WG-2 Neutrino Interactions

Goal of Working Group – Identify Neutrino Scattering Physics of Interest to Particle and Nuclear Physics Community in the Era of the Proton Driver

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Some initial comments

- Considerable work done on how neutrino scattering experimentation helps neutrino oscillation physics (MINERvA collaboration – D. Harris et al. hep-ex/041005)
- I’ll concentrate on how nuclear physics community views neutrino scattering

Nuclear Physics

Nuclear Physics Community has broad range of interests

JLab is largely concentrated on structure of the nucleon

Our interest is in bridging the gap between the quark/gluon regime and the baryon/meson regime

We are all part of the “subatomic physics” community, with more shared interests than differences

Physics Topics

- Elastic Form Factors
- Duality
- Parton Distribution Functions
- Generalized Parton Distribution Functions
- Neutrino Magnetic Moment

Why is Nucleon Structure Important?

- Quark-gluon structure of hadrons remains biggest unresolved problem of Standard Model
- Without understanding *confinement* and nature of bound states, cannot understand 99% of world we live in

Why is Nucleon Structure Important?

- Hadronic structure is vital input into nuclear and astrophysics calculations
- Needed to understand backgrounds in searches for "*new physics*" in high-energy colliders - *e.g.* neutrino oscillations

- Wally Melnitchouk – JLab Theory Group

Elastic Form Factors

- A large part of the JLab program devoted to proton and neutron electromagnetic form factors
- Strange quark contribution and axial form factor through parity violation

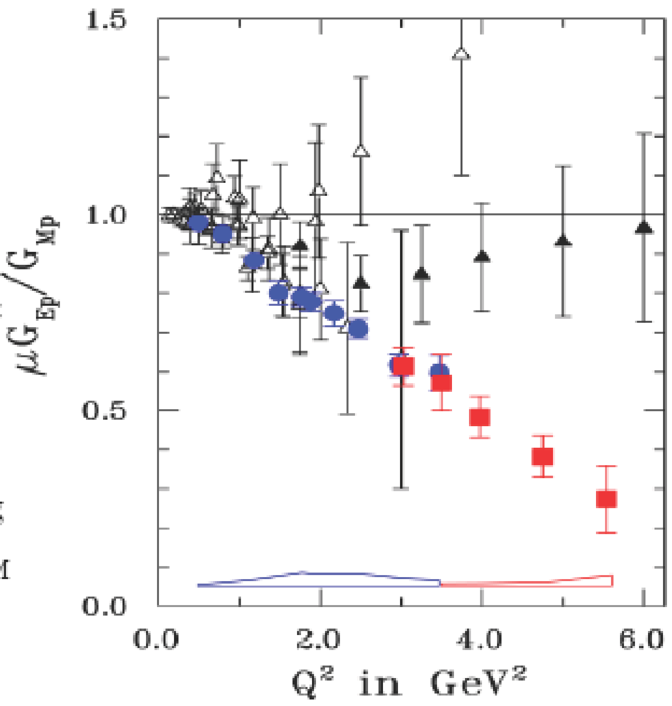
Elastic Form Factors

- E93-027 PRL 84, 1398 (2000)
  Used both HRS in Hall A with FPP
- E99-007 PRL 88, 092301 (2002)
  used Pb-glass calorimeter for electron detection to match proton HRS acceptance
- Reanalysis of E93-027 (Pentchev)
  Using corrected HRS properties

→ Clear discrepancy between polarization transfer anc Rosenbluth data

→ Investigate possible source, first by doing optimized Rosenbluth experiment

Old Rosenbluth results (triangles) wrong because radiative corrections to large G_M impact extraction of small G_E.



Neutrino Scattering

Bring Me the Head of a Strange Quark

- It is possible, likely (?), that the full parity violation program will finish with only upper limits for strange quarks in the nucleon.
- It is hard to do much better with PV (G_0 all ready has large acceptance, high luminosity, and runs for long time).
- Neutrino-nucleon elastic scattering may be only way to make significantly better s quark measurements.
- FINeSSE has best chance, of existing proposals, to find nonzero strange quark content.
- After FINeSSE, even better measurements possible with proton driver.

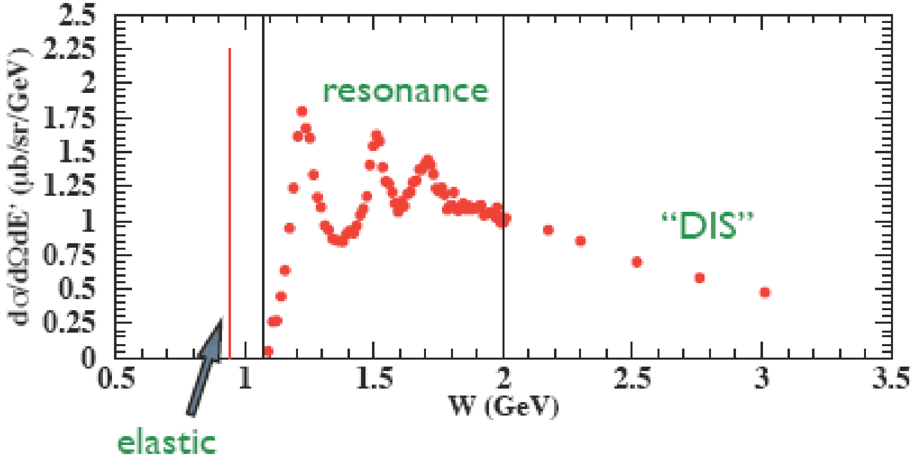
C. Horowitz, Indiana

Also - Direct Access to Axial Form Factor

Duality

Resonances

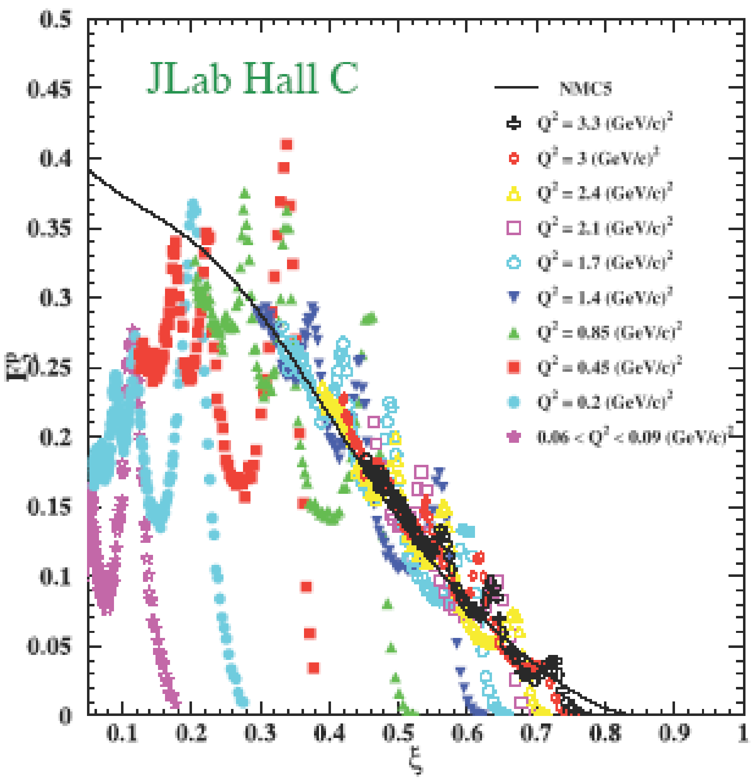
As W decreases, DIS region gives way to region dominated by nucleon resonances



$$x = \frac{Q^2}{W^2 - M^2 + Q^2}$$

Duality-2

Quark-hadron duality



Proton Driver Workshop Oct. 2004

Duality-3

- Not well understood – believed to indicate that higher twist effects are small
- Resonance production by neutrinos would provide insight into origins of duality
- Duality could allow access to the high-x region

Parton Distributions

Why are parton distribution functions (PDFs) important?

- PDFs provide basic information on structure of bound states in QCD
  - momentum, flavor, spin ... distributions of quarks and gluons in hadrons
- Integrals of PDFs (moments) test fundamental sum rules (Adler, Bjorken...)
  - relate *high-energy* observables to *low-energy* hadron properties
- Vital input into modeling hadronic backgrounds in high-energy reactions

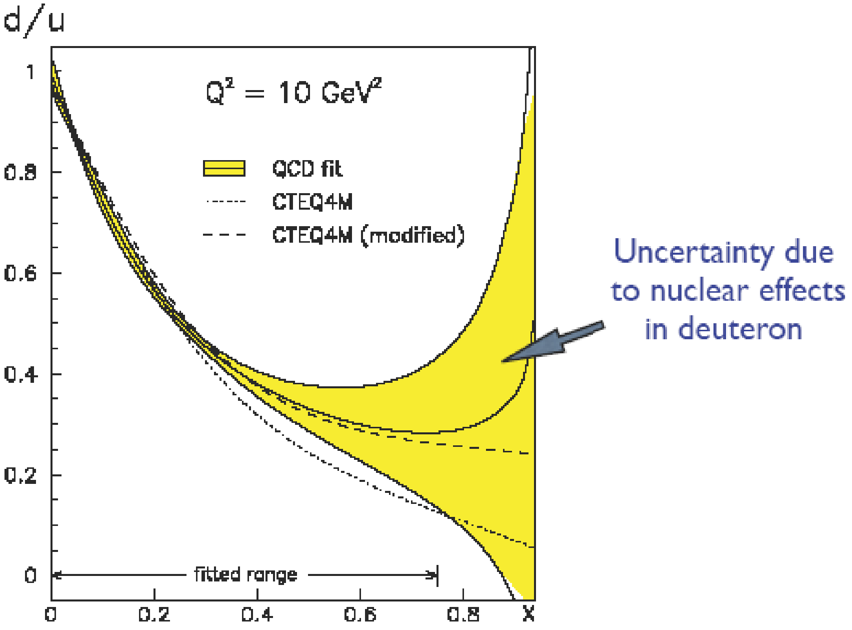
Wally Melnitchouk

Proton Driver Workshop Oct. 2004

Parton Distributions-2
What do Neutrinos Add?

ν and $\bar{\nu}$ DIS from protons can determine d/u ratio at large x, free of nuclear corrections

$$\frac{F_2^{\nu p}}{F_2^{\bar{\nu} p}} = \frac{d}{u}$$



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Parton Distributions - 3

Neutrino DIS

e.g. neutrino - proton scattering

$$F_2^{\nu p} = 2x\ (d + \bar{u} + s)$$

$$F_2^{\bar{\nu} p} = 2x\ (u + \bar{d} + \bar{s})$$

$$xF_3^{\nu p} = 2x\ (d - \bar{u} + s)$$

$$xF_3^{\bar{\nu} p} = 2x\ (u - \bar{d} - \bar{s})$$

→ ν scattering allows $q - \bar{q}$ separation

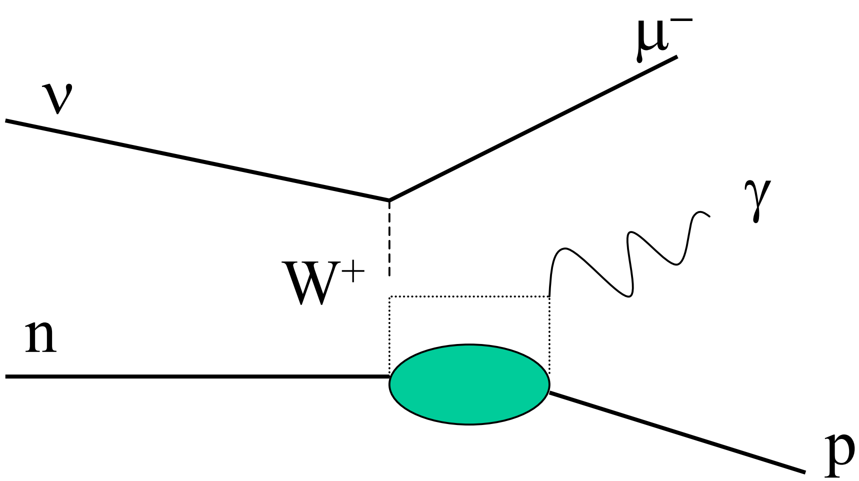
→ test *e.g.* whether $s = \bar{s}$

Generalized Parton Distributions

- Provide a 3-dimensional picture of the nucleus
- Experiments ongoing at JLab using DVCS p(e,e'γp)
- Only access to flavor dependence through weak-DVCS n(ν,$\mu\gamma$p)

Weak DVCS

W> 2 GeV, t small, E_γ large -
Exclusive reaction



GPD -2

- Cross sections are small (~10^41 cm^2)
- Need neutrino and anti-neutrino beams
- Greatly prefer hydrogen target

Neutrino Magnetic Moment

- Fundamental property of the neutrino
- Sizable magnetic moment (near current limits) indication of new physics
- Needs much higher statistics

Neutrino Magnetic Moment-2

Different beyond-the-Standard-Model theories predict different sizes for this neutrino magnetic moment

Minimally Extended Standard Model

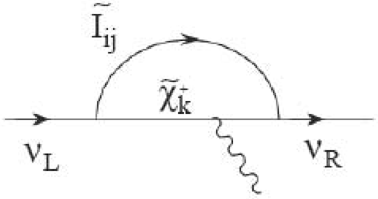
$$\mu_\nu = \frac{3eG_F}{8\sqrt{2}\pi^2} m_\nu \sim 3 \times 10^{-19} \mu_B$$

SUSY models→left-right supersymmetric models

$\mu_{\nu_e} \cong 5.34 \times 10^{-15} - 10^{-16}\ \mu_B$

$\mu_{\nu_\mu} \cong 1.13 \times 10^{-12} - 10^{-13}\ \mu_B$

$\mu_{\nu_\tau} \cong 1.9 \times 10^{-12}\ \mu_B$



Large Extra Dimensions

$\mu_\nu \cong 1.0 \times 10^{-11}\ \mu_B$

order of magnitude lower than present limits

B. Fleming

Status at time of Proton Driver

- Neutrino-Nucleus scattering well measured
- Antineutrino-Nucleus scattering still poorly known
- Neutrino/antineutrino-nucleon (and neutrino-deuterium) scattering still essentially unknown – especially for neutral currents

What's Needed

- Proton and deuterium targets
- Neutrino AND Anti-Neutrino beams with high purity (i.e. sign selected neutrino beam)
- Good intensity (needs proton driver intensities)

A new era

Neutrino-Nucleon experiments have been “back of the envelope experiments” – they only test back of the envelope calculations

Proton driver opens the possibility to do real experiments – ones where we know what’s in the beam, what its energy is, and intensities sufficient to give good statistics

Conclusion

- Lots of neutrino scattering physics possible
- Complementary to JLab program
- Of considerable interest to nuclear physics community
- What is need for nuclear physics is needed to understand systematics of neutrino oscillation physics