Modeling Neutrino Structure Functions at low Q^2

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A Model for all Q^2 region?

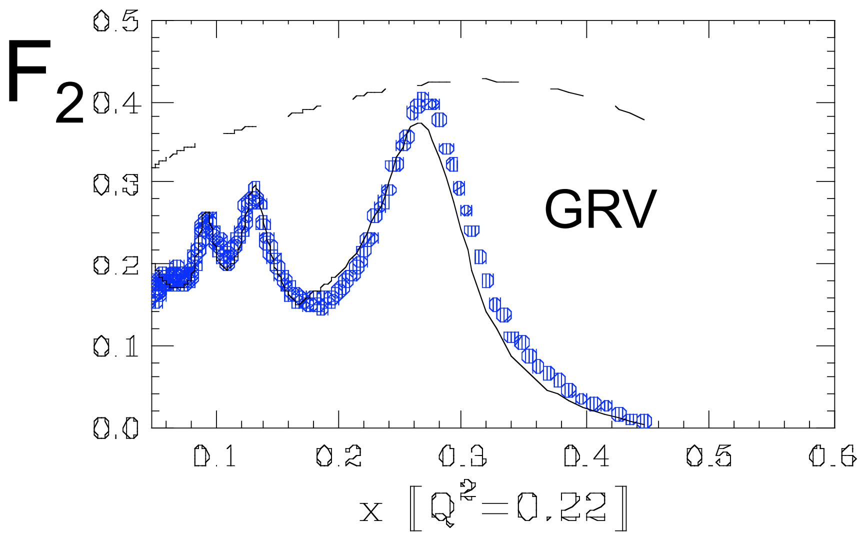
- **The high Q^2 region of lepton-nucleon scattering is well understood in terms of quark-parton model by a series of e/μ/ν DIS experiments.**

- **But the low Q^2 region is relatively poorly understood in neutrino scattering: very important for neutrino oscillation experiments. Many interesting issues…**
  - **PDFs at high x?**
  - **Non-perturbative QCD? target mass, higher twist effects?**
  - **Duality works for resonance region?**
  - **Axial vector contribution?**
  - **Different nuclear effects (e/μ vs ν)?**

- **Build up a model for all Q2 region**

Challenges at Low Q^2

- A model to describe all Q^2 region for e/μ/ν scatterings
  [DIS, resonance, even photo-production(Q^2=0)]
  - Resonance region is overlapped with a DIS region
  - Hard to extrapolate DIS contribution to low Q^2 region from high Q^2 data, because of non-pQCD effects
- Describe DIS+resonance together using quark-parton model



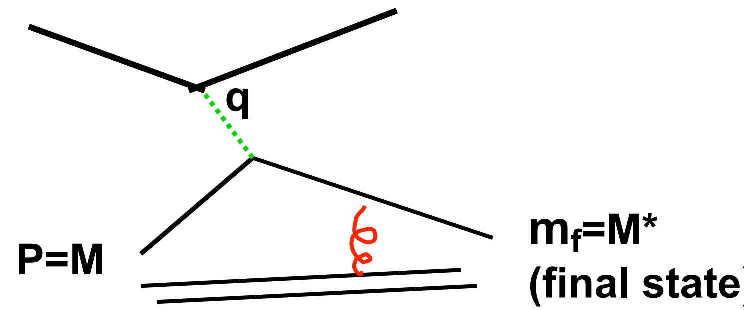
- Resonance scattering in terms of quark-parton model?
  Duality works, many studies by JLab
- Higher twist effects, PDFs at high x PDFs? SLAC, JLab data

Effective LO Approach

➢ **Quark-Parton model:**
- **NLO pQCD +TM+HT, and NNLO pQCD+TM good for DIS and resonance**
- **A HT extracted from the NLO analysis: ~ NNLO pQCD term: indep. of e/μ/ν**

➢ **Effective LO approach:**

Use a LO PDFs with a new scaling variable to absorb TM, HT, higher orders
- **A reference for σ(ν,d): study nuclear effect**



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

$$\frac{Q^2}{Q^2 + C} F_2(\xi_w, Q^2)[\mathrm{LO}]$$

Fit with ξ_w

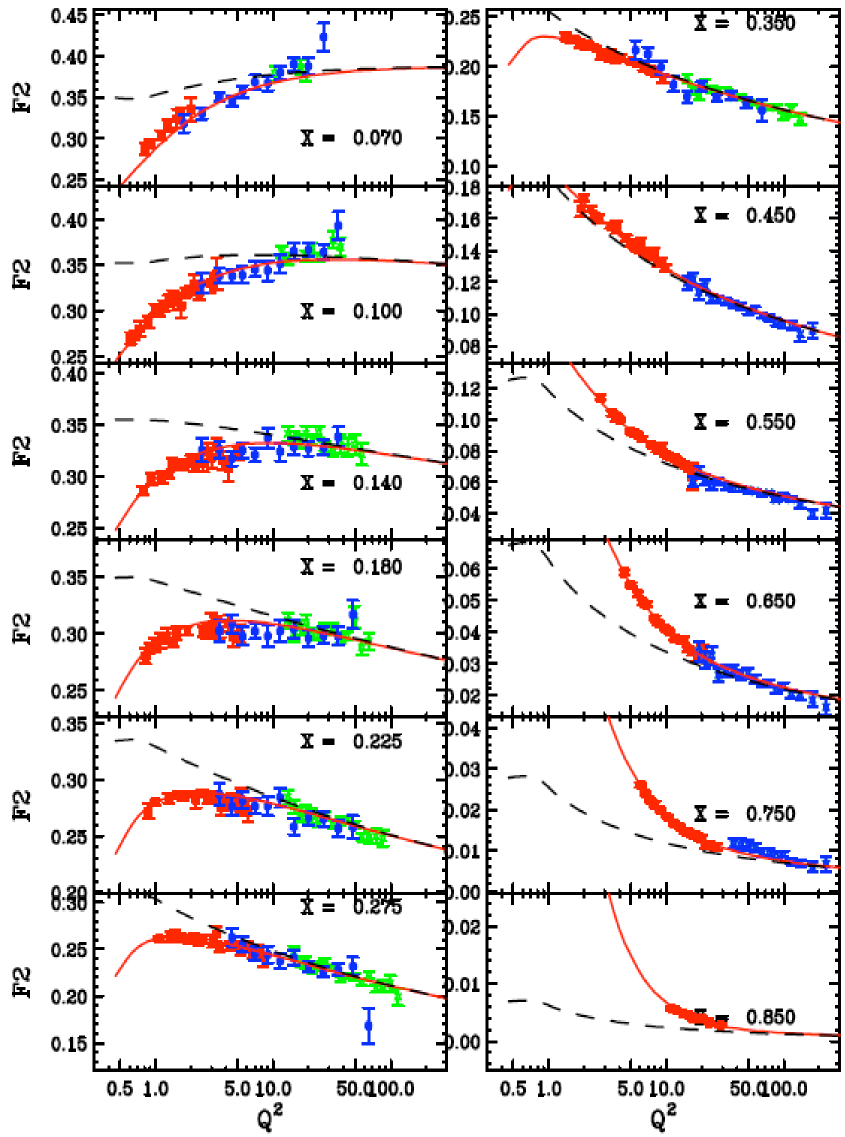
- Use GRV98 LO
- $\xi_w = [Q^2 + \mathbf{B}] / [M\nu (1+(1+Q^2/\nu^2)^{1/2}) + \mathbf{A}]$

- Different K factors for valence and sea
- $K_{sea} = Q^2/[Q^2+C_{sea}]$
  $K_{val} = [1 - G_D^2(Q^2)] * [Q^2+C_{2V}] / [Q^2+C_{1V}]$,
  $G_D^2(Q^2) = 1/[1+Q^2/0.71]^4$

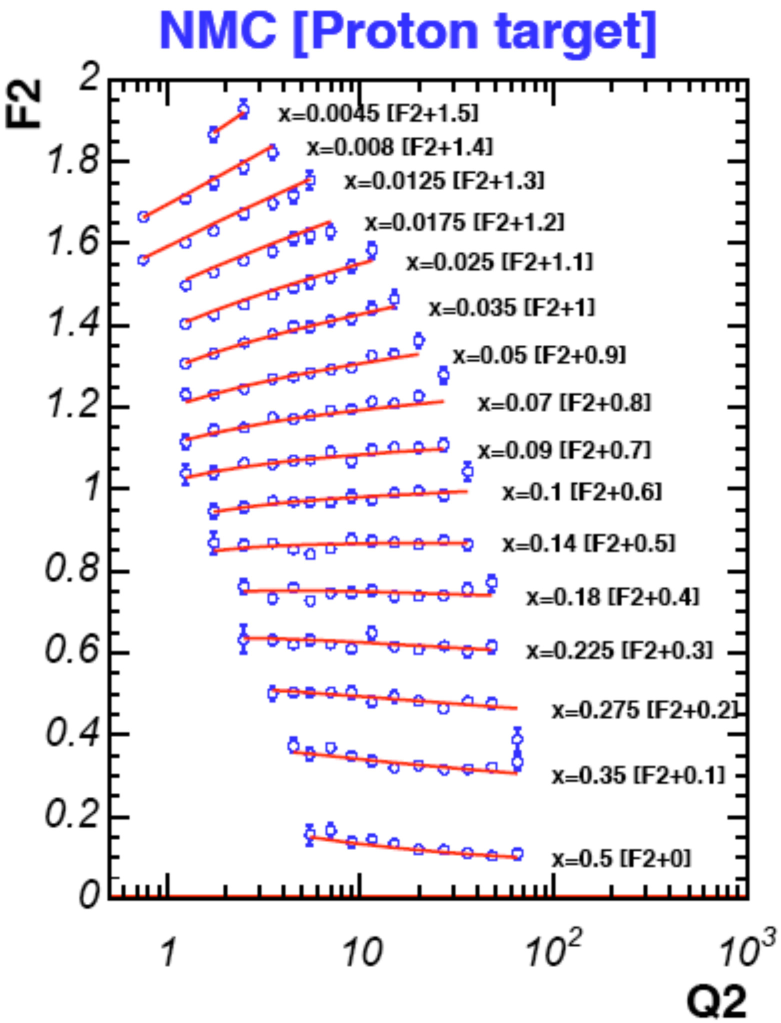
- Freeze the evolution at $Q^2 = 0.8$

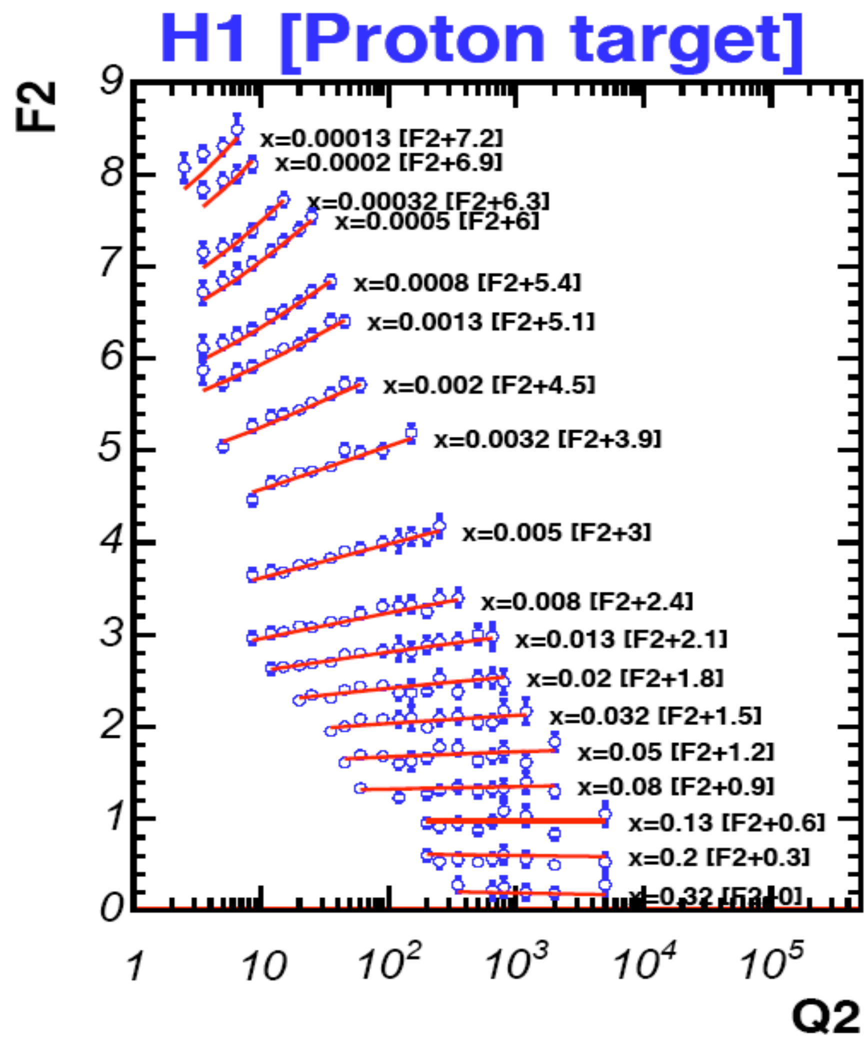
- Very good fits are obtained using SLAC/NMC/BCDMS p, d with low x HERA/NMC F_2
  A=0.418, B=0.222, Csea = 0.381
  $C_{1V} = 0.604$, $C_{2V} = 0.485$
  χ^2/DOF= 1268 / 1200

DIS $F_2(d)$



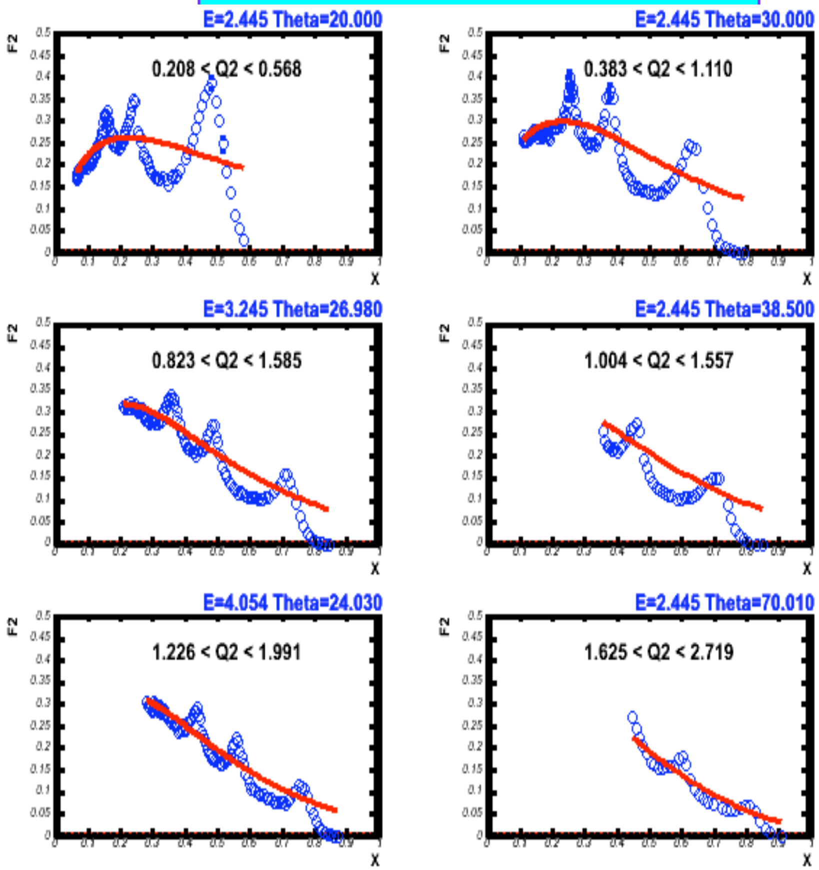
DIS F_2 at low x





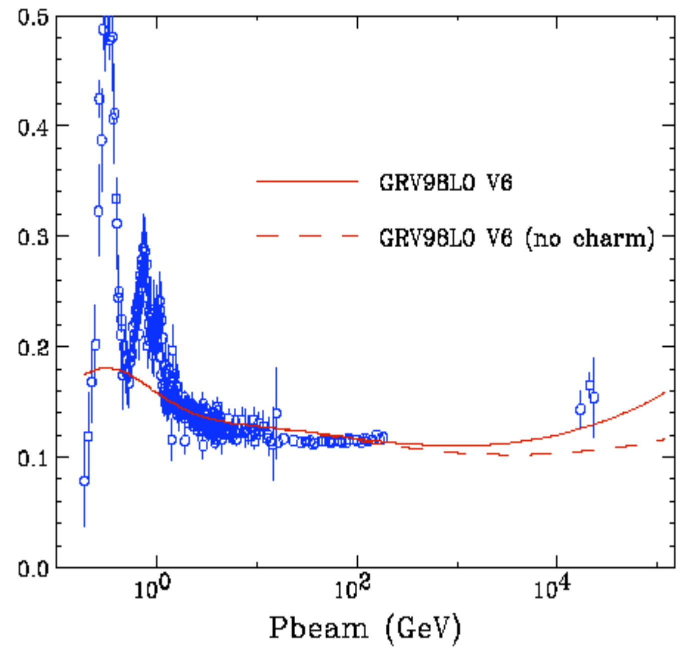
Resonance and photo-production data

$F_2(p)$ resonance



Not included in the fit

Photo-production (p)



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

where $F_2(\xi_w, Q^2)$

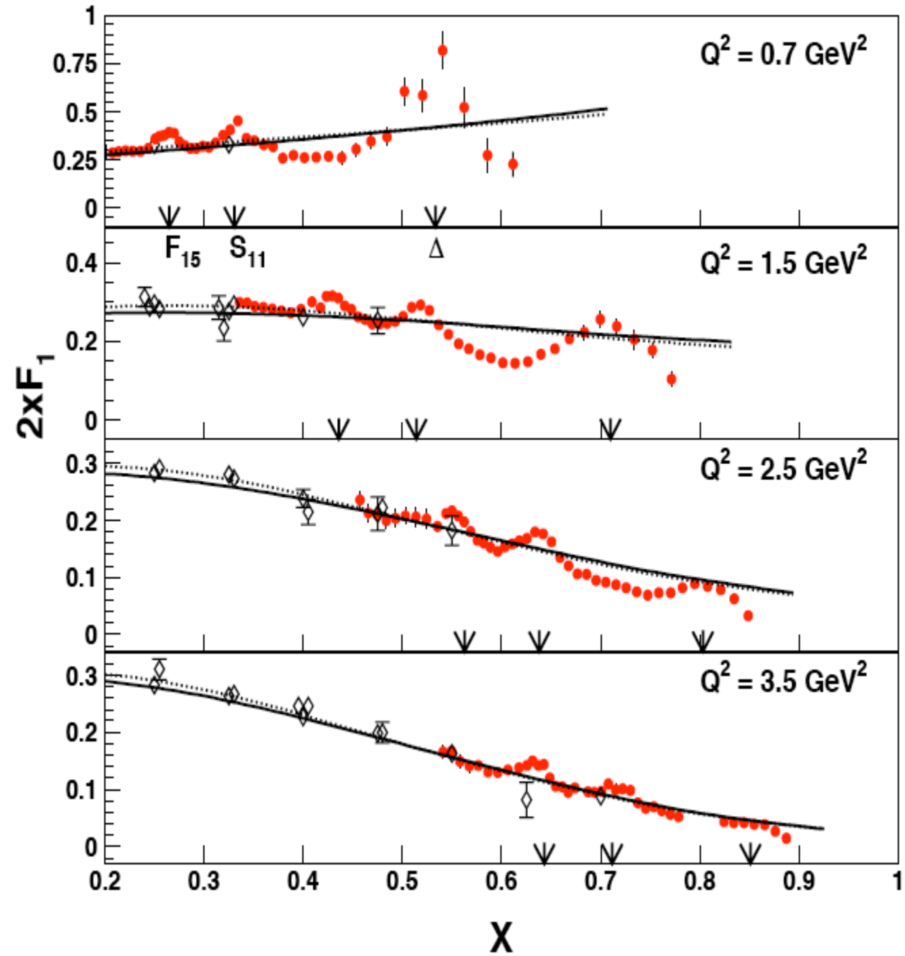
$= Q^2 /(Q^2 + C) * F_2(\xi_w)$

$2xF_1$ data

- All DIS e/μ F_2 data are well described
- Photo-production data (Q^2=0) also work: thus included in the latest fit
- 2xF1 data (Jlab/SLAC) also work:

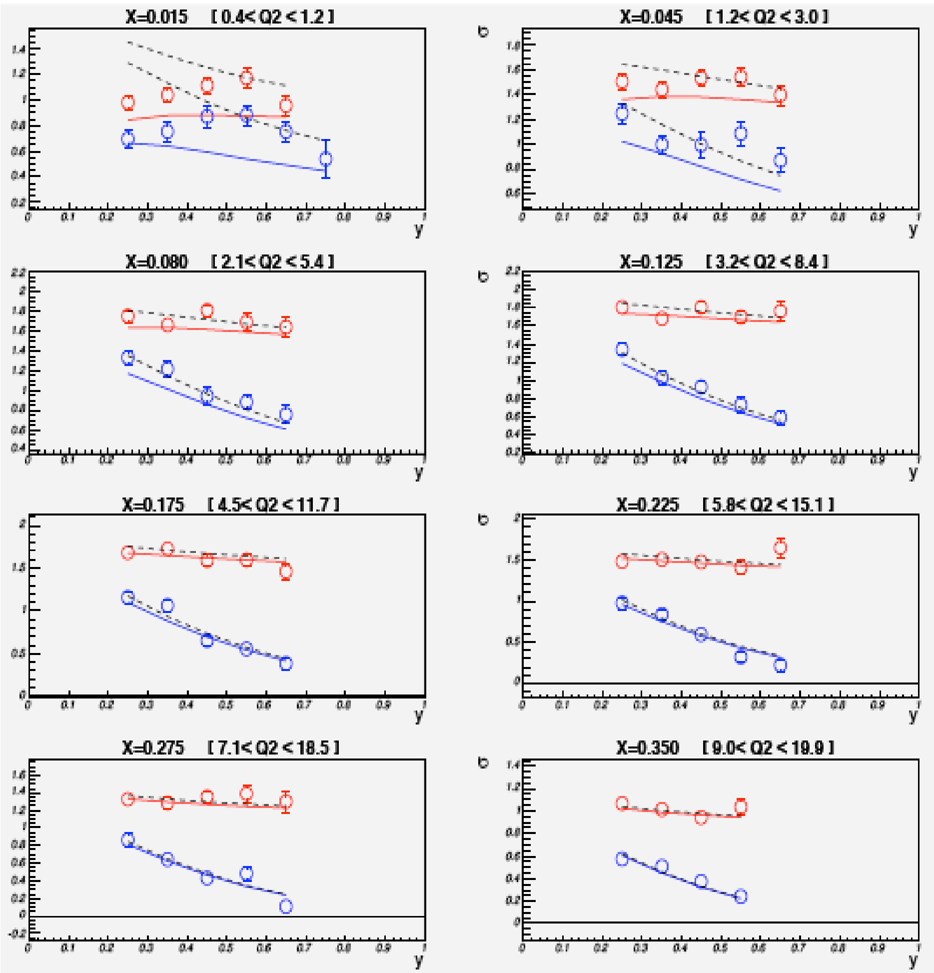
using $F_2(\xi_w)$+R1998

Jlab $2xF_1$



Comparison with neutrino data

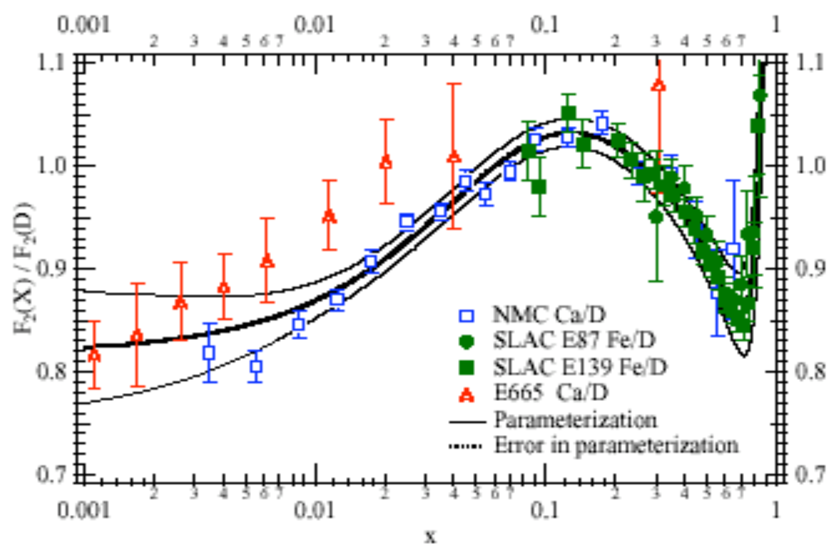
CCFR diff cross at Eν= 55 GeV



- **Assume vector = axial**
- **Apply nuclear corrections using e/μ scattering data**

➢ Underestimated at low x=0.015

➢ Total anti-neutrino cross section lower by 5%?



ν : red, $\bar{\nu}$: blue, −− σ (ξw) **----** σ (x)

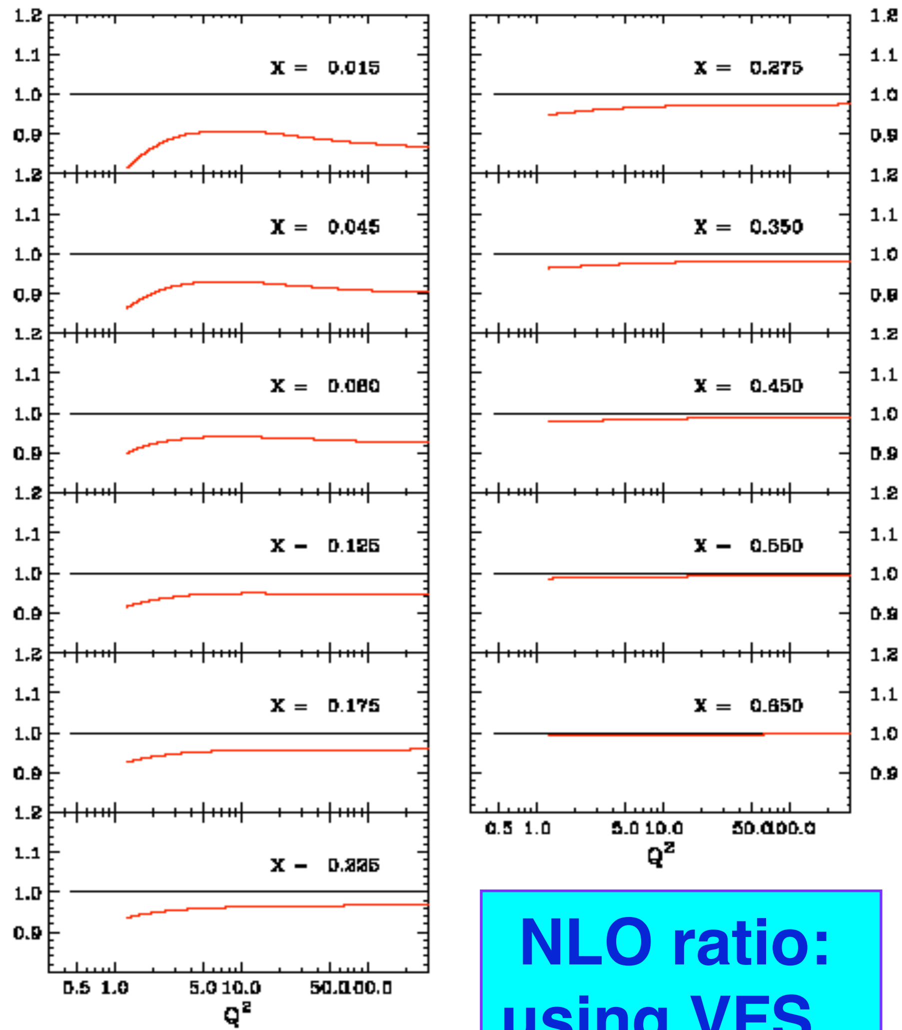
NLO Correction to xF_3?

- **Scaling variable, ξw absorbs higher order effect on F_2, but not xF3; F_2 data used in the fitting**

- **Check double ratio**

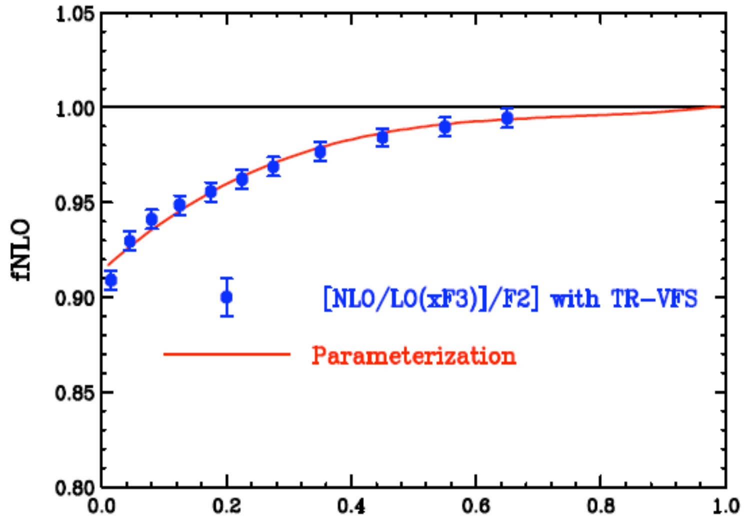
$$\frac{xF_3(\text{NLO})}{xF_3(\text{LO})} / \frac{F_2(\text{NLO})}{F_2(\text{LO})}$$

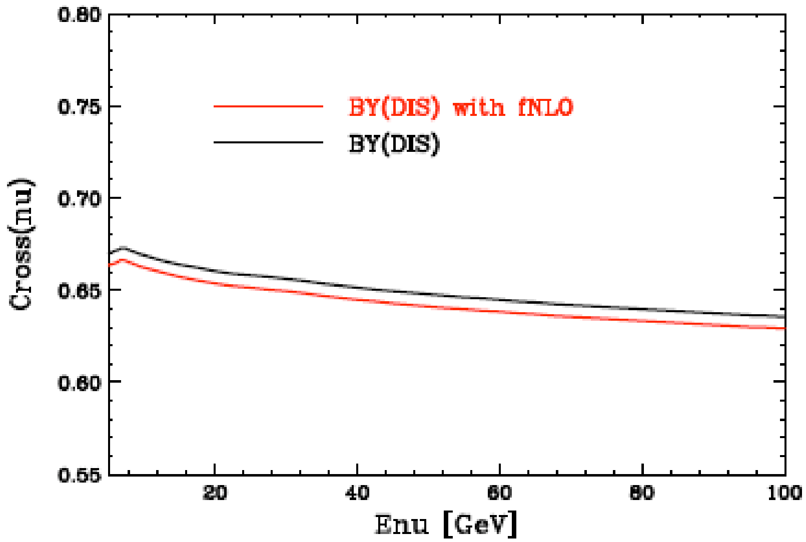
=> not 1 but indep. of Q^2



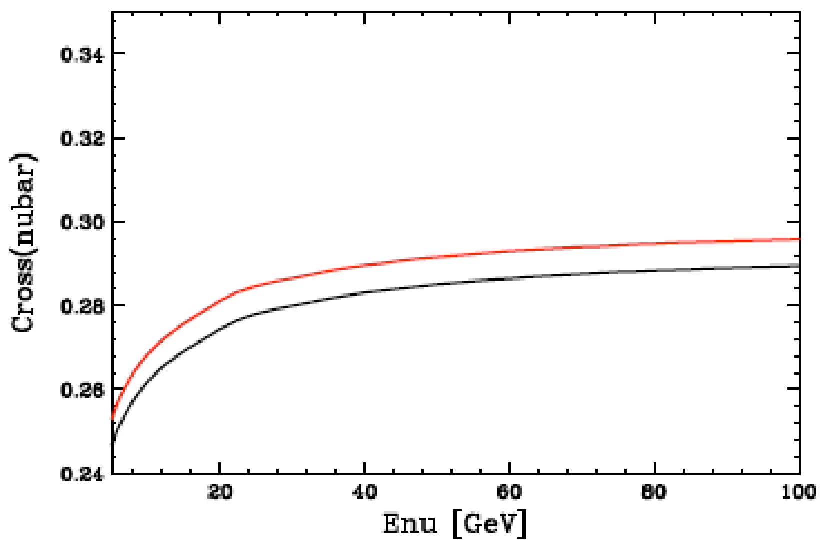
NLO ratio: using VFS

Effect of xF_3 NLO correction





- Parameterized xF3 correction as a function of x
- Neutrino cross section down by 1%
- Anti-neutrino cross section up by 3%



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Axial-vector contribution

$$K_i^{\text{vector}}(Q^2) = \frac{Q^2}{Q^2 + C}, \quad K_i^{\text{axial}}(Q^2) = \frac{Q^2 + C_1}{Q^2 + C_2},$$

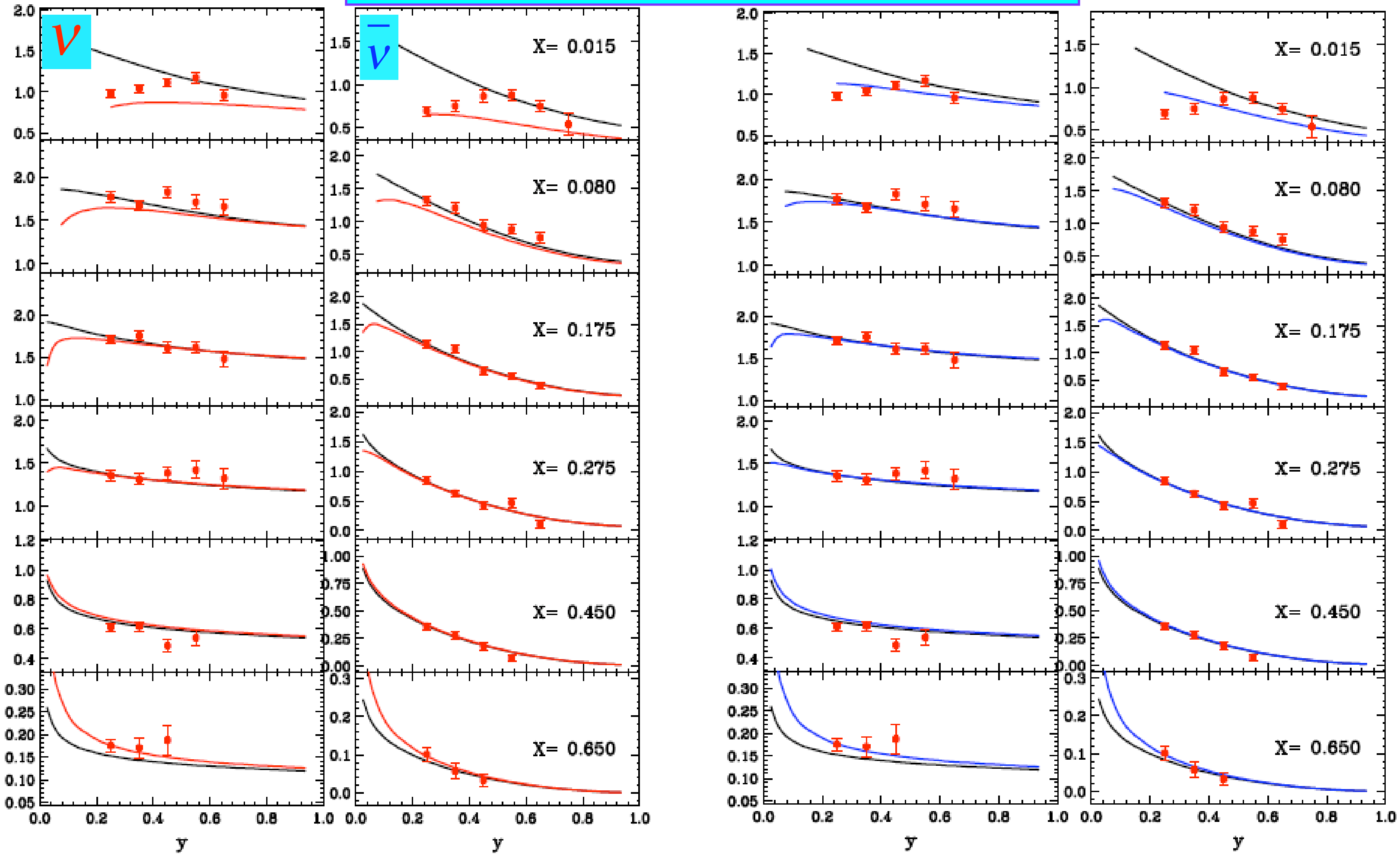
$$F_2^{\nu}(x,Q^2) = \sum_i \left[K_i^{\text{vector}}(Q^2) + K_i^{\text{axial}}(Q^2) \right] \times \xi_W \left[q_i(\xi_W, Q^2) + \bar{q}_i(\xi_W, Q^2) \right]$$

$$xF_3^{\nu}(x,Q^2) = \sum_i 2 \left[K_i^{\text{vector}}(Q^2) K_i^{\text{axial}}(Q^2) \right]^{1/2} \times \xi_W \left[q_i(\xi_W, Q^2) - \bar{q}_i(\xi_W, Q^2) \right]$$

- **In our neutrino cross section model assumed $K^{axial} = K^{vector}$**
- **Toward axial-vector contribution**
  - **$K^{axial} = 1$**
  - **Extract K^{axial} using existent neutrino data (underway)**

Axial-vector contribution

CCFR diff. cross at Eν= 55 GeV

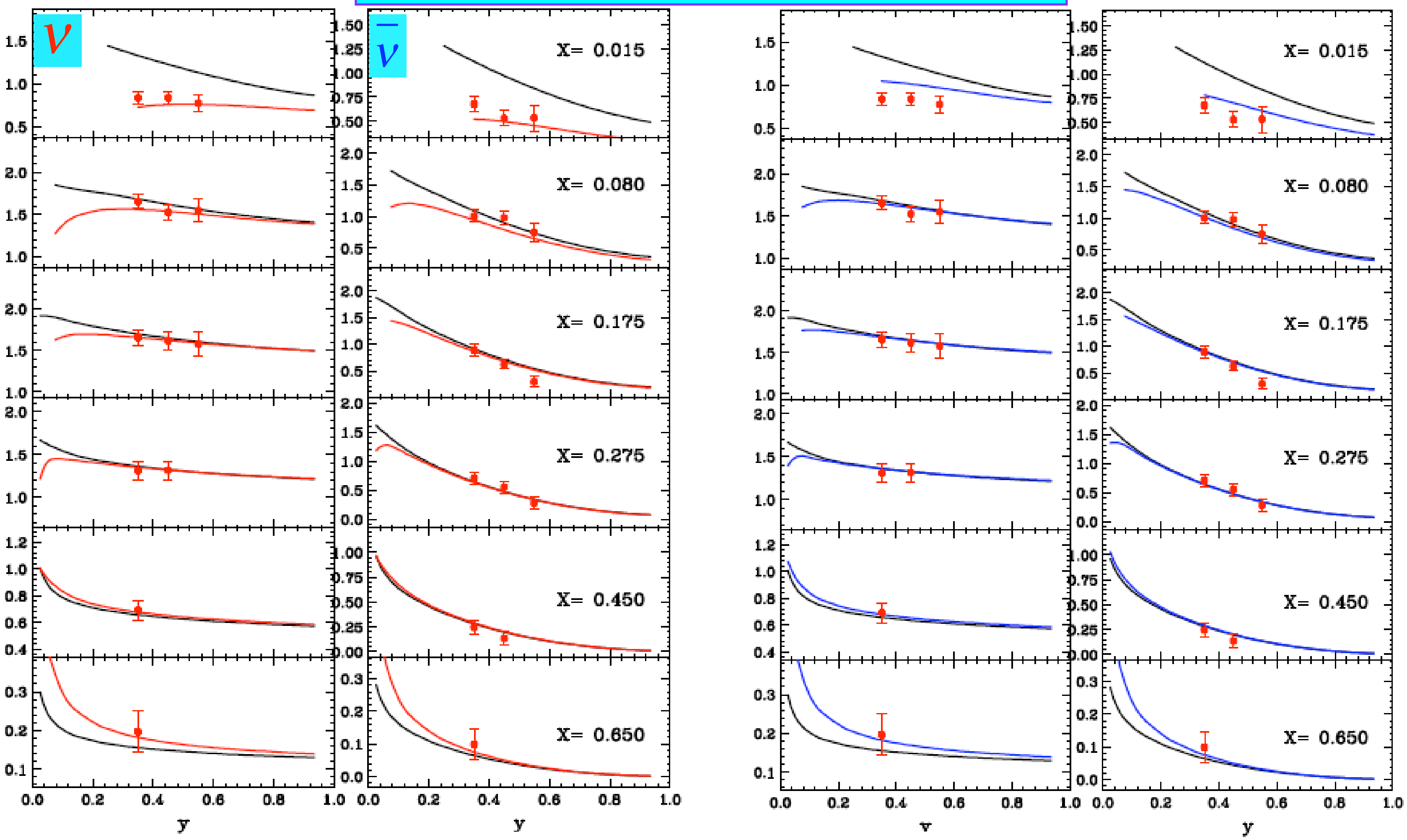


$K^{axial} = Q^2/(Q^2+C)$

$K^{axial} = 1$

Axial-vector contribution

CCFR diff. cross at Eν= 35 GeV



$K^{axial} = Q^2/(Q^2+C)$ **$K^{axial} = 1$**

Summary and Discussions

- Effective LO model with ξw describes all DIS and resonance data as well as photo-production data:
  - Provide a good reference for neutrino cross section, $\sigma(\nu,d)$
  - Possible studies for axial vector contribution at $Q^2<1$ and diff. nuclear effect
  - High energy neutrino data at low Q^2 is in favor of additional axial vector contribution
- Things to do
  - Need to tune axial vector contribution using existent neutrino data and possibly with coming MINERνA
  - Different nuclear effects (e vs ν, F2 vs xF3):

    Jlab and MINERνA data are very crucial

Comparison with CDHSW data

Eν= 23 GeV