La Primera Medida de la Sección Eficaz Doble Diferencial en la Dispersión Quasi-elastica de la Corriente Cargada del Neutrino Muónico

Work based on
PhD thesis at
Indiana University

Teppei Katori for the MiniBooNE collaboration
Massachusetts Institute of Technology
NuInt 09, Sitges, May, 19, 09

Massachusetts
Institute of
Technology

First Measurement of Muon Neutrino Charged Current Quasielastic (CCQE) Double Differential Cross Section

outline

1. Booster neutrino beamline
2. CCQE events in MiniBooNE
3. CC1π background constraint
4. CCQE M_A^{eff}-κ shape-only fit
5. CCQE absolute cross section
6. Conclusion

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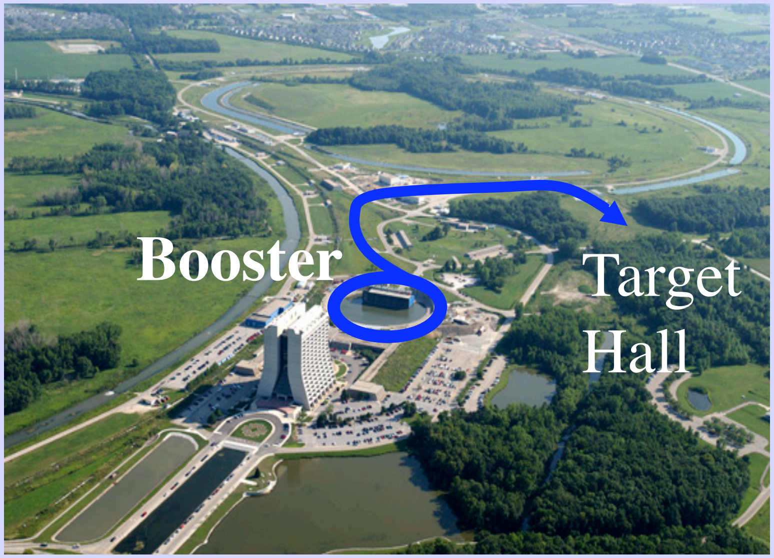
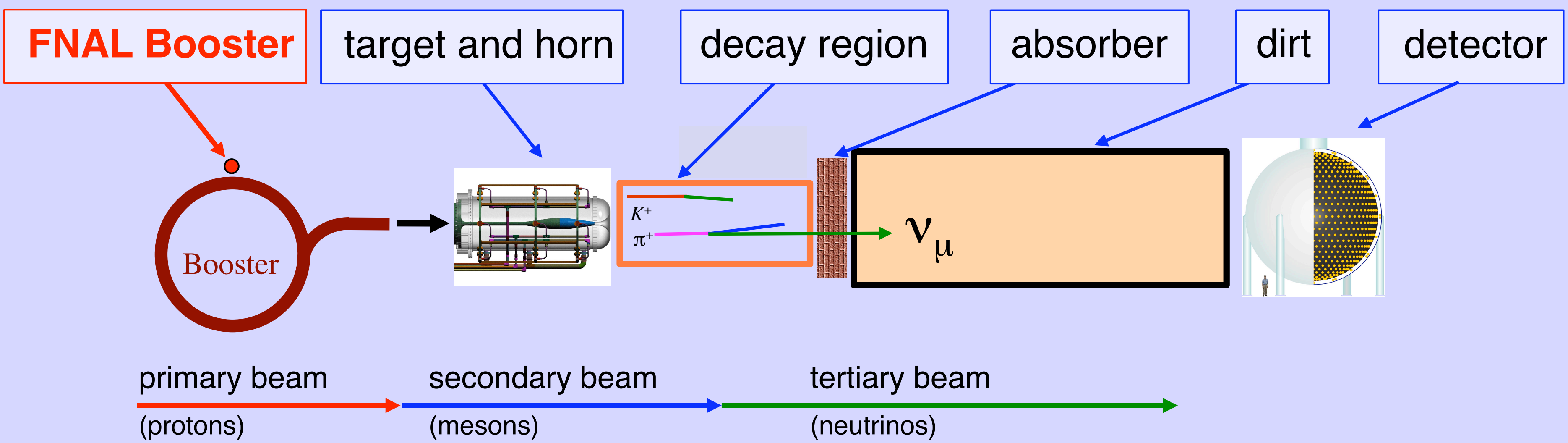
1. Booster Neutrino Beamline

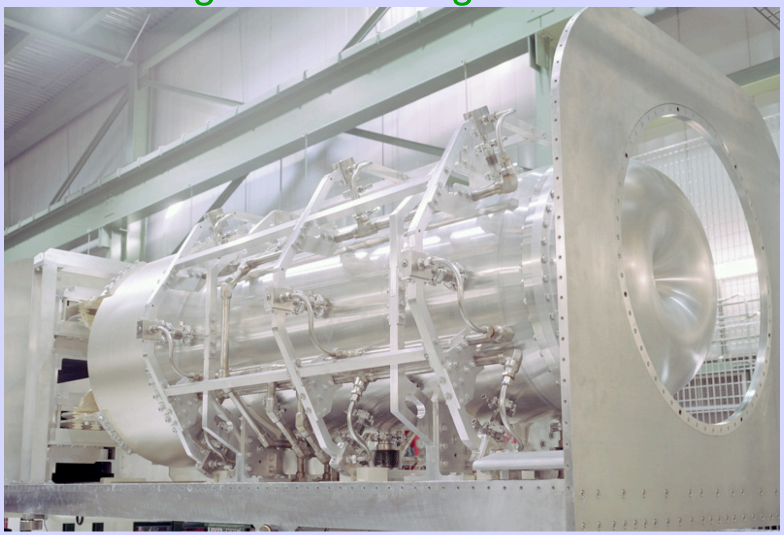


MiniBooNE extracts 8.9 GeV/c momentum proton beam from the Booster

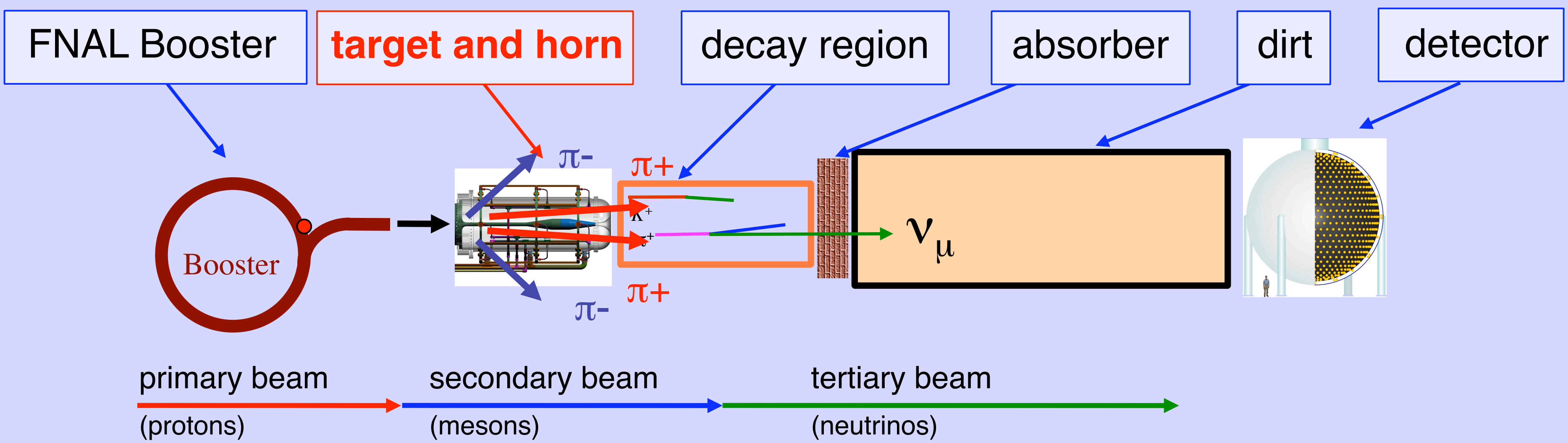


1. Booster Neutrino Beamline

Magnetic focusing horn



Protons are delivered to a beryllium target in a magnetic horn (flux increase ~6 times)

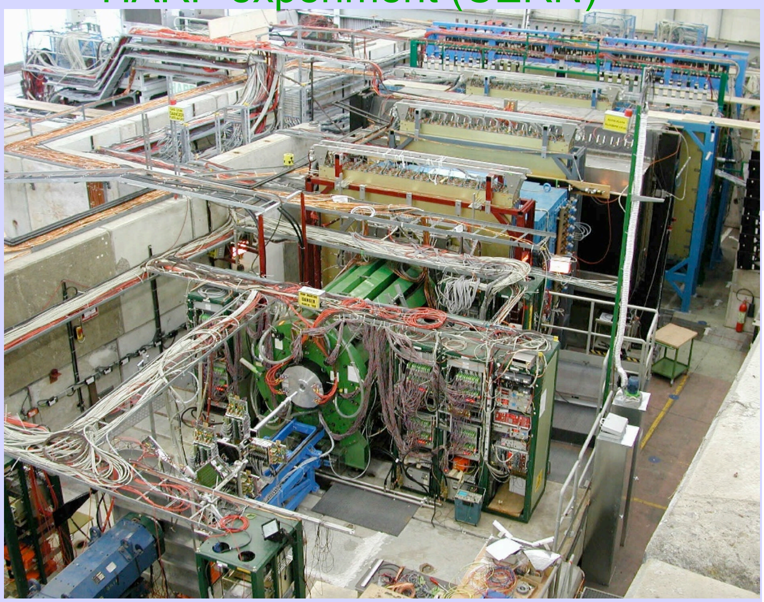


1. Booster Neutrino Beamline

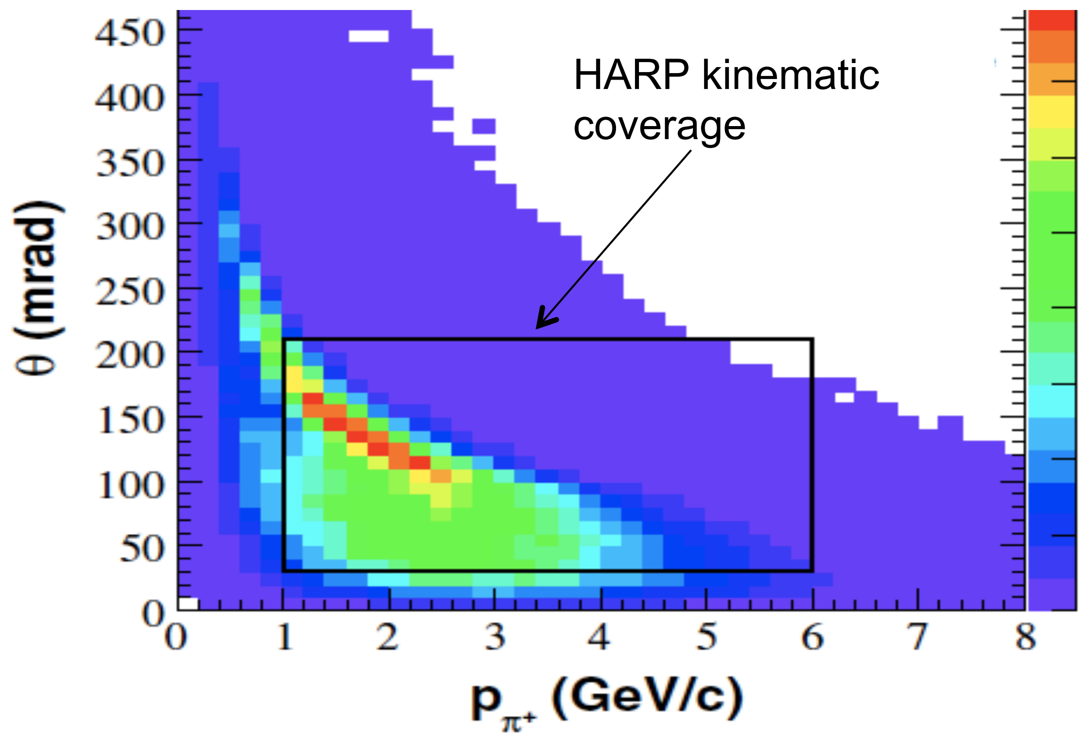
Modeling of meson production is based on the measurement done by HARP collaboration
- Identical, but 5% λ Beryllium target
- 8.9 GeV/c proton beam momentum

HARP collaboration, Eur.Phys.J.C52(2007)29

HARP experiment (CERN)



Booster neutrino beamline pion kinematic space



Majority of pions create neutrinos in MiniBooNE are directly measured by HARP (>80%)

1. Booster Neutrino Beamline

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HARP collaboration,
Eur.Phys.J.C52(2007)29

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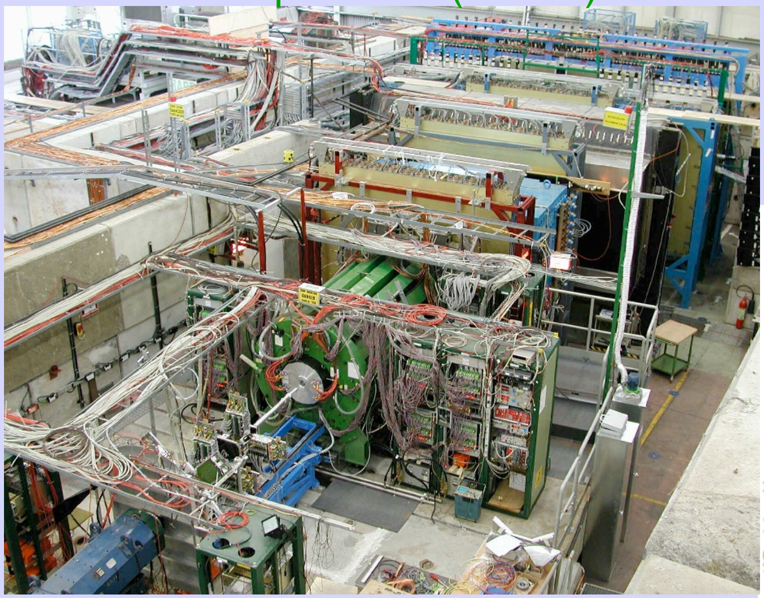
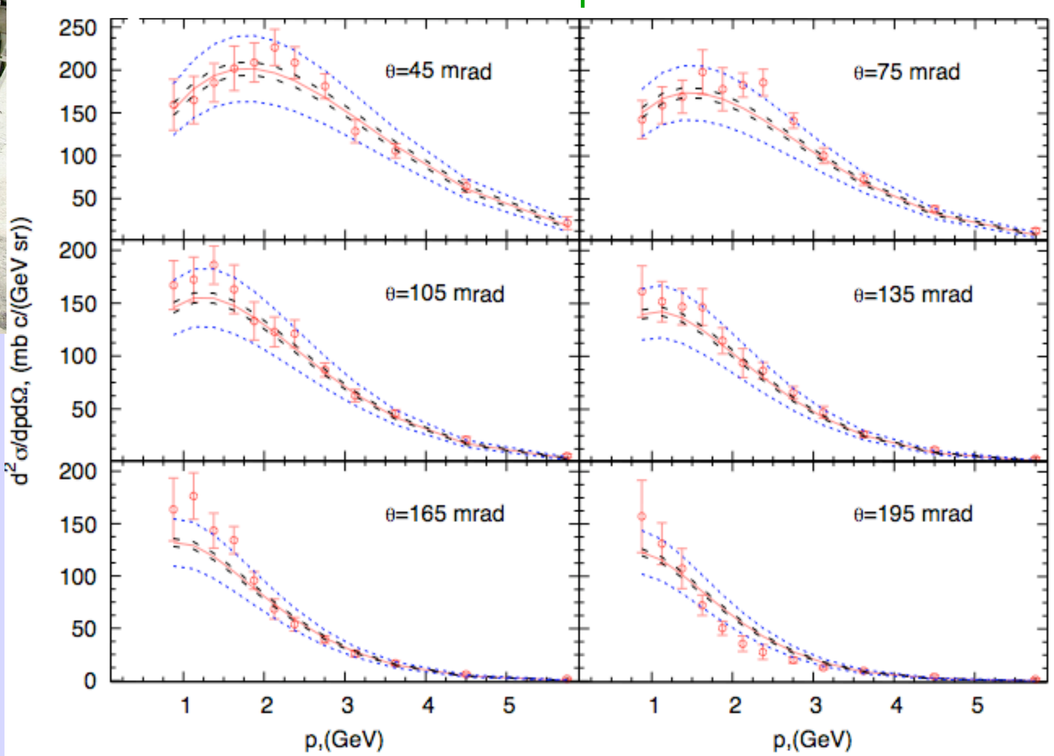
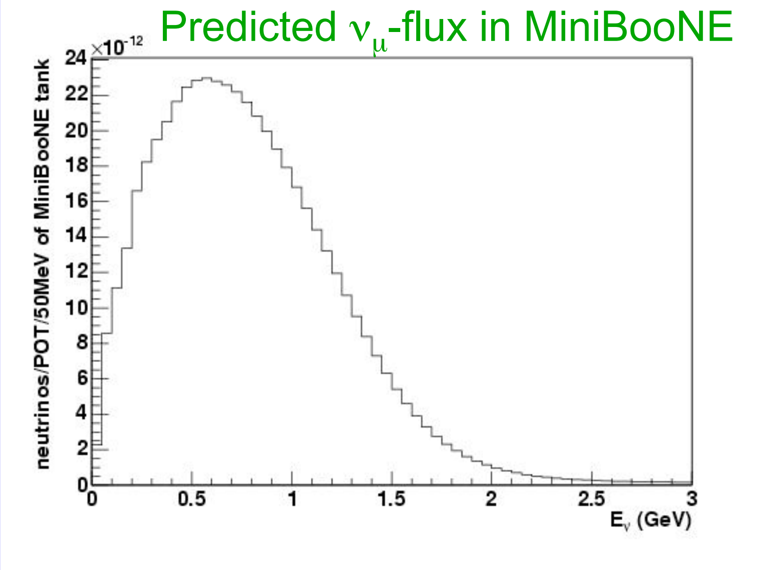


HARP data with 8.9 GeV/c proton beam momentum



The error on the HARP data (~7%) directly propagates.
The neutrino flux error is the dominant source of normalization error for an absolute cross section in MiniBooNE.

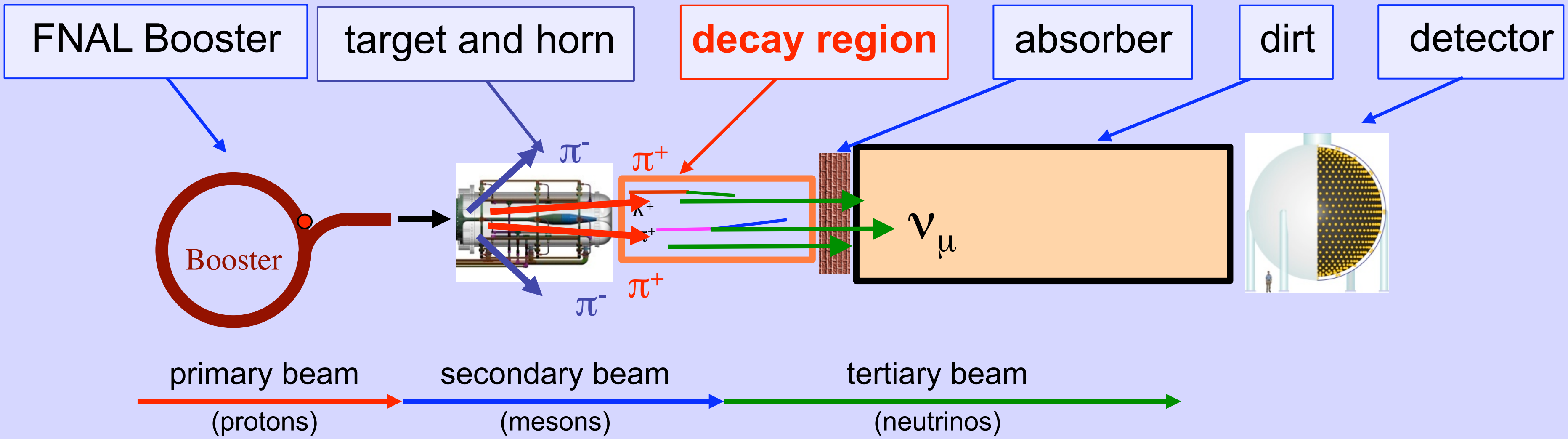
1. Booster Neutrino Beamline



The decay of mesons make the neutrino beam. The neutrino beam is dominated by ν_μ (93.6%), of this, 96.7% is made by π^+-decay

$$\pi^+ \rightarrow \mu^+ + \nu_\mu$$

MiniBooNE collaboration,
PRD79(2009)072002



1. Booster neutrino beamline

2. CCQE events in MiniBooNE

3. CC1π background constraint

4. CCQE M_A^{eff}-κ shape-only fit

5. CCQE absolute cross section

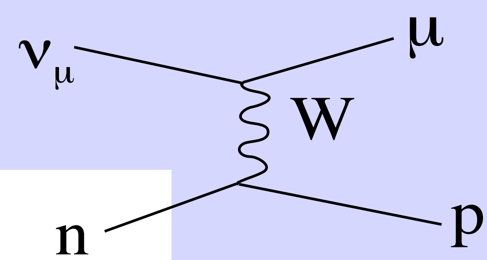
6. Conclusion

2. CCQE event measurement in MiniBooNE

ν_μ charged current quasi-elastic (ν_μ CCQE) interaction is an important channel for the neutrino oscillation physics and the most abundant (~40%) interaction type in MiniBooNE detector

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

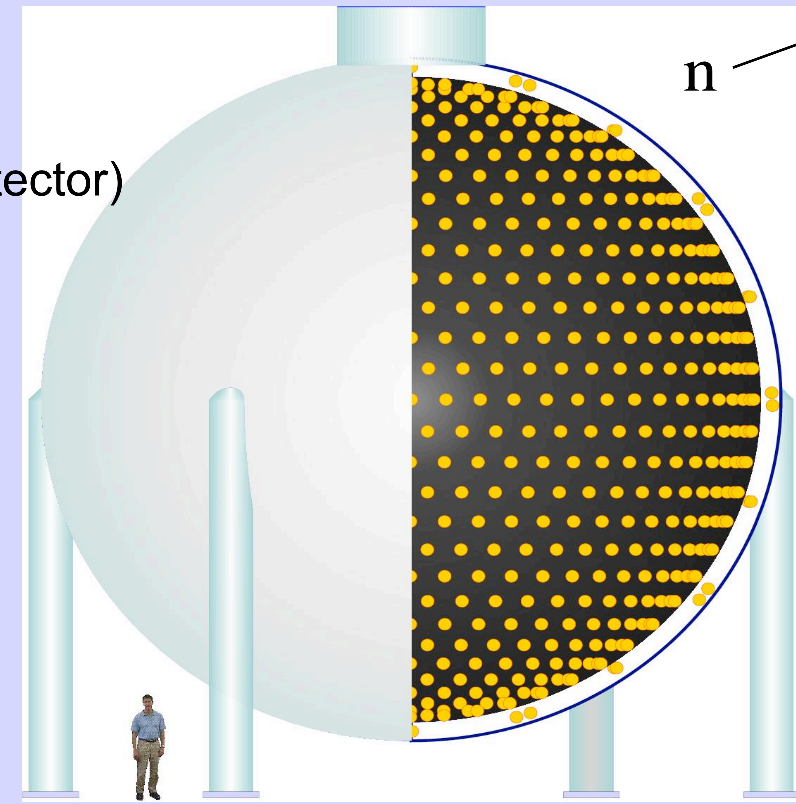
$$(\nu_\mu + {}^{12}C \rightarrow X + \mu^-)$$



MiniBooNE detector

(spherical Cherenkov detector)

MiniBooNE collaboration,
NIM.A599(2009)28



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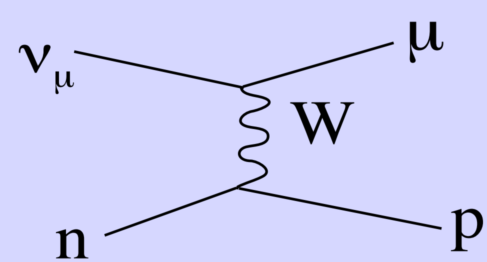

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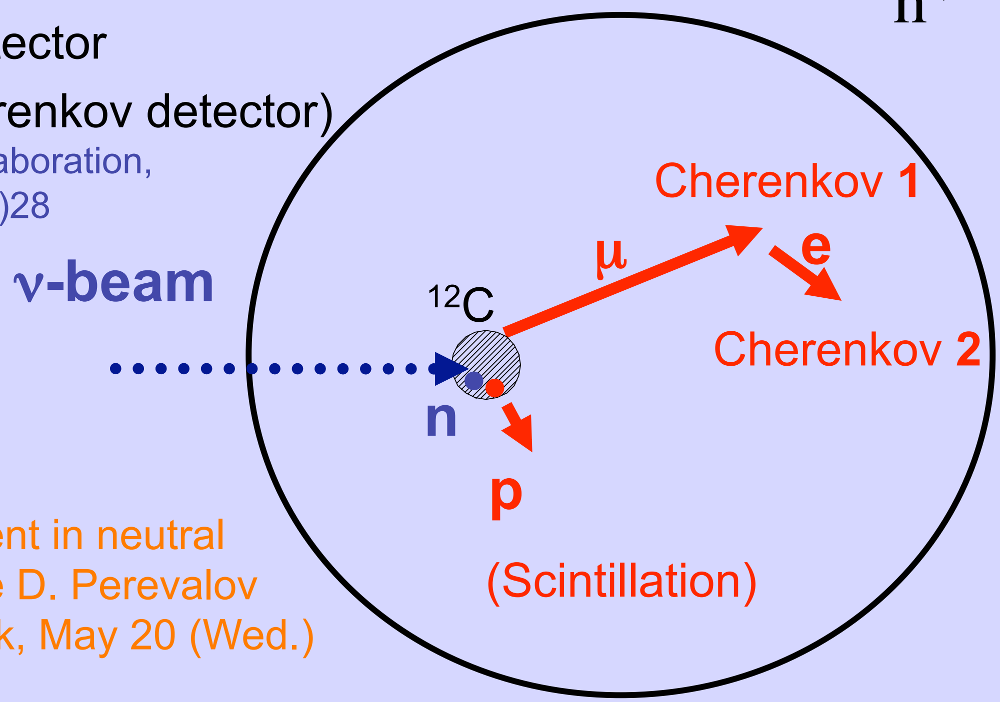
(spherical Cherenkov detector)

MiniBooNE collaboration, NIM.A599(2009)28



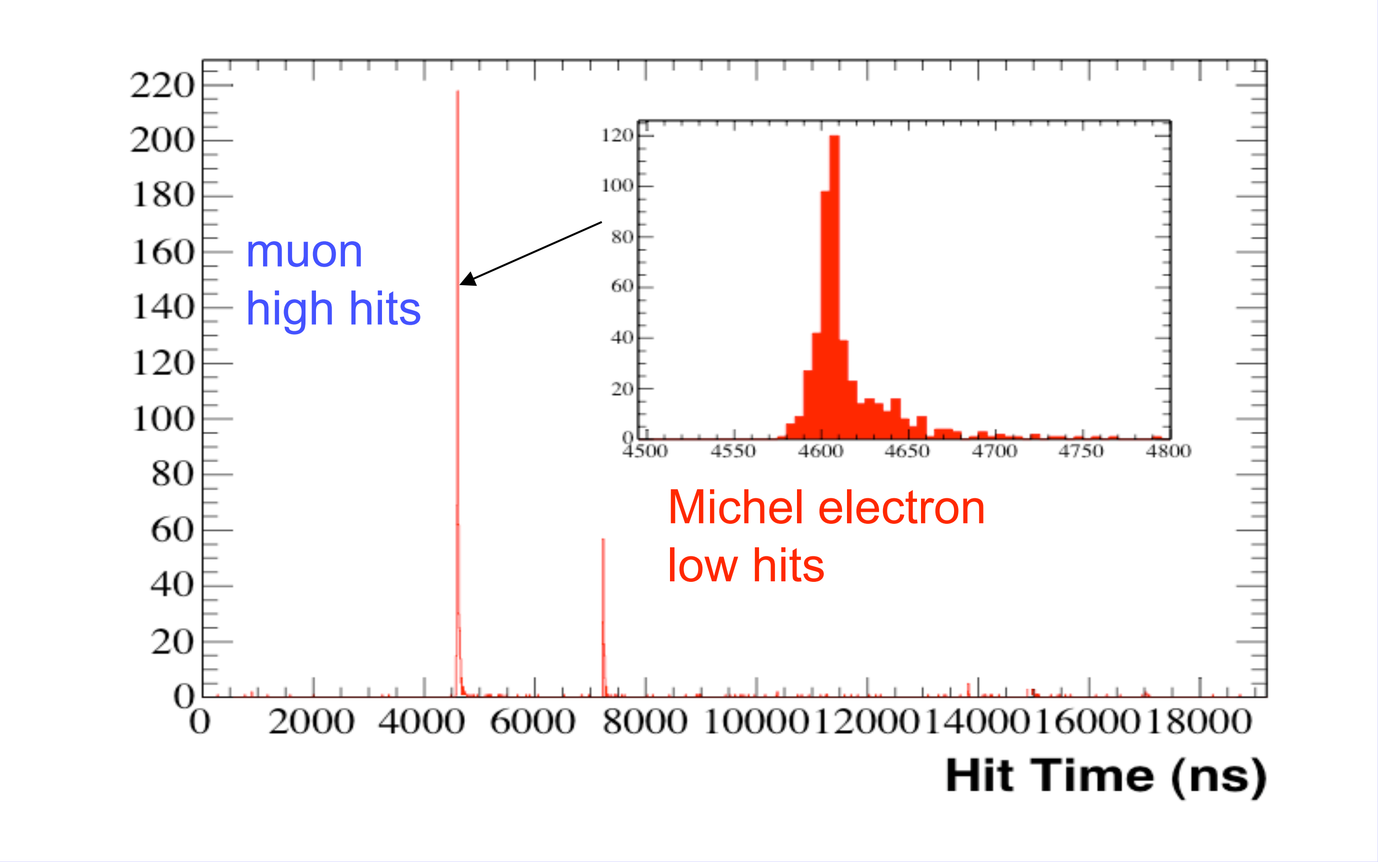
muon like Cherenkov light and subsequent decayed electron (Michel electron) like Cherenkov light are the signal of CCQE event

proton measurement in neutral current elastic, see D. Perevalov and R. Tayloe's talk, May 20 (Wed.)

2. CCQE event measurement in MiniBooNE

ν_μ CCQE interactions (ν+n $\rightarrow$ μ+p) has characteristic two "subevent" structure from muon decay

$$\nu_\mu + n \rightarrow \overset{1}{\boxed{\mu^-}} + p \rightarrow \nu_\mu + \overline{\nu}_e + \overset{2}{\boxed{e^-}} + p$$



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

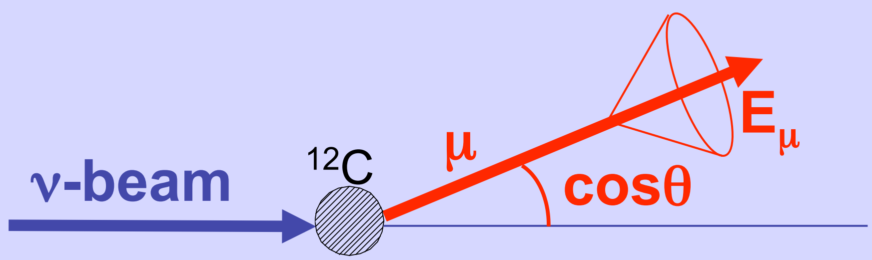
2. CCQE event measurement in MiniBooNE

All kinematics are specified from 2 observables, muon energy E_μ and muon scattering angle θ_μ

Energy of the neutrino E_ν^{QE} and 4-momentum transfer Q^2_{QE} can be reconstructed by these 2 observables, under the assumption of CCQE interaction with bound neutron at rest ("QE assumption")

$$E_\nu^{QE} = \frac{2(M-E_B)E_\mu - (E_B^2 - 2ME_B + m_\mu^2 + \Delta M^2)}{2[(M-E_B) - E_\mu + p_\mu \cos\theta_\mu]}$$

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



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3. CC1π background constraint, introduction

data-MC comparison, in 2 subevent sample (absolute scale)

Problem 1

CCQE sample shows good agreement in shape, because we tuned relativistic Fermi gas (RFG) parameters.

MiniBooNE collaboration,
PRL100(2008)032301

However absolute normalization does not agree.

The background is dominated with CC1π without pion (CCQE-like). We need a background prediction with an absolute scale.

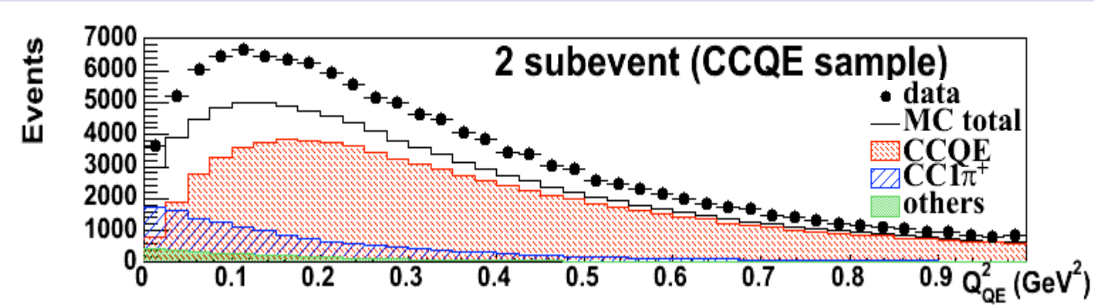
CCQE

$$\nu_\mu + n \rightarrow \overset{1}{\boxed{\mu^-}} + p \rightarrow \nu_\mu + \overline{\nu}_e + \overset{2}{\boxed{e^-}} + p$$

CC1π

$$\nu_\mu + N \rightarrow \overset{1}{\boxed{\mu^-}} + \cancel{\pi^+} + N \rightarrow \nu_\mu + \overline{\nu}_e + \overset{2}{\boxed{e^-}} + N$$

(π-absorption)



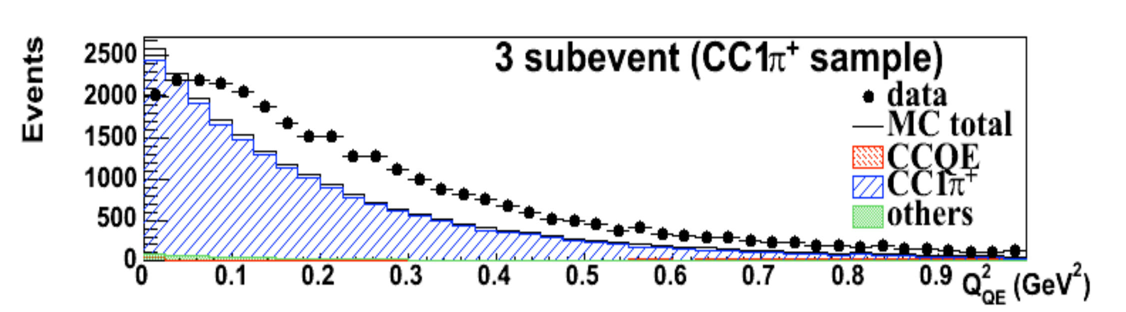
3. CC1π background constraint, introduction

data-MC comparison, in 3 subevent sample (absolute scale)

Problem 2

CC1π sample is worse situation, data and MC do not agree in shape nor normalization.

Under this situation, we cannot use CC1π prediction for background subtraction for CCQE absolute cross section measurement.



CC1π

$$\nu_\mu + N \to \overset{1}{\boxed{\mu^-}} + \pi^+ + N \to \nu_\mu + \overline{\nu}_e + \overset{2}{\boxed{e^-}} + N$$

$$\hookrightarrow \nu_\mu + \mu^+ \to \nu_\mu + \overline{\nu}_e + \overset{3}{\boxed{e^+}} + N$$

recent development of prediction in CC1π, see J. Novak's talk, May 22 (Fri.),

pion measurement in CC1π, see M. Wilking's talk, May 22 (Fri.),

3. CC1π background constraint

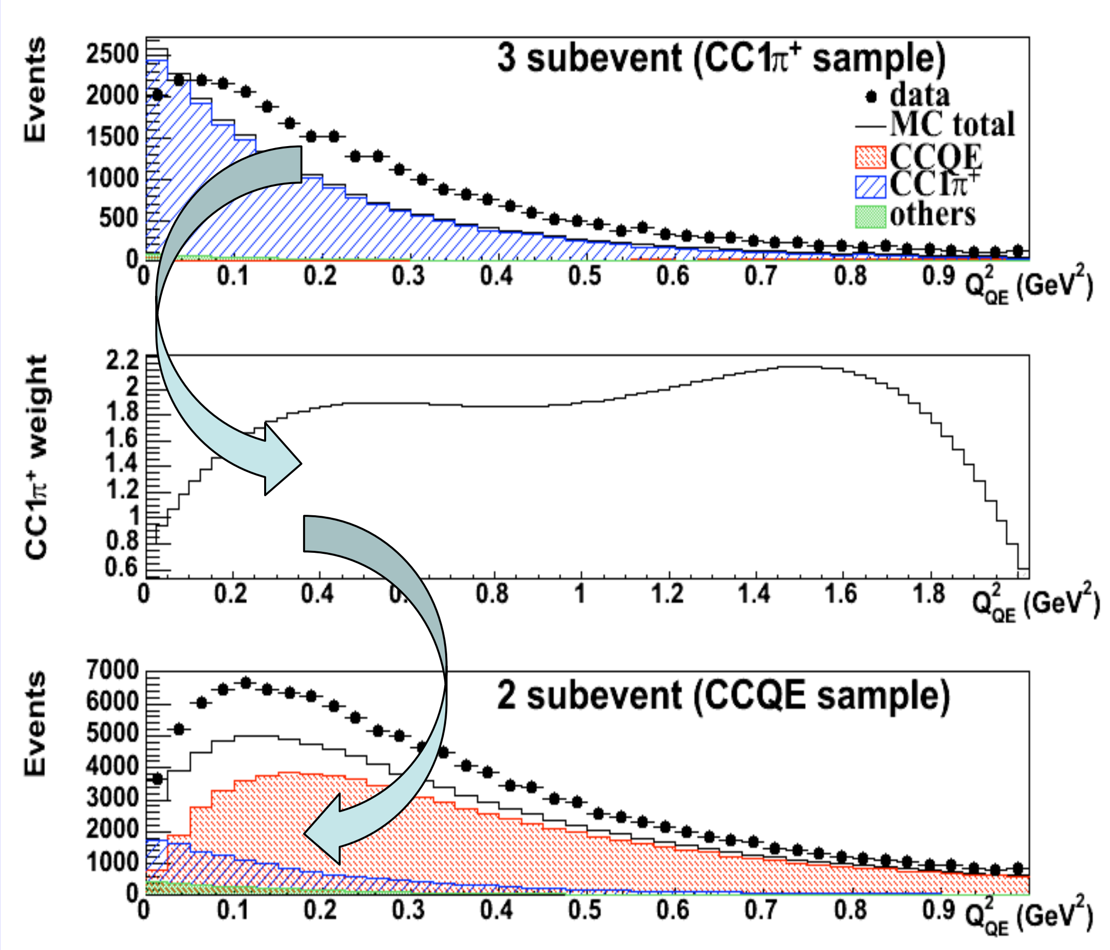
data-MC comparison, before CC1π constraint (absolute scale)

Solution

Use data-MC Q^2 ratio in CC1π sample to correct all CC1π events in MC.

Then, this "new" MC is used to predicts CC1π background in CCQE sample

This correction gives both CC1π background normalization and shape in CCQE sample

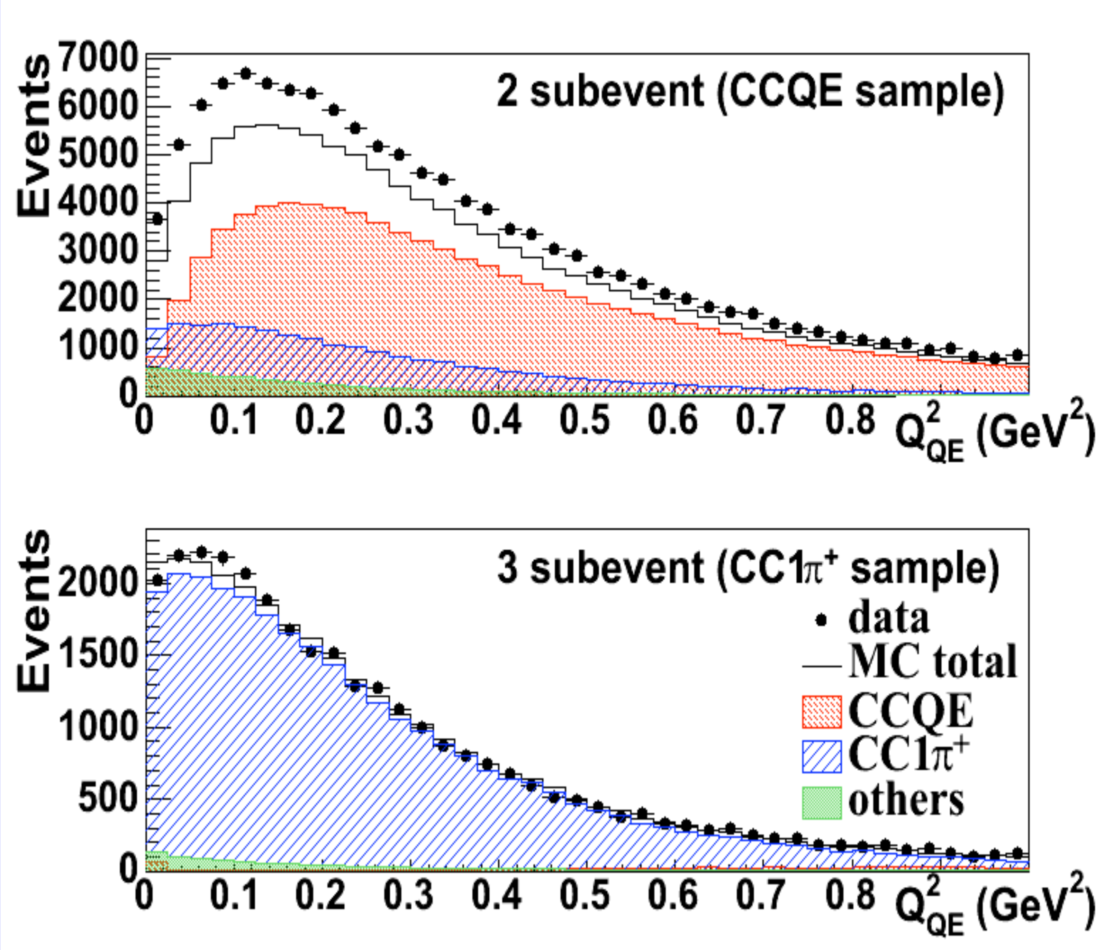


3. CC1π background constraint

data-MC comparison, after CC1π constraint (absolute scale)

Now we have an absolute prediction of CC1π background in CCQE sample.

We are ready to measure the absolute CCQE cross section!



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4. Pauli blocking parameter “kappa”, κ

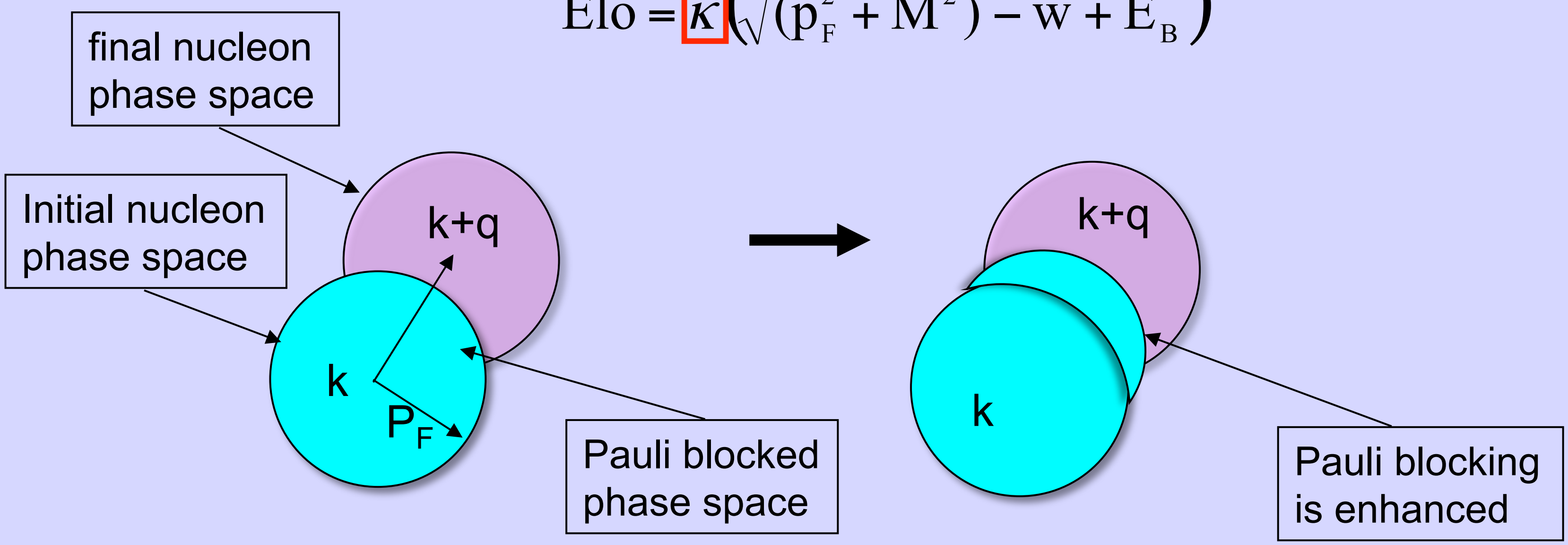
We performed shape-only fit for Q^2 distribution to fix CCQE shape within RFG model, by tuning M_A^{eff} (effective axial mass) and κ

Pauli blocking parameter "kappa”, κ

Smith and Moniz, Nucl.,Phys.,B43(1972)605

To enhance the Pauli blocking at low Q^2, we introduced a new parameter κ, which is the energy scale factor of lower bound of nucleon sea in RFG model in Smith-Moniz formalism, and controls the size of nucleon phase space

$$\mathrm{Elo} = \boxed{\kappa}\left(\sqrt{(p_F^2 + M^2)} - w + E_B\right)$$



4. M_A^{eff}-κ shape-only fit

M_A^{eff} - κ shape-only fit result

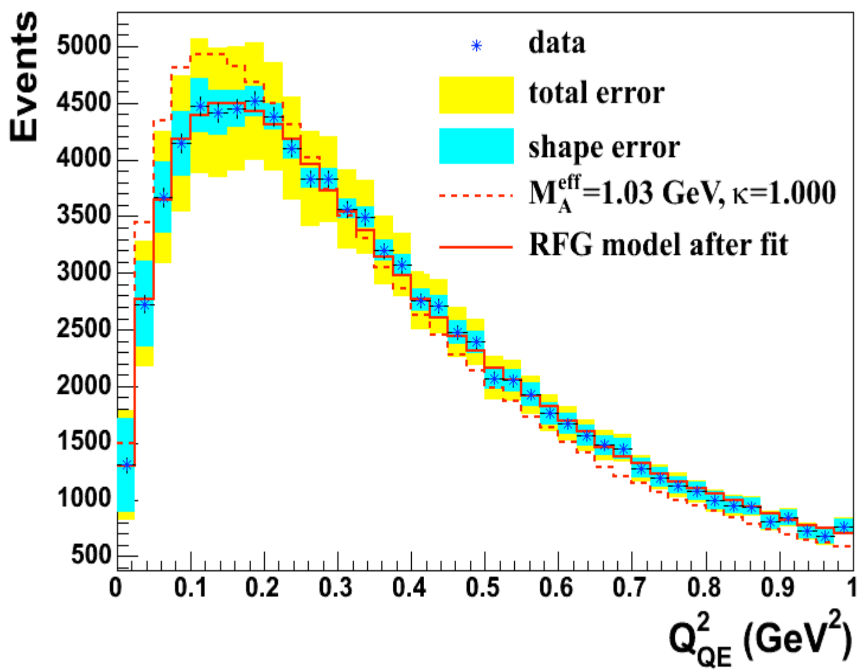
M_A^{eff} = 1.35 ± 0.17 GeV (stat+sys)
κ = $1.007^{+0.007}_{-\infty}$ (stat+sys)
χ^2/ndf = 47.0/38

M_A^{eff} goes even up, this is related to our new background subtraction.

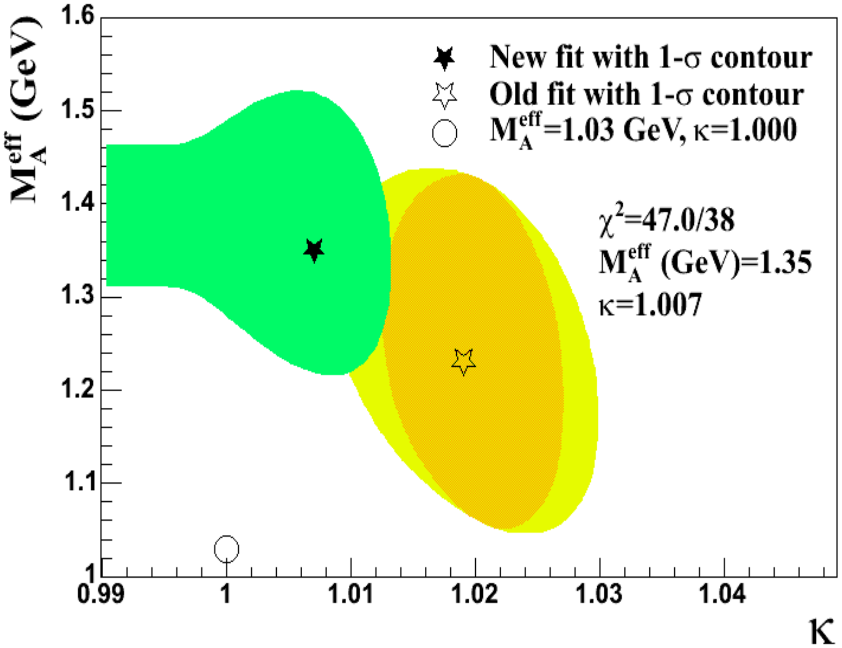
κ goes down due to the shape change of the background. Now κ is consistent with 1.
κ doesn't affects cross section below ~0.995.

M_A^{eff} only fit (M_A^{eff} = 1.37 ± 0.12 GeV, χ^2/ndf = 48.6/39)

data-MC Q^2 comparison before and after fit



Fit parameter space



4. M_A^{eff}-κ shape-only fit

MiniBooNE anti-neutrino CCQE data
J. Grange poster, May 19 (Tue.)

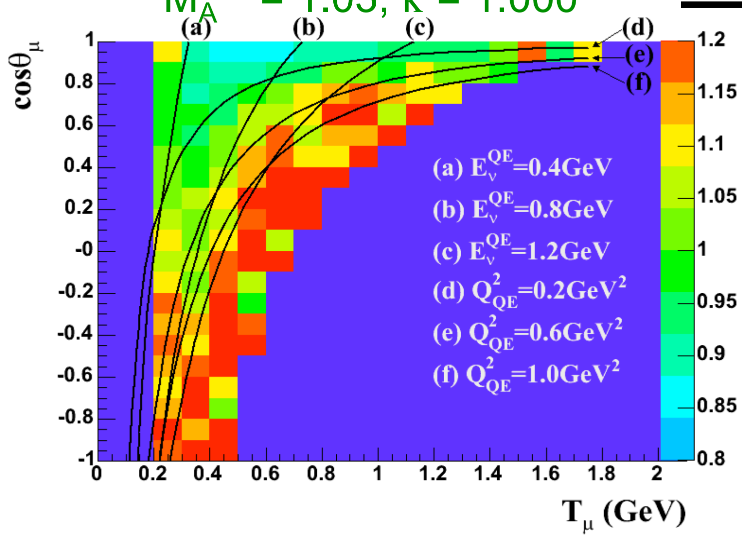
M_A^{eff} - κ shape-only fit result

M_A^{eff} = 1.35 ± 0.17 GeV (stat+sys)
$\kappa = 1.007^{+0.007}_{-\infty}$ (stat+sys)

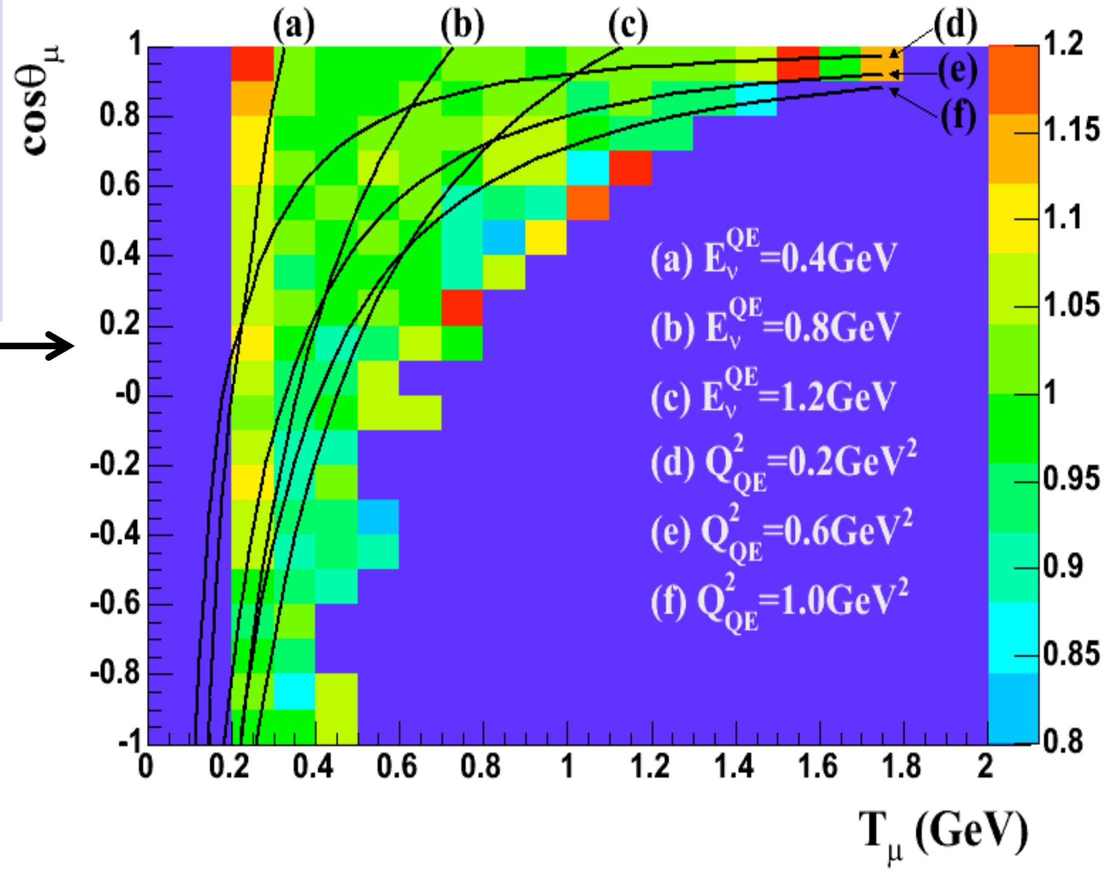
This new CCQE model doesn't affect our cross section result.

Data-MC agreement in T_μ-cosθ kinematic plane is good.

World averaged RFG model
M_A^{eff} = 1.03, κ = 1.000



data-MC ratio in T_μ-cosθ kinematic plane after fit



1. Booster neutrino beamline

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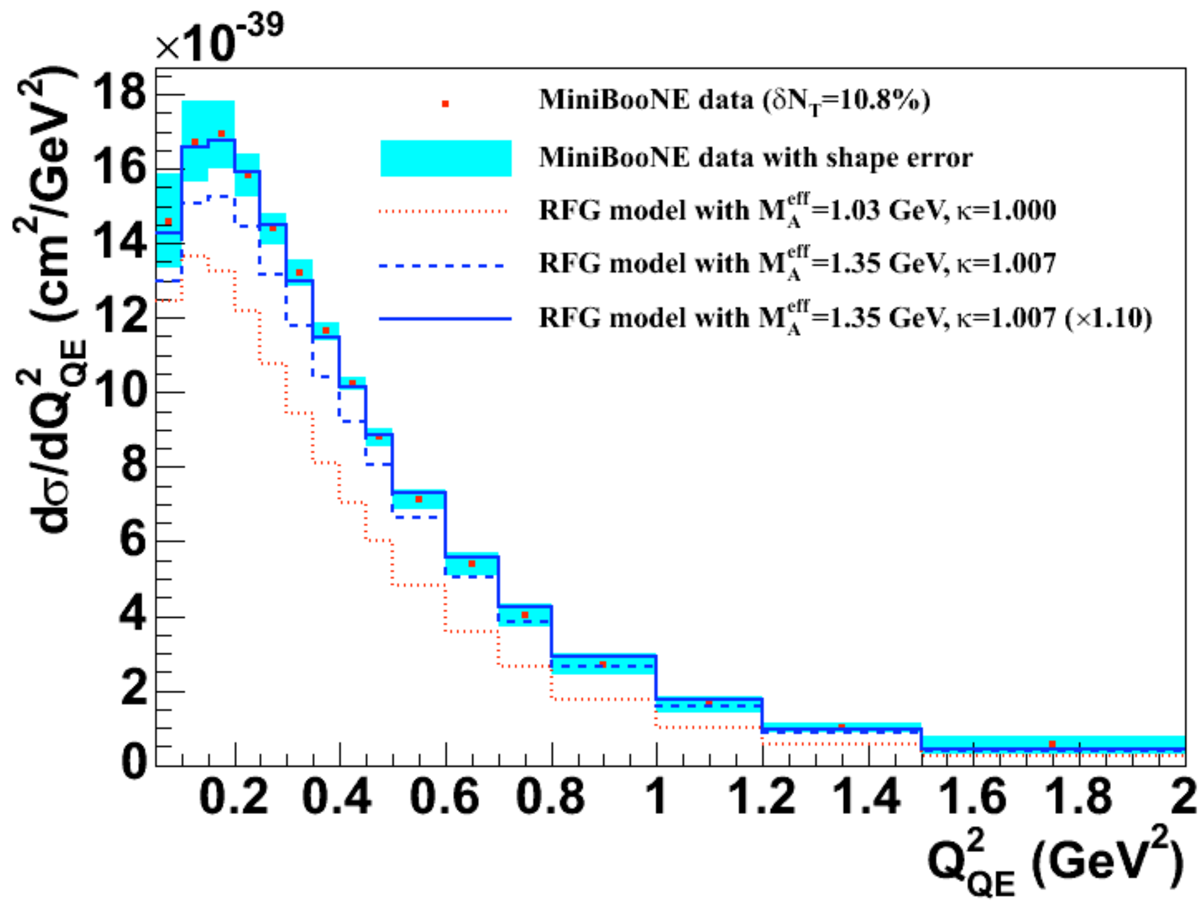
5. CCQE absolute cross section

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

The data is compared with various RFG model with neutrino flux averaged.

Compared to the world averaged CCQE model (red), our CCQE data is 35% high

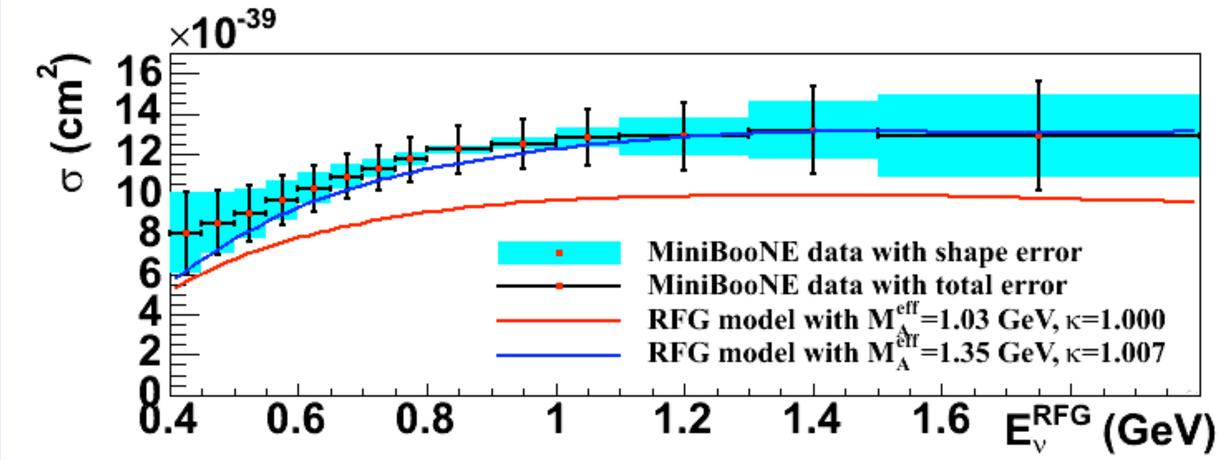
Our model extracted from shape-only fit has better agreement (within our total normalization error).



5. CCQE absolute cross section

Flux-unfolded total cross section (E_ν^{RFG})

New CCQE model is tuned from shape-only fit in Q^2, and it also describes total cross section well.



5. CCQE errors

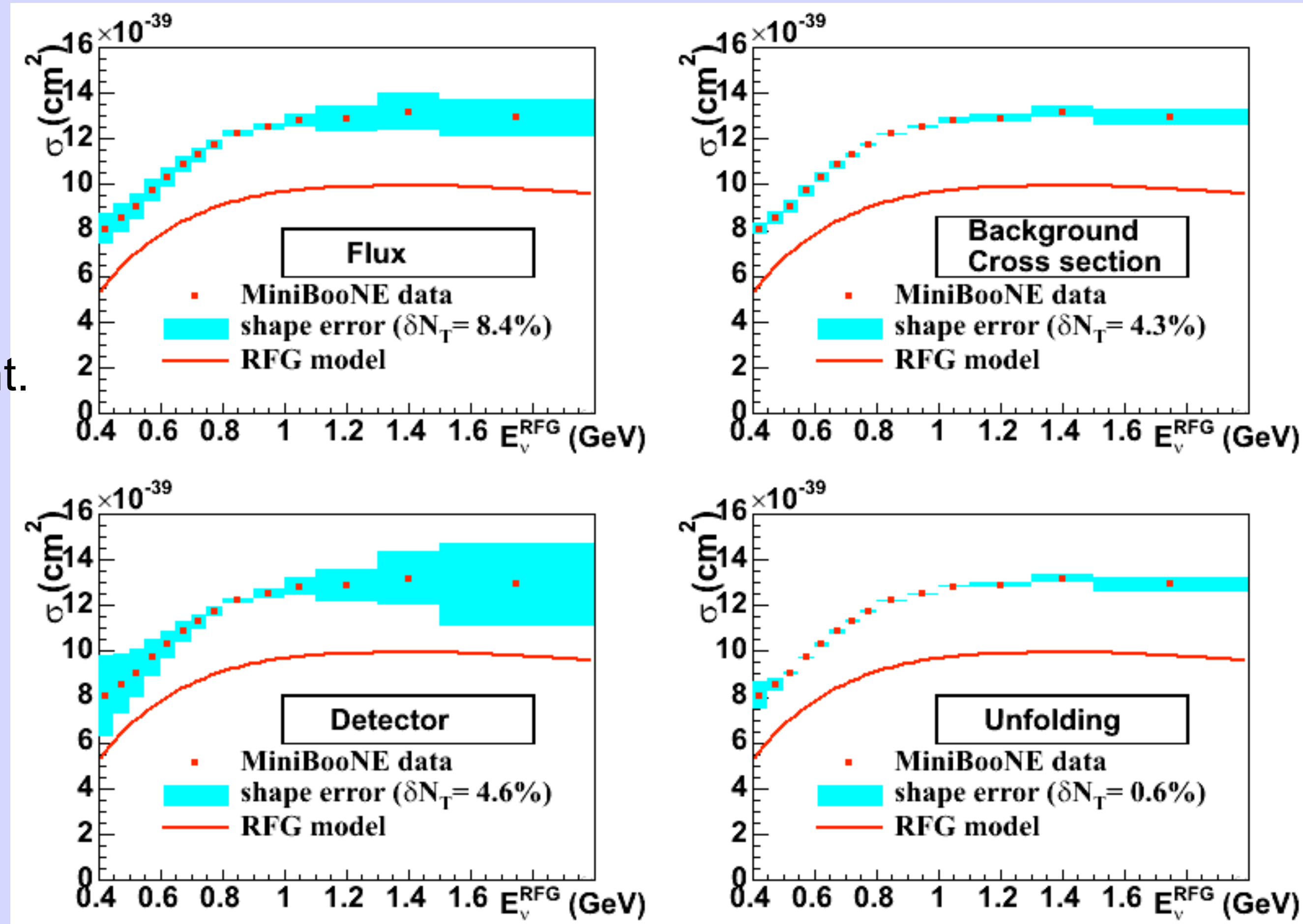
Error summary (systematic error dominant)

Flux error dominates the total normalization error.

Cross section error is small because of high purity and in situ background measurement.

Detector error dominates shape error, because this is related with energy scale.

Unfolding error is the systematic error associated to unfolding.

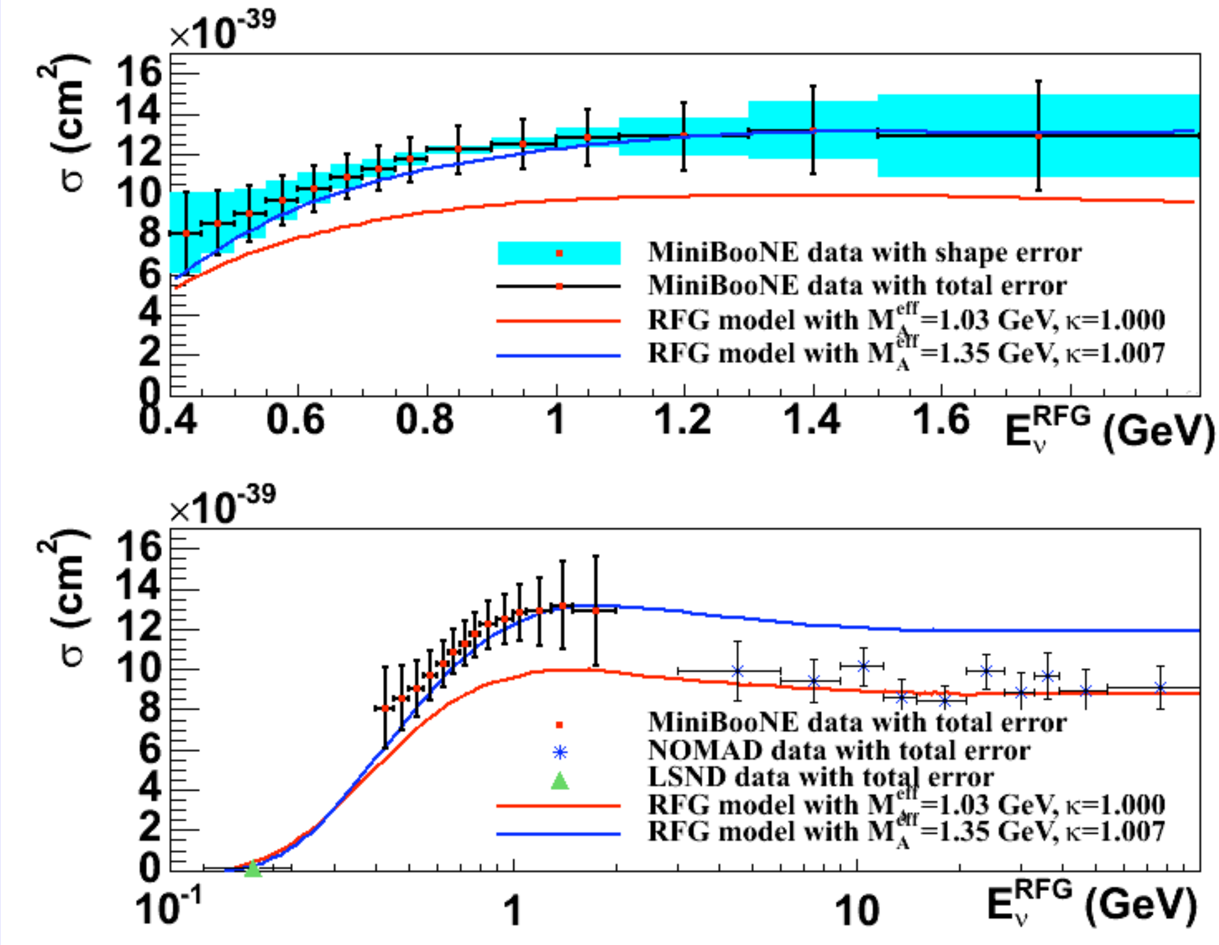


5. QE cross section comparison with NOMAD

Flux-unfolded total cross section (E_ν^{RFG})

New CCQE model is tuned from shape-only fit in Q^2, and it also describes total cross section well.

Comparing with NOMAD, MiniBooNE cross section is 35% higher, but these 2 experiments leave a gap in energy to allow some interesting physics.



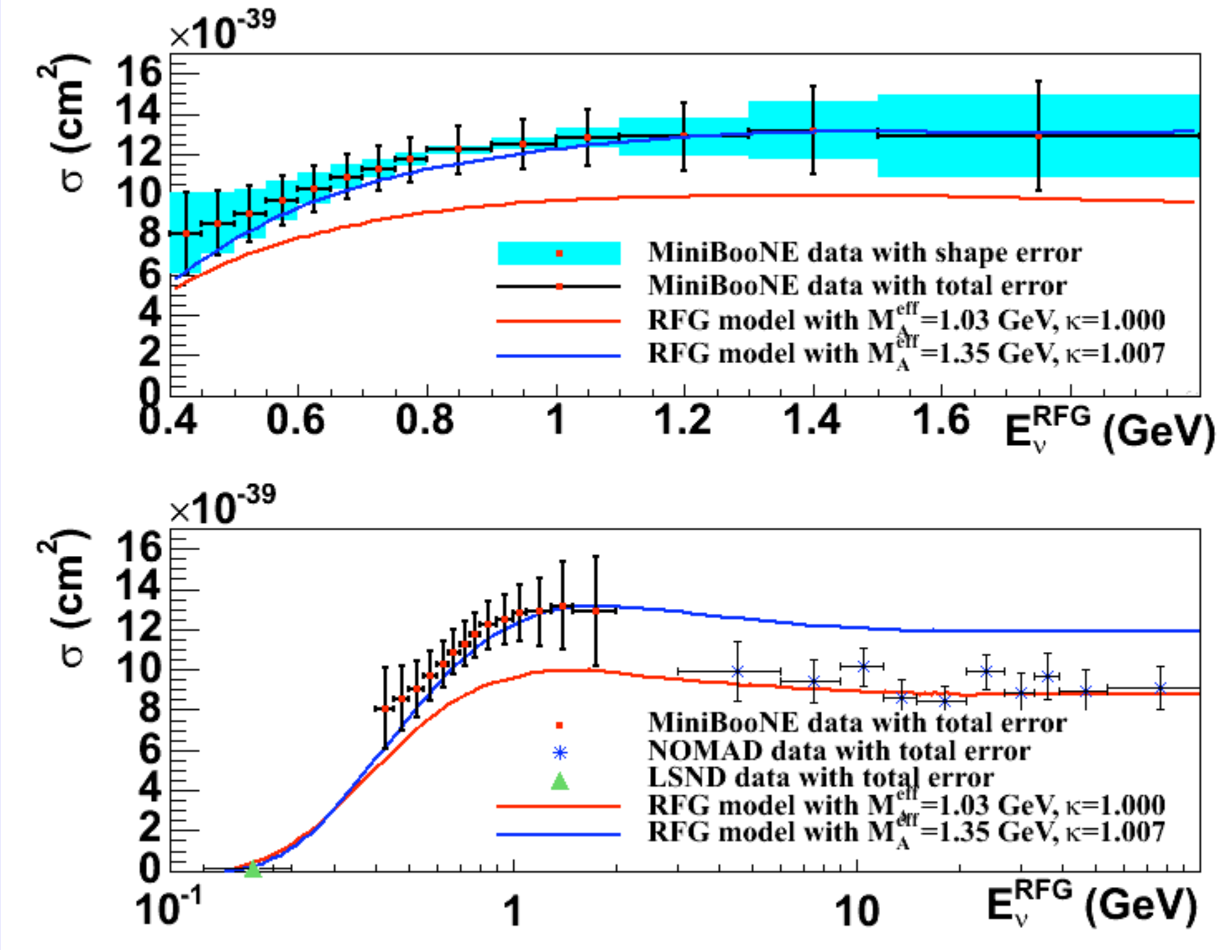
5. CCQE total cross section model dependence

Flux-unfolded total cross section (E_ν^{RFG})

Unfortunately, flux unfolded cross section is model dependent.

Reconstruction bias due to QE assumption is corrected under "RFG" model assumption.

One should be careful when comparing flux-unfolded data from different experiments.



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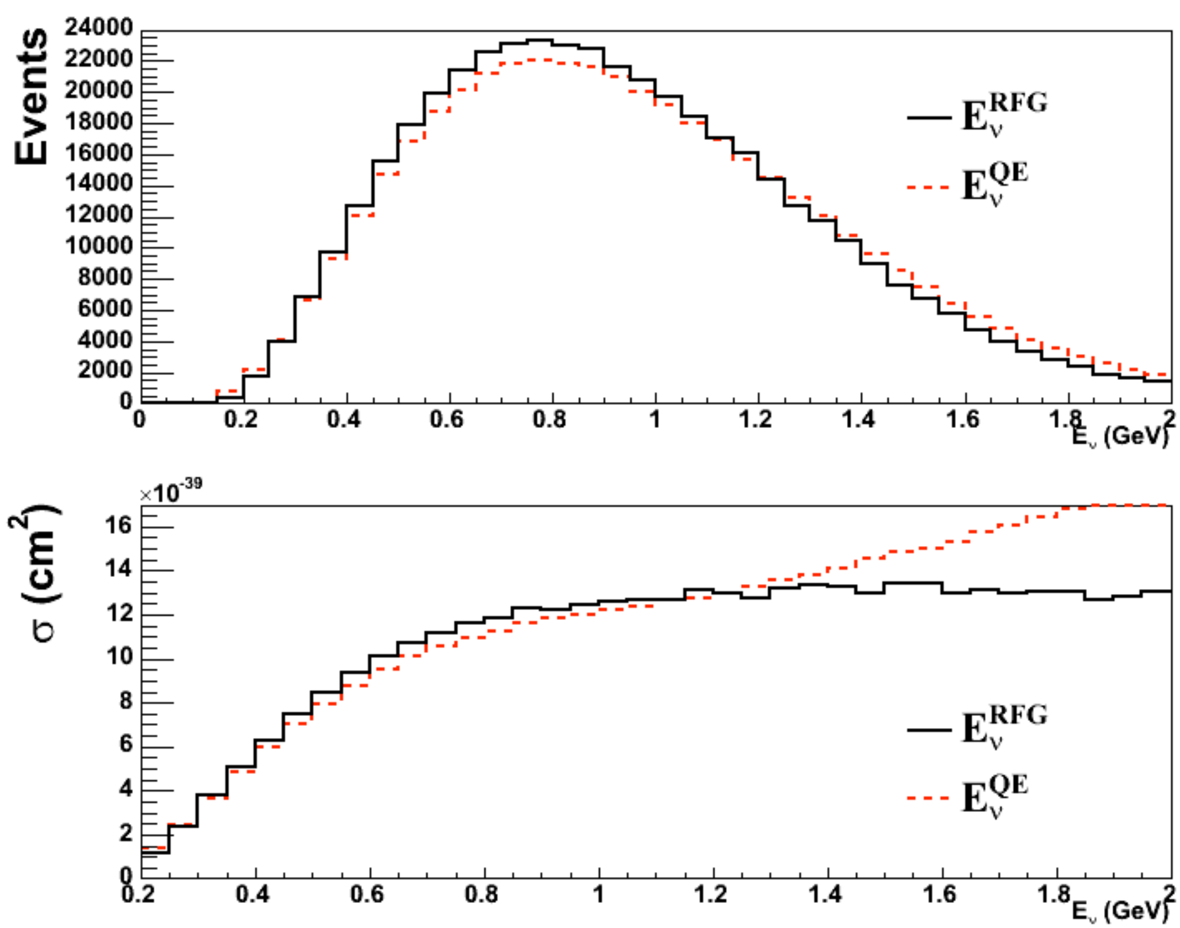
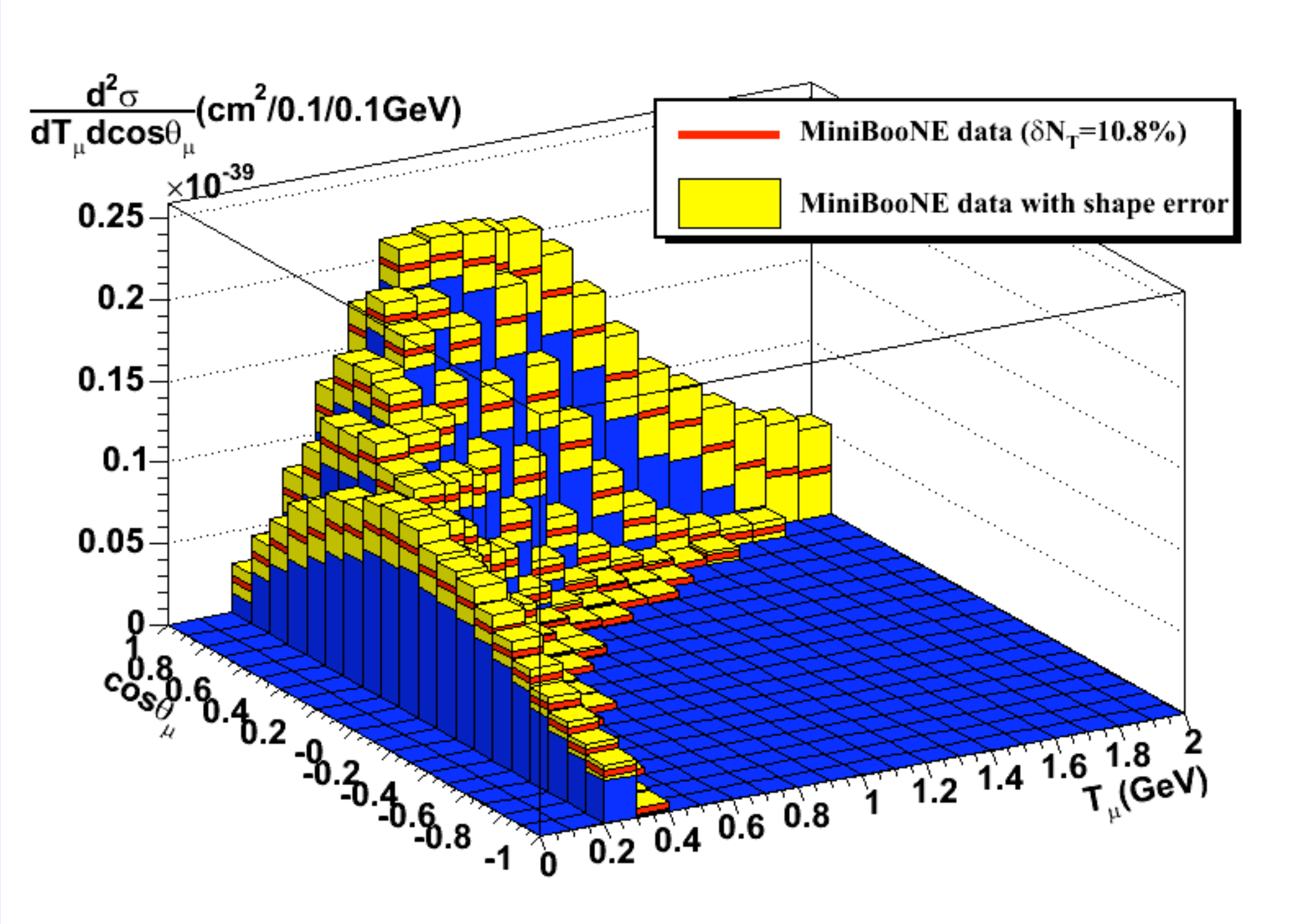


5. CCQE double differential cross section

Flux-averaged double differential cross section (T_μ-$\cos\theta$)

This is the most complete information about neutrino cross section based on muon kinematic measurement.

The error shown here is shape error, a total normalization error (δN_T=10.8%) is separated.



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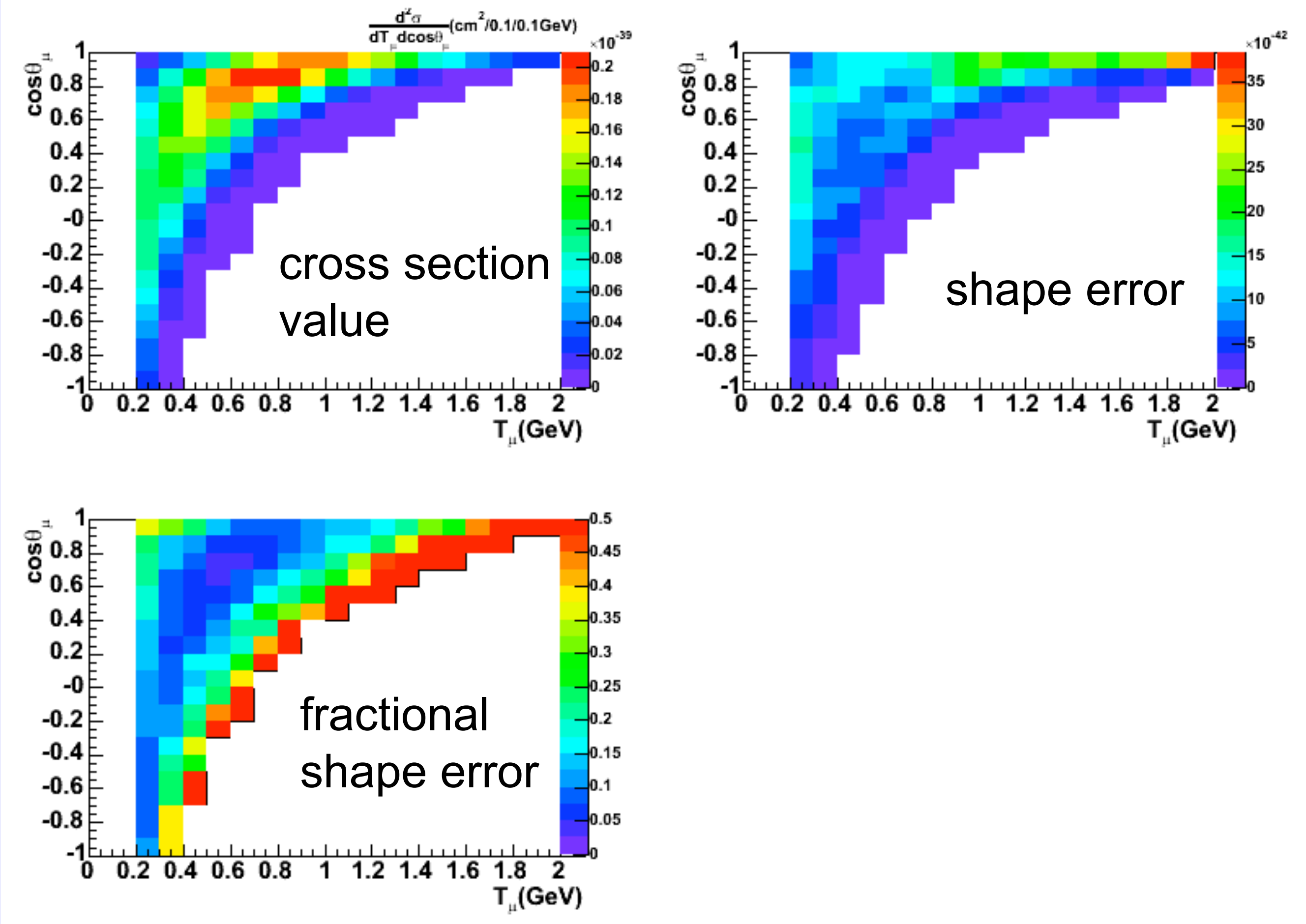


6. Conclusions

Using the high statistics and high purity MiniBooNE ν_μ CCQE data sample (146,070 events, 26.5% efficiency, and 75.8% purity), the absolute cross section is measured. We especially emphasize the measurement of flux-averaged double differential cross section, because this is the most complete set of information for muon kinematics based neutrino interaction measurement. The double differential cross section is the model independent result.

We measured 35% higher cross section than RFG model with the world averaged nuclear parameter. Interesting to note, our total cross section is consistent with RFG model with nuclear parameters extracted from shape-only fit in our Q^2 data.

BooNE collaboration

University of Alabama
Bucknell University
University of Cincinnati
University of Colorado
Columbia University
Embry Riddle Aeronautical University
Fermi National Accelerator Laboratory
Indiana University
University of Florida

Los Alamos National Laboratory
Louisiana State University
Massachusetts Institute of Technology
University of Michigan
Princeton University
Saint Mary's University of Minnesota
Virginia Polytechnic Institute
Yale University

Moltes Grácies!

(¡Muchas Gracias!)

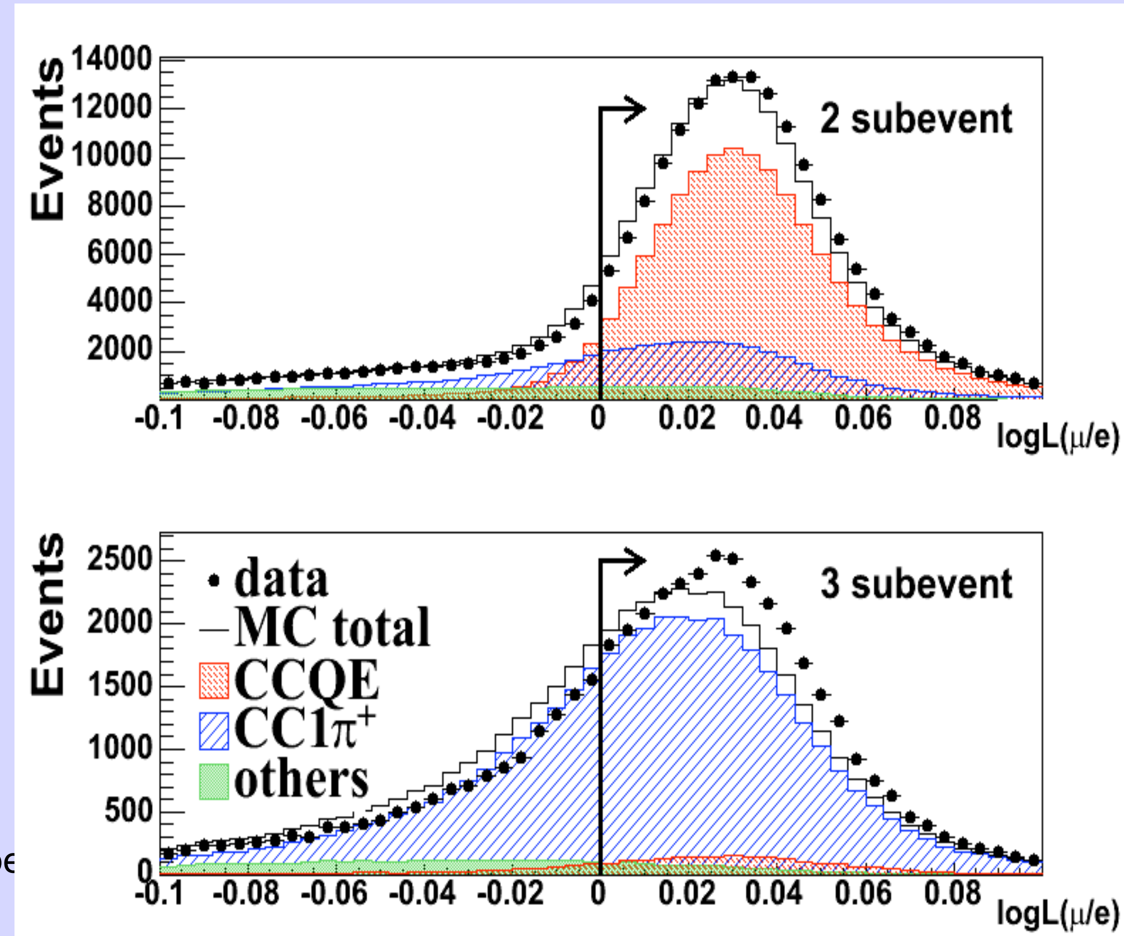
Back up

1. CCQE event measurement in MiniBooNE

CC inclusive cut

This cut is not designed to remove CC1π events, but trying to remove "others". This is an important step for CC1π background fit.

1. veto hits <6 for all subevents
2. 1st subevent is within beam window, 4400<T(ns)<6400
3. fiducial cut, muon vertex <500cm from tank center
4. visible energy cut, muon kinetic energy >200MeV
5. μ to e log likelihood cut
6. 2 and only 2 subevent
7. μ-e vertex distance cut



1. CCQE event measurement in MiniBooNE

CC inclusive cut
→ CCQE cut

ν_μ CCQE interactions (ν+n → μ+p) has characteristic two "subevent" structure from muon decay

$$\nu_\mu + n \rightarrow \boxed{\mu} + p \qquad \mu \rightarrow \nu_\mu + \nu_e + \boxed{e}$$

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2. 1st subevent is within beam window, 4400<T(ns)<6400
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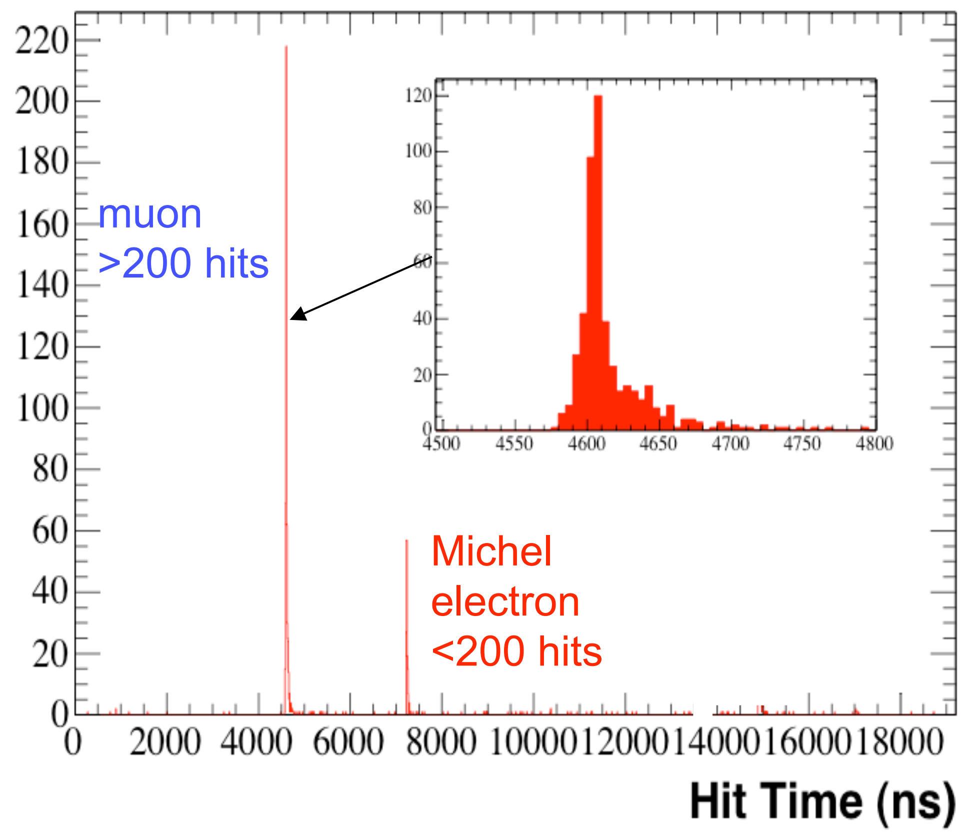

1. CCQE event measurement in MiniBooNE

CC inclusive cut
→ CCQE cut

This cut is not designed to remove CC1π, but trying to remove "mis-reconstructed CC1π" and "others". This is an important step for CC1π background fit.

1. veto hits <6 for all subevents
2. 1st subevent is within beam window, 4400<T(ns)<6400
3. fiducial cut, muon vertex <500cm from tank center
4. visible energy cut, muon kinetic energy >200MeV
5. μ to e log likelihood cut
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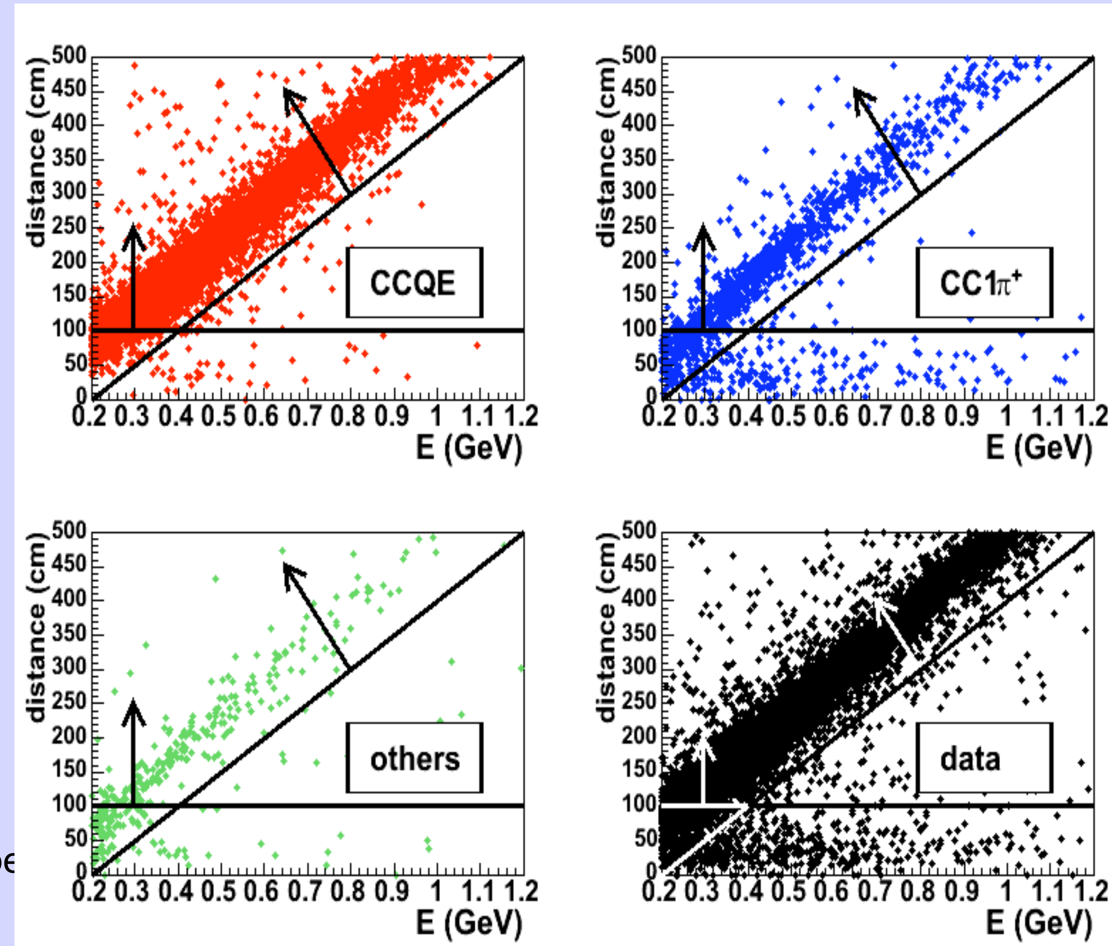


1. CCQE event measurement in MiniBooNE

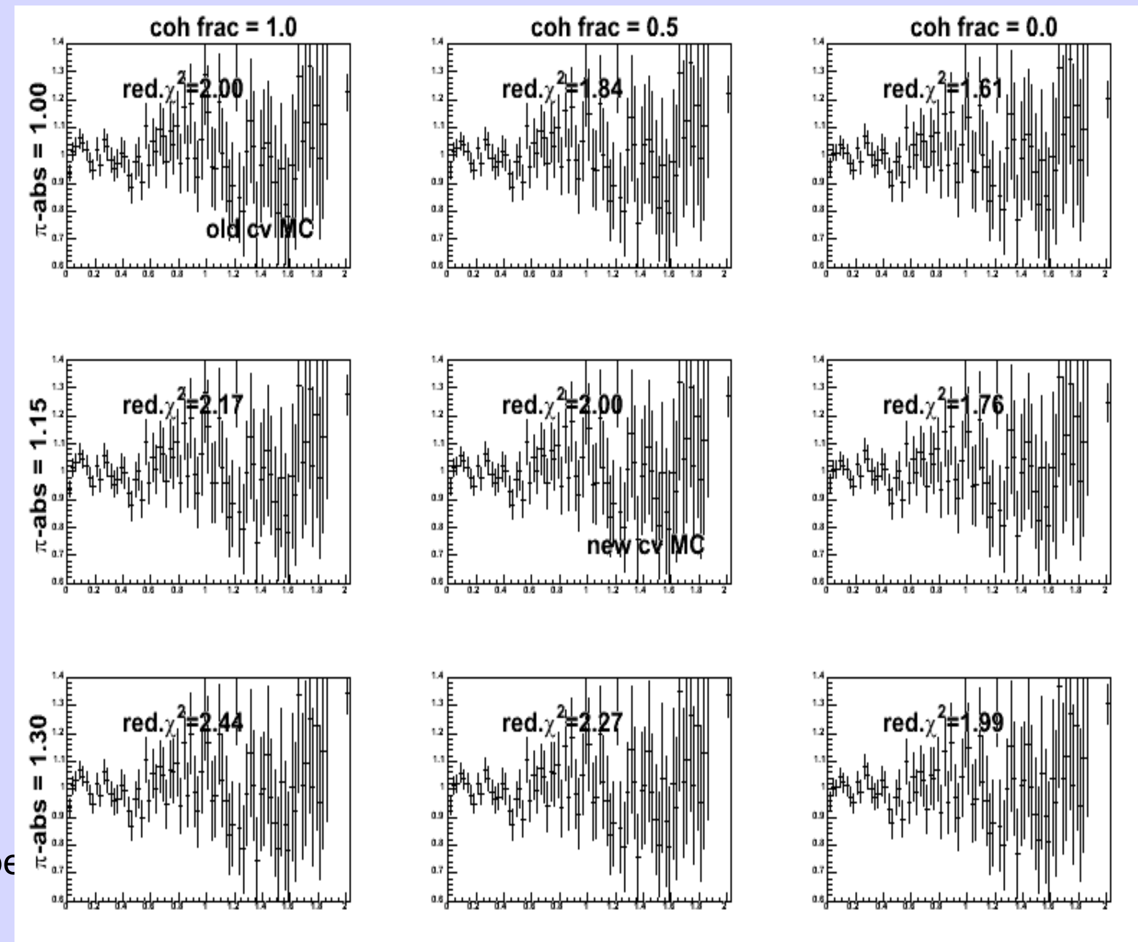
cut type	efficiency
1. veto hits < 6 for all subevents	45.1
2. 1^{st} subevent time T is in beam window	44.7
3. 1^{st} subevent reconstructed vertex < 500 cm	37.5
4. 1^{st} subevent kinetic energy > 200MeV	32.7
5. μ to e log likelihood cut	31.3
6. 2 subevent total	29.0
7. μ-e vertex distance cut	26.5

26.5% cut efficiency
75.8% purity
146,070 events with
5.58E20POT

2. CC1π background fit

data-MC Q^2 ratio in 3subevent after fit with various assumption

Since we can fit with any assumptions, Q^2 ratio is always flat.



2. CC1π background fit

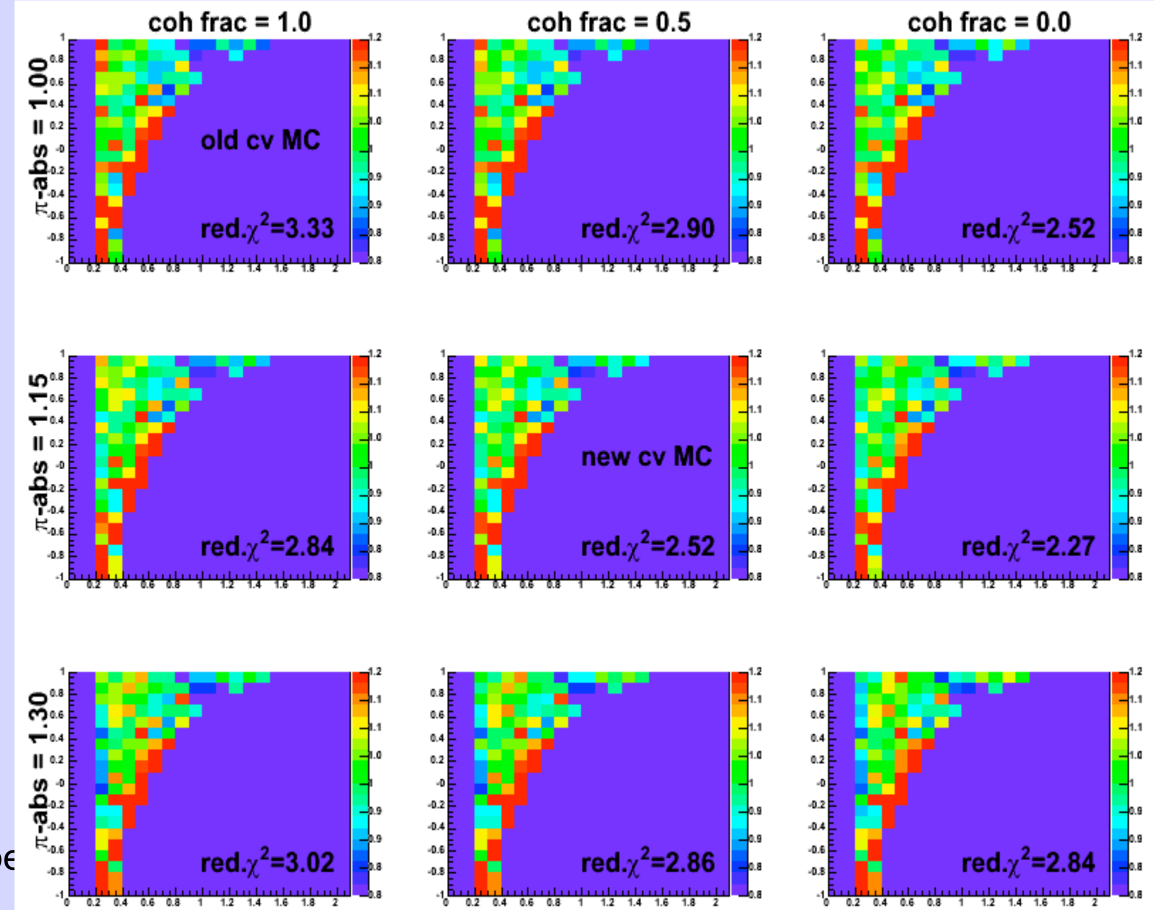
data-MC T_μ-cosθ plane ratio in 3subevent after fit with various assumption

However, we can differentiate them by 2 dimensional kinematic plane.

15% increase of piabs and 0% of coherent fraction gives the best fit.

We chose 15% for piabs, and 50% for cohfrac as new cv MC which will be used to estimate background from all kinematic distribution.

The rest of models go to make a new error matrix



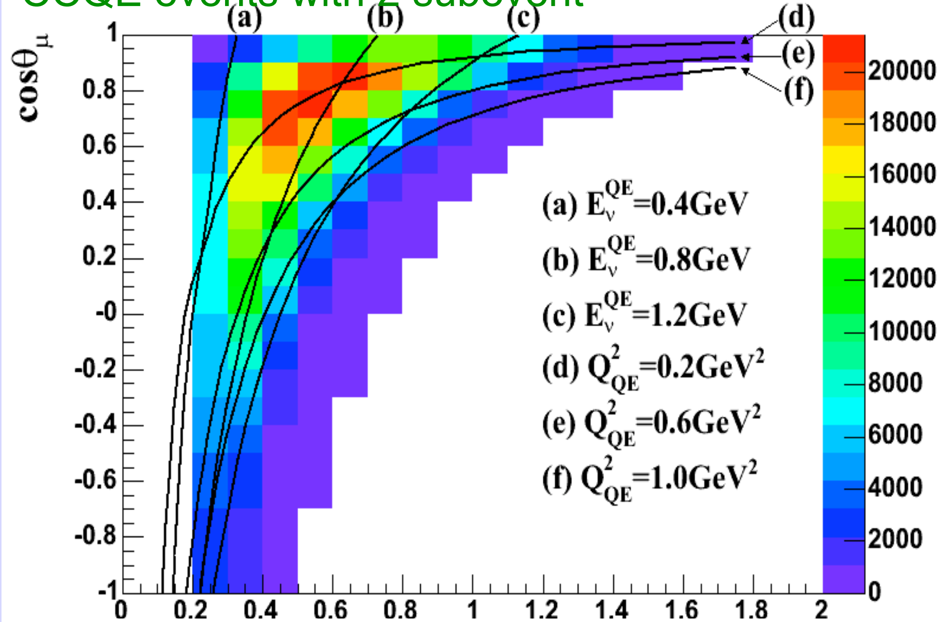
2. CC1π background fit

MC T_μ-cosθ plane

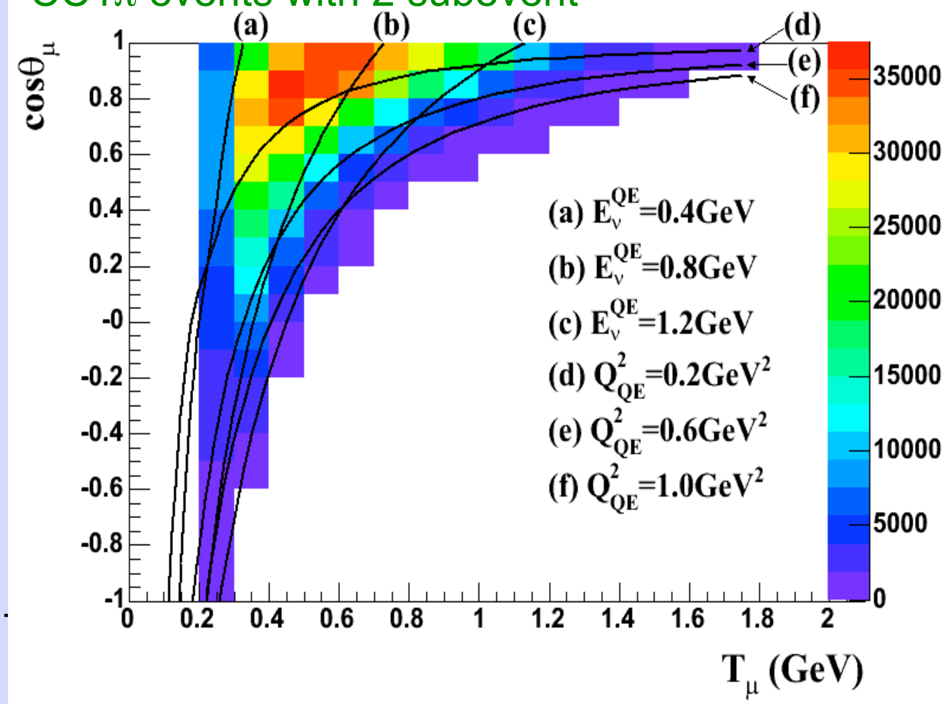
CC1π kinematics has different shape from CCQE kinematics.

The background cross section error is maximum at the bins where CC1π has larger number of event comparing with CCQE.

CCQE events with 2 subevent



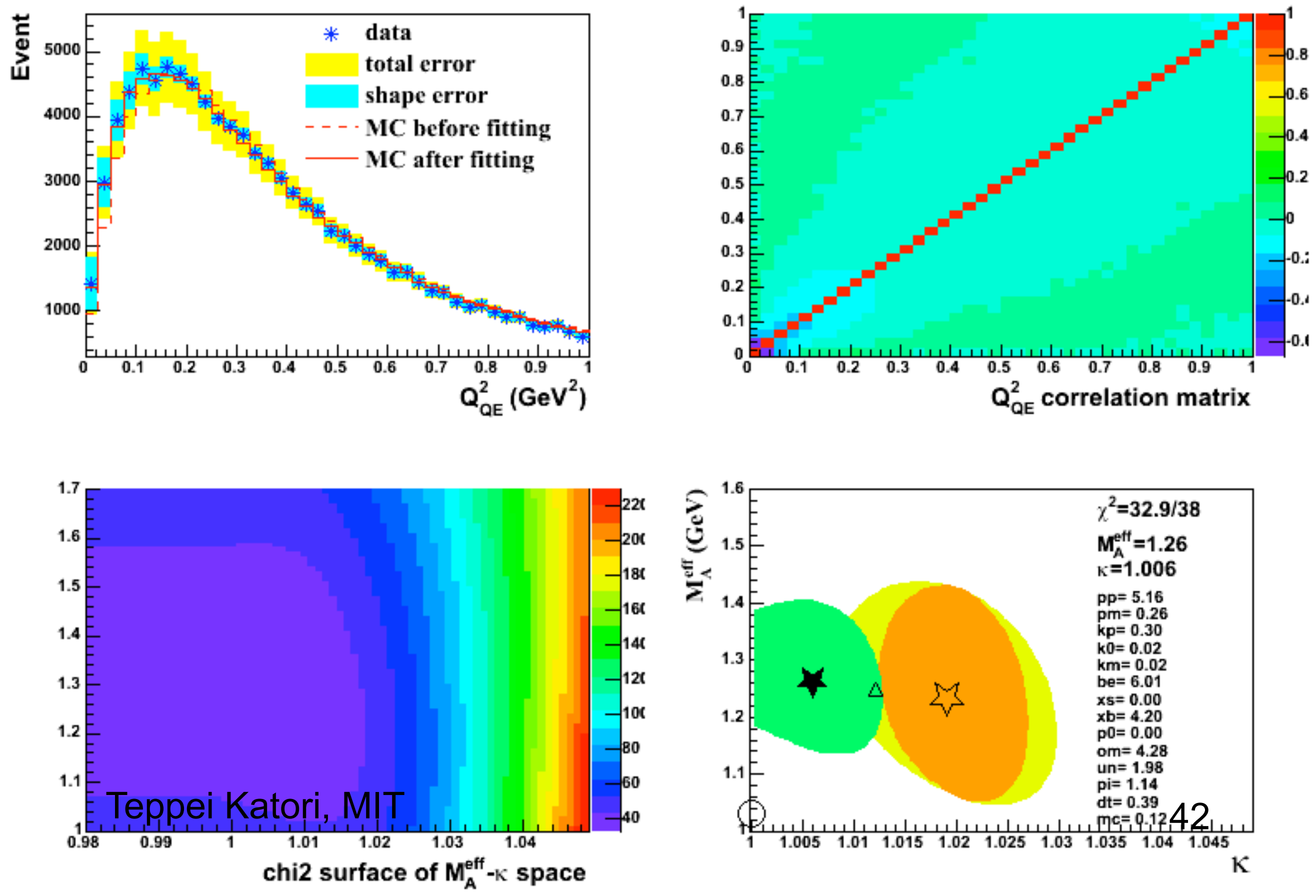
CC1π events with 2 subevent



2. Energy scale of MiniBooNE

Mis-calibration of the detector can mimic large M_A value. Roughly, 2% of energy shift correspond to 0.1GeV change of M_A.

M_A-κ fit for 2% muon energy shifted data



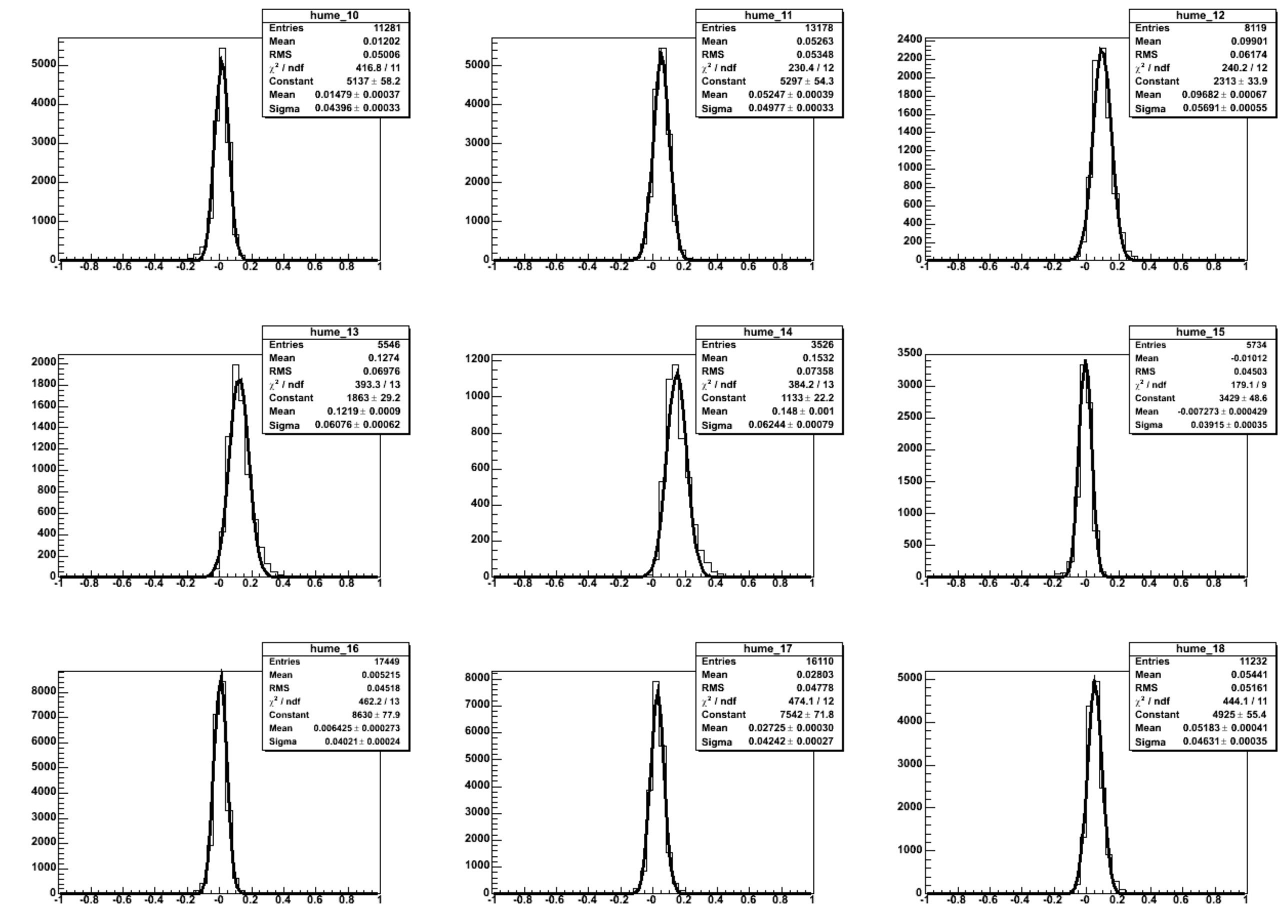
To bring M_A=1.0GeV, 7% energy shift is required, but this is highly disfavored from the data.

Question is what is the possible maximum mis-calibration? (without using muon tracker data)

2. Energy scale of MiniBooNE

Energy resolution is very good.
Typical resolution is <10%, and the error is 20-80MeV.

T_{μ} resolution is various bins of T_{μ}

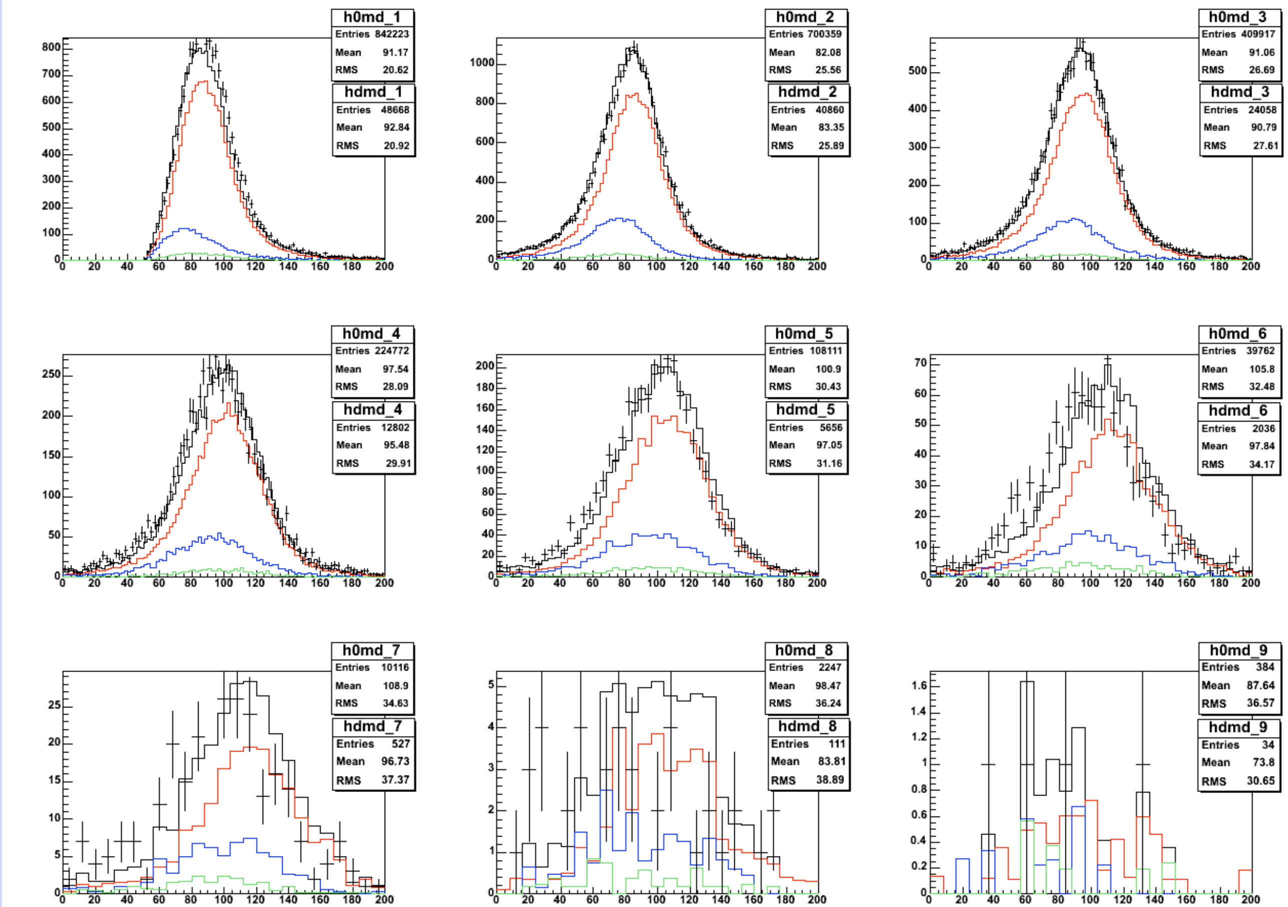


2. Energy scale of MiniBooNE

Range is the independent measure of muon energy. So range-T_μ difference for data and MC can be used to measure the possible mis-calibration.

This variable agrees in all energy regions within 1.5%.

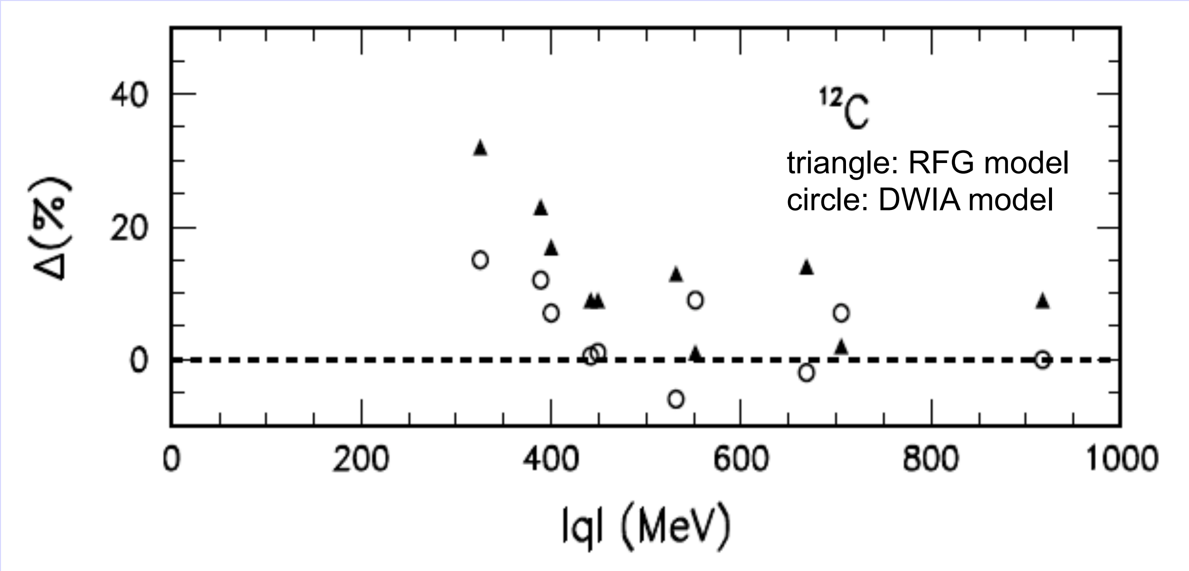
Range - T_μ X 0.5+100



4. Kappa and (e,e') experiments

In low |q|, The RFG model systematically over predicts cross section for electron scattering experiments at low |q| (~low Q^2)

Data and predicted xs difference for ^{12}C



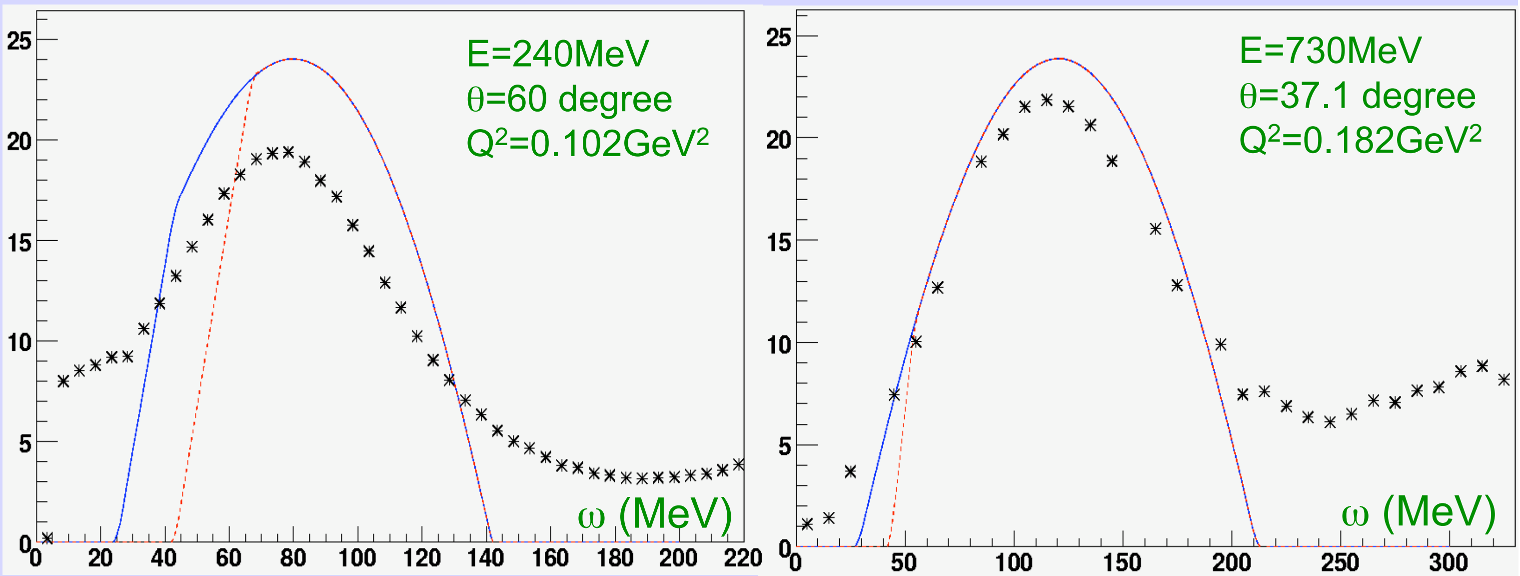
Butkevich and Mikheyev
Phys.Rev.C72:025501,2005

4. Kappa and (e,e') experiments

In low |q|, The RFG model systematically over predicts cross section for electron scattering experiments at low |q| (~low Q^2)

We had investigated the effect of Pauli blocking parameter "κ" in (e,e') data. κ cannot fix the shape mismatching of (e,e') data for each angle and energy, but it can fix integral of each cross section data, which is the observables for neutrino experiments. We conclude κ is consistent with (e,e') data.

black: (e,e') energy transfer data
red: RFG model with kappa (=1.019)
blue: RFG model without kappa



4. Kappa and (e,e') experiments

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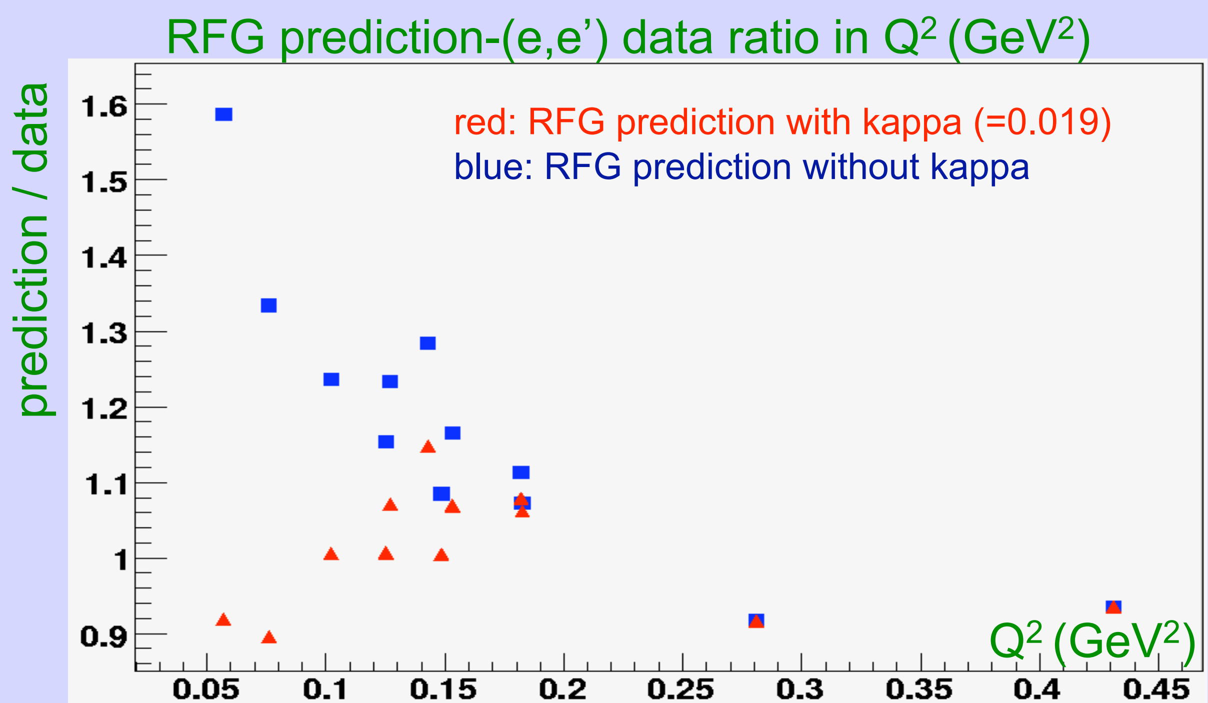


4. CCQE normalization fit

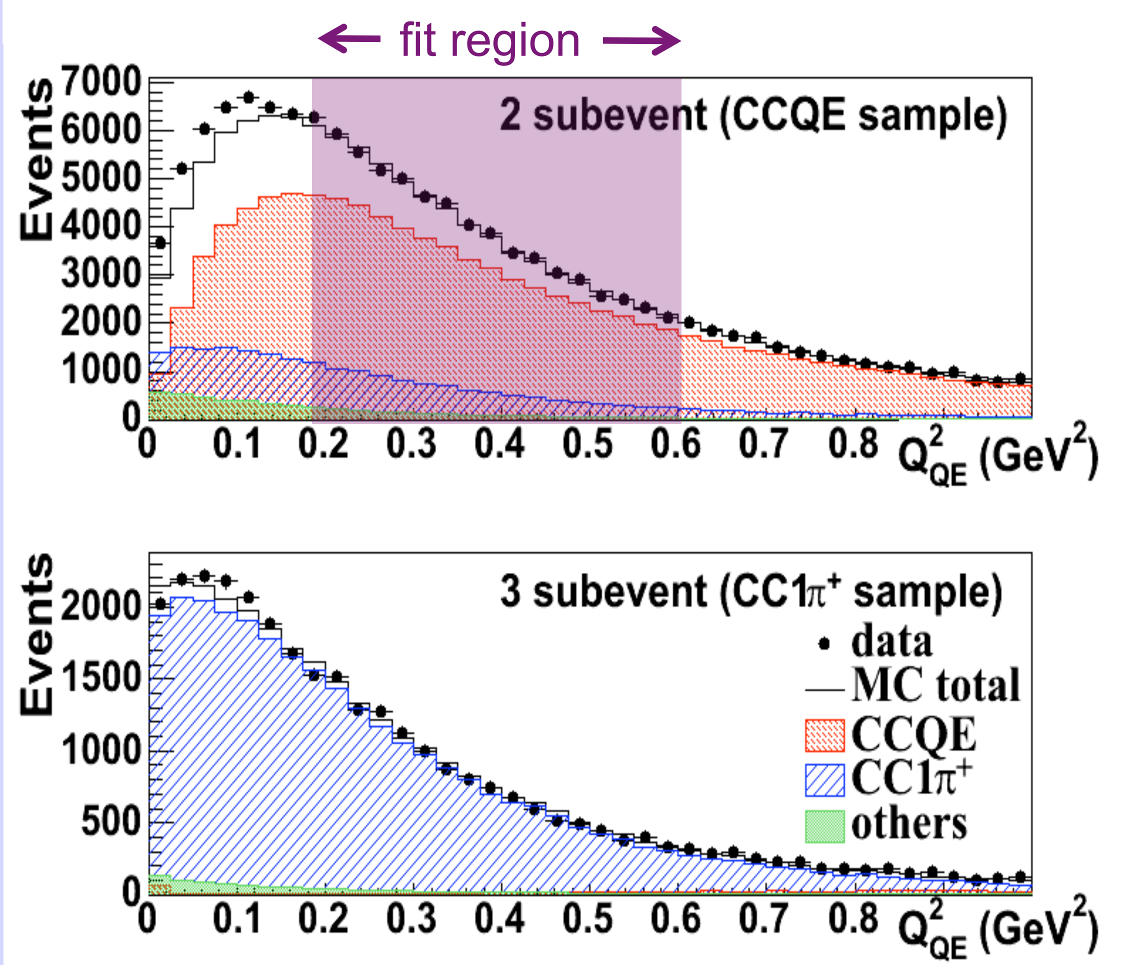
data-MC comparison, after CCQE normalization fit

After the CC1π correction, normalization of CCQE is also found from CCQE sample.

We use limited Q^2 region to find CCQE normalization, so that this fit is insensitive with CCQE shape very much.

Butkevich
arXiv:0904.1472

Now, CCQE normalization and CC1π normalization and CC1π shape looks good, except CCQE shape.



4. M_A-κ fit

Least χ^2 fit for Q^2 distribution

χ^2 = (data - MC)T $(M_{total})^{-1}$ (data - MC)

χ^2 minimum is found by global scan of shape only fit with $0.0<Q^2(GeV^2)<1.0$

Input error matrices

keep the correlation of systematics

dependent

independent

π+ production	(8 parameters)
π- production	(8 parameters)
K+ production	(7 parameters)
K0 production	(9 parameters)
beam model	(8 parameters)
cross section	(20 parameters)
detector model	(39 parameters)

The total output error matrix

keep the correlation of Q2 bins

M_{total} = M(π+ production)
+ M(π- production)
+ M(K+ production)
+ M(K0 production)
+ M(beam model)
+ M(cross section model)
+ M(detector model)
+ M(data statistics)

4. CCQE absolute cross section

Absolute flux-averaged differential cross section formula

i :true index
j : reconstructed index

The cross section is function of true value, for example, $d\sigma^2/T_\mu/\cos\theta_\mu$, $d\sigma/dQ^2_{QE}$, etc

Integrated flux is removed, so it is called flux-averaged cross section

U_{ij} :unsmearing matrix

d_j :data vector

b_j :predicted background

$$\sigma_i = \frac{\sum_j U_{ij}(d_j - b_j)}{\varepsilon_i\,(\Phi T)}$$

T :integrated target number

ε_i :efficiency

Φ :integrated ν-flux

4. CCQE absolute cross section

Absolute flux-unfolded total cross section formula

i :true index
j : reconstructed index

The cross section is function of true neutrino energy, $\sigma[E_\nu^{QE}]$

Flux shape is removed bin by bin, so it is called flux-unfolded cross section

$$\sigma_i = \frac{\sum_j U_{ij}(d_j - b_j)}{\varepsilon_i (\Phi T)}$$

U_{ij} :unsmearing matrix

d_j :data vector

b_j :predicted background

T :integrated target number

ε_i :efficiency

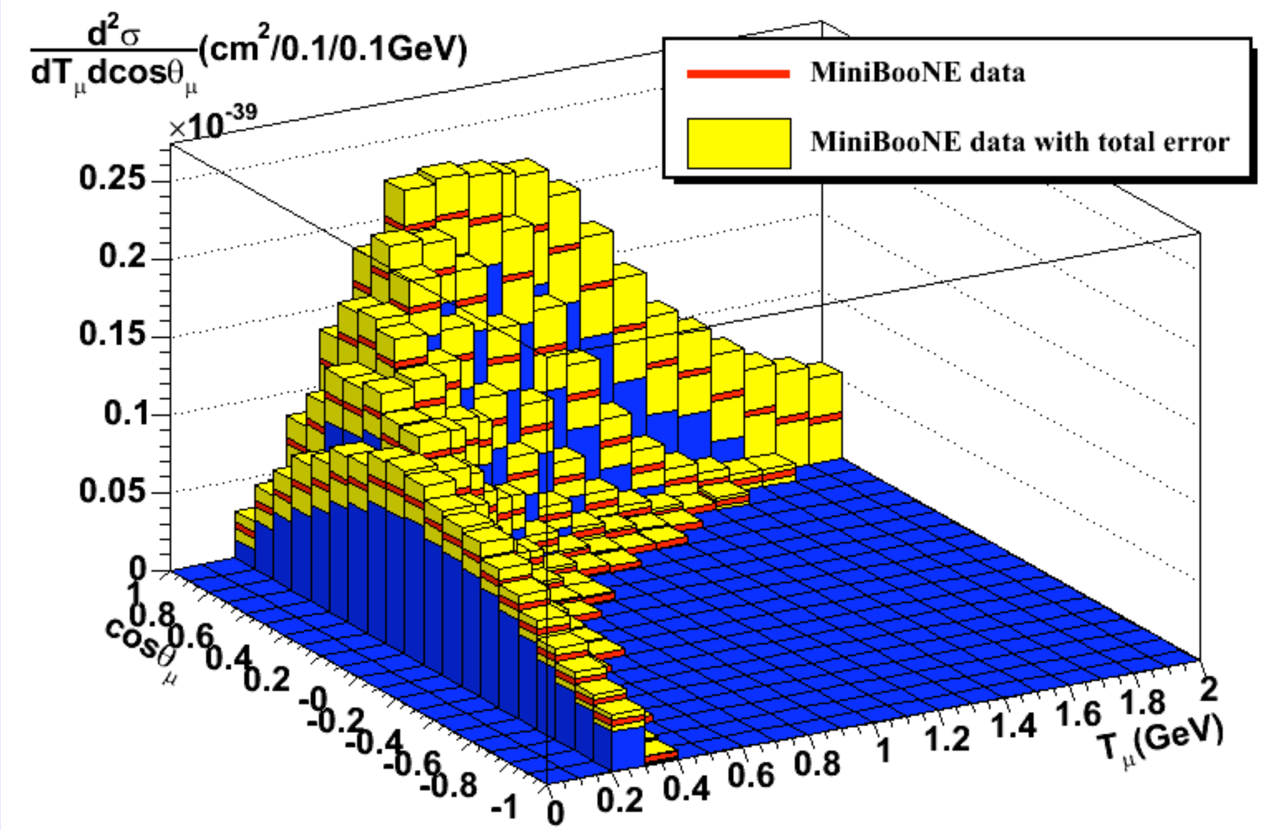
Φ_i :ν-flux vector

5. CCQE double differential cross section

Flux-averaged double differential cross section (T_μ-$\cos\theta$)

This is the most complete information about neutrino cross section based on muon kinematic measurement.

The error shown here is total error.



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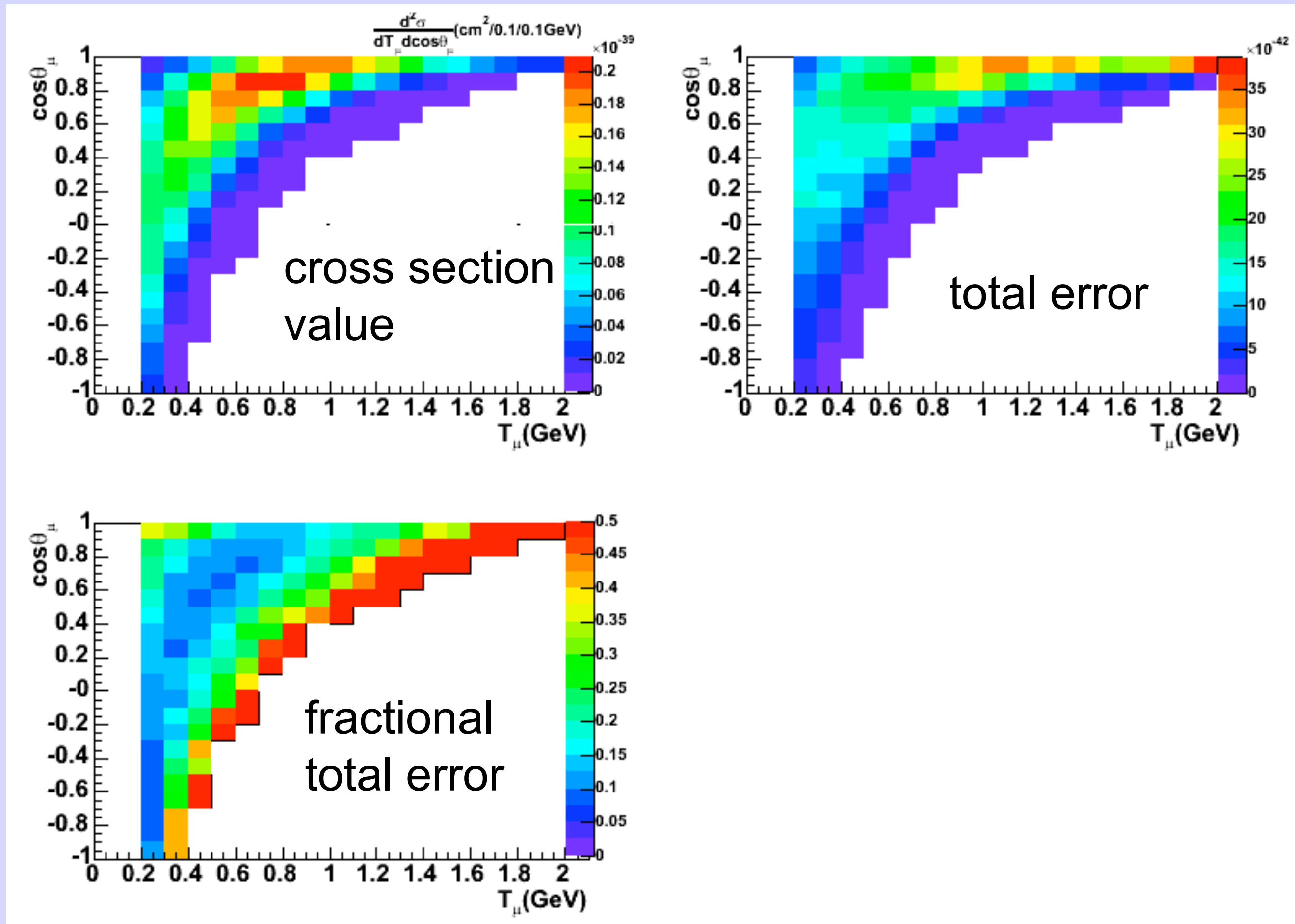
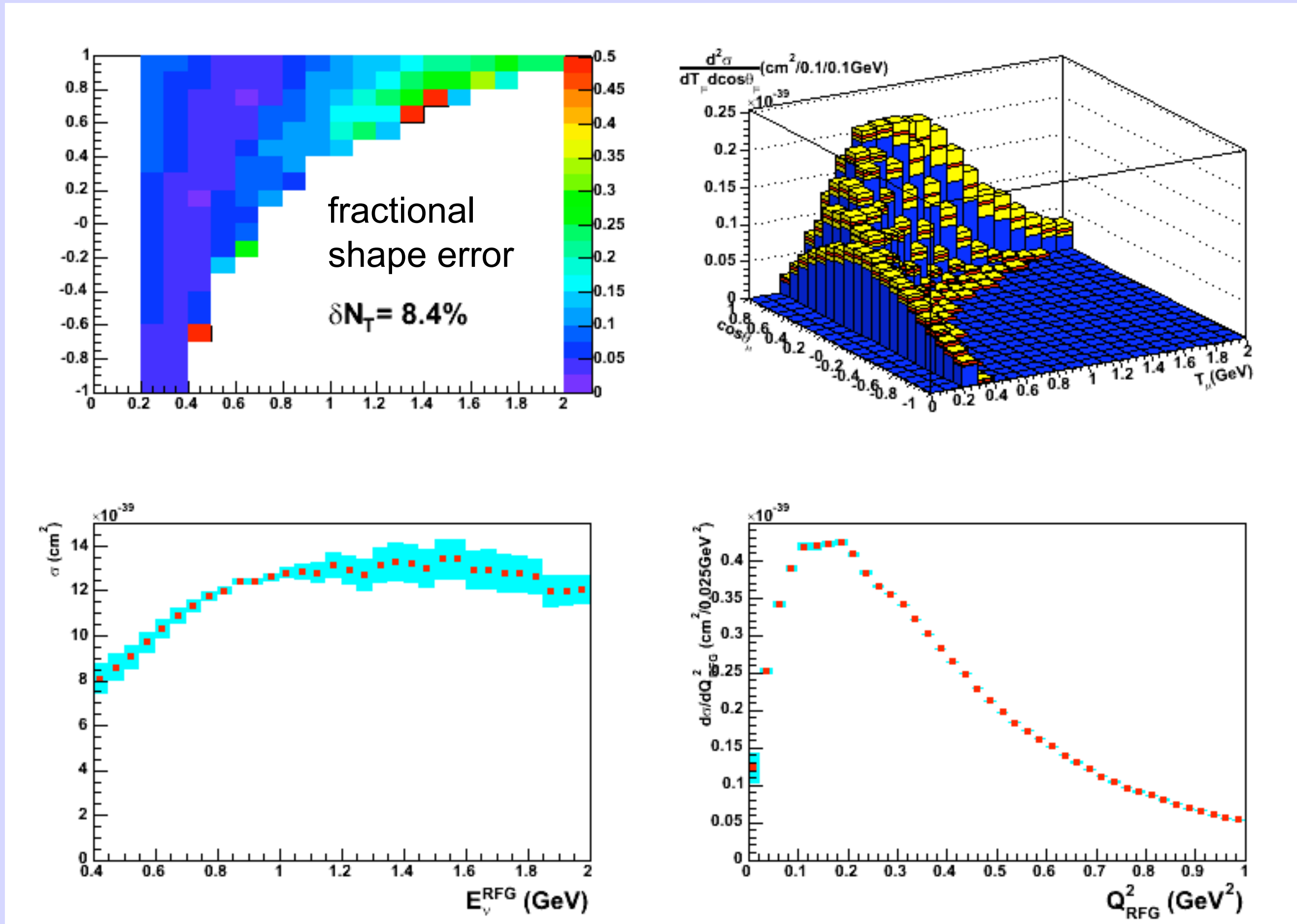


5. CCQE flux error

Flux error

The flux error dominates total normalization error.

The shape error is weak, except high energy region, where HARP measurement has large error and skin effect of horn has large error.

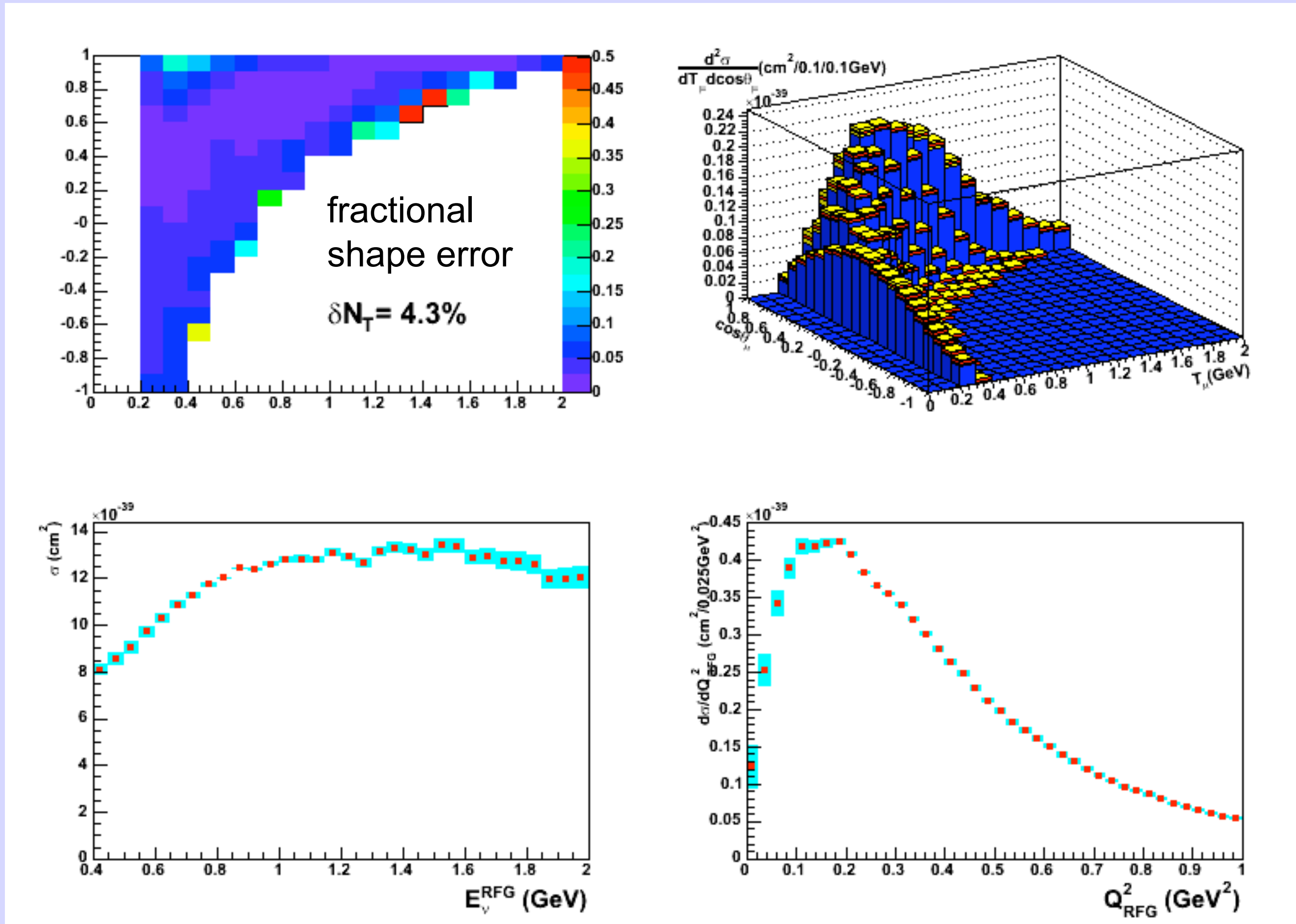


5. CCQE background cross section error

Background cross section error

The background cross section error is small, because of high purity and in situ background constraint.

The large error comes from pion absorption, so the kinematic space of CC1π events has large error

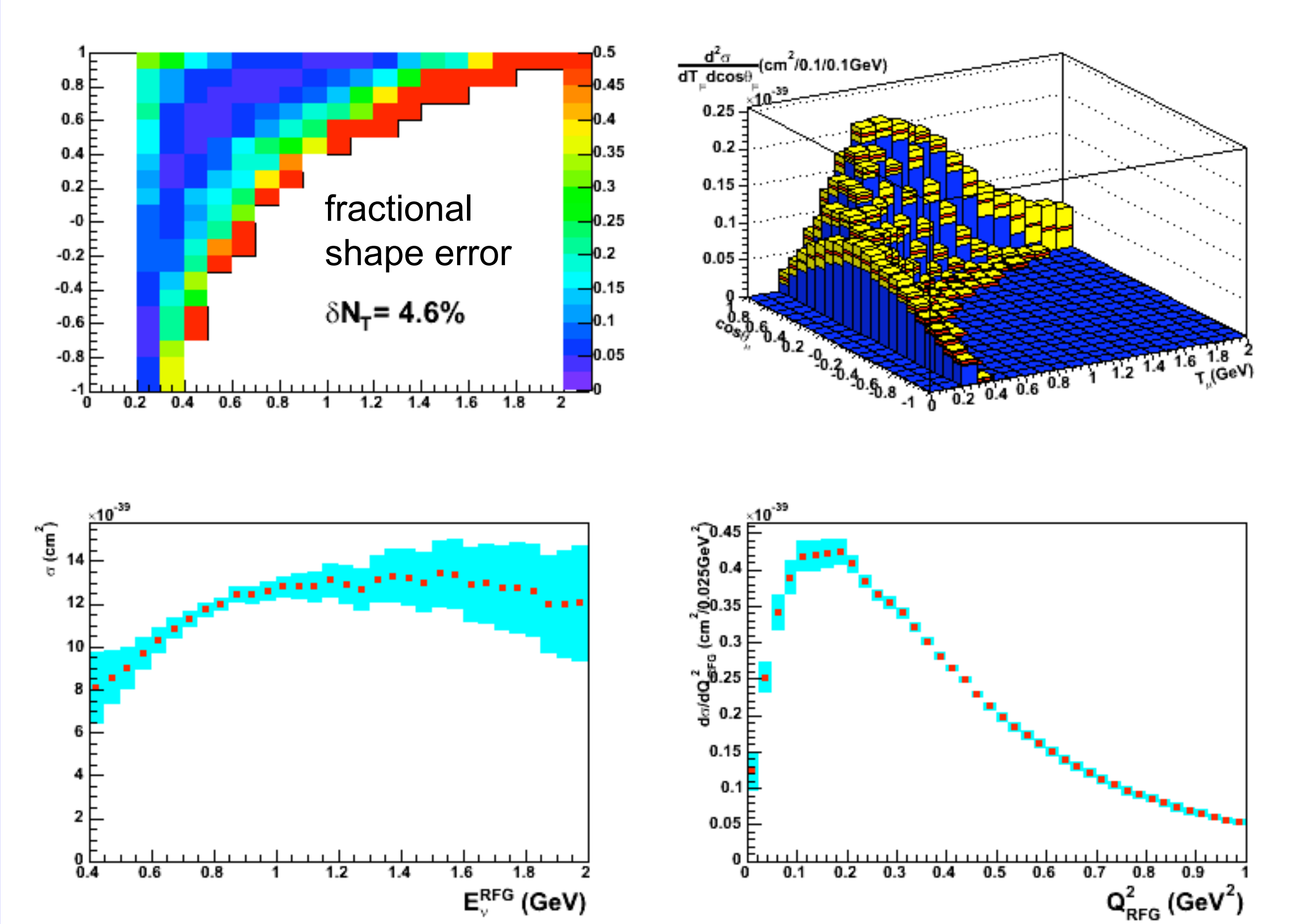


5. CCQE detector error

Detector error

The detector error has the largest contribution to the shape error because it is related with the energy scale of muon.

However the contribution to the total normalization error is not so large.



Jon Link, Nov. 18, 2005
Fermilab Wine & Cheese seminar

E 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)

Brookhaven AGS
7ft D_2 Bubble Chamber

The quasielastic reaction $\nu_\mu n \to \mu^- p$ was studied in an experiment using the BNL 7-foot deuterium bubble chamber exposed to the wide-band neutrino beam with an average energy of 1.6 GeV. A total of 1138 quasielastic events in the momentum-transfer range $Q^2 = 0.06-3.00$ $(\text{GeV}/c)^2$ were selected by kinematic fitting and particle identification and were used to extract the axial-vector form factor $F_A(Q^2)$ from the Q^2 distribution. In the framework of the conventional $V-A$ theory, we find that the dipole parametrization is favored over the monopole. The value of the axial-vector mass M_A in the dipole parametrization is 1.07 ± 0.06 GeV, which is in good agreement with both recent neutrino and electroproduction experiments. In addition, the standard assumptions of conserved vector current and no second-class currents are checked.

We have used a maximum likelihood method to extract M_A from the shape of the Q^2 distribution for each observed neutrino energy. This likelihood function $\mathfrak{L}^I$ is independent of the shape of the neutrino spectrum ...

They didn't even try to determine their ν flux from pion production and beam dynamics.

Phys. Rev. D **25**, 617 (1982)

The distribution of events in neutrino energy for the 3C $\nu d \to \mu^- p p_s$ events is shown in Fig. 4 together with the quasielastic cross section $\sigma(\nu n \to \mu^- p)$ calculated using the standard $V-A$ theory with $M_A = 1.05 \pm 0.05$ GeV and $M_V = 0.84$ GeV. The absolute cross sections for the CC interactions have been measured using the quasielastic events and its known cross section.[4]

In subsequent cross section analyses the theoretical ("known") quas-ielastic cross section and observed quasi-elastic events were used to determine the flux.

Jon Link, Nov. 18, 2005
Fermilab Wine & Cheese seminar

Fermilab
15ft D_2 Bubble Chamber

REVIEW LETTERS 12 JULY 1982

Neutrino Flux and Total Charged-Current Cross Sections in High-Energy Neutrino-Deuterium Interactions

T. Kitagaki, S. Tanaka, H. Yuta, K. Abe, K. Hasegawa, A. Yamaguchi, K. Tamai, T. Hayashino, Y. Ohtani, and H. Hayano
Tohoku University, Sendai 980, Japan

To obtain the total cross section from the number of events, the neutrino flux has to be measured on an absolute scale. In this analysis, we determine the neutrino flux using 362 quasielastic events identified in our data[10] and the cross section for reaction (2) derived from the $V-A$ theory.

Again, they use QE events and theoretical cross section to calculate the ν.

When they try to get the flux from meson (π and K) production and decay kinematics they fail miserably for E_ν<30 GeV.

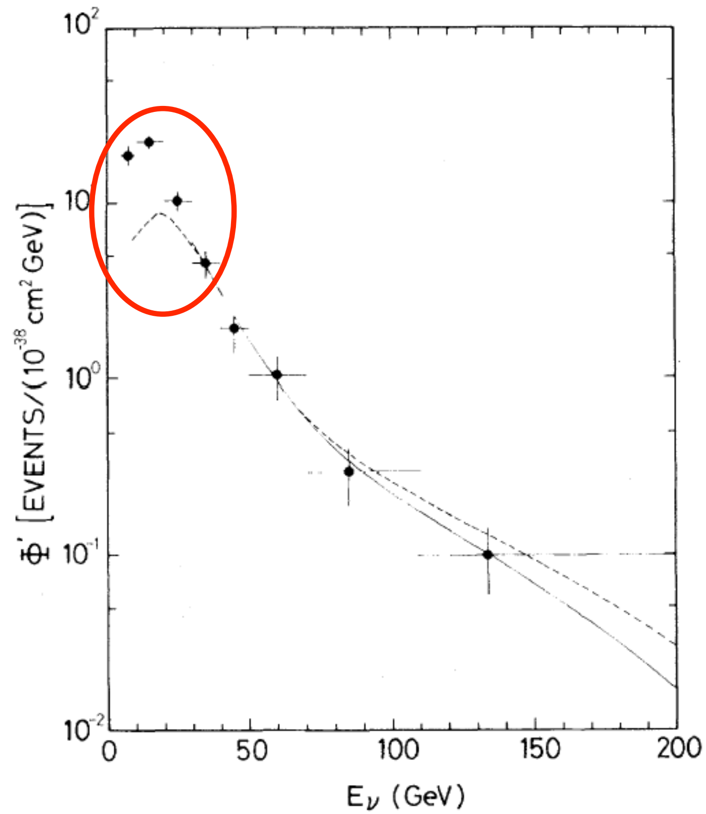


FIG. 2. Neutrino flux distribution obtained from the quasielastic events and the predicted cross section with M_A = 1.05 GeV. The solid curve is obtained from the best fit to the flux data for E_ν > 30 GeV. The dashed curve is taken from the Monte Carlo simulation of the flux.

Jon Link, Nov. 18, 2005
Fermilab Wine & Cheese seminar

ME 34, NUMBER 1 1 JULY 1986

Determination of the neutrino fluxes in the Brookhaven wide-band beams

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S. Terada, and D. H. White
Physics Department, Brookhaven National Laboratory, Upton, New York 11973

Brookhaven
AGS
Liquid Scintillator

The beam calculations described here were based on the Grote, Hagedorn, and Ranft (GHR) (Ref. 11) parametrization; that of Sanford and Wang was used for comparison. An estimate was made of pion production by reinteracting protons guided by the shape of the observed ν_μ spectrum and the observed angular distribution of muons from quasielastic events. The procedure is described[12] in the Appendix.

The Procedure

- Pion production cross sections in some low momentum bins are scaled up by 18 to 79%.
- The K^+ to π^+ ratio is increased by 25%.
- Overall neutrino (anti-neutrino) flux is increased by 10% (30%).

All driven by the neutrino events observed in the detector!

Jon Link, Nov. 18, 2005
Fermilab Wine & Cheese seminar

Argonne ZGS
12ft D_2 Bubble Chamber

16, NUMBER 11 1 DECEMBER 1977

Study of neutrino interactions in hydrogen and deuterium: Description of the experiment and study of the reaction $\nu + d \rightarrow \mu^- + p + p_s$†

S. J. Barish,* J. Campbell,‡ G. Charlton,§ Y. Cho, M. Derrick, R. Engelmann,‖ L. G. Hyman, D. Jankowski, A. Mann,¶ B. Musgrave, P. Schreiner, P. F. Schultz, R. Singer, M. Szczekowski,** T. Wangler, and H. Yuta††
Argonne National Laboratory, Argonne, Illinois 60439

Flux derived from pion production data. Were able to test assumptions about the form of the cross section using absolute rate and shape information.

TABLE IV. Results of axial-form-factor fits.

Likelihood function	M_A^{Dipole} (GeV)	M_A^{Monopole} (GeV)	M_A^{Tripole} (GeV)
Rate	$0.75^{+0.13}_{-0.11}$	$0.45^{+0.11}_{-0.07}$	$0.96^{+0.17}_{-0.14}$
Shape	1.010 ± 0.09	0.56 ± 0.08	1.32 ± 0.11
Rate and shape	0.95 ± 0.09	0.52 ± 0.08	1.25 ± 0.11
Flux independent	0.95 ± 0.09	0.53 ± 0.08	1.25 ± 0.11

- Pion production measured in ZGS beams were used in this analysis
- A very careful job was done to normalize the beam.
- Yet they have a 25% inconsistency between the axial mass they measure considering only rate information verses considering only spectral information.

Interpretation: Their normalization is wrong.

First Measurement of Muon Neutrino Charged Current Quasielastic (CCQE) Double Differential Cross Section

Teppei Katori for the MiniBooNE collaboration
Massachusetts Institute of Technology
NuInt 09, Sitges, May, 18, 09

Massachusetts
Institute of
Technology