LBNE Collaboration Meeting
May 27, 2010

Complementarity of ν & e probes of hadron structure

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Outline

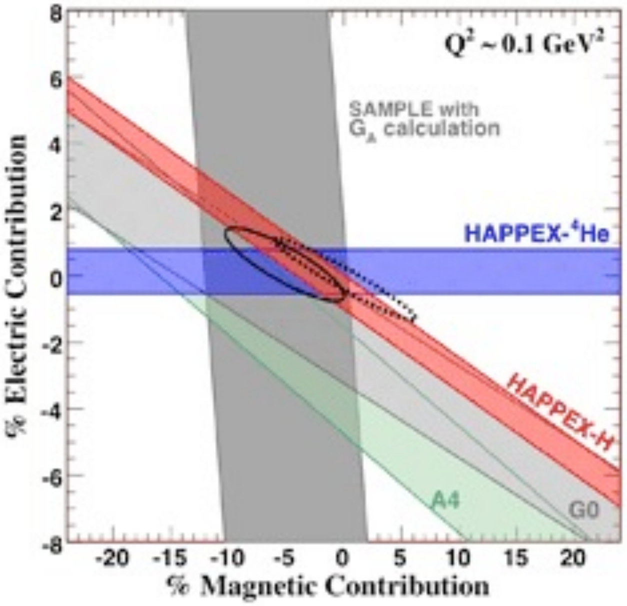
- Many areas of overlap for nucleon (& nuclear) structure studies with neutrino (LNBE) *vs.* electron (JLab) beams
  - → strange content of the nucleon
  - → parton distribution functions
  - → higher twists & quark-hadron duality
  - → nuclear modification of nucleon properties
  - → generalized parton distributions

- Cooperation between communities already exists
  (*e.g.* MINERνA, CTEQX)

- Workshop on *Intersections of Nuclear Physics with Neutrinos and Electrons* (2006)
  http://conferences.jlab.org/neutrino/

Strange content of the nucleon

- Strange vector form factors measured to high precision in parity-violating e scattering at JLab, MAMI & elsewhere



$$G_E^s = \rho_s Q^2 + \rho_s' Q^4$$

$$G_M^s = \mu_s + \mu_s' Q^2$$

$$\rho_s = -0.03 \pm 0.63 \text{ GeV}^{-2}$$

$$\mu_s = 0.37 \pm 0.79$$

*Young et al., PRL **99**, 122003 (2007)*

→ strange quark contribution to proton magnetic moment less than 10%

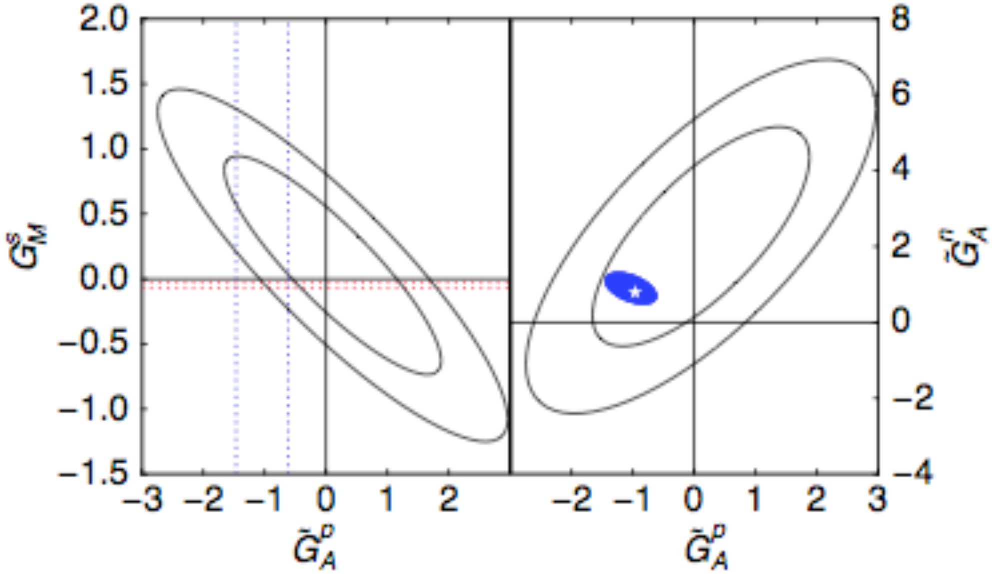
→ strange electric form factor consistent with zero

→ consistent with theory (lattice + phenomenology)

*Leinweber et al., PRL **94**, 212001 (2005)*

Strange content of the nucleon

- Strange axial vector form factors not as well determined



$$\tilde{G}_A^N = \tilde{g}_A^N (1 + Q^2/M_A^2)^{-2}$$

$$M_A = 1.026\,\mathrm{GeV}$$

$$\tilde{g}_A^p = -0.80 \pm 1.68$$
$$\tilde{g}_A^n = 1.65 \pm 2.62$$

*Young et al., PRL **99**, 122003 (2007)*

→ includes "anapole" contribution (weak interaction within target)

→ complementary measurement in neutrino-nucleon elastic scattering

Strange content of the nucleon

- Strange axial form factor at $Q^2 = 0$ related to spin carried by strange quarks through sum rule

$$\int_0^1 dx\, g_1^p(x,Q^2) = \left(\frac{1}{12} g_A^{(3)} + \frac{1}{36} g_A^{(8)}\right) C_{NS}(Q^2) + \frac{1}{9} g_A^{(0)}|_{\text{inv}} C_S(Q^2)$$

→ from elastic neutrino-proton scattering (NC) measure

$$2g_A^{(Z)} = (\Delta u - \Delta d - \Delta s)_{\text{inv}} + \mathscr{P}\, g_A^{(0)}|_{\text{inv}} + O(m_{t,b,c}^{-1})$$

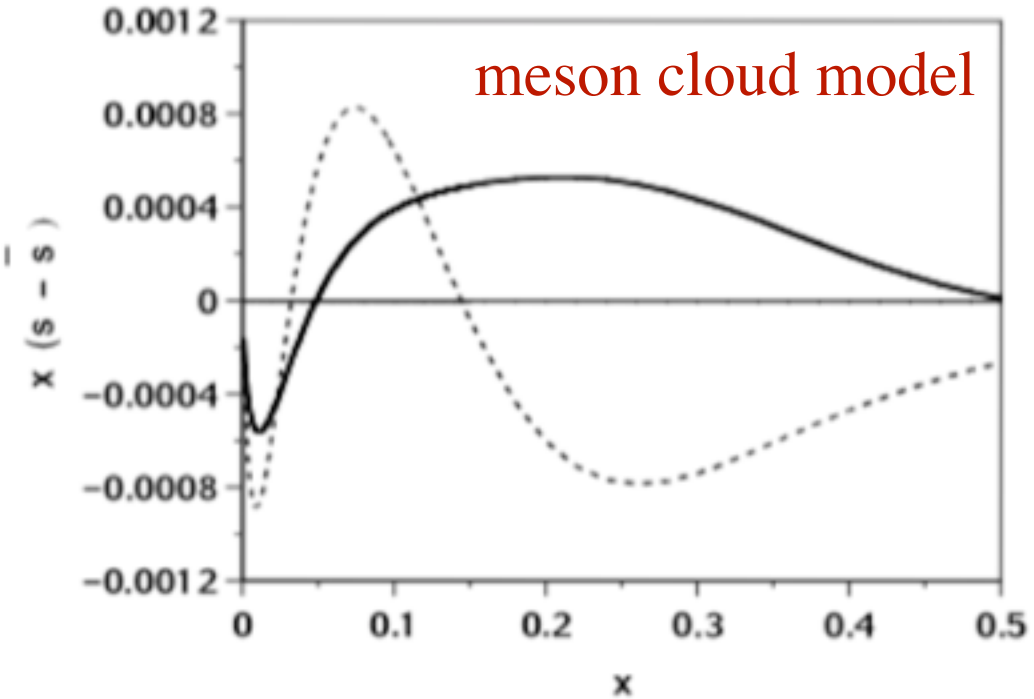
→ using $(\Delta u - \Delta d - \Delta s)_{\text{inv}} = g_A^{(3)} + \frac{1}{3} g_A^{(8)} - \frac{1}{3} g_A^{(0)}|_{\text{inv}}$

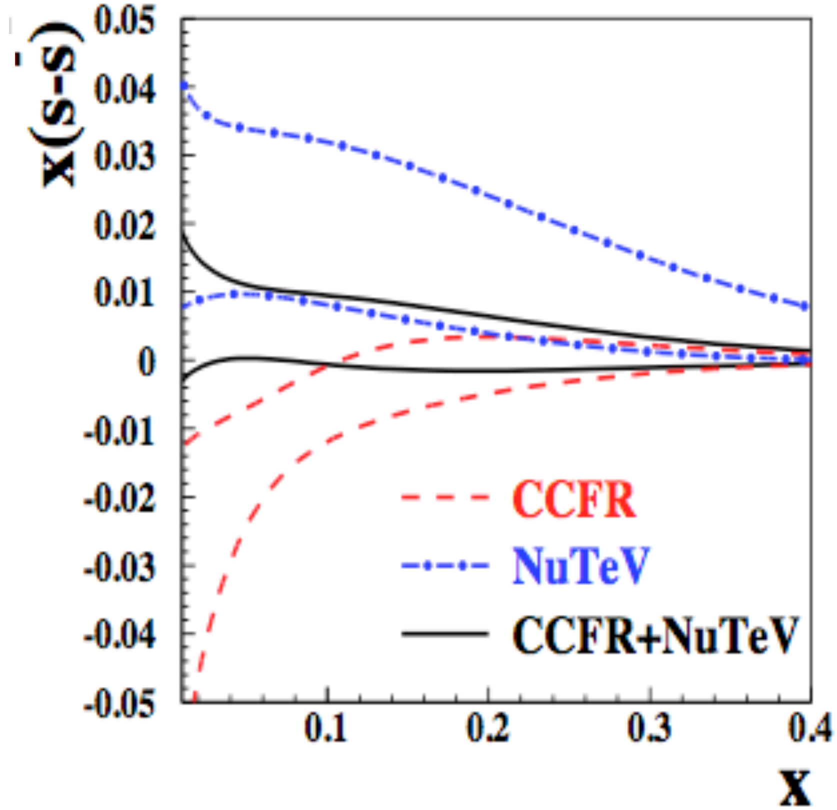
extract $g_A^{(0)}|_{\text{inv}} = (\Delta u + \Delta d + \Delta s)_{\text{inv}}$ to obtain independent determination of Δs

*Bass, Crewther, Steffens, Thomas, PRD **66**, 031901 (2002)*

Strange content of the nucleon

- Neutrino/antineutrino DIS sensitive to strange-antistrange asymmetry in proton





*Alekhin, Kulagin, Petti, PLB **675**, 433 (2009)*

→ integrated asymmetry -0.001 ± 0.04

→ asymmetry small but important indicator of nonperturbative physics

Parton distribution functions

- Vital to have precise F_3 structure function input into global PDF fits

  → most useful if measurements are on hydrogen (or deuterium) targets to avoid nuclear effects

- High-precision data on F_2 and F_L from JLab at large x

  → desirable to have $F_2\,/\,F_L$ separation for neutrinos at similar kinematics

- Data at low Q^2 and W would also be useful

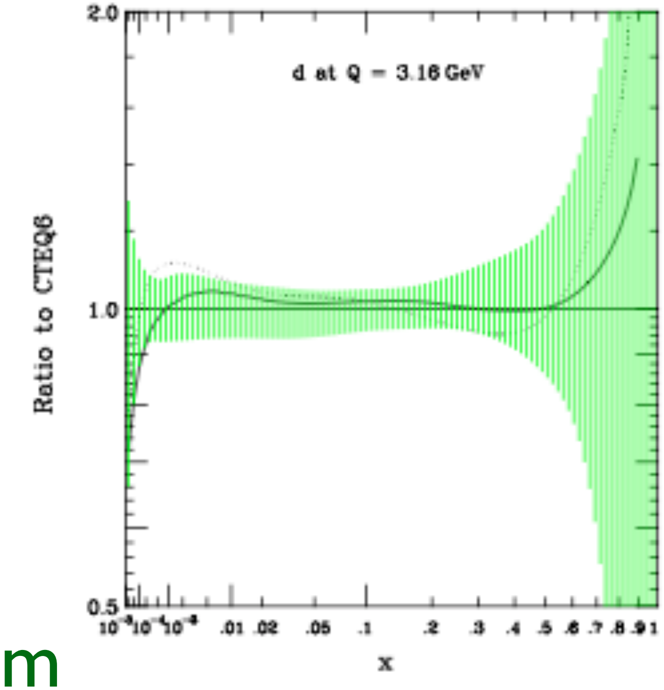
  → *e.g.* CTEQ6X global fit with $Q^2 > 1.69\ \mathrm{GeV}^2,\ W^2 > 3\ \mathrm{GeV}^2$ *doubled* number of DIS data points available

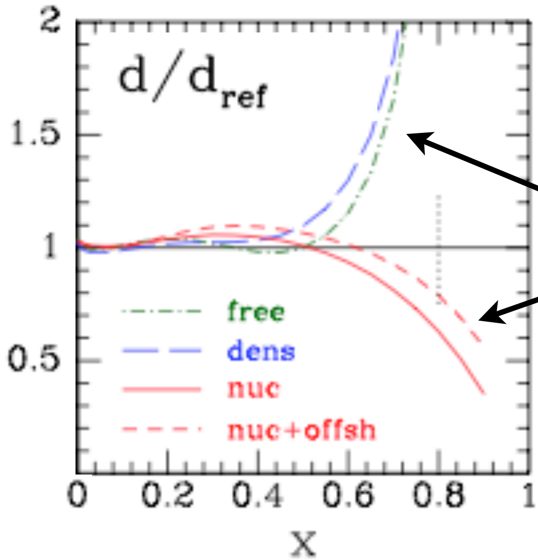
Accardi et al., PRD ***81****, 034016 (2010)*

Parton distribution functions

- At large x ($x > 0.5$–0.6) d quark distribution (or d/u ratio) is very poorly determined

  → recent CTEQ6X fit attempts to better constrain d quark to $x \sim 0.8$, but is limited by nuclear corrections in deuterium





different models for nuclear effects

Accardi et al., PRD ***81***, *034016 (2010)*

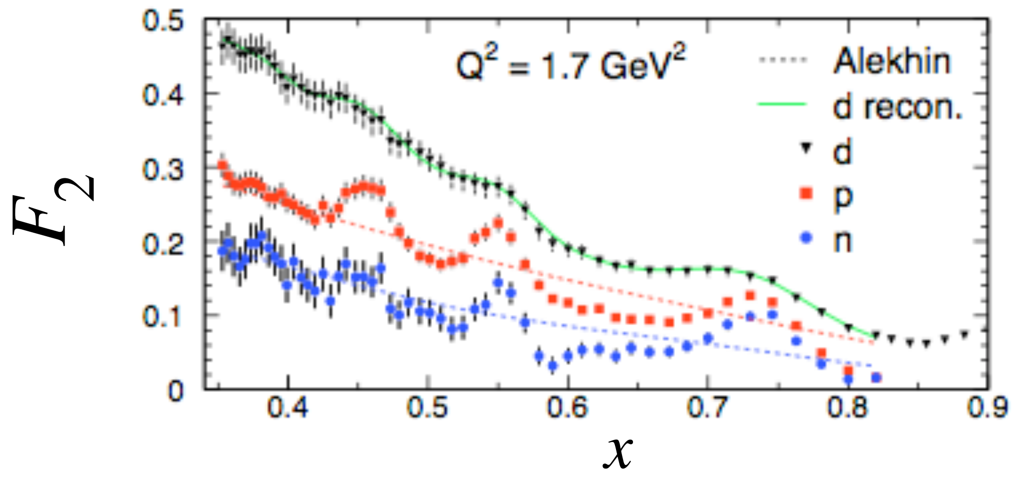
Parton distribution functions

- Several planned experiments at JLab with $12\ \mathrm{GeV}$ will measure d/u to $x \sim 0.85$ with minimal nuclear corrections
  - → SIDIS from D with slow backward proton ("BONUS"); inclusive $^3\mathrm{He}\,/\,^3\mathrm{H}$ ratio; and PVDIS from proton

- Cleanest and most direct method is to use neutrino and antineutrino DIS on hydrogen
  - → selects d and u quark PDFs at large x
  - → need reach up to $x \sim 0.85$, with as large a Q^2 range as possible to control for higher twists

Higher twists and quark-hadron duality

- Accuracy of quark-hadron duality being established in through high-precision measurements of electromagnetic structure functions in resonance region

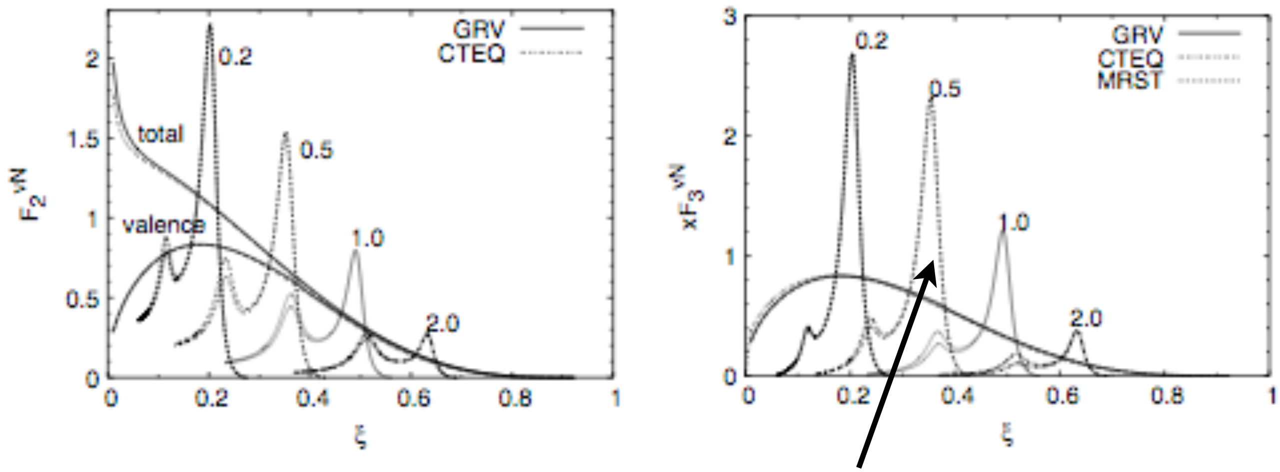


Malace et al., PRL ***104****, 102001 (2010)*

→ higher-twist (duality-violating) corrections appear to be ~10−20% for low structure function moments

Higher twists and quark-hadron duality

- Neutrino DIS will allow test of universality of duality, and determine size of higher twist matrix elements in P-odd *vs.* P-even structure functions



model relies on very old neutrino resonance-production data

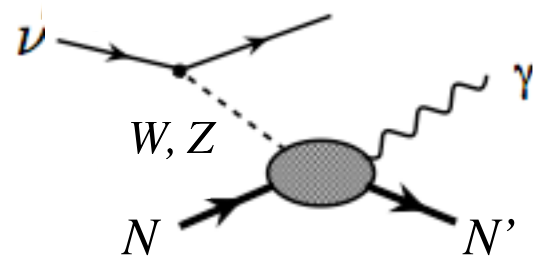
Lalakulich, Paschos, WM
PRC ***75****, 015202 (2007)*

→ can lead to better constraints on large-x PDFs

→ precise mapping out of resonance spectrum vital

Generalized parton distributions

- Comprehensive program of hard exclusive reactions ($e.g.$ DVCS) at JLab to extract GPDs
  - → determine orbital angular momentum of quarks
  - → map out $3D$ structure of nucleon



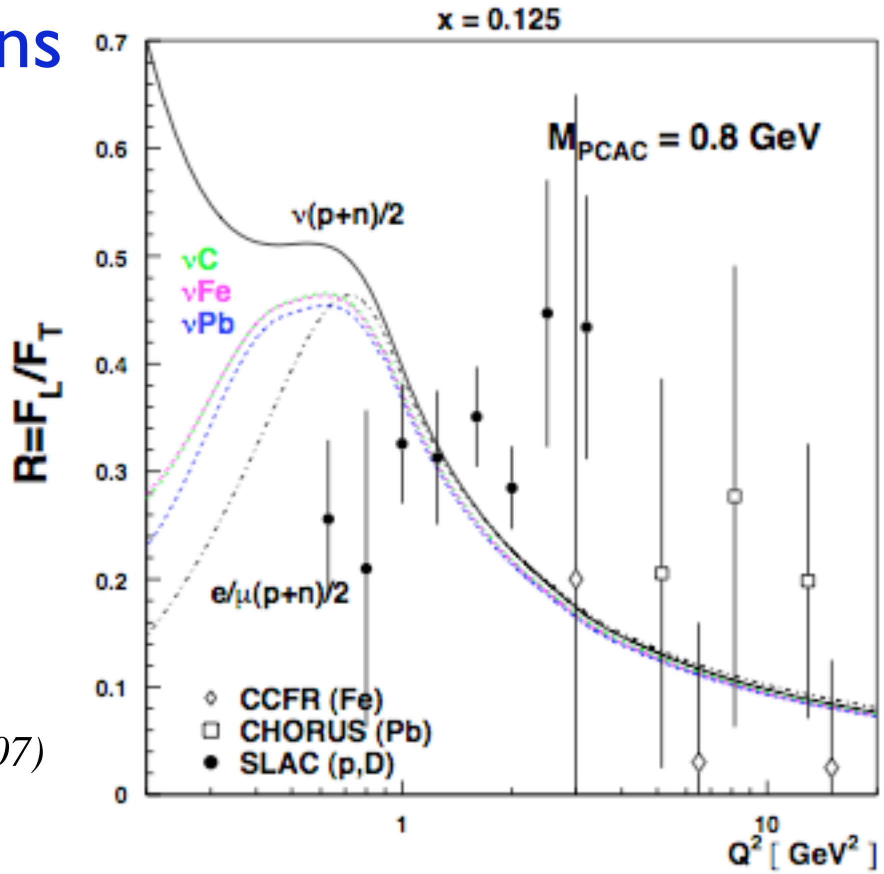
- Neutrino DVCS uniquely sensitive to C-odd combinations of GPDs, not accessible with e scattering
  - → flavor decomposition, non-diagonal transitions
  - → can extract spin-dependent valence & sea distributions with an unpolarized target!

Psaker, WM, Radyushkin
PRD ***75****, 054001 (2007)*

Nuclear effects

- Important to understand differences between nuclear EMC effect for photons *vs.* W/Z bosons

→ significant differences predicted, especially at low Q^2 and low x



Kulagin, Petti
PRD ***76****, 094023 (2007)*

→ critical for extracting nucleon information from nuclear target data (most neutrino experiments)

– remain to be tested!

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