A Unified Model for DIS e/ν-N Cross Sections at all Q^2

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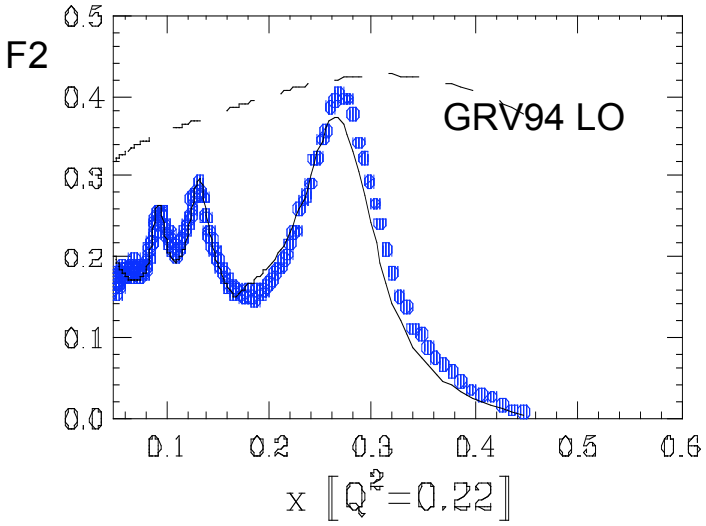
A model for all Q^2 region?

- The high energy region of neutrino (or charged lepton)-nucleon scatterings is well understood in terms of quark-parton model by a series of e/μ/ν DIS experiments
- But the low energy region is relatively poorly understood, especially, in neutrino scattering: many interesting issues for nuclear physics, neutrino physics, and even hadron collider physics communities
  - PDFs at high x?
  - Non-perturbative QCD? (target mass, higher twist effects)
  - Duality works for resonance region? (DGLAP evolution?)
  - Axial vector contribution?
  - Nuclear effects?
- Can we build up a model for all Q2 region?

Challenges

- A model to describe all Q^2 region from high down to very low energies for charged lepton and neutrino scatterings
  [DIS, resonance, even photo-production(Q^2=0)]
  - Resonance region is overlapped with a DIS contribution
  - Hard to extrapolate DIS contribution to low Q^2 region from high Q^2 data, because of non-perturbative QCD effects.



- A model in terms of quark-parton model (easy to convert charged lepton scattering to neutrino scattering)
  - Understanding of high x PDFs at low Q^2? wealthy 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 shows that..

  [Ref:PRL 82, 2467 (1999) by Bodek and Yang]

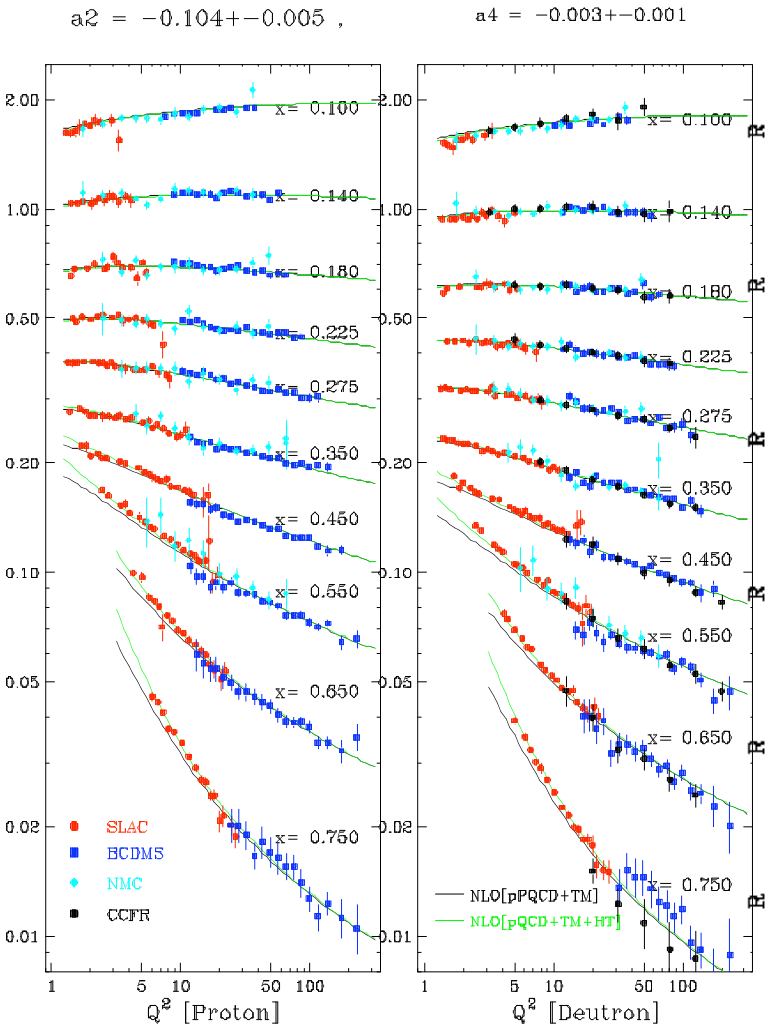
  - Kinematic higher twist (target mass) effects are large, and must be included in the form of Georgi & Politzer ξ scaling.
  - Dynamic higher twist effects (multi-quark correlation etc) are smaller, but need to be included.
  - Very high x(=0.9) region is described by NLO pQCD with target mass + higher twist effects, (better than 10%).
  - Resonance region is also well described (duality works).

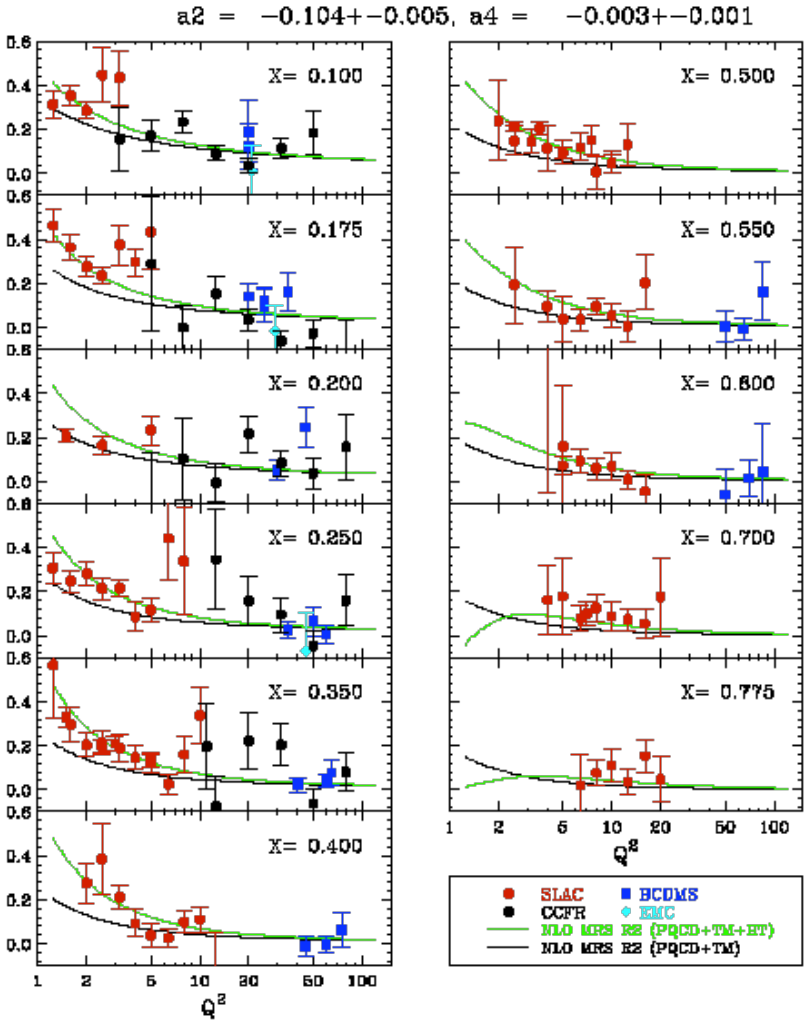
- Most of dynamic higher twist corrections (in NLO analysis) are similar to missing NNLO higher order terms. [Ref:Eur. Phys. J. **C13**, 241 (2000)]

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

Comparisons with NLO pQCD+TM+Higher Twist

F2



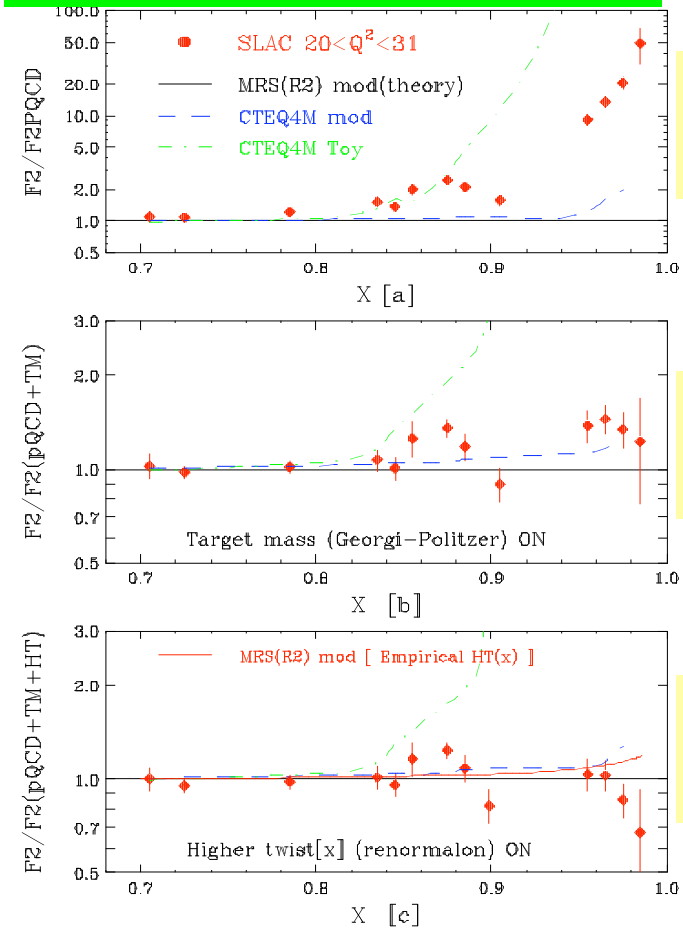


R

The data are well described by the predictions

Very high x F_2 proton data (DIS + resonance)

SLAC high x data/theory

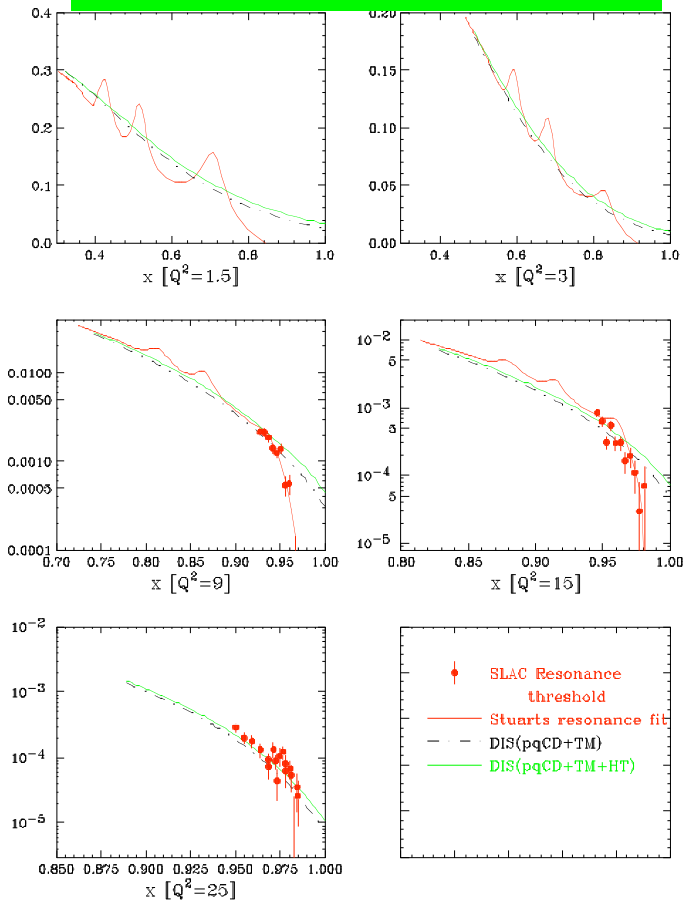


pQCD only

pQCD +TM

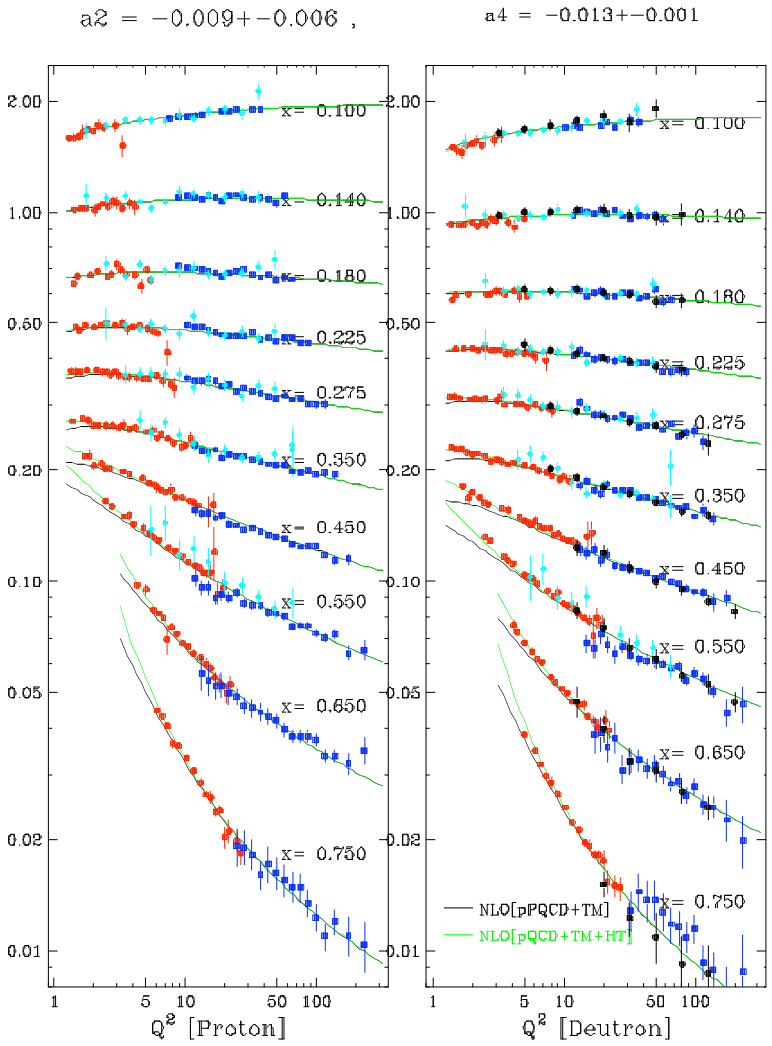
pQCD +TM+HT

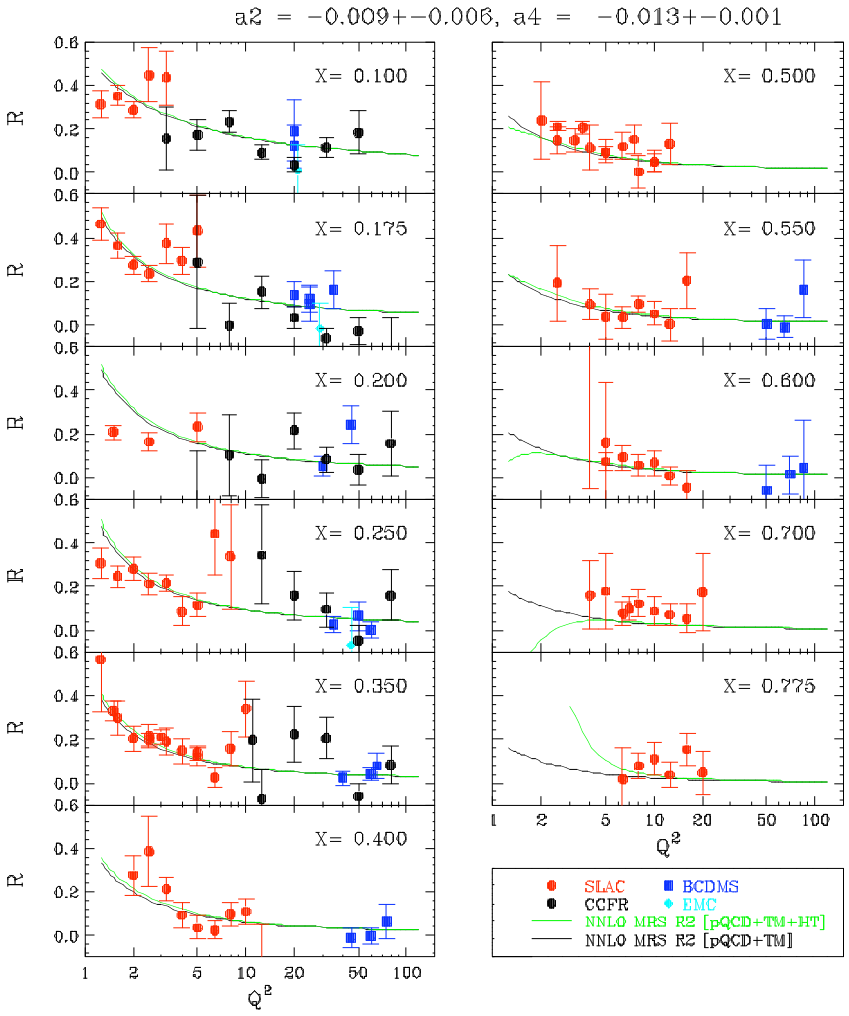
SLAC resonance data



The data are well described by the predictions (duality works!)

F2, R comparison with NNLO pQCD+TM



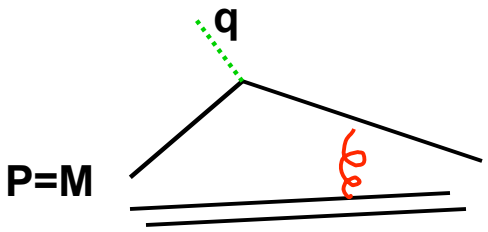


Size of the higher twist effect with NNLO analysis is really small (a2=-0.009(NNLO) vs –0.1(NLO)

Pseudo NLO approach

Original approach (NNLO pQCD+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 even missing higher orders



m_f=M*
(final state interaction)

resonance, higher twist, and TM

$$\xi_W = \frac{Q'^2}{Mv[1+\sqrt{(1+Q^2/v^2)}]},$$

$$\text{where } 2Q'^2 = (Q^2 + m_f^2 - m_i^2)$$

$$+\sqrt{(Q^2 + m_f^2 - m_i^2)^2 + 4Q^2(m_i^2 + P_t^2)}$$

$$\xi_W = \frac{Q^2 + B}{\{Mv[1+\sqrt{(1+Q^2/v^2)}] + A\}}$$

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

B: final state mass m_f^2 , Δm^2, and photo-protduction

Early Fits (2001)

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
   - **$Xw = [Q^2+B] / [2M\nu+A]$**
     used in 1972
   - **$\xi_w = [Q^2+B] / [M\nu\,(1+(1+Q^2/\nu^2)^{1/2}) + A]$**
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 $Q^2 = 0.25\text{GeV}^2$
   - $F_2(x, Q^2 < 0.25) = Q^2/[Q^2+C]\ F_2(Xw, Q^2=0.25)$

➢ Do a fit to SLAC/NMC/BCDMS H, D

A=1.735, B=0.624, and C=0.188
χ^2/DOF= 1555/958
but using ξ_w
A=0.700, B=0.327, and C=0.197
χ^2/DOF= 1351/958

Fit with ξ_w (2002)

➢ 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**

$K_{sea} = Q^2/[Q^2+C_{sea}]$
K_{val} = **$[1- G_D^{\,2}(Q^2)]$ $*[Q^2+C2V] / [Q^2+C1V]$**

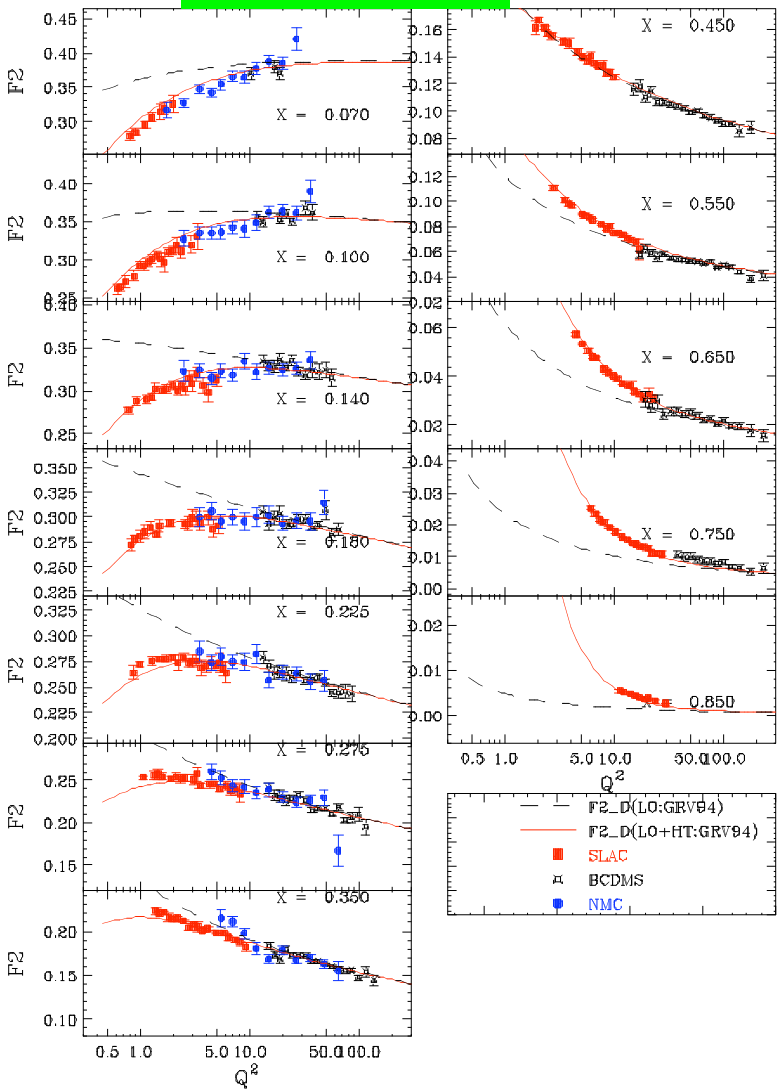
where $G_D^{\,2}(Q^2) = 1/[1+Q^2/0.71]^4$
(elastic nucleon dipole form factor)

❑ **Very good fits are obtained (with additional low x HERA/NMC F2 data included)**

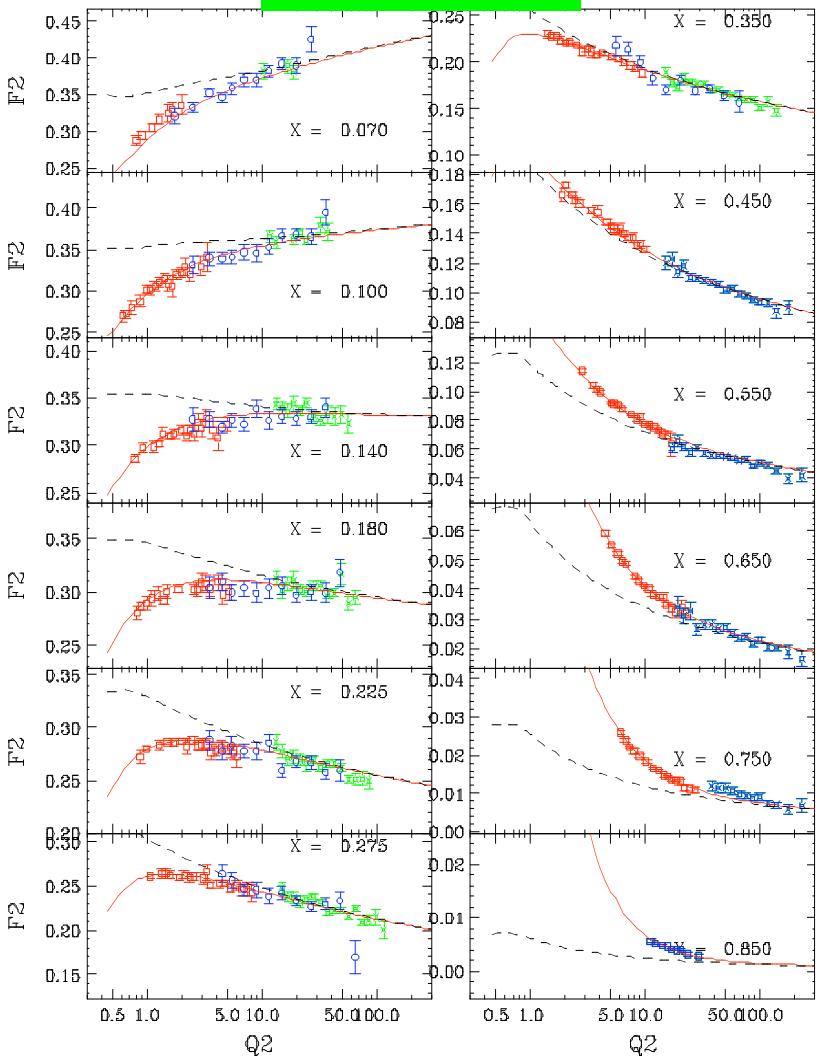
A=0.418, B=0.222, C_{sea} = 0.381
C1V = 0.604, C2V= 0.485
χ^2/DOF= 1268 / 1200

Fit Results on DIS $F_2(d)$ data

Fit using Xw



Fit using ξw



Comparisons with resonance and photo-production data (not used in fitting)

F_2(d) resonance

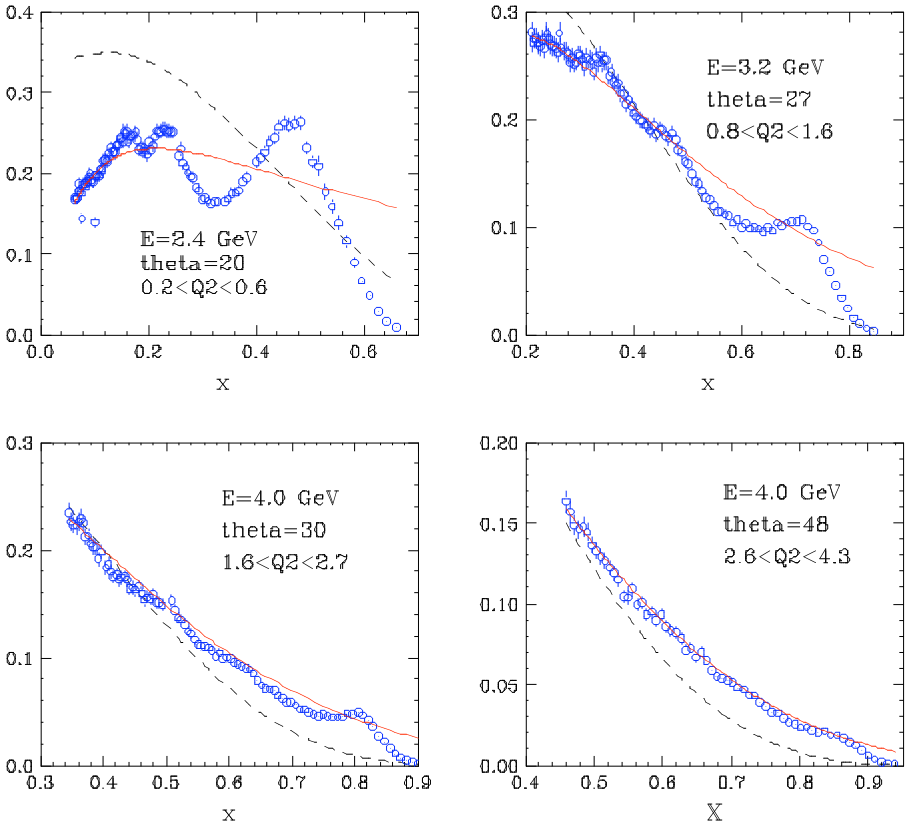
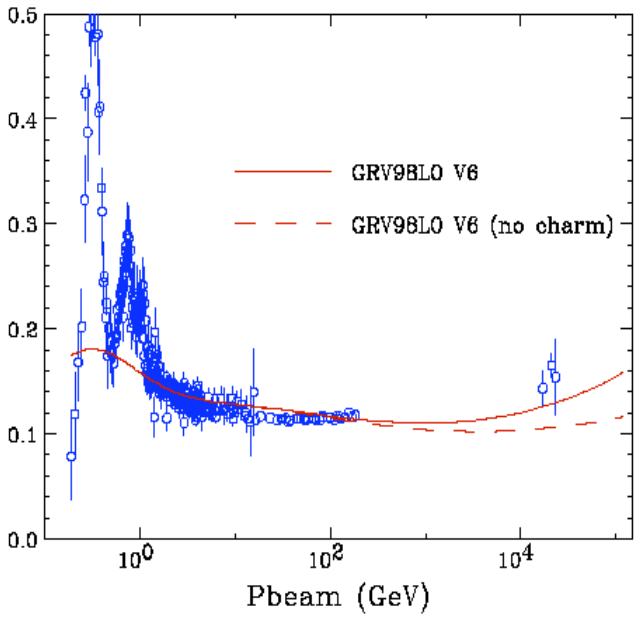


Photo-production (p)



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

where $F_2(x, Q^2)$

$= Q^2/(Q^2 + C) * F_2(\xi_w)$

Improved Fits

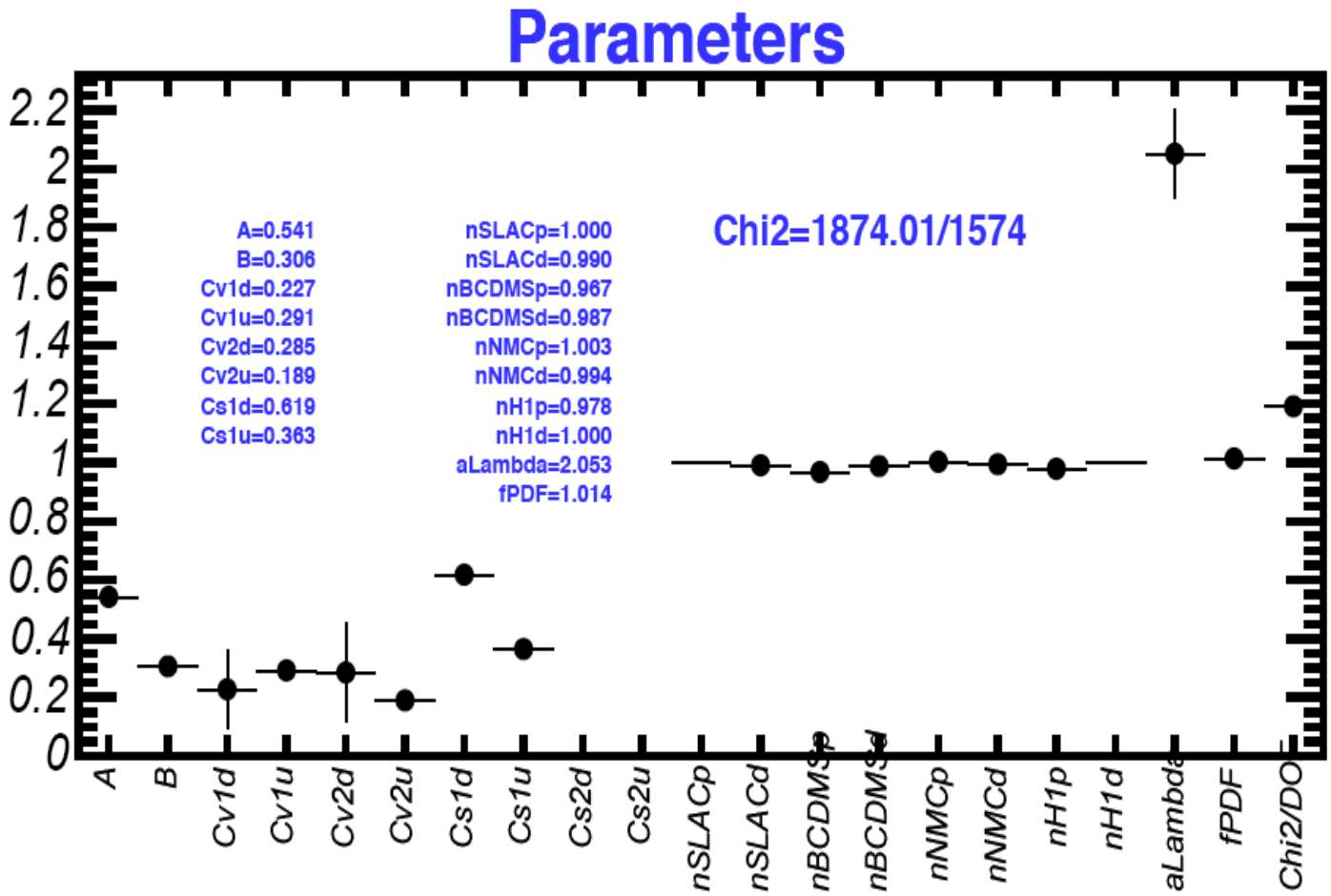
- Improvements in our model
  - Separate low Q^2 corrections to d and u valence quarks, and sea quarks
  - Include all inelastic F2 proton/deuterium (SLAC/NMC/BCDMC/HERA), photo-production on proton/deuteron in the fits (the c-cbar photon-gluon fusion contribution is included, important at high energy)

- Toward axial PDFs (vector PDFs vs axial PDFs)
  - Compare to neutrino data (assume V=A)

    CCFR-Fe, CDHS-Fe, CHORUS-Pb differential cross section (without c-cbar boson-fusion in yet - to be added next since it is high energy data)
  - We have a model for axial low Q2 PDFs, but need to compare to low energy neutrino data to get exact parameters (not done)

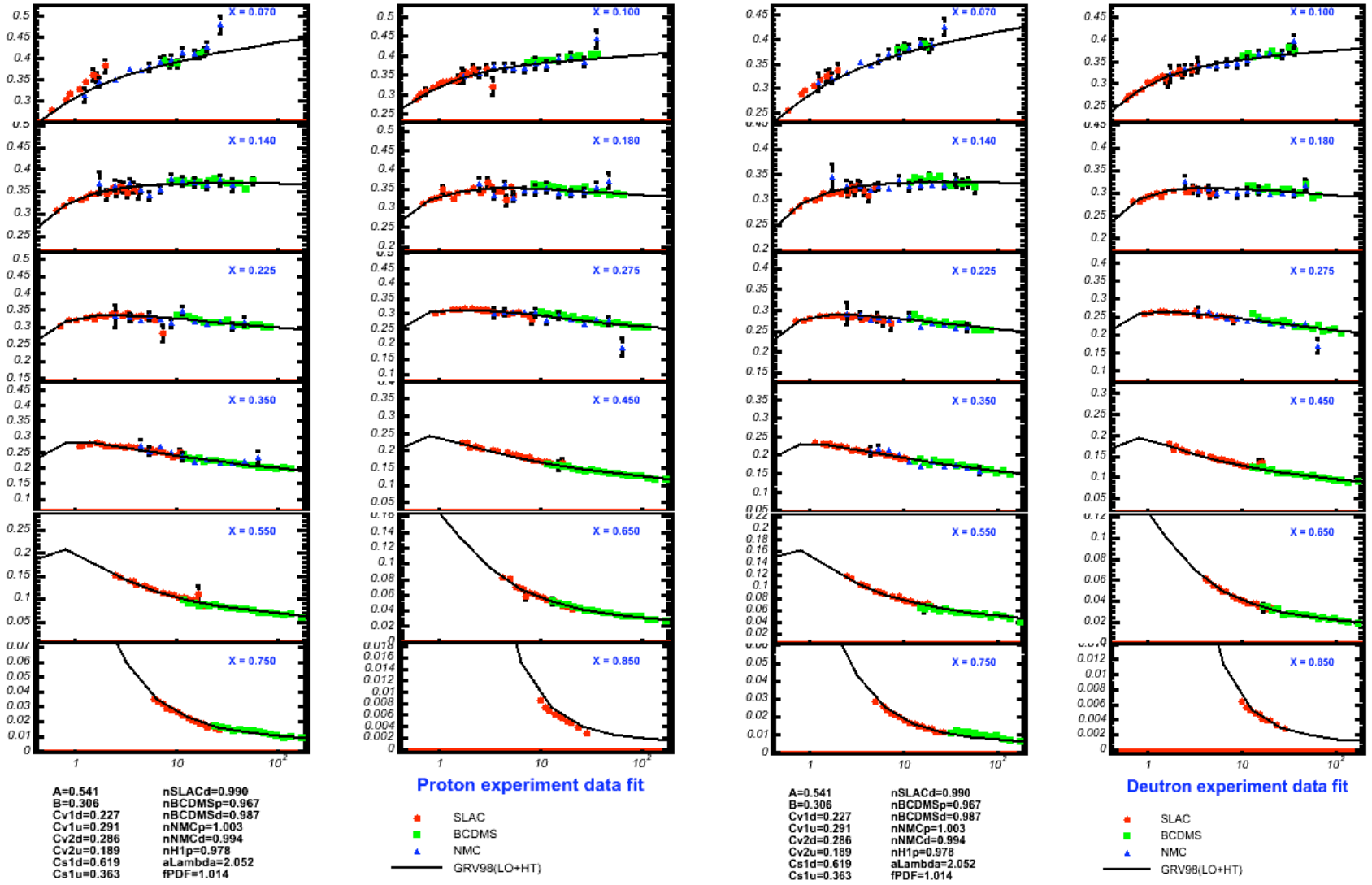
    Kvec = $Q^2/[Q^2+C1]$ -> Kax = $[Q^2+C2]/[Q^2+C1]$

Fit Results



8 model parameters + 7 exp. Norm + 1 PDFs

Fit results to $F_2(p)$ and $F_2(d)$



Proton

Deuteron

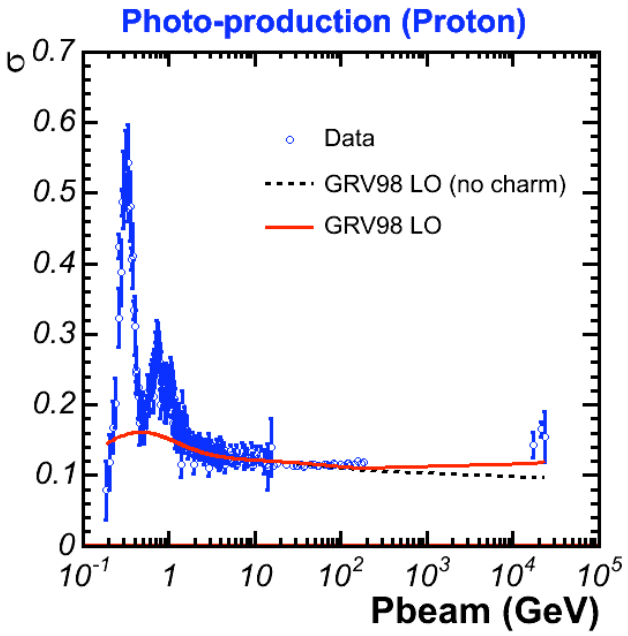


Photo-production (Proton)
σ
Data
GRV98 LO (no charm)
GRV98 LO
Pbeam (GeV)

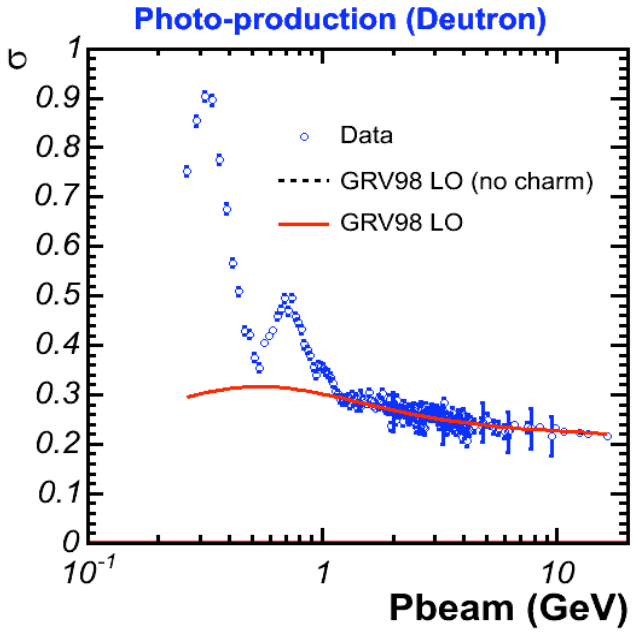
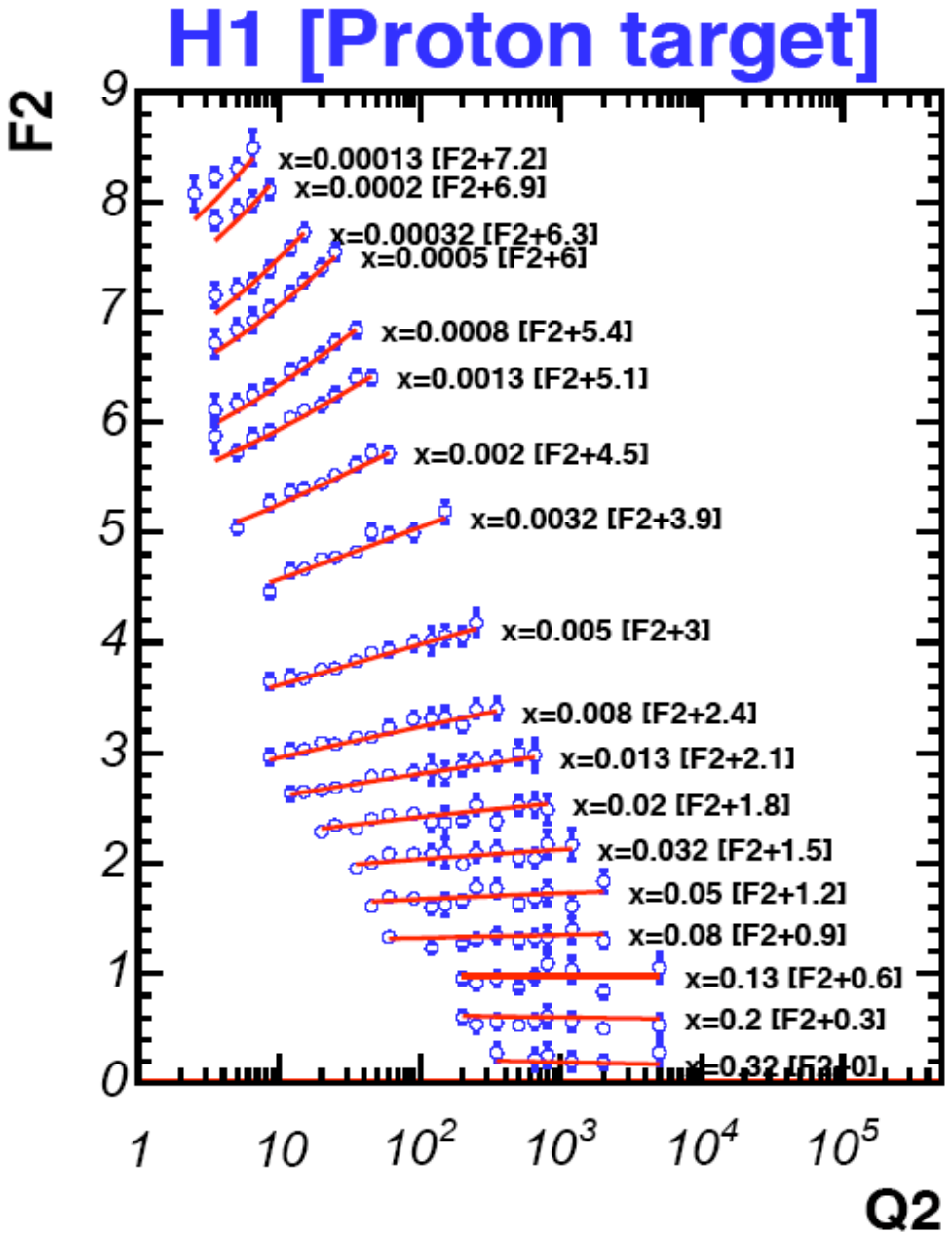
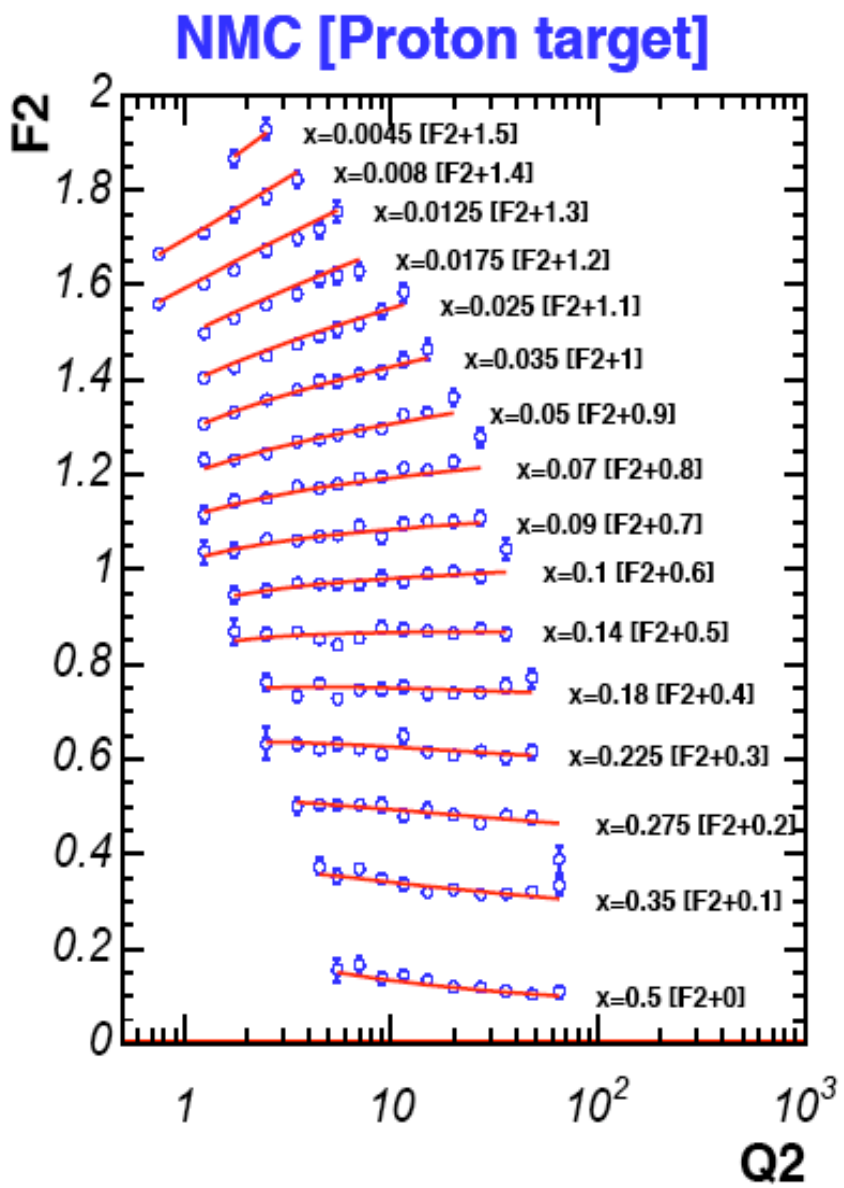
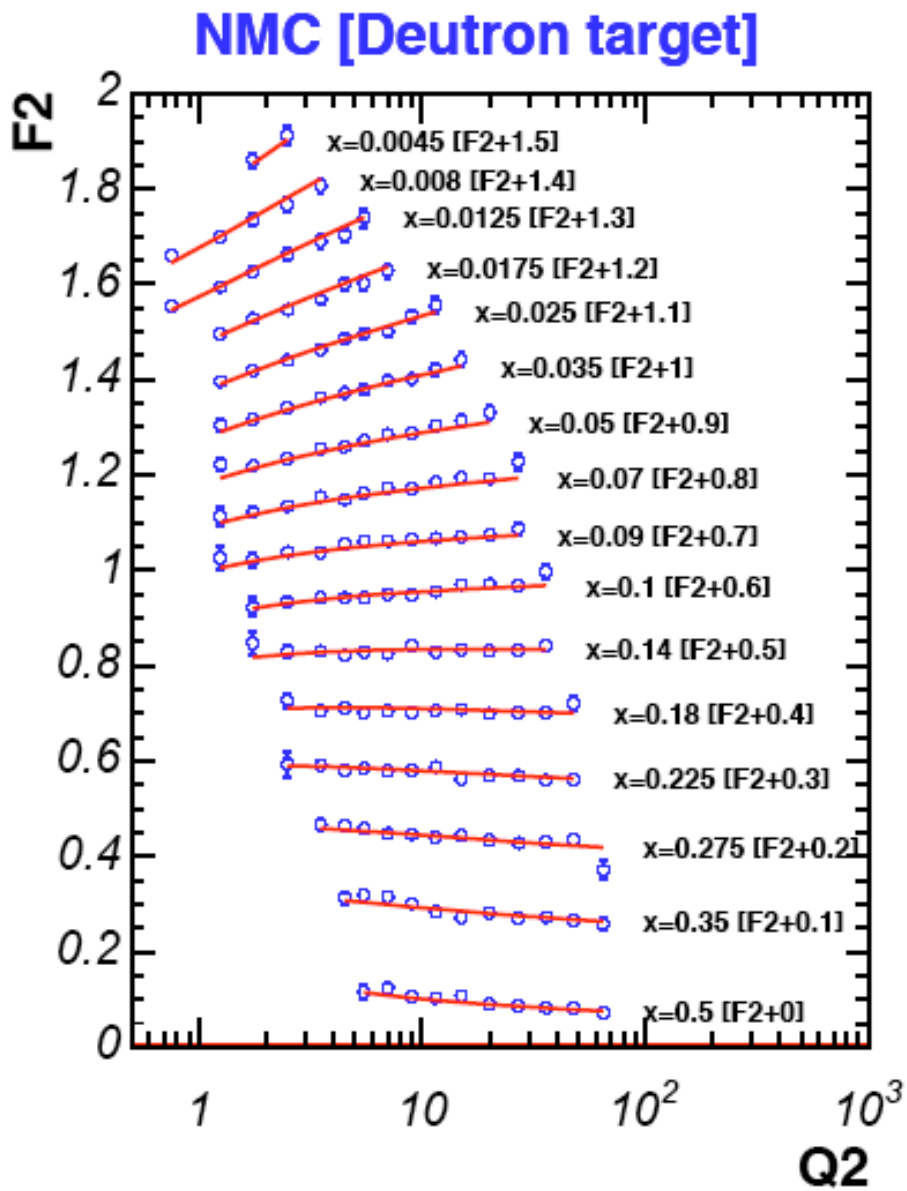


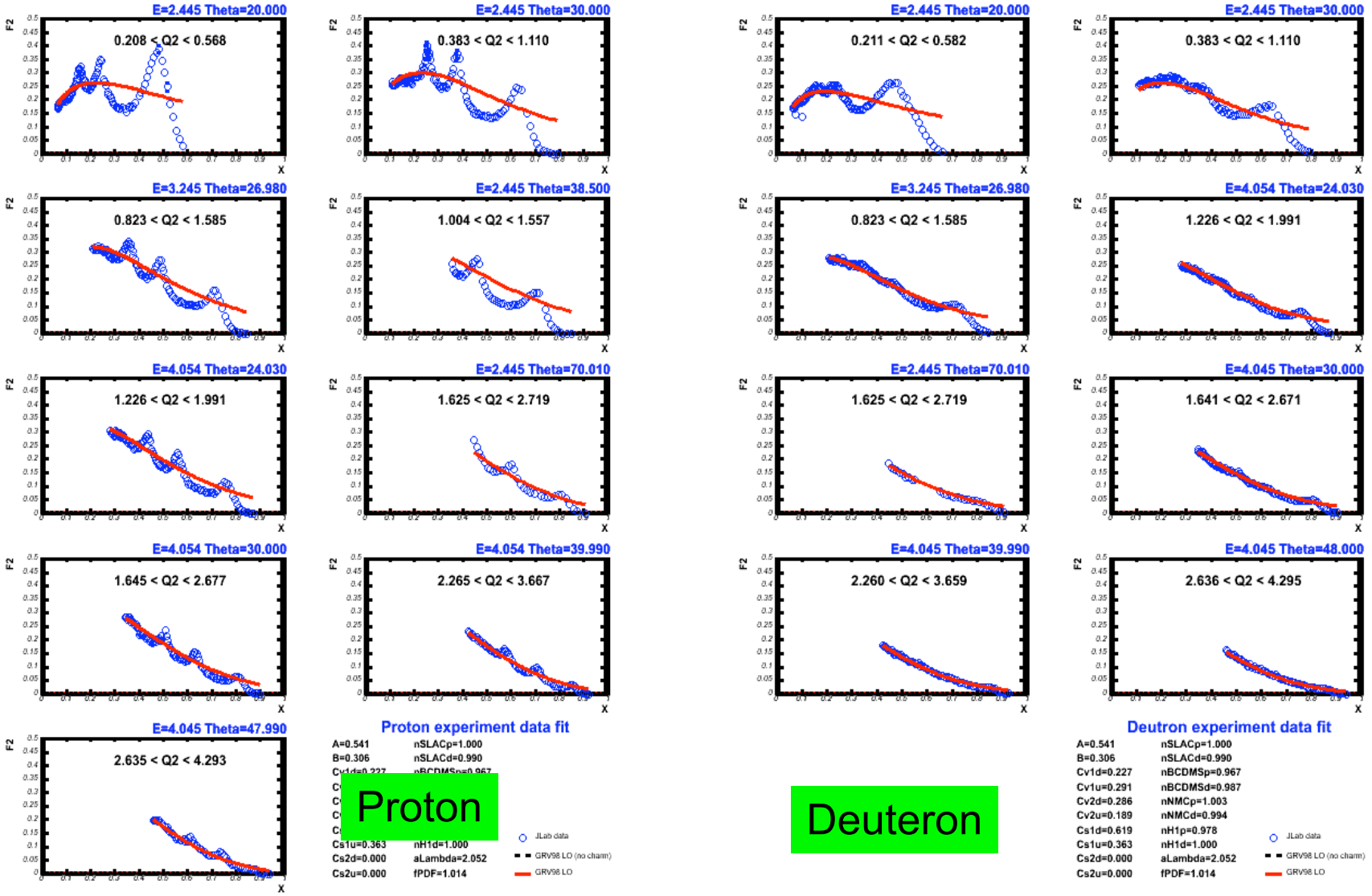
Photo-production (Deutron)
σ
Data
GRV98 LO (no charm)
GRV98 LO
Pbeam (GeV)


H1 [Proton target]
F2
x=0.00013 [F2+7.2]
x=0.0002 [F2+6.9]
x=0.00032 [F2+6.3]
x=0.0005 [F2+6]
x=0.0008 [F2+5.4]
x=0.0013 [F2+5.1]
x=0.002 [F2+4.5]
x=0.0032 [F2+3.9]
x=0.005 [F2+3]
x=0.008 [F2+2.4]
x=0.013 [F2+2.1]
x=0.02 [F2+1.8]
x=0.032 [F2+1.5]
x=0.05 [F2+1.2]
x=0.08 [F2+0.9]
x=0.13 [F2+0.6]
x=0.2 [F2+0.3]
Q2


NMC [Proton target]
F2
Q2
x=0.0045 [F2+1.5]
x=0.008 [F2+1.4]
x=0.0125 [F2+1.3]
x=0.0175 [F2+1.2]
x=0.025 [F2+1.1]
x=0.035 [F2+1]
x=0.05 [F2+0.9]
x=0.07 [F2+0.8]
x=0.09 [F2+0.7]
x=0.1 [F2+0.6]
x=0.14 [F2+0.5]
x=0.18 [F2+0.4]
x=0.225 [F2+0.3]
x=0.275 [F2+0.2]
x=0.35 [F2+0.1]
x=0.5 [F2+0]

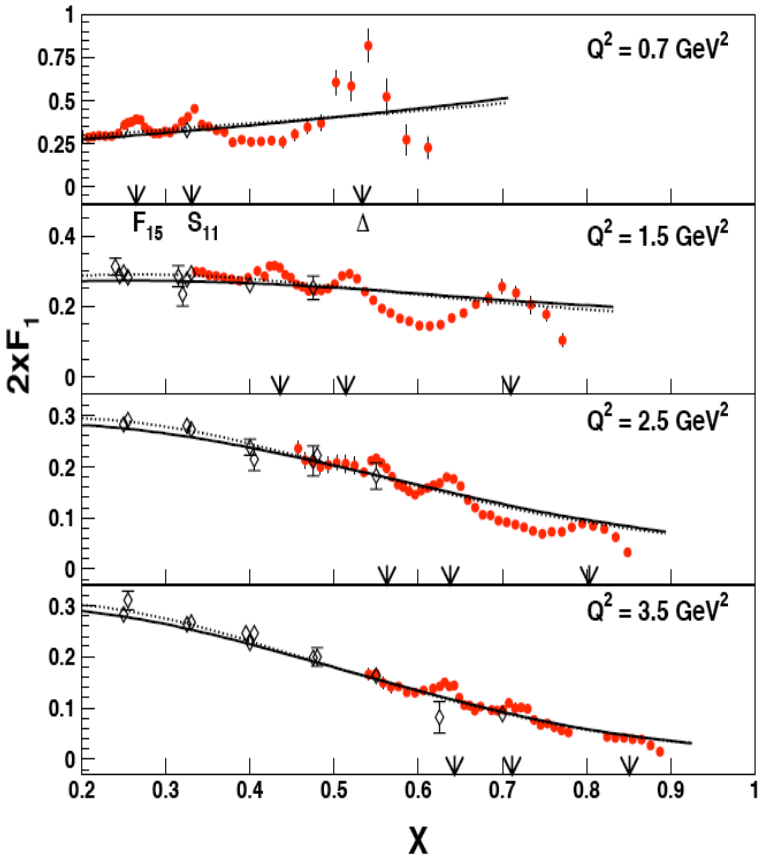

NMC [Deutron target]
F2
Q2
x=0.0045 [F2+1.5]
x=0.008 [F2+1.4]
x=0.0125 [F2+1.3]
x=0.0175 [F2+1.2]
x=0.025 [F2+1.1]
x=0.035 [F2+1]
x=0.05 [F2+0.9]
x=0.07 [F2+0.8]
x=0.09 [F2+0.7]
x=0.1 [F2+0.6]
x=0.14 [F2+0.5]
x=0.18 [F2+0.4]
x=0.225 [F2+0.3]
x=0.275 [F2+0.2]
x=0.35 [F2+0.1]
x=0.5 [F2+0]

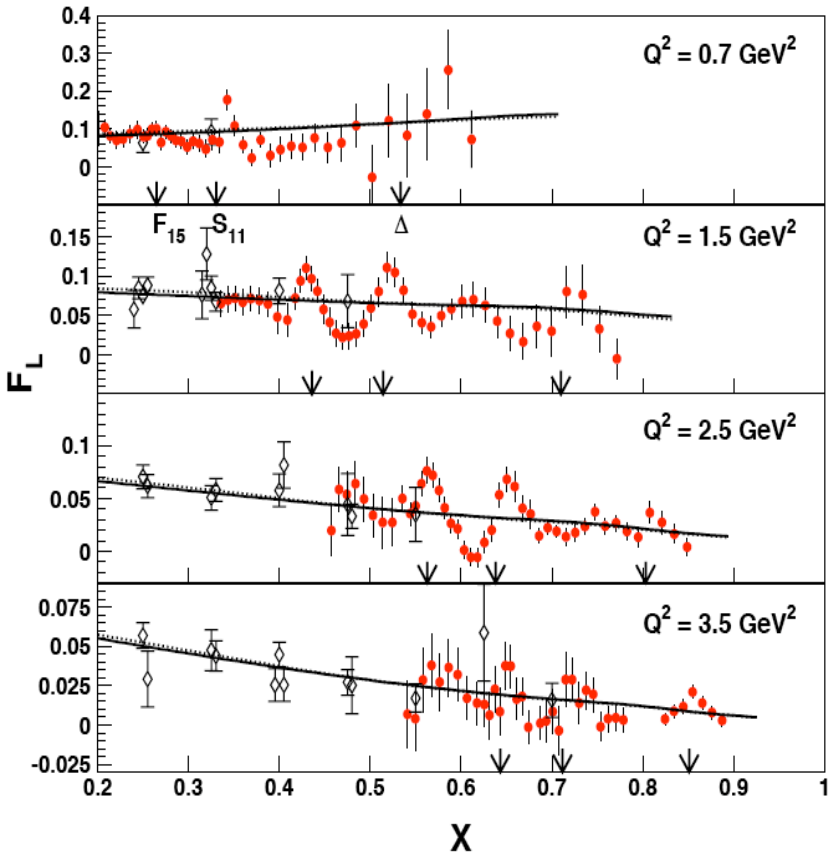
Comparisons with resonance data



Resonance data are not included in the fit!!!

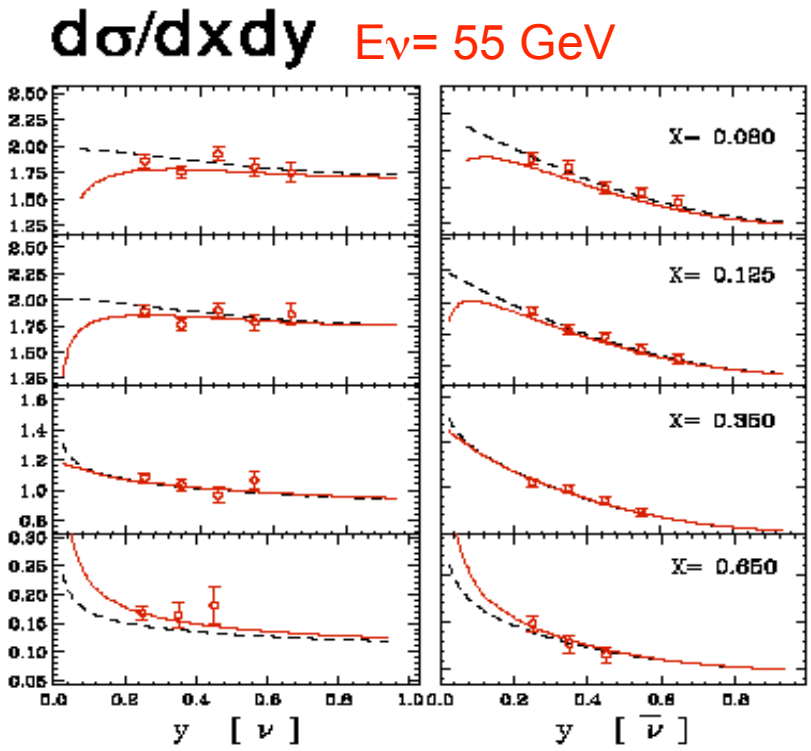
2xF1 and FL Jlab resonance data





Solid: latest fit ξw
Dashes: GRV94 ξw

Comparison with neutrino data (assume V=A)



--ξw PDFs GRV98 modified

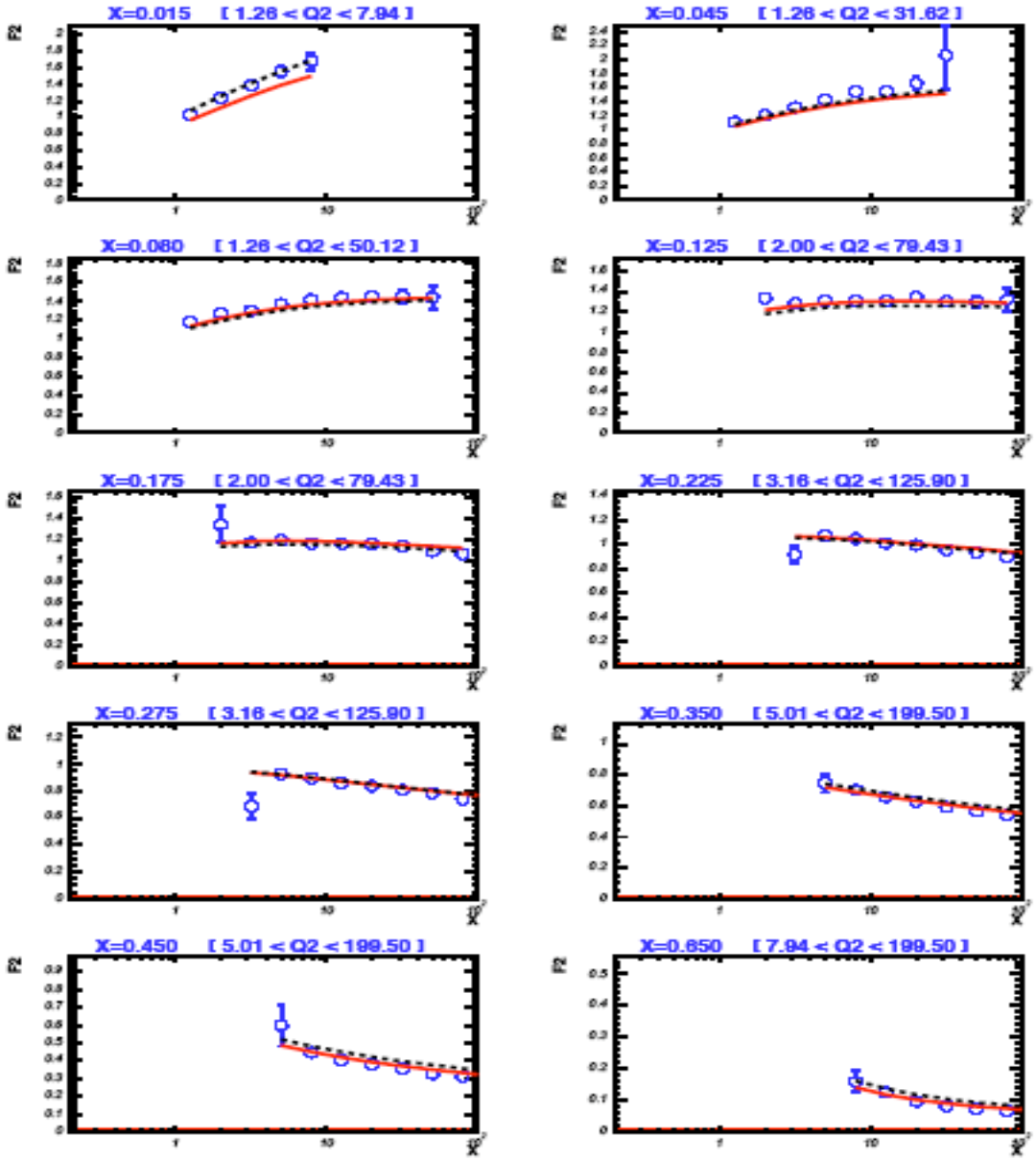
---- GRV98 (x,Q^2) unmodified

Left: (neutrino), right anti-neu

- Apply nuclear corrections using e/μ scattering data.
- Calculate F_2 and xF_3 from the modified PDFs using xw
- Use R=Rworld fit to get $2xF_1$ from F_2
- Implement charm mass effect through xw slow rescaling algorithm for F_2, $2xF_1$, and xF_3
- But contribution with charm-scattering is not included.

Plots for all energy regions:
http://web.pas.rochester.edu/~icpark/MINERvA/

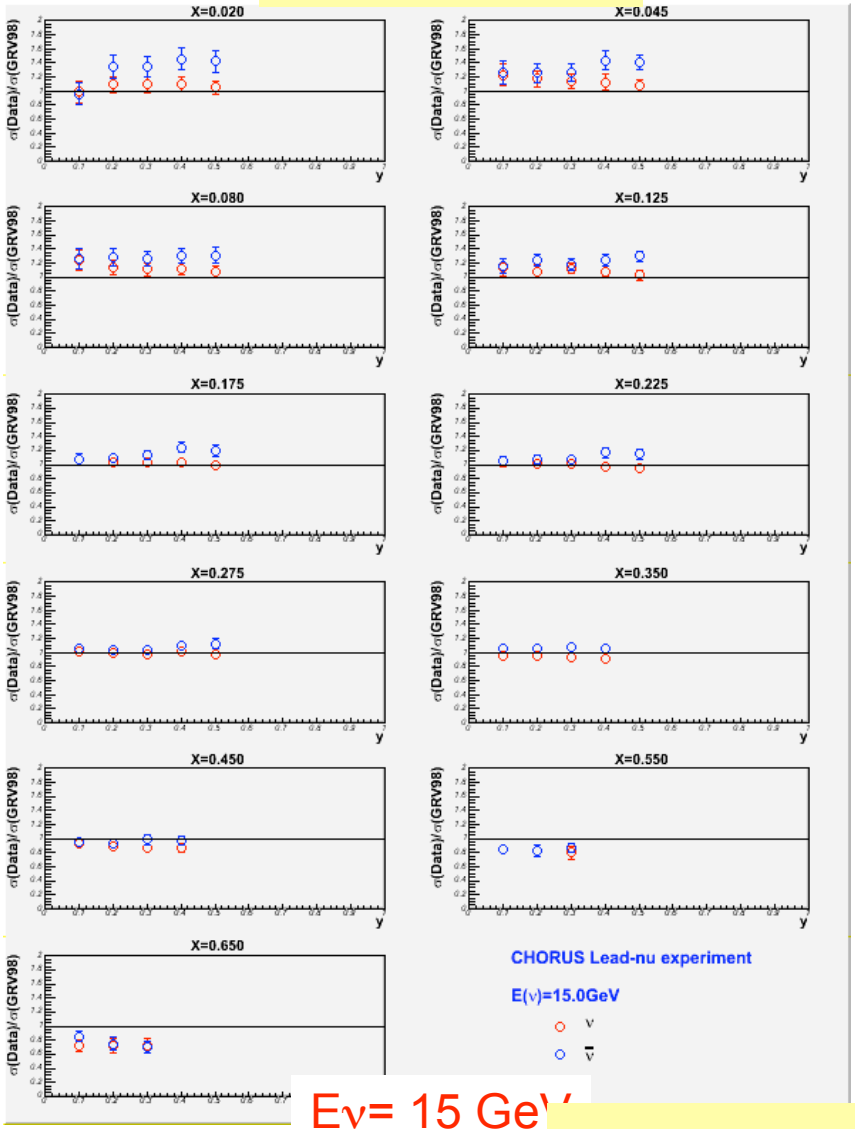
Comparison with CCFR F_2 data



Dashes: no EMC
Solid: with EMC

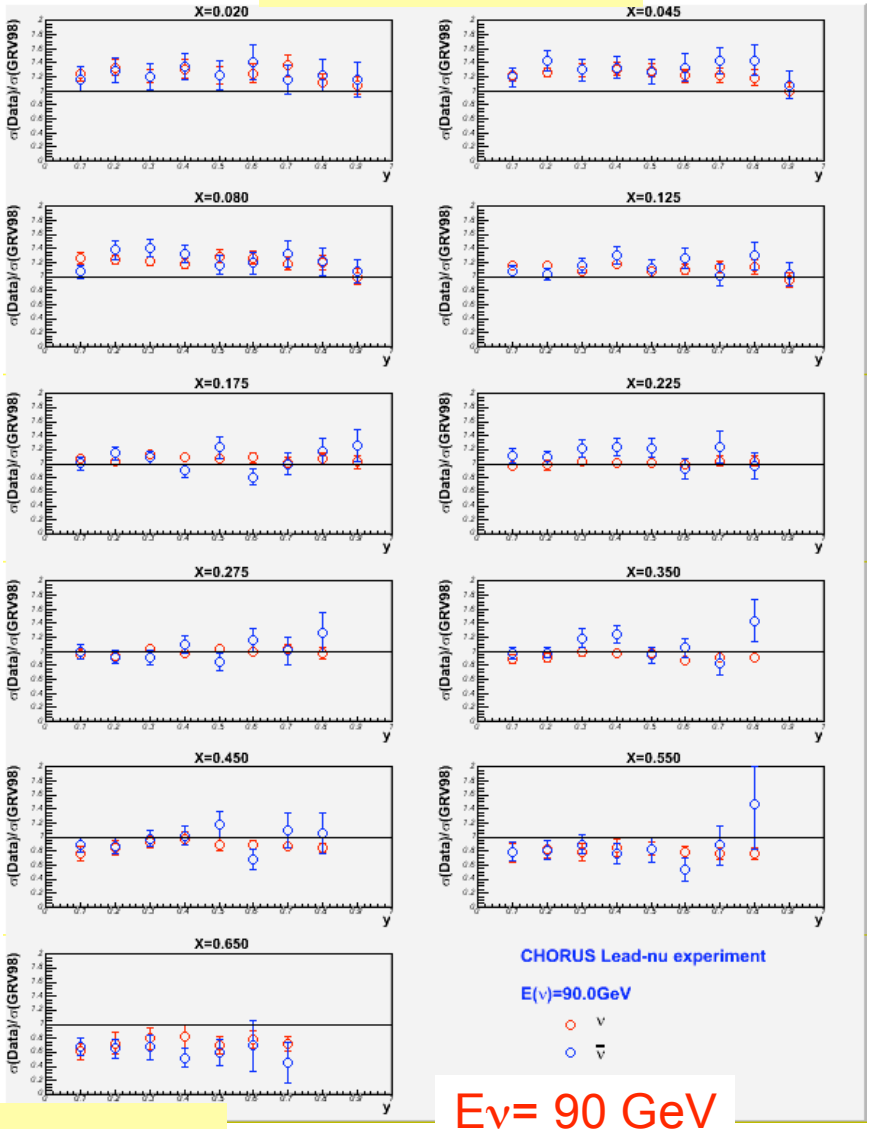
Comparison with CHORUS data (lead)

Data/theory



Eν= 15 GeV

Data/theory



Eν= 90 GeV

Iron correction is used

Summary

- Our modified GRV98 LO PDFs with a scaling variable ξ_w describe all SLAC/BCDMS/NMC/HERA DIS data as well as photo-production data.

- Our predictions in good agreement with resonance data, and with high-energy neutrino data.

- This model should also describe a low energy neutrino cross sections reasonably well, except the region where axial vector contribution is significant ($Q^2<1$)

Discussions

- Things can be improved
  - Resonance effect, A(W) from Jlab data
  - Implement nuclear correction (from charged lepton data)
  - Fits to the axial contribution at low Q2 using low energy neutrino data.

- Things needed to be measured or better understood
  - Measurements for different nuclei targets for charged lepton (from JUPITER at JLAB) and neutrino scattering (like MINERvA exp).
  - Understanding of nuclear effects in neutrino scattering requires a precise knowledge of valence quarks at high x (from charged lepton data): SLAC and Jlab F2 proton will be powerful.
    - even 10% reduction in u quark helps a lot to resolve δd (d/u=0.2)
  - Different nuclear corrections to sea and valence quarks?
    - xF3(valence), and F2-xF3(sea) data vs models?
  - Measurements for axial vector contributions.