Unified approach for modeling ν-N and e-N scattering cross sections from high energy to very low energy,

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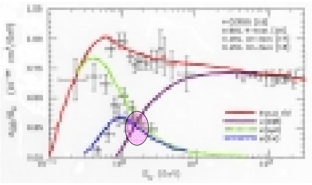
1. Neutrino cross sections at low energy?

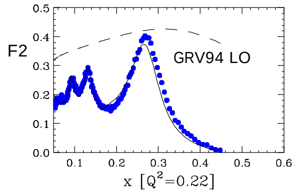
- Many neutrino oscillation experiments (K2K, MINOS, CNGS, MiniBooNE, and neutrino programs at the JHF) are in few GeV region.
- But neutrino cross sections in this low energy region is poorly understood (especially, resonance and low Q2 DIS contributions).
- Thus, neutrino cross section model at low energy is crucial for the precise next generation neutrino oscillation experiments.



- Quasi-Elastic / Elastic (W=Mn): $\nu_\mu + n \rightarrow \mu^- + p$
  - well measured and described by form factors
- Resonance (low Q^2, W< 2): $\nu_\mu + p \rightarrow \mu^- + p + p$
  - poorly measured and only 1st resonance described by Rein and Seghal (double counting issue with DIS)
- Deep Inelastic: $\nu_\mu + p \rightarrow \mu^- + X$
  - well measured by high energy experiments and described by quark-parton model.

2. Building up a model for all Q^2 region

- Describe DIS, resonance, even photo- production (Q^2=0) in terms of quark-parton model. With PDFS, it is straightforward to convert charged-lepton scattering cross sections into neutrino cross section.
- Challenge:
  - Understanding of high x PDFs at very low Q^2?
    - non-perturbative QCD effects
  - Understanding of resonance scattering in terms of quark-parton model?



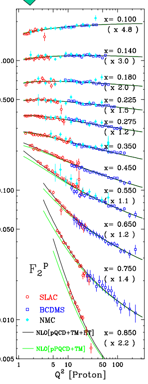
- The PDFs do not describe the data at low Q^2

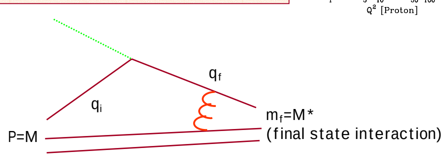
3. Lessons from previous QCD studies

- The DIS data are well described by NLO pQCD with following non-perturbative corrections.
  - Kinematic higher twist (target mass:TM) in the form of Georgi & Politzer ξ scaling.
  - Dynamic higher twist (multi-quark correlation etc:HT) using power corrections.
- Most of dynamic higher twist corrections (in NLO analysis) are similar to missing NNLO higher orderterms (NNLO+TM~NLO+TM+HT).
- Resonance region also works (duality works).

[Ref: Yang& Bodek: PRL 82, 2467 (1999). Eur. Phys. J. **C13**, 241 (2000)]

- Thus, low energy neutrino data should be described by the PDFs with target mass and higher twist effects from low energy e/m scattering data.





Resonance: scattered with very high x parton, then final state int.

4. Effective LO model

- NNLO QCD+TM approach: good to explain the non-perturbative QCD effects at low Q^2
- Effective LO approach (for MC cross section): Use effective LO PDFs with a new scaling variable, ξ_w to absorb target mass, higher twist, missing higher orders

$$\xi = \frac{Q^2 + m_f^2 + O(m_f^2 - m_i^2)}{Mv\,(1+(1+Q^2/v^2))^{1/2}} \rightarrow \quad Xbj = Q^2/2Mv$$

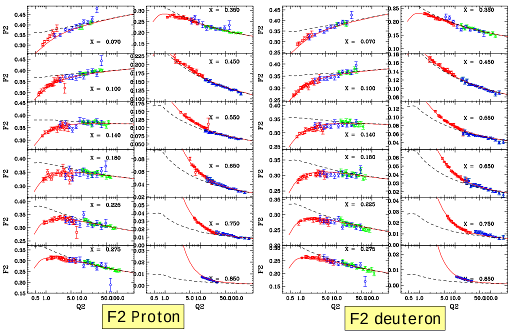
ξ=parton momentum fraction with finite initial and final quark masses

Use ξ_w= [Q^2+B] /[Mv (1+(1+$Q^2/v^2)^{1/2}$) +A]

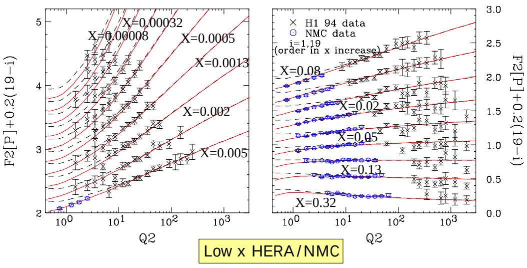
1. Start with GRV98 LO (Q^2_{min}=0.80 GeV^2)
   - describe F2 data at high Q^2
2. Replace the X with a new scaling, ξ_w
3. Multiply all PDFs by K factors for photo prod. limit and higher twist [$\sigma(\gamma) = 4\pi\alpha/Q^2 * F_2(x, Q^2)$]
   Ksea = Q^2/[Q^2+Csea]
   Kval = **[1- G_D^2 (Q^2)] *[Q^2+C2V] / [Q^2+C1V]**
   where G_D^2 (Q^2) = 1/ [1+Q^2 / 0.71] ^{4}
4. Freeze the evolution at $Q^2 = Q^2_{min}$
   - $F_2(x, Q^2 < 0.8) = K(Q^2)*F_2(Xw, Q^2=0.8)$

- Fit to all DIS F2 P/D (with low x HERA data)
  A=0.418, B=0.222
  Csea = 0.381,C1V = 0.604, C2V= 0.485
  χ^2/DOF = 1268 / 1200

5. LO model fit results

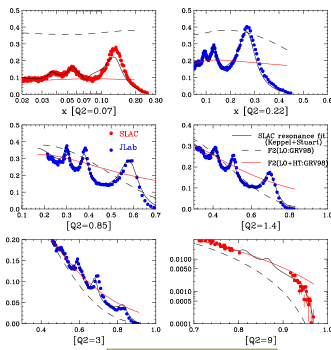


F2 Proton F2 deuteron



Low x HERA/NMC

6. Comparison with resonance, photo-production, neutrino data



F2 (p) resonance data

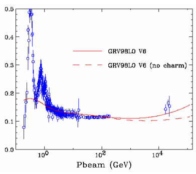
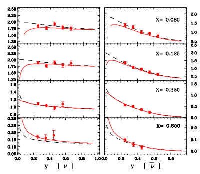


Photo-production (γ-P)



CCFR diff. Xsection at 55 GeV

Summary and Plan

- Our modified GRV98LO PDFs with a scaling variable, ξ_w describe all SLAC/BCDMS/NMC/HERA DIS data.
- Our predictions in good agreement with resonance data (down to Q^2 = 0) , photo-production data, and with high-energy neutrino data.
- This model should describe a low energy neutrino cross sections reasonably well. (implemented in NUANCE,NEUGEN)

Can be added from electron scattering
•Resonance effect from Jlab data.
• Nuclear effects on various targets

Cannot be added from electron scattering
•Axial vector effects at very low Q2
•Different nuclear effects in neutrino scatt.

Collaborative approach with nuclear physics community

1. High x and low Q^2 PDFs for e/neutrino
2.Electron scattering exp. at JLAB.
2.Off-axis neutrino exp. at Fermilab/JHF