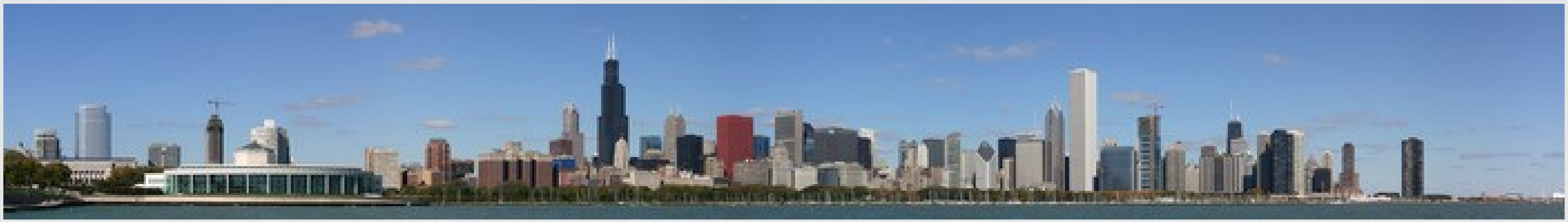
Quasielastic neutrino scattering:
Low energy results
(and interpretations)

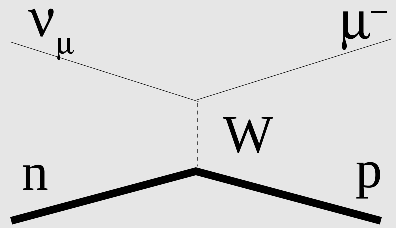


Outline:

- Overview of CCQE process
- Previous experiments
- Current “low-E” results:
  MiniBooNE,SciBooNE, etal
- interpretations, opinions
- future

ν_μ CCQE

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



R. Tayloe,
NuFact'09
Chicago, IL
7/09

CCQE motivation

Crucial to understand this fundamental process
for precision measurements of ν oscillations.

Need understanding of underlying theory over wide range of variables (energies, outgoing kinematics, nuclei, etc)

A significant challenge:

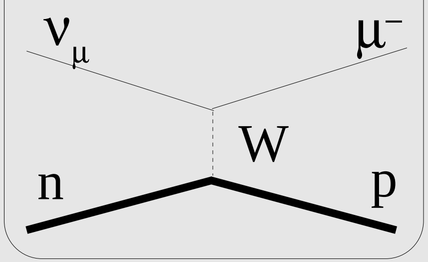
- non-monoenergetic beams
- different detection details (inclusive, exclusive, etc)
- backgrounds (some irreducible, eg CCπ w/π absorption)
- nucleons embedded in nuclei

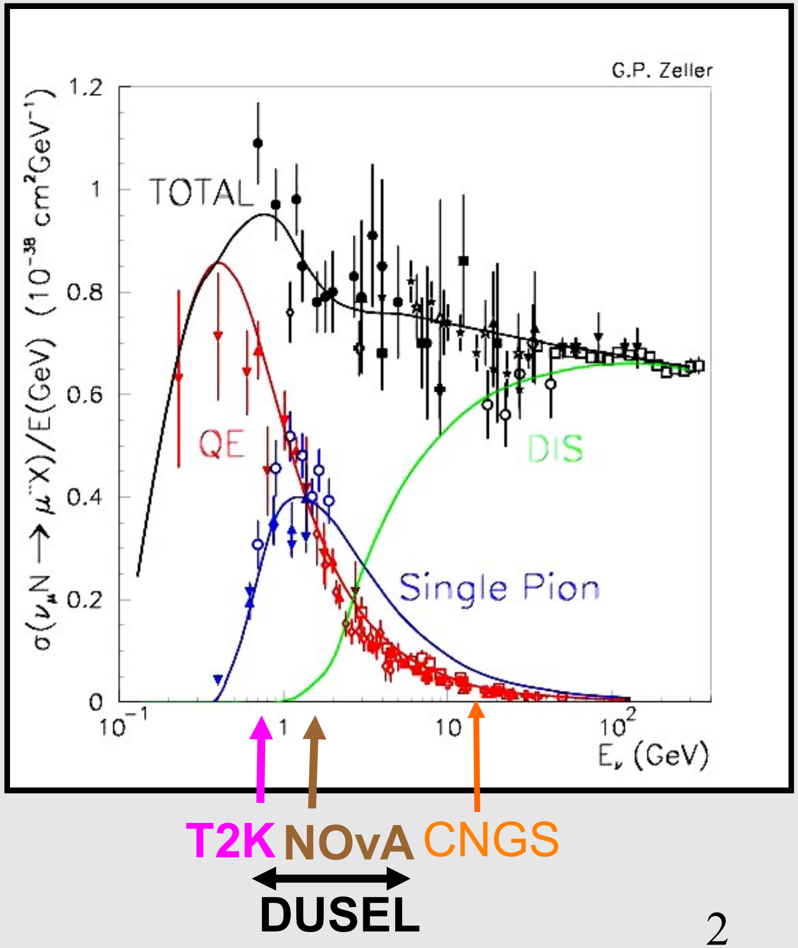
Requires:

- precision data
- model-independent, unbiased results
- careful interpretation

ν_μ CCQE

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

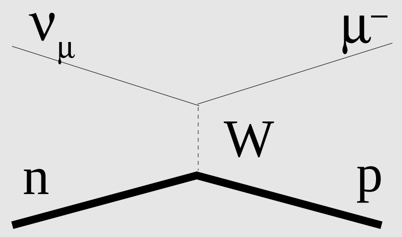




CCQE models

ν_μ CCQE

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



The canonical model for the CCQE process is straightforward, and well-constrained. It looks something like this:

- Llewellyn-Smith formalism for diff cross section

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

  - Q^2 = 4-momentum transfer
  - lepton vertex well-known, with negligible radiative corrections
  - nucleon structure parameterized with 2 vector (F_1,F_2), 1-axial vector (F_A). These are functions of Q^2 and contained in A,B,C.

- To apply:
  - bound nucleons, use a Fermi Gas model (typically Smith-Moniz version), with parameters known from e-scattering
  - F_1,F_2 from e scattering measurements
  - F_A is large(st) contribution
  - F_A (Q^2=0) = g_A.. known from beta-decay , 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, model can be used for prediction of CCQE rates and final state particle distributions.

Apologies to theorists: There are many more solid and sophisticated theoretical approaches. No time to cover.

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

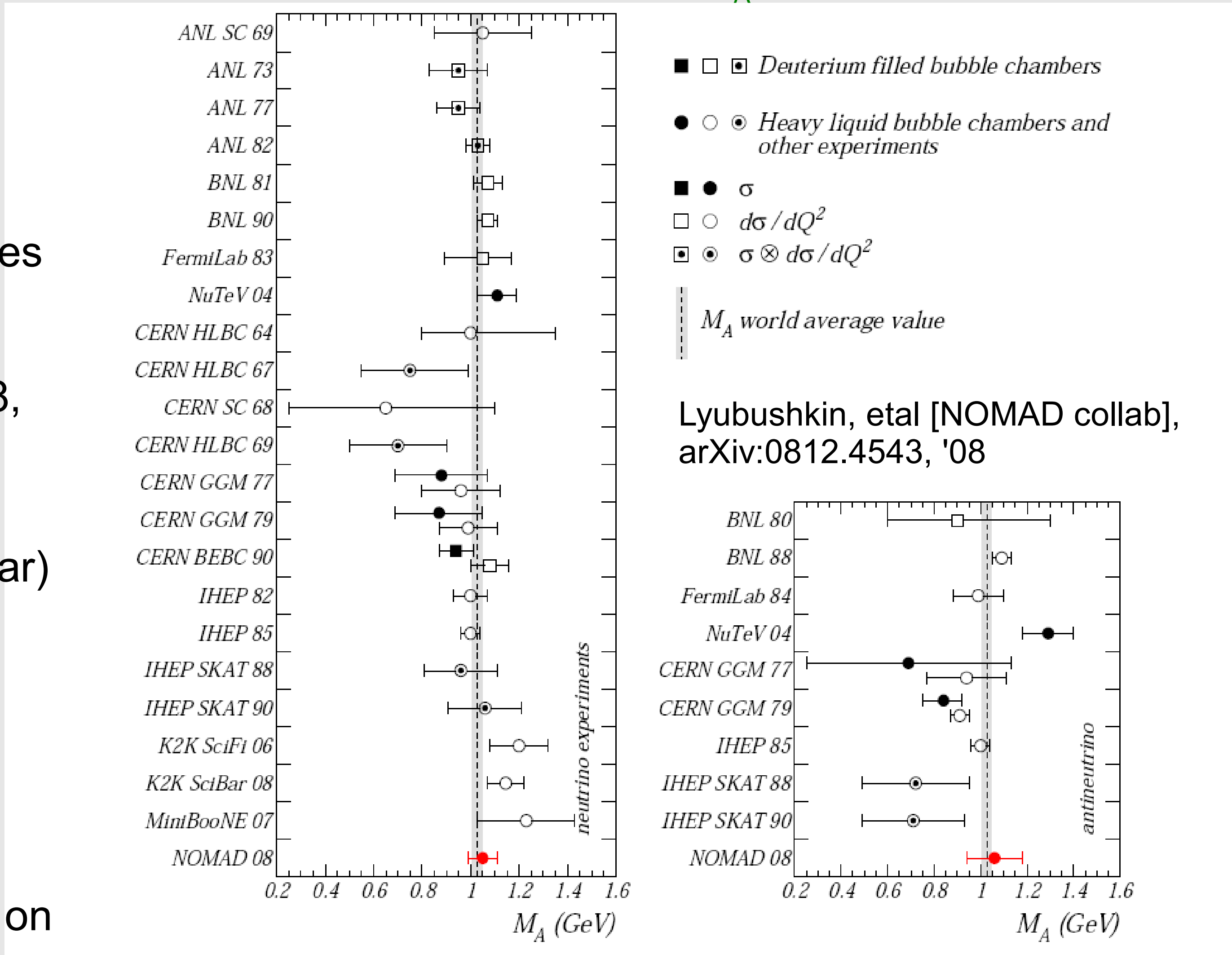


Fig. 18. A summary of existing experimental data: the axial mass M_A as measured in neutrino (left) and antineutrino (right) experiments. Points show results obtained both from deuterium filled BC (squares) and from heavy liquid BC and other experiments (circles). Dashed line corresponds to the so-called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

Previous CCQE results

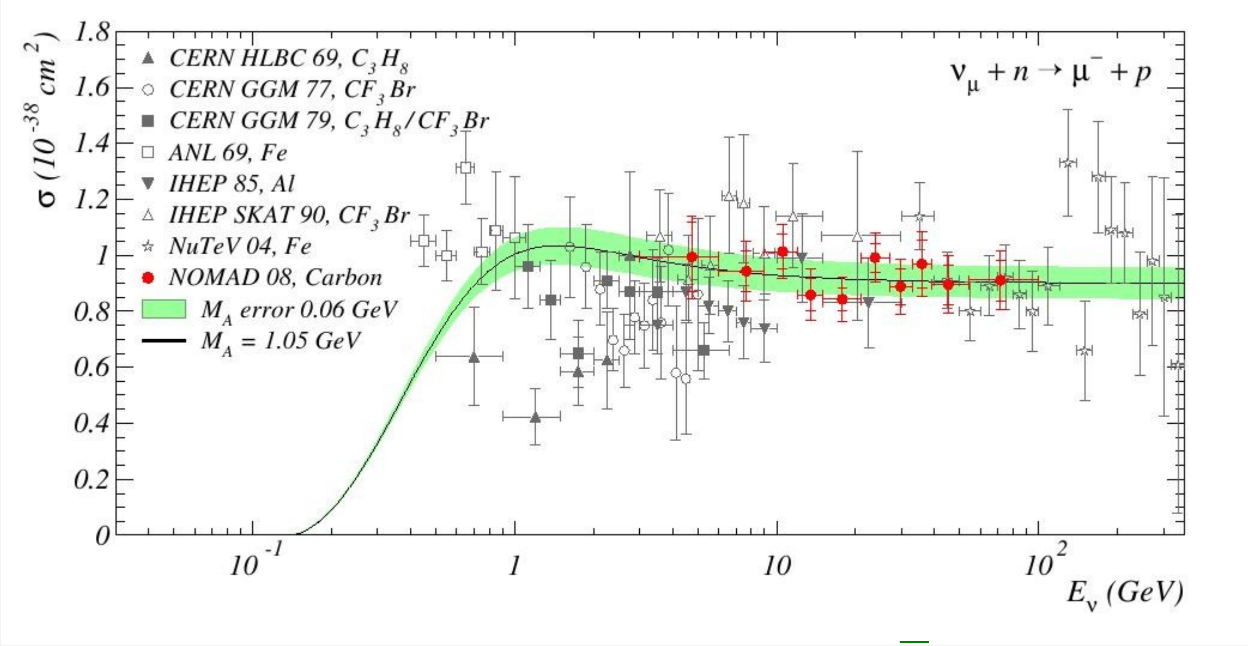
- total cross section measurements as func of E_ν

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

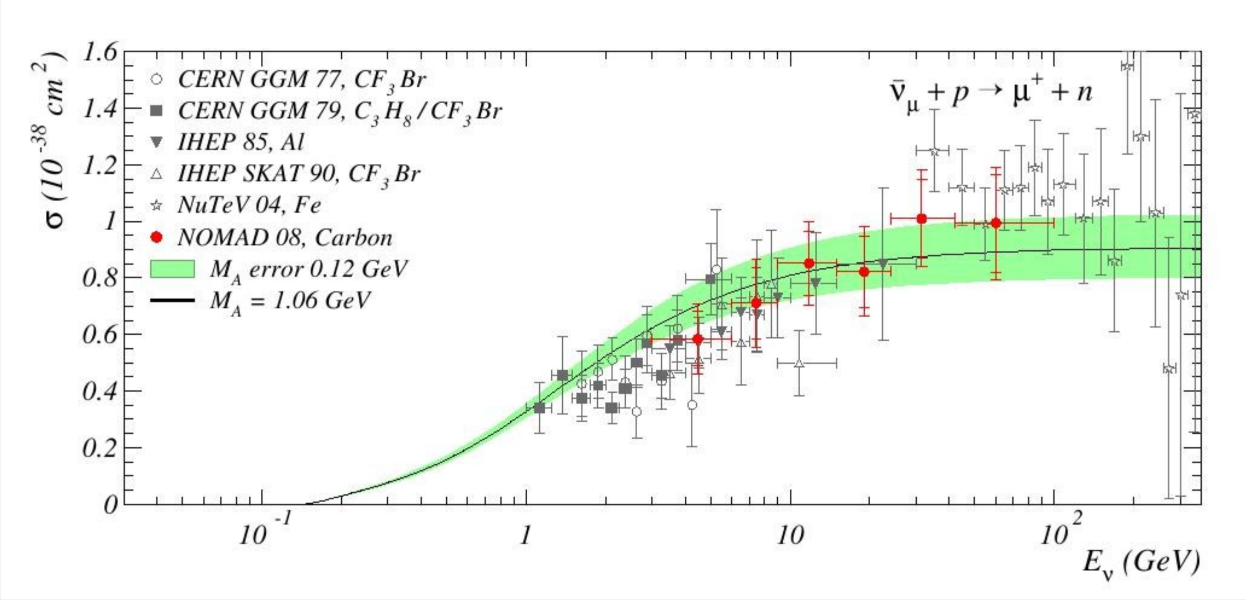
- different targets, different energies

- curve is that predicted with M_A of this NOMAD measurement

ν cross section



$\bar{\nu}$ cross section



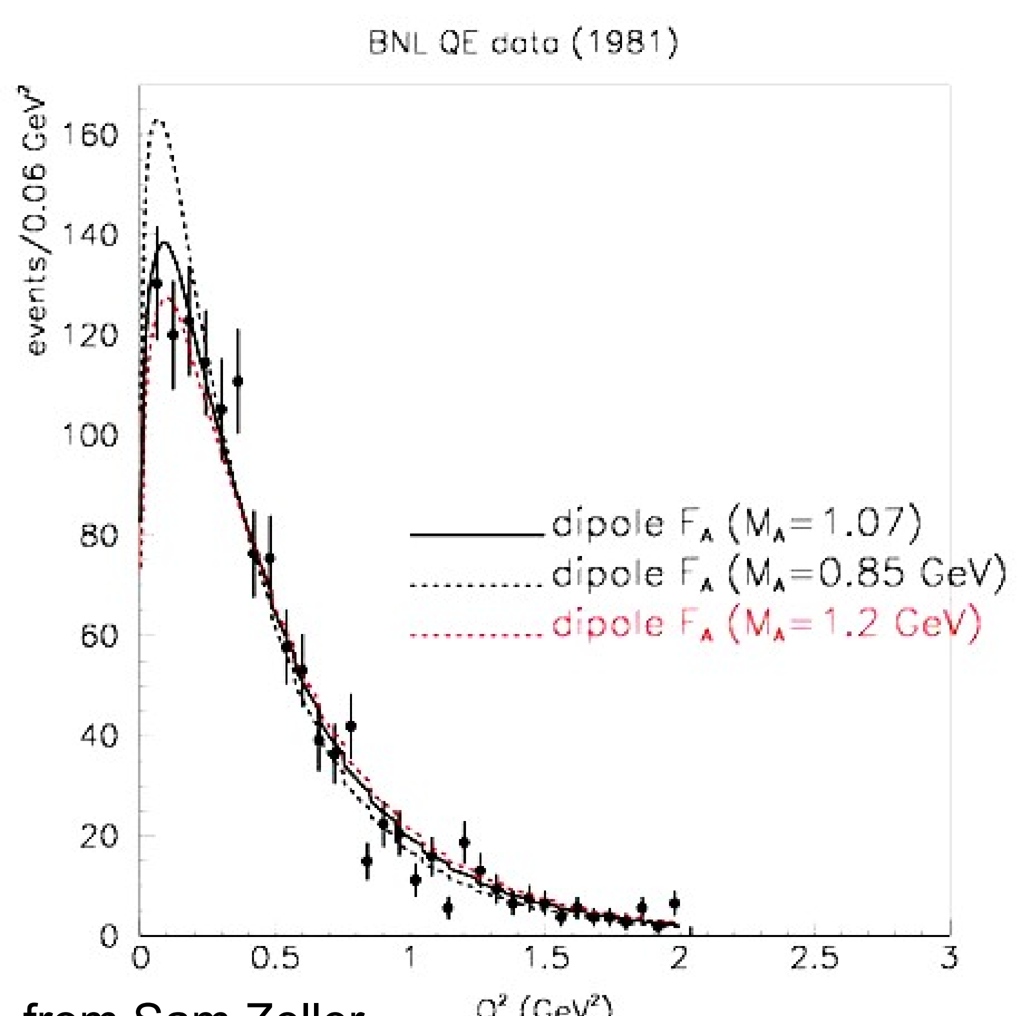
Previous CCQE results

BNL QE data:
- Baker, PRD 23, 2499 (1981)
- data on D_2
- M_A=1.07 +/- 0.06 GeV

1,236 ν_μ QE events

- 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

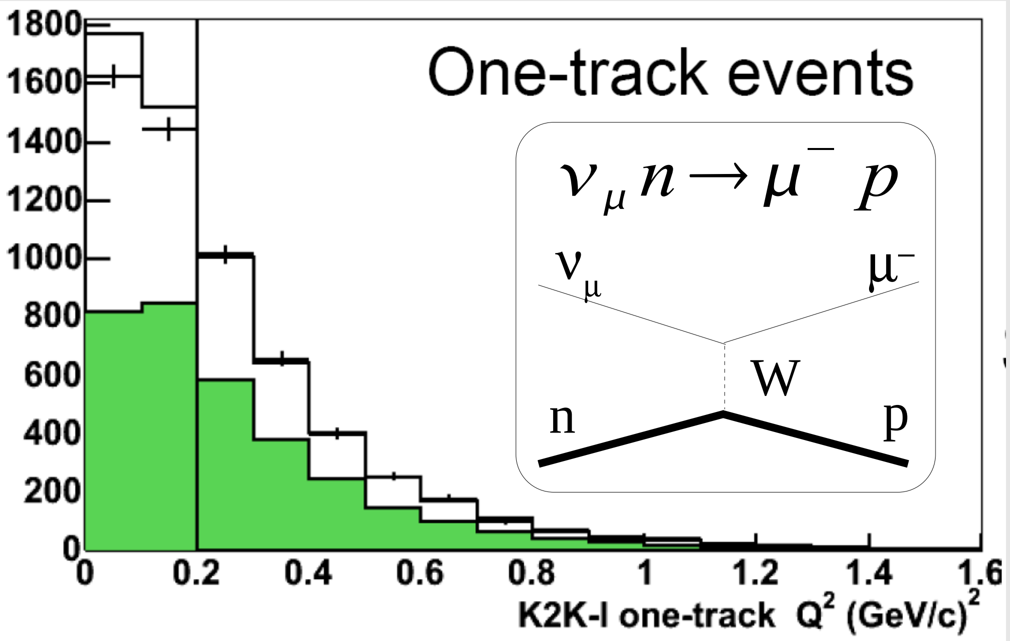
Previous CCQE results

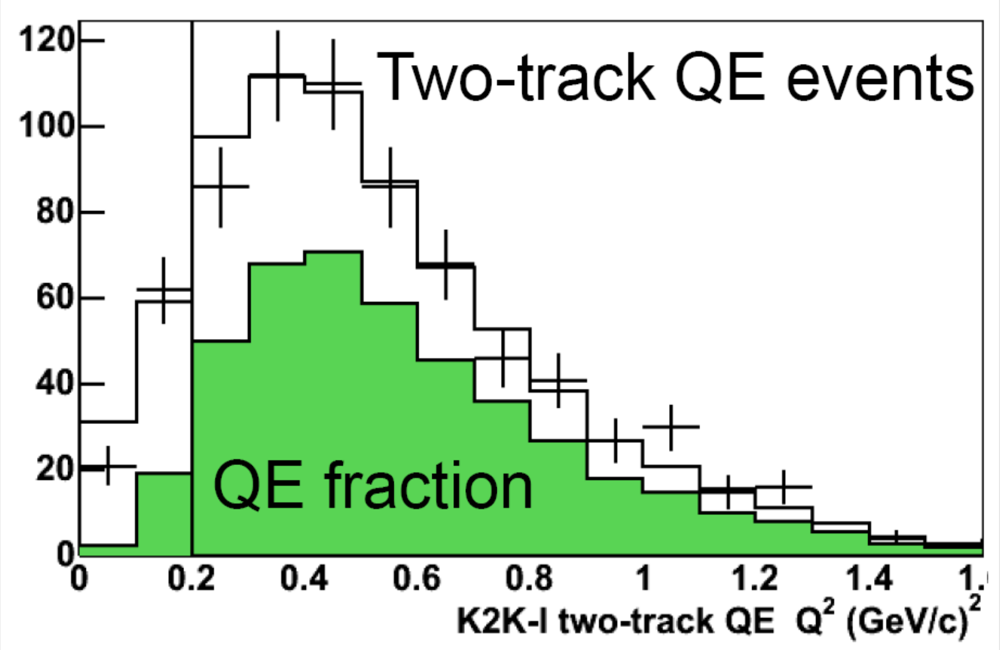
- K2K results from scifi (in water) detector (PRD74, 052002, '06)

- 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±0.12





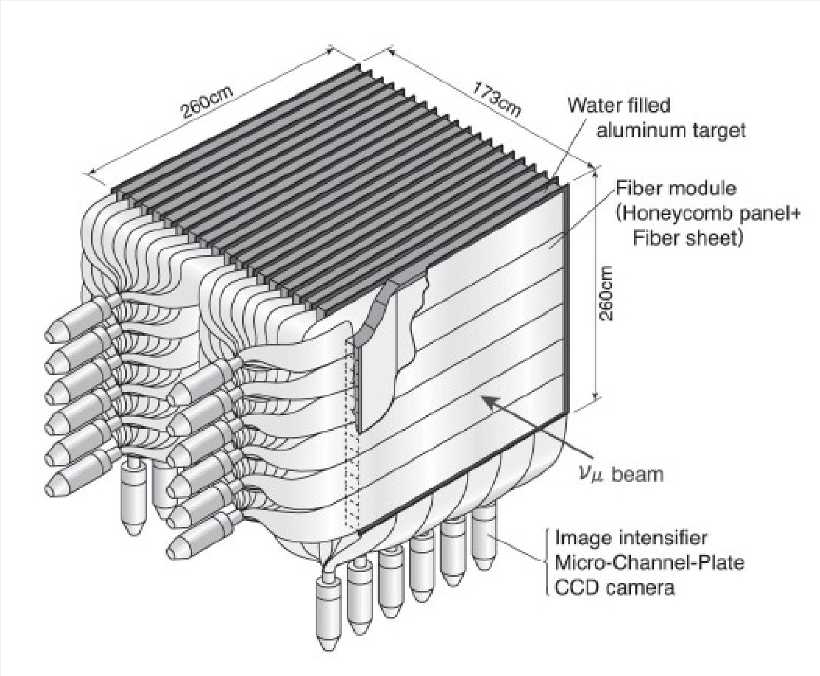


FIG. 2. A schematic diagram of the SciFi detector.

from Rik Gran, Nuint09

Recent CCQE results: MiniBooNE

- Requires observation of stopping muon and 1 decay electron

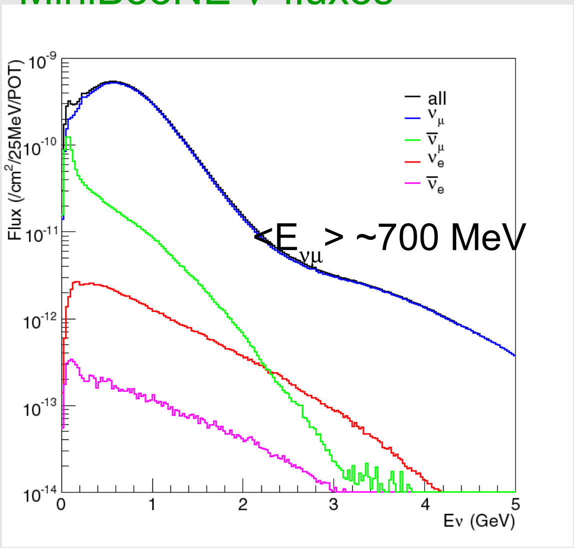
$$\nu_\mu + n \rightarrow \mu^- + p$$
$$\quad\quad \lfloor\!\rightarrow \nu_\mu + \nu_e + e^- \quad (\tau\sim 2\mu s)$$

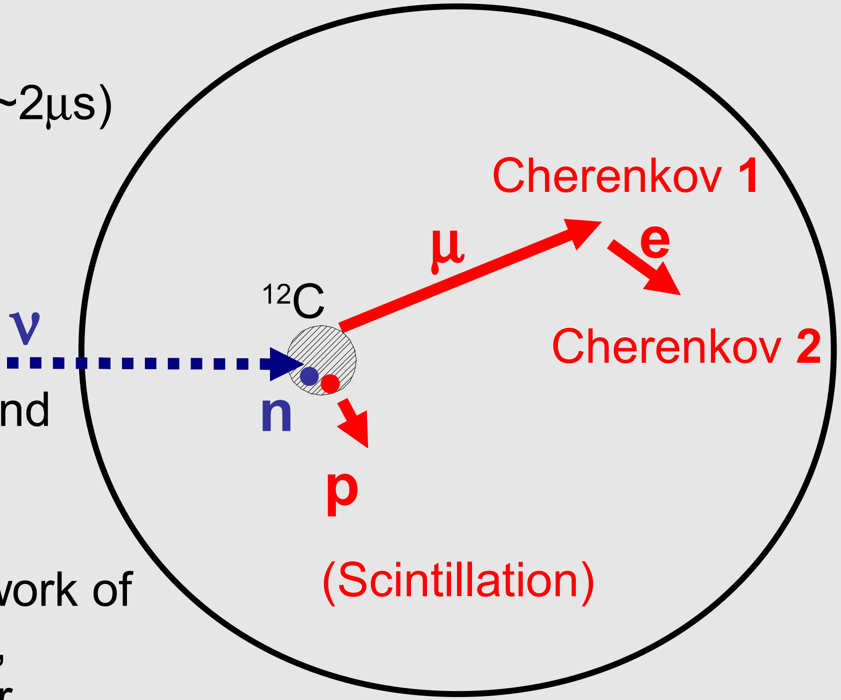
- No selection on (and ~no sensitivity to) final state nucleon
- Absolute ν_μ flux prediction from HARP π production experiment + geant4 MC. No tuning of ν_μ flux from MiniBooNE data.
- CCπ produces 2 decay electrons

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

- CCπ is (largest) background when e^{+-} missed. (because of π absorption, μ^- capture)
- MiniBooNE data used to measure this background

MiniBooNE ν fluxes





26.5% efficiency
75.8% purity
146,070 events from
5.58E20POT

From thesis work of
Teppei Katori,
see his poster

MiniBooNE CCQE results

- CCπ (absolute) background measurement:
- Use events with 2 observed μ decays to measure CCπ

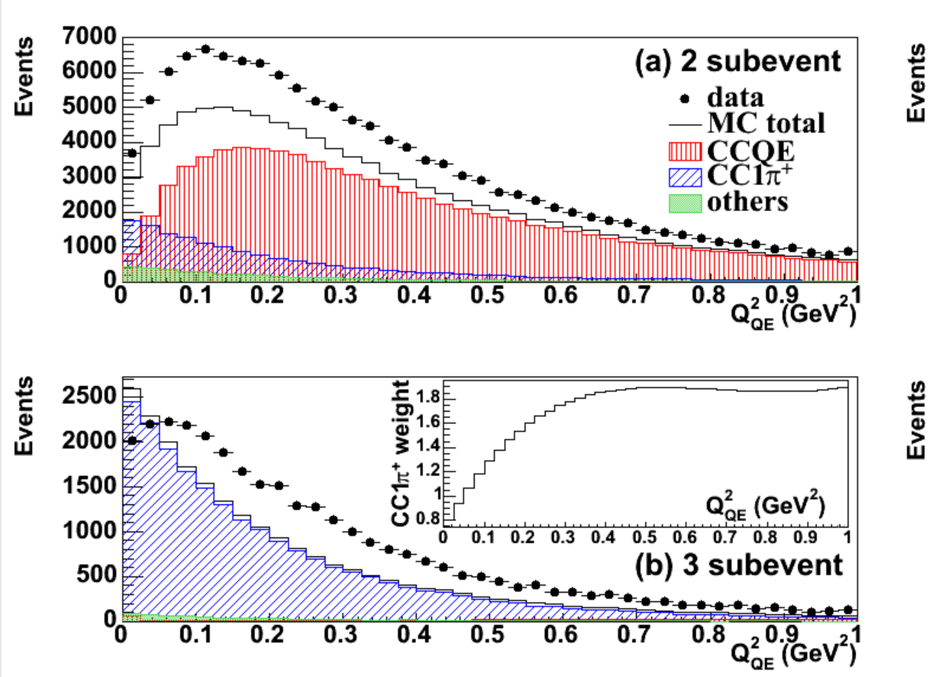
$\nu_\mu + N \to \mu^- + N + \pi^+$

$\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad \to \mu^+ \to \nu_\mu + \nu_e + e^+$ (τ~2μs)

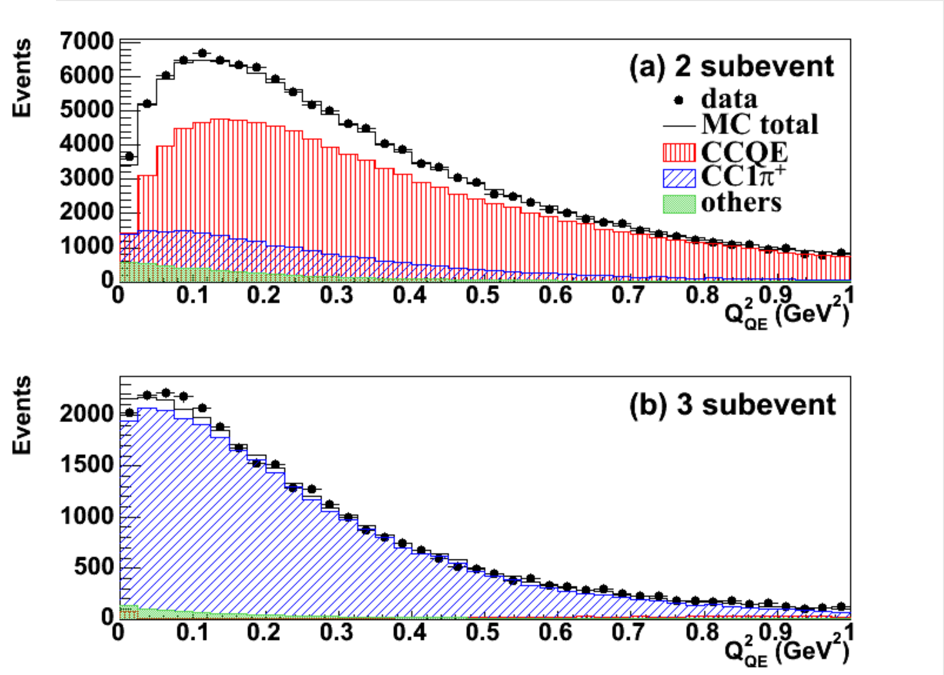
$\quad\quad\quad\quad \to \nu_\mu + \nu_e + e^-$ (τ~2μs)

- determine weighting function to apply to MC to better describe CCπ

before CCπ measurement



after CCπ measurement



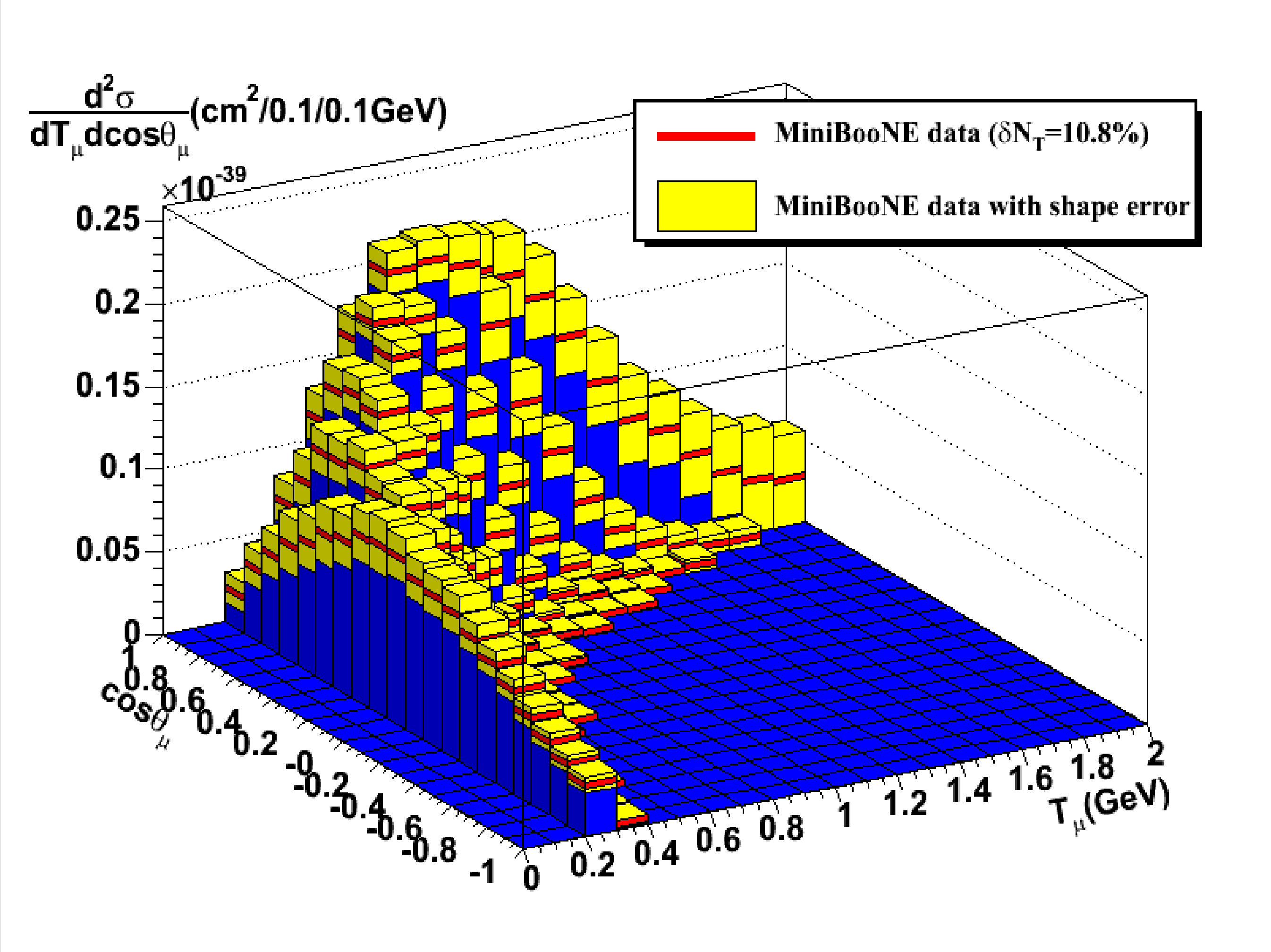
Getting CCπ correct (and correct assessment of errors) is very important in CCQE measurement

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

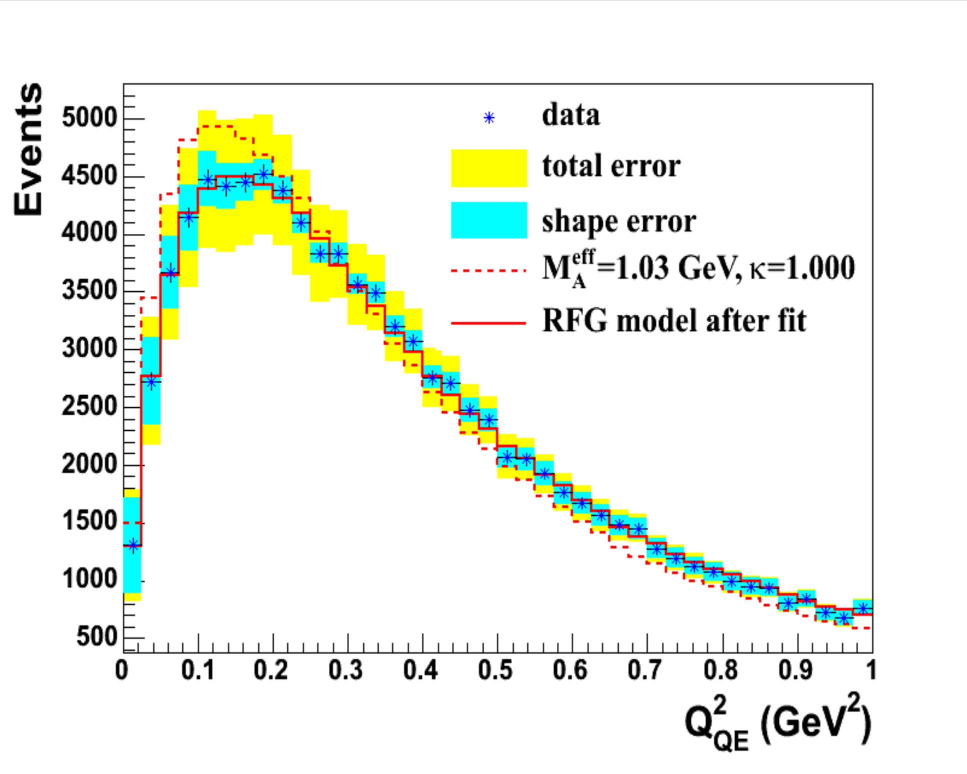
M_A^{eff} - κ shape-only fit result

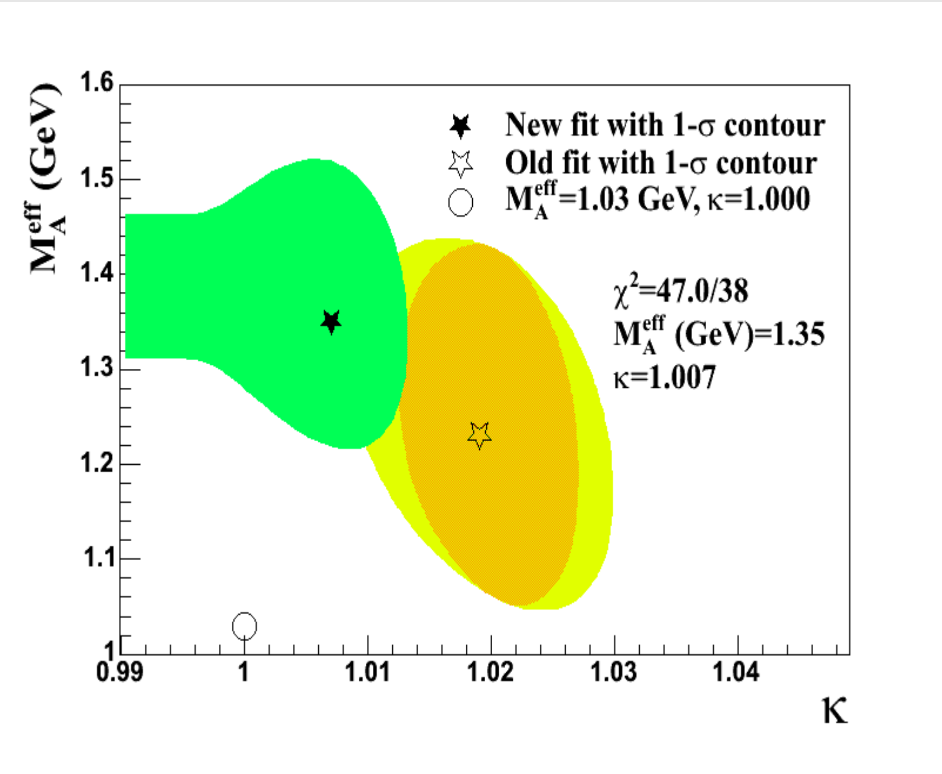
M_A^{eff} = 1.35 ± 0.17 GeV (stat+sys)

$\kappa = 1.007 ^{+0.007}_{-\infty}$ (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

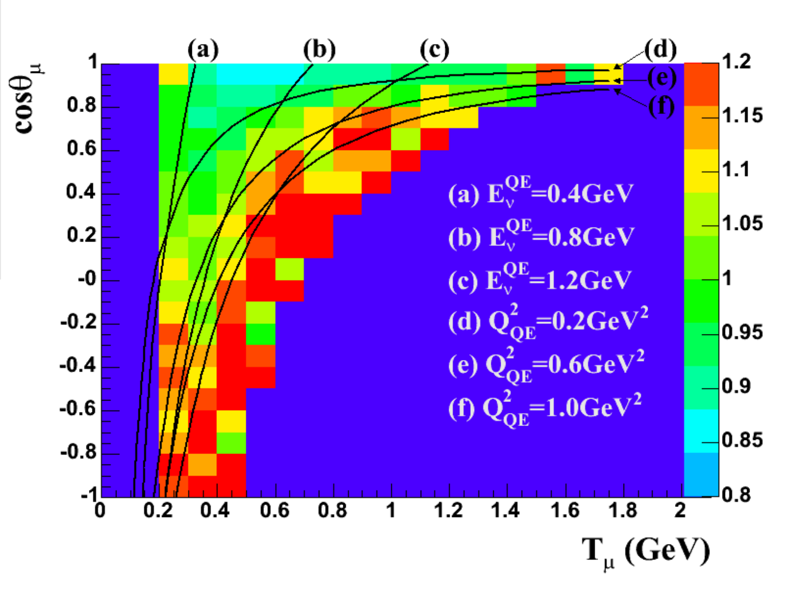




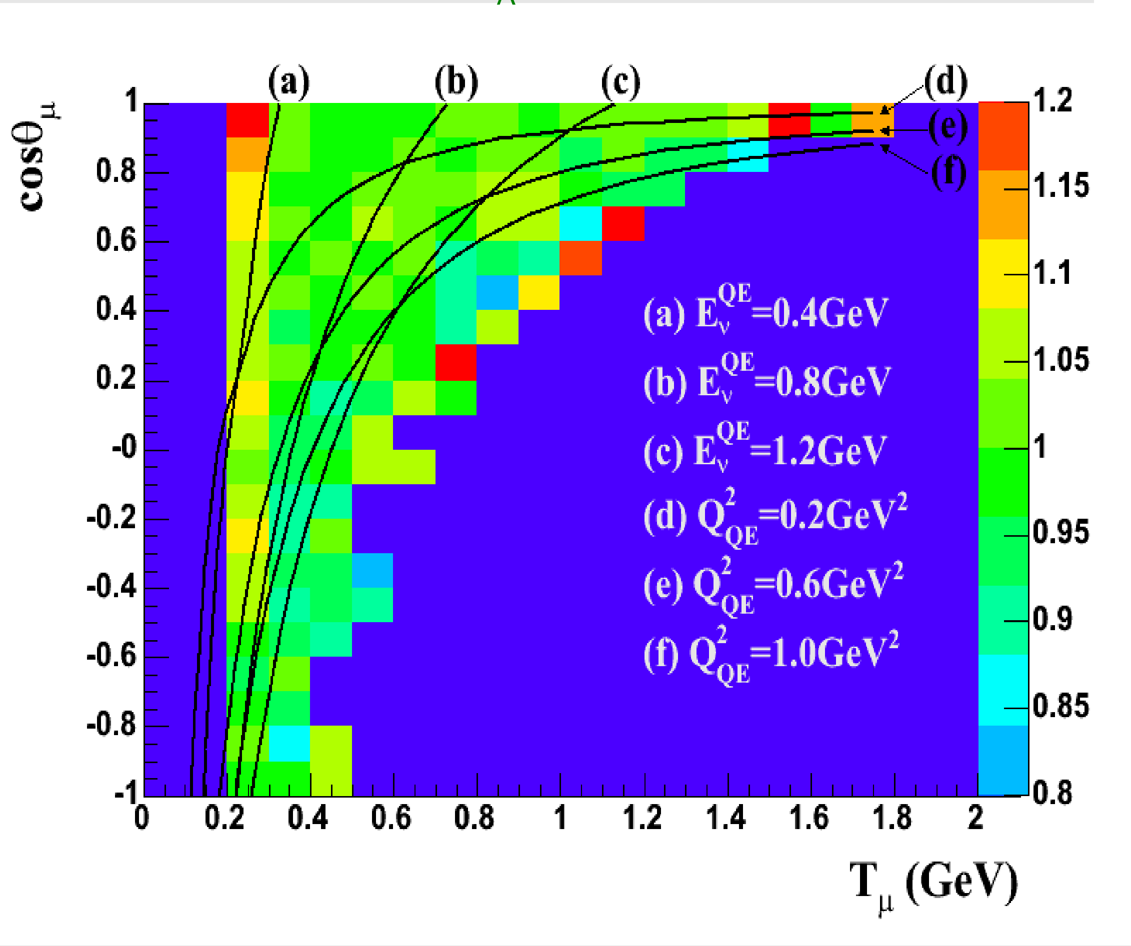
MiniBooNE CCQE results

- data is well described in $T_\mu - \Theta_\mu$ space.
- A check that Q^2 shape is not just poor understanding of E_ν distribution

data/MC ratio with world average M_A



data/MC ratio with fit M_A



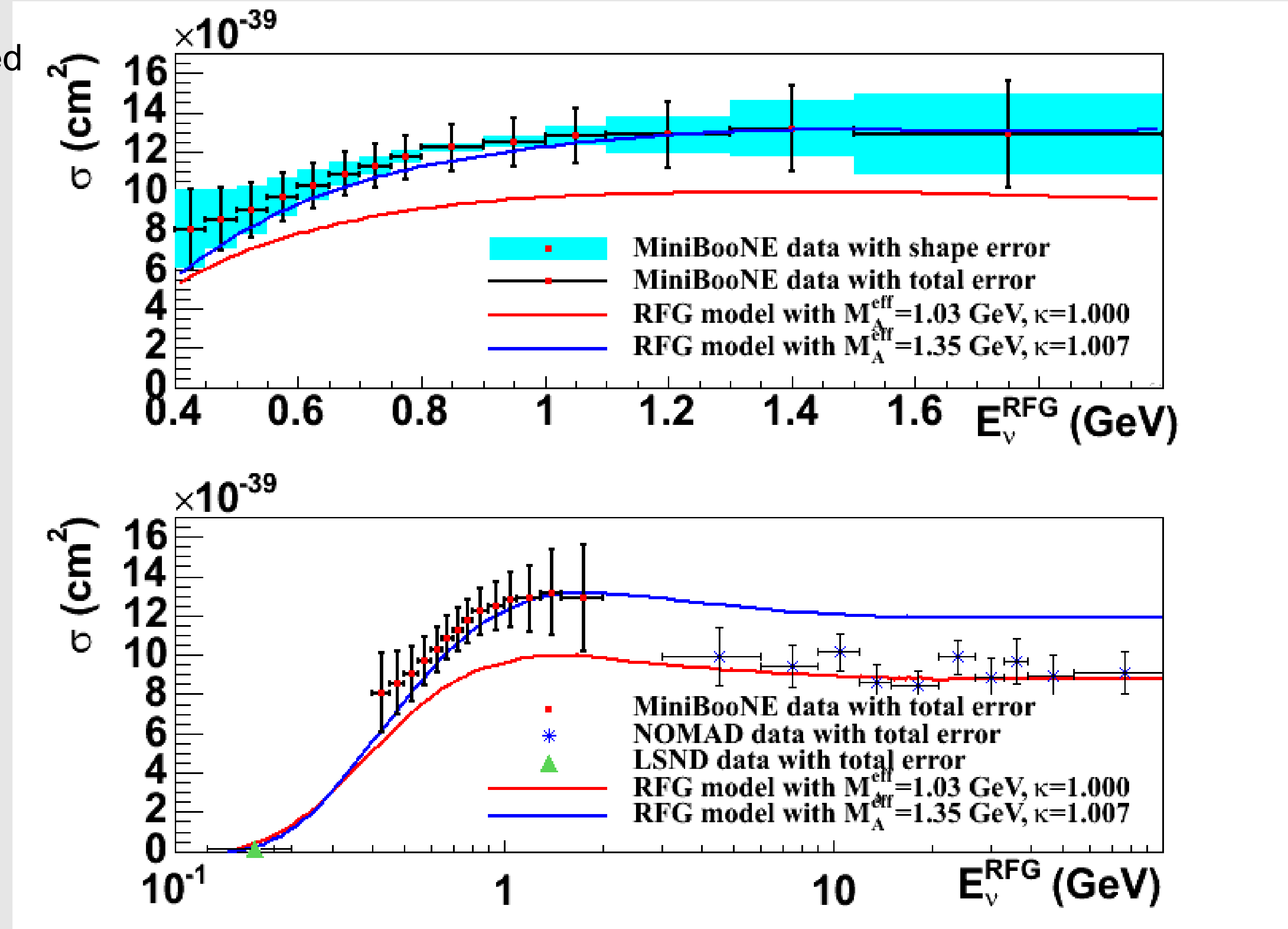
MiniBooNE CCQE results

- "flux-unfolded" total CCQE cross section.

- M_A fit was performed using only shape of Q^2 distribution. Predicted rate with M_A agrees (to ~10%) with data. Coincidence?

- not a model-independent result:
  - assumes a nuc model to determine E_ν
  - σ determined with (limited) detector acceptance

extracted total cross section

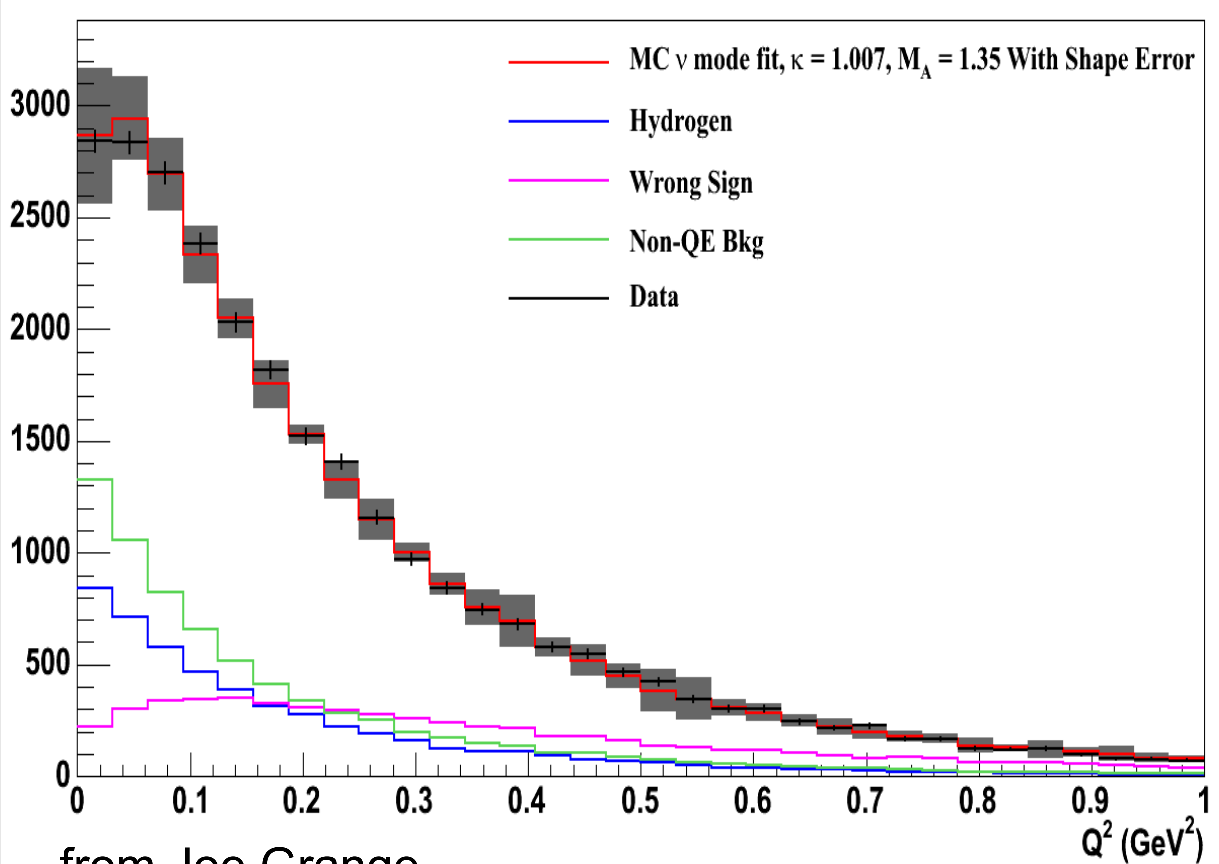


MiniBooNE $\bar{\nu}$ CCQE results

- MB has a large $\bar{\nu}$ CCQE data set currently under investigation
- more challenging analysis
    - “wrong-sign” backgrounds
    - free proton contribution
    - different CCπ backgrounds

- However, preliminary results show good description of $\bar{\nu}$ CCQE data with ν parameters

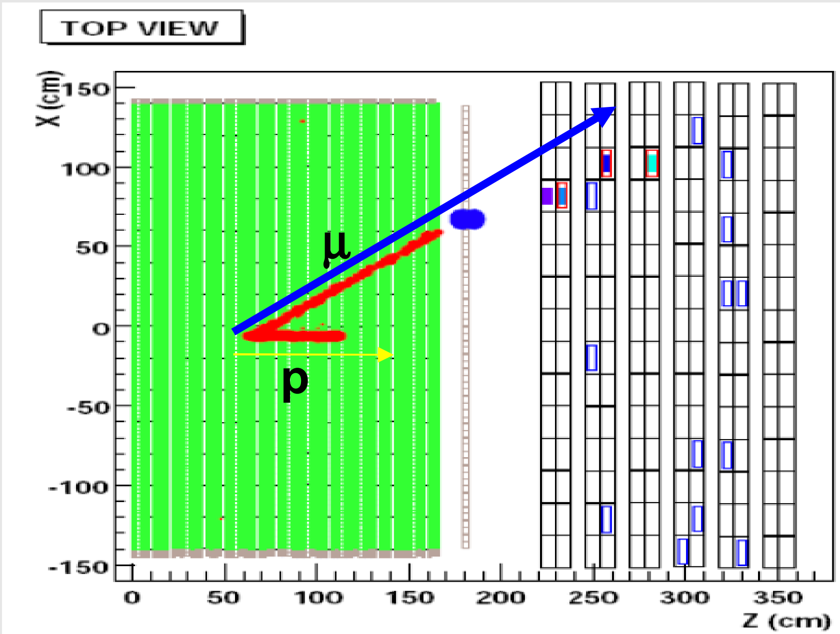
$\bar{\nu}$ Q^2 distribution data, MC

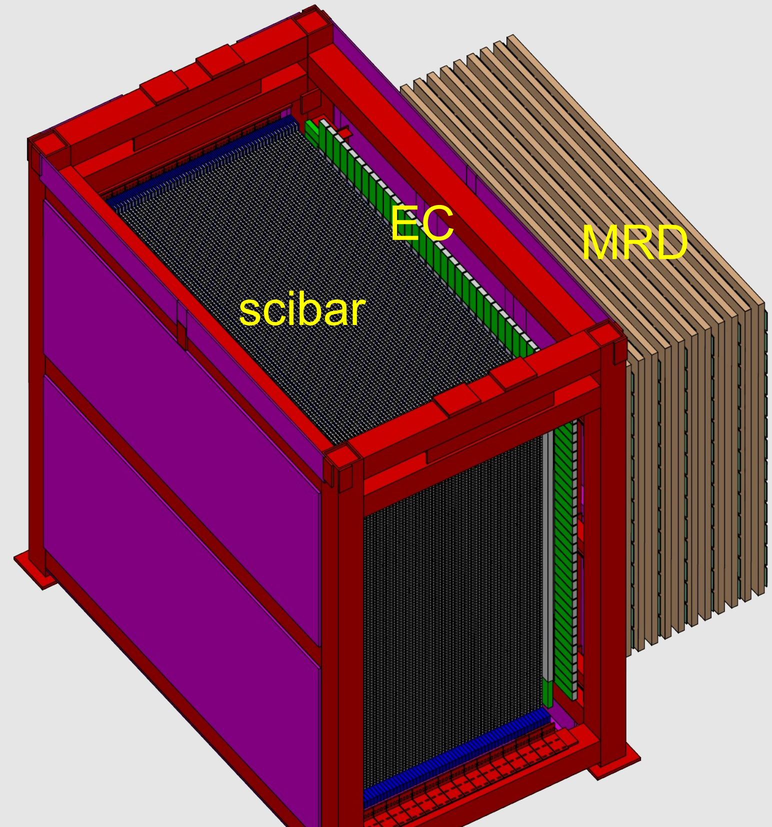


from Joe Grange

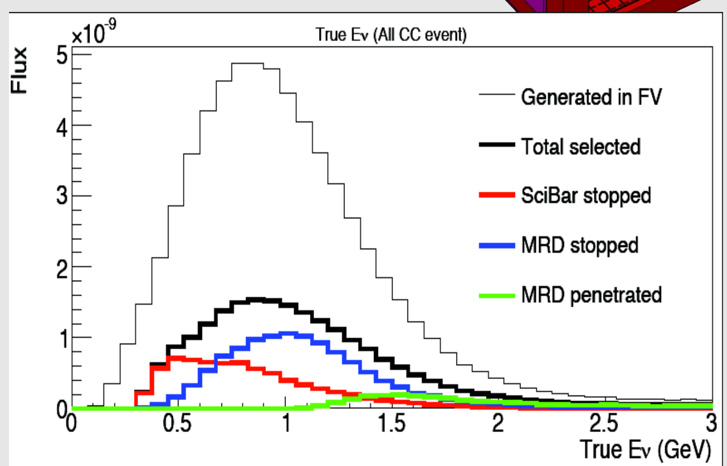
Preliminary CCQE results from SciBooNE

SciBooNE display of a typical muon neutrino CCQE event candidate.





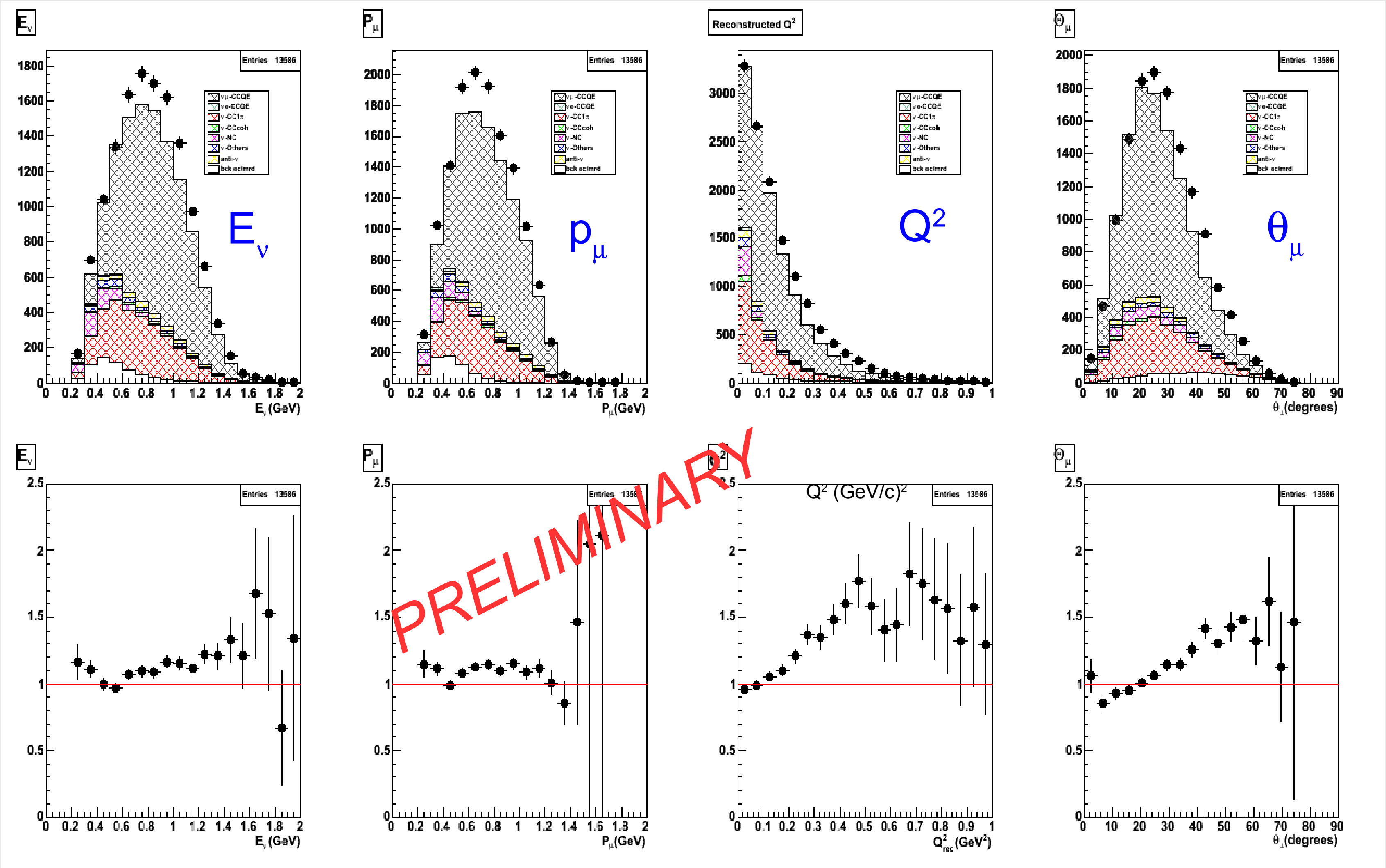
- booster ν beam (as MiniBooNE)
- a precision (~1cm) tracking detector
- CCQE samples:
  - both 1 (μ) and 2 (μ,p) observed
  - both scibar-stopped and MRD-tracked event samples



From recent work of J. Walding, J. Alcaraz, presented at Nuint09

Preliminary CCQE results from SciBooNE

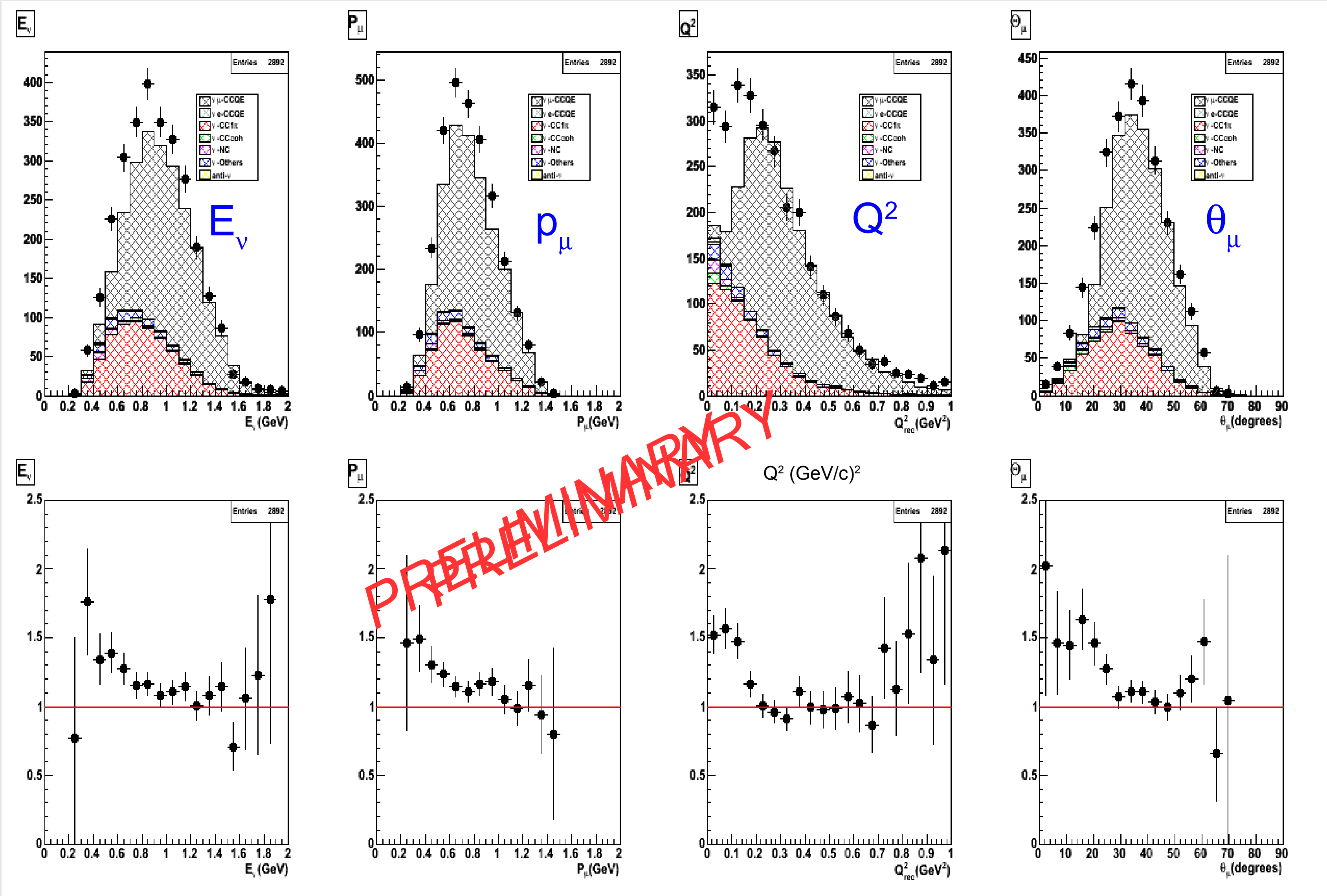
- 1 track (μ) MRD-stopped sample



- 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

Preliminary CCQE results from SciBooNE

- 2 track (μ+p) MRD-stopped sample

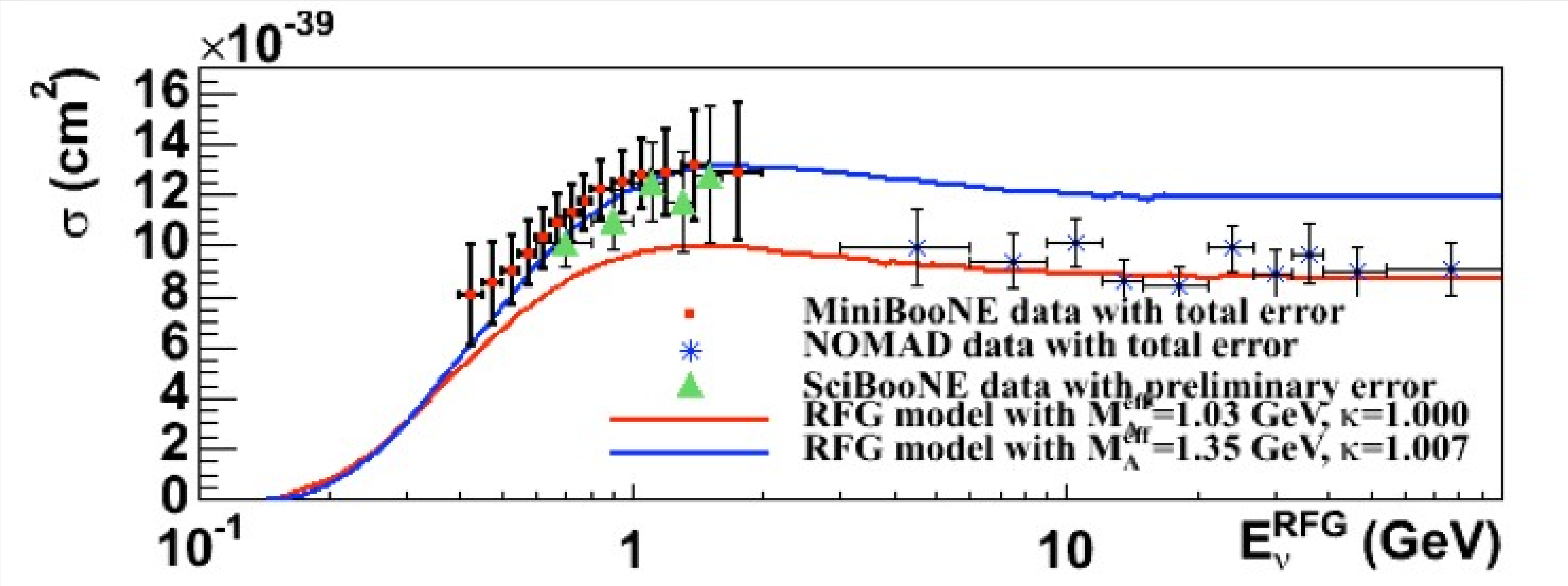


- total measured rate data in excess compared to MC (Neut) (M_A=1.2GeV)
- this sample is not separable (from 1 track) in MiniBooNE
- will offer opportunity to better tune final state interations of p, π

SciBooNE/MiniBooNE/NOMAD CCQE results

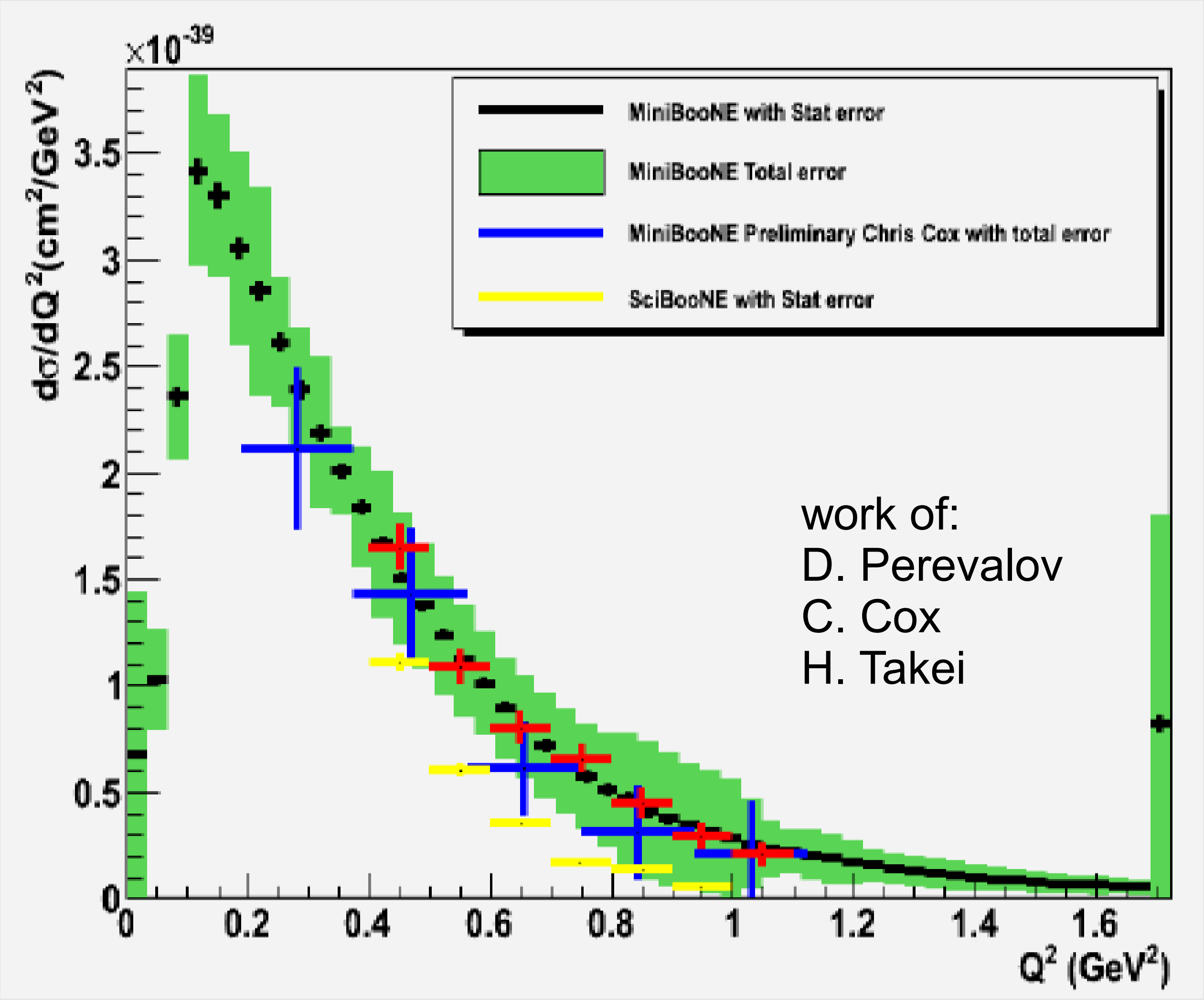
- SciBooNE extracts total cross section from fit to 1,2 track (CCQE) and bckgd data
- That result shown here together with MiniBooNE and (recent) result from NOMAD.
- SciBooNE CCQE rate high compared to M_A=1.03
- However, NOMAD data, well described with this lower M_A

extracted total cross section

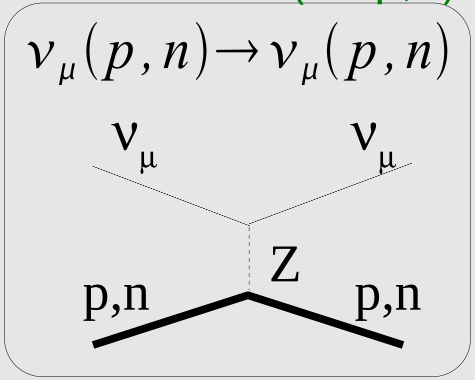


SciBooNE/MiniBooNE NC elastic scattering

-The NC elastic channel is nicely complementary to CCQE. Does an understanding of CCQE specify NCelastic? Or is there something extra contributing to NCelastic?.. such as strange quarks?



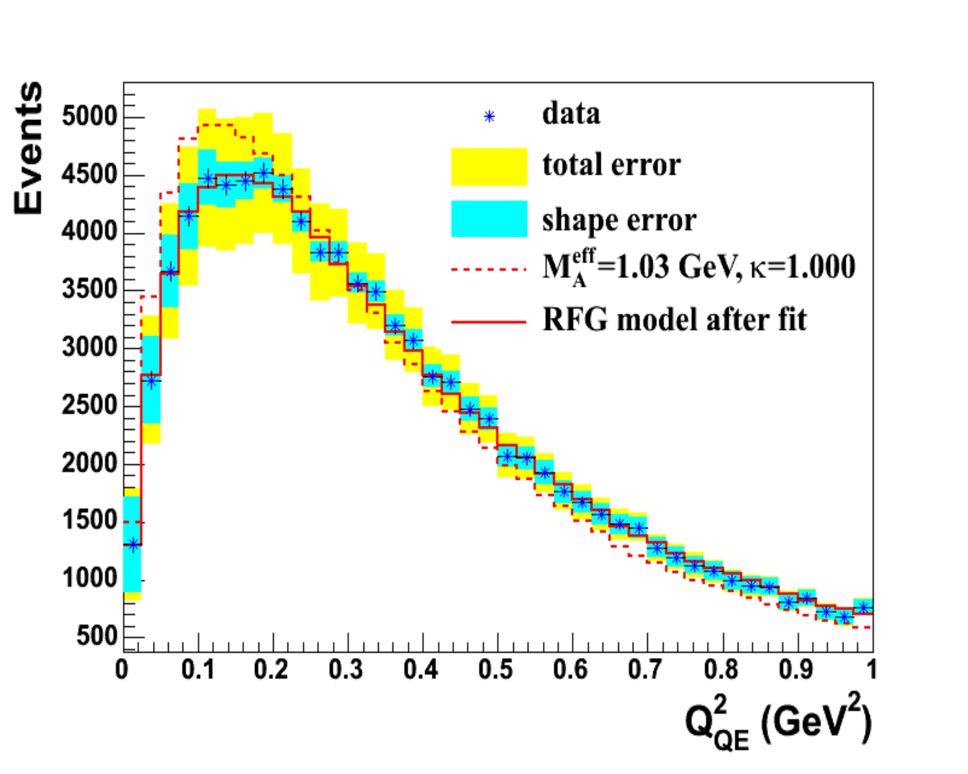
neutral-current
elastic (NCp,n)



Discussion: CCQE mysteries

Recent CCQE data are not well described with canonical model.

- MiniBooNE data show excess over that expected from model with M_A~1.0GeV (in 0.3-0.8GeV^2 region). Independent of total rate. (K2K saw this also)
- The MiniBooNE rate/ total cross section data supports this. Cooincidence?
- SciBooNE (prelim) data seem to follow these trends.
- MINOS data (on Fe!) do also (next talk).
- However, NOMAD data, at higher energies, do not. (next talk).



- What is going on?
  - "nuclear" effects?
  - nuclear medium effects on form factors?
  - experimental problems?

- All interesting questions that we need to answer in order to realize precision neutrino oscillation measurements.

To sort this out, need:

- Model-independent observables
- No experimental bias from tuning flux based on CCQE spectra. Need absolute flux predictions.
- Background measurements, CCπ in particular.

Discussion: CCQE

- Example of flux-tuning intertwined with CCQE M_A results

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 ν_μ flux spectrum obtained from the observed E_ν distribution of the events after correcting for the deuteron effects and the Q_{min}^2 cut.

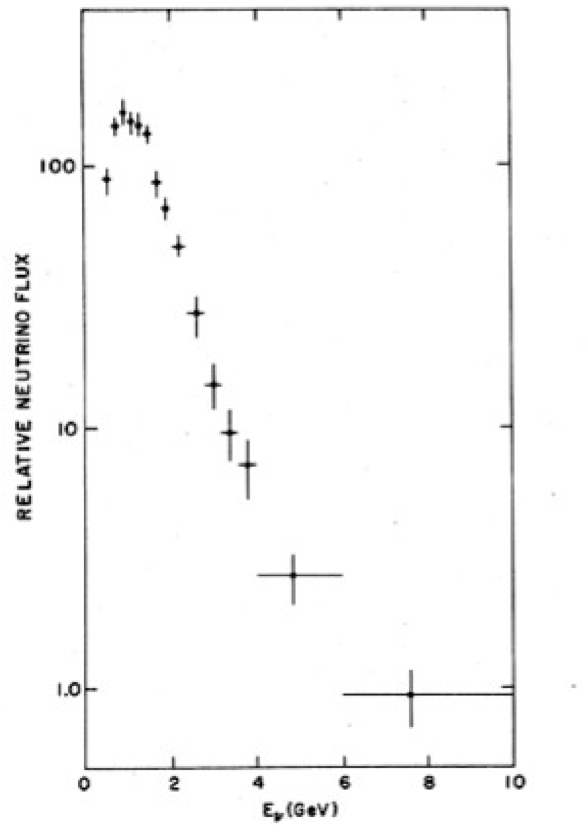


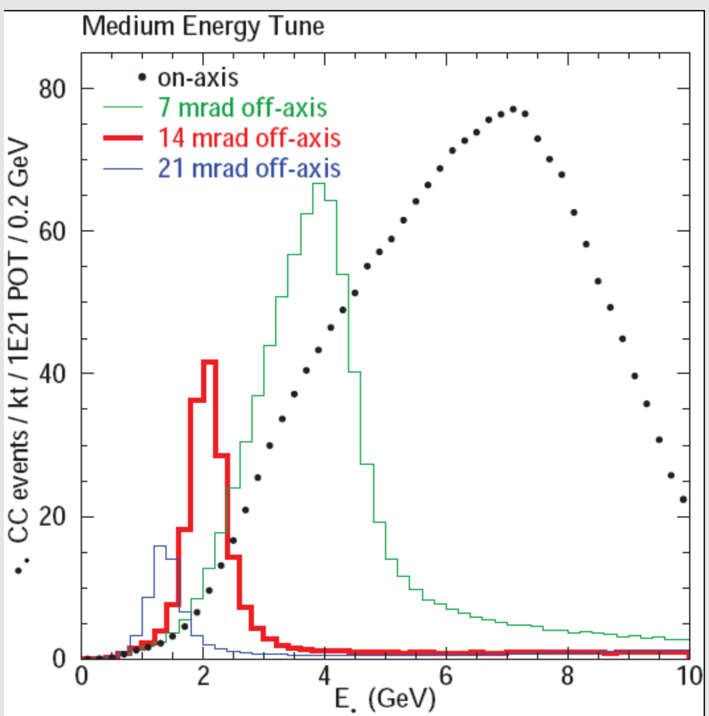
FIG. 7. The relative ν_μ flux spectrum obtained from the observed E_ν distribution of the events with $M_A = 1.07$ GeV.

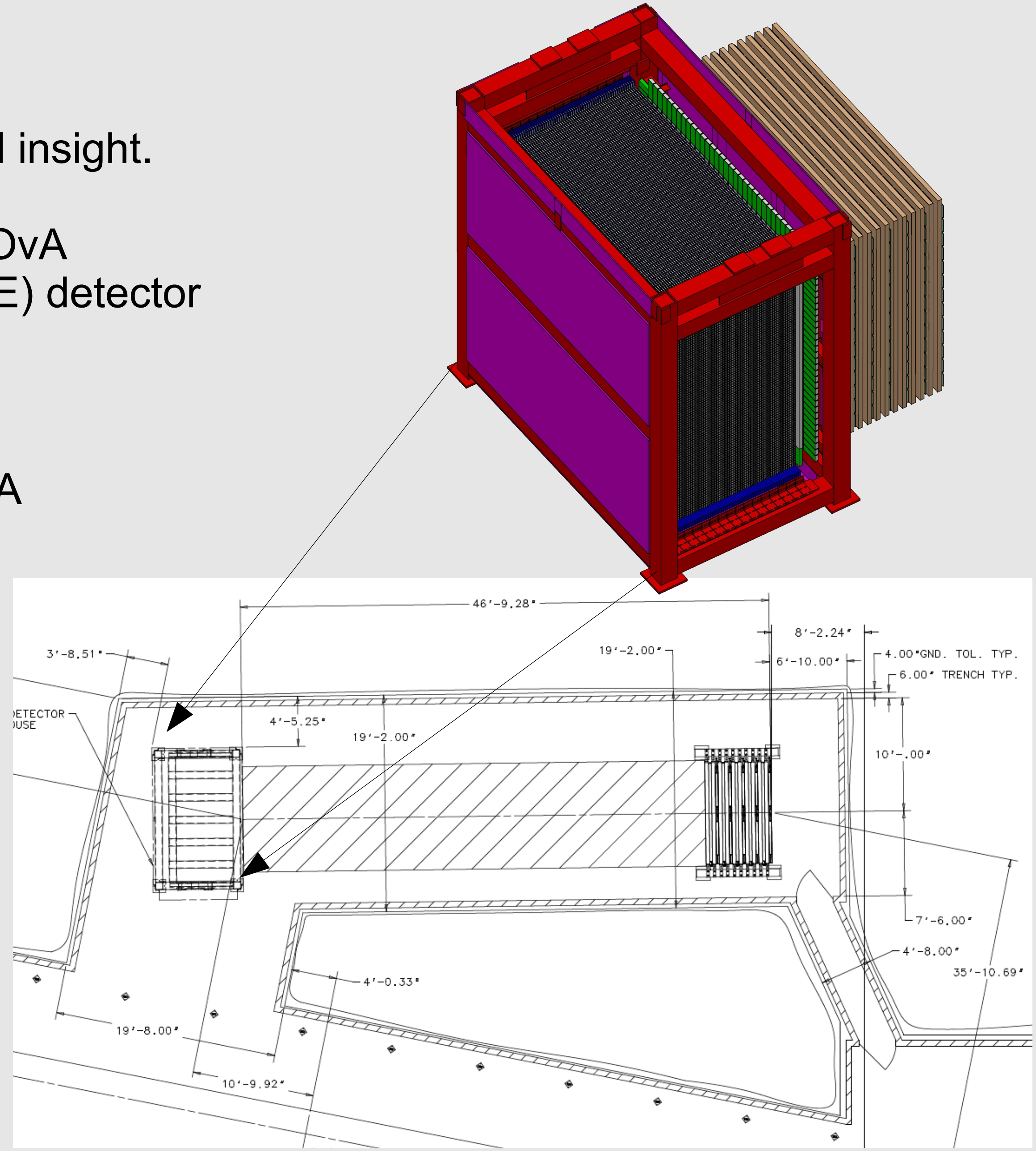
- Should be avoided when possible in order to guide detailed models.

CCQE Future

- Minerva, TK2 will provide additional insight.

- Another possibility, new idea: SciNOvA
  - put existing scibar (from SciBooNE) detector in from of NOvA near detector
  - measure:
    - CCQE, in narrow band beam
    - $NC\pi^0$, to better constrain NoVA background

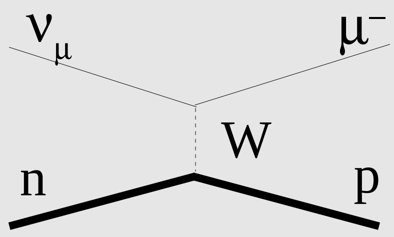




Conclusions

ν_μ CCQE

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



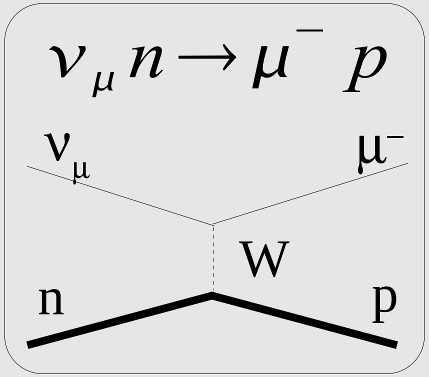
- Important to understand the CCQE process as it is a fundamental process and needed for measuring neutrino oscillations.

- Recent results from measurments on carbon, oxygen, Fe, dont agree with what we thought we knew about CCQE, ~10 years ago.

- IMO, need to dig into problem and sort this out with:
    - unbiased, cross section (model-independent) measurements
    - complementary measurements with different (but understood) flux
    - detailed work modeling, understanding data (including backgrounds)

Conclusions

ν_μ CCQE



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