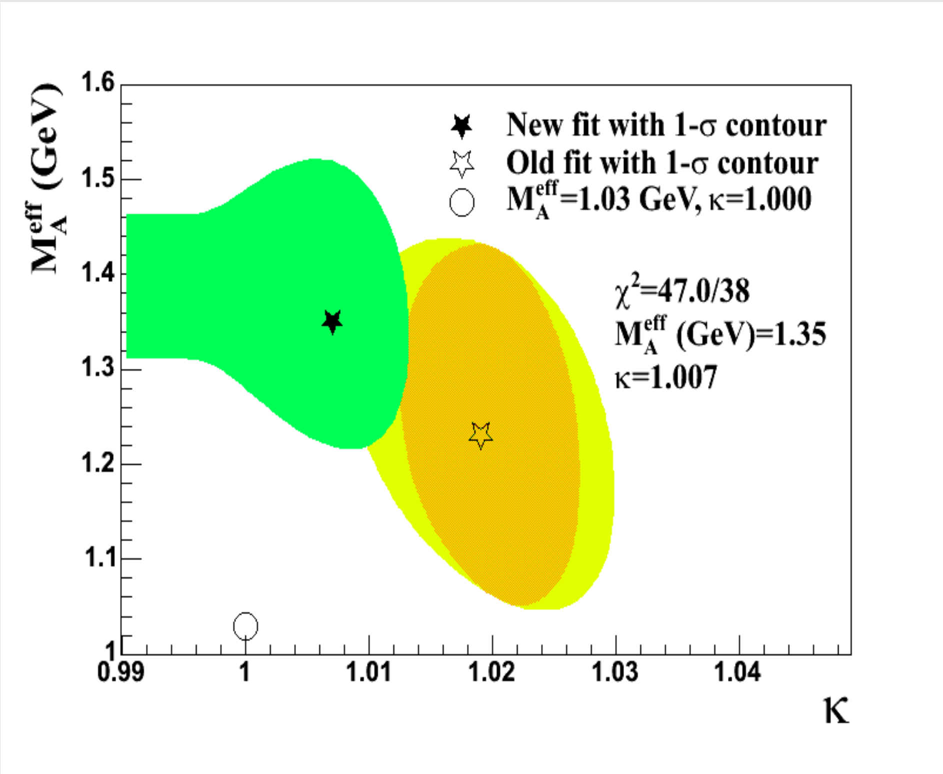
MiniBooNE CCQE results

M_A^{eff} - κ shape-only fit result

M_A^{eff} = 1.35 ± 0.17 GeV (stat+sys)
$\kappa = 1.007^{+0.007}_{-\infty}$ (stat+sys)
χ^2/ndf = 47.0/38

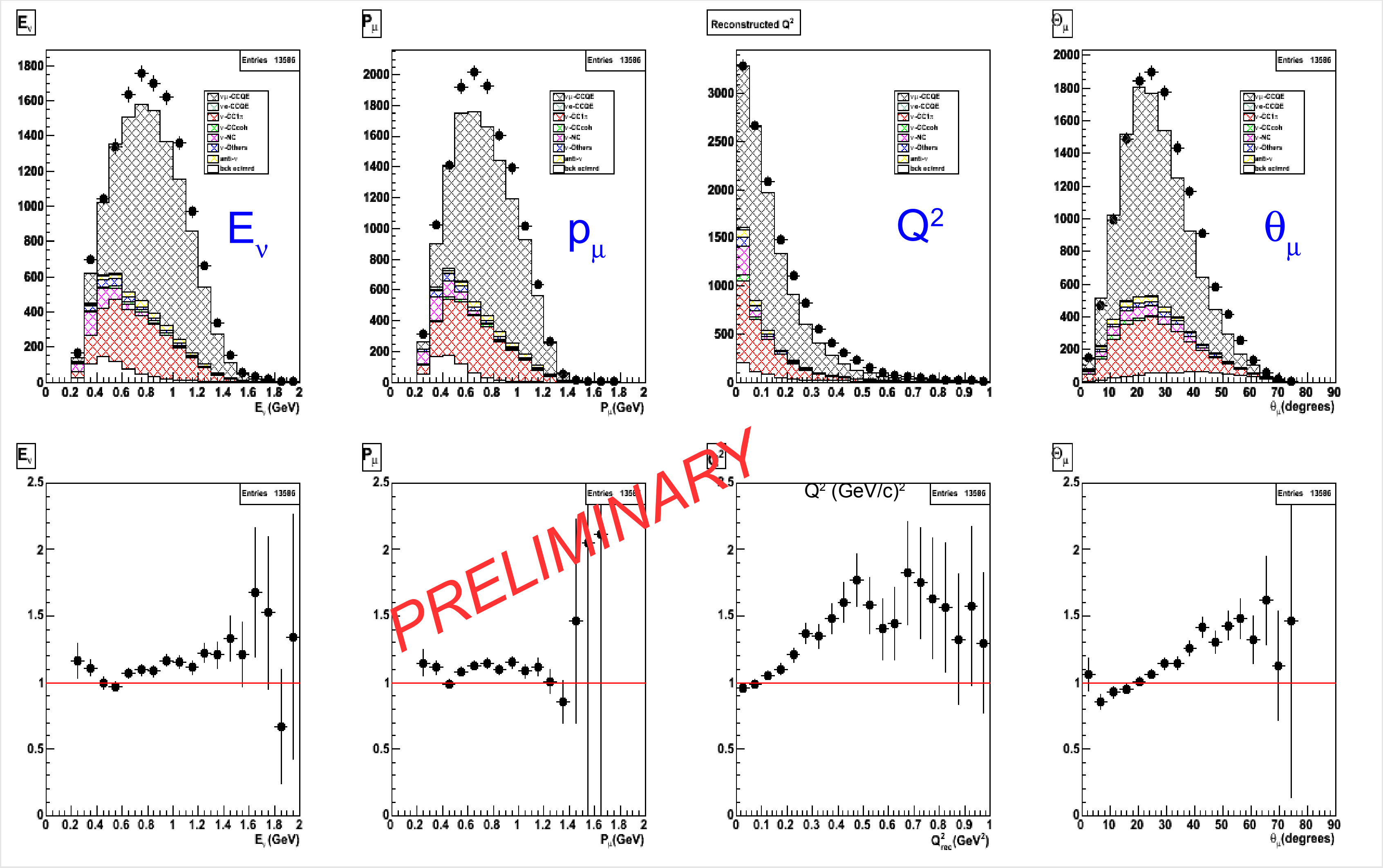
- κ is Pauli-Blocking adjustment parameter that gives extra dof to fit at low-Q^2 .
- MB data now consistent with κ = 1. Change from earlier result due to new CCπ background





Preliminary CCQE results from SciBooNE

- 1 track (μ) MRD-stopped sample



- total measured rate data in excess compared to Neut MC (M_A=1.2GeV)
- excess of data at Q^2>0.2 GeV^2
- both are (qualitatively) similar to MiniBooNE observations