ν-N quasielastic scattering in MiniBooNE

Outline:

- Intro/Overview/Motivation
- Previous Results
- New results from MiniBooNE
  - ν CCQE scattering
  - ν NC elastic scattering
- Interpretations/conclusions

R. Tayloe, Indiana U.
FNAL joint exp-theory seminar
07/2010

ν scattering measurements and oscillations

In order to understand ν oscillations, it is crucial to understand the detailed physics of ν scattering (at 1-10 GeV)

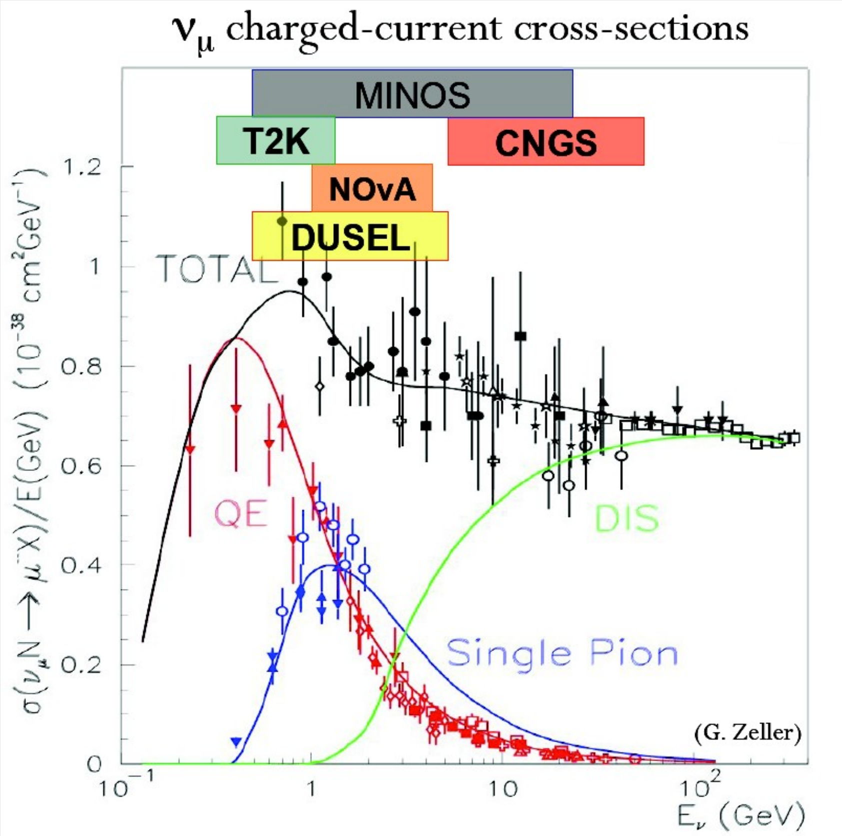
- for MiniBooNE, both signal and backgrounds
- and for others (T2K, NOvA, DUSEL etc)
- especially for *precision* (e.g. 1%) measurements.

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 with neutrino experiments:

- non-monoenergetic beams
- large backgrounds
- nuclear scattering (bound nucleons)

New measurements are appearing:
- SciBooNE, MINOS (currently)
- MINERvA, T2K, μBooNE, NOvA (soon)
...
- and MiniBooNE....



D. Schmitz, nufact'09

ν-N (quasi)elastic scattering in MiniBooNE

Today: MiniBooNE measurements of these 2 fundamental processes

- ν_μ charged-current (CC) quasielastic (CCQE)
    - detection and normalization signal for oscillations
- ν_μ neutral-current (NC) elastic (NCel)
    - an important test of our scattering model

.. at 0.5-2.0 GeV neutrino energy

- Together they comprise >50% of all neutrino interactions in MB

- Nucleons are (mostly) bound as MiniBooNE target/detector is CH_2 (some free for NCel)

- Historically, "quasielastic" in "CCQE" comes from high-energy ν experiments where muon mass is negligible. But should be approximately QE in the nuclear physics sense (bound, but independent nucleons). An important point to test.

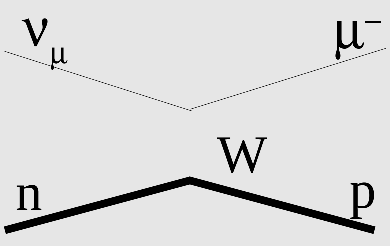
Recent publications from MB on these channels:

CCQE: Phys. Rev. D81, 092005 (2010),
Thesis: Teppei Katori (Indiana U, now at MIT)

NCel: (just) submitted to arXiv (will appear monday)
Thesis: Denis Perevalov (Alabama U, now at FNAL)

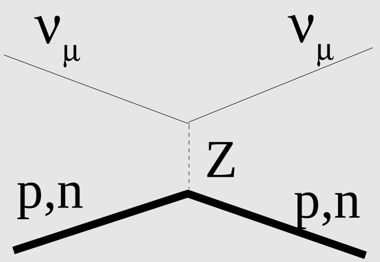
ν_μ CCQE

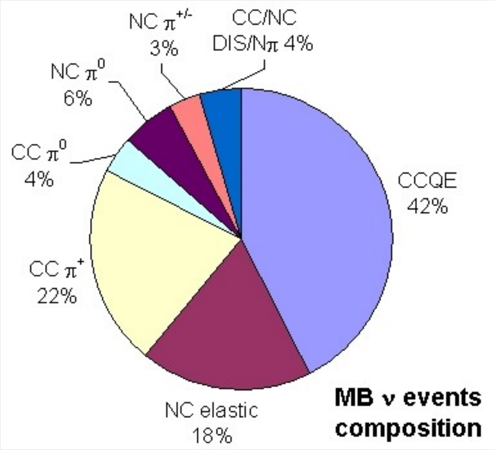
$$\nu_\mu n \rightarrow \mu^- p$$



ν_μ NC elastic

$$\nu_\mu N \rightarrow \nu_\mu N$$

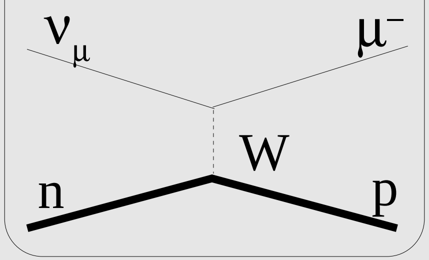




modeling ν QE scattering

ν_μ CCQE

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



The canonical model for the ν QE process is fairly simple.

Based on impulse-approximation (IA) together with rel Fermi gas (RFG).

- start with Llewellyn-Smith formalism for differential cross section:

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

 - lepton vertex well-known
 - nucleon vertex parameterized with 2 vector formfactors (F_1,F_2), and 1 axial-vector (F_A)
 - F_1, F_2, F_A (inside of A,B,C) are functions of Q^2 = 4-momentum transfer

- To apply (for a nucleus, such as carbon)
 - assume bound but independent nucleons (IA)
 - use Rel. Fermi Gas (RFG) model (typically Smith-Moniz), with params from e-scattering
 - F_1,F_2 also from e-scattering measurements
 - F_A is largest contribution, not well known from e scattering, but
 - F_A (Q^2=0) = g_A known from beta-decay and
 - assume dipole form, same M_A should cover all experiments.

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

- No unknown parameters (1 if you want to fit for M_A)

- can be used for prediction of CCQE rates and final state particle distributions.

- Until recently, this approach has appeared adequate and
 all common neutrino event generators use a model like this..

Summary of M_A from CCQE scattering

- M_A values extracted from various experiments

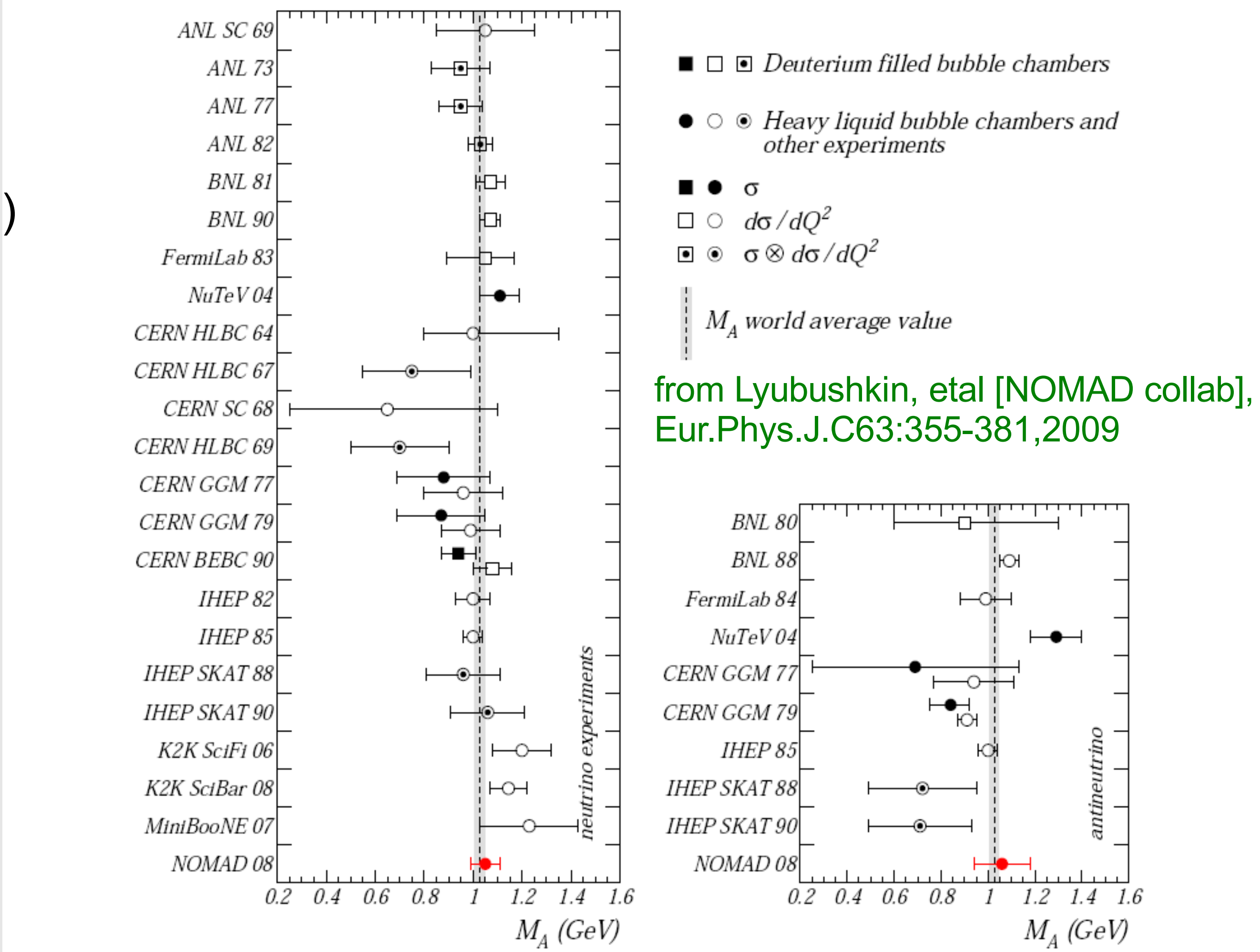
- different targets/energies, fit strategies

- world average (as of 2002)
  M_A=1.026±0.021 GeV
  (Bernard, etal, JPhysG28, 2002)

- Also, M_A from π electro-production similar

- However, recent data from some high-stats experiments not well-described with this M_A . (or perhaps the physics model).

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



from Lyubushkin, etal [NOMAD collab], Eur.Phys.J.C63:355-381,2009

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

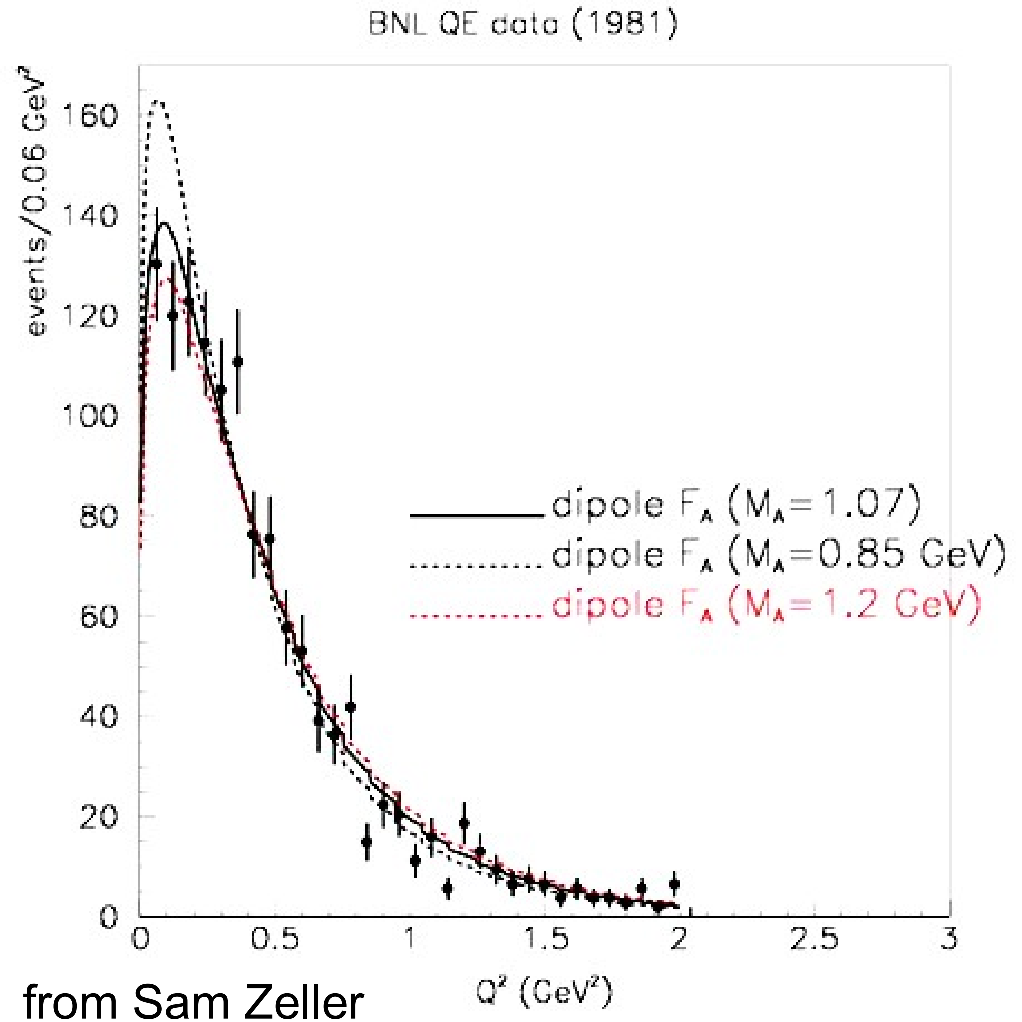
For example, BNL CCQE data:

- Baker, PRD 23, 2499 (1981)
- data on D_2
- 1,236 ν_μ QE events
- M_A=1.07 +/- 0.06 GeV

- curves with diff M_A values, relatively norm'd, overlaid.

- M_A extracted from the shape of this data in Q^2

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



from Sam Zeller

Previous CCQE results

- K2K results from scifi (in water) detector (PRD74, 052002, '06)

- Q^2 spectrum: more events at $Q^2 > 0.2\ GeV^2$

- also note data deficit $Q^2 < 0.2\ GeV^2$

- shape only fit of Q^2 distribution yields $M_A = 1.20 \pm 0.12$

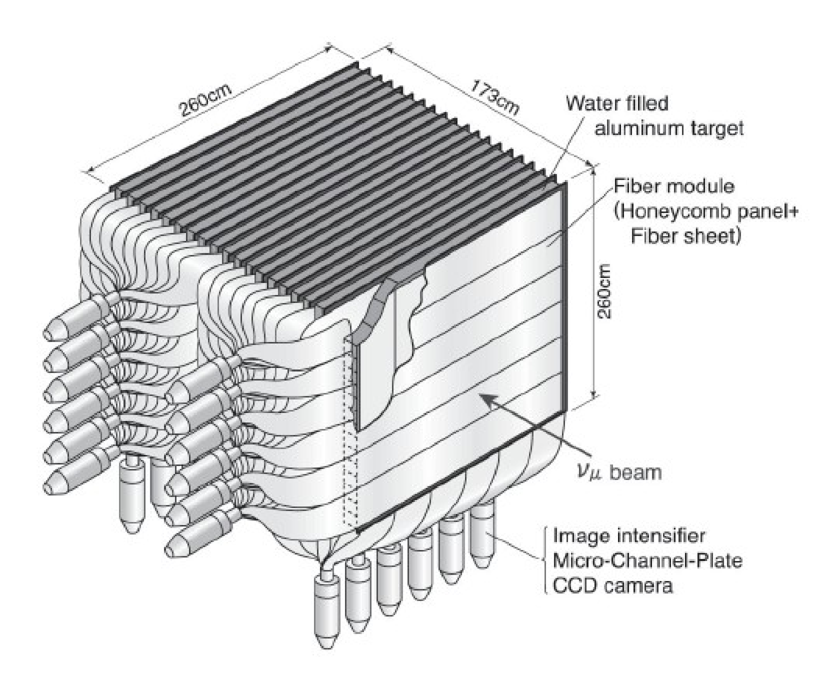
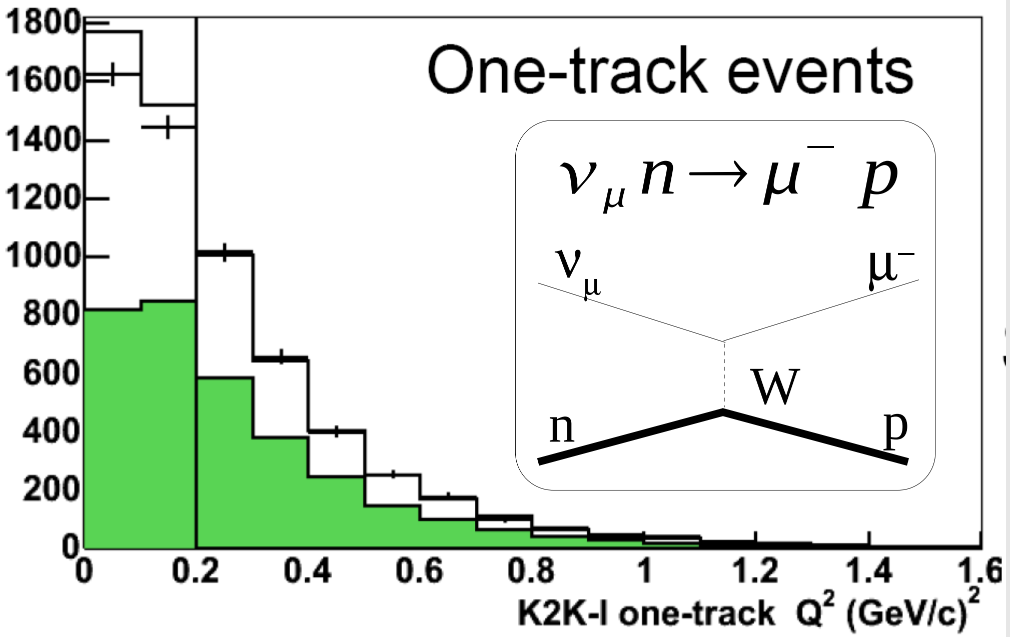
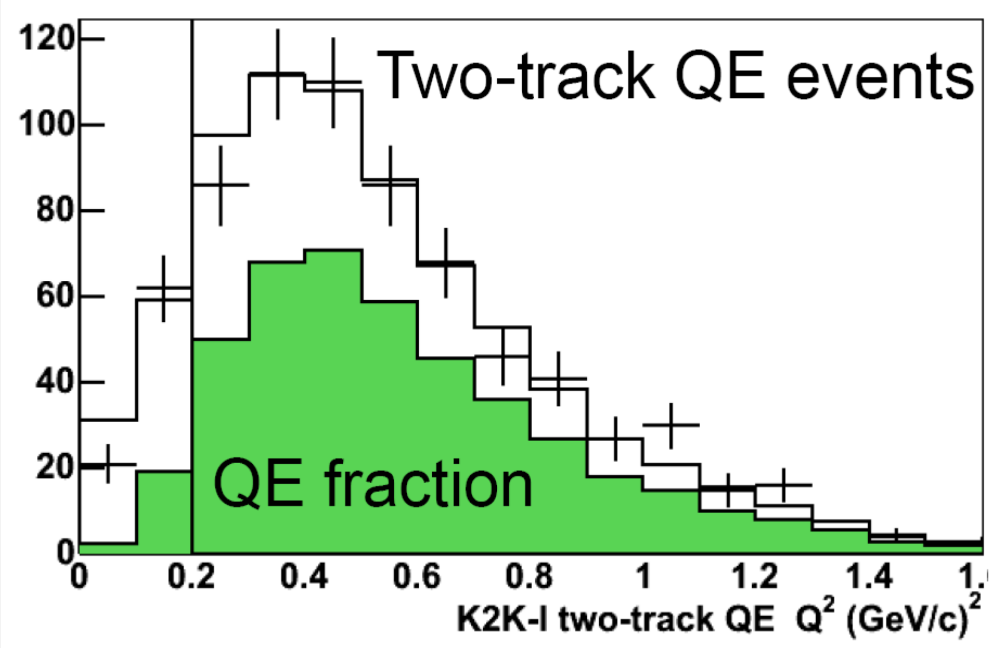


FIG. 2. A schematic diagram of the SciFi detector.





from Rik Gran, Nuint09

Previous CCQE results

- MiniBooNE results (from CH_2)
  (PRL100, 0323021, '08)

- Q^2 spectrum of data, compared to world-average M_A (dashed)
  shows substantial event excess at $Q^2 > 0.2$ GeV^2.
  ⇒ requires larger M_A

- Also event deficit at $Q^2 < 0.2$ GeV^2
  ⇒ requires new parameter, κ, to increases "Pauli-blocking" of FS nucleon

- shape-only fit of Q^2 distribution yielded:

$$M_A^{\text{eff}} = 1.23 \pm 0.20 \text{ GeV},$$

$$\kappa = 1.019 \pm 0.011.$$

- "eff" = effective to acknowledge possible nuc. effects.

- fit with Q2 > 0.2 GeV^2 yields:
  M_A=1.25±0.12 GeV

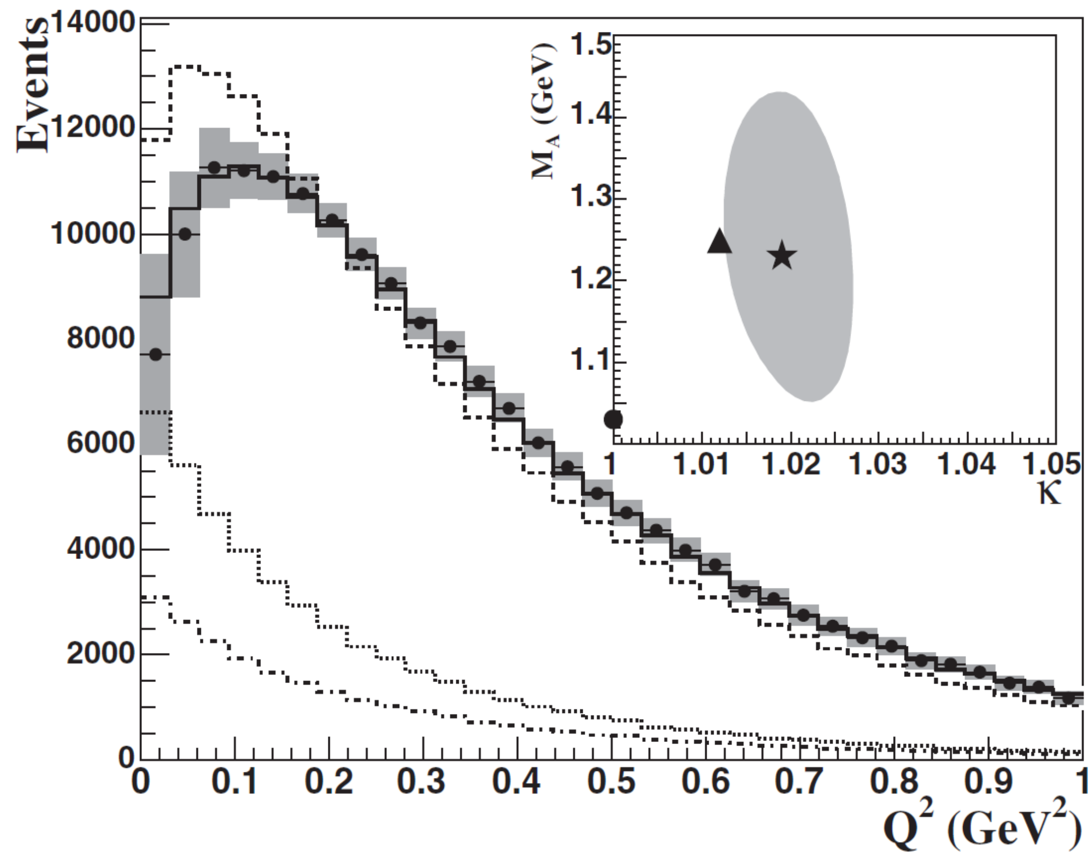


FIG. 2. Reconstructed Q^2 for ν_μ CCQE events including systematic errors. The simulation, before (dashed curve) and after (solid curve) the fit, is normalized to data. The dotted curve (dot-dashed curve) shows backgrounds that are not CCQE (not "CCQE-like"). The inset shows the 1σ C.L. contour for the best-fit parameters (star), along with the starting values (circle), and fit results after varying the background shape (triangle).

Previous CCQE results

- MINOS results (from Fe)
  (AIP Conf.Proc.1189:133-138,2009, M. Dorman thesis)

- M_A from Q^2-shape fit also larger than world-average

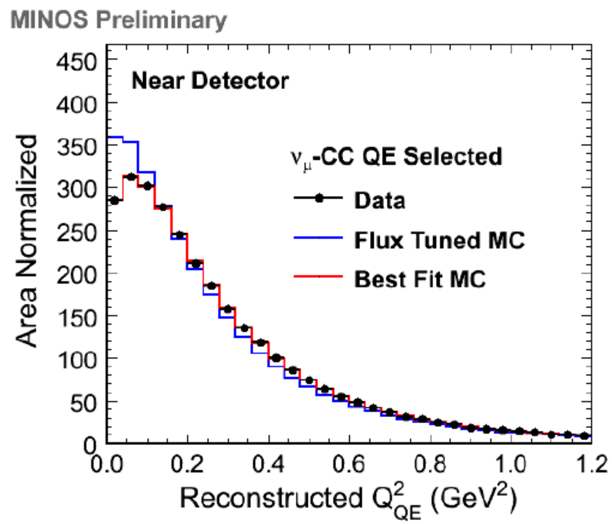
- Pauli-blocking-like tuning also req'd.

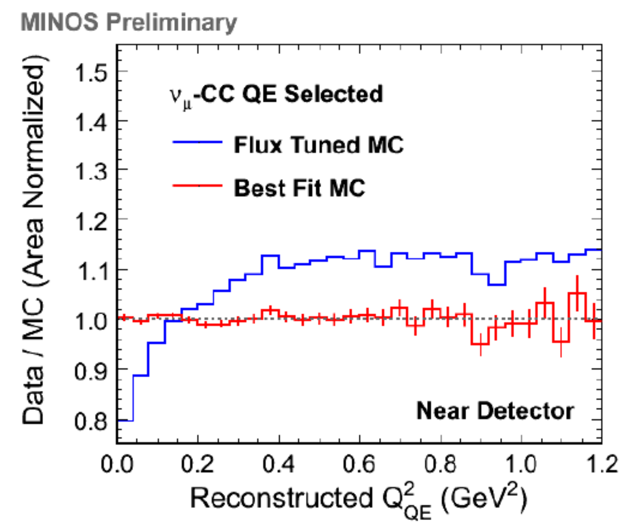
- similar themes to that of MiniBooNE results.. on Fe (!?)

from MINOS public plots

Quasi-Elastic Axial Mass

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





Effective $M_A^{QE} = 1.19\ ^{+0.09}_{-0.10}\ \text{(fit)}\ ^{+0.12}_{-0.14}\ \text{(syst) GeV}$

Parameter	M_A^{QE} (GeV)	E_μ-Scale	M_A^{RES} (GeV)	k_{Fermi}-Scale
Best Fit	1.192	0.988	1.112	1.284

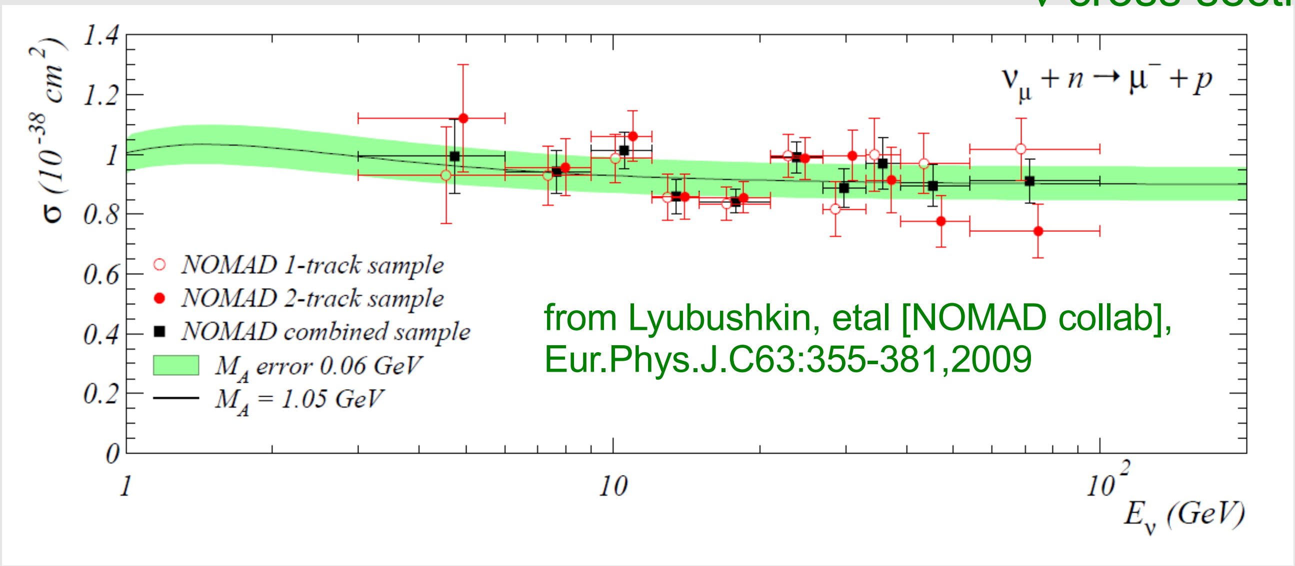
Fit needs to warp nuclear model to reduce cross-section at low Q^2

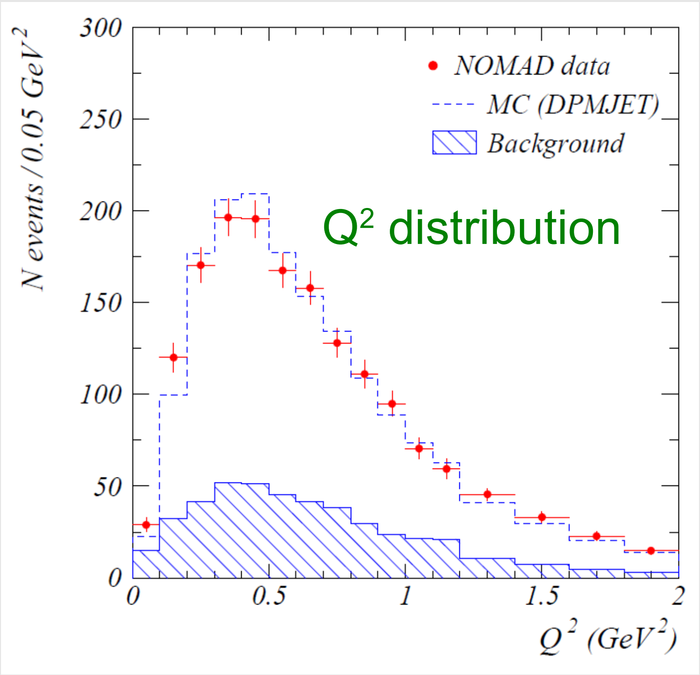
14 June 2010 MINOS 2010 Highlights

Previous CCQE results

- NOMAD (carbon target), total cross section as function of E_ν

ν cross section





- from total cross section (normalized to inverse μ decay) of 1 and 2-track samples:

M_A =1.05±0.02±0.06 GeV

- Q^2 shape consistent with this M_A

Previous CCQE results

- So there exists a mystery in CCQE scattering
  - What is M_A ?

  - Different for different nuclei?

  - Is that even the right question (for nuclei)?

  - Inadequate model?

- In addition: Have old experimental assumptions clouded the issue?

  EG: ν flux tuning based on ν data ?

- This overall situation motivated the MiniBooNE extraction of absolutely normalized (differential) cross sections...

PHYSICAL REVIEW D VOLUME 23, NUMBER 11 1 JUNE 1981

Quasielastic neutrino scattering: A measurement of the weak nucleon axial-vector form factor

N. J. Baker, A. M. Cnops,* P. L. Connolly, S. A. Kahn, H. G. Kirk, M. J. Murtagh, R. B. Palmer, N. P. Samios, and M. Tanaka
Brookhaven National Laboratory, Upton, New York 11973
(Received 12 February 1981)

BNL QE data, Baker, PRD 23, 2499 (1981)

with the data. Figure 7 shows the relative v_μ flux spectrum obtained from the observed E_v distribution of the events after correcting for the deuteron effects and the Q_{min}^2 cut.

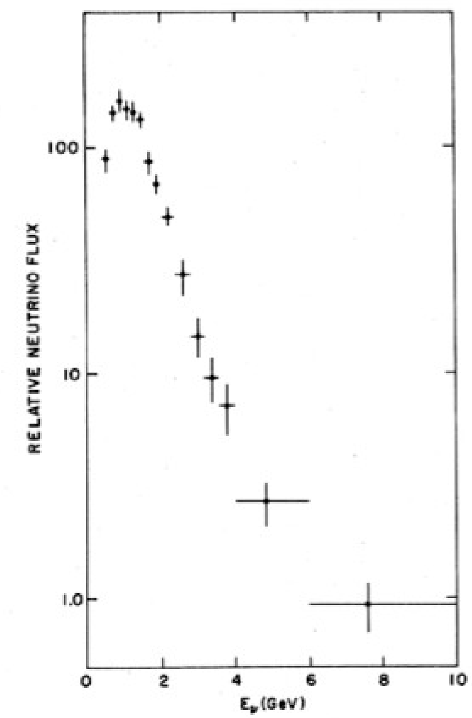
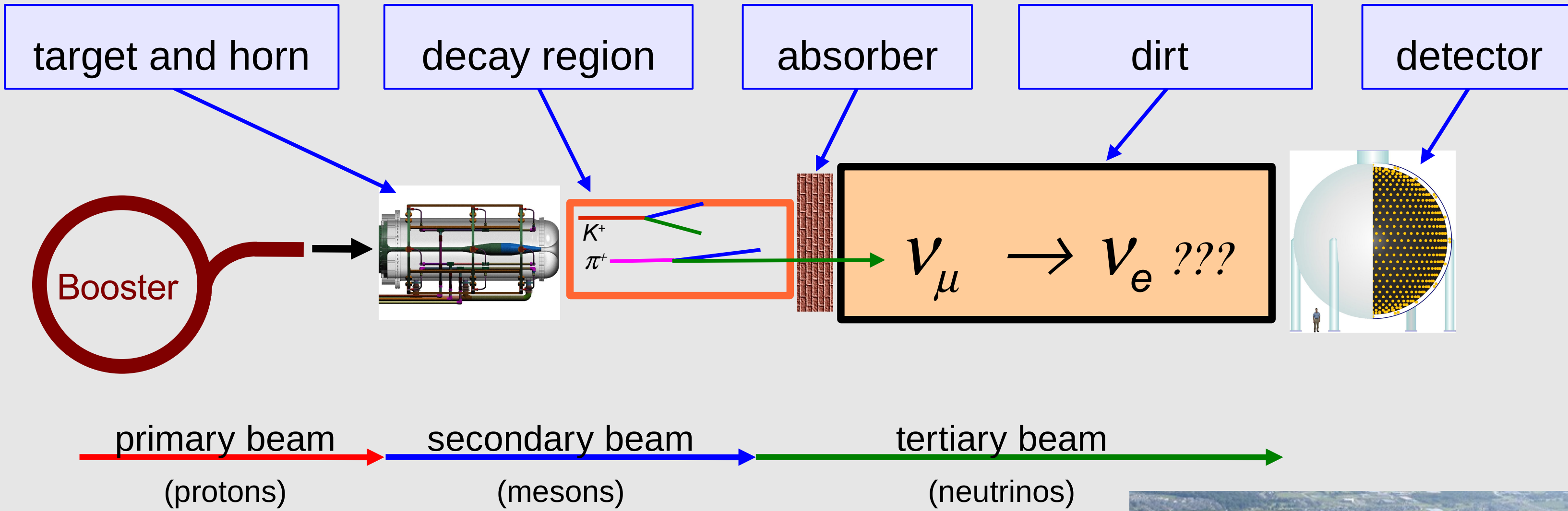


FIG. 7. The relative ν_μ flux spectrum obtained from the observed E_ν distribution of the events with $M_A = 1.07$ GeV.

MiniBooNE experiment, overview

- Built to test the LSND observation of ν oscillations via $\nu_\mu \rightarrow \nu_e$ (and $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$) appearance.
- Currently running. 2002-2005, 2007 in ν_μ mode, 2005-2006, 2008-2012(ish) $\bar{\nu}_\mu$ mode.
- ~15 papers published (so far, on oscillations, scattering, details) See http://www-boone.fnal.gov/publications/ (theses available there also)



MiniBooNE experiment, ν flux

- Crucial to produce absolute cross sections

- determined from π prod measurements plus detailed MC simulations of target+horn (PRD79(2009)072002)

- no flux tuning based on MB data

- most important π prod measurements from HARP (at CERN) at 8.9 GeV/c beam momentum (as MB), 5% int. length Be target (Eur.Phys.J.C52(2007)29)

- error on HARP data (7%) is dominant contribution to flux uncertainty

- overall 9% flux uncertainty, dominates cross section normalization (“scale”) error

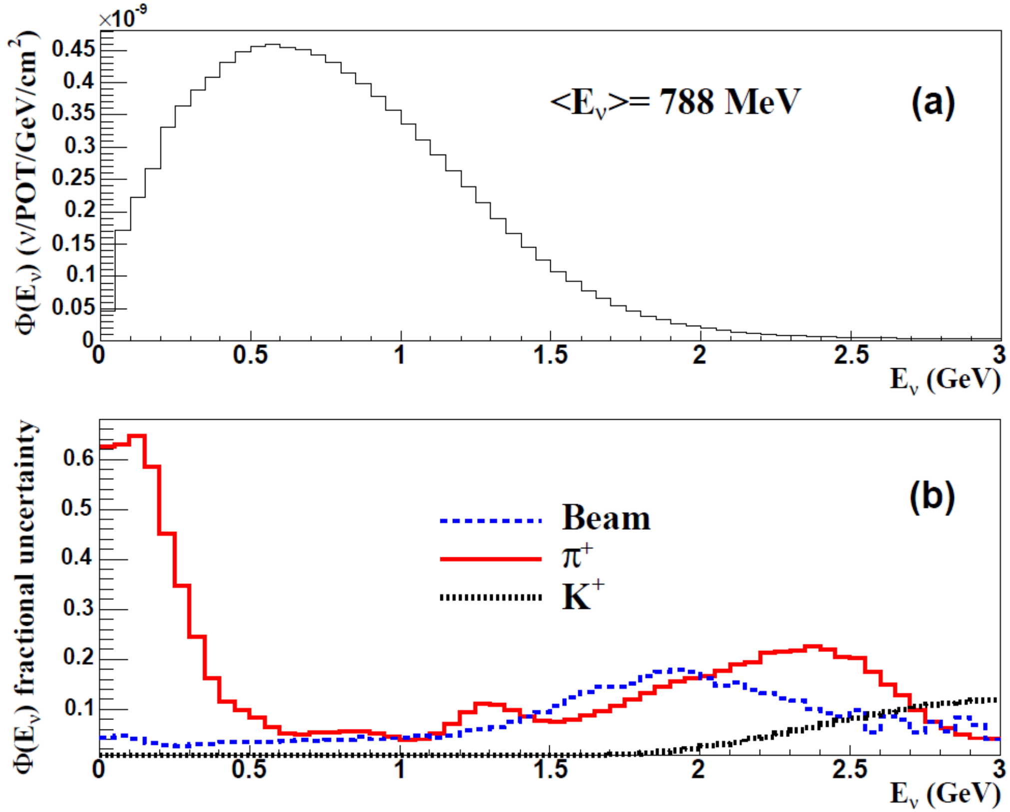
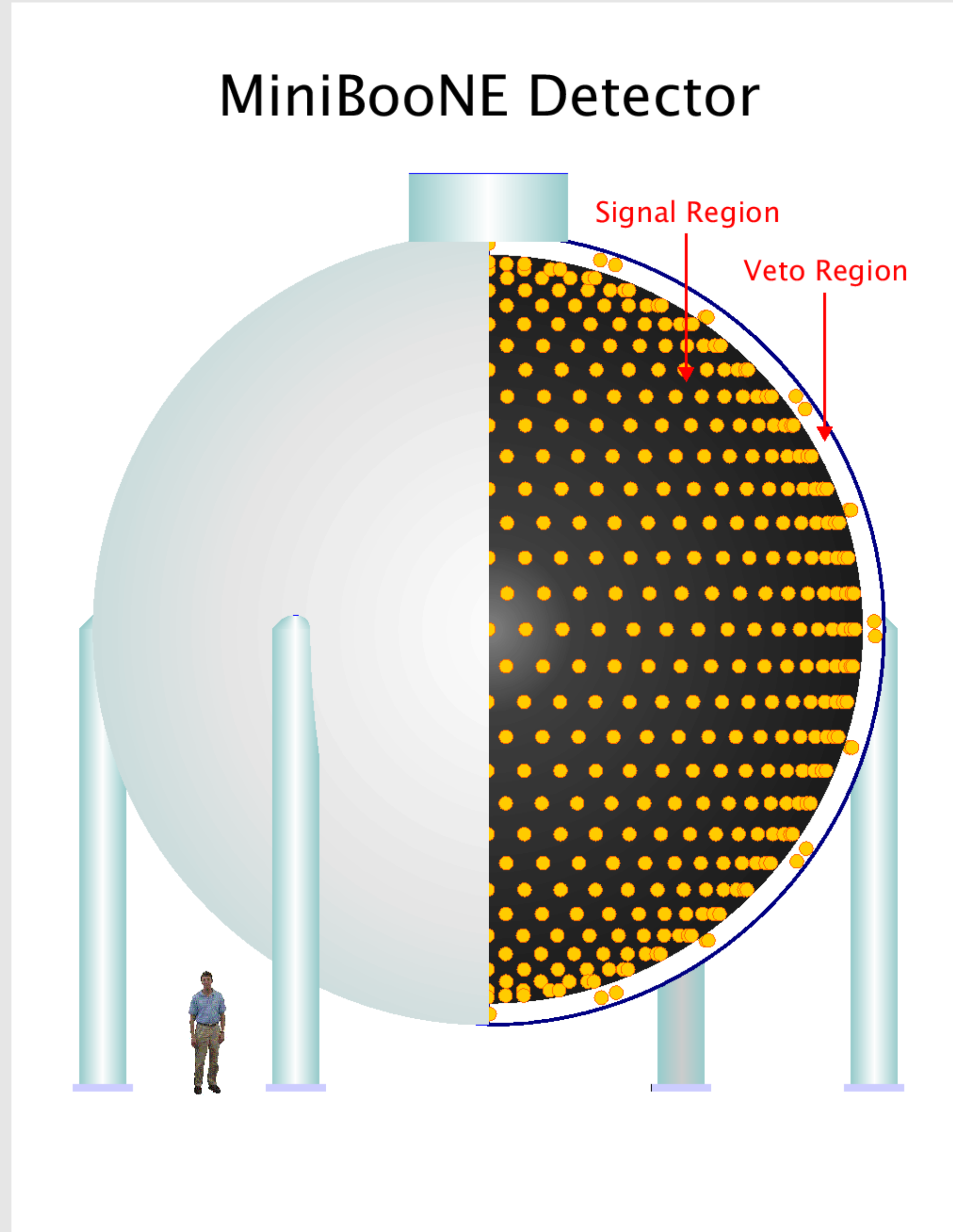


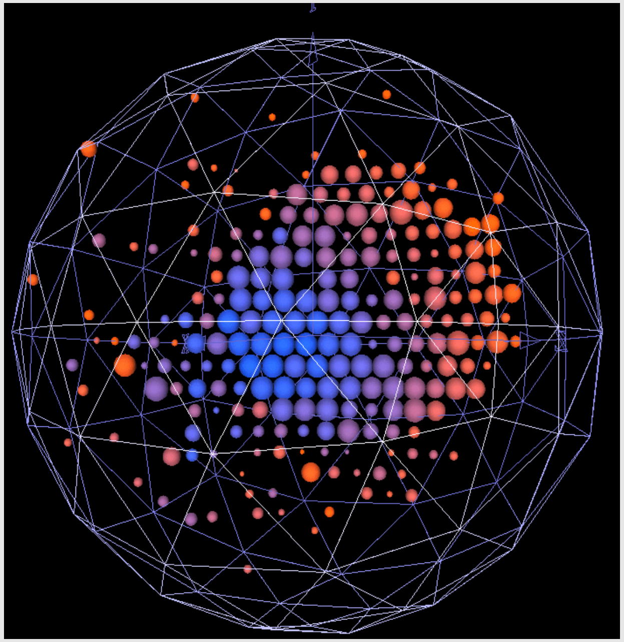
FIG. 2: (color online) Predicted ν_μ flux at the MiniBooNE detector (a) along with the fractional uncertainties grouped into various contributions (b). The integrated flux is 5.16×10^{-10} $\nu_\mu/\mathrm{POT/cm}^2$ ($0 < E_\nu < 3$ GeV) with a mean energy of 788 MeV. Numerical values corresponding to the top plot are provided in Table V in the Appendix.

MiniBooNE experiment, ν detector

- 541 meters from target
- 12 meter diameter sphere
- 800 tons mineral oil (CH_2)
- 3 m overburden
- includes 35 cm “veto region”
- viewed by 1280 8” PMTs (10% coverage) + 240 veto
- Simulated with a GEANT3 Monte Carlo program



MiniBooNE experiment, event reconstruction



- Charged particles in MB create cherenkov (and some scintillation) light

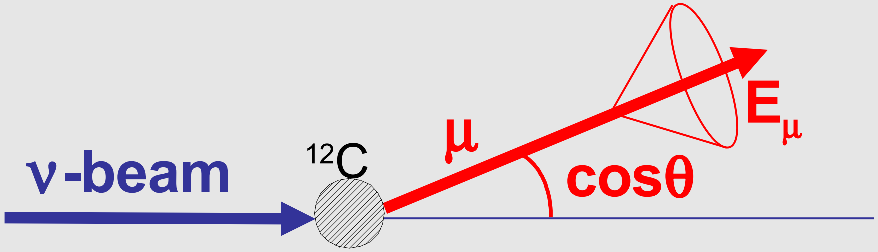
- Tracks reconstructed (energy, direction, position) with likelihood method utilizing time, charge of PMT hits (NIM, A 608 (2009), pp. 206-224)

- In addition, muon, pion decays are seen by recording PMT info for 20μs around 2μs beam spill

- In CCQE analysis, all observables are formed from muon energy (E_μ) and muon scattering angle (θ_μ)

- E_ν^{QE} and Q^2_{QE} reconstructed from E_μ , θ_μ with assumption of interaction with bound neutron at rest (“QE assumption”)

- For NCel, observables from new proton fitter, no E_ν^{QE} possible and $Q^2_{QE} = 2m_pT_p$



$$E_\nu^{QE} = \frac{2(M_n')E_\mu - ((M_n')^2 + m_\mu^2 - M_p^2)}{2\cdot[(M_n') - E_\mu + \sqrt{E_\mu^2 - m_\mu^2}\cos\theta_\mu]}, \quad (1)$$

$$Q^2_{QE} = -m_\mu^2 + 2E_\nu^{QE}(E_\mu - \sqrt{E_\mu^2 - m_\mu^2}\cos\theta_\mu), \quad (2)$$

MiniBooNE CCQE analysis

- CCQE experimental defintion: 1 μ^- , no π
- Requires id of stopping μ^- and 1 decay e^- (2 “subevents”)

$$\nu_\mu + n \rightarrow \mu^- + p$$
$$\quad \hookrightarrow \nu_\mu + \nu_e + e^- \quad (\tau \sim 2\mu s)$$

- (No selection on (and ~no sensitivity to) f.s. nucleon)
- CCπ produces 2 decay electrons (3 subevents)

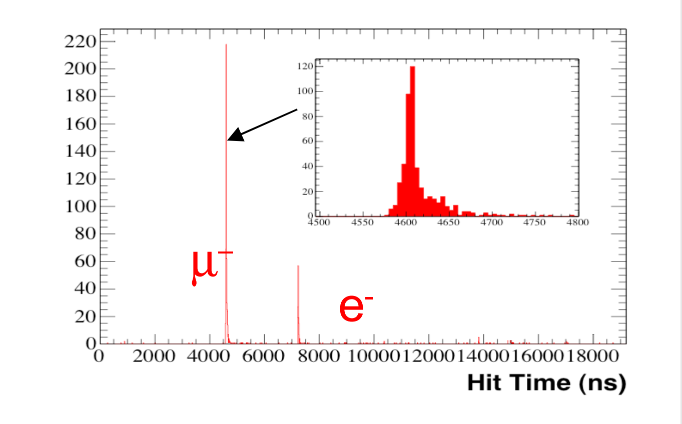
$$\nu_\mu + N \rightarrow \mu^- + N + \pi^+$$
$$\quad \hookrightarrow \mu^+ \rightarrow \nu_\mu + \nu_e + e^+ \quad (\tau \sim 2\mu s)$$
$$\quad \hookrightarrow \nu_\mu + \nu_e + e^- \quad (\tau \sim 2\mu s)$$

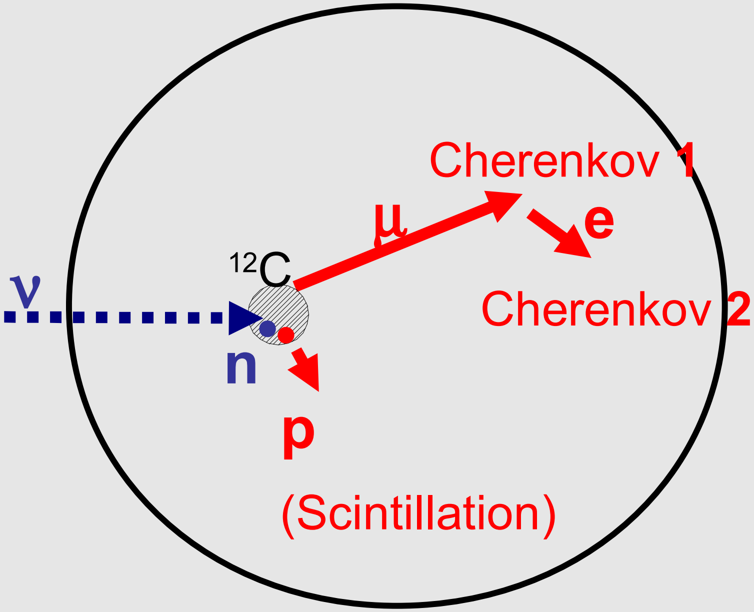
- CCπ^+ is (largest) background,
  (e^{+-} missed because of π absorption, μ^- capture)

- Important detail:
  - MiniBooNE data used to measure this background
  - ~1/2 of CCπ background is “irreducible”
    (no π in final state)

Final CCQE sample:
- 146k CCQE candidates
- 27% efficiency
- 77% purity

evt time dist in (19μs) DAQ window





MiniBooNE CCQE analysis

- At this stage, fit (shape-only) for M_A, κ
  (but, not main result of analysis and has no effect on cross section results).

  M_A^{eff} = 1.35 ± 0.17 GeV (stat+sys)
  κ = 1.007± 0.007(stat+sys)
  χ^2/ndf = 47.0/38

- Compared to prev result, best fit values change somewhat with new background (CCπ) measurement and subtraction.

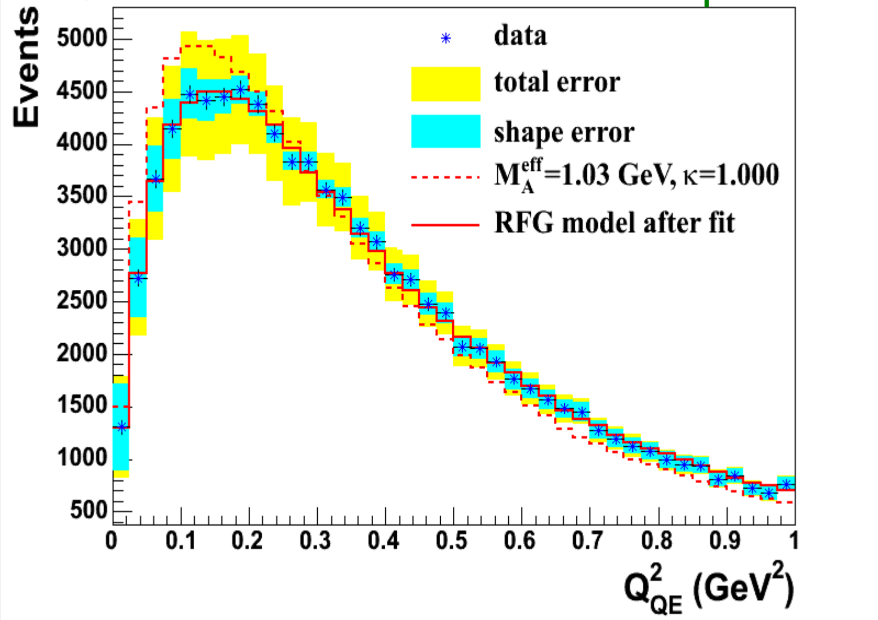
- data compared to world-average M_A and κ = 1.0 (no PB correction):
  χ^2/ndf = 67.5/40 (0.5% prob)

- M_A^{eff} only fit:
  M_A^{eff} = 1.37 ± 0.12 GeV
  χ^2/ndf = 48.6/39

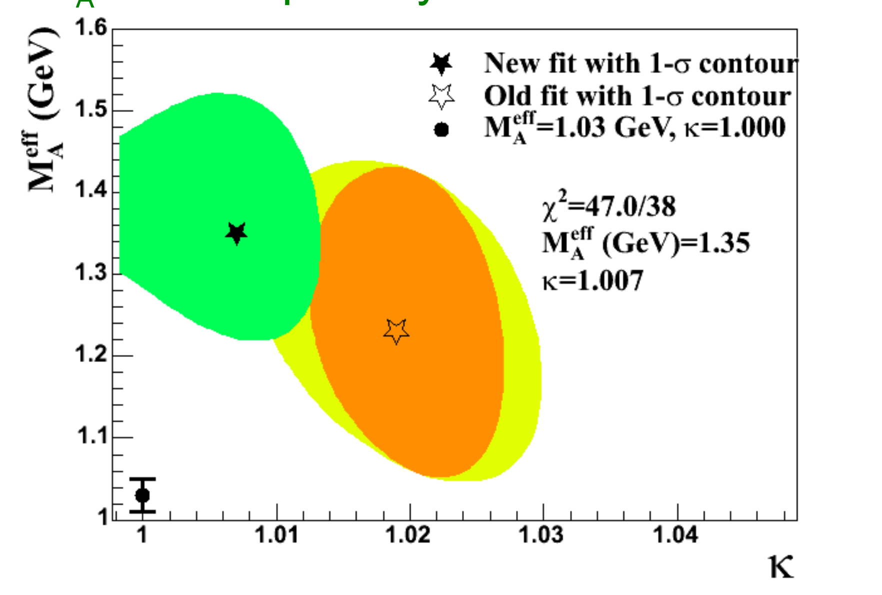
These fit parameters can now be used within MB RFG model for good description of data (modulo possible cross section normalization factors).

... then on to cross section extraction...

Q^2 distribution before/after shape-fit



M_A^{eff} - κ shape-only fit result



MiniBooNE CCQE results

Double-differential cross section:

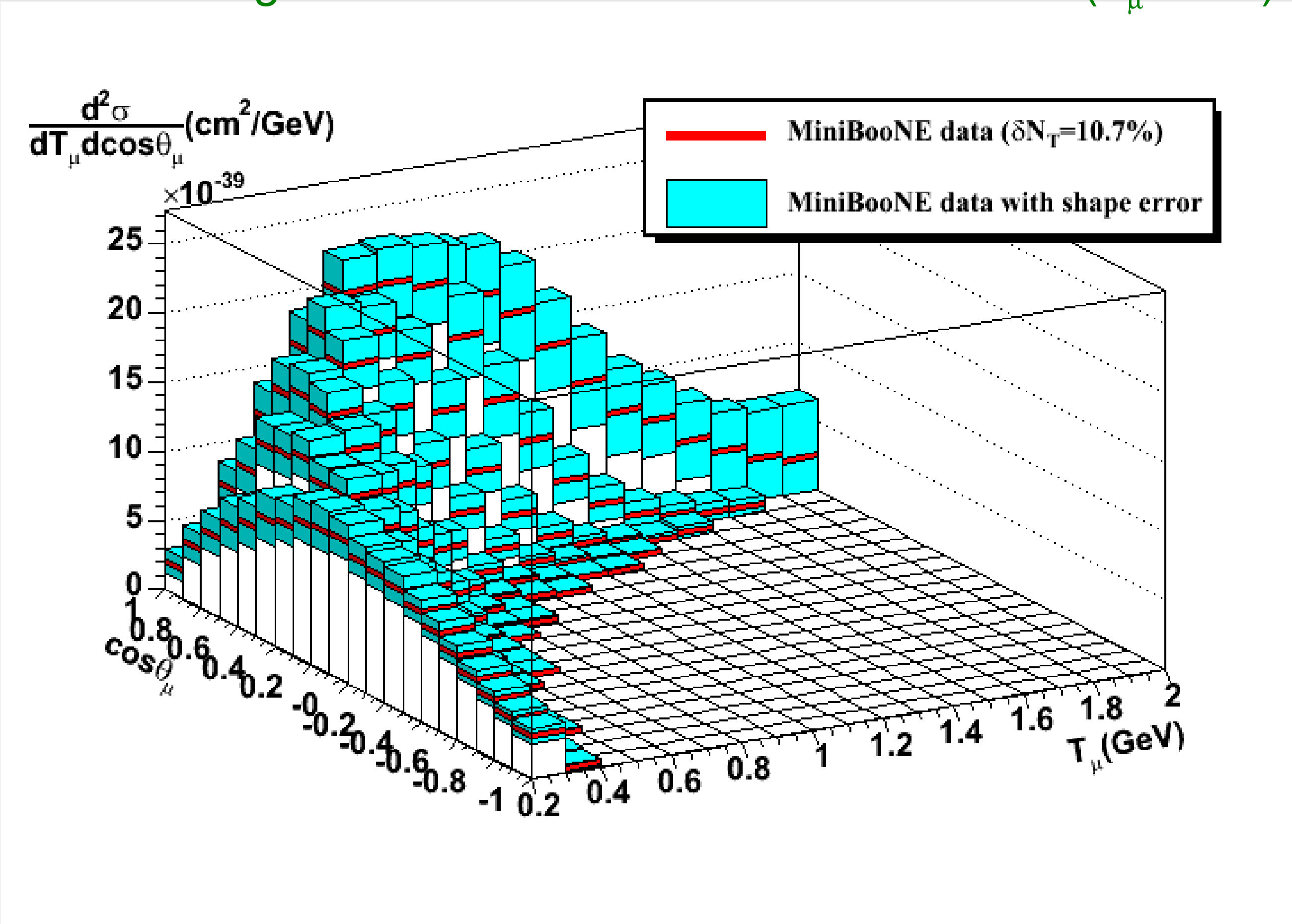
- Maximum information possible on CCQE process from MB (which uses muon only)

- model-independent result

- normalization (scale) error is 10.7% (not shown)

- error bars is remaining (shape) error

Flux-integrated double differential cross section (T_μ-cosθ):



MiniBooNE CCQE results

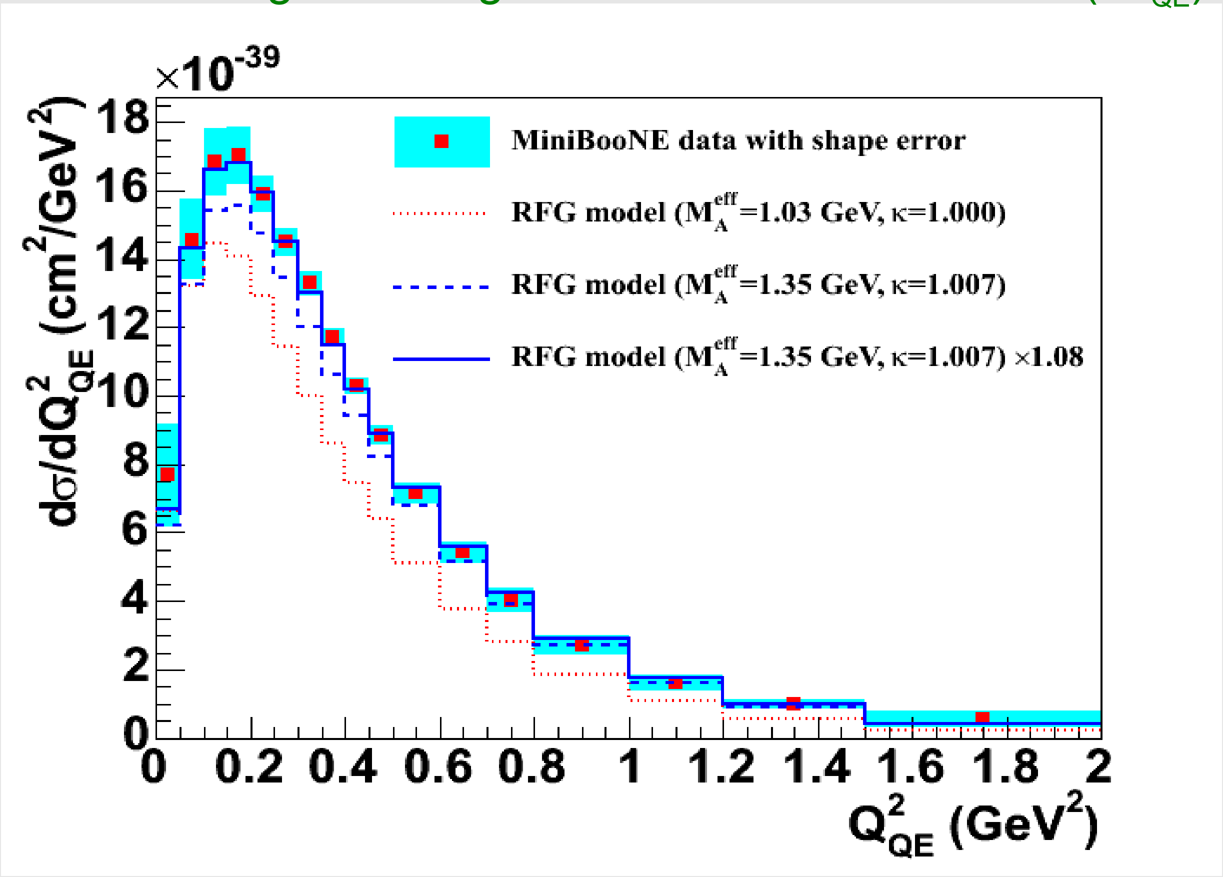
Single-differential cross section:

- data is compared (absolutely) with CCQE (RFG) model with various parameter values

- Compared to the world-averaged CCQE model (red), our CCQE data is 30% high

- model with our CCQE parameters (extracted from *shape-only* fit) agrees well with over normalization (to within normalization error).

Flux-integrated single differential cross section (Q^2_{QE}):



MiniBooNE CCQE results

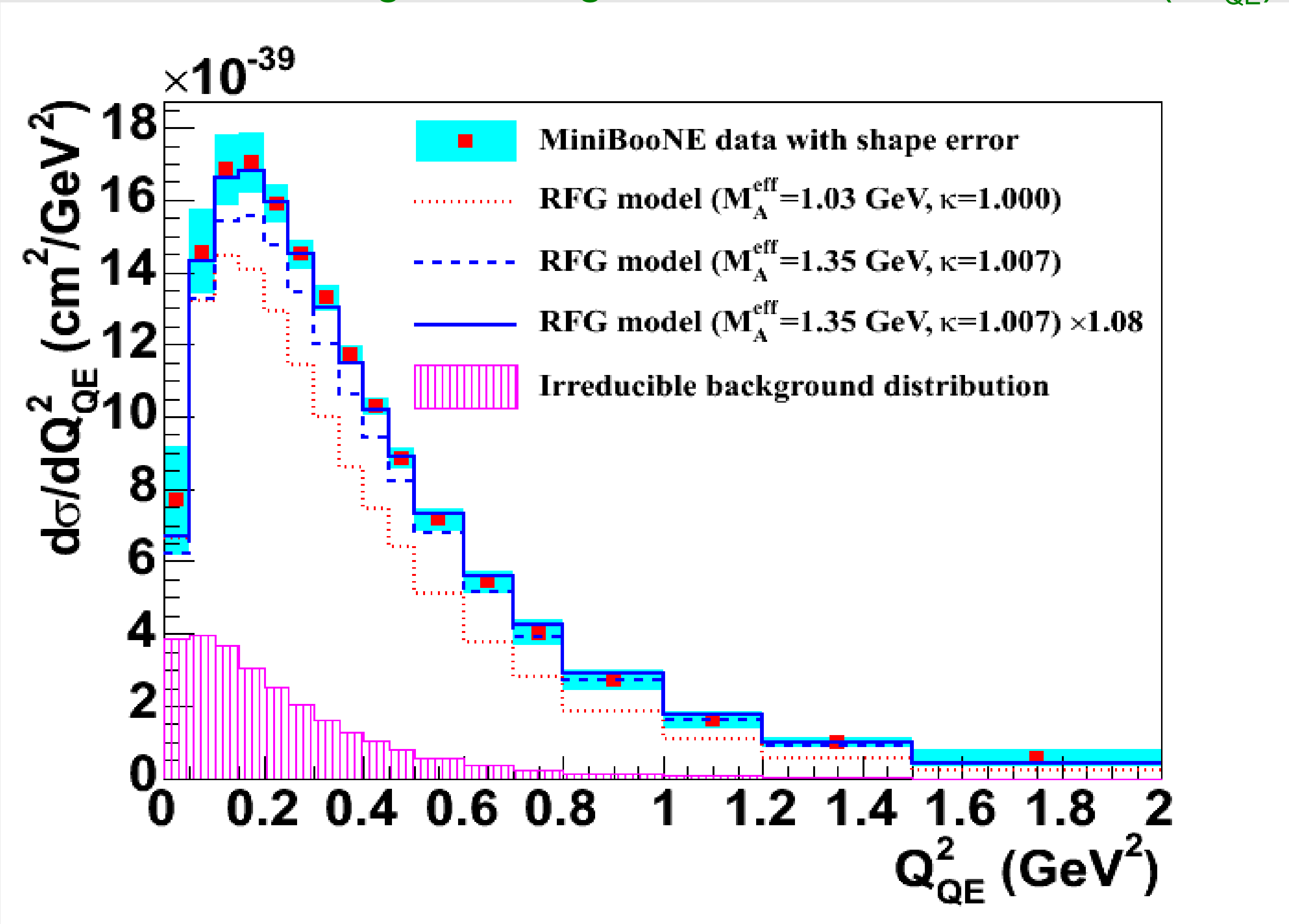
Single-differential cross section (again):

- same plot as previous but with "irreducible" (CCπ with π intra-nuc absorption) background shown.

- this background is subtracted, but may be undone (if desired) to produce "CCQE-like" sample

- also report this for double-diff xsection

Flux-integrated single differential cross section (Q^2_{QE}):



MiniBooNE CCQE results

Total cross section:

- Total cross section is extracted by binning in "true"
neutrino energy bins.
" $E_\nu^{QE,RFG}$ "

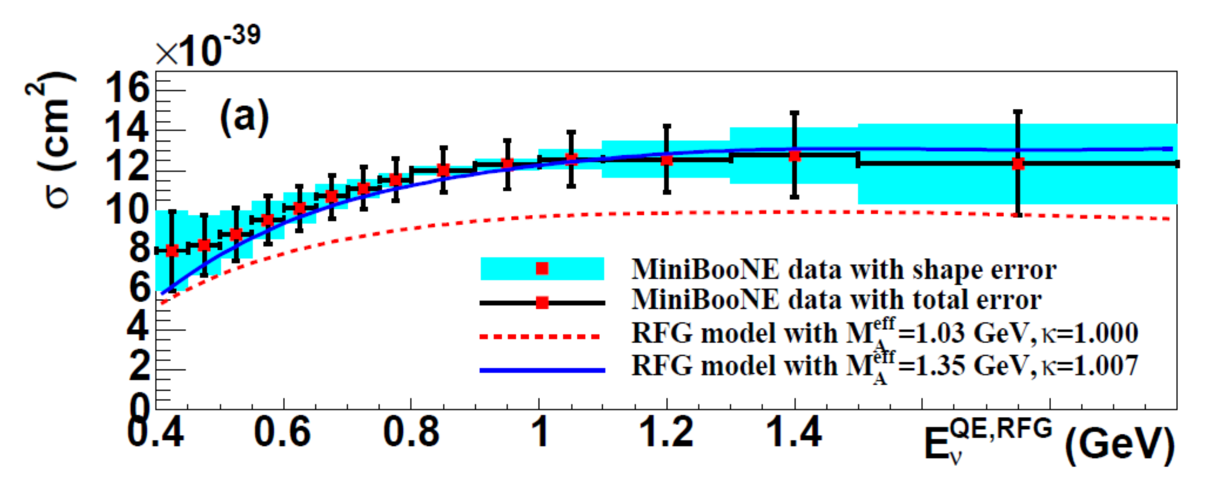
- Caution, model dependent,
(but this is conventional)

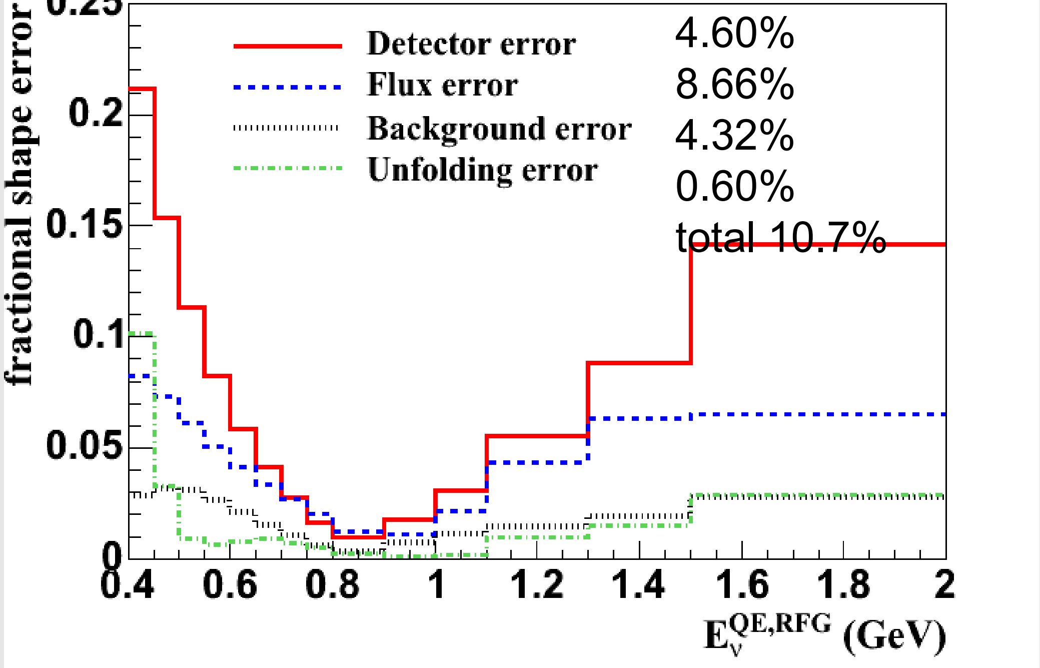
- Again, total cross section value well-reproduced from extracted CCQE model parameters

- Fractional errors (as function of neutrino energy) and overall normalization errors reported

- Note how frac errors grow "off-peak" of flux. Important to consider for extracting energy-dependence

Flux-unfolded total cross section ($E_\nu^{QE,RFG}$)





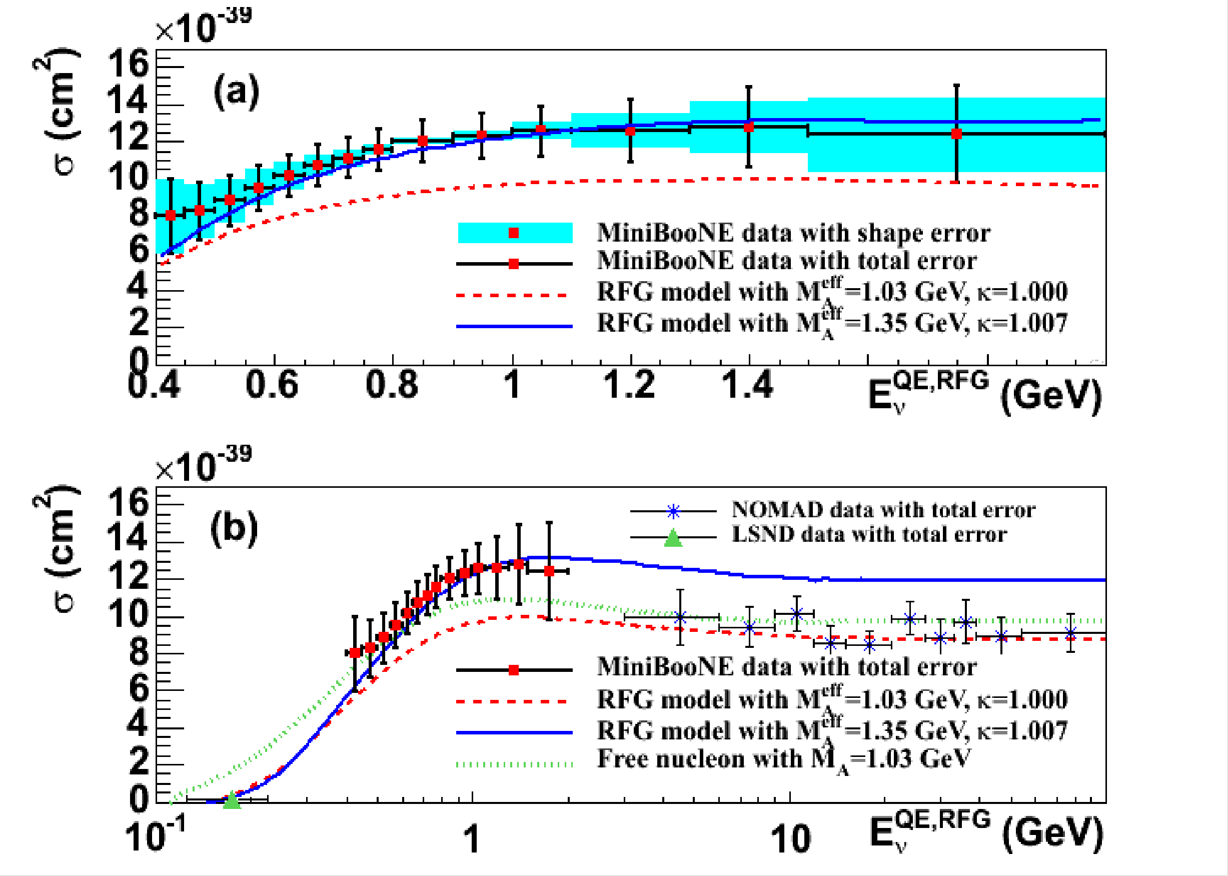
MiniBooNE CCQE results

- MiniBooNE total cross section:

  - ~30% larger than expected with world-average M_A
  - ~10% larger than free-nuc (world-average M_A) value

  - ~30% larger than NOMAD (at 5-100 GeV) !?

Flux-unfolded total cross section ($E_\nu^{QE,RFG}$)



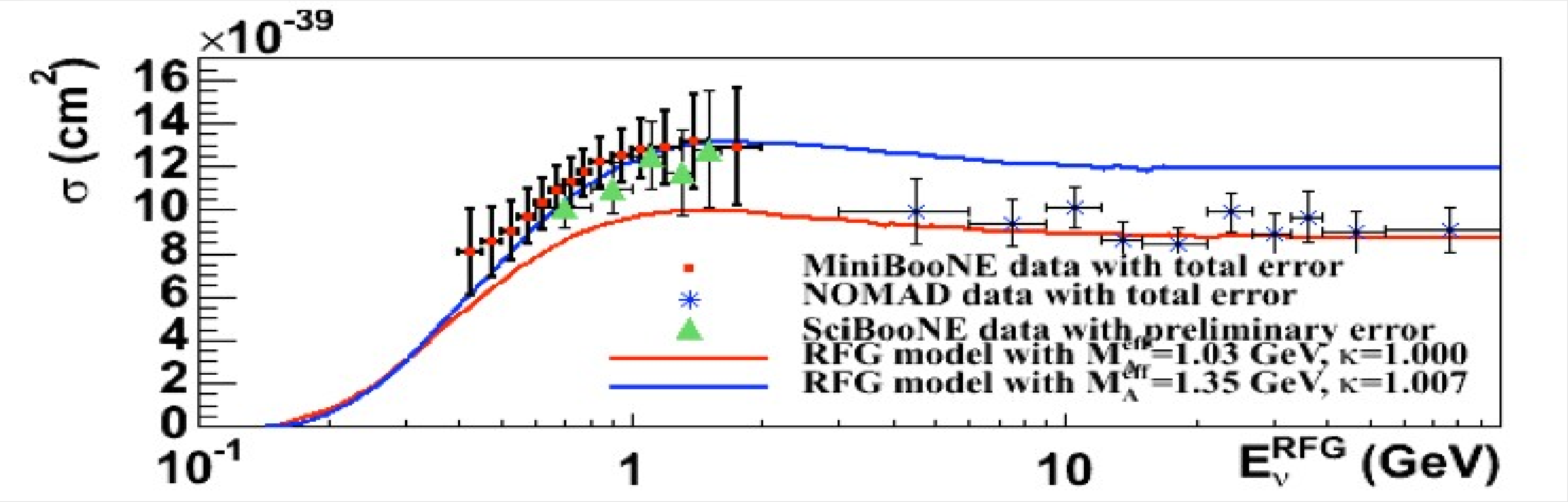
- M_A~1.35 GeV descibes data in both Q^2 shape and total cross section (within RFG model), coincidence?

SciBooNE CCQE results

CCQE results from SciBooNE

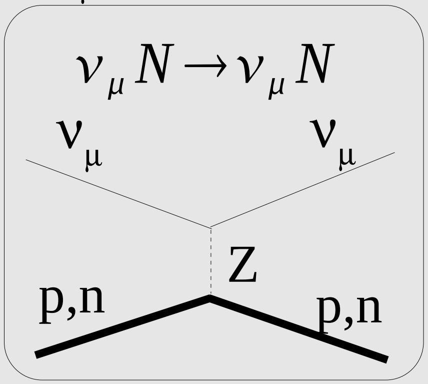
- SciBooNE: (highly segmented) scibar in Booster ν beam at FNAL (as MiniBooNE)
- (preliminary) results indicate higher cross section, consistent with MiniBooNE (arXiv:0909.5647)

total cross section



ν NC elastic scattering from MiniBooNE

ν_μ NC elastic



- The most fundamental NC probe of the nucleus/nucleon.

- Does our knowledge of CCQE (usually measured via muon) completely predict NCel (measured via recoil nucleon) for nuclear targets?

- Unlike CC quasielastic, sensitive to isoscalar component of nucleon (strange quarks) via isoscalar or "strange" axial-vector formfactor, $G_A^s(Q^2)$ and $\Delta s = G_A^s(Q^2 = 0)$

axial nucleon weak neutral current

$$\langle N|A_\mu^Z|N\rangle = -\left[\frac{G_F}{\sqrt{2}}\right]^{1/2} \langle N|\frac{1}{2}\{\bar{u}\gamma_\mu\gamma_5 u - \bar{d}\gamma_\mu\gamma_5 d - \bar{s}\gamma_\mu\gamma_5 s\}|N\rangle$$

$$\Delta u \qquad \Delta d \qquad \Delta s$$

$$= -\left[\frac{G_F}{\sqrt{2}}\right]^{1/2} \langle N|\frac{1}{2}\{-G_A(Q^2)\gamma_\mu\gamma_5\tau_z + G_A^s(Q^2)\gamma_\mu\gamma_5\}|N\rangle$$

- Experimental sensitivity to isoscalar effects best via ratios:

  - NC(p)/NC(n), NC(p)/NC(p+n), NC(p)/CCQE

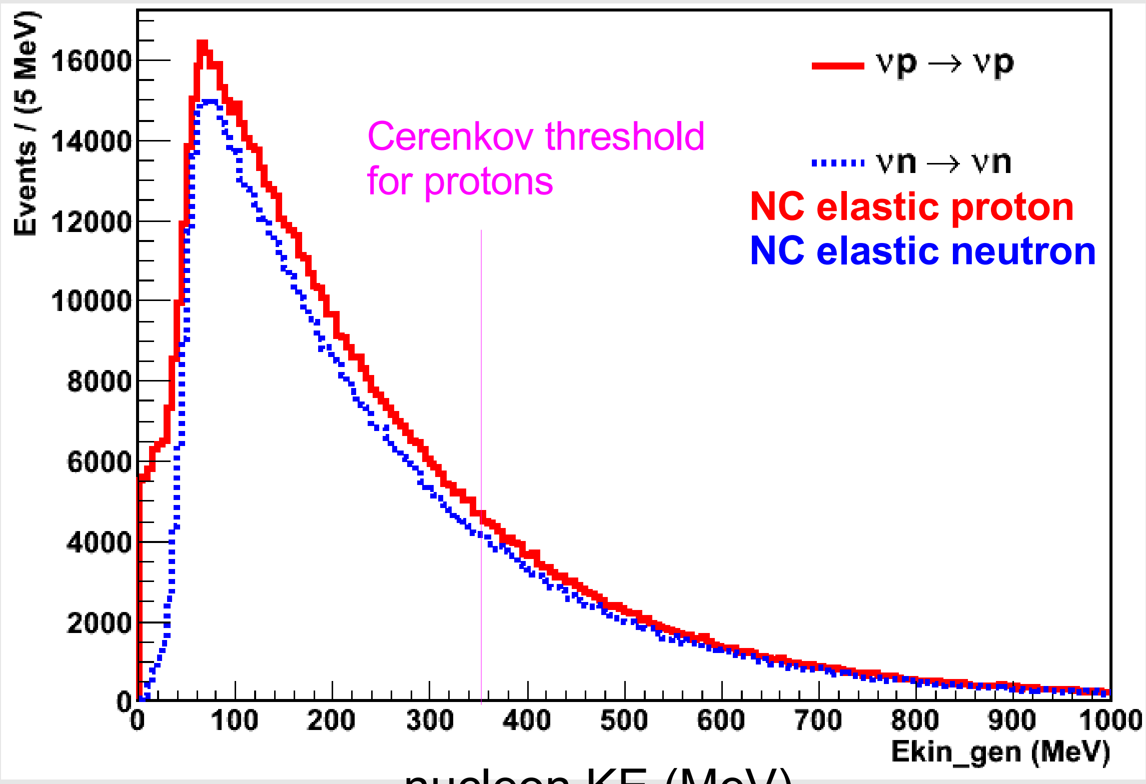
as many systematics (flux, nuc. effects) should cancel.
Requires separation of protons/neutrons.

MiniBooNE NC elastic analysis

- NCel experimental definition: 1 p/n , no μ^- , π

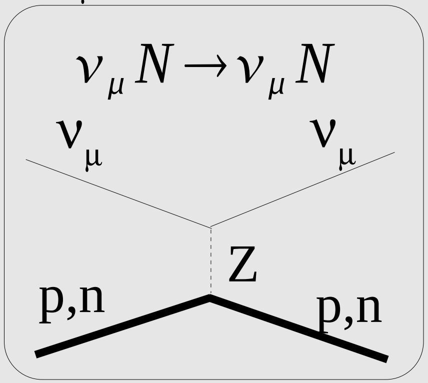
- below Cerenkov threshold, p/n separation not possible, p/n recon'd via small amount of scintillation

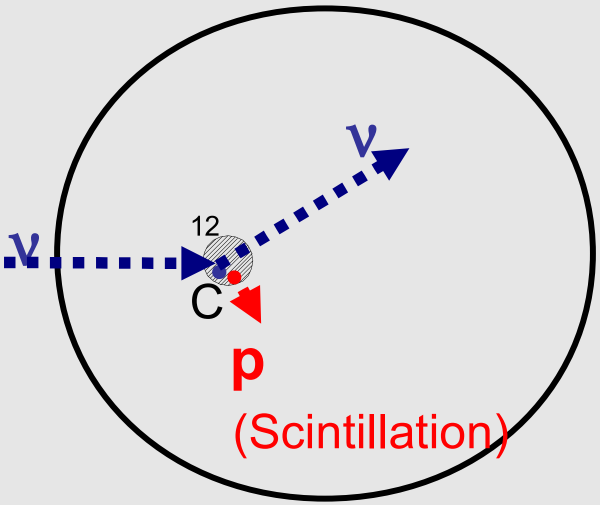
MC NCel event distribution



nucleon KE (MeV)

ν_μ NC elastic

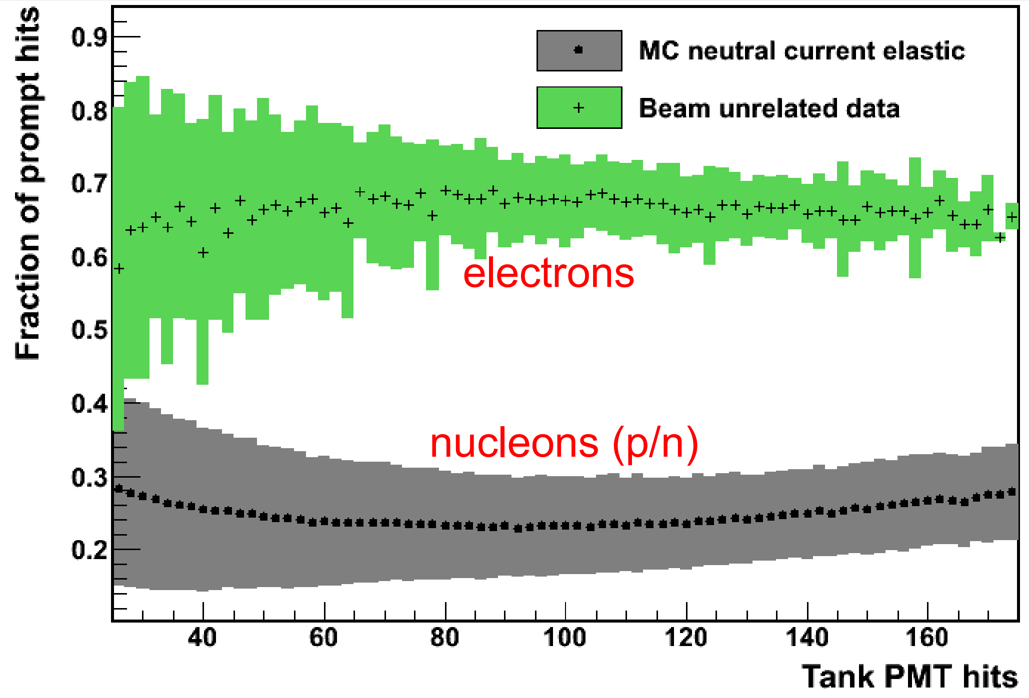




MiniBooNE NC elastic analysis

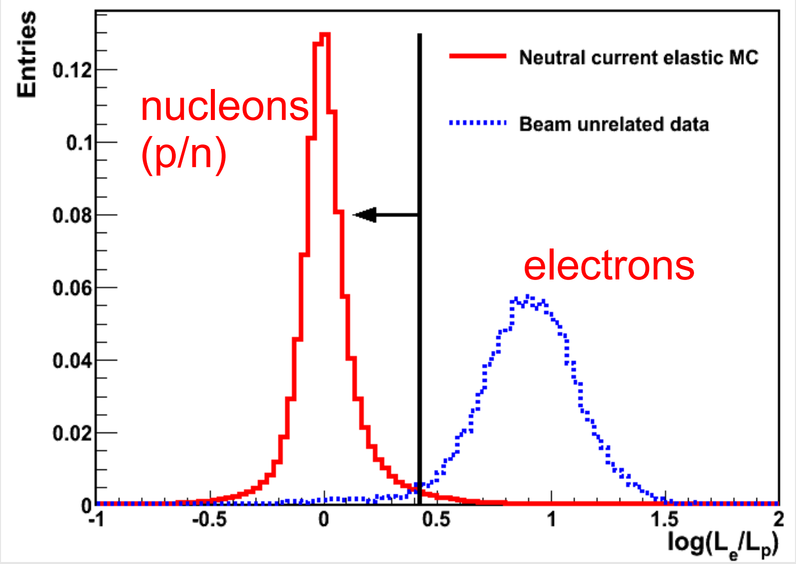
- requires dedicated reconstruction for protons (new to this analysis)

- proton fitter provides good separation between nucleons/electrons



- NCel sample:
  - 94.5K candidate evts
  - efficiency = 26%
  - purity = 65%

- NC$\pi^{+/-}$ is (largest) background, (π^{+-} missed because of π absorption)
- ~1/3 of background is NCel-like



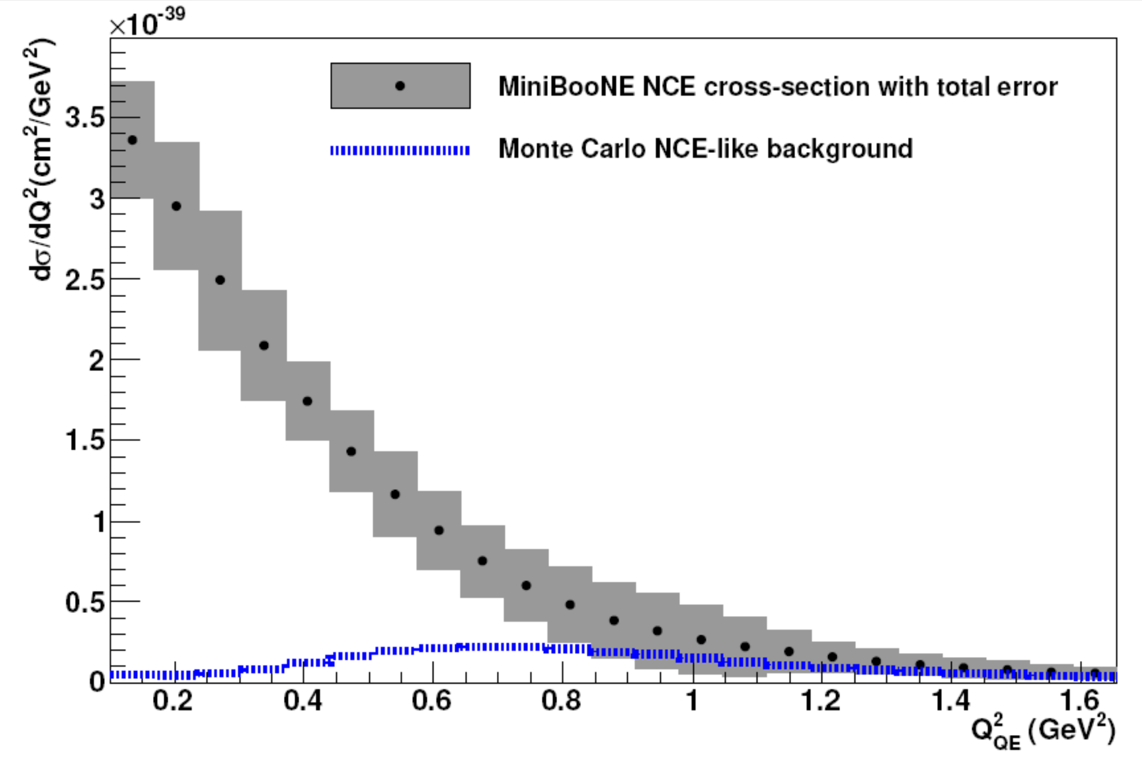
MiniBooNE NC elastic results

- differential cross section:

- actually the wtd sum of 3 different processes:

$$\frac{d\sigma_{\nu N\to\nu N}}{dQ^2} = \frac{1}{7}\,C_{\nu p,H}(Q^2)\,\frac{d\sigma_{\nu p\to\nu p,H}}{dQ^2} + \frac{3}{7}\,C_{\nu p,C}(Q^2)\,\frac{d\sigma_{\nu p\to\nu p,C}}{dQ^2} + \frac{3}{7}\,C_{\nu n,C}(Q^2)\,\frac{d\sigma_{\nu n\to\nu n,C}}{dQ^2},$$

NCel differential cross section



- ~1/3 of background is NCel-like (NCπ with π abs). This calc'd background is reported so NCel-like may be calculated.

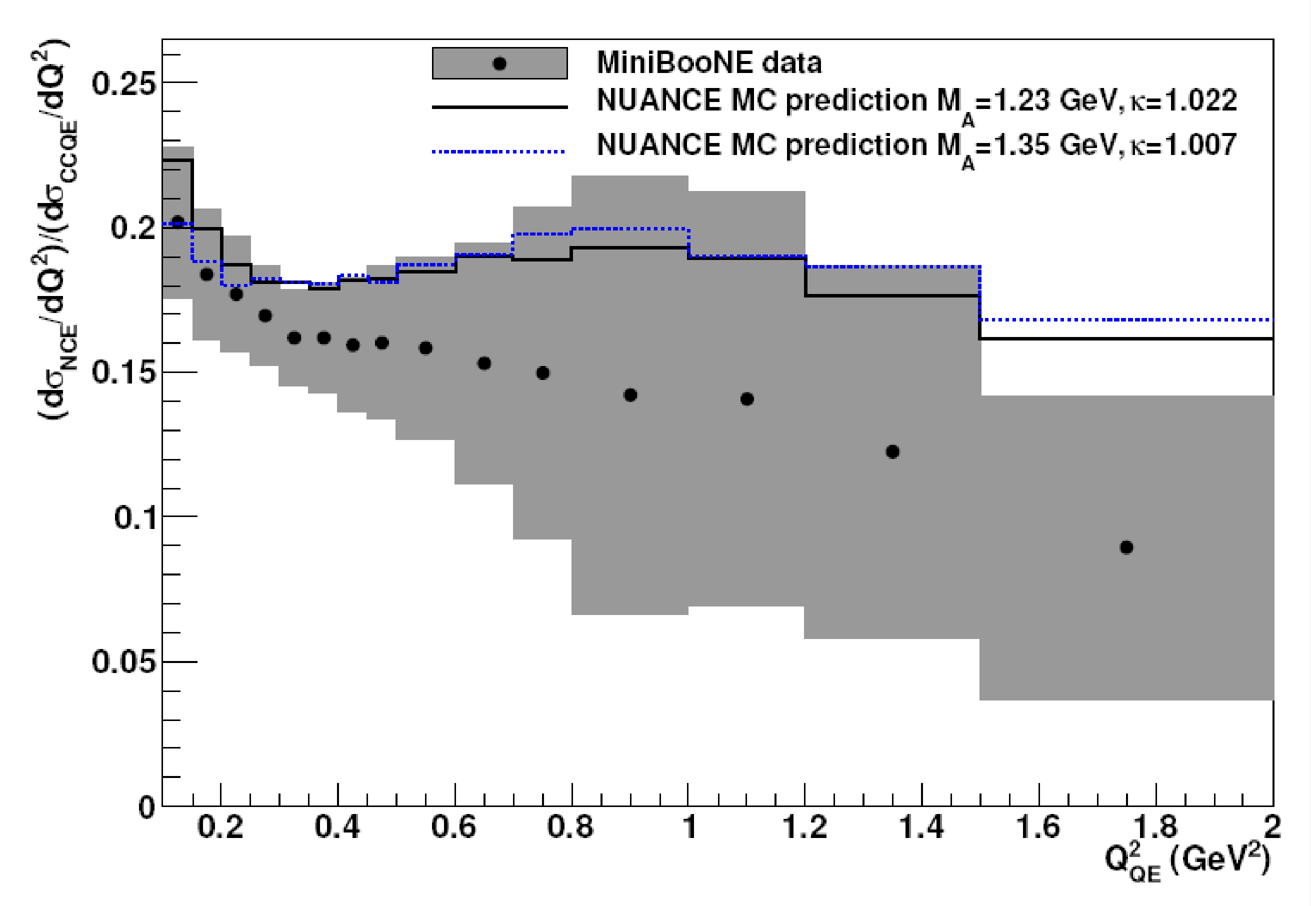
MiniBooNE NC elastic results

- NCel to CCQE differential cross section ratio:

- flux error cancels between the 2 channels

- ratio is consistent with our RFG model. So no discrepency in NCel compared to CCQE

NCel to CCQE differential cross section ratio



MiniBooNE NC elastic results

- M_A extraction:

- from an absolute fit to proton KE distribution

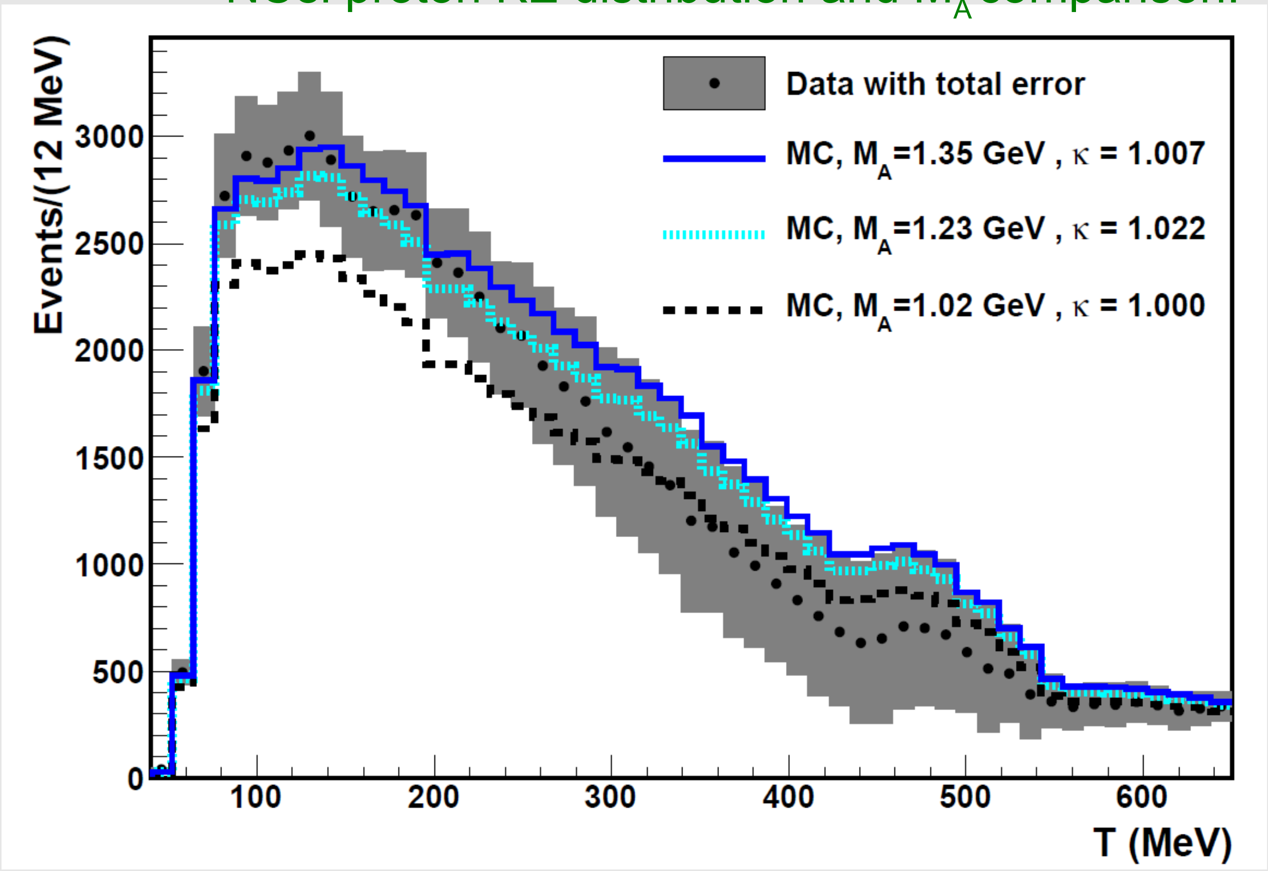
M_A = 1.39 ± 0.11 GeV
χ^2/ndf = 26.9/50

- small sensitivity to Δs, assume $\Delta s = 0$.

- negligible sensitivity to κ

- consistent with M_A from CCQE (shape) fit

NCel proton KE distribution and M_A comparison:



MiniBooNE NC elastic results

- Δs extraction:

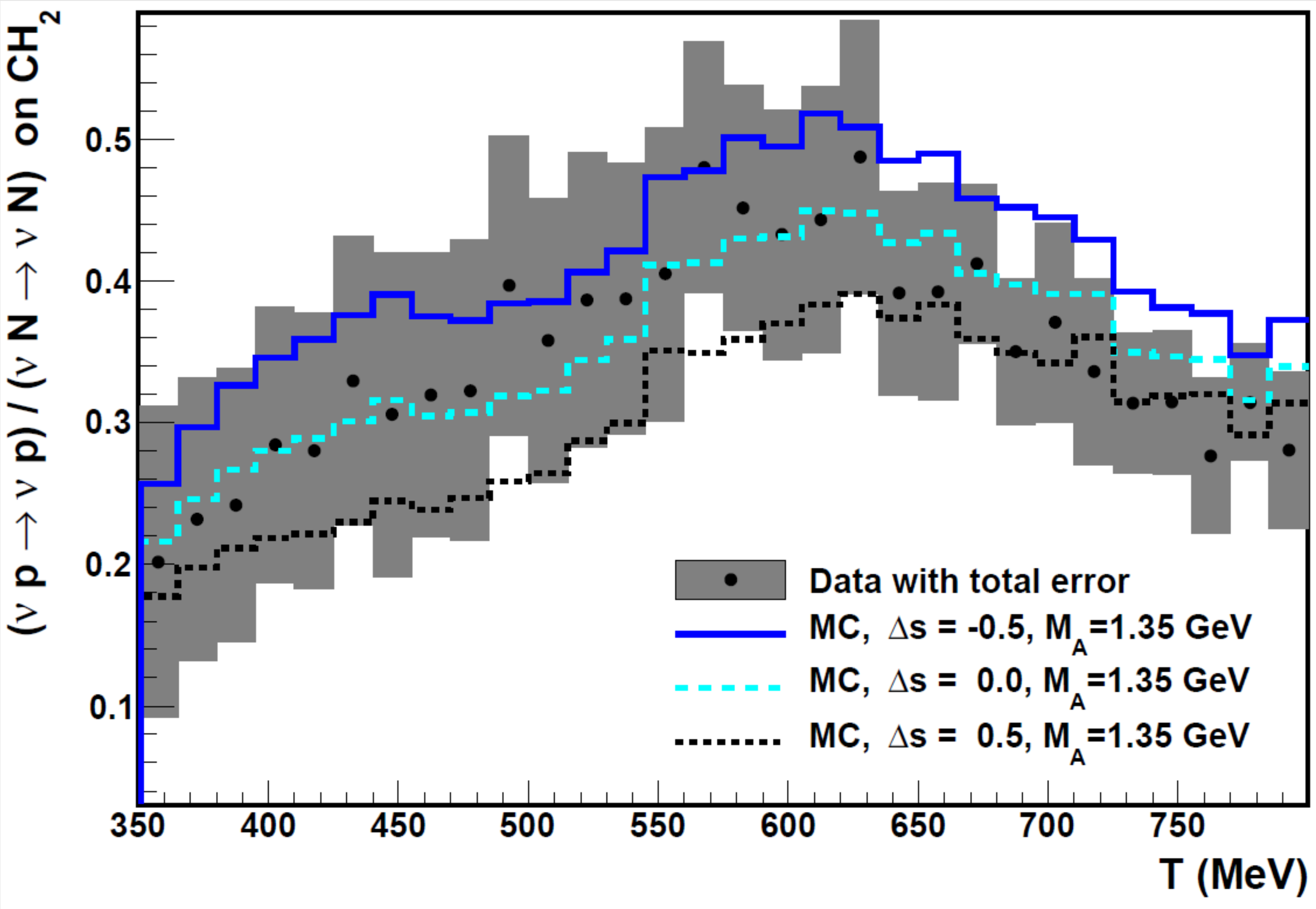
- from NC(p)/NC(p+n) above proton cerenkov threshold where proton separation is possible

- Δs = 0.08±0.26

- limited by large errors but good demo of method

- consistent with expectations from deep0-inelastic scattering meas:

Δs ~ -0.10

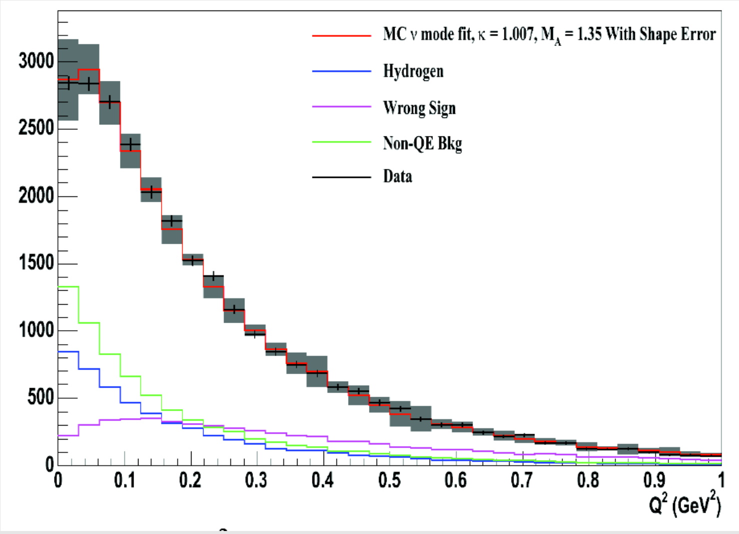


Antineutrino quasielastic scattering in MiniBooNE

Interesting and important to check antineutrino quasielastic channels as they should differ from neutrino in well-known fashion:

$\bar{\nu}$ CCQE:

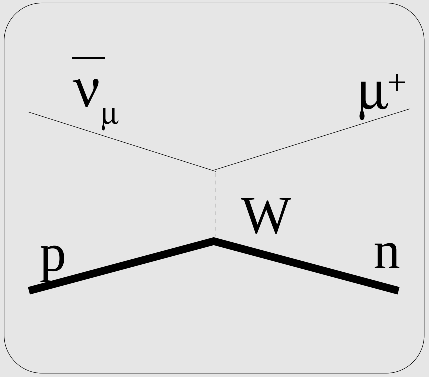
- preliminary results presented (arXiv:0910.1802)
- results consistent with neutrino mode CCQE scattering (higher M_A prefered)
- thesis work of J. Grange, U. Florida



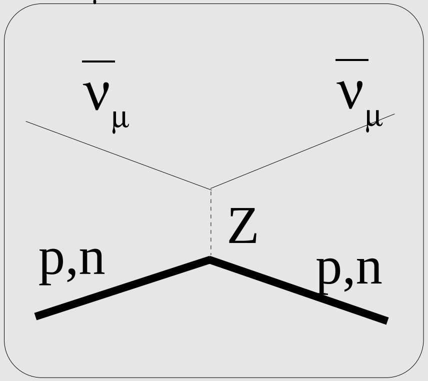
$\bar{\nu}$ NC elastic:

- analysis underway
- thesis work of R. Dharmapalan, U. Alabama

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



$\bar{\nu}_\mu$ NC elastic



pion-production in MiniBooNE

CC pion production:

- $CC\pi^+/CCQE$ ratio measured

(Phys. Rev. Lett. 103, 081801 (2009))

$$\nu_\mu + p(n) \rightarrow \mu + \Delta^{+(+)} \rightarrow \mu + p(n) + \pi^+$$
$$\nu_\mu + A \rightarrow \mu + A + \pi^+$$

- $CC\pi^+/CCQE$ ratio in agreement with model.
- So $CC\pi^+$ rate (cross section) is also larger than expected.
- In both FSI corrected/uncorrected samples

- Many other pion-production measurements from MiniBooNe have been/will be soon published:
    - $NC\pi^0$, $NC\pi^+$, $CC\pi^+$
    - including absolutely normalized (differential) cross sections

- coming soon to seminar near you

$CC\pi^+$ /CCQE ratio, no FSI corrections

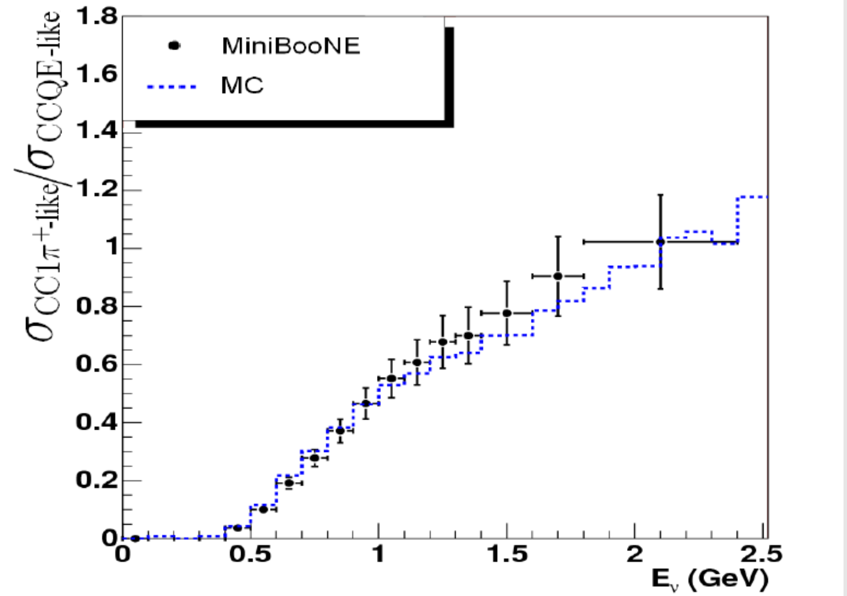


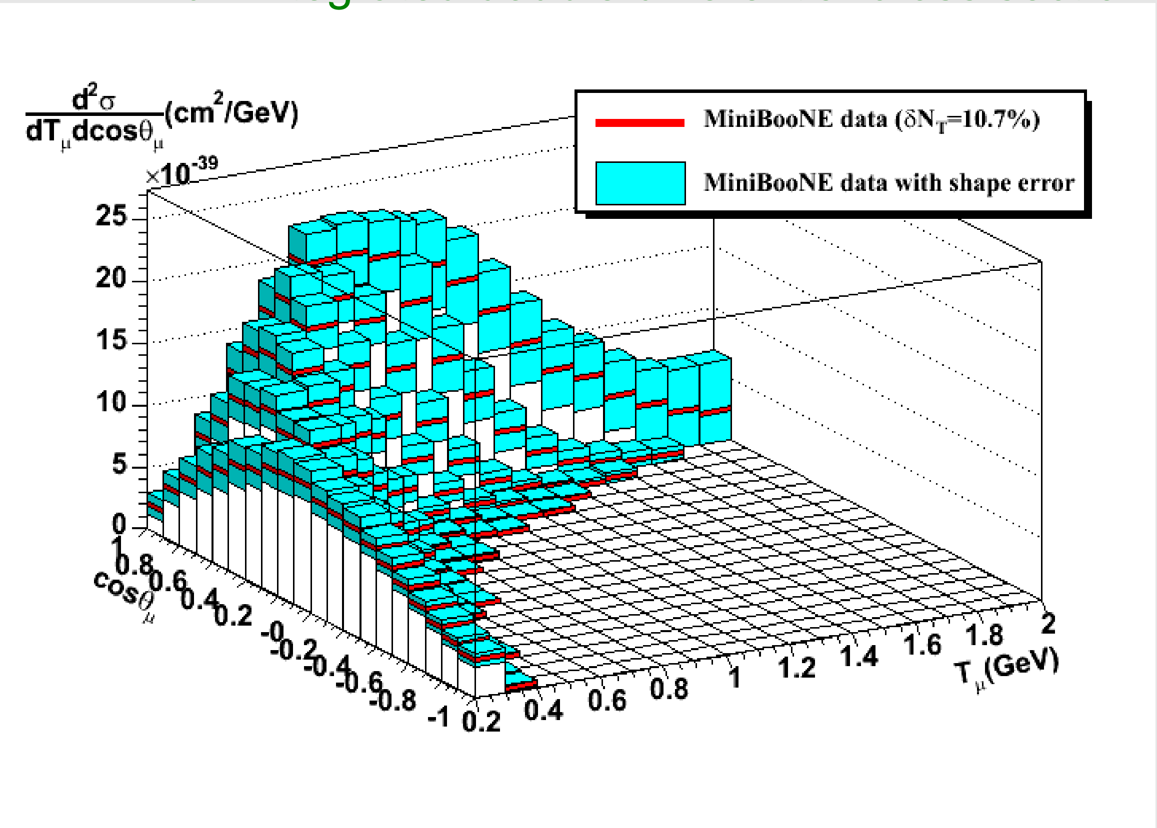
FIG. 1: Observed $CC1\pi^+$-like/CCQE-like cross section ratio on CH_2, including both statistical and systematic uncertainties, compared with the MC prediction [6]. The data have not been corrected for hadronic re-interactions.

Modeling neutrino quasielastic scattering

Recent MB neutrino QE results are confronting the physics models:
- Both Q2 "shape" and total cross section indicates a larger effective M_A
- much work in this area prior to recent MB CCQE

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).

Flux-integrated double differential cross section



- And very recently, with fits to MB cross section data:

Martini et al, http://arxiv.org/abs/0910.2622
Butkevich et al, http://arxiv.org/abs/1006.1595
Benhar et al, http://arxiv.org/abs/1006.4783
Sobczyk, http://arxiv.org/abs/1007.2195

Modeling neutrino quasielastic scattering

For example, a model beyond the RFG...
SUSA (superscaling) model of
Amaro et al (Phys. Rev. C 71 , 015501 (2005))

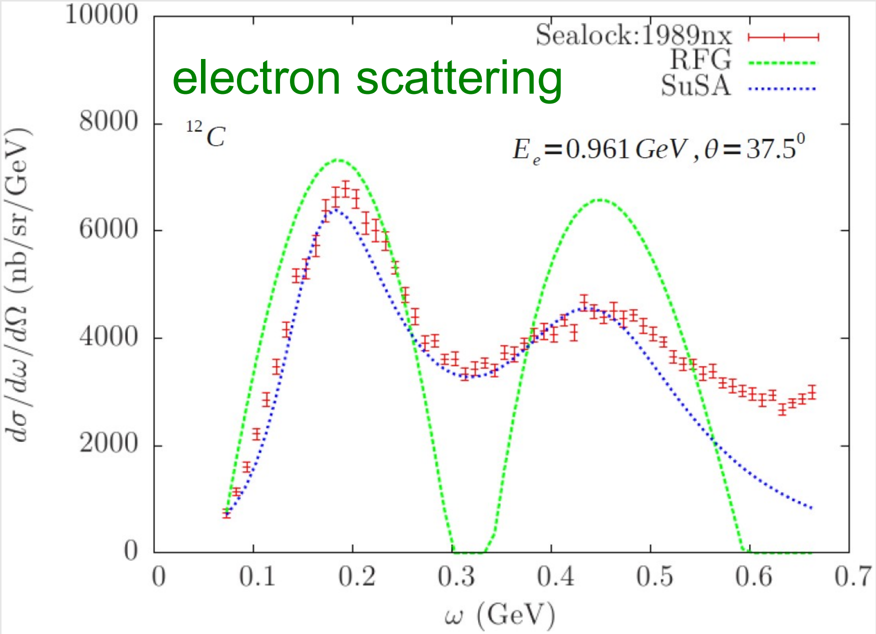
- scaling of various types demonstrated and tuned with electron scattering data on nuclei

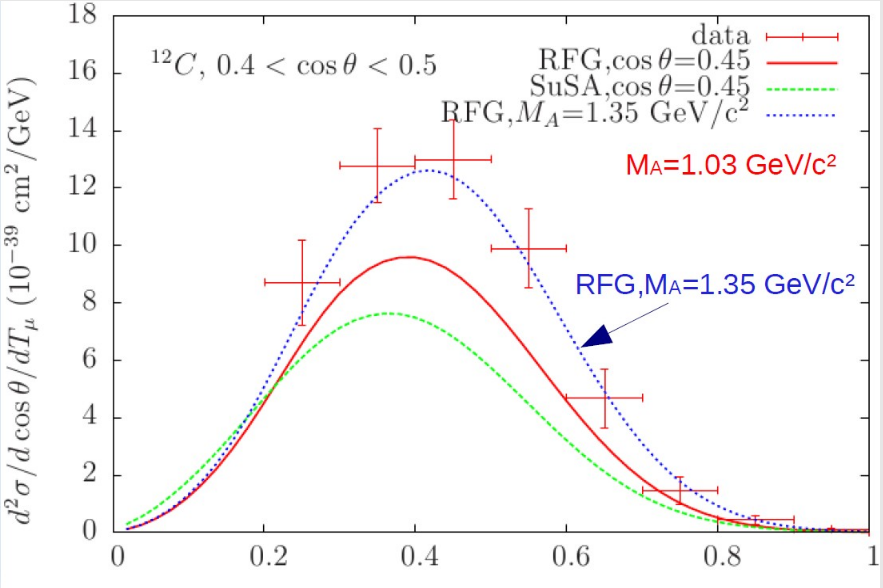
- application to neutrino QE scattering should allow solid predictions

- however, this approach significantly underpredicts reported MB cross section

- similar results from other models such as
  - spectral functions, RMF, DWIA, etc

- indications are that a fundamental process is neglected...





plots from M. Barbaro

Modeling neutrino quasielastic scattering

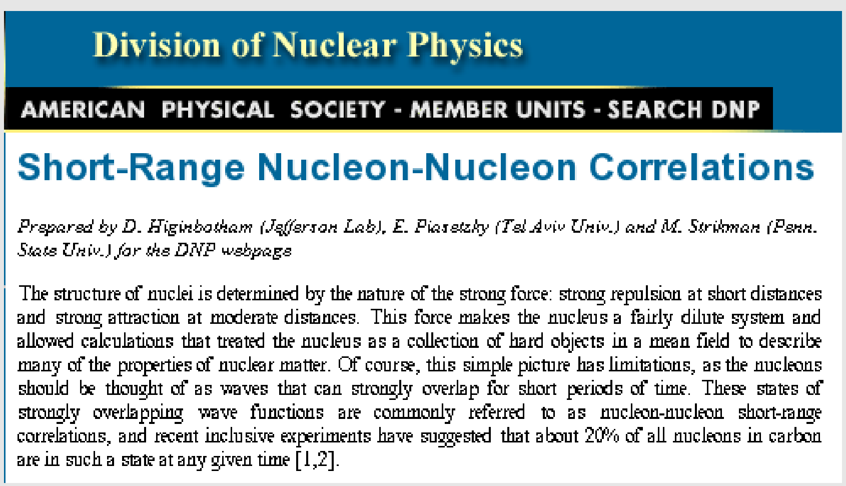
A possible explanation of excess cross section compared to model:

- neglected “transverse” response
- in SUSA (and most) models $f_L = f_T$ (“0-th kind scaling”)

- also see (Carlson etal, PRC65, 024002, '02)

- Expected with nucleon short range correlations (SRC) and 2-body exchange currents

- recent results from e-scattering suggest 20% of nucleons in carbon are in a “SRC state” (K. S. Egiyan et al., PRL 96, 082501 (2006), PR C68, 014313 (2003).)

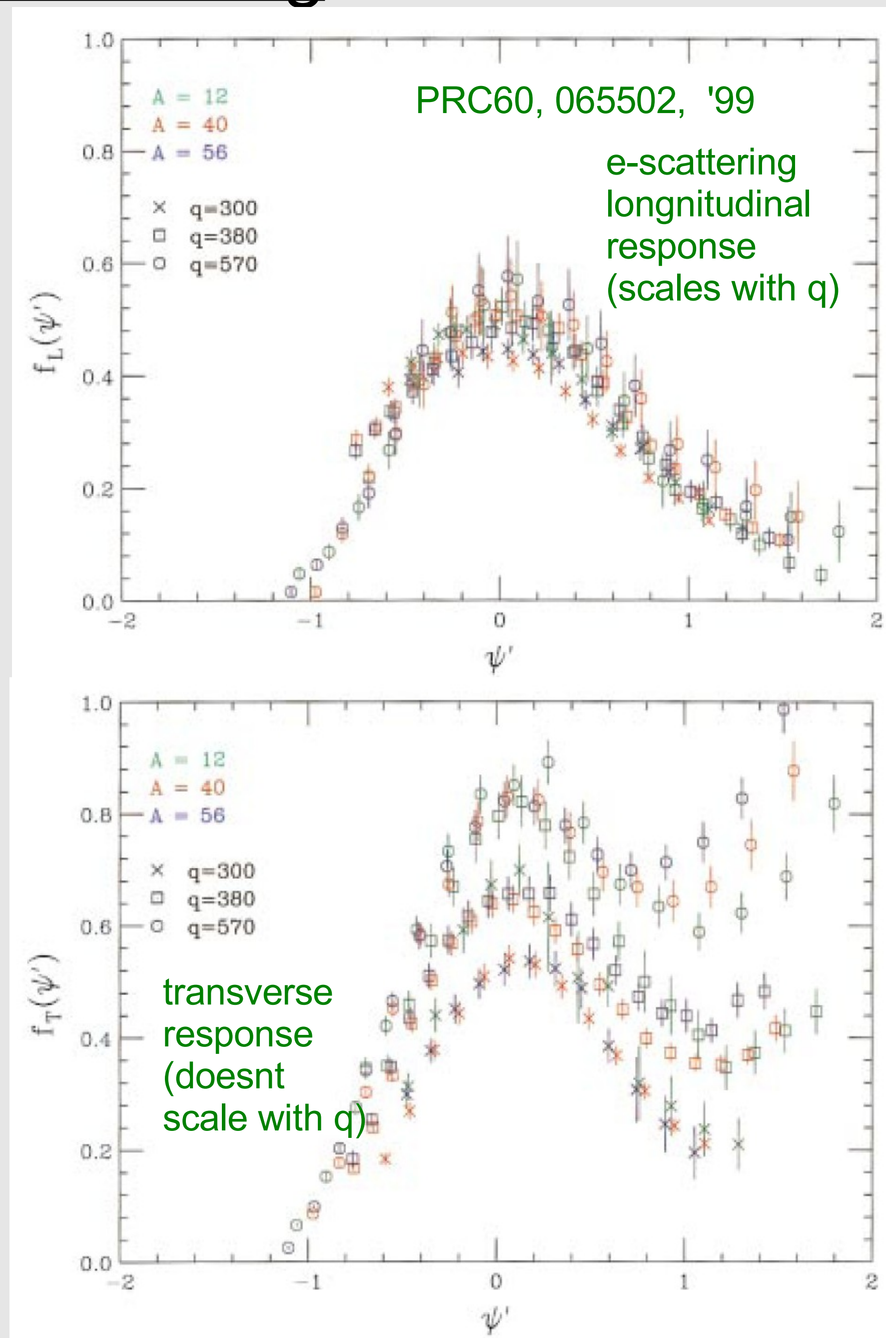

Division of Nuclear Physics

AMERICAN PHYSICAL SOCIETY - MEMBER UNITS - SEARCH DNP

Short-Range Nucleon-Nucleon Correlations

Prepared by D. Higinbotham (Jefferson Lab), E. Piasetzky (Tel Aviv Univ.) and M. Strikman (Penn. State Univ.) for the DNP webpage

The structure of nuclei is determined by the nature of the strong force: strong repulsion at short distances and strong attraction at moderate distances. This force makes the nucleus a fairly dilute system and allowed calculations that treated the nucleus as a collection of hard objects in a mean field to describe many of the properties of nuclear matter. Of course, this simple picture has limitations, as the nucleons should be thought of as waves that can strongly overlap for short periods of time. These states of strongly overlapping wave functions are commonly referred to as nucleon-nucleon short-range correlations, and recent inclusive experiments have suggested that about 20% of all nucleons in carbon are in such a state at any given time [1,2].

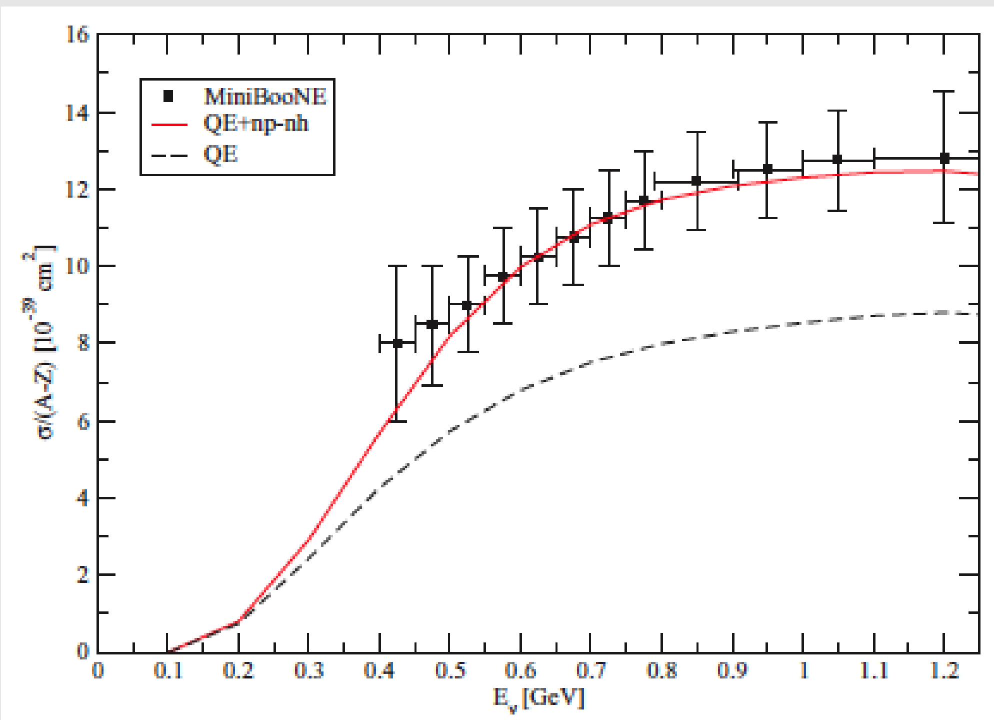


Modeling neutrino quasielastic scattering

- A recent work by Martini et al (PRC80, 065501, '09) proposes a model that reproduces larger CCQE cross section.

- Involves large contribution from multinucleon (np-nh) correlations in nuclear medium

- Details of Q2 distribution (larger "M_A") has yet to be quantitatively shown



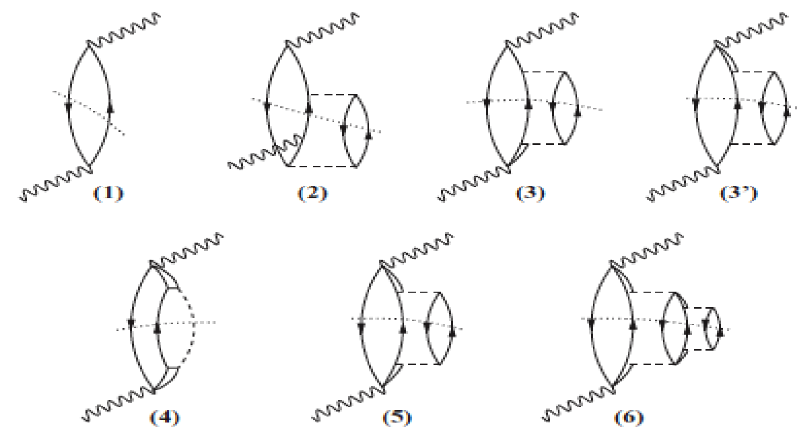


FIG. 1. Feynman graphs of the partial polarization propagators: NN quasielastic (1), NN (2p-2h) (2), $N\Delta$ (2p-2h) (3), ΔN (2p-2h) (3'), $\Delta\Delta$ (πN) (4), $\Delta\Delta$ (2p-2h) (5), $\Delta\Delta$ (3p-3h) (6). The wiggled lines represent the external probe, the full lines correspond to the propagation of a nucleon (or a hole), the double lines to the propagation of a Δ and the dashed lines to an effective interaction between nucleons and/or Δs. The dotted lines show which particles are placed on-shell.

$$\begin{aligned}\frac{\partial^2\sigma}{\partial\Omega\,\partial k'} = {} & \frac{G_F^2\cos^2\theta_c\,(\boldsymbol{k}')^2}{2\,\pi^2}\cos^2\frac{\theta}{2}\left\{G_E^2\,\left(\frac{q_\mu^2}{\boldsymbol{q}^2}\right)^2 R_\tau^{NN}\right.\\ & +G_A^2\,\frac{(M_\Delta-M)^2}{2\,\boldsymbol{q}^2}\,R^{N\Delta}_{\sigma\tau(L)}+G_A^2\,\frac{(M_\Delta-M)^2}{\boldsymbol{q}^2}\\ & \times R^{\Delta\Delta}_{\sigma\tau(L)}+\left(G_M^2\,\frac{\omega^2}{\boldsymbol{q}^2}+G_A^2\right)\left(-\frac{q_\mu^2}{\boldsymbol{q}^2}+2\tan^2\frac{\theta}{2}\right)\\ & \times\left[R^{NN}_{\sigma\tau(T)}+2R^{N\Delta}_{\sigma\tau(T)}+R^{\Delta\Delta}_{\sigma\tau(T)}\right]\pm 2G_AG_M\frac{k+k'}{M}\\ & \left.\times\tan^2\frac{\theta}{2}\left[R^{NN}_{\sigma\tau(T)}+2R^{N\Delta}_{\sigma\tau(T)}+R^{\Delta\Delta}_{\sigma\tau(T)}\right]\right\} \qquad (1)\end{aligned}$$

Modeling neutrino quasielastic scattering

So, perhaps, as reported by O. Benhar at Neutrino 2010,
we need a new model paradigm.

Modeling Neutrino-Nucleus Interactions
Do we need a new paradigm ?

Omar Benhar

INFN and Department of Physics
Università "La Sapienza"
I-00185 Roma, Italy

Neutrino 2010
Athens, June 18th, 2010

However, additional results..
- in a different beam,
- from different exclusive quasielastic channels

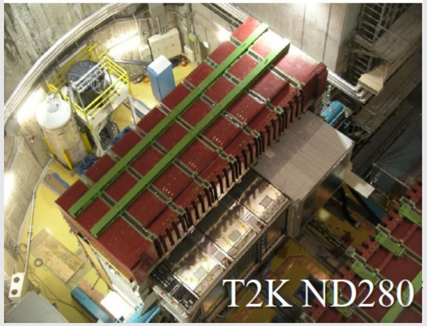
would be also be a nice double-check...

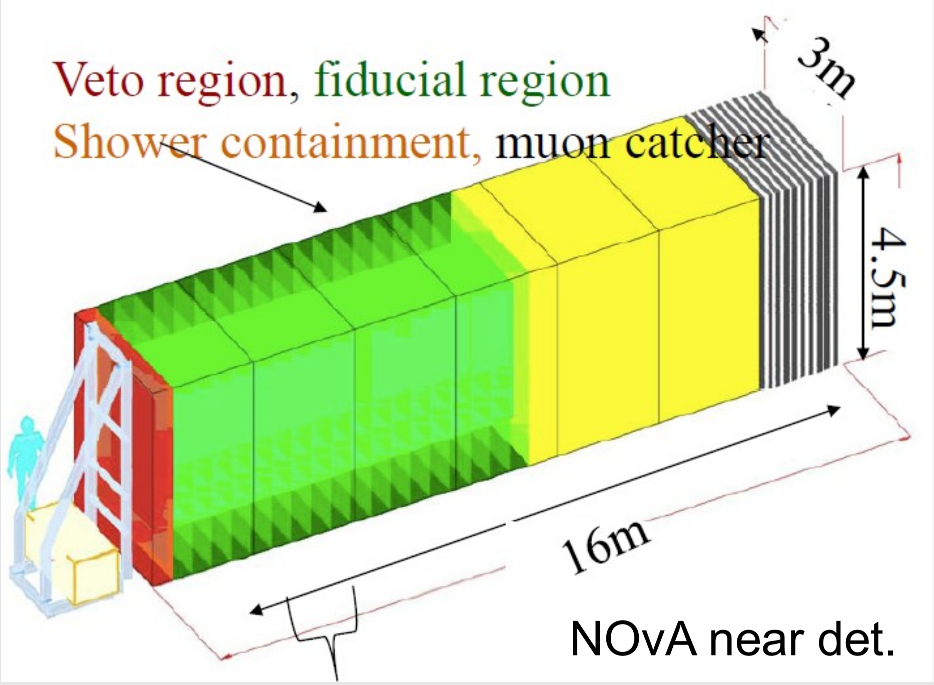
Future neutrino quasielastic scattering experiments

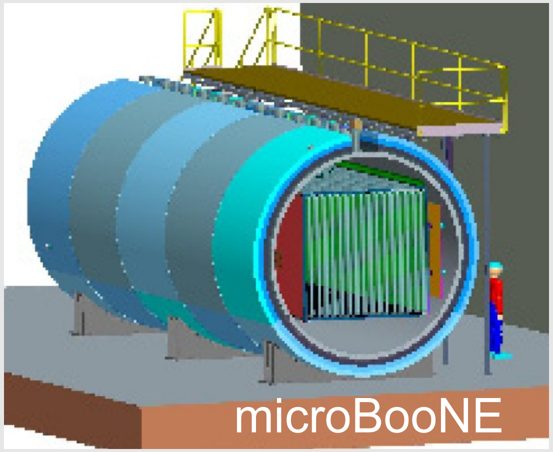
- Requires experiments in well known and absolutely normalized neutrino flux.

- Dont forget: supporting pion production measurements (and other techniques) for determination ν flux are crucial!

- microBooNE
- T2K
- MINERvA
- and NOvA near detector ...



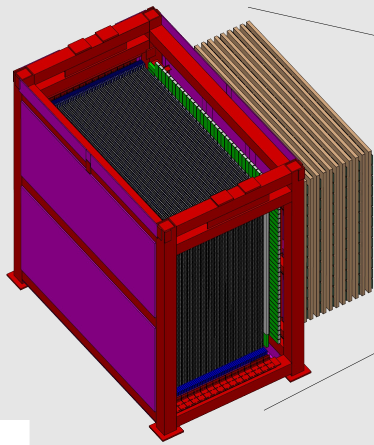


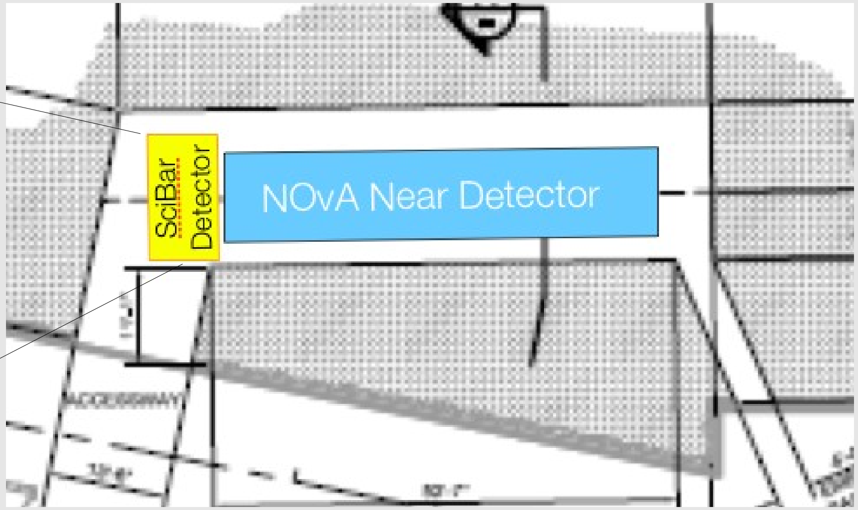


Future neutrino quasielastic scattering results

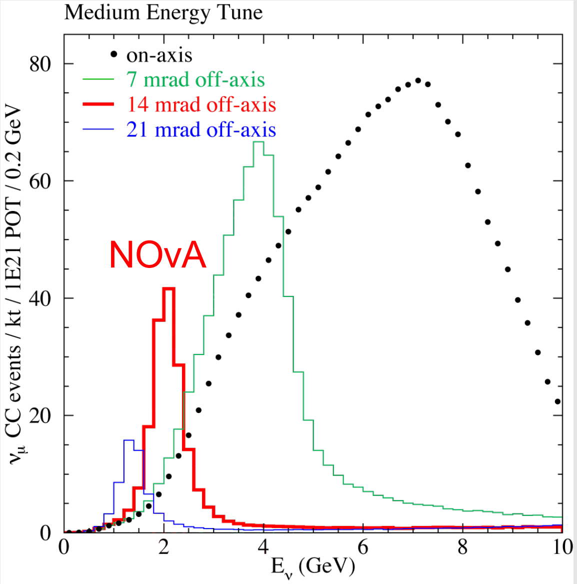
- SciNOvA: Add a scibar-type detector the NOvA near detector in the NuMI (off-axis) 2 GeV narrow-band beam. A fine-grained detector in this location will enable important and unique ν scattering measurements (and enhance the NOvA ν oscillation program).

- can check the MiniBooNE - NOMAD "discrepency" right at 2GeV with narrow-band beam (to complement MINERvA)

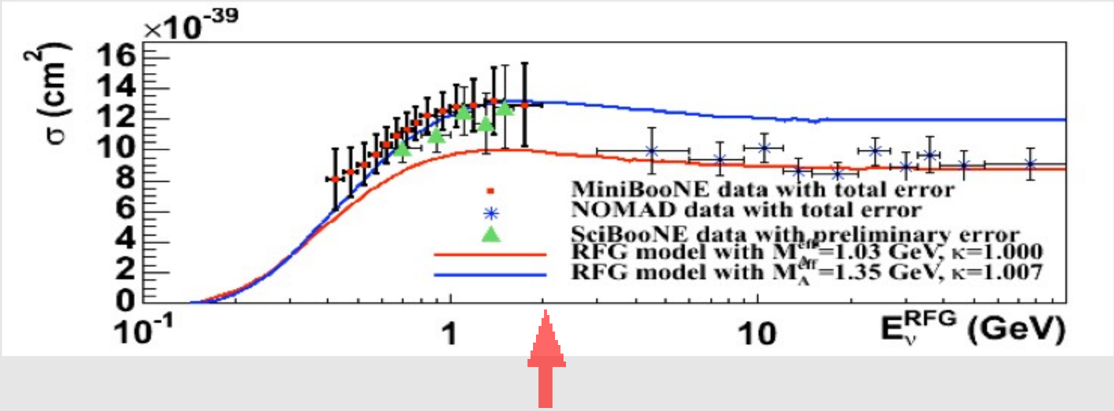




event rate from NuMI near locations



MiniBooNE & others CCQE data

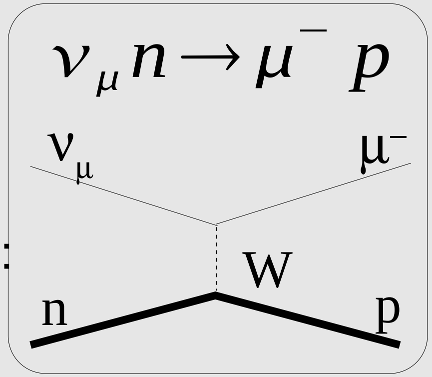


Summary

- New results from MiniBooNE on quasielastic scattering are confronting our current understand of these fundamental processes.

- Need to (continue) digging into problem and better understand with:
  - Unbiased, cross section (model-independent) measurements
  - Multiple complementary measurements with different (but understood) fluxes
  - Theoretical work modeling and understanding the data (including backgrounds)

ν_μ CCQE



ν_μ NC elastic