Relating electron & neutrino cross sections in Quasi-Elastic, Resonance and DIS regimes

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Joint Lepton Hadron & Had-Had Scattering/Neutrino Session

(35 Min)

Neutrino cross sections at low energy?

- Many dedicated neutrino oscillation experiments (K2K, MINOS, CNGS, MiniBooNE, and at JHF) are in the few GeV region.

- ✓ Neutrino cross section models at low energy are crucial for precise next generation neutrino oscillation experiments.

- The high energy region of neutrino-nucleon scatterings (30-300 GeV) is well understood at the few percent level in terms of the quark-parton mode constrained by data from a series of e/μ/ν DIS experiments.

- However, neutrino cross sections in the low energy region are poorly understood. (especially, resonance and low Q2 DIS contributions).

Neutrino cross sections at low energy

- Quasi-Elastic / Elastic (W=Mn)

– $\nu_\mu + n \longrightarrow \mu^- + p$

- Input from both Electron and Neutrino Experiments and and described by form factors

- Resonance (low Q^2, W< 2)

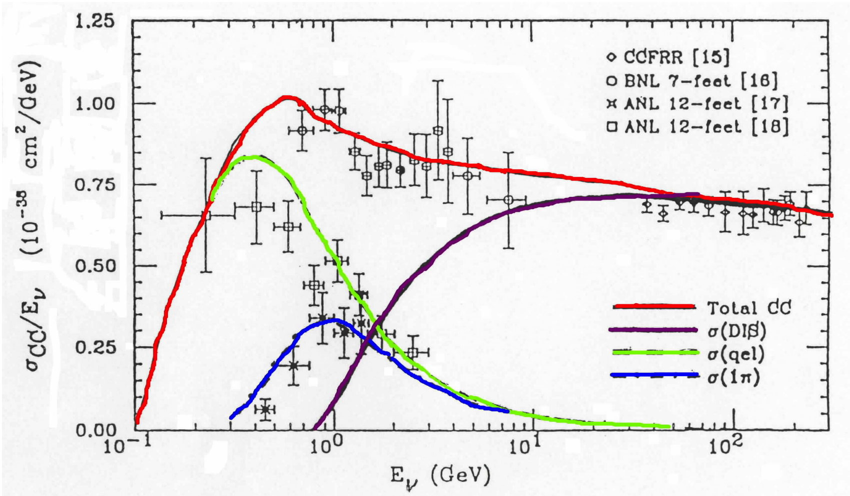
$\nu_\mu + p \longrightarrow \mu^- + p + \pi$

- Can be well measured in electon scattering but poorly measured in neutrino scattering (fits by Rein and Seghal

- Deep Inelastic

– $\nu_\mu + p \longrightarrow \mu^- + X$

- well measured in high energy experiments and well described by quark-parton model (pQCD with NLO PDFs, but doesn't work well at low Q2).



Issues at few GeV

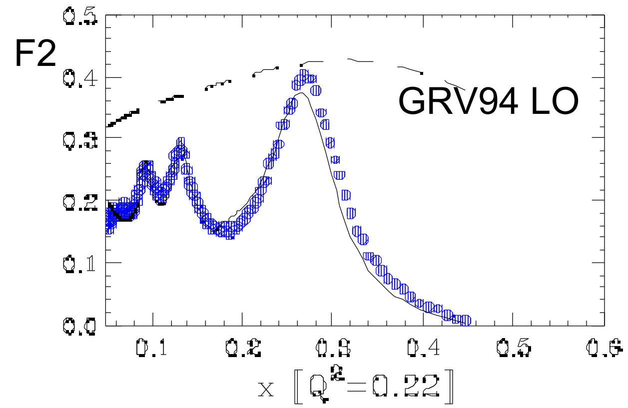
- Resonance scattering and low Q^2 DIS contribution meet, (difficult to avoid double counting problem).
- Challenge: to describe all these three processes at all neutrino (or electron) energies.

Building up a model for all Q^2

- Can we build up a model to describe all Q^2 from high down to very low energies ?
- [DIS, resonance, even photo-production(Q^2=0)]

- Describe them in terms of quark-parton model.

- \- With PDFS, it is straightforward to convert charged-lepton scattering cross sections into neutrino cross section. (just matter of different couplings)



Challenges

- Understanding of high x PDFs at very low Q^2?
  - Requires understanding of non-perturbative QCD effects, though there is a wealth of SLAC, JLAB data.
- Understanding of resonance scattering in terms of quark-parton model? (duality works, many studies by JLAB)

Lessons from previous QCD studies

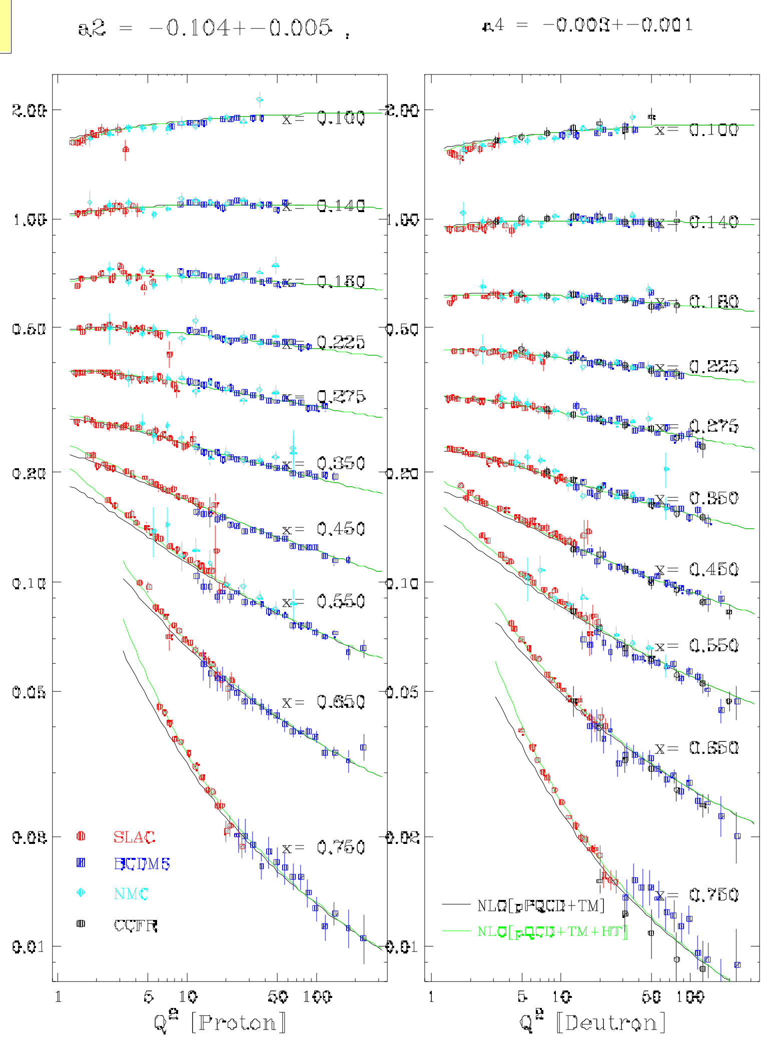
- Our previous studies of comparing NLO PDFs to DIS data: SLAC, NMC, and BCDMS e/μ scattering data show that.. [Ref:PRL 82, 2467 (1999)]
  - Kinematic higher twist (target mass) effects are large,
  - and must be included in the form of Georgi & Politzer ξ scaling.
  - Dynamic higher twist effects(multi-quark correlation etc) are smaller, but need to be included.
  - Very high x(=0.9) is described by NLO pQCD with target mass + higher twist effects, (better than 10%).
  - Average over resonance region is well described for $Q^2 > 1$ (duality works).

- The dynamic higher twist corrections (in NLO analysis) are mostly due to the missing QCD NNLO higher order terms. [Ref:Eur. Phys. J**. C13**, 241 (2000)]

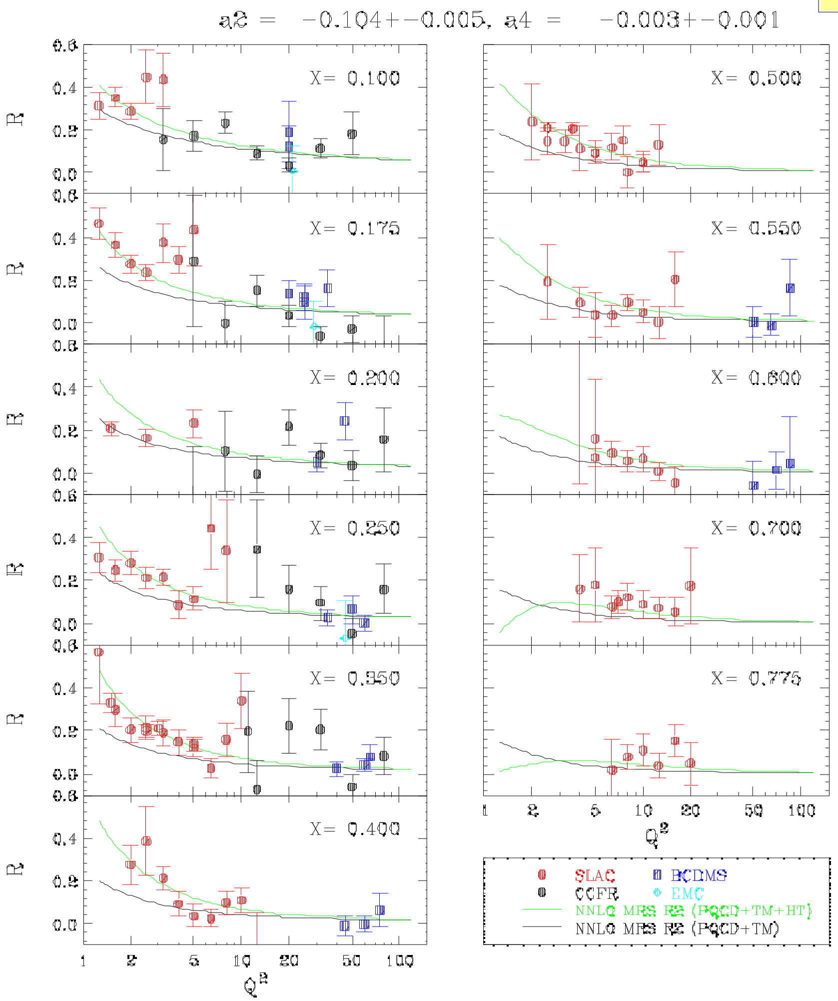
- Therefore, low energy neutrino data should be described by the PDFs which are modified for target mass and higher twist effects and extracted from low energy e/μ scattering data.

The predictions using NLO + TM + higher twist describe the data reasonably well

F2

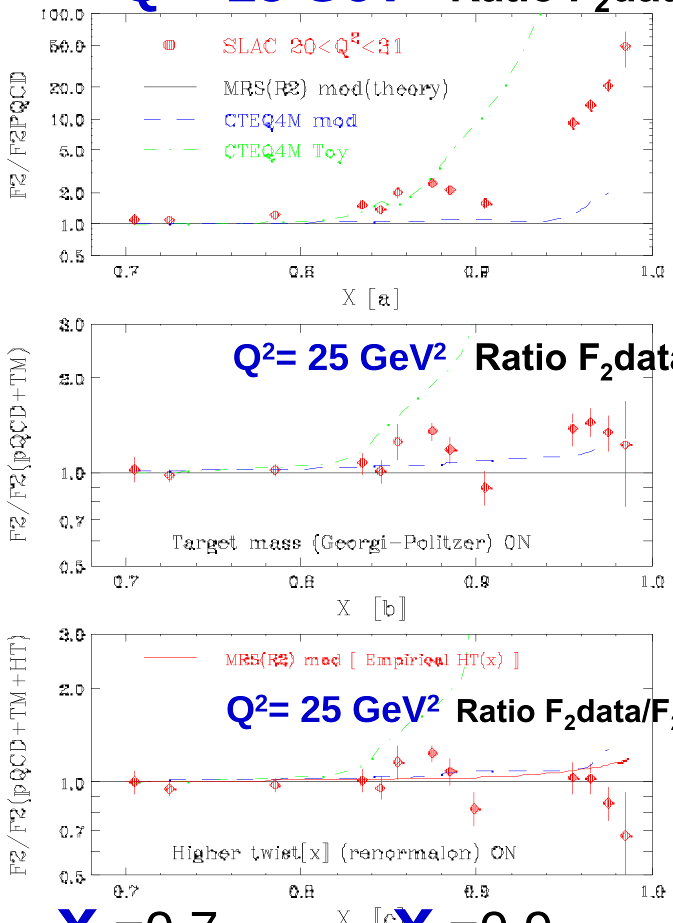


R



Very high x F2 proton data (DIS + resonance)
(not included in the original fits Q^2=1. 5 to 25 GeV^2)

Q^2= 25 GeV^2 **Ratio F_2data/F_2pQCD**



pQCD ONLY

Q^2= 25 GeV^2 **Ratio F_2data/ F_2pQCD+TM**

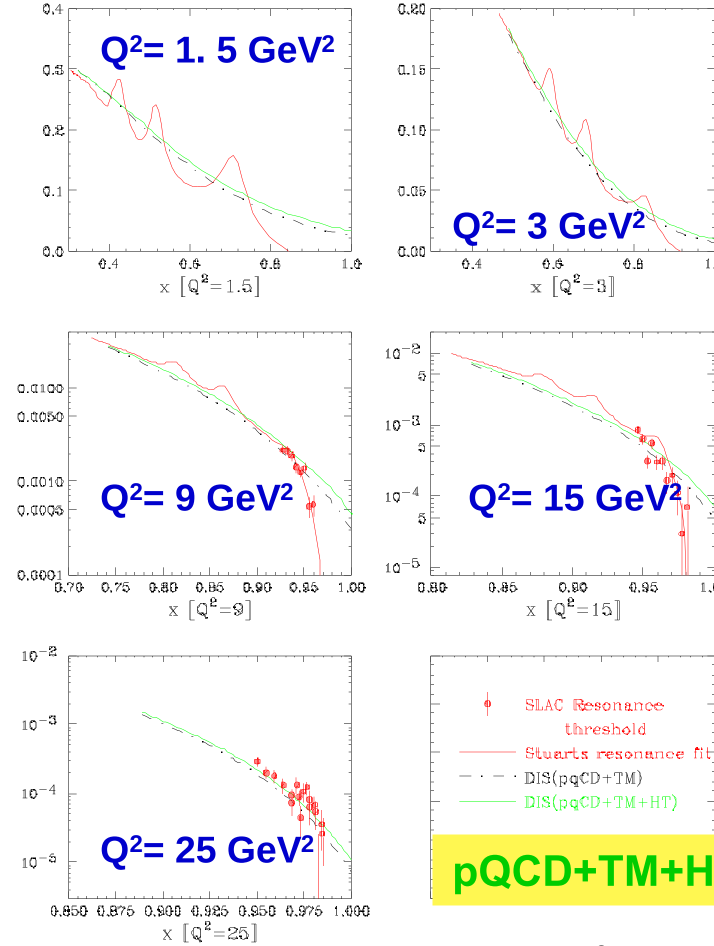
pQCD+TM

Q^2= 25 GeV^2 **Ratio F_2data/F_2pQCD+TM+HT**

pQCD+TM+HT

X =0.7 **X** =0.9

F2 resonance Data versus F_2pQCD+TM+HT



Q^2= 1. 5 GeV^2

Q^2= 3 GeV^2

Q^2= 9 GeV^2

Q^2= 15 GeV^2

Q^2= 25 GeV^2

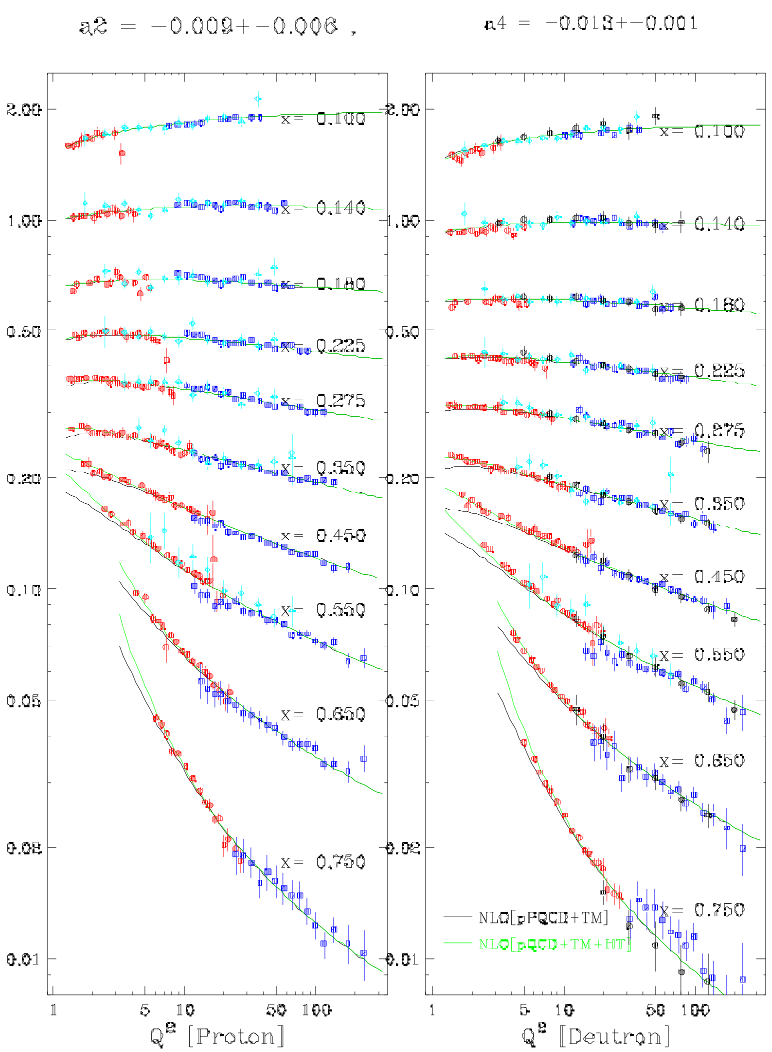
pQCD+TM+HT

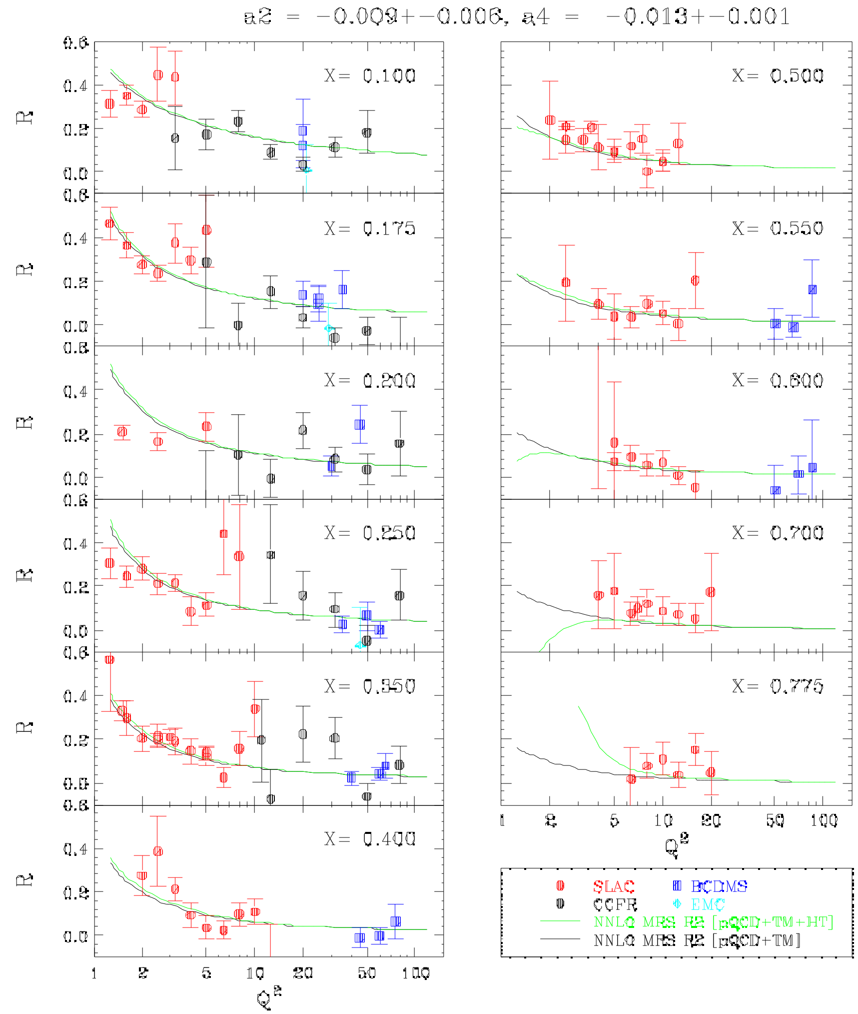
NLO pQCD + ξ TM + higher twist describes very high x DIS F_2 and resonance F_2 data well. (duality works) Q^2=1. 5 to 25 GeV^2

A_w (w, Q^2) will account for interactions with spectator quarks

F2, R comparison with NNLO QCD

Size of the higher twist effect with NNLO analysis is really small (a2=-0.009(NNLO) vs –0.1(NLO)



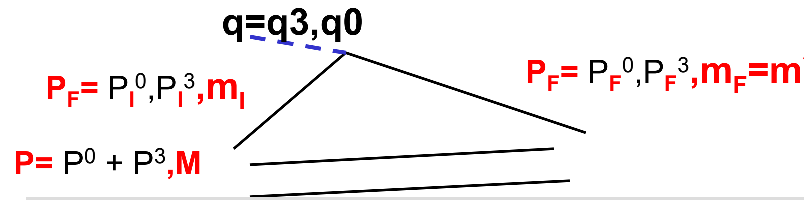


Initial quark mass m_I and final mass ,$m_F=m^*$ bound in a proton of mass M -- Summary: INCLUDE quark initial Pt) Get ξ scaling (not $x=Q^2/2M\nu$)

for a general parton Model

ξ Is the correct variable which is Invariant in any frame : q3 and P in opposite directions.

ξ



$PI,P0$ $\quad$ $q3\ q0$

$$\xi = \frac{P_I^0 + P_I^3}{P_P^0 + P_P^3} \qquad \text{quark} \longrightarrow \quad \longleftarrow \text{photon}$$

$$(q + P_I)^2 = P_F^2 \quad \rightarrow q^2 + 2P_I\ q + P_I^2 = m_F^2$$

$$\xi_W = \frac{Q^2 + m_F^2 + A}{\{M\nu[1 + \sqrt{(1 + Q^2/\nu^2)}] + B\}} \quad for\ m_I^2, Pt = 0$$

Special cases:

(1) Bjorken x, $x_{BJ}=Q^2/2M\nu$, ξ, -> x

For $m_F^2 = m_I^2 = 0$ and High ν^2,

(2) Numerator m_F^2 : Slow Rescaling ξ as in charm production

(3) Denominator: Target mass term

ξ =Nachtman Variable

ξ =Light Cone Variable

ξ =Georgi Politzer Target Mass var. (all the same ξ)

Most General Case: (Derivation in Appendix)

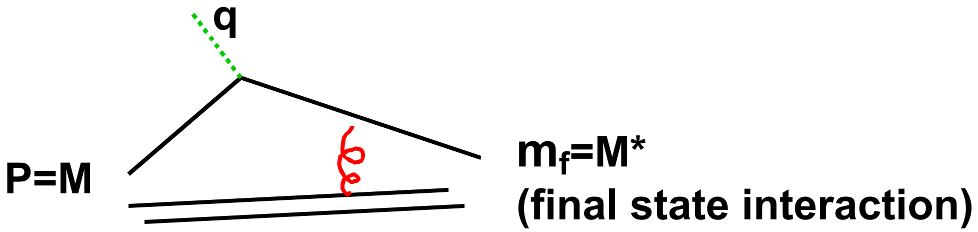
ξ'_w= [Q'^{2} +B] / [Mν (1+(1+Q^2/ν^2)) $^{1/2}$ +A] (with A=0, B=0)

where $2Q'^2 = [Q^2 + m_F^2 - m_I^2] + \{ (Q^2 + m_F^2 - m_I^2)^2 + 4Q^2 (m_I^2 + P^2t) \}^{1/2}$

Bodek-Yang: Add B and A to account for effects of additional Δm^2 from NLO and NNLO (up to infinite order) QCD effects. For case ξ_w with **P^2t** =0 see R. Barbieri et al Phys. Lett. 64B, 1717 (1976) and Nucl. Phys. B117, 50 (1976)

Pseudo NLO approach

- Original approach (NNLO QCD+TM) was to explain the non-perturbative QCD effects at low Q^2, but now we reverse the approach: Use LO PDFs and "effective target mass and final state masses" to account for initial target mass, final target mass, and missing higher orders



Resonance, higher twist, and TM

$$\xi = \frac{Q^2 + m_f^2 + O(m_f^2 - m_i^2)}{M\nu\,(1+(1+Q^2/\nu^2))^{1/2}} \longrightarrow X_{bj} = Q^2/2M\nu$$

First Try:

Use $x_w = \frac{Q^2+B}{M\nu + A}$

K factor to PDF, $Q^2/[Q^2+C]$

A : initial binding/target mass effect plus higher order terms

B: final state mass m_f^2 , Δm^2, and photo-production limit ($Q^2 = 0$)

Fit with Xw +GRV94 PDFs SIMPLE

1. Start with GRV94 LO (Q^2_{min}=0.24 GeV^2)
   - describe F2 data at high Q^2
2. Replace the X with a new scaling, Xw
   - $X= [Q^2] / [2M\nu]$
   - $Xw=[Q^2+B] / [2M\nu+A]=X[Q^2+B]/[Q^2+ Ax]$
3. Multiply all PDFs by a factor of $Q^2/[Q^2+C]$ for photo prod. limit and higher twist
   $[\sigma(\gamma)= 4\pi\alpha/Q^2 * F_2(x, Q^2)]$
4. Freeze the evolution at $Q^2 = 0.25 GeV^2$
   - $F_2(x, Q^2 < 0.25) = Q^2/[Q^2+C] F_2(Xw, Q^2=0.25)$

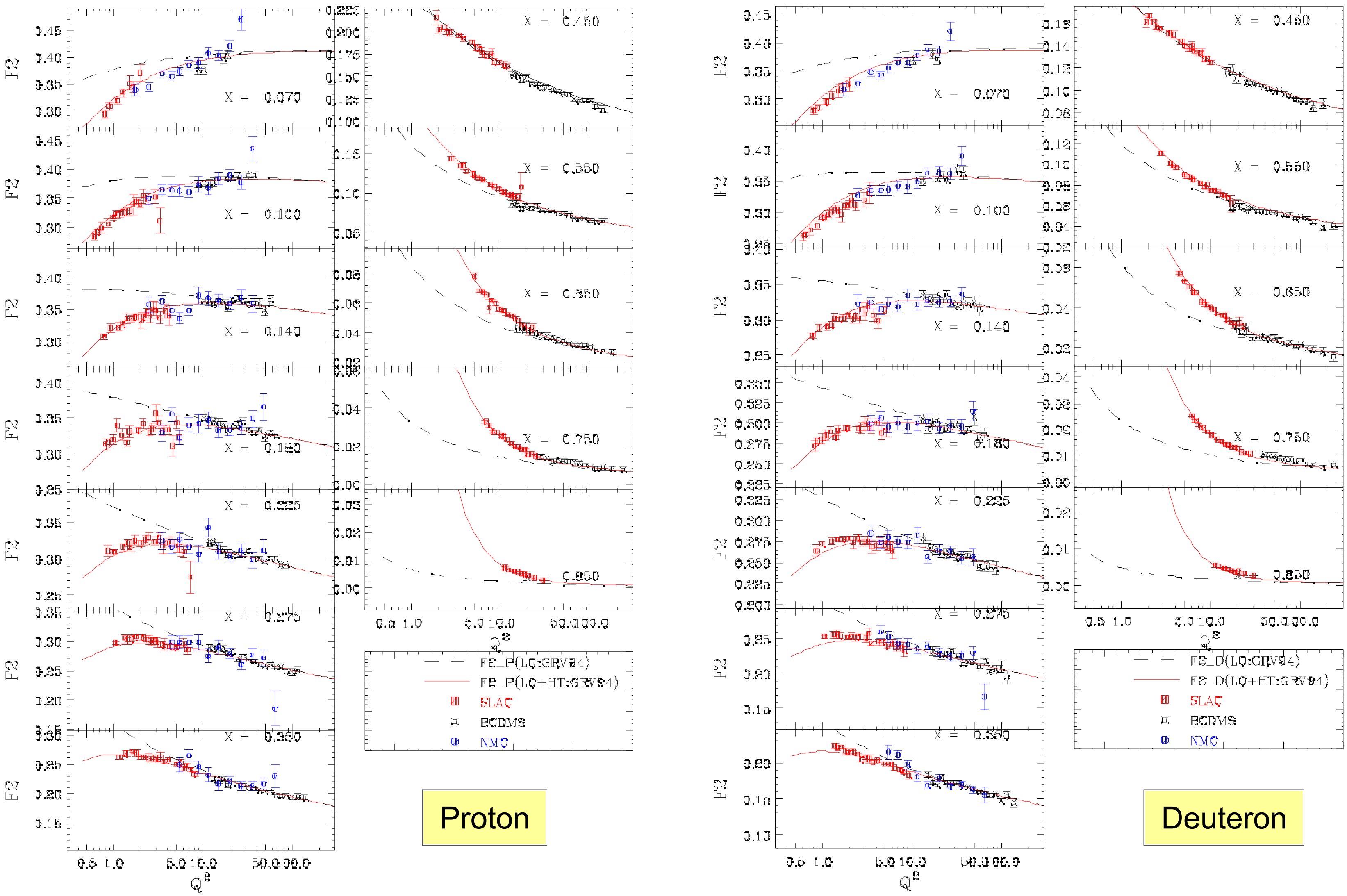
- Do a fit to SLAC/NMC/BCDMS H, D
  A=1.735, B=0.624, and C=0.188
  χ^2/DOF**= 1555/958**

Results

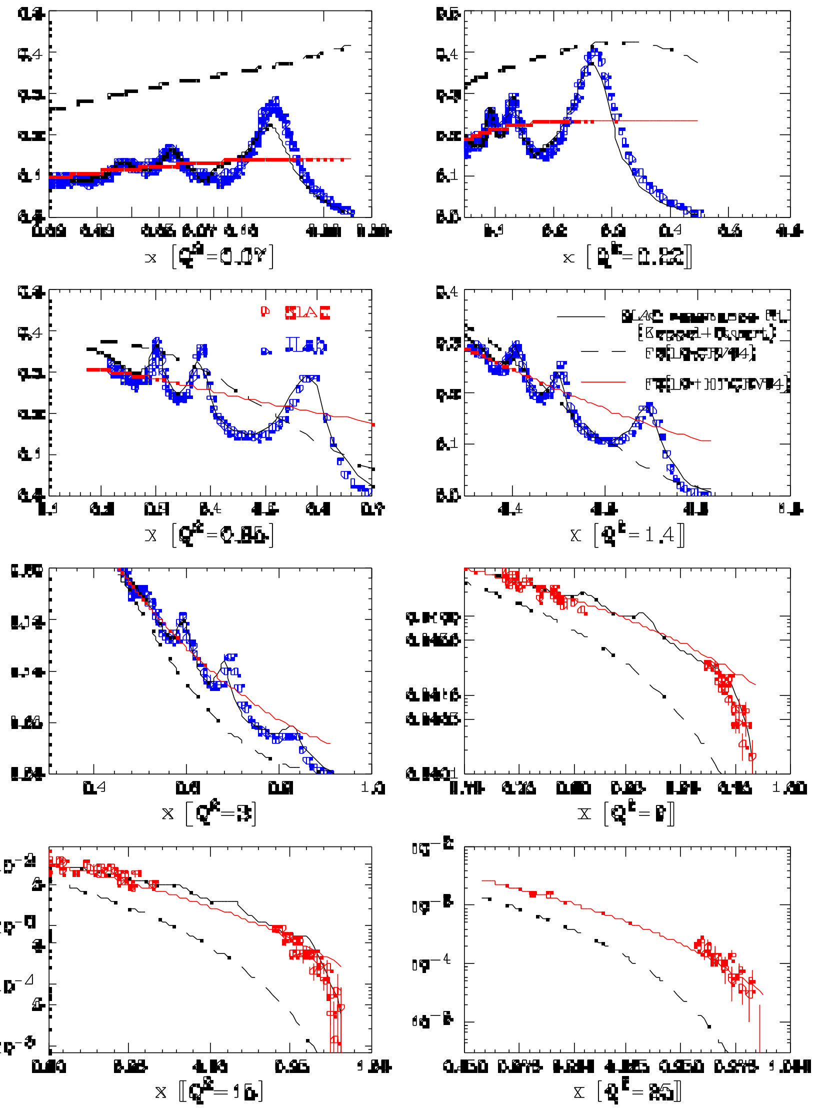
- ✓ Comparison with resonance data (not used in the fit)?
- ✓ Comparison with photo production data (not used in fit)
- ✓ Comparison with neutrino data (not used in fit)

Comparison with DIS F_2 (H, D) data [x_w fit]

[SLAC/BCDMS/NMC] Fit to these DATA



Comparison with $F_2(p)$ resonance data
[SLAC/ Jlab]

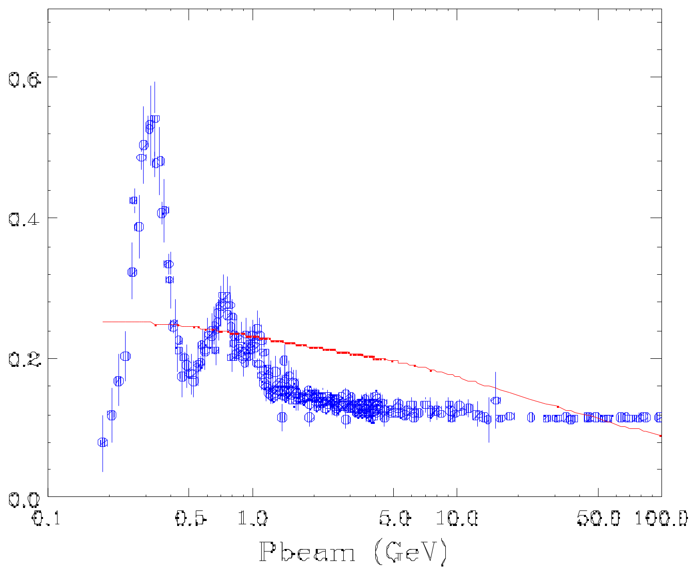


- Modified LO GRV94 PDFs
- with a new scaling variable, Xw describe the SLAC/Jlab resonance data well.
  - Even down to Q^2 = 0.07 GeV²
  - Duality works: DIS curve

---- unmodifed

modified

Comparison with photo-production data (p) (not included in fit)



Fit with Xw and modified GRV94 PDFs

- Not bad!!!
- Shape is sensitive to $F_2(x)$ at low x.

$\sigma(\gamma\text{-proton}) = 4\pi\alpha/Q^2 * F_2(x, Q^2)$

$= 0.112\text{mb} * F_2(x_w)/C$

where $F_2(x, Q^2) = Q^2/(Q^2 + C) * F_2(x_w)$

old Fit with Xw and GRV94 PDFs

1. Start with GRV94 LO (Q^2_{min}=0.24 GeV^2)
   - describe F2 data at high Q^2
2. Replace the X with a new scaling, Xw
   - $X= [Q^2] / [2M\nu]$
   - $Xw=[Q^2+B] / [2M\nu+A]=X[Q^2+B]/[Q^2+ Ax]$
3. Multiply all PDFs by a factor of $Q^2/[Q^2+C]$ for photo prod. limit and higher twist
   $[\ \sigma(\gamma)= 4\pi\alpha/Q^2 * F_2(x, Q^2)\ ]$
4. Freeze the evolution at $Q^2 = Q^2_{min}$
   - $F_2(x, Q^2 < 0.24) = Q^2/[Q^2+C]\ F_2(Xw, Q^2=0.24)$

- Do a fit to SLAC/NMC/BCDMS F2 P, D
  A=1.735, B=0.624, and C=0.188
  χ^2/DOF= 1555/ 958 ***

New Better: Fit with ξw - Improved scaling variable, better GRV98 PDFs, better form at low Q^2

- Use GRV98 LO (Q^2_{min}=0.80 GeV^2)
- $\xi_w= [Q^2+B] / [M\nu (1+(1+Q^2/\nu^2)^{1/2}) +A]$
- **Different K factors for valence and sea**

  $Ksea = Q^2/[Q^2+Csea]$
  $Kval = [1- G_D{}^2 (Q^2)] * [Q^2+C2V] / [Q^2+C1V]$

  where $G_D{}^2 (Q^2) = 1/ [1+Q^2 / 0.71]^4$
  (elastic nucleon dipole form factor)
  (Form Motivated by Adler Sum Rule)

- **Very good fits are obtained (low x HERA/NMC F2 data iare now included)**
  A=0.418, B=0.222, Csea = 0.381
  C1V = 0.604, C2V= 0.485
  χ^2/DOF= 1268 / 1200 ***

Origin of low Q^2 K factor for Valence Quarks

Adler Sum rule EXACT all the way down to $Q^2=0$ includes W_2 quasi-elastic

- $\beta- = W_2$ (Anti-neutrino -Proton)
- $\beta+ = W_2$ (Neutrino-Proton) $q0=\nu$

The vector current part of the original sum rule of Adler for neutrino scattering can be written

$$\int_0^\infty dq_0[\beta^{(-)}(q_0,q^2)-\beta^{(+)}(q_0,q^2)]=1. \qquad (18)$$

If we explicitly separate out the nucleon Born term in Eq. (18), we have

$$[F_1^V(q^2)]^2+q^2\left(\frac{\mu^V}{2M_N}\right)^2[F_2^V(q^2)]^2 + \int_{M_\pi+(q^2+M_\pi^2)/2M_N}^\infty dq_0[\beta^{(-)}(q_0,q^2)-\beta^{(8)}(q_0,q^2)]=1,$$

Vector Part of W2

$$g_A(q^2) + \int_{M_\pi+(q^2+M_\pi^2)/2M_N}^\infty dq_0[\beta^{(-)}(q_0,q^2)-\beta^{(8)}(q_0,q^2)]=1,$$

AXIAL Vector part of W_2

Adler is a number sum rule at high Q^2

$$\int_0^\infty dq_0[\beta^{(-)}(q_0,q^2)-\beta^{(+)}(q_0,q^2)] = 1 \text{ is}$$

$$\int_0^1 \frac{[F_2^-(\xi)-F_2^+(\xi)]}{\xi}d\xi = \int_0^1 [U_v(\xi)-D_v(\xi)]d\xi = 2-1$$

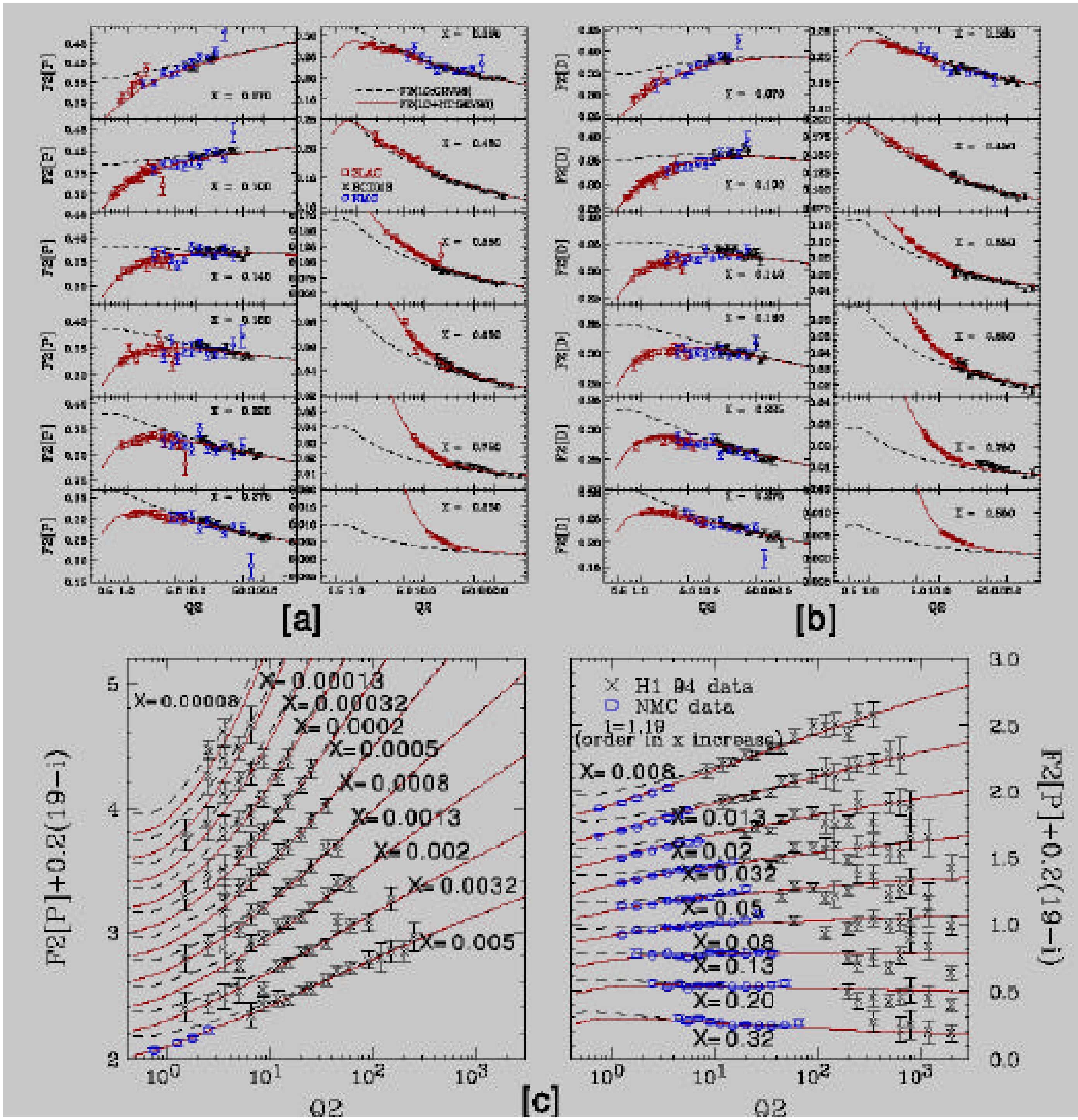
$F_2^- = F_2$ (Anti-neutrino -Proton) $= \nu W_2$

$F_2^+ = F_2$ (Neutrino-Proton) $= \nu W_2$

we use: $d(q0) = d(\nu) = (\nu) d\xi / \xi$

[see Bodek and Yang hep-ex/0203009] and references therein

at fixed $q^2 = Q^2$



χ^2 = 1268 / 1200 DOF

Dashed ---unmodified

GRV98LO QCD $F_2 = F_{2QCD}(x,Q^2)$

Solid —— =modified GRV98LO QCD

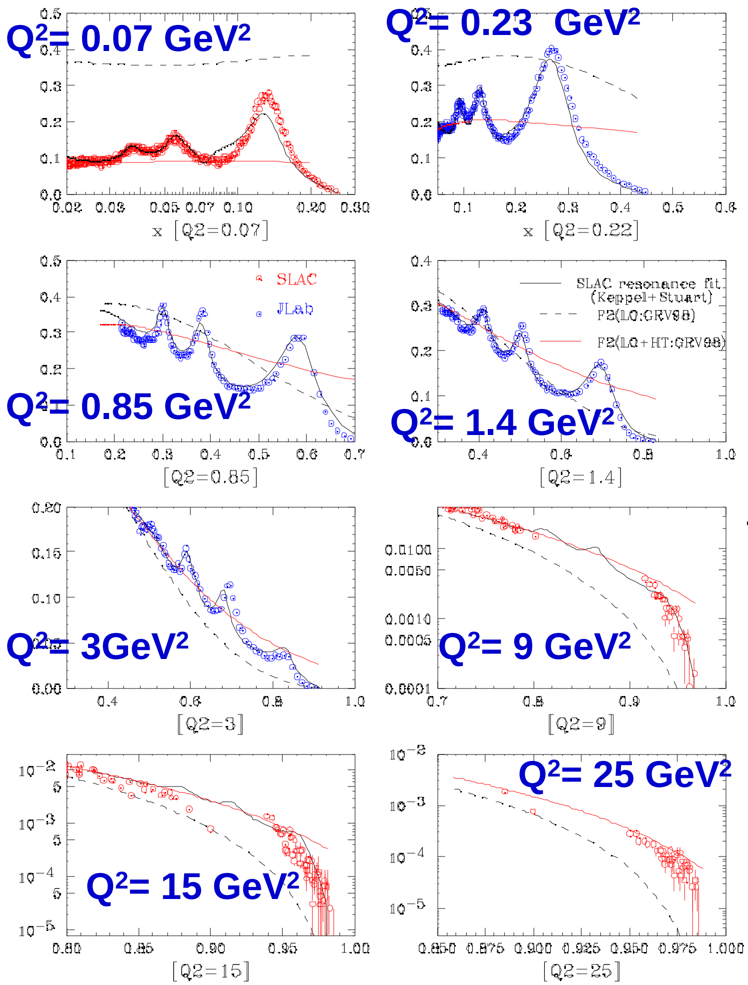
$F_2 = K(Q^2) * F_{2QCD}(\xi_w, Q^2)$

SLAC, NMC,BCDMS (H,D)

+HERA 94 Data ep

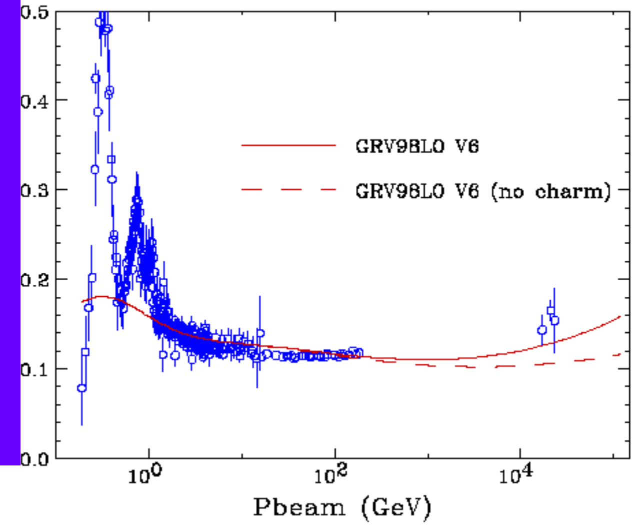
Fit with ξw modified GRV98 PDFs

F_2(P) resonance



Predictions of the modified GRV98 PDFs with ξw to electroproduction Photoproduction data on proton and neutrino data on iron (not included in the fit)

Photo-production (P) Q^2= 0



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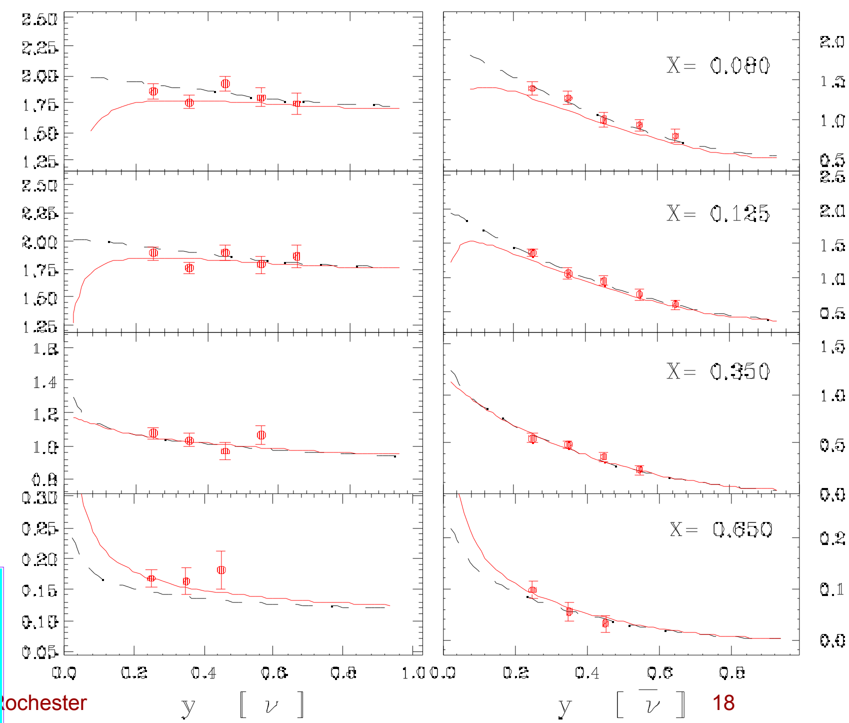
modified



Neutrino Xsection on iron at 55GeV (CCFR)

Predictions of the modified GRV98 PDFs with ξw to Electron and photo-production Data on Deuterium (not included in the fit)

F_2(d) resonance

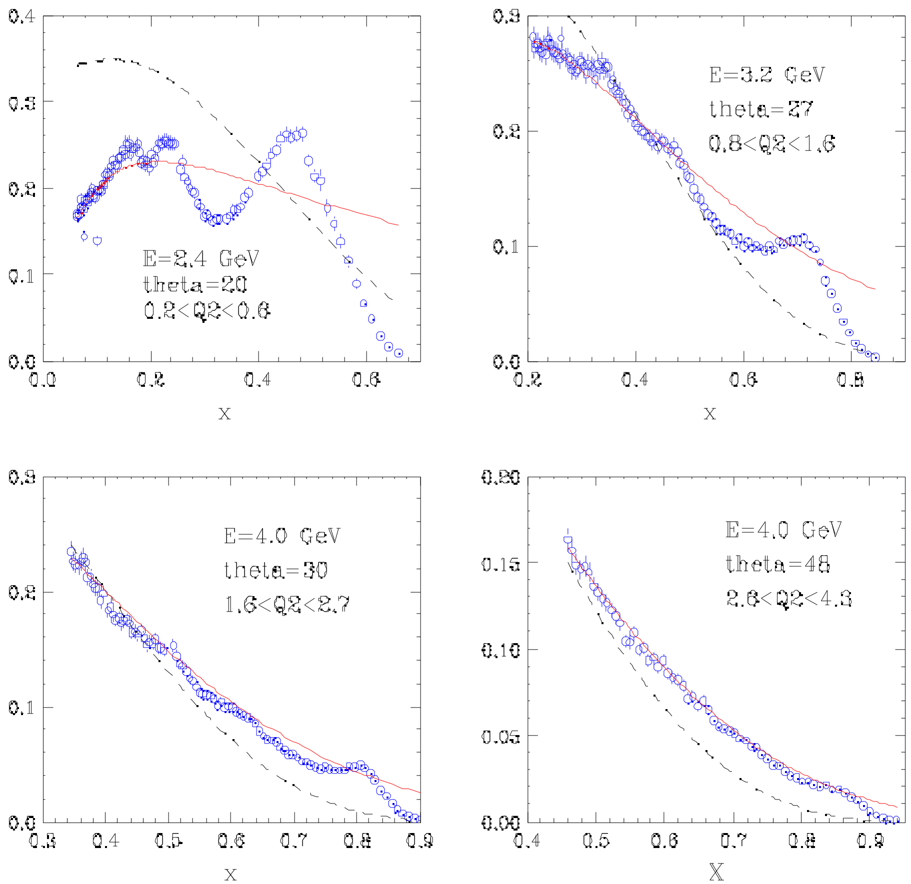
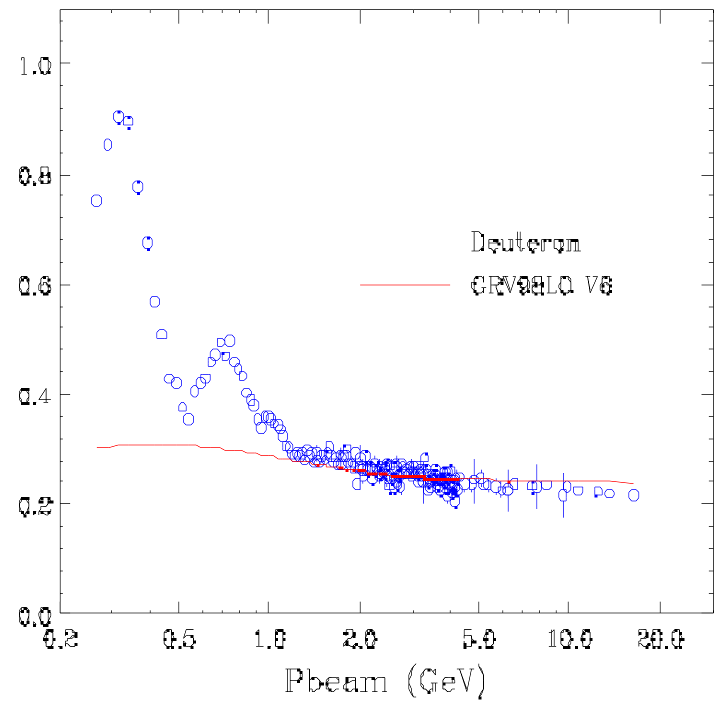


Photo-production (d) Q2=0



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modified

Correct for Nuclear Effects measured in e/μ expt.

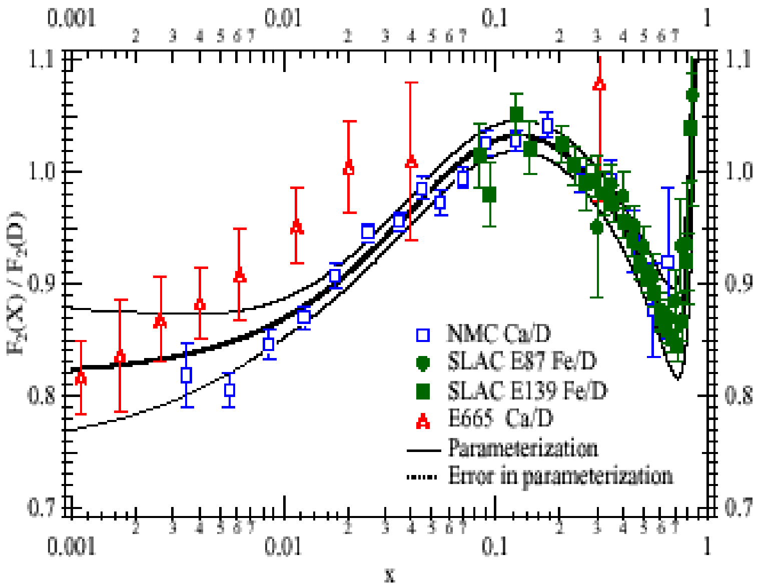
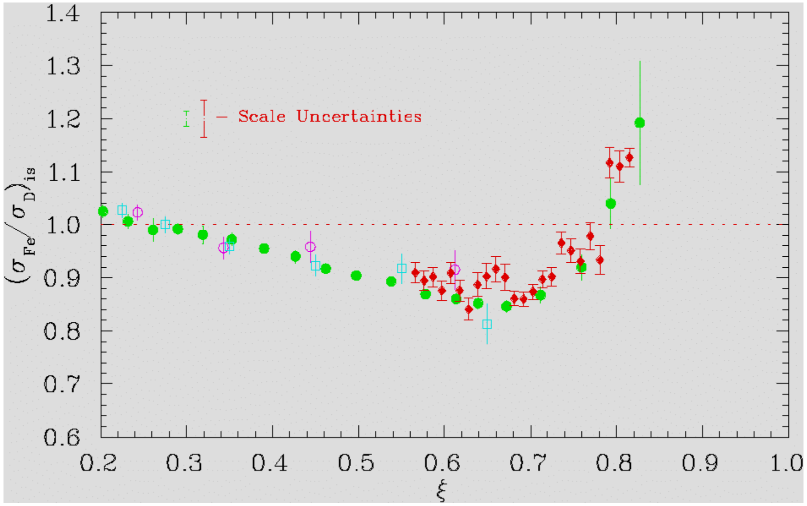


Figure 5. The ratio of F_2 data for heavy nuclear targets and deuterium as measured in charged lepton scattering experiments(SLAC,NMC, E665). The band show the uncertainty of the parametrized curve from the statistical and systematic errors in the experimental data [16].



Comparison of Fe/D F2 data

In resonance region (JLAB)

Versus DIS SLAC/NMC data

In ξ_{TM} (C. Keppel 2002).

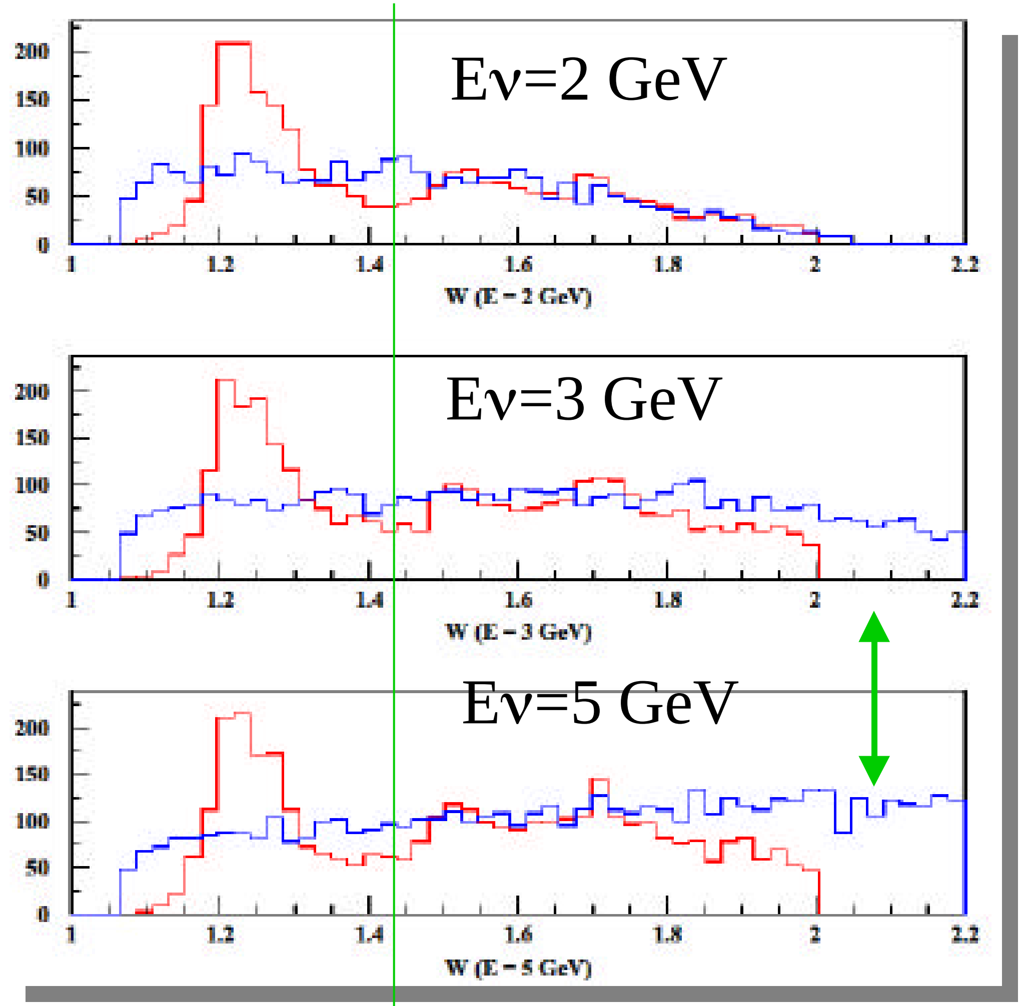
From: D. Casper, UC Irvine K2K NUANCE MC 2003

W, Final Hadronic Mass Comparison

------ Bodek/Yang modified ξ_w scaling + GRV98 PDFs 2003

------ D. Rein and L. M. Sehgal, Annals Phys. 133, 79 (1981) Resonance +Non Resonance model

Best-->use Rein Sehgal for first resonance. Use Bodek/Yang above



------ Bodek/Yang modified ξ_w scaling + GRV98 PDFs 2003

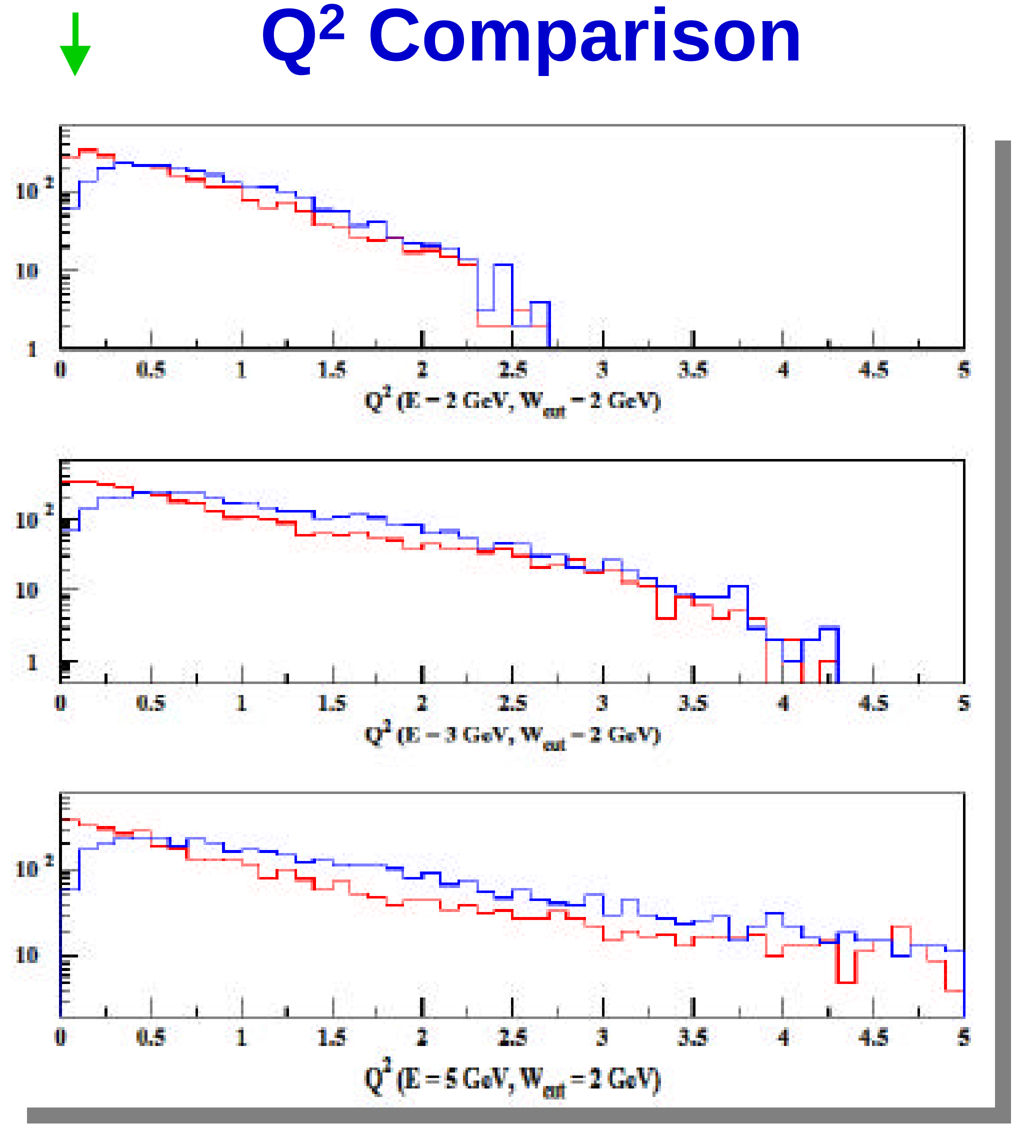
First assume V=A

V=0 at Q2=0

------ D. Rein and L. M. Sehgal, Annals Phys. 133, 79 (1981) Resonance +Non Resonance model-> for first resonance --Vector not equal Axial At Very low Q2. For Quasielastic Ga=1.27 Gv=1.0

From: D. Casper, UC Irvine K2K NUANCE MC 2003

Q^2 Comparison



PART 1: DIS+ Resonance: Summary and Plan (Bodek/Yang)

- **Our modified GRV98LO PDFs with the scaling variable ξw describe all SLAC/BCDMS/NMC/HERA DIS data.**
- **Predictions in good agreement with resonance data (down to $Q^2 = 0$) , photo-production data, and with high-energy neutrino data on iron.**
- **This model should also describe a low energy neutrino cross sections reasonably well.**

Things can be added from electron scattering

- Resonance effect, A(w) from Jlab data.
- Nuclear effects on various targets.
- R=σL/σT

Things can't be added from electron scattering

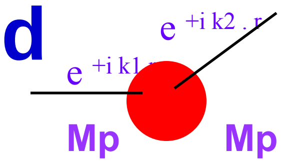
- Axial vector contribution at very low Q^2
- Different nuclear effects in neutrino scatt.

Collaborative approach with nuclear physics community

High x and low Q^2 PDFs for e/neutrino, resonance form factors, nuclear corrections

1. Electron scattering exp. at JLAB E03-110
2. New Near Detector neutrino exp. at Fermilab-NUMI/ + JHF MINERVA

Update on Quasielstic Scattering and Axial Form Factor extraction



- Part II (What is the difference in the quasi-elastic cross sections if:

1. We use the most recent very precise value of $g_A = F_A (Q^2) = 1.263$ (instead of 1.23 used in earlier analyses.) Sensitivity to g_A and $m_{A,}$
2. Use the most recent Updated $G_E^{P.N} (Q^2)$ and $G_M^{P.N}$ ((Q^2) *from Electron Scattering (instead of the dipole form assumed in earlier analyses)* In addition *There are new precise measurments of* $G_E^{P.N} (Q^2)$ Using polarization transfer experiments
3. How much does $m_{A,}$ measured in previous experiments change if current up to date form factors are used instead --- Begin updating m_A

Neutrino Cross Sections

NuMI-112
PDK-626
Nov. 10, 1995

They implemented
The Llewellyn-Smith
Formalism for NUMI

H. M. Gallagher and M. C. Goodman

$$\frac{d\sigma}{d|q^2|}\begin{pmatrix}\nu n \to l^- p \\ \bar{\nu} p \to l^+ n\end{pmatrix} = \frac{M^2 G^2 cos^2\theta_c}{8\pi E_\nu^2}\left[A(q^2) \mp B(q^2)\frac{(s-u)}{M^2} + \frac{C(q^2)(s-u)^2}{M^4}\right]. \qquad (2)$$

In this expression, G is the Fermi coupling constant and θ_c is the Cabibbo mixing angle ($G = 1.16639 \times 10^{-5}\mathrm{GeV}^{-2}$). The functions A, B, and C are convenient combinations of the nucleon form factors.

Contraction of the hadronic and leptonic currents yields:

Non zero

$$A = \frac{(m^2 - q^2)}{4M^2}\left[\left(4 - \frac{q^2}{M^2}\right)|F_A|^2 - \left(4 + \frac{q^2}{M^2}\right)|F_V^1|^2 - \frac{q^2}{M^2}|\xi F_V^2|^2\left(1 + \frac{q^2}{4M^2}\right) - \frac{4q^2 ReF_V^{1*}\xi F_V^2}{M^2} \qquad (3)\right.$$

$$\left. + \frac{q^2}{M^2}\left(4 - \frac{q^2}{M^2}\right)|F_T|^2 - \frac{m^2}{M^2}\left(|F_V^1 + \xi F_V^2|^2 + |F_A + 2F_P|^2 + \left(\frac{q^2}{M^2} - 4\right)\left(|F_S|^2 + |F_P|^2\right)\right)\right]$$

$$B = -\frac{q^2}{M^2} ReF_A^*(F_V^1 + \xi F_V^2) - \frac{m^2}{M^2} Re\left[\left(F_V^1 + \frac{q^2}{4M^2}\xi F_V^2\right)^* F_S - \left(F_A + \frac{q^2 F_P}{2M^2}\right)^* F_T\right] \qquad (4)$$

$$C = \frac{1}{4}\left(|F_A|^2 + |F_V^1|^2 - \frac{q^2}{M^2}\left|\frac{\xi F_V^2}{2}\right|^2 - \frac{q^2}{M^2}|F_T|^2\right), \qquad (5)$$

where m is the final state lepton mass. Ignoring second-class currents (those which violate G-parity) allows us to set the scalar and tensor form factors to zero. According to the CVC

$$F_V^1(q^2) = \left(1 - \frac{q^2}{4M^2}\right)^{-1}\left[G_E^V(q^2) - \frac{q^2}{4M^2}G_M^V(q^2)\right] \quad (6)$$

$$\xi F_V^2(q^2) = \left(1 - \frac{q^2}{4M^2}\right)^{1}\left[G_M^V(q^2) - G_E^V(q^2)\right]. \quad (7)$$

The electromagnetic form factors are determined from electron scattering experiments:

UPDATE: Replace by $G_E^V = G_E^P - G_E^N$

$$G_E^V(q^2) = \frac{1}{\left(1 - \frac{q^2}{M_V^2}\right)^2} \qquad G_M^V(q^2) = \frac{1 + \mu_p - \mu_n}{\left(1 - \frac{q^2}{M_V^2}\right)^2}.$$

UPATE: Replace by $G_M^V = G_M^P - G_M^N$

The situation is slightly more complicated for the hadronic axial current. $F_A(q^2 = 0) = -1.261 \pm .004$ is known from neutron beta decay. The q^2 dependence has to be inferred or measured. By analogy with the vector case we assume the same dipole form:

$M_A = 1.032 \pm .036$ GeV [7].

$$F_A(q^2) = \frac{-1.23}{\left(1 - \frac{q^2}{M_A^2}\right)^2}. \quad (9)$$

$Q^2 = -q^2$

g_A, M_A need to Be updated

$$F_P(q^2) = \frac{2M^2 F_A(q^2)}{M_\pi^2 - q^2}. \quad (10)$$

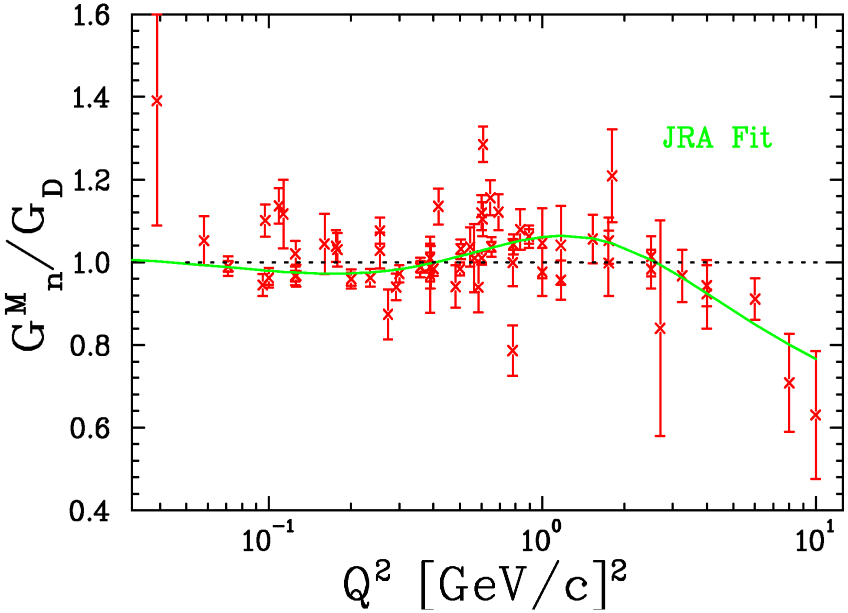
Fp important for Muon neutrinos only at Very Low Energy

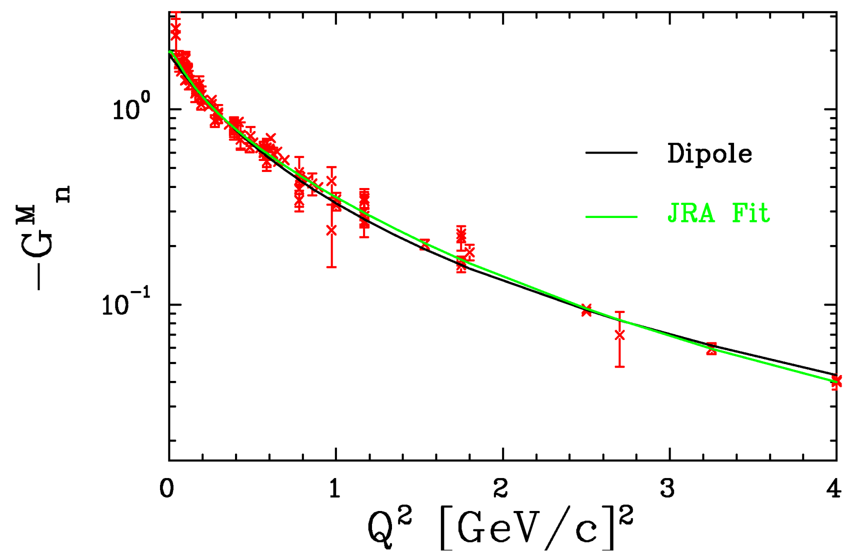
The inclusion of F_P leads to an approximately 5% reduction in both the ν_τ and ν_τ quasi-elastic cross sections. The only remaining parameters needed to describe the quasi-elastic cross section are thus M_V and M_A. $M_V = .71$ GeV, as determined with high accuracy

From C.H. Llewellyn Smith (SLAC). SLAC-PUB-0958 Phys.Rept.3:261,1972

Neutron G_M^N is negative

Neutron (G_M^N / $G_M^{N\ dipole}$)
Our fit





Neutron (G_M^N / $G_M^{N\ dipole}$)

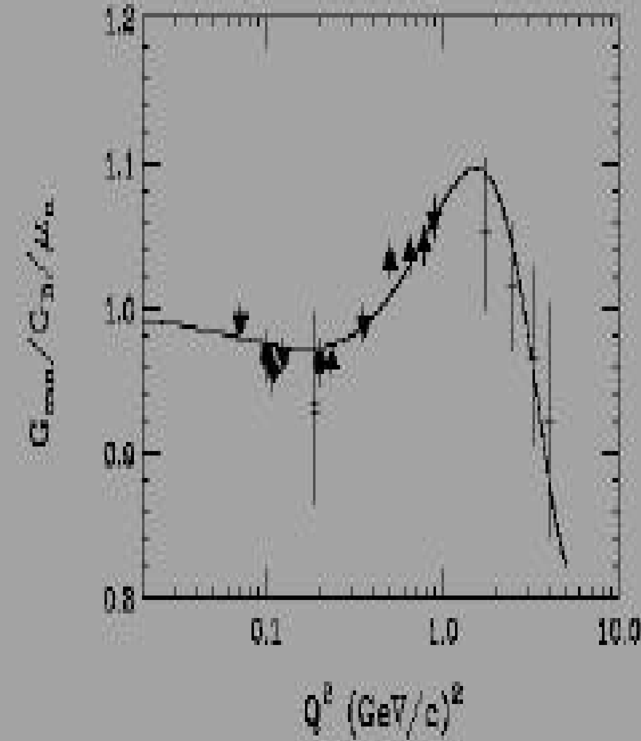


Fig. 2. The figure shows the continued fraction fit to the data. Symbols for the data as in figure 1) plus the data by Lung et al. (+) [23].

At low Q2 Our Ratio to Dipole similar to that nucl-ex/0107016 G. Kubon, et al Phys.Lett. B524 (2002) 26-32

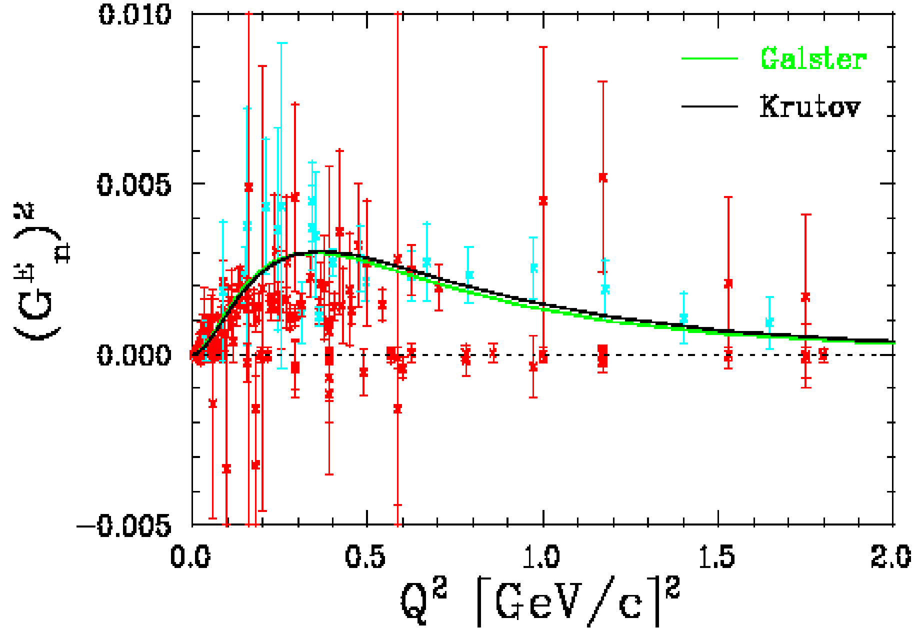
Earlier fit

$$G_{mn}(Q^2) = \frac{\mu_n}{1+\frac{Q^2 b_1}{1+\frac{Q^2 b_2}{1+\cdots}}} \quad (2)$$

show_gen_new.pict

Neutron, G_E^N is positive - Imagine N=P+pion cloud

Neutron G_E^N is positive New Polarization data gives Precise non zero G^E_N hep-ph/0202183(2002)



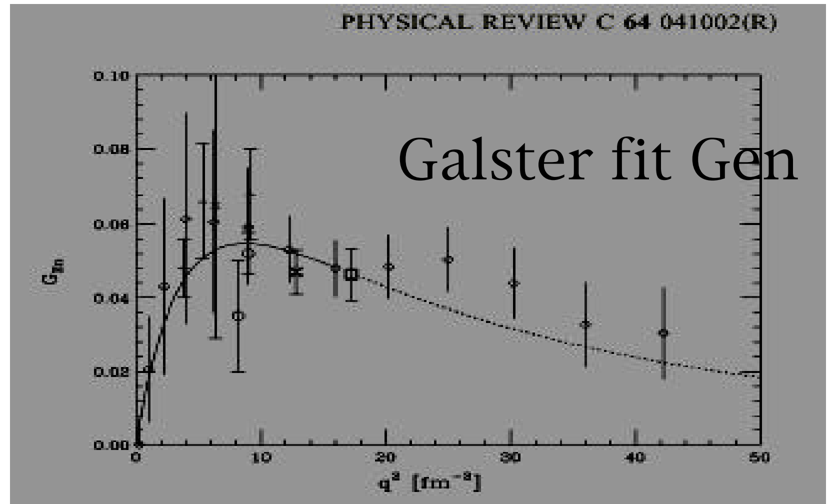
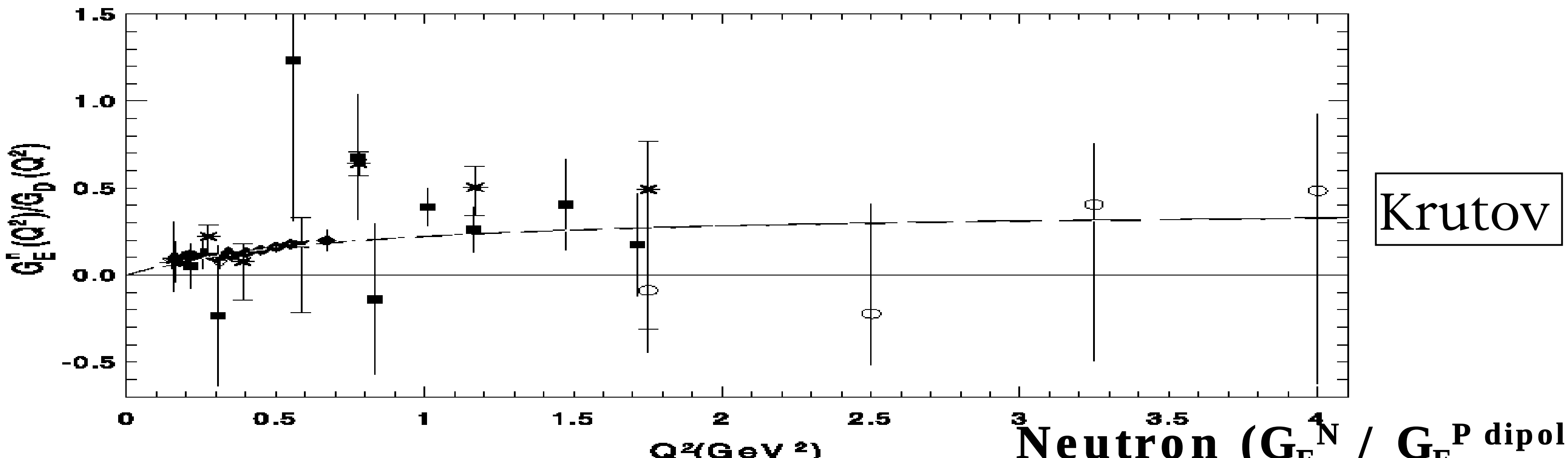
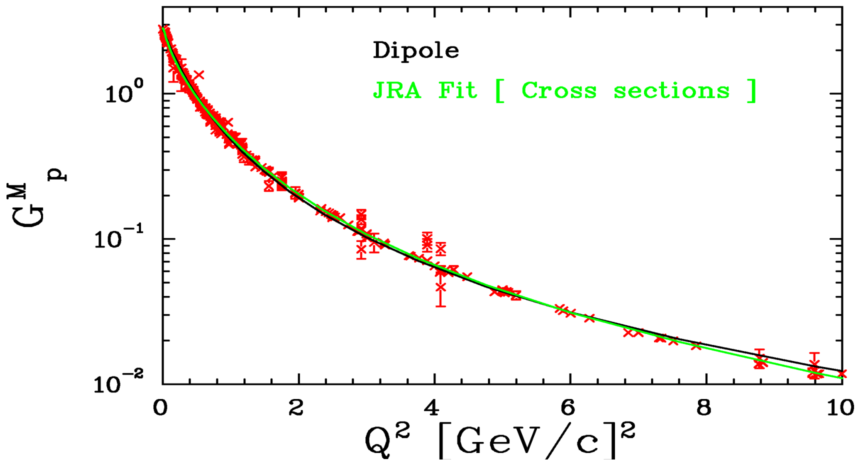


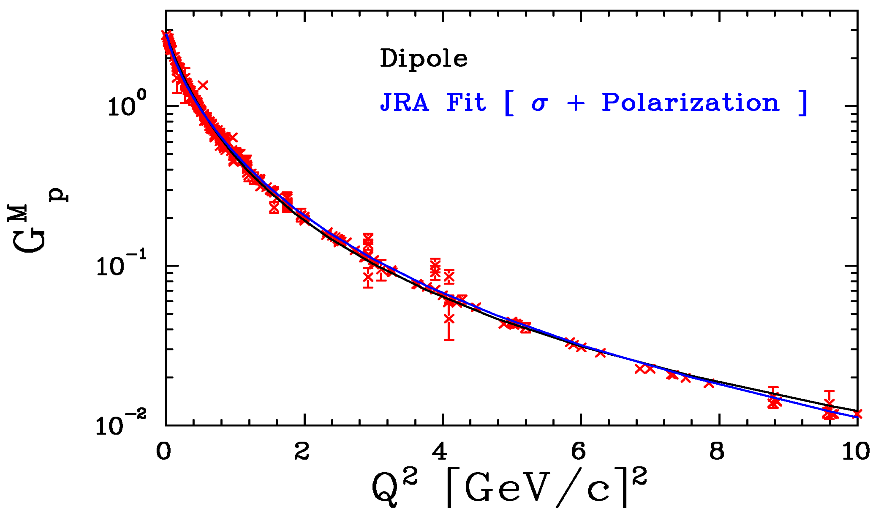
FIG. 3. The G_{En} extracted from the $C2$ data (◇). Also shown are the values obtained from double-polarization experiments, and the Galster parametrization with its extrapolation into the region not covered by previous experiments (dotted line).



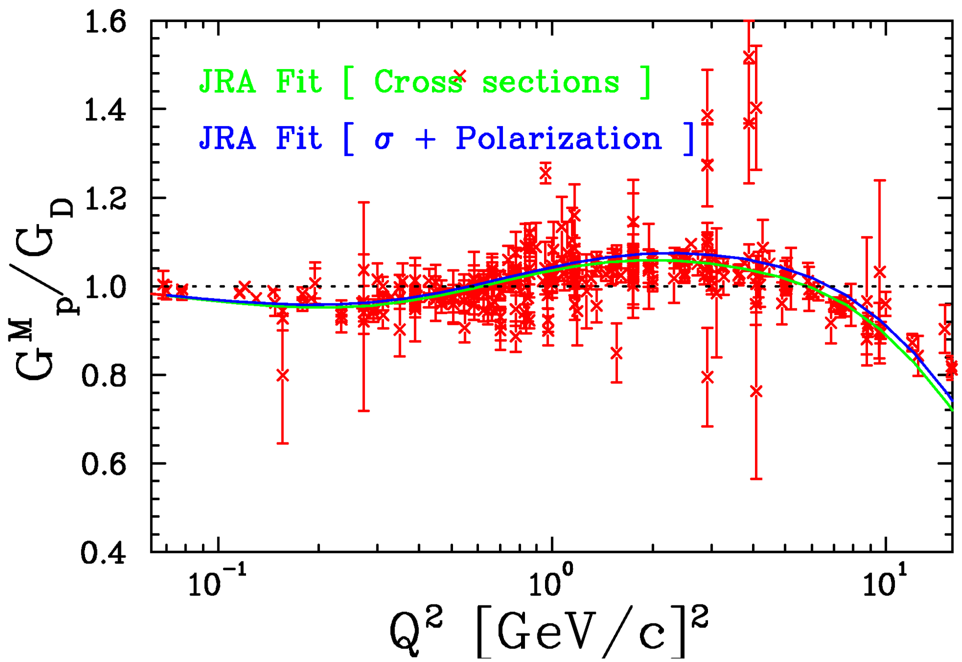
Neutron (G_E^N / $G_E^{P\ dipole}$)

Extract Correlated Proton G_M^P , G_E^P simultaneously from e-p Cross Section Data with and without Polarization Data



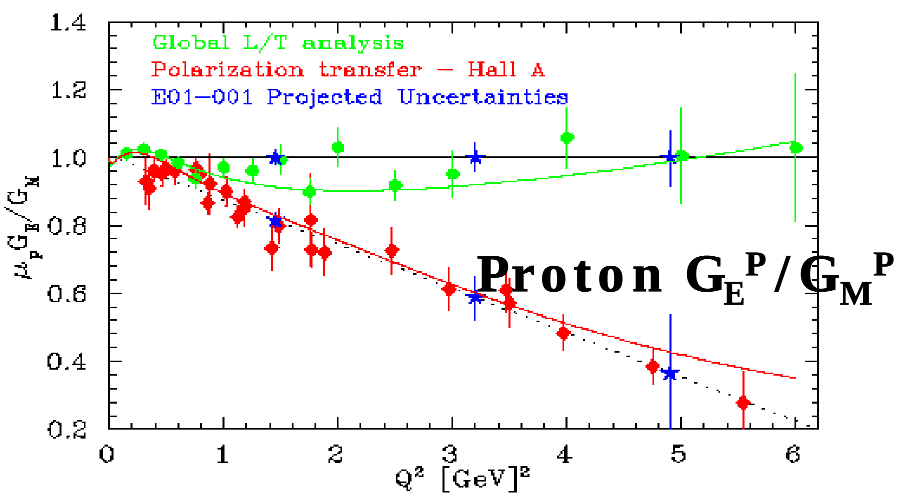


Proton G_M^P / G_M^P -DIPOLE



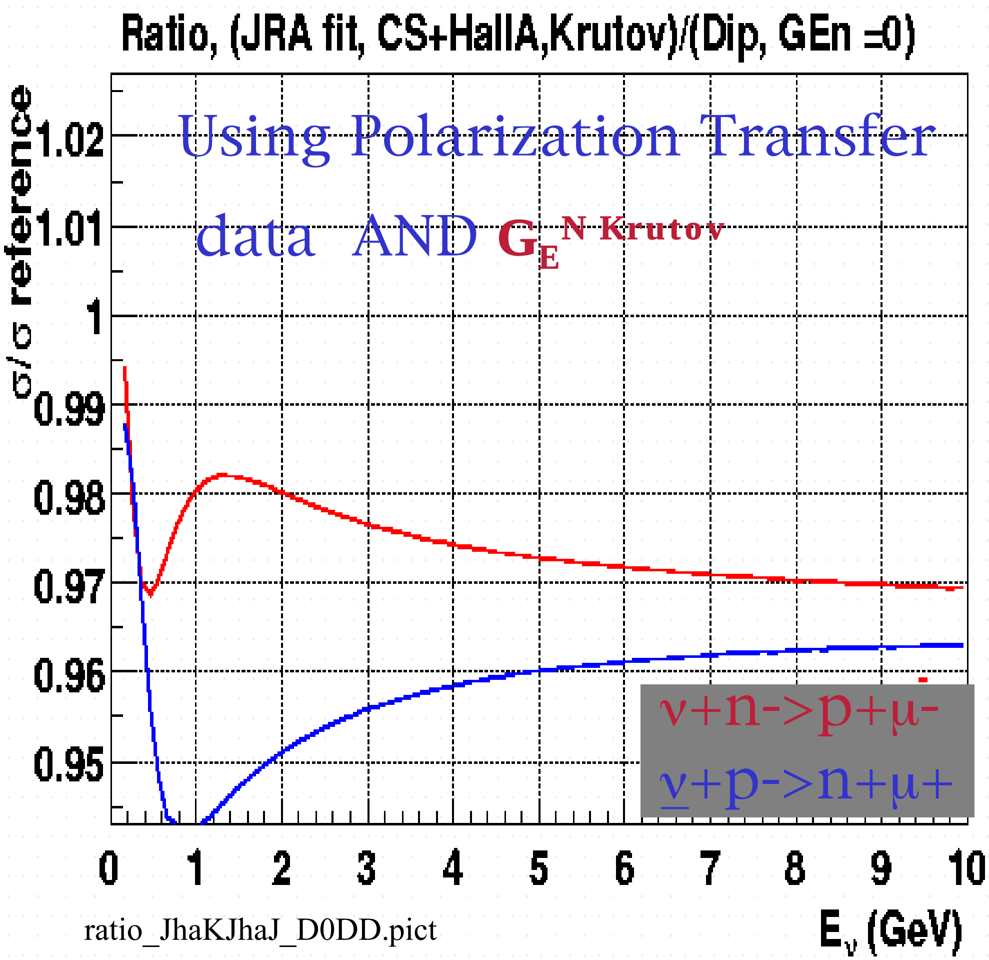
Proton G_M^P

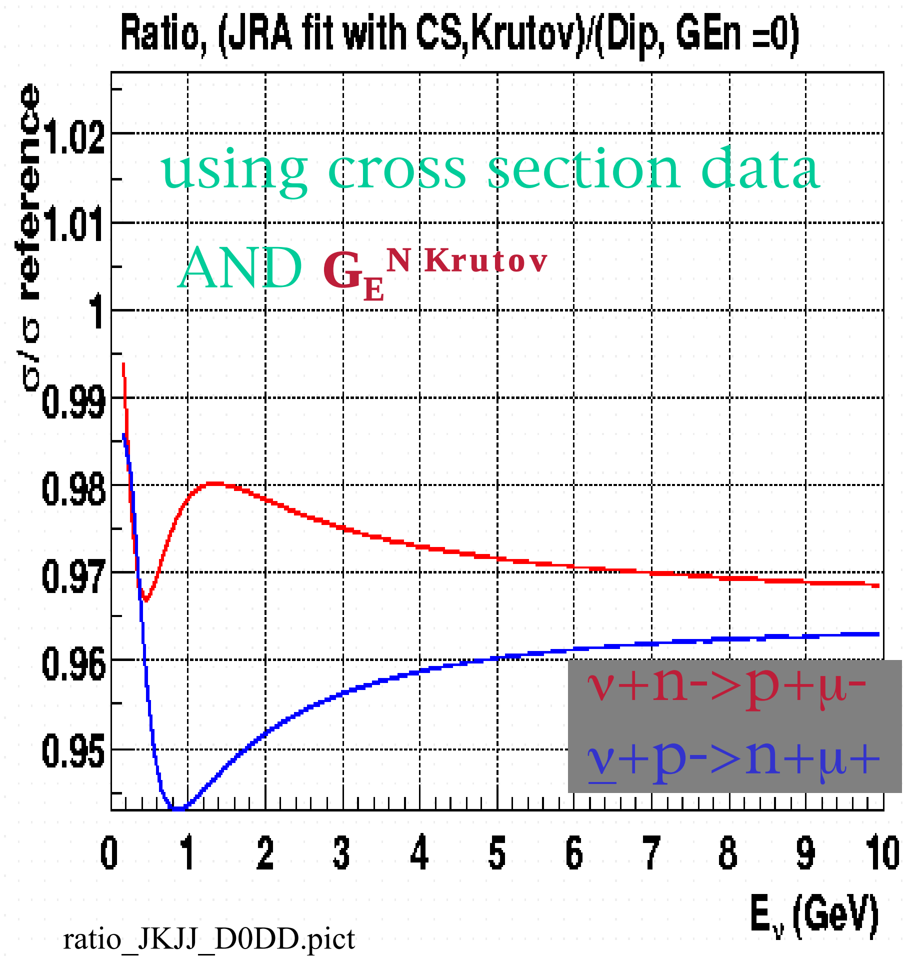
Compare Rosenbluth Cross section Form Factor Separation Versus new Hall A Polarization measurements



Effect of G_M^N + (G_M^P, G_E^P using POLARIZATION data AND non zero G_E^N Krutov) - Versus Dipole Form

-> Discrepancy between G_E^P Cross Section and Polarization Data Not significant for Neutrino Cross Sections





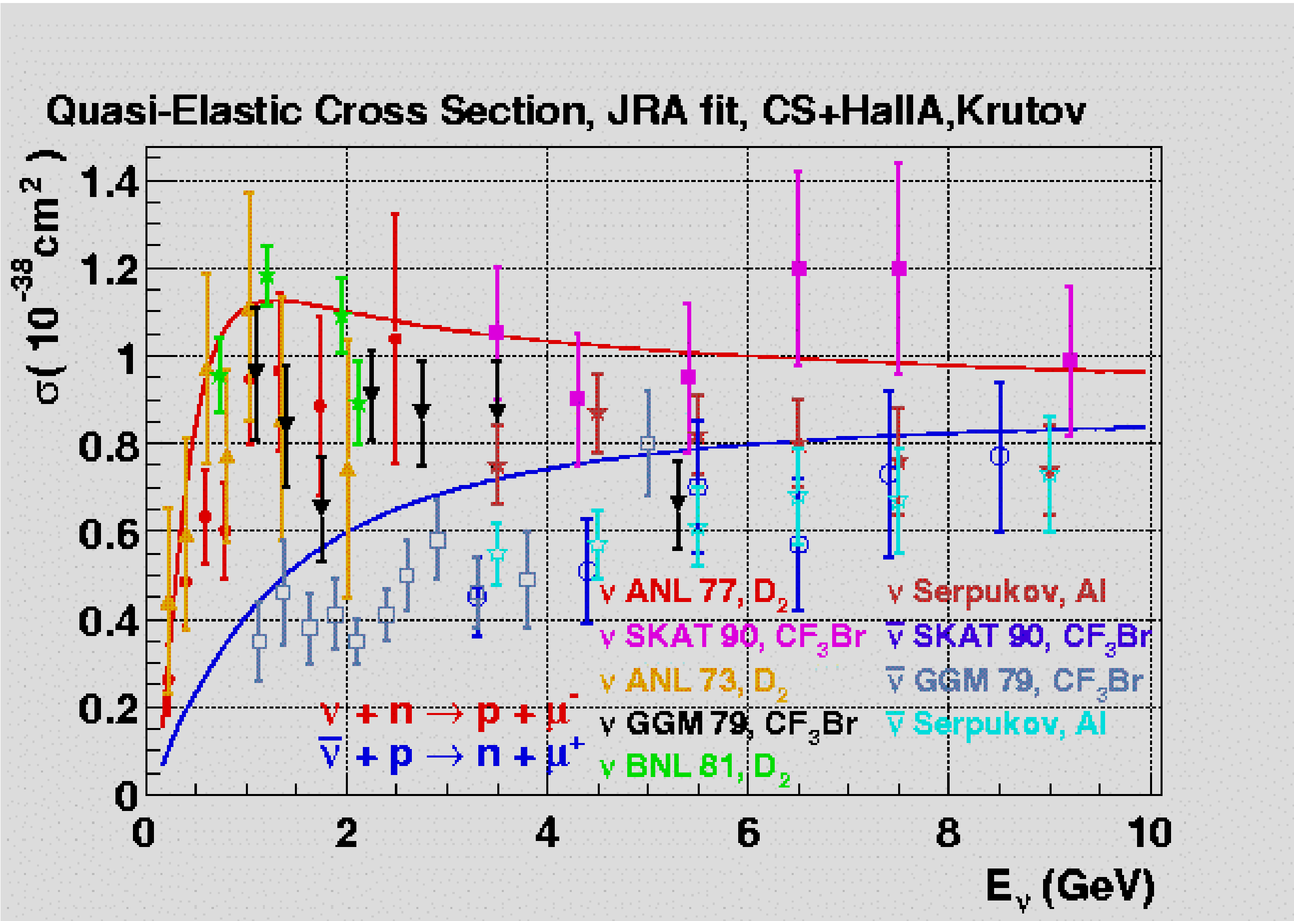
G_M^P, G_E^P extracted with both e-p Cross section and Polarization data

G_M^P, G_E^P extracted With e-p Cross Section data only

σ quasi-elastic neutrinos on Neutrons-(- Calculated

σ quasi-elastic Antineutrinos on Protons - Calculated

From H. Budd -U of Rochester (NuInt02) (with Bodek and Arrington) DATA - FLUX ERRORS ARE 10%



Even with the most

Up to date

Form Factors

The agreement

With data is ***not spectacular***

Antineutrino data mostly on nuclear targets- ***Nuclear Effects are important***

Reanalysis of

PARTICLES AND FIELDS

Experiment 1

F

HIRD SERIES, VOLUME 26, NUMBER 3 — 1 AUGUST 1982

Study of the reaction $\nu_\mu d \to \mu^- p p_s$

K. L. Miller,* S. J. Barish,† A. Engl
Carnegie-Mellon University, P

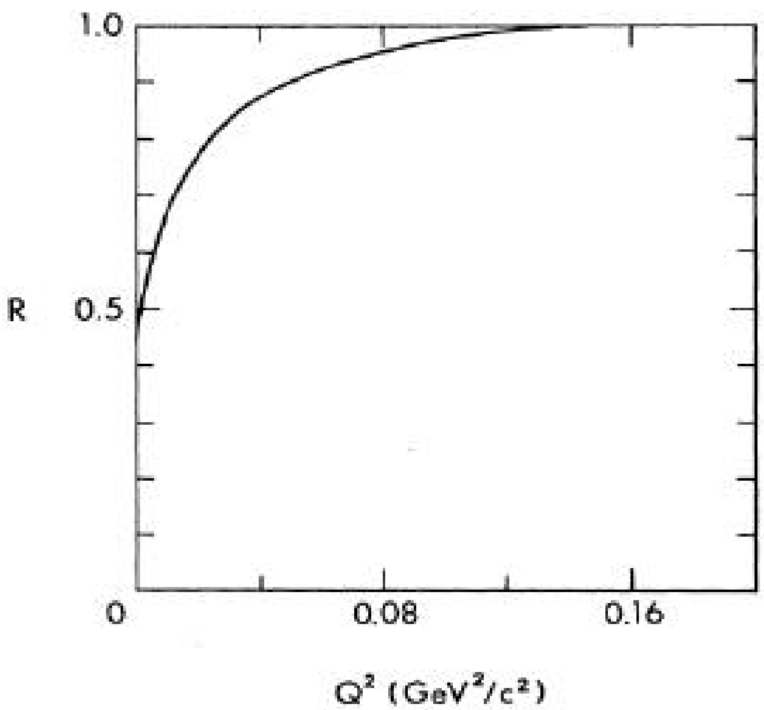


FIG. 3. Deuterium correction factor $R(Q^2)$.

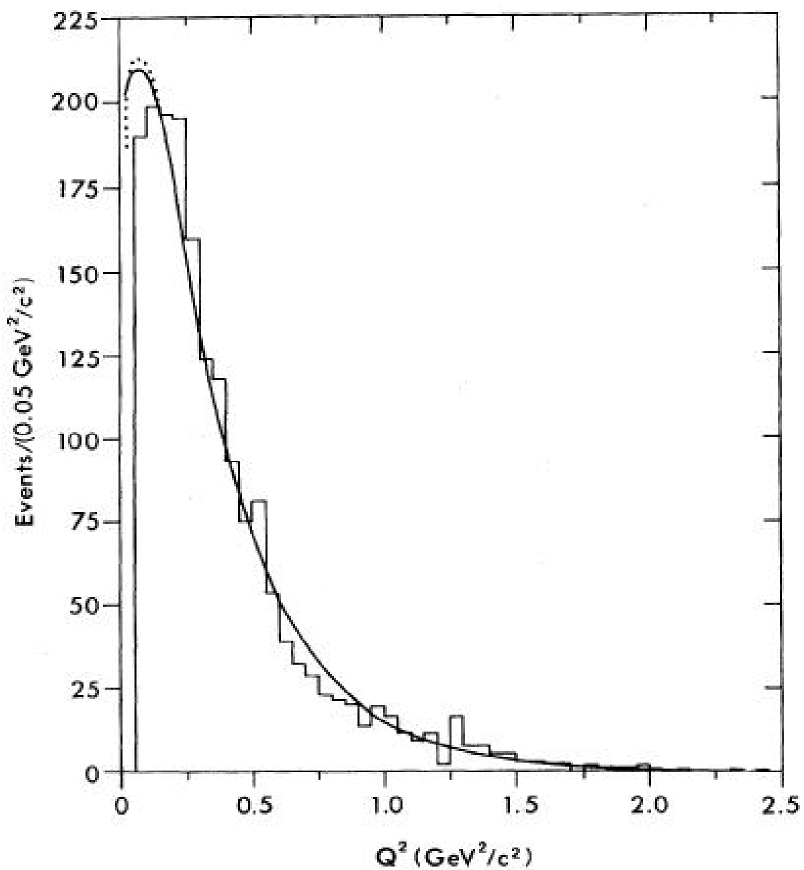


FIG. 4. Weighted Q^2 distribution. The solid curve is from a maximum-likelihood fit to the dipole model ($M_A = 1.00$ GeV/c^2). The dotted curve is from a fit to the AVMD model ($M_A = 1.11$ GeV/c^2).

Arie

Experiment 1

STUDY OF THE REACTION $\nu_\mu d \rightarrow \mu^- p p_s$

TABLE I. Maximum-likelihood values of M_A (GeV/c^2) for each model.

	Monopole	Dipole	Tripole	QM-AVMD
Rate	0.45±0.11	0.74±0.12	0.95±0.16	0.69±0.26
Shape	0.57±0.05	1.05±0.05	1.38±0.06	1.25±0.17
Total	0.55±0.05	1.03±0.05	1.35±0.07	1.20±0.17
Flux independent	0.54±0.05	1.00±0.05	1.31±0.07	1.11±0.16

Type in their dσ/dQ2 histogram. Fit with our best

Knowledge of their parameters : Get M_A=1.118+-0.05

(A different central value, but they do event likelihood fit

And we do not have their the event, just the histogram.

If we put is best knowledge of form factors, then we get

M_A=1.090+-0.05 or ΔM_A= -0.028. So all their

Values for M_A. should be reduced by 0.028

Using these data we get ΔM_A to update to for latest ga+form factors.
(note different experiments have different neutrino energy Spectra, different fit region, different targets, so each experiment requires its own study).

A Pure Dipole analysis, with ga=1.23 (Shape analysis)

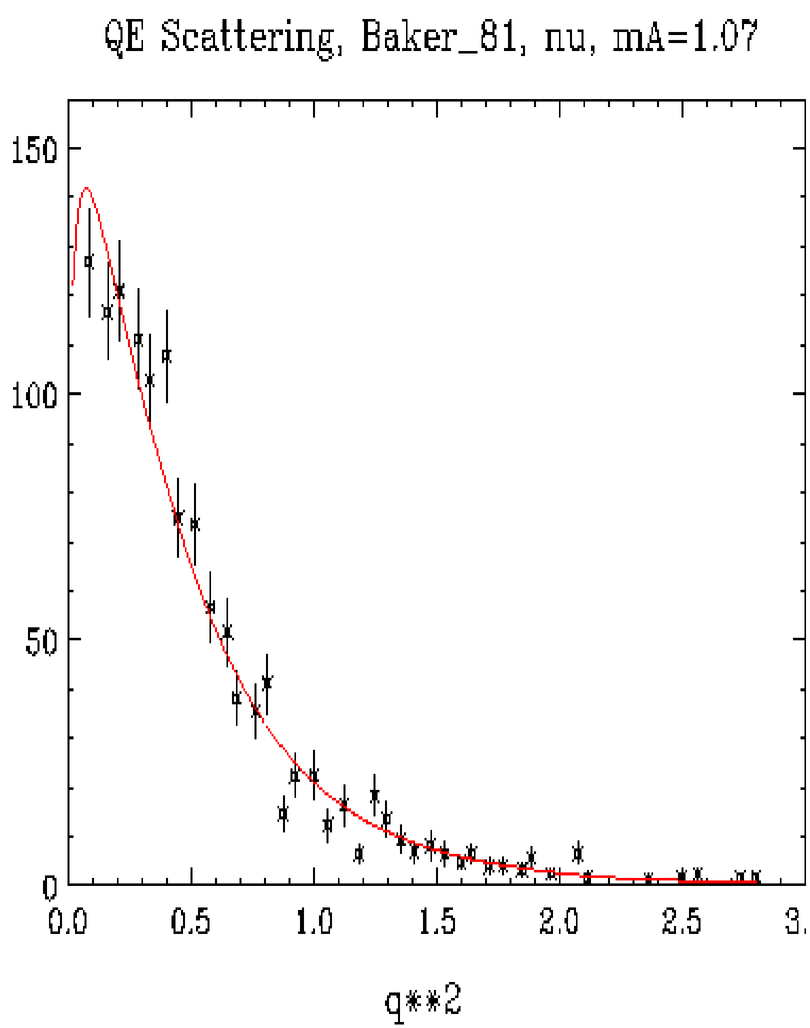
- if redone with best know form factors --> ΔM_A = -0.047

(I.e. results need to be reduced by 0.047)

for different experiments can get ΔM_A from -0.025 to -0.060

Miller did not use pure dipole (but did use Gen=0)

Experiment 2



Redo Baker 81 analysis

They quote M_A=1.07

We get with their assumptions

M_A=1.075 --> Agree

Best Form Factors versus What they used [(Olsson) and Gen=0]

Gives ΔM_A = -0.026

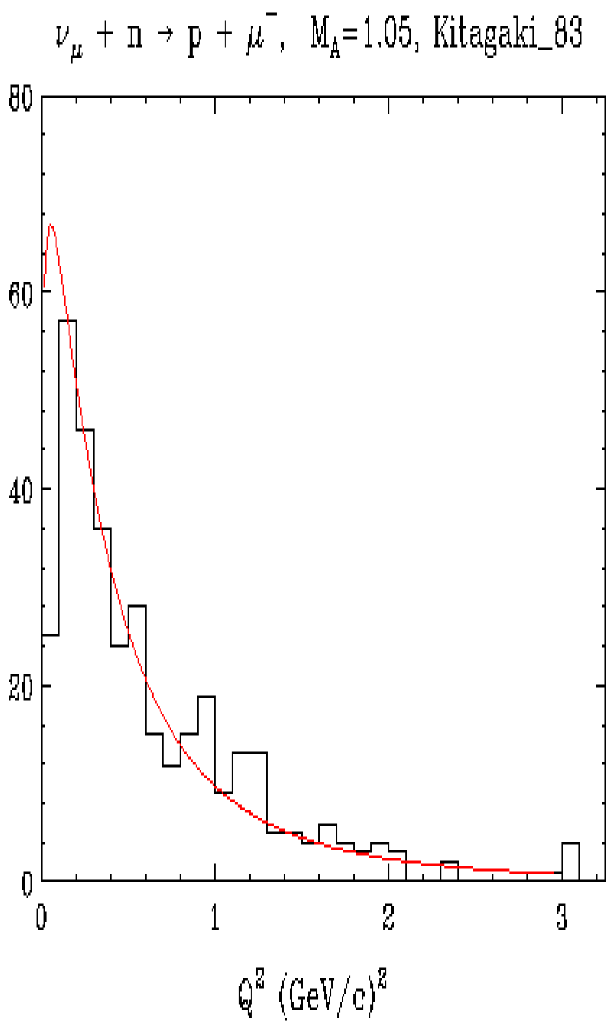
Best form factors versus

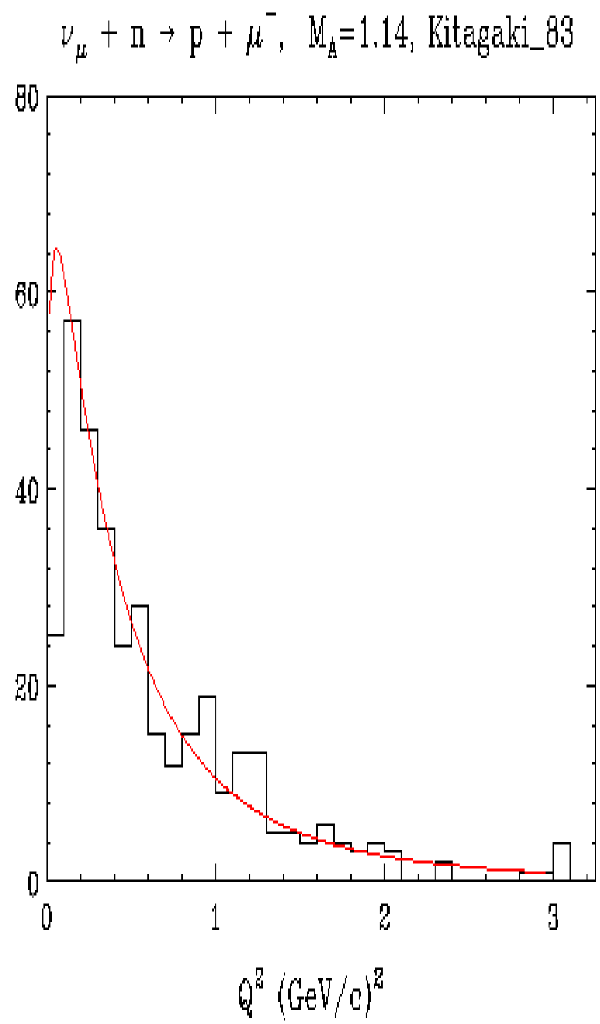
[pure Dipole and Gen=0]

Gives

Gives ΔM_A = -0.051

Experiment 3





Kitagaki paper gets

Ma=1.05+0.12-0.16

When we fit the Q2 spectra with their assumptions (Ollson) we get 1.14+-0.11

Difference between using

Their assumptions and best

Form factors and ga is that the

Answer will be changed by

-0.025 (smaller)

Difference between the Dipole form factors and the best form factors for this data is

-0.057

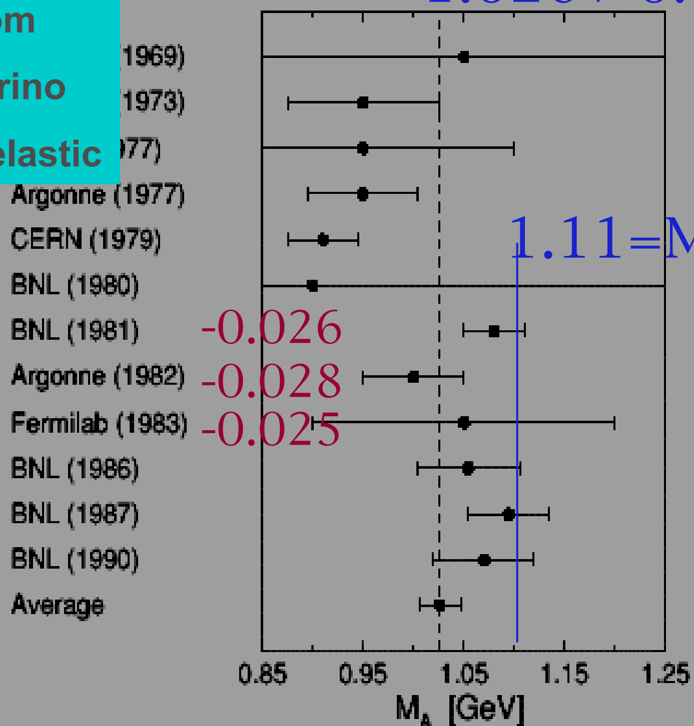
Axial structure of the nucleon

Hep-ph/0107088 (2001)

Véronique Bernard†, Latifa Elouadrhiri‡, Ulf-G Meißner§

$1.026{+-}0.021 = M_A$ average $1.069{+-}0.016$

From Neutrino quasielastic



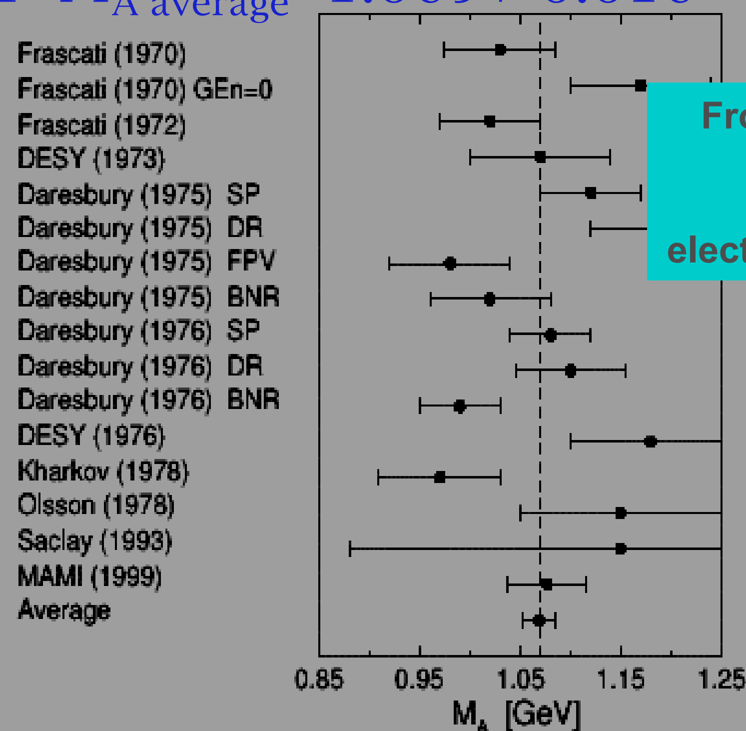
$1.11 = M_A$

-0.026

-0.028

-0.025

From charged Pion electroproduction



For updated M_A expt. need to be reanalyzed with new g_A, and G_E^N

Probably more correct to use $1.00{+-}0.021 = M_A$

Difference In Ma between Electroproduction And neutrino Is understood

and antineutrino scattering experiments. The weighted average is $M_A = (1.026 \pm 0.021)$ GeV. Right panel: From charged pion electroproduction experiments. The weighted average is $M_A = (1.069 \pm 0.016)$ GeV. Note that value for the MAMI experiment contains both the statistical and systematical uncertainty; for other values the systematical errors were not explicitly given. The labels SP, DR, FPV and BNR refer to different methods evaluating the corrections beyond the soft pion limit as explained in the text.

M_A from neutrino expt. No theory corrections needed

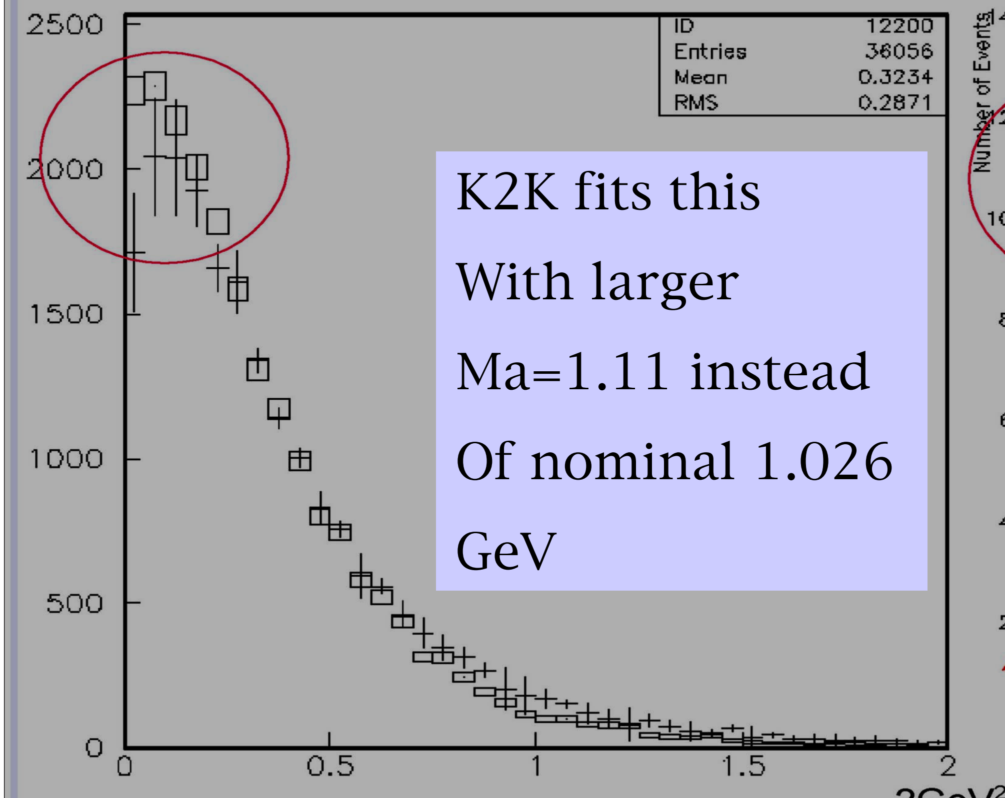
NuInt02- K2K USED DIPOLE FORM FACTORS

Low-Q2 suppression or Larger M_A?

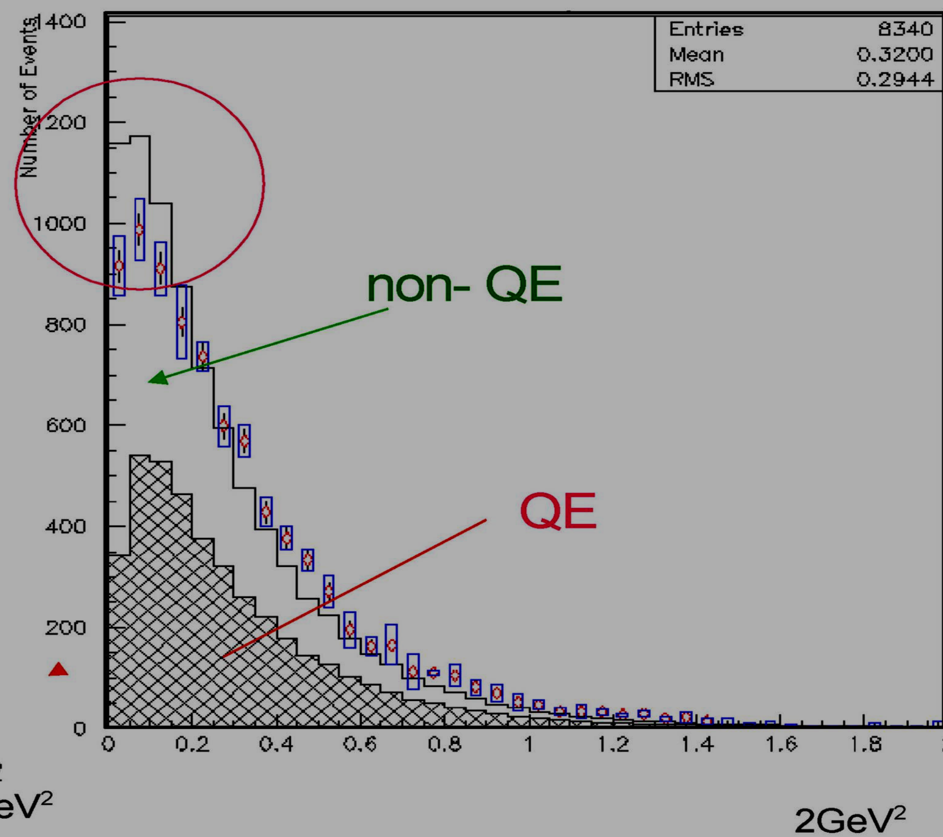
From Ito NuInt02 — 1kt

Q^2

T.Ishida's talk @NuInt01 — SciFi



K2K fits this
With larger
Ma=1.11 instead
Of nominal 1.026
GeV

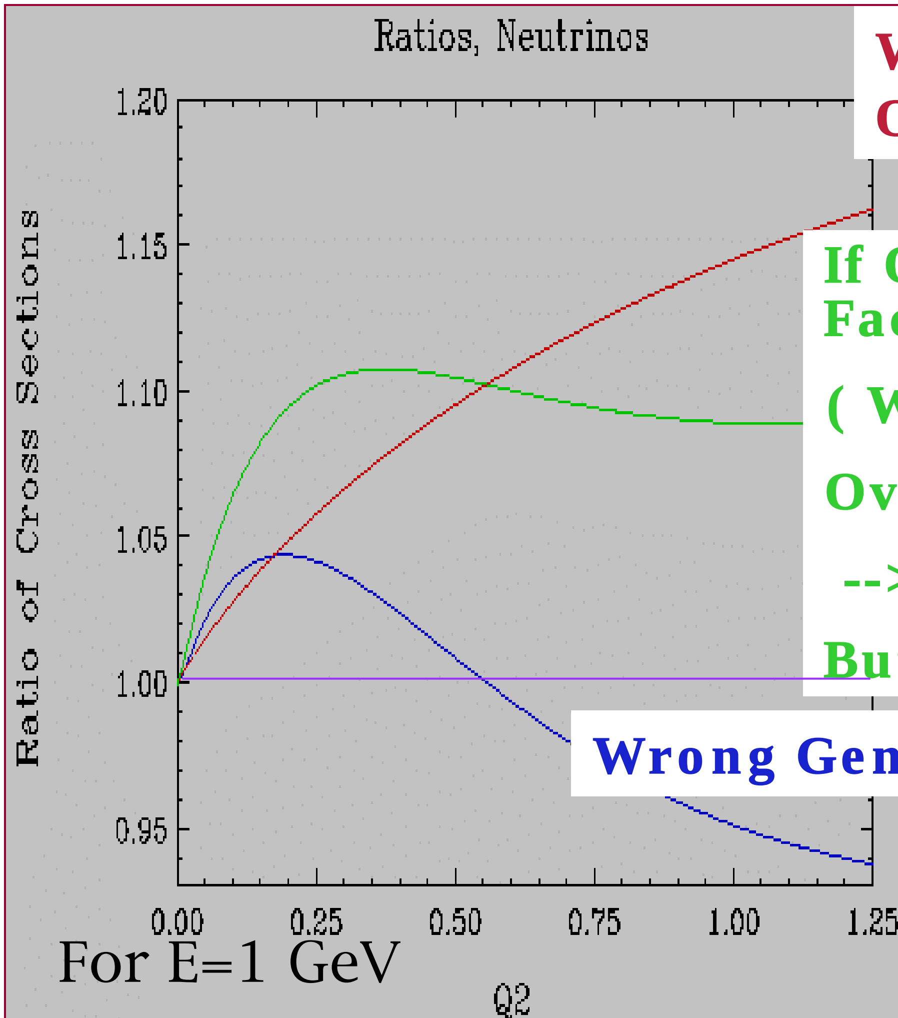


* Errors shown here is an energy scale error (±5%)
* Nuclear binding energy is not taken into account..

* Errors shown here is a typical energy scale error (±3%).
* Nuclear binding energy B = - 30MeV (for Oxygen) is taken into account.

Reason - Neutrino Community Using Outdated Form Factors

Effect is Low Q2 suppression from non Zero Gen



Wrong Ma=1.1 (used by K2K)
Over Ma=1.02 (Ratio)

If One Uses Both wrong Form Factors (used in K2K MC)

(Wrong Gen =0 +Wrong Ma=1.1)

Over Best Form Factors (Ratio)

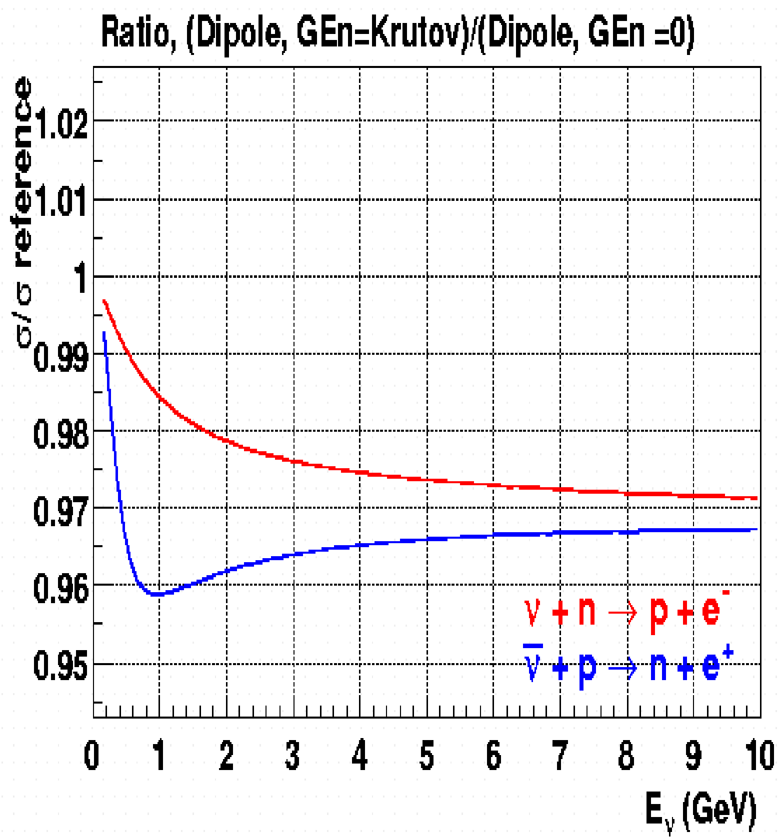
--> Get right shape

But wrong normalization of 10%

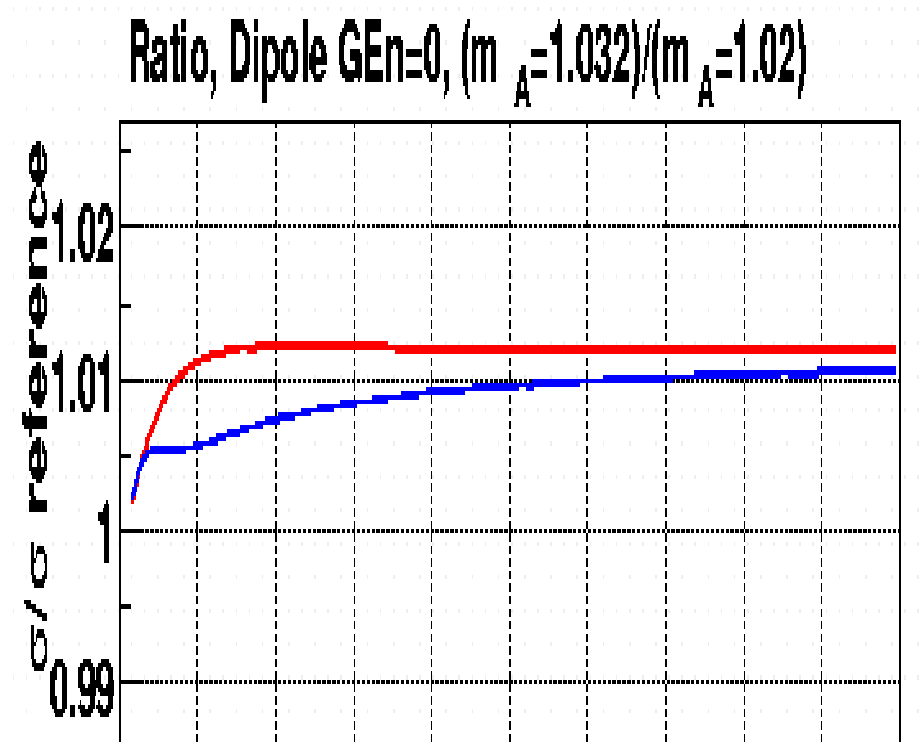
Wrong Gen /Best Form Factors (Ratio)

Can fix the Q2 dependence either way, but the overall **cross sections will be 14% too high if one chooses wrong.**

Gen (right)/Gen=0 (wrong) gives 6% lower cross section



Wrong Ma=1.1 (used by K2K) Over Ma=1.02 (Ratio) gives 8% higher cross Section (1% for each 0.01 change in Ma



A re-analysis of previous neutrino data on nucleons and nuclei is under way (Bodek, Budd). On average Ma is reduced by 0.026 ----> In addition to improved Ma, There are Indications that just like the Simple dipole form is only an approximation to vector Form factors (the axial form factors may not be best described by a simple dipole (which is expected for a pure exponential charge distribution) - Problem, with some experiments we reproduce their central value, with others we do not -> Why?

Future improvements in Quasi-elastic, Resonance, DIS

1. New Better data - NUMI Near Detector Proposal - MINERVA

   (McFarland, Morfin (Rocheser-Fermilab) Spokespersons)

2. Combined with new data on nucleons and nuclei at Jlab.

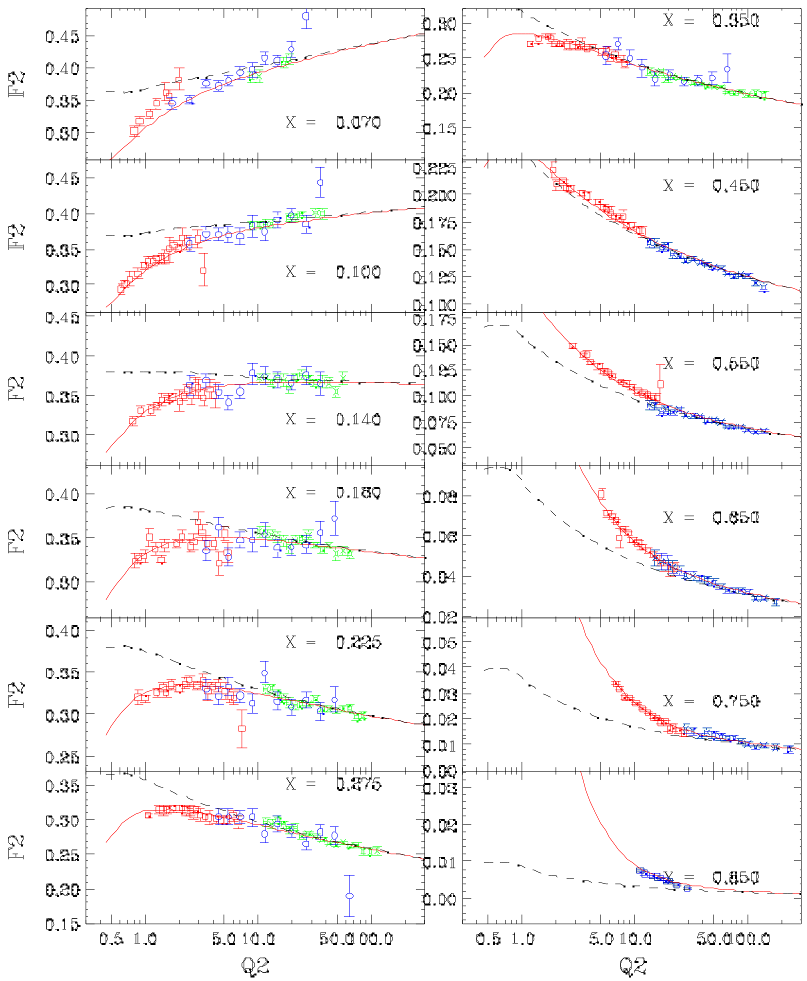
   A. New Jlab experiment E03-110 - Bodek, Keppel (Rochester, Hampton) Spokespersons. (also previous Jlab data)

   B. Jlab Quasielastic data (nucleons/nuclei) - John Arrington (Argonne)

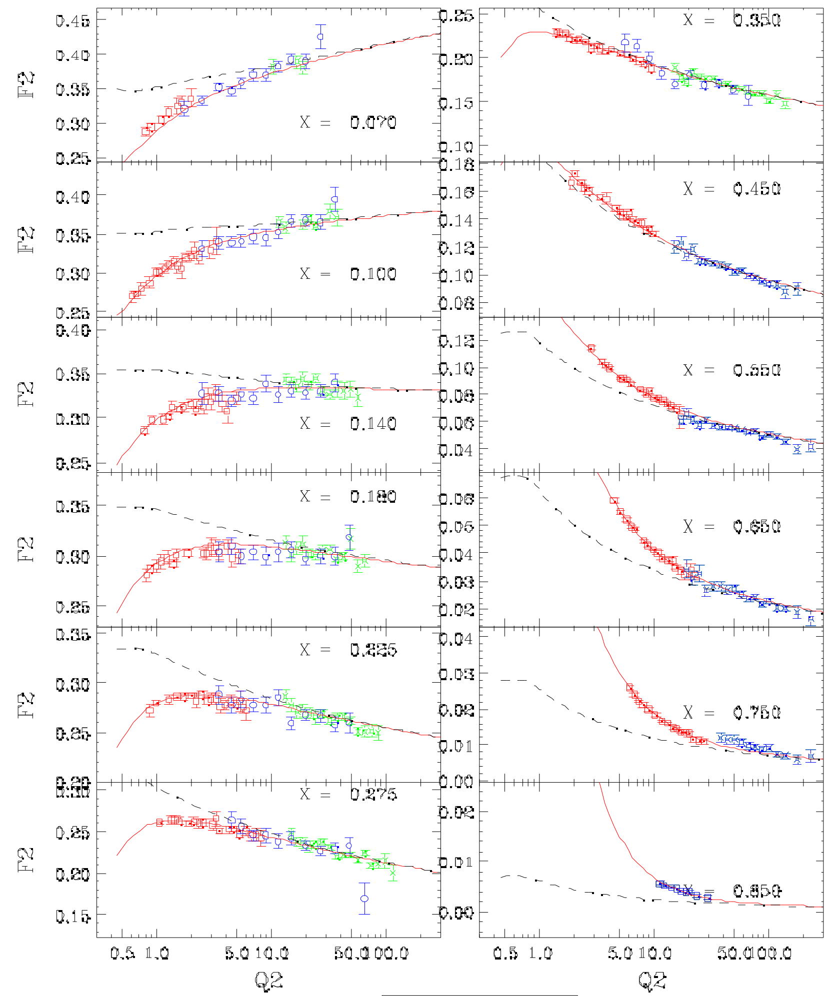
Backup Slides

Comparison with DIS F_2 (H, D) data [ξ_w fit]

[SLAC/BCDMS/NMC]

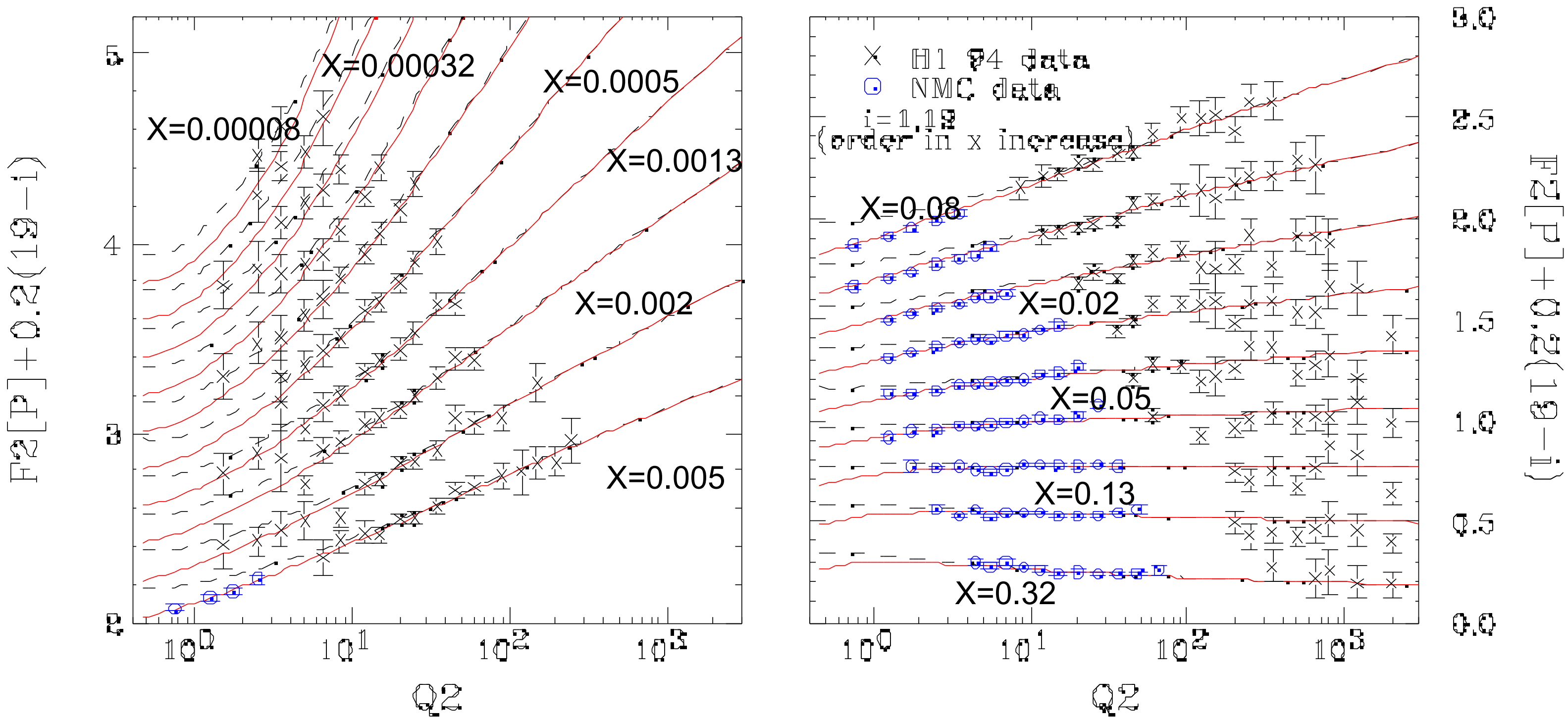


Proton



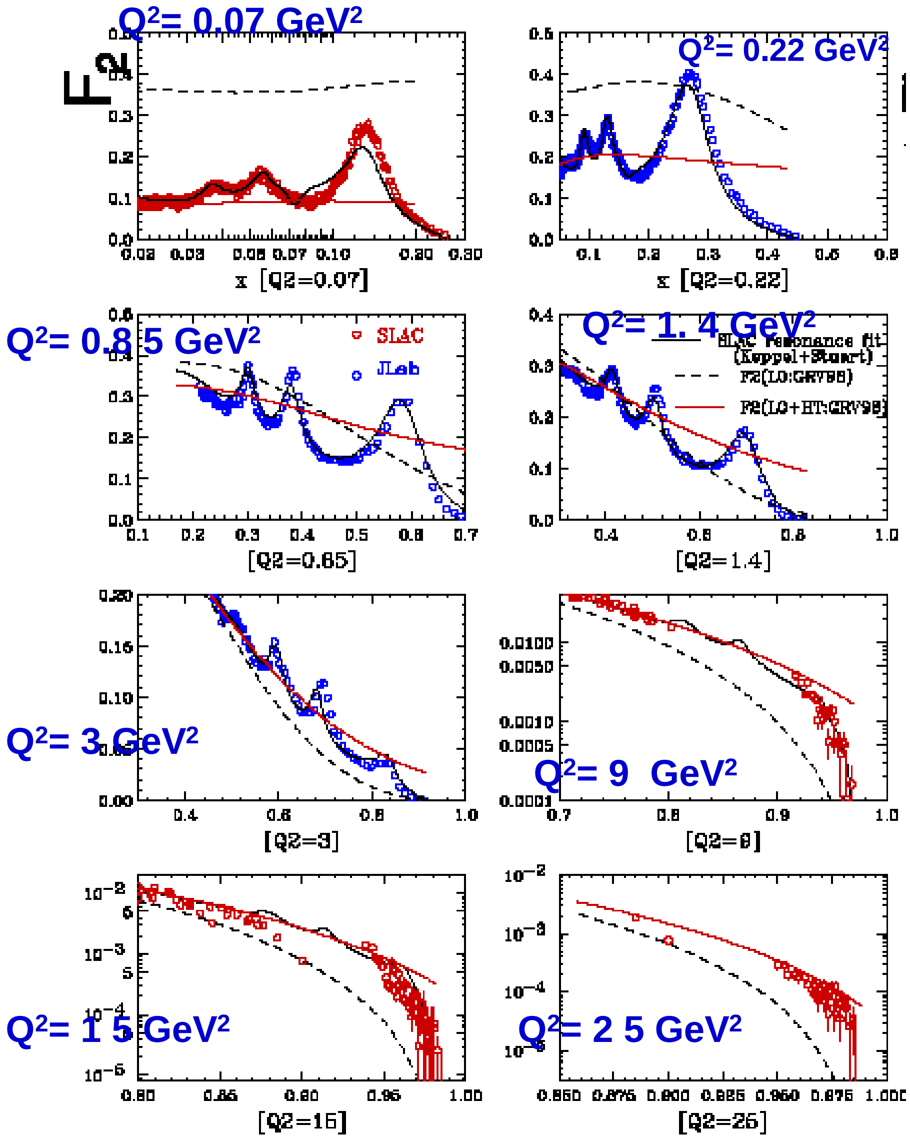
Deuteron

Low x HERA/NMC data [ξ_w fit]



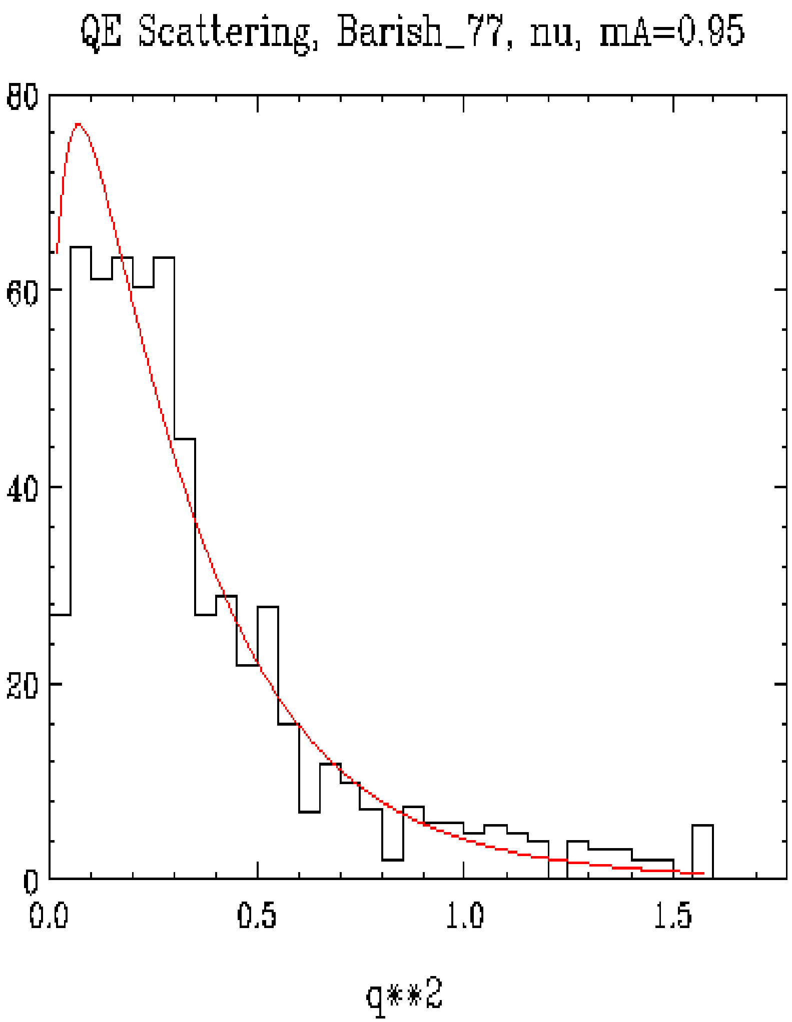
Comparison with F2 resonance data

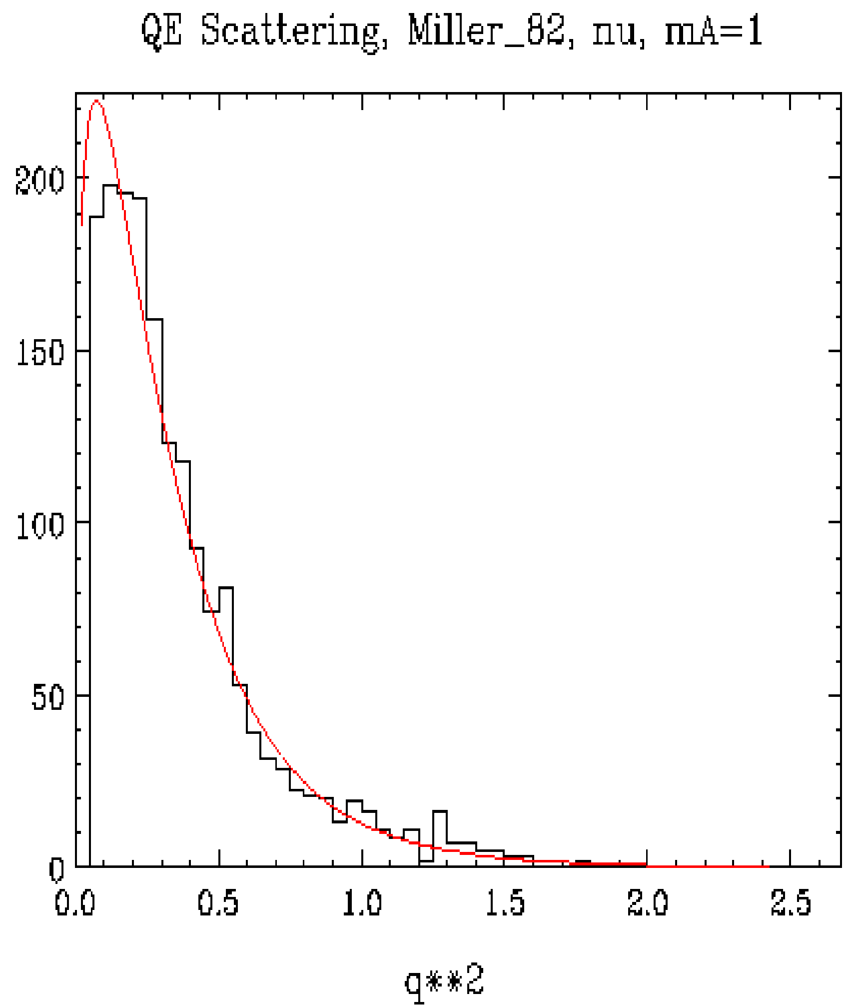
[SLAC/ Jlab] (These data were not included in this ξw fit)



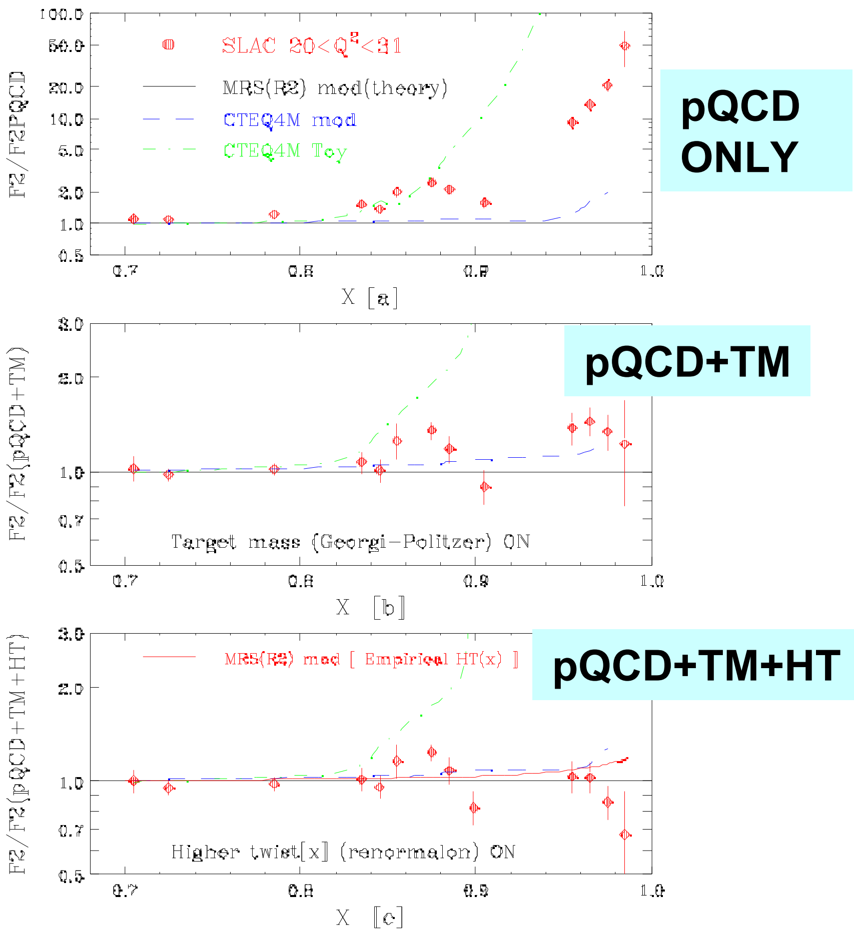
- **ξw fit**
- **The modified LO GRV98 PDFs with a new scaling variable, ξw describe the SLAC/Jlab resonance data very well (on average).**
  - **Even down to $Q^2 = 0.07$ GeV²**
  - **Duality works: The DIS curve describes the average over resonance region (for the First resonance works for $Q^2 > 0.8$ GeV²)**

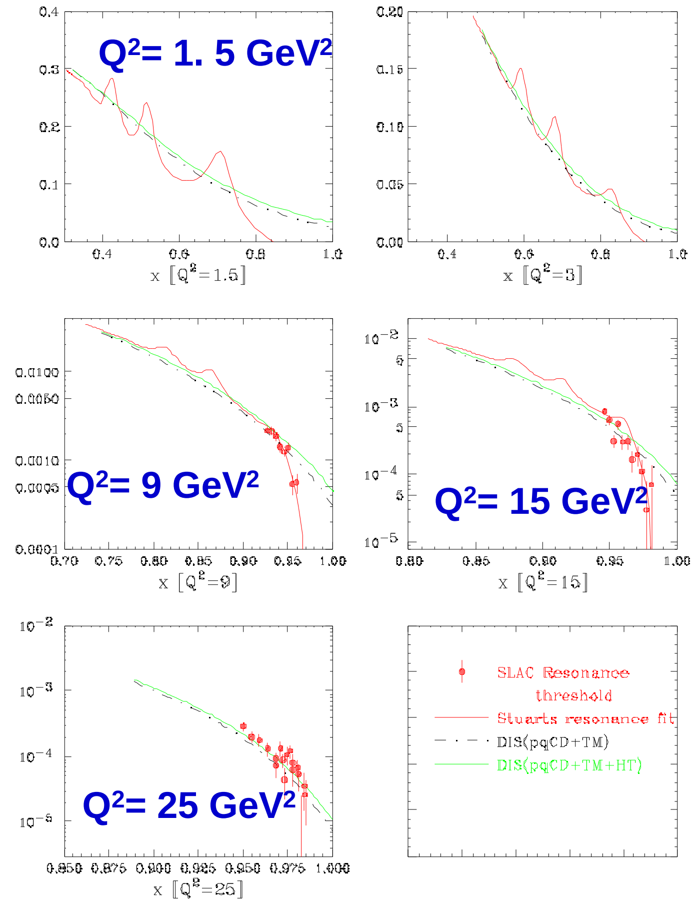
❖ **These data and photo-production data and neutrino data can be used to get A(W,Q2).**


QE Scattering, Barish_77, nu, mA=0.95
80
60
40
20
0
0.0
0.5
1.0
1.5
q**2


QE Scattering, Miller_82, nu, mA=1
200
150
100
50
0
0.0
0.5
1.0
1.5
2.0
2.5
q**2

Very high x F2 proton data (DIS + resonance)





pQCD+TM+HT

NLO pQCD + TM + higher twist describe very high x DIS F_2 and resonance F_2 data well. (duality works)