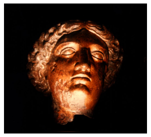
Exclusive reactions

R. Ransome
Rutgers, The State University of New Jersey

August 9, 2010

Outline



- Nuclear physics
- Quasi-elastic scattering and the nucleon form factors
- Coherent pion production

RUTGERS

Nuclear Physics

- Nuclear physics has expanded in recent years to include many topics formerly considered in particle physics domain
  - The 100% duty factor, high polarization, high intensity beam at JLab has allowed tremendous improvements in precision over, e.g., SLAC
- Considerable efforts at JLab are now devoted to studying the structure of the nucleon and modifications of that structure in the nucleus
- Understanding the transition region from quarks and gluons to baryons and mesons is a major goal of intermediate energy nuclear physics
- Neutrino scattering contributes to understanding these questions in a qualitatively different way than electron scattering

RUTGERS

Nucleon Form Factor

- We have known since the historic experiments of Hofstadter that the nucleon is not a point particle
- The scattering of an electrons from nucleons probes the spatial distribution of the nucleon.
- Can be described in terms of two form factors

$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_{mott} \left[\tau G_M^2\left(Q^2\right) + \varepsilon G_E^2\left(Q^2\right)\right] / \varepsilon\left(1+\tau\right) \quad \tau = Q^2 / 4m_p^2 \qquad \varepsilon = 1/\left[1 + 2\left(1+\tau\right)\tan^2\left(\theta/2\right)\right]$$

G_E and G_M are fixed at $Q^2=0$ by charge and magnetic moment of the nucleon and in a non-relativisitic view are Fourier transforms of charge and magnetization

Also frequently expressed in terms of the helicity conserving (Dirac) form factor F_1 and non-conserving (Pauli) form factor F_2

$G_E=F_1-(Q^2/4m^2)F_2$ and $G_M=F_1+F_2$

RUTGERS

Form Factors

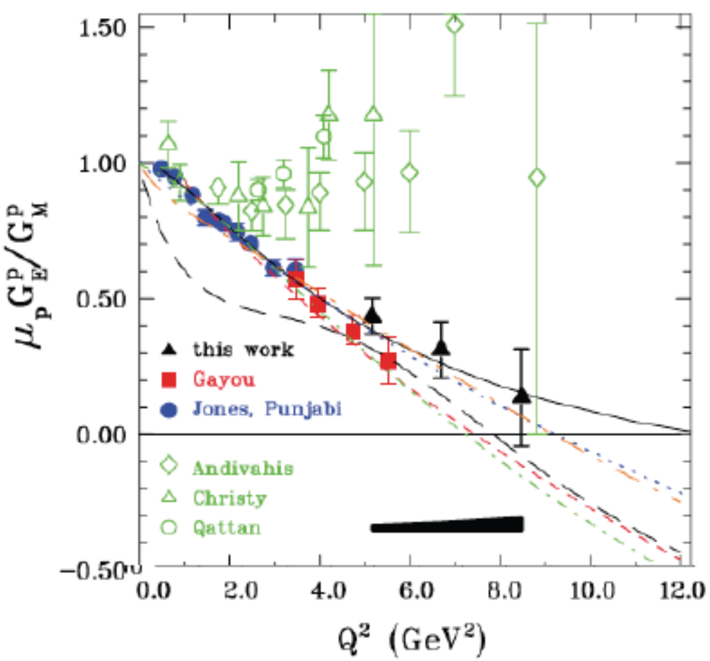
- Form factor is fundamental property of the nucleon
  - Determined through elastic scattering of electrons, quasi-elastic scattering of neutrinos
- Assumed to be a consequence of QCD
  - We can't yet calculate it, but hope for eventual confirmation
- Even without exact calculations, gives insight into the structure of the nucleon and constrains models of the nucleon
- May change within the nuclear environment

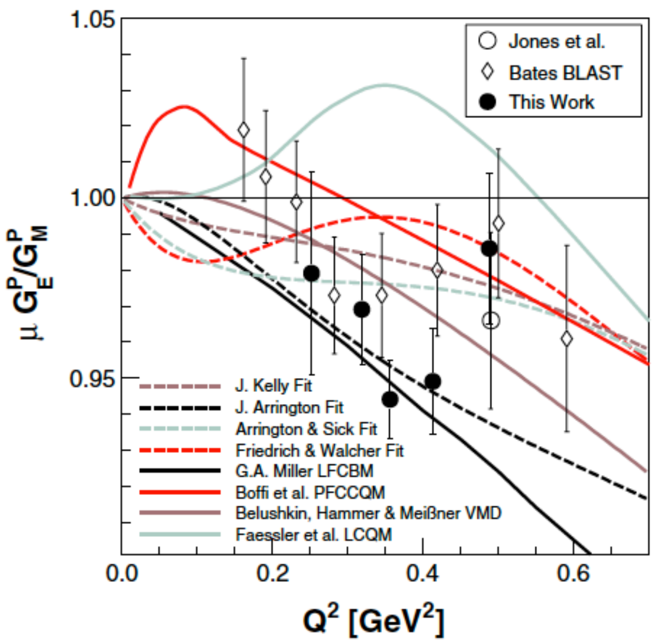
Except for G_{En} all form factors seemed to be well described by the dipole approximation $$G(Q^2) = G(0)/(1+Q^2/.71)^2$$

No clear reason why, but it worked and there seemed to be little of interest

As the century turned…

New high precision results from JLab showed significant deviations from the dipole at low and high Q^2 AND significantly different behavior for G_E and G_M for the proton.





AJR Puckett et al., PRL 104, 242301 (2010)

G. Ron et al, PRL 99, 202002 (2007)

Rutgers

CC scattering of neutrinos also involves the same EM form factors plus form factors sensitive to the weak charge

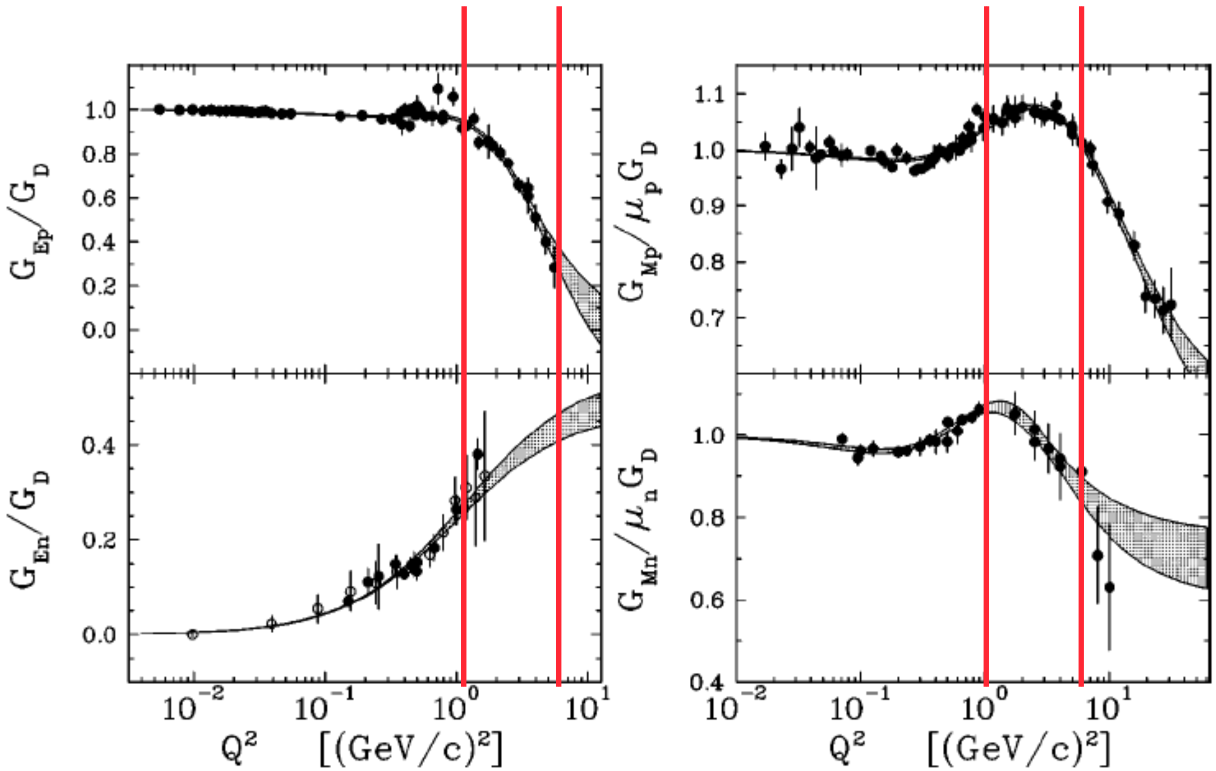
The axial form factor appears also to approximately the dipole form

$$G_A\left(Q^2\right) = G_A(0) / \left(1 + Q^2 / M_A^2\right)$$

$G_A(0)$ can be determined from beta decay of the neutron (generally written g_A in that case), and M_A from the differential cross section, which MINERvA will do

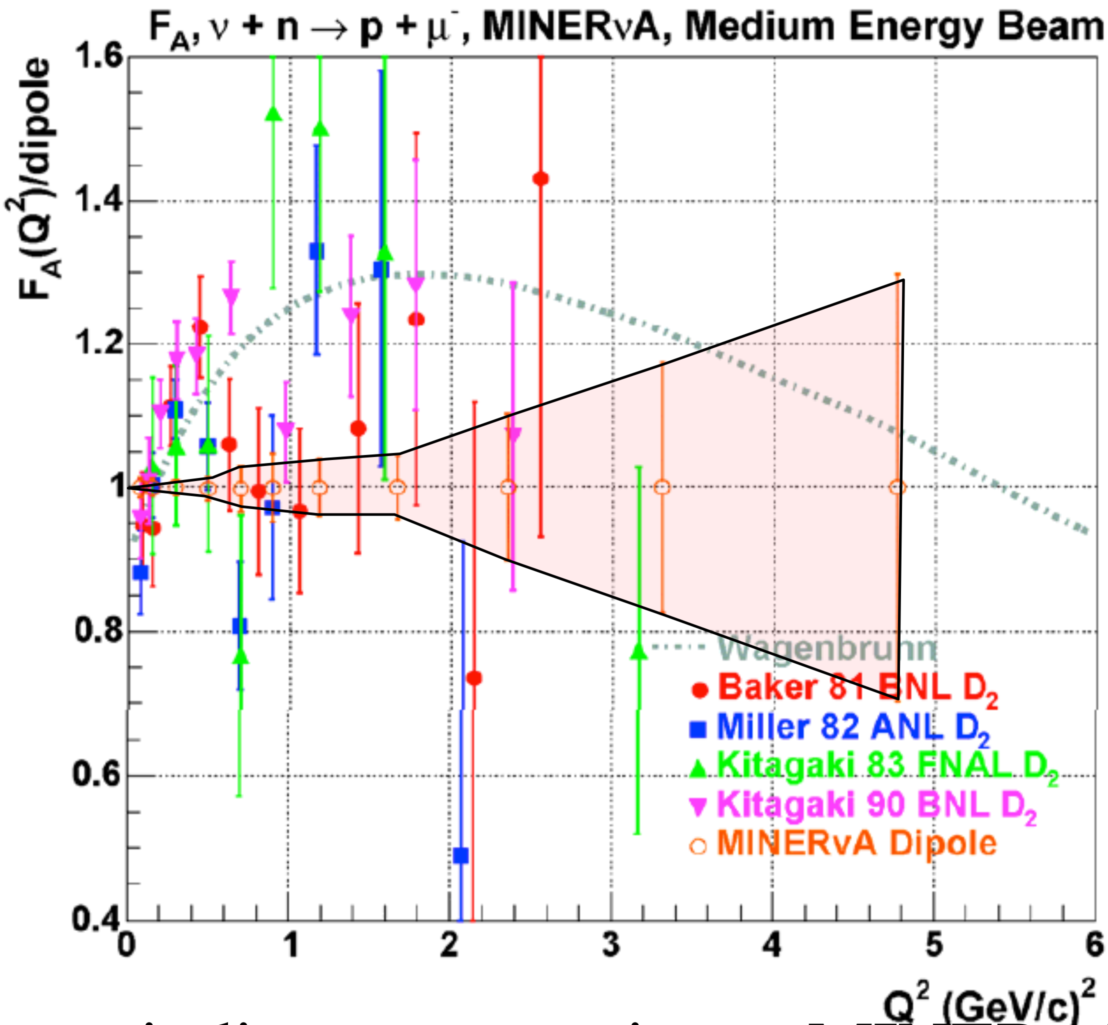
RUTGERS

EM FF do not follow dipole in 1-5 GeV^2 region



Electromagnetic form factors divided by the dipole approximation
JJ Kelly, PRC 70, 068202 (2004)

MINERvA will measure G_A region with sufficient precision in the Q^2 1-5 GeV^2 region to compare with dipole approximation



Shaded area indicates approximate MINERvA uncertainty including acceptance – 4 year run

RUTGERS

But, there is a complication….

We are not doing the measurement on free nucleons and there is evidence that we cannot use the same form factors for bound nucleons

Studies of nuclear beta decay indicate an effective value of $G_A(0)$ about 10% less than for the free case - 1.14 (bound) vs. 1.26 (free)

JLab polarization measurements on ^{4}He also indicate a modification of the EM form factors

Theory predictions

The Thomas group predicts modification of the all form factor, with the change in axial in approximate agreement with the change seen in beta decay

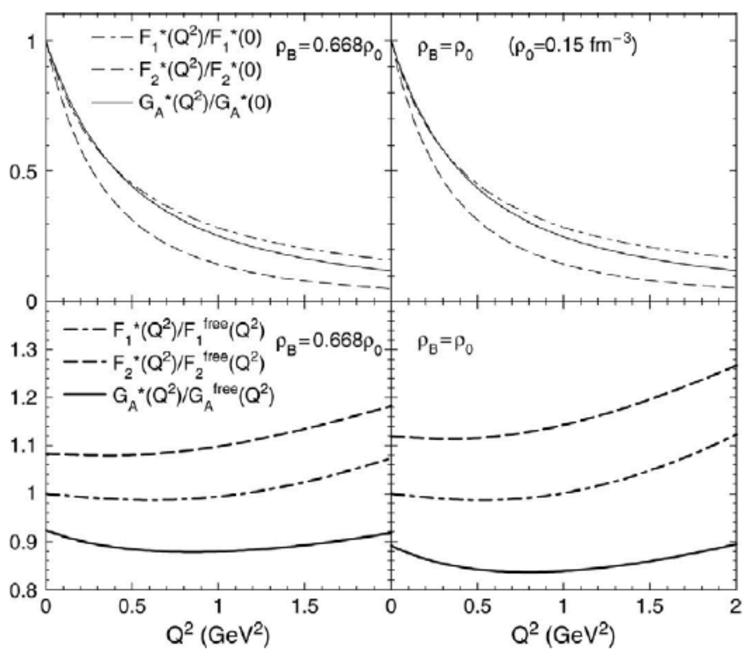
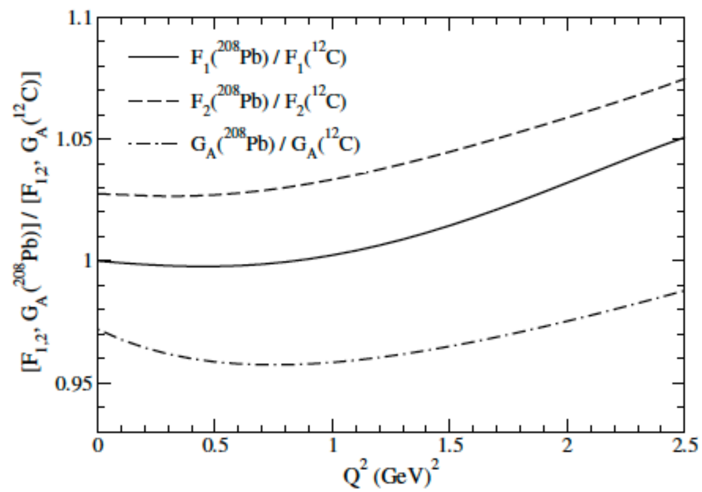
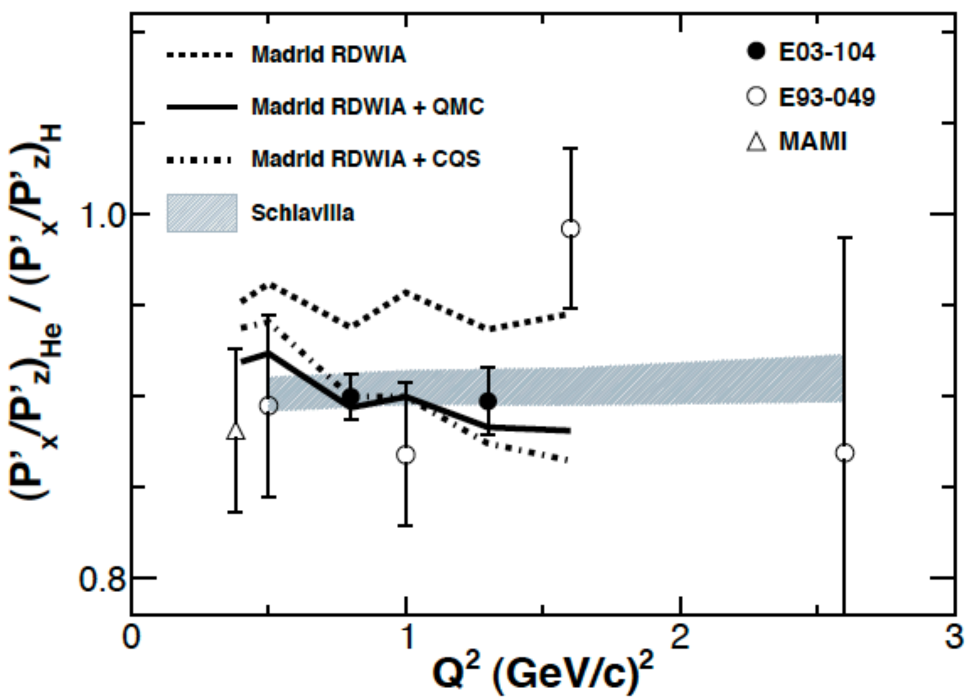


Fig. 45. Calculated ratios for the bound nucleon form factors (from Ref. [210]).



Tsushima calculated Pb/C ratio for us. Effect is small but we will have the statistics, systematics will be the issue.

JLab data in agreement with prediction of modification, but another models without modification also agrees, although there is some controversy on this.



MINERvA

Precision studies (~1-2% level) of medium effects which require absolute cross sections are essentially impossible with neutrinos BUT studies which make precision ratio studies can be done. The low Q^2 QEL can be studied with statistical precision much better than 1%, thus allowing study of medium effects on the form factors

MINERvA's multiple nuclear targets give a unique measurement of the nuclear medium dependence of G_A

Coherent Pion Production

Coherent pion production refers to the process where a pion is produced coherently on the scattering nucleus, which is left in the ground state

$\nu A \rightarrow \nu A \pi^0$ (NC production)

$\nu A \rightarrow \mu^- A \pi^+$ (CC production)

Requirement that nucleus left in ground state puts restrictions on models which explain interaction with the nucleus

RUTGERS

A similar reaction occurs for electron scattering and photon absorption – sensitive to properties of Δ in nuclear environment

Difficult to study with electrons and photons because of kinematics and requirement to detect π^0

Neutrino induced has different mechanisms

Higher energies explained PCAC mechanism

Lower energy microscopic models sensitive to N->Reson.

Pion interaction in nucleus

Energy and A dependence of cross section is very poorly known. More recent measurements give conflicting results.

CC process is not observed by K2K or SciBooNE
NC process is observed by MiniBooNE
CC expected to be ~2 NC

MINERνA's large solid angle will allow a high statistics measurement of this reaction and its A dependence