1. Neutrino cross sections at low energy?

- Many neutrino oscillation experiments (K2K, MINOS, CHORUS, 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.

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 effects
  - Understanding of resonance scattering in terms of quark-parton model?

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 George & Politzer 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 NLO higher order terms (NNLO-TM-NLO+TM-HT).
- Resonance region also works (duality works).


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.

4. Effective LO model

- N-NLO 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 \( x_w \) to absorb target mass, higher twist, missing higher orders: \( F_2(x, Q^2) = F_2(x_w, Q^2) \cdot K(Q^2) \).
  - Use parton momentum fraction with finite initial and final quark masses: \( \xi \).\( \xi = (P^2 + m_f^2)/m_q^2 \).
  - describe the data

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

5. LO model fit results

Our modified GRV98-LO PDFs with a scaling variable \( x_w \) describe all SLAC/BDMS/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).

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

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

Summary and Plan

Collaborative approach with nuclear physics community

- 1. High x and low Q2 PDFs for e/neutrino
- 2. Electron scattering exp. at JLAB.
- 2. Off-axis neutrino exp. at Fermilab/JHF.