Axial and Vector SFs for e/ν-N Scattering using Effective LO PDFs

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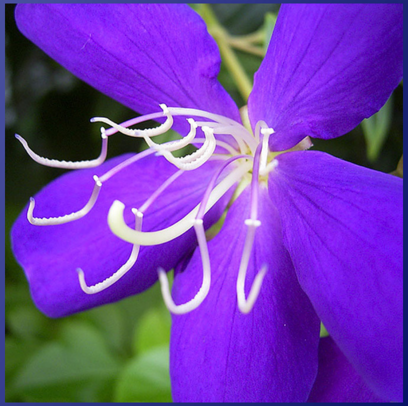


DIS 2011, Apr 11-15, Newport News

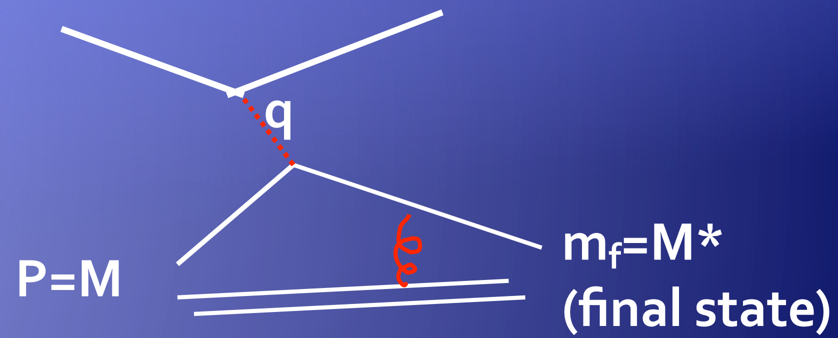
Neutrino Cross Sections

- Quasi-Elastic / elastic (W=M): $\nu_\mu + n \longrightarrow \mu^- + p$
  - use form factors
- Resonance (low Q^2, W< 2 GeV): $\nu_\mu + p \longrightarrow \mu^- + p + \pi$
  - eg. Rein and Seghal model (overlaps with DIS, W>1.4)
- Deep Inelastic Scattering: $\nu_\mu + p \longrightarrow \mu^- + X$
  - Use Bodek-Yang quark-parton model -non-pQCD effects, high x PDFs (for W>1.8 GeV , or W>1.4 GeV for overlap)

- Describe DIS, resonances within quark-parton model: with these PDFs, it is simple to convert $\sigma(e)$ into $\sigma(\nu)$
- Challenges
  - High x PDFs at very low Q^2
  - Resonance scattering within quark-parton model (duality)
  - What happens at Q^2=0?
  - Axial-vector contribution

Modeling neutrino cross sections

- NNLO pQCD +TM approach: describes e/μ DIS and resonance data well for $Q^2>1$ GeV^2
  Bodek-Yang PRL 82, 2487 (1999); EPJ C13, 241 (2000)



- Bodek-Yang LO approach:
  (pseudo NNLO)
  Use effective LO PDFs with a new scaling variable, ξ_w to absorb target mass, higher twist, missing NLO, NNLO QCD terms.

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

+ Add low Q^2 K factors to make model work at Q^2=0.

$$F_2(x,Q^2) \rightarrow \frac{Q^2}{Q^2+C} F_2(\xi_w,Q^2)$$

Bodek-Yang Effective LO PDFs Model

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

1. Start with GRV98 LO (Q^2_{min}=0.80)
2. Replace x_{bj} with a new scaling, ξ_w
3. Multiply all PDFs by K factors for photo prod. limit and higher twist

   [$\sigma(\gamma) = 4\pi\alpha/Q^2 * F_2(x, Q^2)$]

   Ksea = $Q^2/[Q^2+Csea]$

   Kval = $[1- G_D^2 (Q^2)] * [Q^2+C_{2V}] / [Q^2+C_{1V}]$

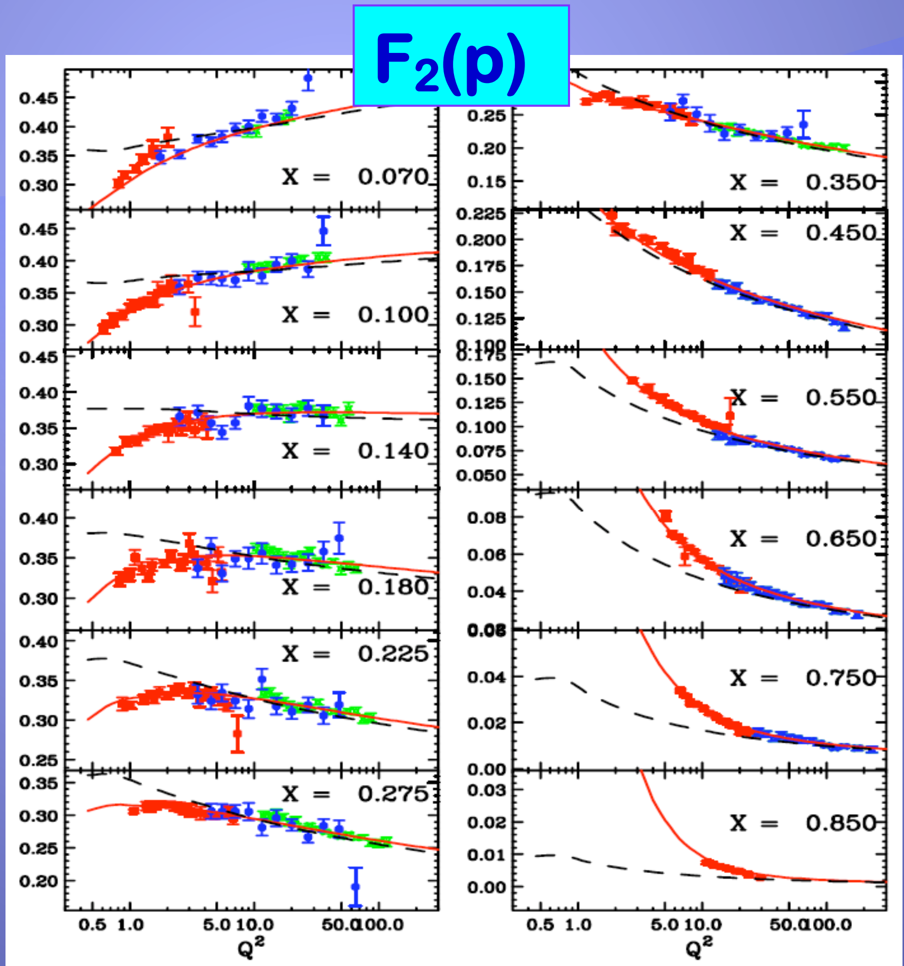
   motivated by Adler Sum rule

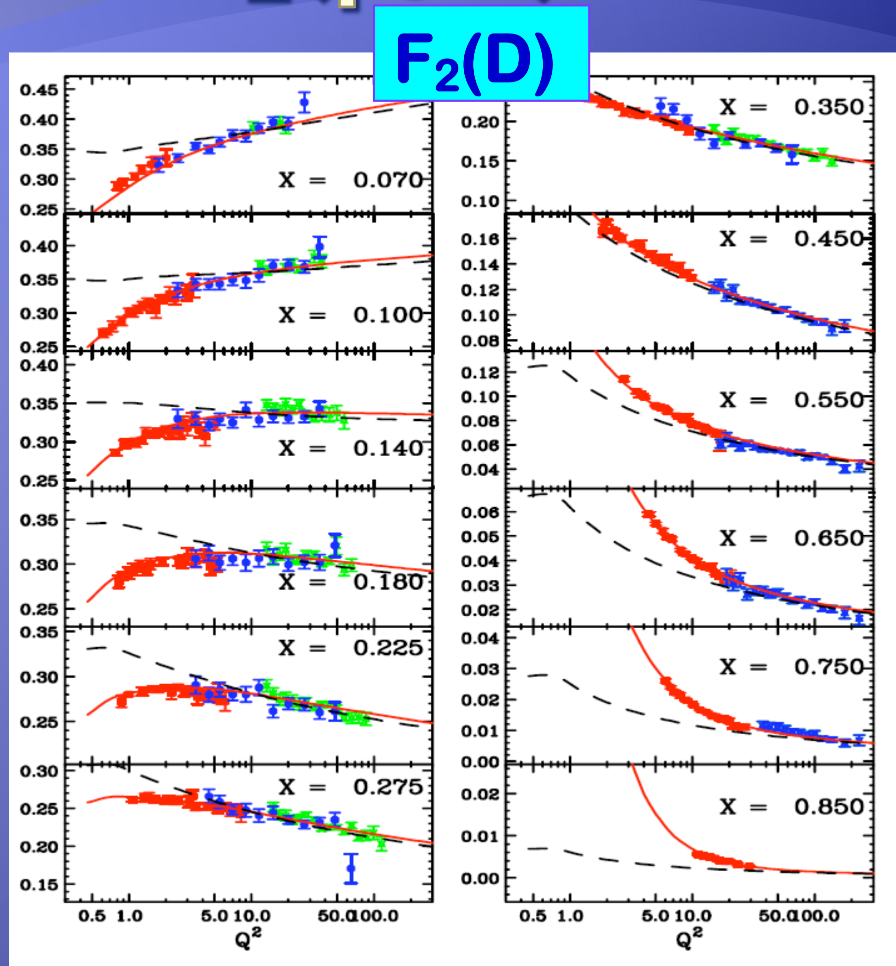
   where $G_D^2 (Q^2) = 1/ [1+Q^2 / 0.71]^4$
4. Freeze the evolution at $Q^2 = Q^2_{min}$

   - $F_2(x, Q^2 < 0.8) = K(Q^2) * F_2(\xi w, Q^2=0.8)$
5. Fit all DIS F_2(p/D) with low x HERA data, photo-production data

A =0.621	B =0.380
C2v(u) =0.264	C2v(d) =0.323
C1v(u) =0.417	C1v(d) =0.341
Csea(u) =0.369	Csea(d,s) =0.561

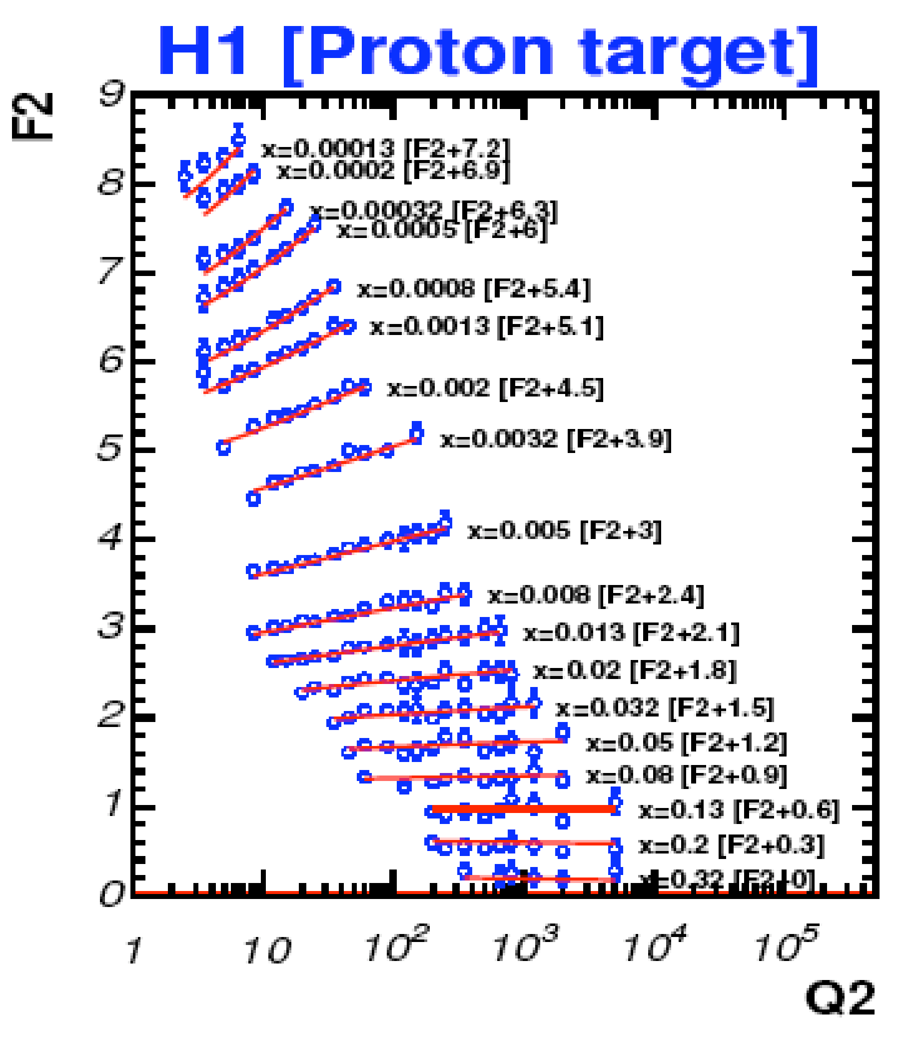
Fit Results on DIS F_2(p/D) data

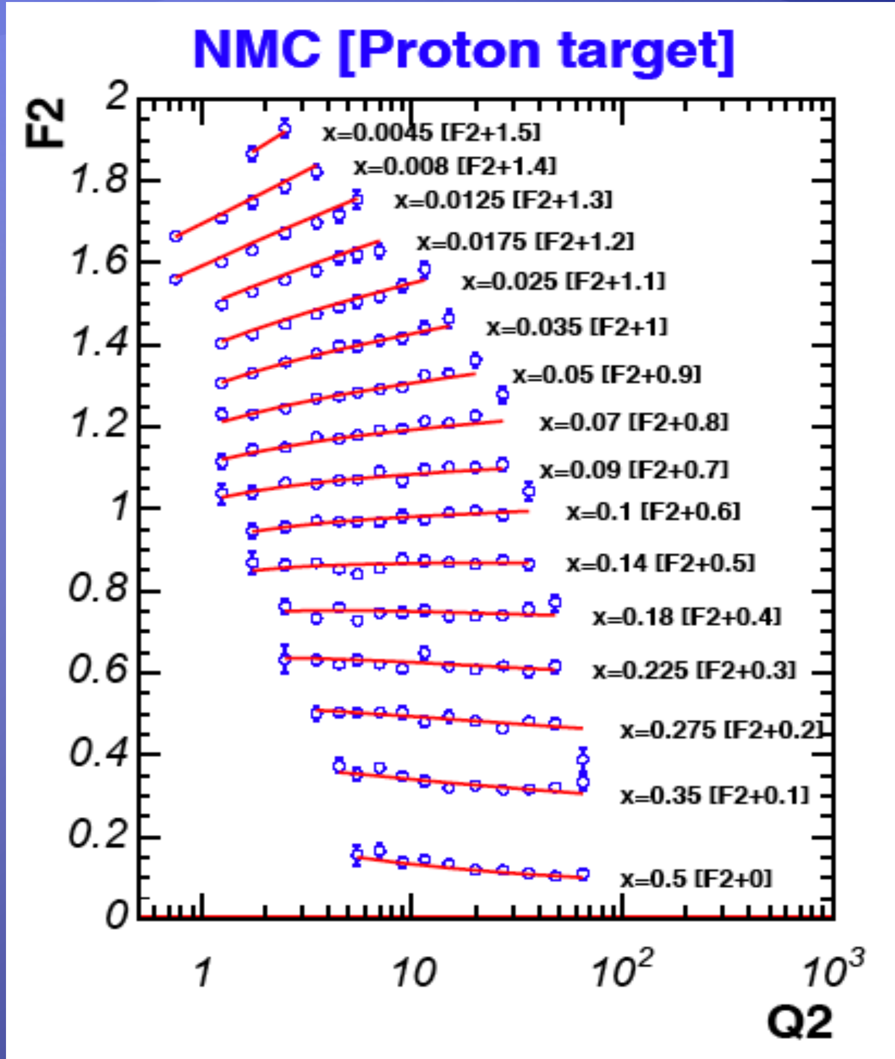




- Excellent Fit:
  - red solid line: effective LO using ξw (modified GRV98 PDFs)
  - black dashed line: GRV 98 with x_{bj}

Low x HERA and NMC data





- Fit works at low x

Photo-production data for W< 2 GeV

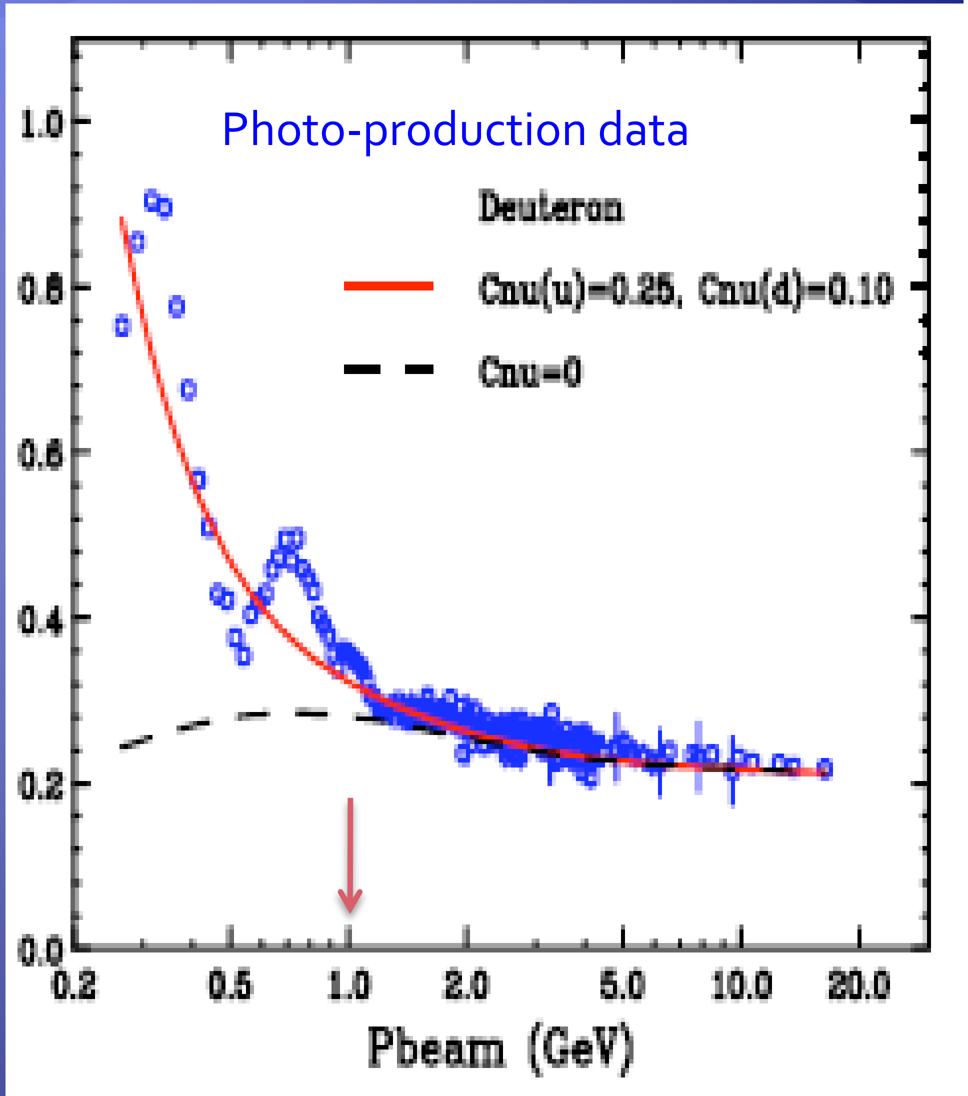
- 2011- Additional K^{LW} factor for valence quarks:

  Kval = K^{LW} *[1- $G_D{}^2$ (Q^2)] * [Q^2+C_{2V}] / [Q^2+C_{1V}]

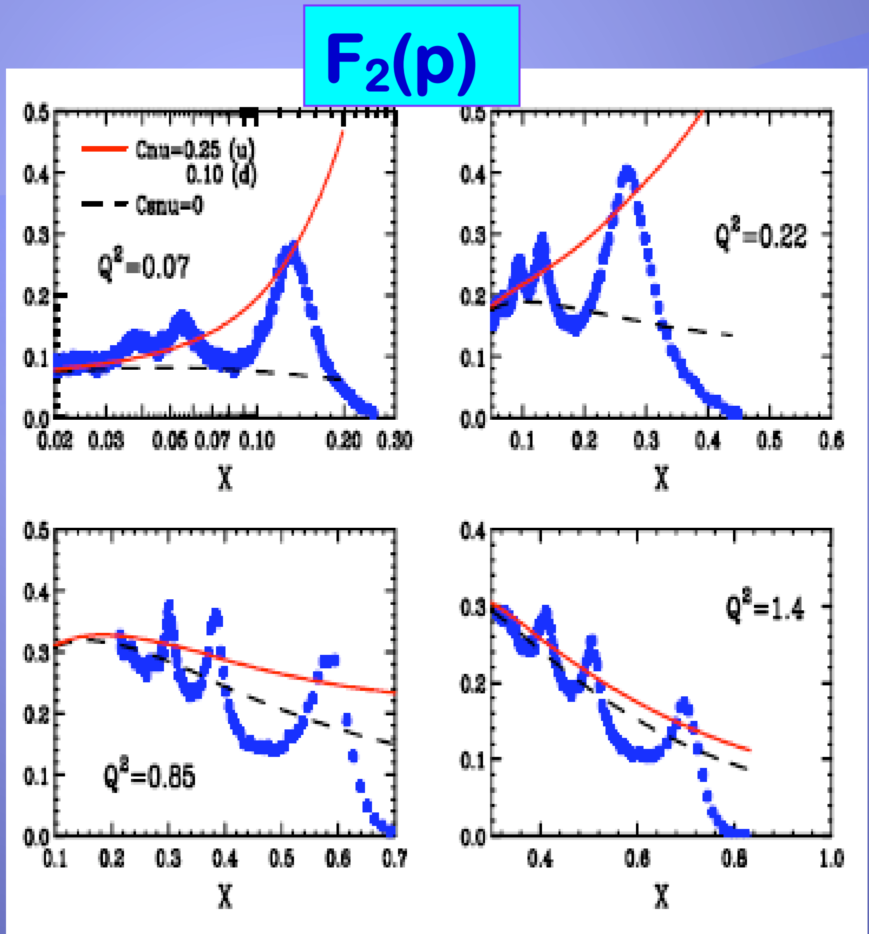
  $K^{LW} = (\nu^2+C^\nu)/\nu^2$

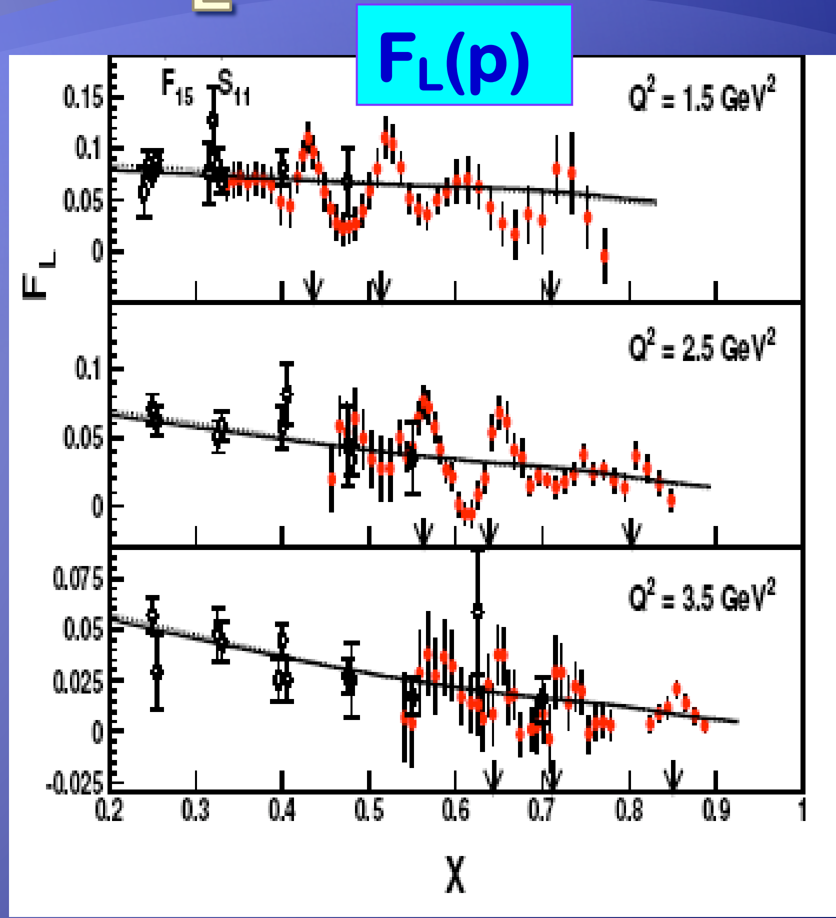
  This makes a duality work all the way down to Q^2=0 (for charged leptons) !!!

- Photo-production Data with ν>1 GeV are included in the fitting



F2 Resonance and F_L





- Predictions are in good agreement with resonance data (not included in the fitting process) – duality works for electrons and muons for our effective LO PDFs.

Neutrino cross sections

- Effective LO model with ξw describe all DIS and resonance F_2 (electron/μ) data as well as photo-production data (Q^2=0 limit): → Vector contribution well known at all W, Q2
- Neutrino Scattering needs additional input:
  - Need effective LO model for xF_3
  - Need Axial-vector contribution at low Q^2 (at high Q2 V=A)
  - Need Nuclear corrections -> use e/μ scattering data for now
  - Use R=R1998 to get $2xF_1$
  - Implement effect of finite charm mass through ξw slow rescaling algorithm for F_2, $2xF_1$, and xF_3

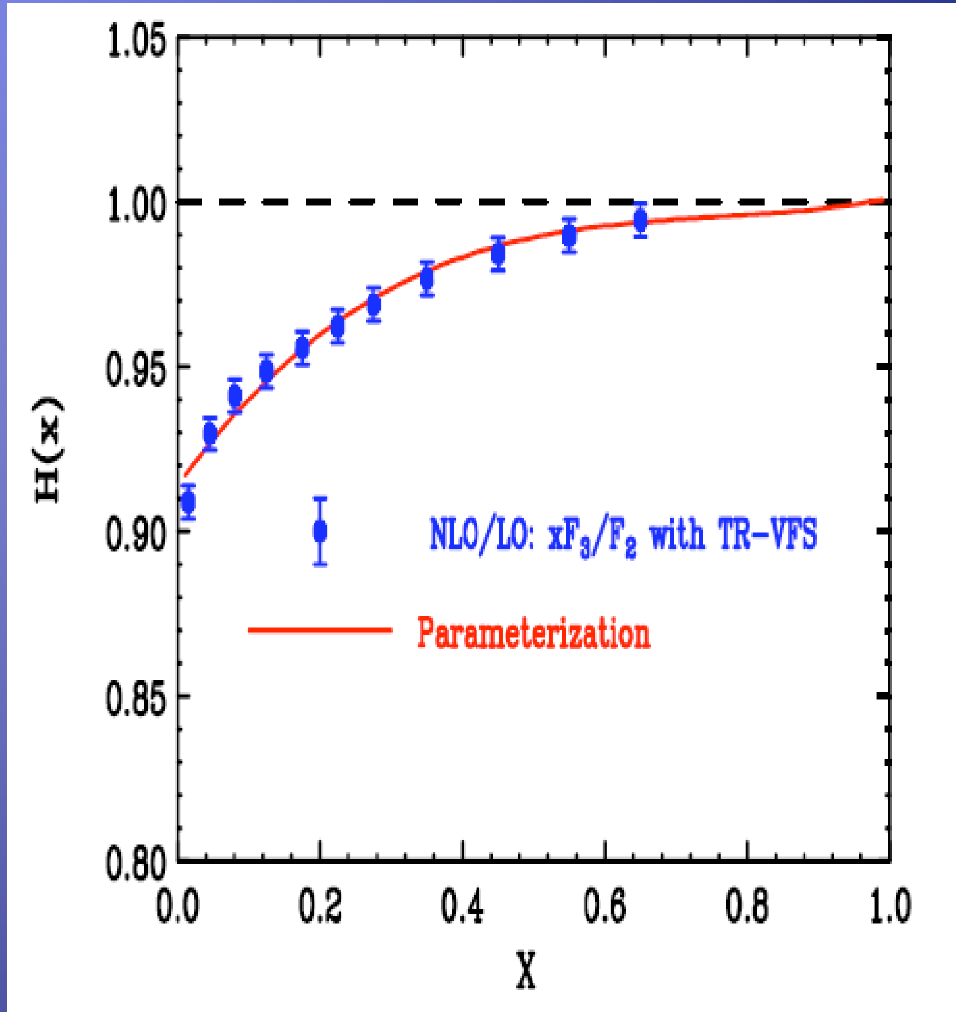
Effective LO model for xF_3

- Scaling variable, ξw absorbs higher order effect for F_2, but the higher order QCD terms for F_2 and xF_3 are not the same

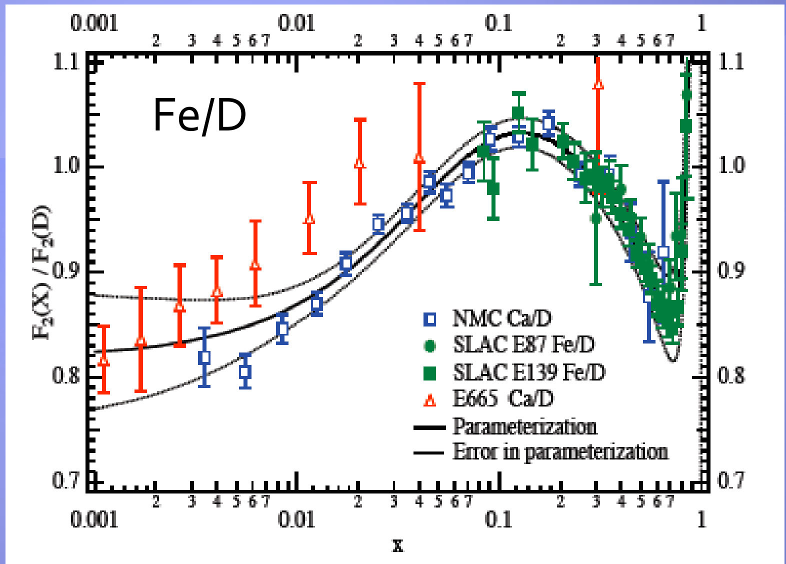
- Use NLO QCD to get double ratio

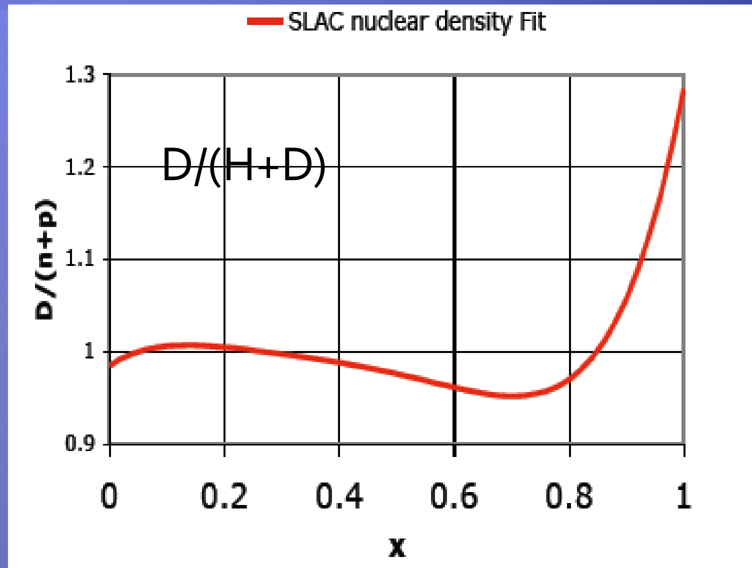
$$H(x) = \frac{xF_3(\text{NLO})}{xF_3(\text{LO})} / \frac{F_2(\text{NLO})}{F_2(\text{LO})}$$

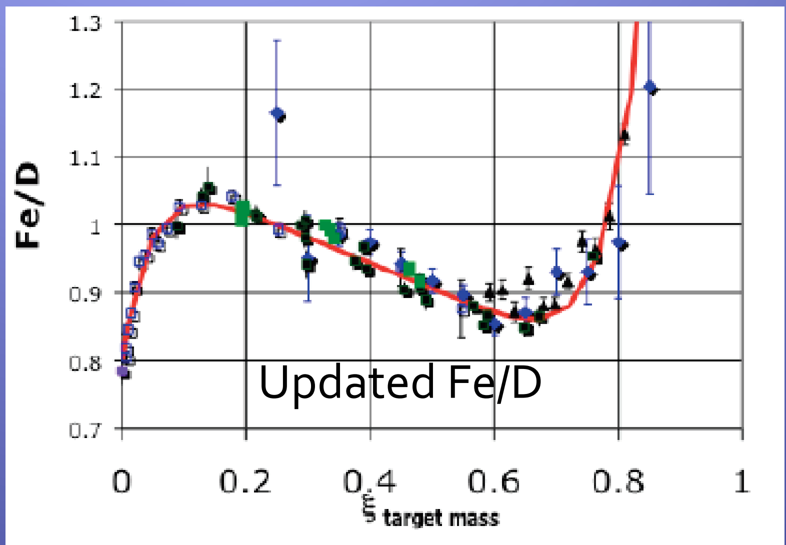
- BY 2011- Apply this correction to the model
- Enhances anti-neutrino cross section by 3%. (1% change in neutrino cross section).

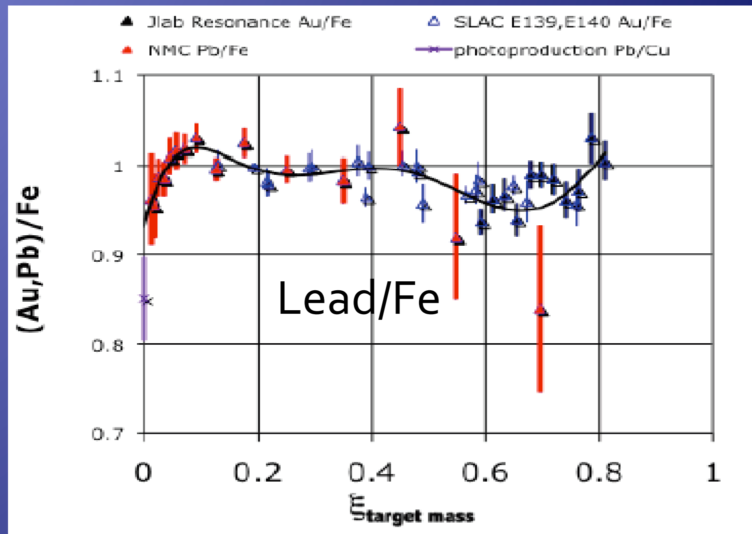


Nuclear Effects: Use e/μ data









Axial Vector Structure Functions

- Type I: Axial = Vector (A=V) (currently implemented in neutrino Monte Carlos).
- BY 2011 Updated to Type II: Axial = PCAC constraint (A=PCAC)

$$K_{sea}^{vector} = \frac{Q^2}{Q^2 + C} \Rightarrow K_{sea}^{axial} = \frac{Q^2 + 0.6C^{axial}}{Q^2 + C^{axial}}$$

$$C^{axial} = 0.3$$

0.6 was chosen to satisfy the prediction from PCAC by Kulagin, agrees With CCFR/Chorus data for F2 extrapolated to (Q2=0)

$$K_{valence}^{vector} = K_{valence}^{axial}$$

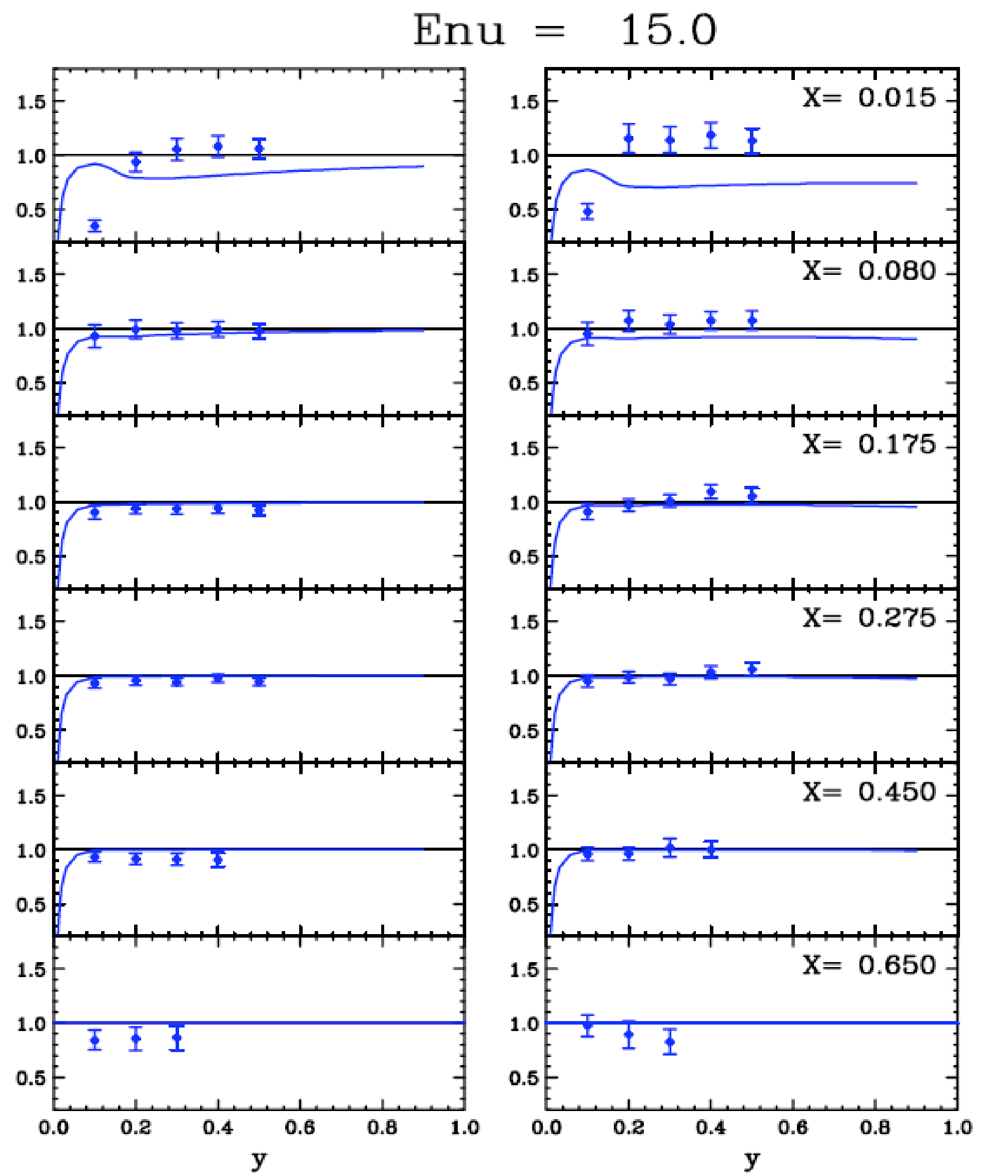
For W> 1.4 GeV (unchanged)

Note: Kaxial (valence) = 1 for W<1.4 GeV . Delta resonance (I=3/2) must be treated separately and differently (Quasielastic also must be treated separately). In neutrino scattering, 5/18 rule does not work for W<1.4 GeV because Delta resonance is I=3/2. (quarks are I=1/2).

Comparison with CCFR (Fe) (red) CHORUS (Pb) data (Blue)

neutrino

antineutrino



- Left: neutrino
- Right: anti-neutrino

- Blue points:

CHORUS / Type II updated theory (A=PCAC)

- Blue line:

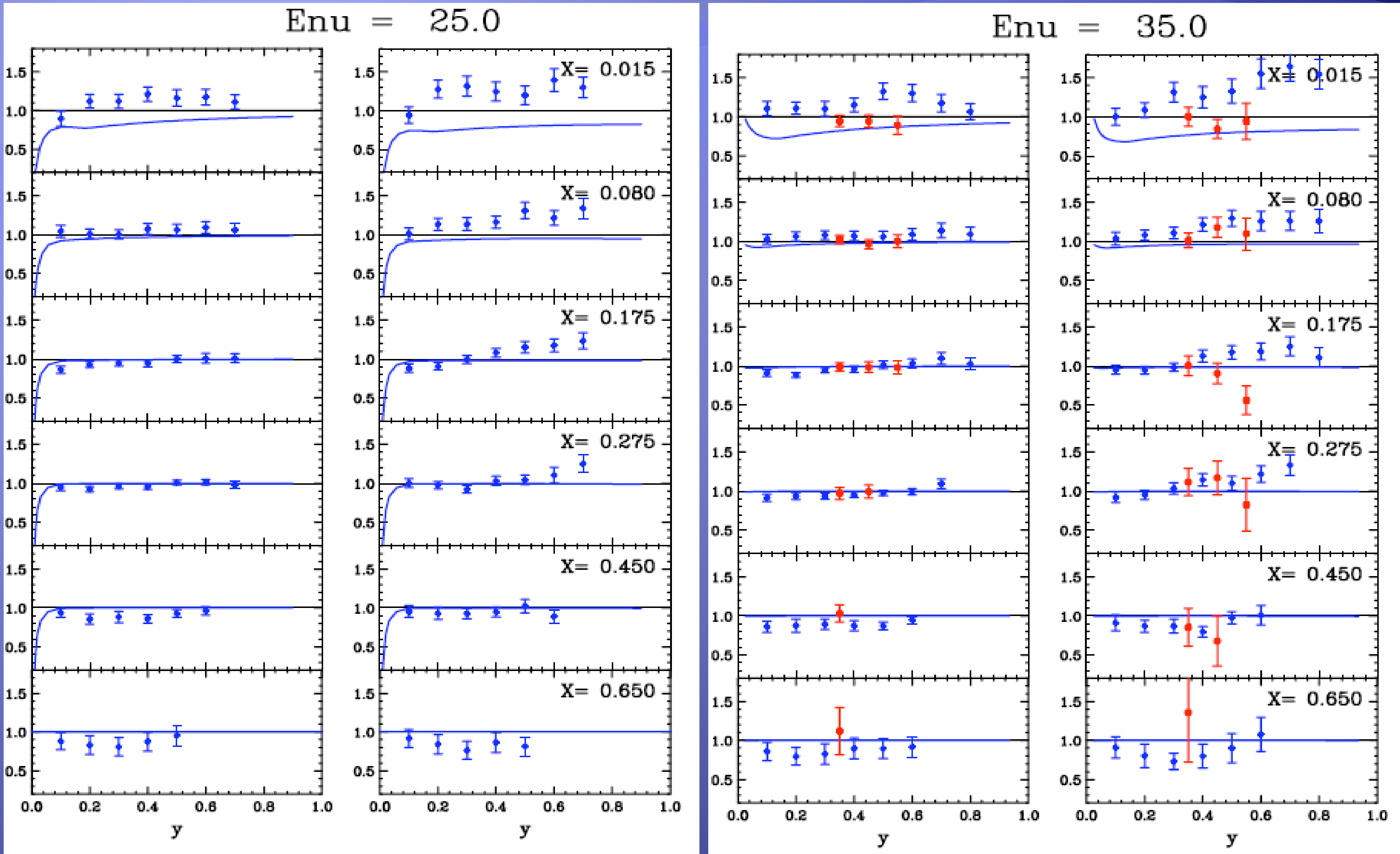
Type I Theory (A=V) / Type II updated theory (A=PCAC)

- Red points:

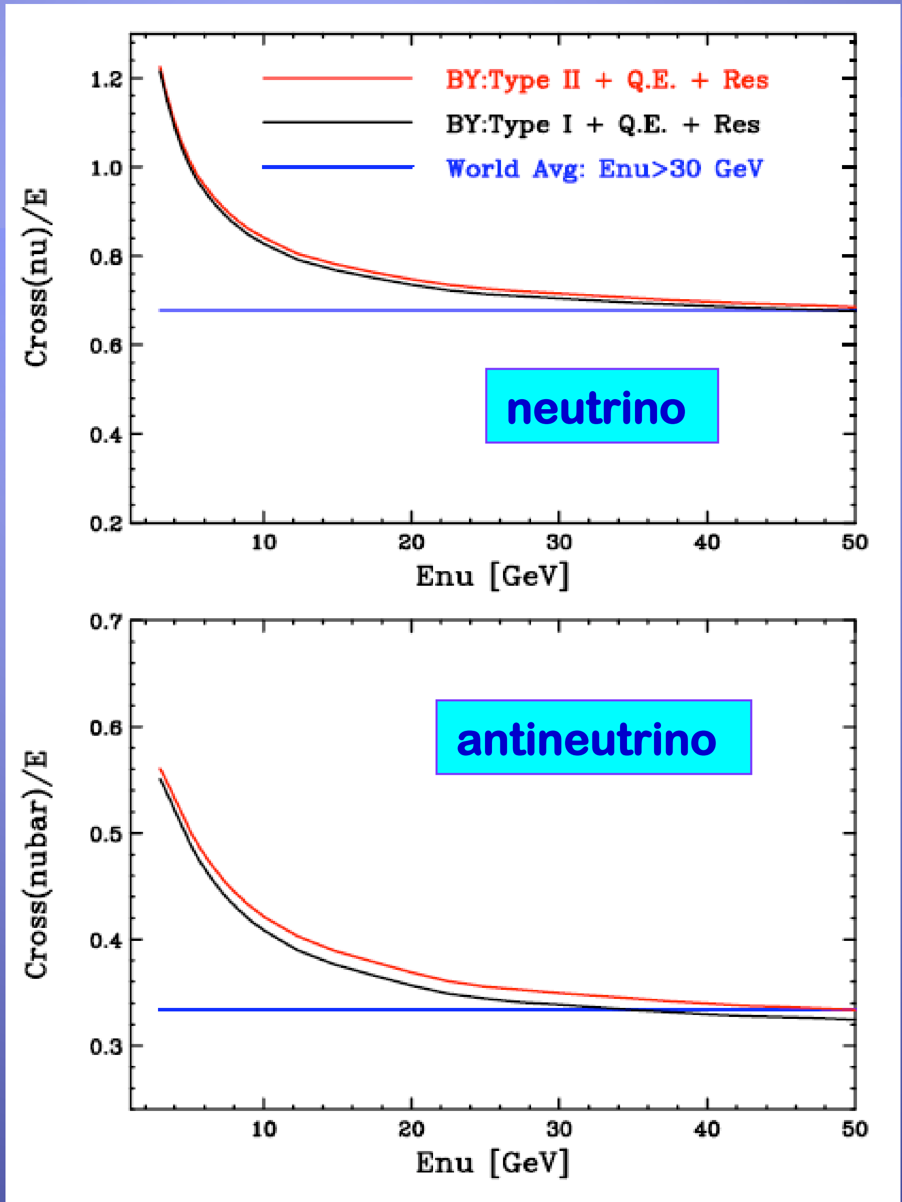
CCFR / Type II updated theory (Ax=PCAC)

Comparison with CCFR (Fe) (red) CHORUS (Pb) data (Blue)

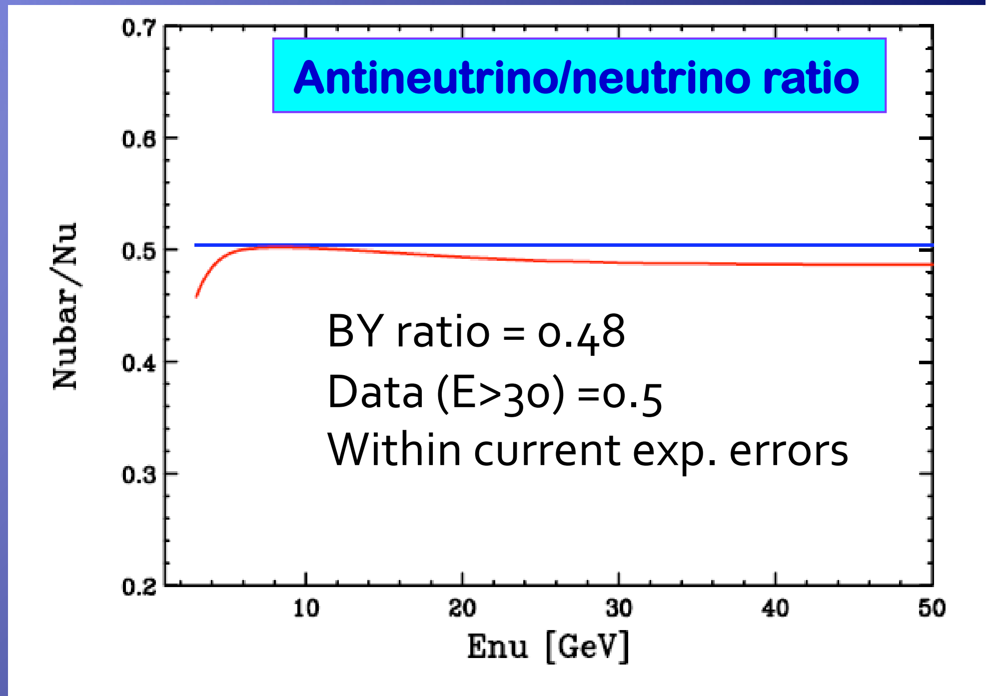
neutrino | antineutrino | neutrino | antineutrino



Total cross sections: type I (A=V) black, type II (A=PCAC) (red). <1% effect on neutrino, larger change in antineutrino. (Cross sections are in better agreement with experimental data.



- BY(DIS, W>1.4) + Q.E. + Resonance



Summary of changes from 2004

2004: BY Model (currently implemented in Neutrino Monte Carlos) has H(x) = 1 (i.e same scaling violations in F2 and XF3) and V=A. It has been used for W>1.8 GeV.

2011: Addition of H(x) correction to XF_3; plus sea axial K factors motivated by PCAC (A=PCAC) to F_2.

1. Yield a small change in the total neutrino cross sections.
2. Change antineutrino cross sections by about 6% (in better agreement with experimental data).
3. Yield better agreement in dσ/dxdy at very small x.
4. Addition of Low W (K^{LW}) K factor extend the validity of model down to W=1.4 GeV, thus providing overlap with resonance models.

Summary & Discussions

- BY Effective LO model with ξ_w describe all e/μ DIS and resonance data as well as photo-production data (down to $Q^2=0$): Provide a good reference for vector neutrino SF.
- dσ/dxdy Data favor updated BY(DIS) type II model (axial=PCAC)
- K factors for axial vectors in BY(DIS) type II model (axial=PCAC) are based on PCAC and could be further tuned with new neutrino data ($Q^2<0.3$, e.g. MINERvA)
- BY(DIS) type II model (axial=PCAC) provide a good reference for both neutrino and antineutrino cross sections for W>1.8 DIS region. Low energy neutrino experiments can normalize their DIS data to our model to determine their flux.
- Model also works well down to W=1.4 GeV, thus providing overlap with resonance models.