Predictions for Neutrino and Antineutrino Quasielastic Scattering Cross Sections with the Latest Elastic Form Factors

A Review of Weak and Electromagnetic Form Factors

Howard Budd, Arie Bodek

Univ. of Rochester

and

John Arrington

Argonne National Laboratory

NuInt02 Conference http://nuint.ps.uci.edu/

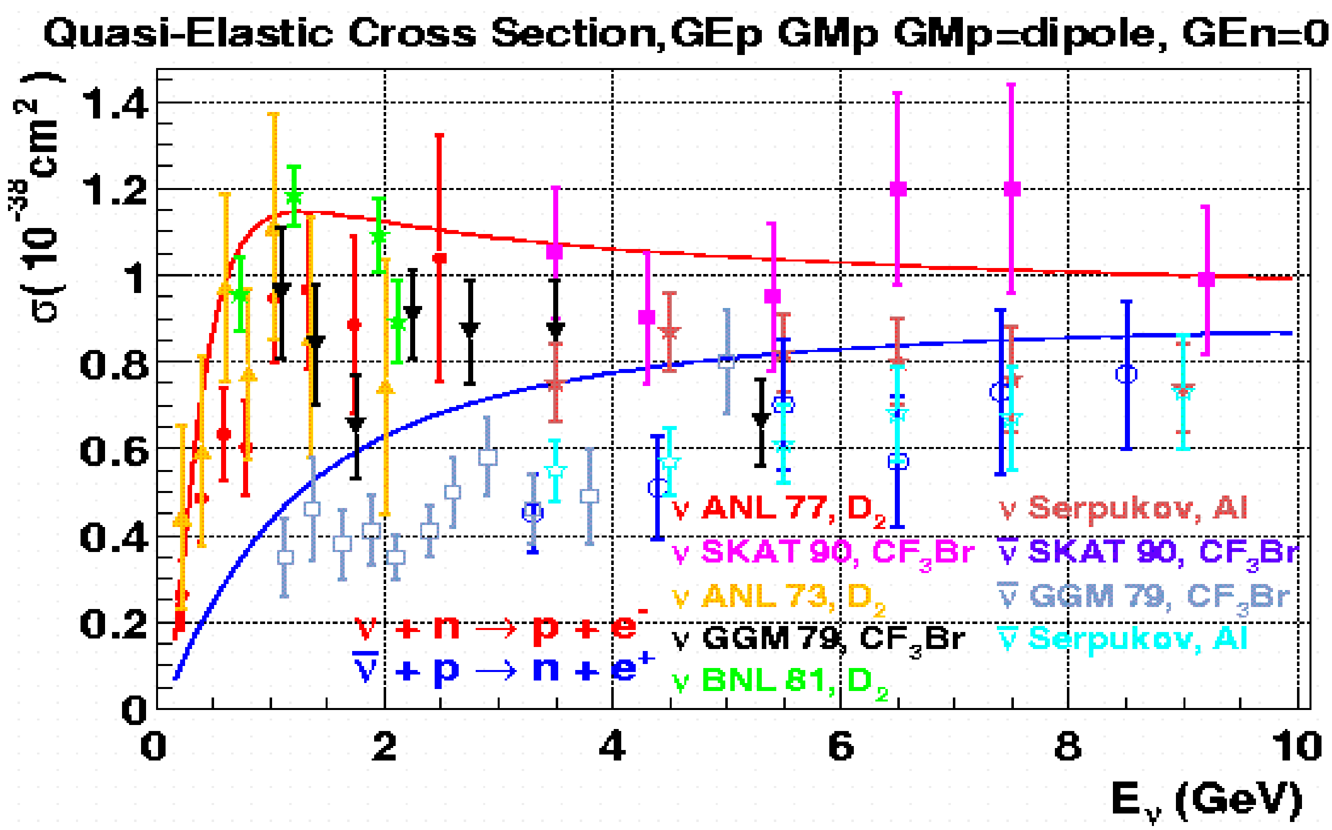
UC Irvine, California - Dec 12-15,2002

http://www.pas.rochester.edu/~bodek/FormFactors.ppt

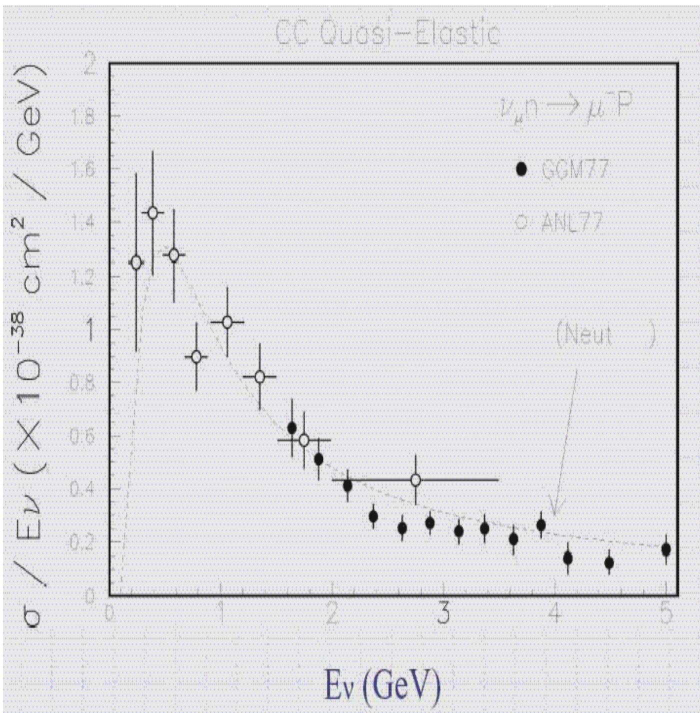
$\sigma_{\text{quasi-elastic neutrinos on Neutrons}}$**-Dipole**

$\sigma_{\text{quasi-elastic Antineutrinos on Protons}}$ **-Dipole**

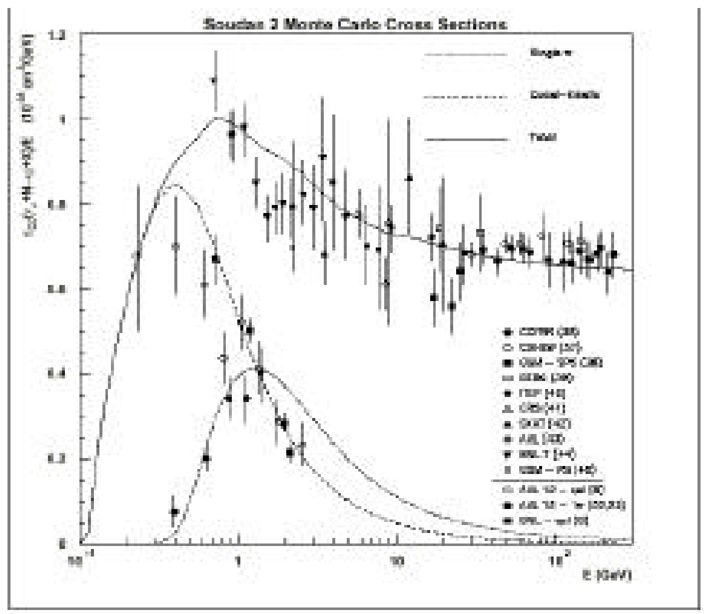
DATA - FLUX ERRORS ARE 10%. Note some of the data on nuclear Targets appear smaller (e.g. all the antineutrino data)



Examples of Low Energy Neutrino Data: cross sections divided by Energy

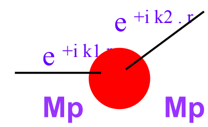


σ_{quasit}/E on neutron target
Quasielastic only



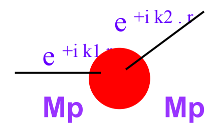
σ_{tot}/E on Iso-scalar target, with
Different contributions
Quasi-elastic important in the
0-4 GeV region

fixed W scattering - form factors



- Electron Scattering:
- Elastic Scattering, Electric and Magnetic Form Factors (G_E and G_M) versus Q^2 measure size of object (the electric charge and magnetization distributions). Final State $W = M^p = M$
- (G_E and G_M) TWO Form factor measures Matrix element squared $| \langle p_f | V(r) | p_i \rangle |^2$ between initial and final state lepton plane waves. Which becomes:
- $| \langle e^{-i\, k2 \cdot r} | V(r) | e^{+i\, k1 \cdot r} \rangle |^2$ $q = k1 - k2$ = momentum transfer
- $G_E^{P.N}(Q^2) = \int \{ e^{i\, q \cdot r} \rho(r)\, d^3r \}$ = Electric form factor is the Fourier transform of the charge distribution for Proton And Neutron
- The magnetization distribution $G_M^{P.N}((Q^2)$ Form factor is relates to structure functions by:
- $2xF_1(x, Q^2)_{elastic} = x^2 G_M^2{}_{elastic}\, \delta(x-1)$
  - Neutrino Quasi-Elastic (W=Mp)
  - $\nu_\mu + N \to \mu^- + P$ (x =1, W=Mp)
  - Anti-$\nu_\mu + P \to \mu^+ + N$ (x =1, W=Mp)
  - $F_1^V(Q^2)$ and $F_2^V(Q^2)$ = Vector Form Factors which are related by CVC to
  - $G_E^{P.N}(Q^2)$ and $G_M^{P.N}((Q^2)$ *from Electron Scattering*
  - $F_A(Q^2)$ = Axial Form Factor *need to be measured* in Neutrino Scattering.
  - Contributions proportional to Muon Mass (which is small)
  - $F_P(Q^2)$ = Pseudo-scalar Form Factor. estimated by relating to $F_A(Q^2)$ via PCAC, Also extracted from pion electro-production
  - $F_S(Q^2)$, $F_T(Q^2)$, = scalar, tensor form factors=0 if no second class currents.

Need to update - Axial Form Factor extraction



1. Need to account for Fermi Motion/binding Energy effects in nucleus e.g. Bodek and Ritchie (Phys. Rev. D23, 1070 (1981), Re-scattering corrections etc (see talk by Sakuda in this Conference for feed-down from single pion production)
2. Need to to account for muon mass effects and other structure functions besides $F_1^V(Q^2)$ and $F_2^V(Q^2)$ and $F_A(Q^2)$ (see talk by Kretzer this conference for similar terms in DIS). This is more important in Tau neutrinos than for muon neutrinos [here use PCAC for Gp(Q2).]

- <u>This Talk (What is the difference in the quasi-elastic cross sections if:</u>

1. We use the most recent very precise value of $g_A = F_A(Q^2) = 1.263$ (instead of 1.23 used in earlier analyses.) Sensitivity to g_A and $m_{A,}$
2. Sensitivity to knowledge of $Gp(Q^2)$
3. Use the most recent Updated $G_E^{P.N}(Q^2)$ and $G_M^{P.N}((Q^2)$ <u>*from Electron Scattering (instead of the dipole form assumed in earlier analyses)*</u> In addition

- <u>*There are new precise measurments of*</u> $G_E^{P.N}(Q^2)$ Using polarization transfer experiments

Neutrino Cross Sections

NuMI-112
PDK-626
Nov. 10, 1995

H. M. Gallagher and M. C. Goodman

They implemented
The Llewellyn-Smith
Formalism for NUMI

$$\frac{d\sigma}{d|q^2|}\begin{pmatrix}\nu n \rightarrow l^- p \\ \overline{\nu} p \rightarrow l^+ n\end{pmatrix} = \frac{M^2 G^2 \cos^2\theta_c}{8\pi E_\nu^2}\left[A(q^2) \mp B(q^2)\frac{(s-u)}{M^2} + \frac{C(q^2)(s-u)^2}{M^4}\right]. \quad (2)$$

In this expression, G is the Fermi coupling constant and θ_c is the Cabibbo mixing angle ($G = 1.16639 \times 10^{-5}\mathrm{GeV}^{-2}$). The functions A, B, and C are convenient combinations of the nucleon form factors.

Contraction of the hadronic and leptonic currents yields: Non zero

$$A = \frac{(m^2 - q^2)}{4M^2}\left[\left(4 - \frac{q^2}{M^2}\right)|F_A|^2 - \left(4 + \frac{q^2}{M^2}\right)|F_V^1|^2 - \frac{q^2}{M^2}|\xi F_V^2|^2\left(1 + \frac{q^2}{4M^2}\right) - \frac{4q^2 ReF_V^{1*}\xi F_V^2}{M^2} \quad (3)\right.$$

$$\left. + \frac{q^2}{M^2}\left(4 - \frac{q^2}{M^2}\right)|F_T|^2 - \frac{m^2}{M^2}\left(|F_V^1 + \xi F_V^2|^2 + |F_A + 2F_P|^2 + \left(\frac{q^2}{M^2} - 4\right)\left(|F_S|^2 + |F_P|^2\right)\right)\right]$$

$$B = -\frac{q^2}{M^2}ReF_A^*(F_V^1 + \xi F_V^2) - \frac{m^2}{M^2}Re\left[\left(F_V^1 + \frac{q^2}{4M^2}\xi F_V^2\right)^* F_S - \left(F_A + \frac{q^2 F_P}{2M^2}\right)^* F_T\right] \quad (4)$$

$$C = \frac{1}{4}\left(|F_A|^2 + |F_V^1|^2 - \frac{q^2}{M^2}\left|\frac{\xi F_V^2}{2}\right|^2 - \frac{q^2}{M^2}|F_T|^2\right), \quad (5)$$

where m is the final state lepton mass. Ignoring second-class currents (those which violate G-parity) allows us to set the scalar and tensor form factors to zero. According to the CVC

$$F_V^1(q^2) = \left(1 - \frac{q^2}{4M^2}\right)^{-1} [G_E^V(q^2) - \frac{q^2}{4M^2} G_M^V(q^2)] \quad (6)$$

$$\xi F_V^2(q^2) = \left(1 - \frac{q^2}{4M^2}\right)^{1} [G_M^V(q^2) - G_E^V(q^2)]. \quad (7)$$

The electromagnetic form factors are determined from electron scattering experiments:

UPDATE: Replace by $G_E^V = G_E^P - G_E^N$

$$G_E^V(1^2) = \frac{1}{(1 - \frac{q^2}{M_V^2})^2} \qquad G_M^V(q^2) = \frac{1 + \mu_p - \mu_n}{(1 - \frac{q^2}{M_V^2})^2}.$$

UPATE: Replace by $G_M^V = G_M^P - G_M^N$

The situation is slightly more complicated for the hadronic axial current. $F_A(q^2 = 0) = -1.261 \pm .004$ is known from neutron beta decay. The q^2 dependence has to be inferred or measured. By analogy with the vector case we assume the same dipole form:

$M_A = 1.032 \pm .036$ GeV [7].

$$F_A(q^2) = \frac{-1.23}{(1 - \frac{q^2}{M_A^2})^2}. \quad (9)$$

$Q^2 = -q^2$

g_A, M_A need to Be updated

$$F_P(q^2) = \frac{2M^2 F_A(q^2)}{M_\pi^2 - q^2}. \quad (10)$$

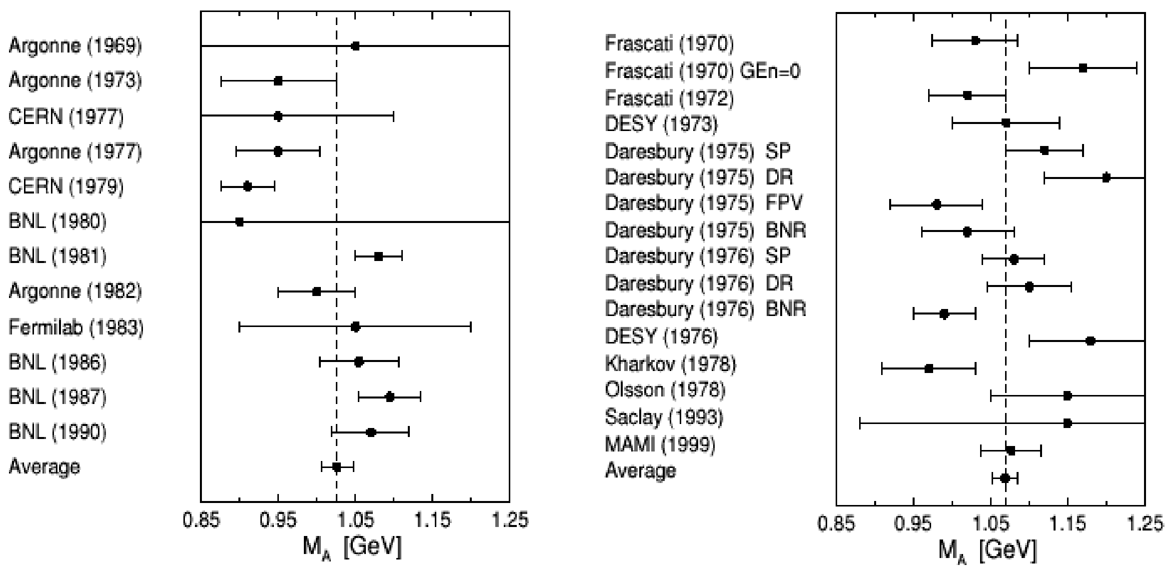
Fp important for Muon neutrinos only at Very Low Energy

The inclusion of F_P leads to an approximately 5% reduction in both the ν_τ and ν_τ quasi-elastic cross sections. The only remaining parameters needed to describe the quasi-elastic cross section are thus M_V and M_A. $M_V = .71$ GeV, as determined with high accuracy

From C.H. Llewellyn Smith (SLAC). SLAC-PUB-0958 Phys.Rept.3:261,1972

Axial structure of the nucleon Hep-ph/0107088 (2001)

Véronique Bernard†, Latifa Elouadrhiri‡, Ulf-G Meißner§



For updated M_A expt. need to be reanalyzed with new g_A, and G_E^N

Difference In Ma between Electroproduction And neutrino Is understood

Figure 1. Axial mass M_A extractions. Left panel: From (quasi)elastic neutrino and antineutrino scattering experiments. The weighted average is $M_A = (1.026 \pm 0.021)$ GeV. Right panel: From charged pion electroproduction experiments. The weighted average is $M_A = (1.069 \pm 0.016)$ GeV. Note that value for the MAMI experiment contains both the statistical and systematical uncertainty; for other values the systematical errors were not explicitly given. The labels SP, DR, FPV and BNR refer to different methods evaluating the corrections beyond the soft pion limit as explained in the text.

M_A from neutrino expt. No theory corrections needed

Use: N. Nakamura et al. Nucl-th/0201062 April 2002 as default DIPOLE Form factors

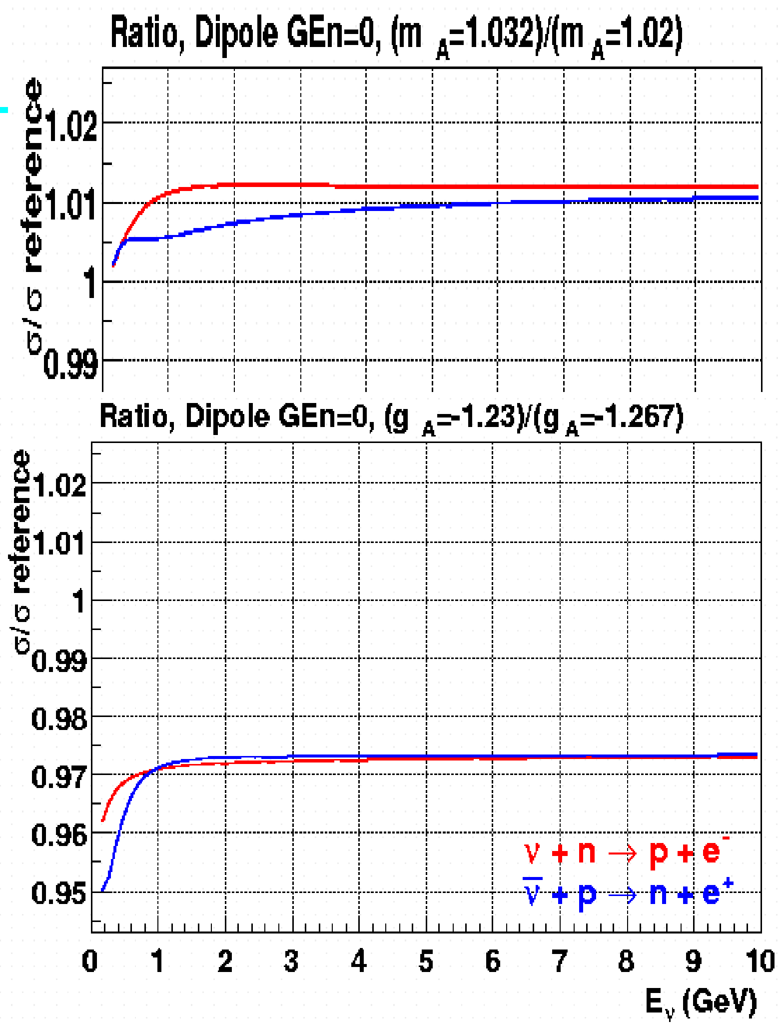
For the weak coupling constant, instead of $G_F = 1.16637 \times 10^{-5}$ GeV^{-2} employed in NSGK, we adopt here $G_F' = 1.1803 \times 10^{-5}$ GeV^{-2} obtained from $0^+ \to 0^+$ nuclear β-decays [26].[4] G_F' subsumes the bulk of the *inner* radiative corrections.[5] The K-M matrix element is taken to be V_{ud} = 0.9740[26] instead of $V_{ud} = 0.9749$ used in NSGK.

$$G_D(q_\mu^2) = \left(1 - \frac{q_\mu^2}{0.71\mathrm{GeV}^2}\right)^{-2}, \quad (19)$$

$$G_A(q_\mu^2) = \left(1 - \frac{q_\mu^2}{1.04\mathrm{GeV}^2}\right)^{-2}, \quad (20)$$

where $\mu_p = 2.793$, $\mu_n = -1.913$, $\eta = -\frac{q_\mu^2}{4m^2}$ and m_π is the pion mass. For g_A, we adopt the current standard value, g_A=1.267[29], instead of g_A=1.254 used in NSGK. In addition, as the axial-vector mass in Eq.(20), we use the value which was obtained in the latest analysis[28] of (anti)neutrino scattering and charged-pion electroproduction. The change in $G_A(q_\mu^2)$ is in fact not consequential for $\sigma_{\nu d}$ in the solar-ν energy region. Regarding f_P, we assume PCAC and pion-pole dominance. A contribution from this term is known to be proportional to the lepton mass, which leads to very small contribution from the induced pseudoscalar term in our case. Although deviations from the naive pion-pole dominance of f_P have been carefully studied[30], we can safely neglect those

Effect of g_A and M_A



Use precise

Value **g_A =1.267** from beta Decay- **with M_A =1.02 (Nakamura 2002)**

Compare to **g_A =1.23 with M_A =1.032 (used by MINOS)**

NuMI 112 Gallagher and Goodman (1995)

Note: **M_A**

Should be re-extracted with new the value of

g_A =1.267

ratio_ma1032_D0DD.pict

ratio_ga123_D0DD.pict

er

Parametrization of Fits to Form Factors

GEP, GMP: - Simultaneous fit to 1/(1+p1*q+p2*q**2+...) and mu_p/(1+...) - Fit to cross sections (rather than the Ge/Gm tables). Added 5 cross section points from Simon to help constrain Q^2<0.1 GeV^2 - Fit normalization factor for each data set (break up data sets from different detectors).
- Up to p6 for both electric and magnetic
- Fits with and without the polarization transfer data. Allow systematic error to 'float' for each polarization experiment.

GEP, GMP : CROSS SECTION DATA ONLY FIT:

p1= -0.53916 **!p1-p6 are parameters for GMP**
p2= 6.88174
p3= -7.59353
p4= 7.63581
p5= -2.11479
p6= 0.33256

q1= -0.04441 **!q1-q6 are parameters for GEP**
q2= 4.12640
q3= -3.66197
q4= 5.68686
q5= -1.23696
q6= 0.08346
chi2_dof= 0.81473

GEP, GMP:
CROSS SECTION AND POLARIZATION DATA Fit:
GMP
p1= -0.43584
p2= 6.18608
p3= -6.25097
p4= 6.52819
p5= -1.75359
p6= 0.28736
q1= -0.21867
GEP
q2= 5.89885
q3= -9.96209
q4= 16.23405
q5= -9.63712
q6= 2.90093
chi2_dof= 0.95652

GMN: - Fit to -1.913/(1+p1*q+p2*q**2+...)
- NO normalization uncertainties included.
- Added 2% error (in quadruture) to all data points.
Typically has small effect, but a few points had <1% errors.

PARAMETER	VALUE						
P1	-0.40468,	P2	5.6569 ,	P3	-4.664, 5	P4	3.8811

GEN: Use Krutov parameters for Galster form see below

[21] M. Garcon and J.W. Van Orden, Adv.Nucl. Phys. 26 (2001) 293.

Krutov-> (a = 0.942, b=4.61)
Hep-ph/0202183(2002)

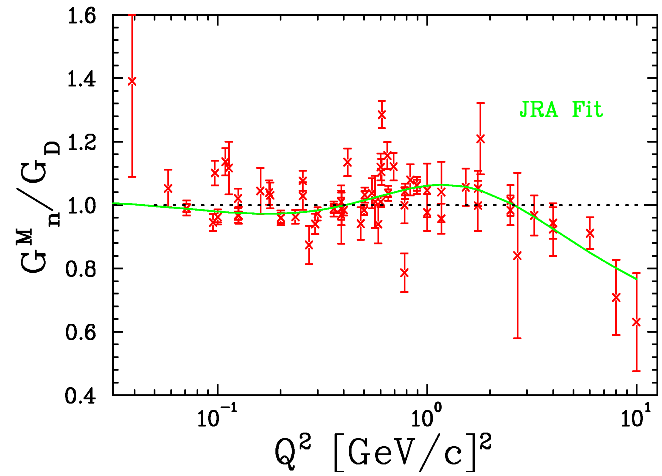
vs. Galster ->(a=1 and b=5.6)
[15] S. Galster *et al.*, Nucl.Phys. B 32 (1971) 221.

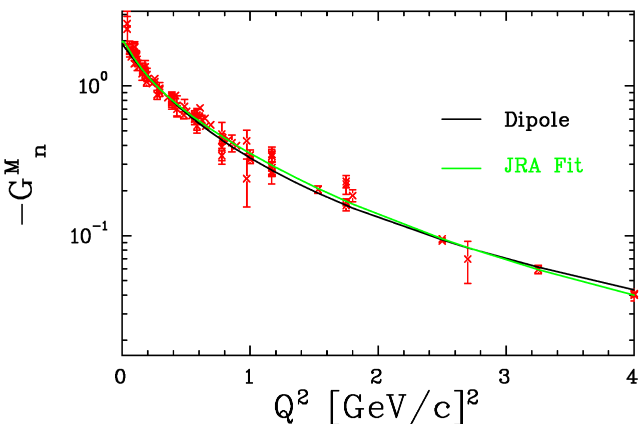
$$G_E^n(Q^2) = -\mu_n \frac{a\tau}{1+b\tau} G_D(Q^2), \quad G_D(Q^2) = \left(1+\frac{Q^2}{0.71}\right)^{-2}, \quad \tau = \frac{Q^2}{4M^2}. \qquad (13)$$

The neutron magnetic moment μ_n = -1.91304270(5) [49]. Q^2 in $G_D(Q^2)$ is given in (GeV^2).

Neutron G_M^N is negative

Neutron (G_M^N / G_M^N dipole)





Neutron (G_M^N / G_M^N dipole)

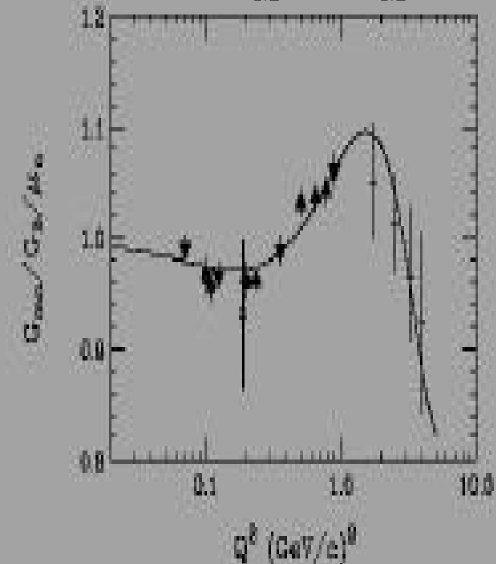
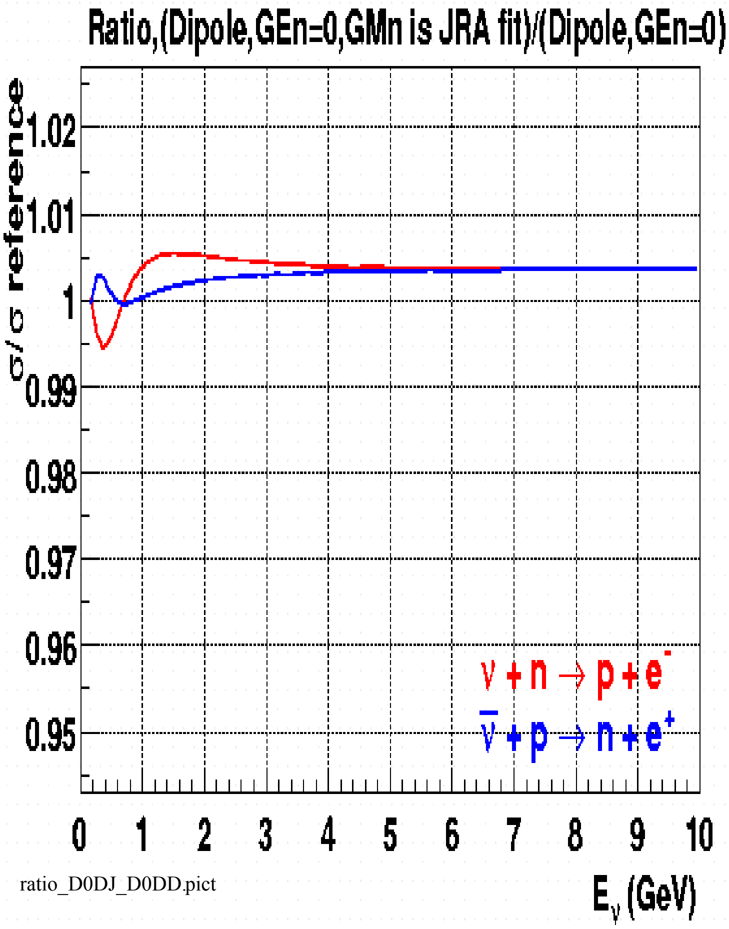


Fig. 2. The figure shows the continued fraction fit to the data. Symbols for the data as in figure 1] plus the data by Lung et al. (+) [33].

At low Q2 Our Ratio to Dipole similar to that nucl-ex/0107016 G. Kubon, et al Phys.Lett. B524 (2002) 26-32

$$G_{Mn}(Q^2) = \frac{\mu_n}{1+\frac{Q^2 b_1}{1+\frac{Q^2 b_2}{1+\cdots}}} \quad (2)$$

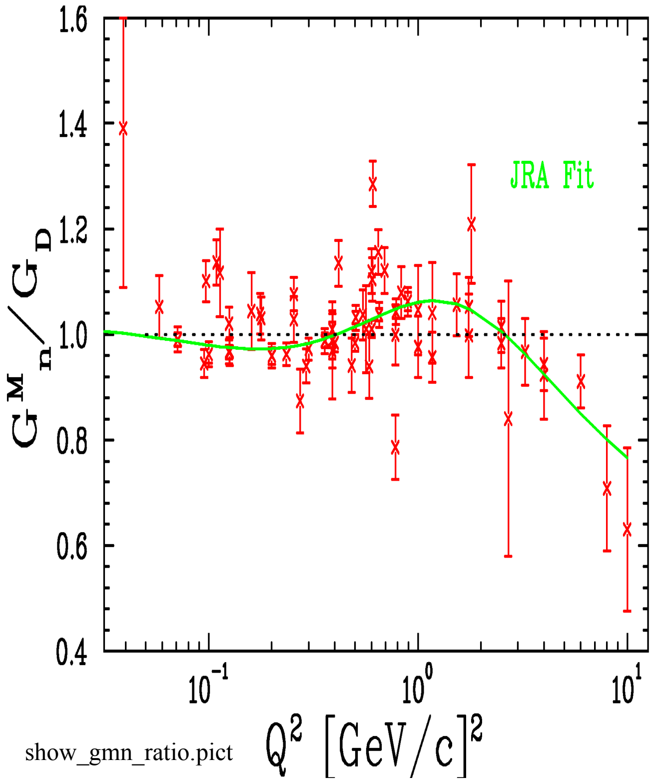
Effect **of using Fit to G_M^N** versus using $\mathbf{G_M^N}$ $^{\text{Dipole}}$



ratio_D0DJ_D0DD.pict

Neutron G_M^N is negative

Neutron (G_M^N / G_M^N $^{\text{dipole}}$)

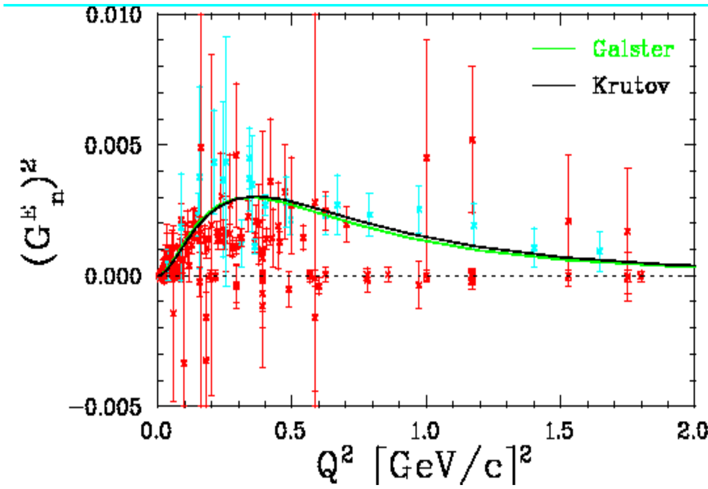


show_gmn_ratio.pict

show_gen_new.pict

Neutron, G_E^N is positive

Neutron G_E^N is positive New Polarization data gives Precise non zero G^E_N hep-ph/0202183(2002)



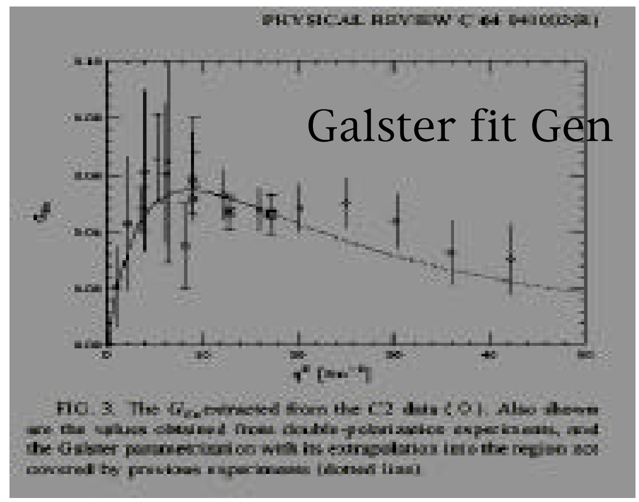
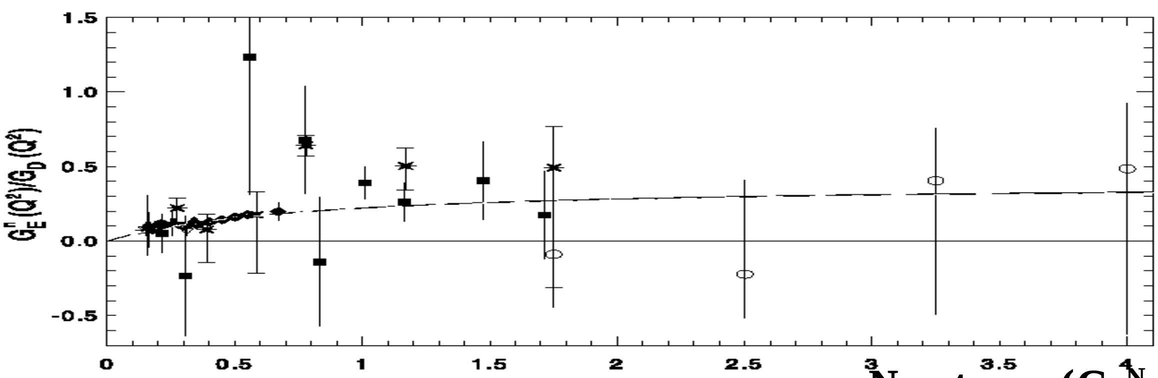


FIG. 3. The G_{En} extracted from the C2 data (O). Also shown are the values obtained from double-polarization experiments, and the Galster parametrization with its extrapolation into the region not covered by previous experiments (dotted line).



Krutov

Neutron (G_E^N / G_E^P dipole)

[21] M. Garcon and J.W. Van Orden, Adv.Nucl. Phys. 26 (2001) 293.

Krutov-> (a = 0.942, b=4.61)
Hep-ph/0202183(2002)

Galster ->(a=1 and b=5.6)
[15] S. Galster *et al.*, Nucl.Phys. B 32 (1971) 221.

$$G_E^n(Q^2) = -\mu_n \frac{a\,\tau}{1+b\,\tau} G_D(Q^2)\,, \quad G_D(Q^2) = \left(1+\frac{Q^2}{0.71}\right)^{-2}, \quad \tau = \frac{Q^2}{4\,M^2}\,. \qquad (13)$$

The neutron magnetic moment μ_n = -1.91304270(5) [49]. Q^2 in $G_D(Q^2)$ is given in (GeV^2).

[14, 39]:

$$\left.\frac{dG_E^n}{dQ^2}\right|_{Q^2=0} = 0.0199 \pm 0.0003\ \mathrm{fm}^2\,. \qquad (14)$$

The fitting of the slope (14) gives a=0.942 with the accuracy $\approx$ 1.5%.

This value of a gives the slope of $G_E^n(Q^2)$ at $Q^2 = 0$ which is measured directly in the experiment.

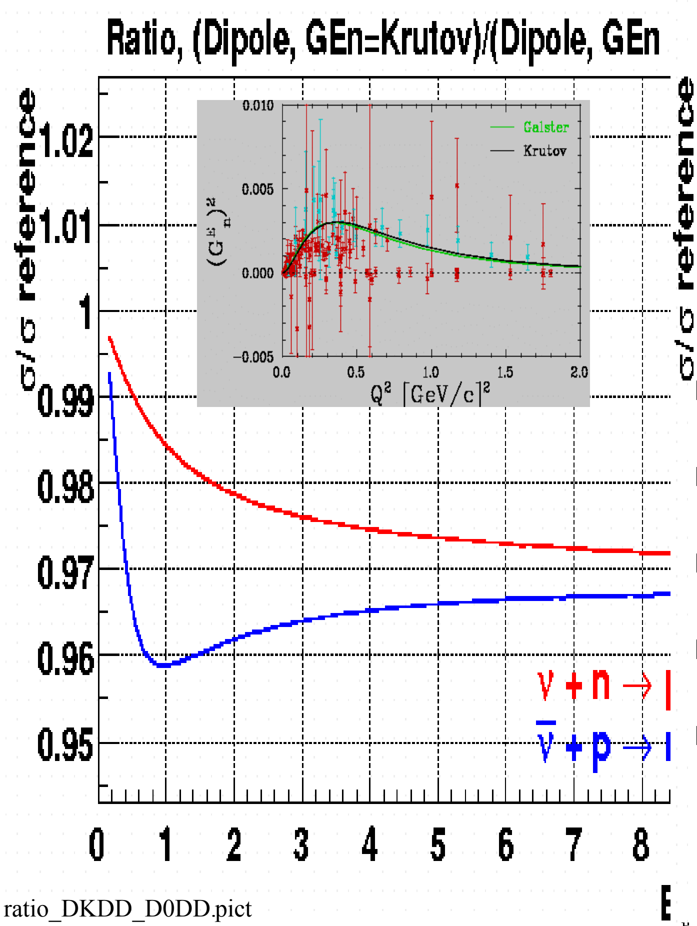
The parameter b is fitted using the χ^2 criterion. If we use all the 35 points we obtain b = 4.61 with χ^2 = 69.0. Note that the fit DRN–GK(3) [39] of 23 points has χ^2 = 63.9.

If we exclude the points # 4–8 then the 30–point fitting gives b = 4.62 with χ^2 = 61.5.

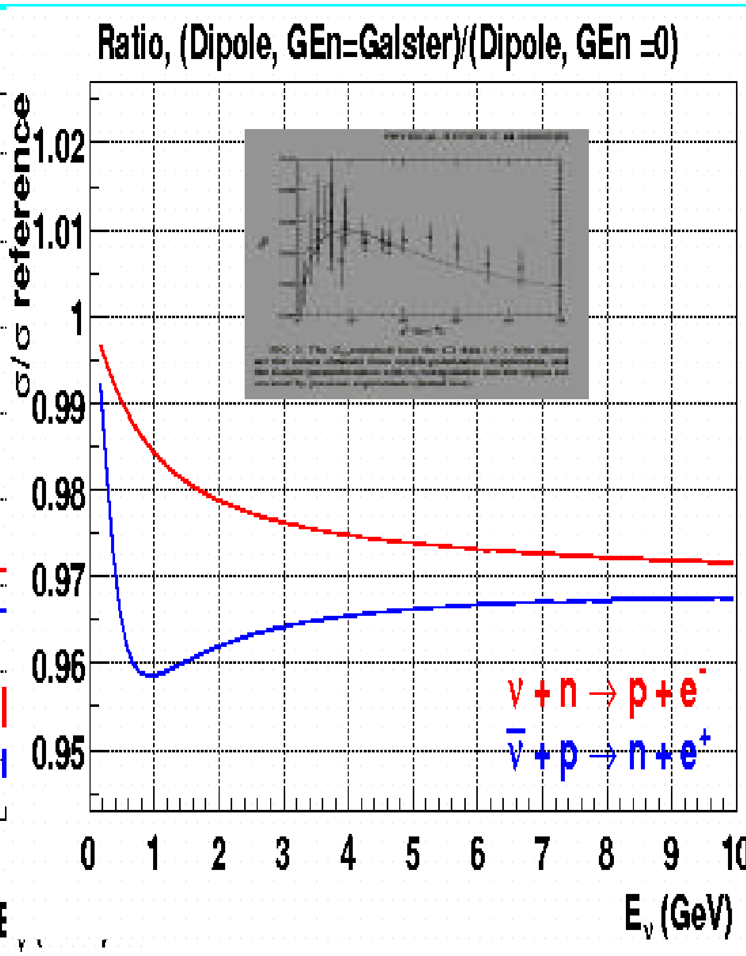
Effect **of** using $\mathbf{G_E^N}$ (Krutov) or (Galster) versus using

show_gen_new.pict

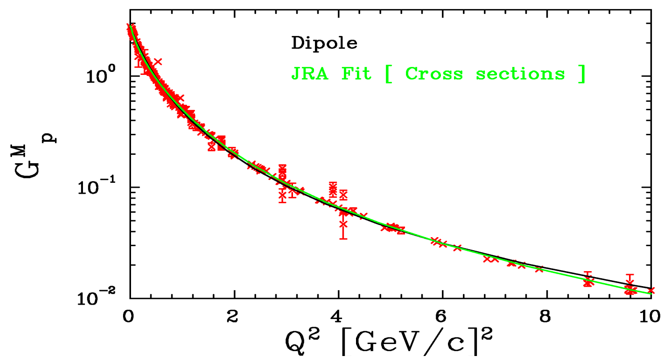
$\mathbf{G_E^N}$=0 (Dipole Assumption) Krutov and Galster very similar

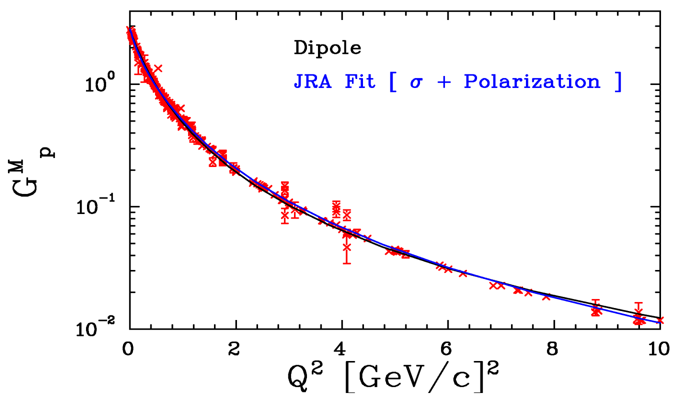


ratio_DKDD_D0DD.pict



Extract Correlated Proton G_M^P, G_E^P simultaneously from e-p Cross Section Data with and without Polarization Data

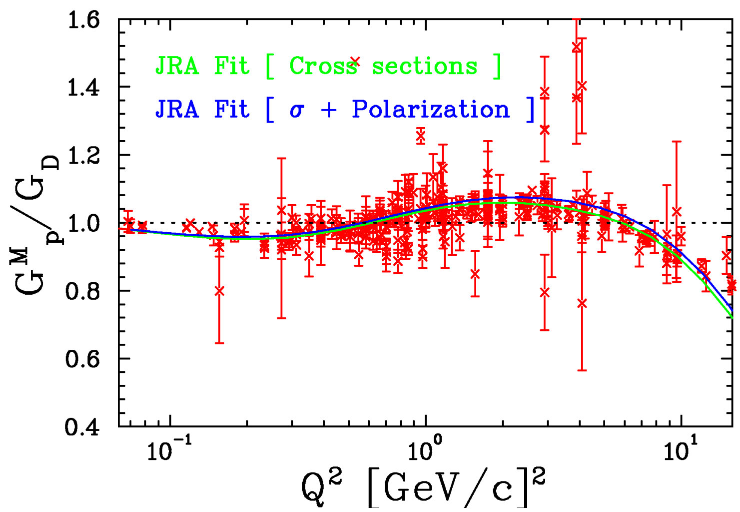




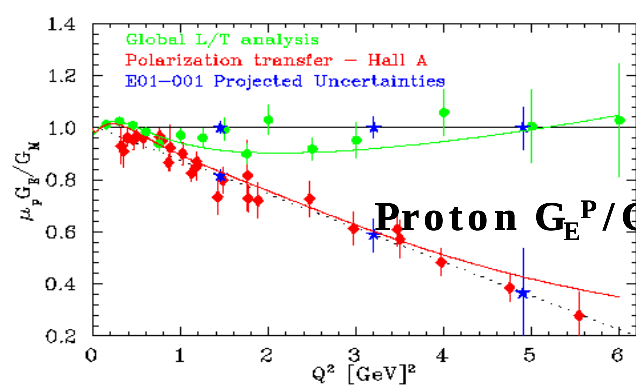
Proton G_M^P

Compare Rosenbluth Cross section Form Factor Separation Versus new Hall A Polarization measurements

Proton G_M^P / G_M^P -DIPOLE

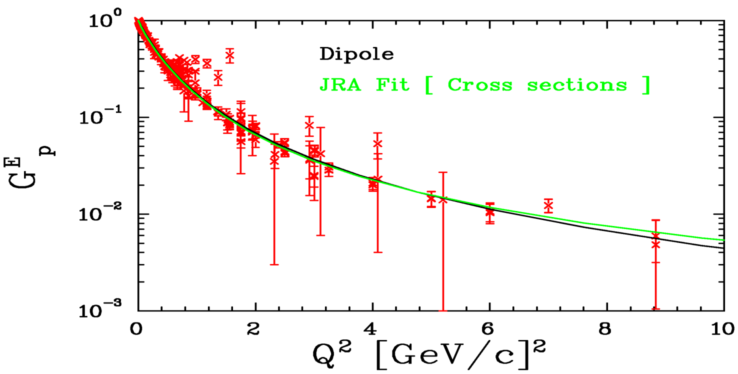


Proton G_E^P/G_M^P

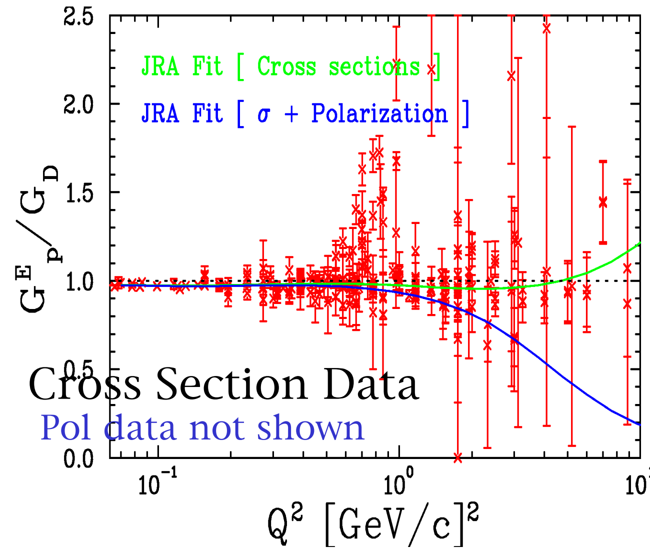


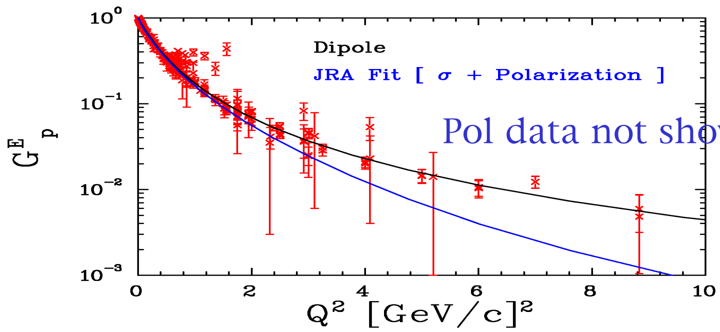
Howard Budd, U

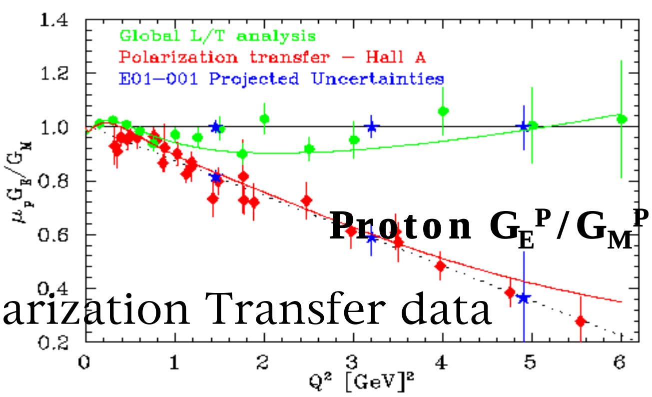
Proton G_E^P



Proton G_E^P / G_E^P -DIPOLE



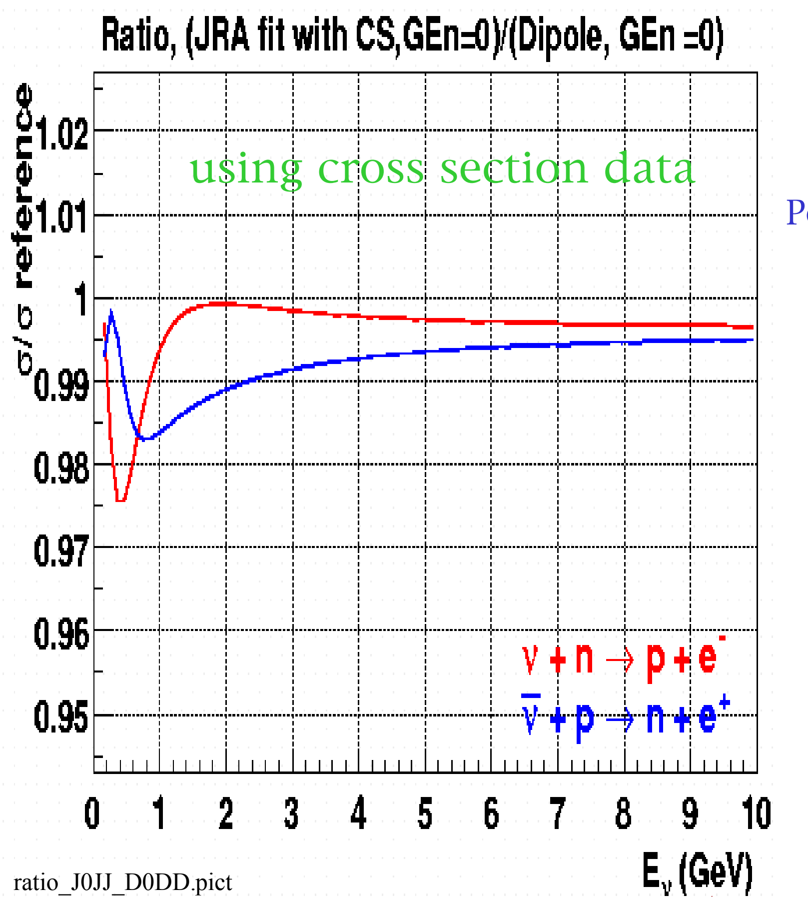




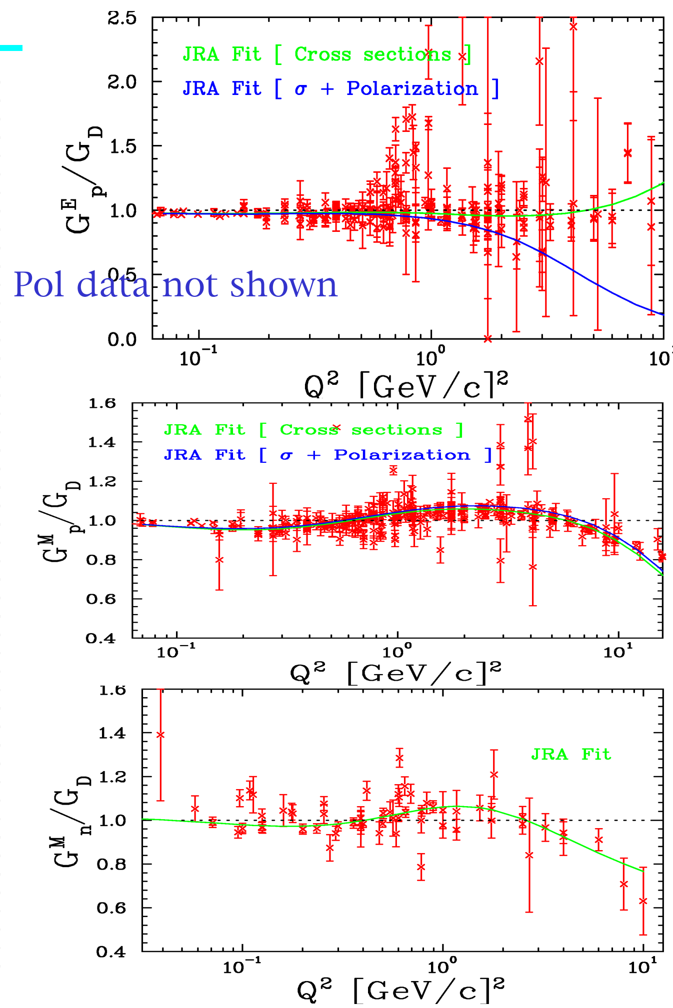
Proton G_P^E

Compare Rosenbluth Cross section Form Factor Separation Versus new Hall A Polarization measurements

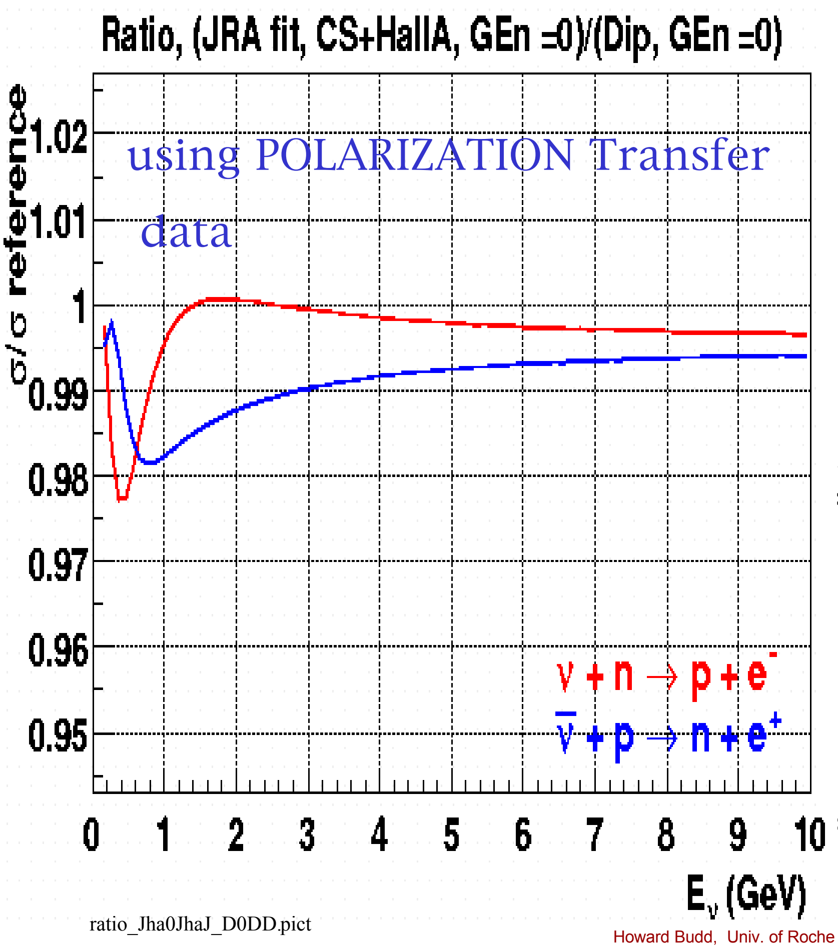
Effect of $\mathbf{G_M^N}$, **and** $\mathbf{G_M^P}$, $\mathbf{G_E^P}$ (using cross section data)(with $\mathbf{G_E^N}$ =0) Versus Dipole Form factor

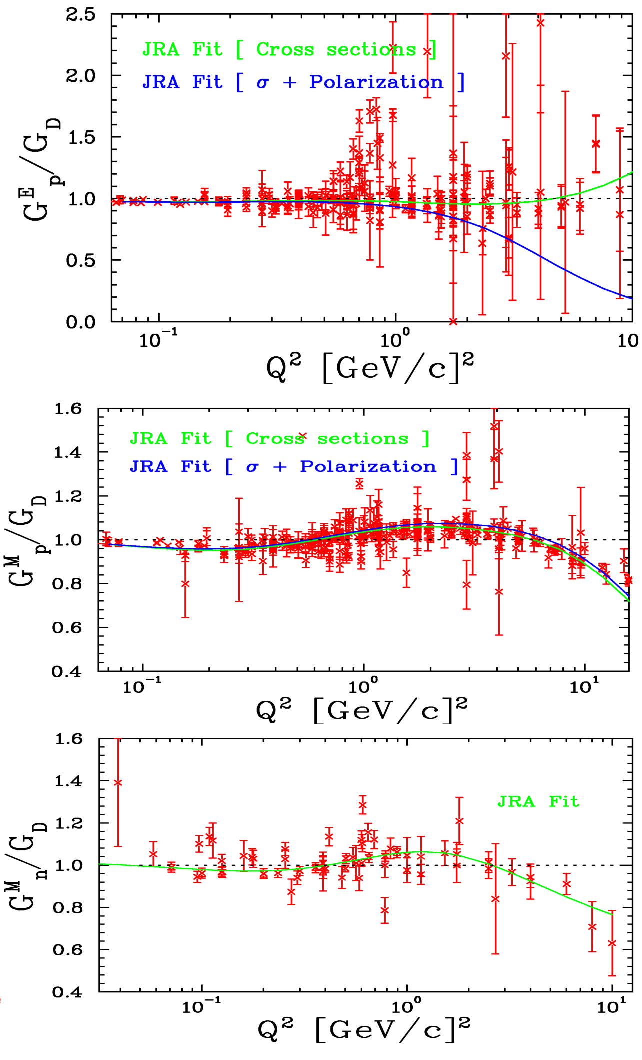


ratio_J0JJ_D0DD.pict

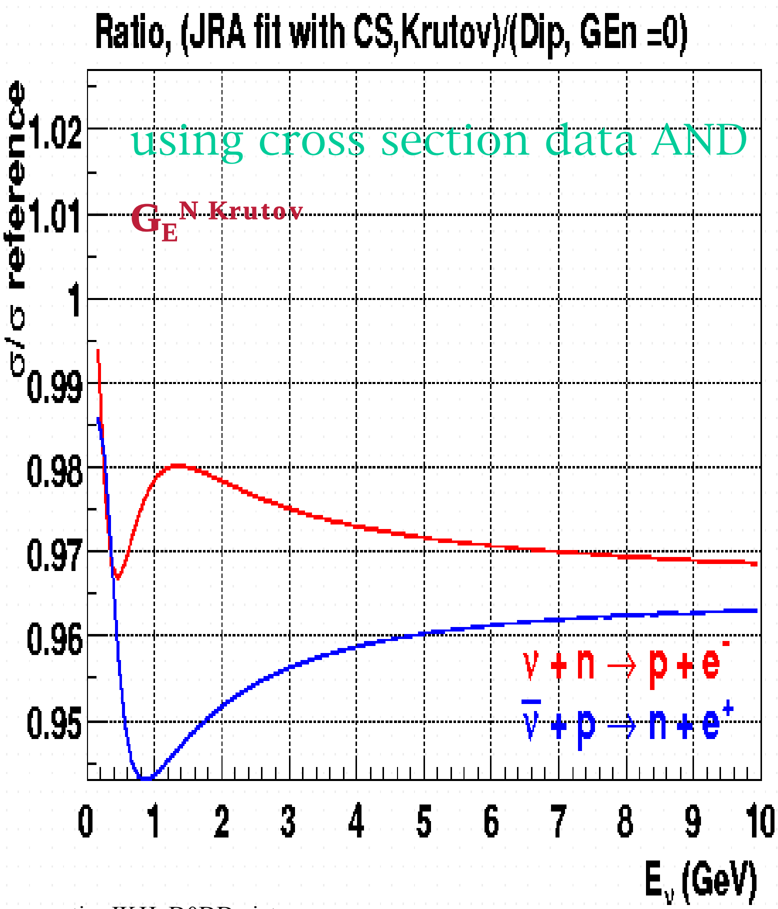


Effect of G_M^N, G_M^P, G_E^P (using POLARIZATION data) (with $G_E^N = 0$) Versus Dipole Form Factor

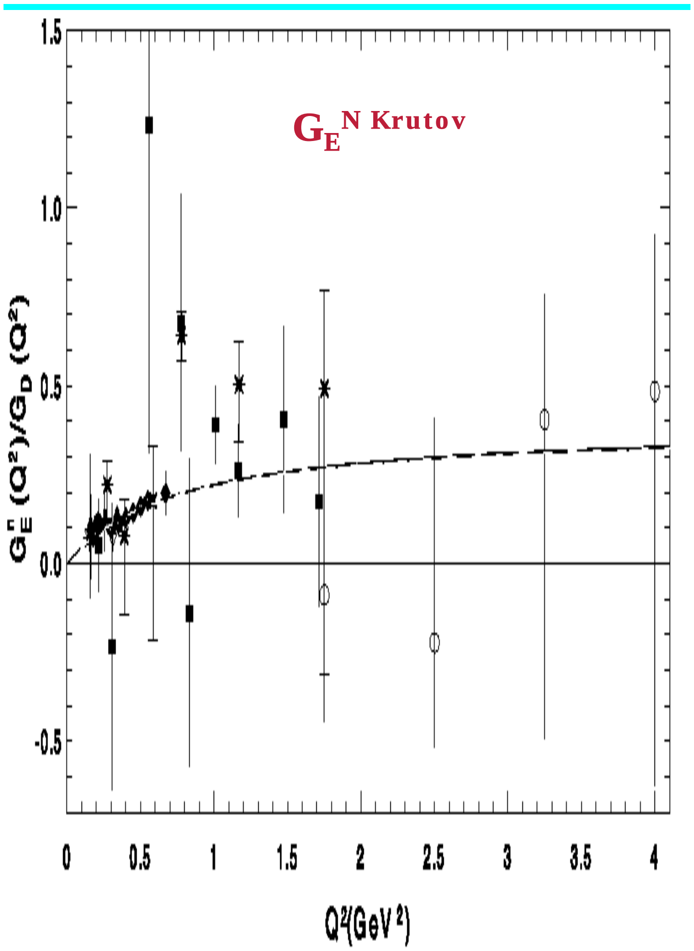




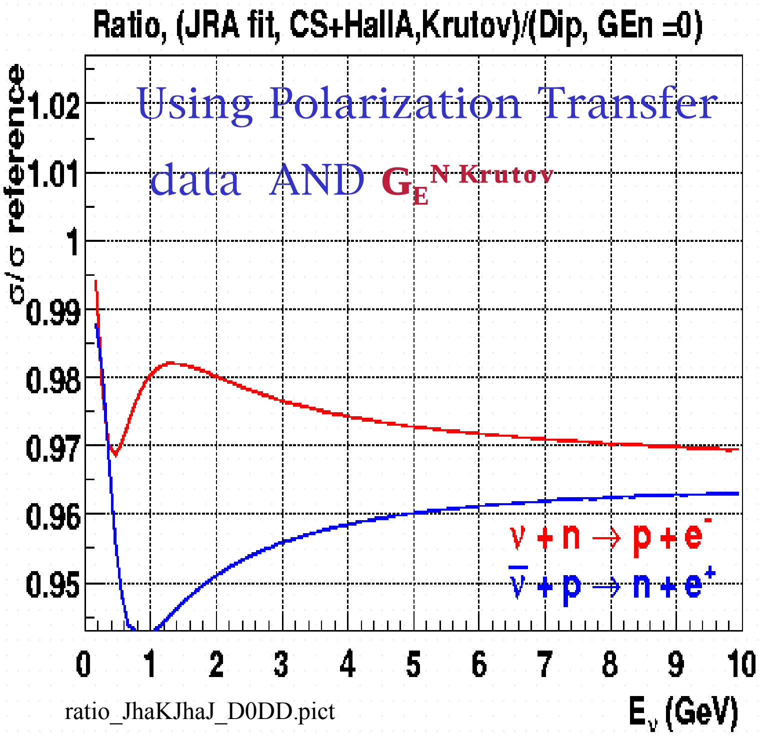
Effect of G_M^N, G_M^P, G_E^P (using cross section data AND non zero $G_E^{N\ Krutov}$) Versus Dipole Form



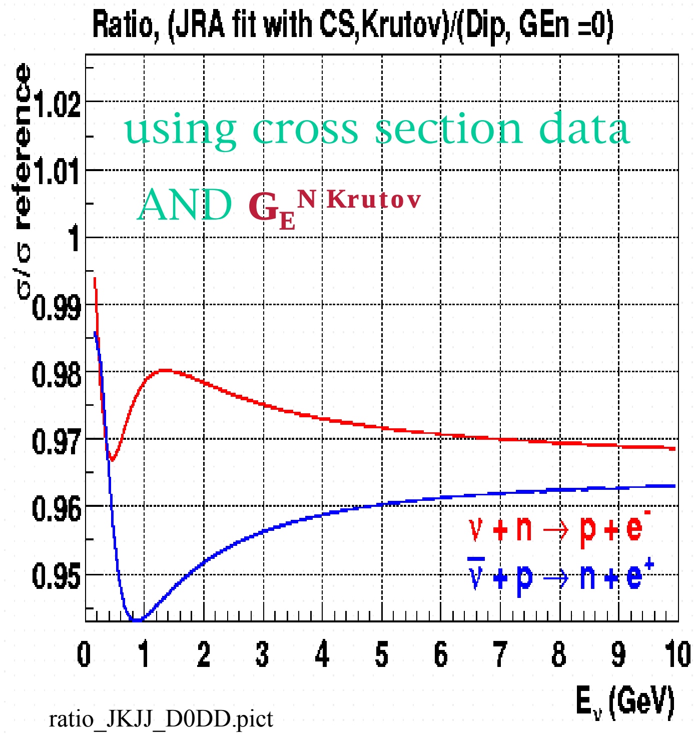
ratio_JKJJ_D0DD.pict



Effect of G_M^N + (G_M^P ,G_E^P using POLARIZATION data AND non zero G_E^N Krutov) - Versus Dipole Form
-> Discrepancy between G_E^P Cross Section and Polarization Data Not significant for Neutrino Cross Sections



ratio_JhaKJhaJ_D0DD.pict



ratio_JKJJ_D0DD.pict

G_M^P ,G_E^P extracted with both e-p Cross section and Polarization data

G_M^P ,G_E^P extracted With e-p Cross Section data only

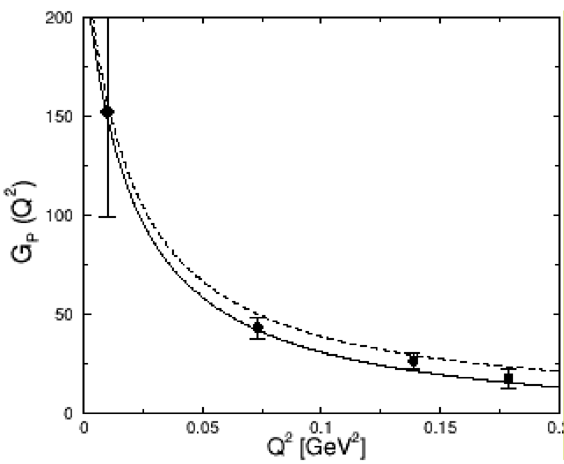
Axial structure of the nucleon

Hep-ph/0107088 (2001)

Véronique Bernard†, Latifa Elouadrhiri‡, Ulf-G Meißner§

induced pseudoscalar form factor is the least well known of all six electroweak nucleon form factors.

Seonho Choi, et al PRL V71 page 3927 (1993) Near Threshold Pion Electro-production and lowest Q2 point from Ordinary Muon Capture (**OMC)** both **agree with PCAC**



Current algebra Assumption for for Fp is OK. 5% effect For Tau neutrinos For muon neutrino Only needed near E=0

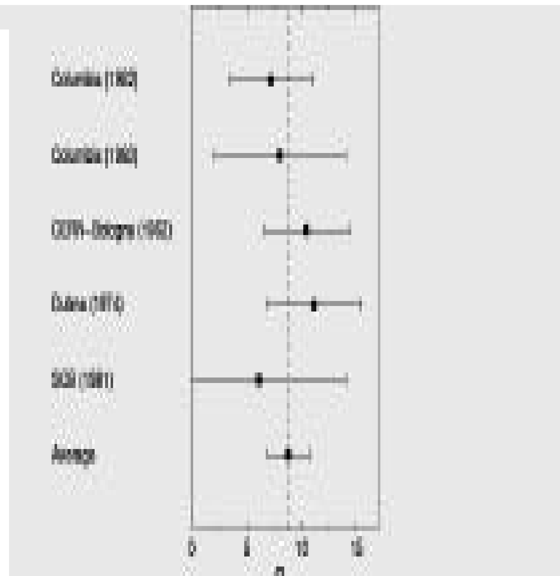
A third way to measure gp. is from Radiative Muon Capture (**RMC**), but the first measurement is factor of 1.4 larger

Figure 5. The "world data" for the induced pseudoscalar form factor $G_P(Q^2)$. The pion electroproduction data (filled circles) are from reference [65]. Also shown is the world average for ordinary muon capture at $Q^2 = 0.88M_\mu^2$ (diamond). For orientation, we also show the theoretical predictions discussed later. Dashed curve: Pion–pole (current algebra) prediction. Solid curve: Next–to–leading order chiral perturbation theory prediction.

Table 1. Pseudoscalar coupling constant determined from OMC in light nuclei.

Nucleus	g_P	Reference
^{3}He (capture to triton)	8.6 ± 1.5	[58]
^{12}C (capture to ground state)	8.3 ± 2.5	[59]
^{16}O (capture to ^{16}N(0^-))	10.0 ± 1.2	[60] [61]

From OMC



backgrounds. Precisely for this reason only very recently a first measurement of RMC on the proton has been published [62, 63]. The resulting number for g_P, which was obtained using a relativistic tree model including the Δ–isobar [64] to fit the measured photon spectrum, came out significantly larger than expected from OMC,

$$g_P^{\rm RMC} = 12.35 \pm 0.88 \pm 0.38 \simeq 1.4\, g_P^{\rm OMC} \;, \qquad (15)$$

From RMC

and thus also about 40% above all theoretical expectations (see section 4.1). It should

$$g_P = (8.74 \pm 0.23) - (0.48 \pm 0.02) = 8.26 \pm 0.16 \;.$$

From PCAC

Axial structure of the nucleon

Hep-ph/0107088 (2001)

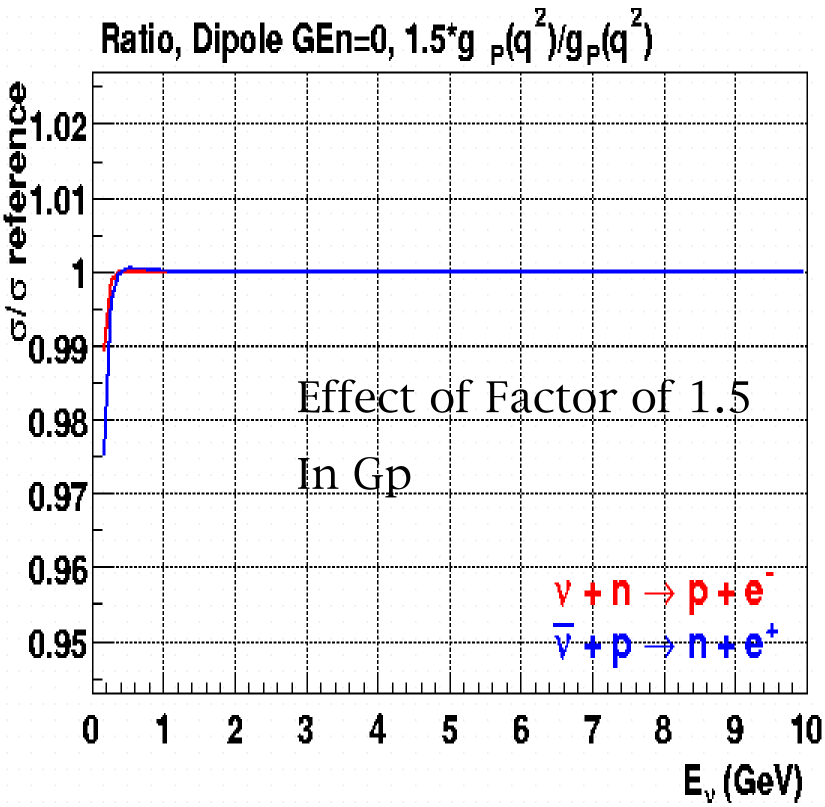
Véronique Bernard†, Latifa Elouadrhiri‡, Ulf-G Meißner§

Note , one measurement of gp from Radiative Muon Capture (RMC) at Q=Mmuon quoted in the above Review disagrees with PCAC By factor of 1.4. PRL V77 page 4512 (1996) .

In contrast Seonho Choi, et al PRL V71 page 3927 (1993) from OMC, agrees with PCAC.

The plot (ratio_gp15_D0DD.pict) shows the sensitivity of the cross section to a factor of 1.5 increase in Gp.

IT IS ONLY IMPORTANT FOR the lowest energies.



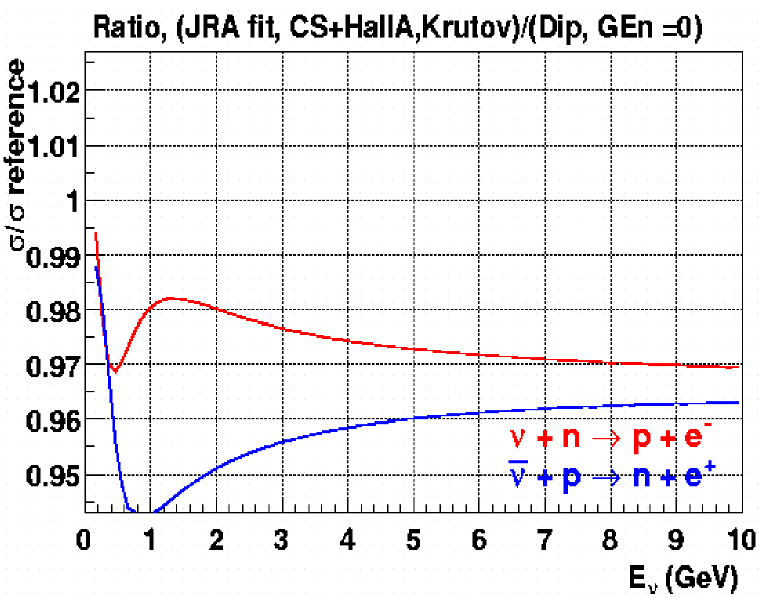
Conclusions

1. Non Zero Value of $\mathbf{G_E^N}$ is the most important (5% effect)

---

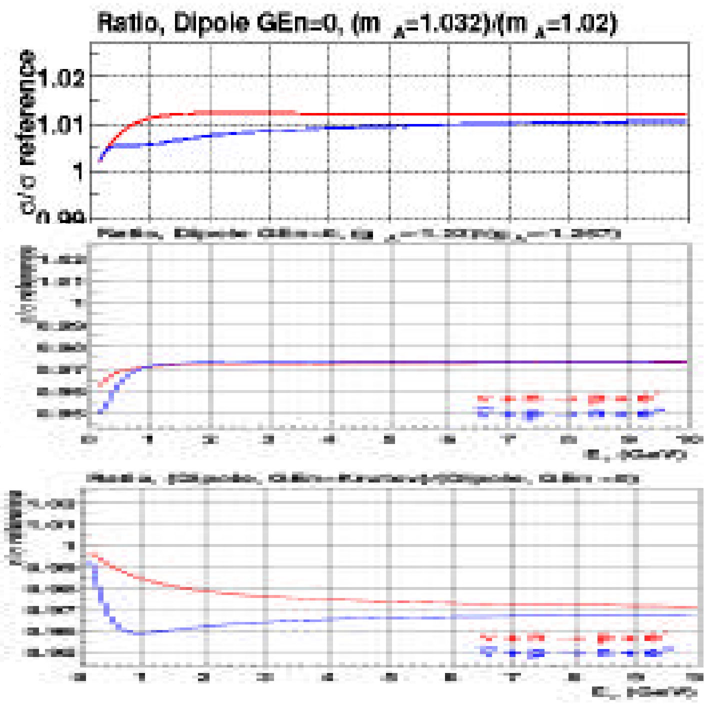
2. We plan to do re-analysis of neutrino quasielastic data for $d\sigma/dQ^2$ to obtain update values of M_A <u>*with*</u>

- Latest values of $\mathbf{G_E^N}$, $\mathbf{G_M^N}$, $\mathbf{G_M^P}$, $\mathbf{G_E^P}$ which affect the shape.
- Latest value of g_A (not important if normalization is not used in $d\sigma/dQ^2$ Flux errors are about 10%).



ratio_JhaKJhaJ_D0DD.pict

Howard Budd, Univ



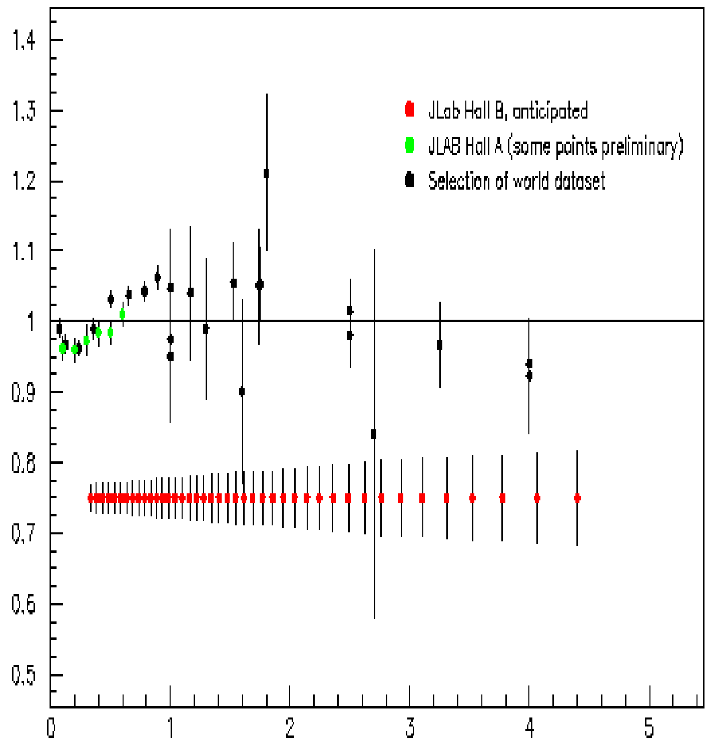
Thanks To: The following Experts (1)

Will Brooks, Jlab - Gmn brooksw@jlab.org

•High-precision low Q2 Gmn: nucl-ex/0107016 Precise Neutron Magnetic Form Factors; G. Kubon, et al , Phys.Lett. B524 (2002) 26-32

•Recent, moderate precision low Q2 data nucl-ex/0208007

•The best high Q2 data:
http://prola.aps.org/pdf/PRL/v70/i6/p718_1
http://prola.aps.org/pdf/PRL/v70/i6/p718_1
They will have a new Gmn measurement from Q2=0.2 or 0.3 out to Q2 approaching 5 GeV2. plot of the expected data quality versus old data (shown as Ratio to Dipole).



The new jlab experiment for GMN is E94-017. It has much more sensitivity (in the sense of statistical information that influences a fit) than existing measurements, just not much more Q2 coverage. The errors will be smaller and will be dominated by experimental systematic errors; previous measurements were dominated by theory errors that could only be estimated by trying different models (except for the new data below 1 GeV). The new experiment's data will dominate any chi-squared fit to previous data, except for the new high-precision data below 1 GeV2 where it will rival the new data. Time scale for results: preliminary results this coming spring or summer, publication less than 1 year later.

Thanks To: The following Experts (2)

Gen: Andrei Semenov, - Kent State, semenov@jlab.org

Who provided tables from (Dr. J.J.Kelly from Maryland U.) on Gen, Gmn, Gen, Gmp .

The new Jlab data on Gen are not yet available, but is important to confirm since non-zero Gen effect is large. The experiment is JLab E93-038. Data were taken in Jefferson Lab (Hall C) in October 2000/April 2001. Data analysis is in progress

The New Jlab Data on Gep/Gmp will help resolve the difference between the Cross Section and Polarization technique. However, it has little effect on the neutrino cross sections. For most recent results from Jlab see: hep-ph/0209243

Neutrino Cross Section Data

http://neutrino.kek.jp/~sakuda/nuint02/

charged current quasi-elastic neutrino
Gargamelle 79 ccqe.nu.ggm79.vec,
ccqe.nub.ggm79.vec -- CF3Br target

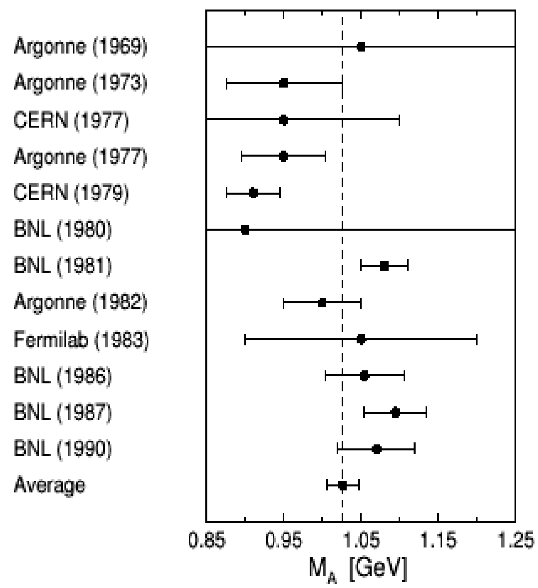
ccqe.serpukhov85.vec,
ccqe.nub.serpukov.vec -- Al. target

charged current quasi-elastic neutrino
Gargamelle 77 ccqe.ggm77.vec
- Propane-Freon

ccqe.nu.skat90.vec
ccqe.nub.skat90.vec -- CF3Br

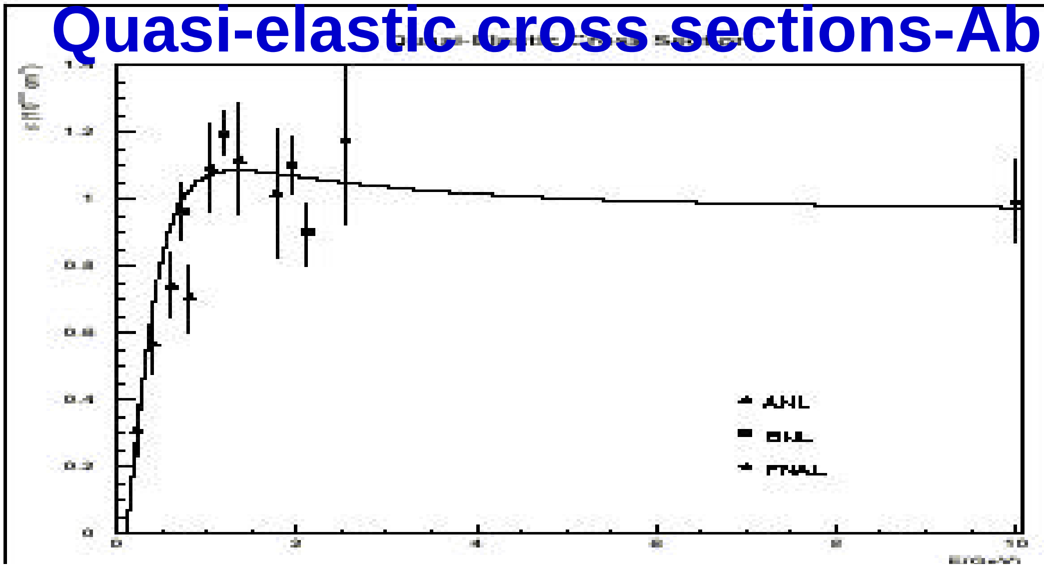
ccqe.nu.bebc90.vec -- D2

Cross section in units of 10^(-38) cm^2.
E Xsection X +-DX Y +-DY or (x1, x2) y +-dy

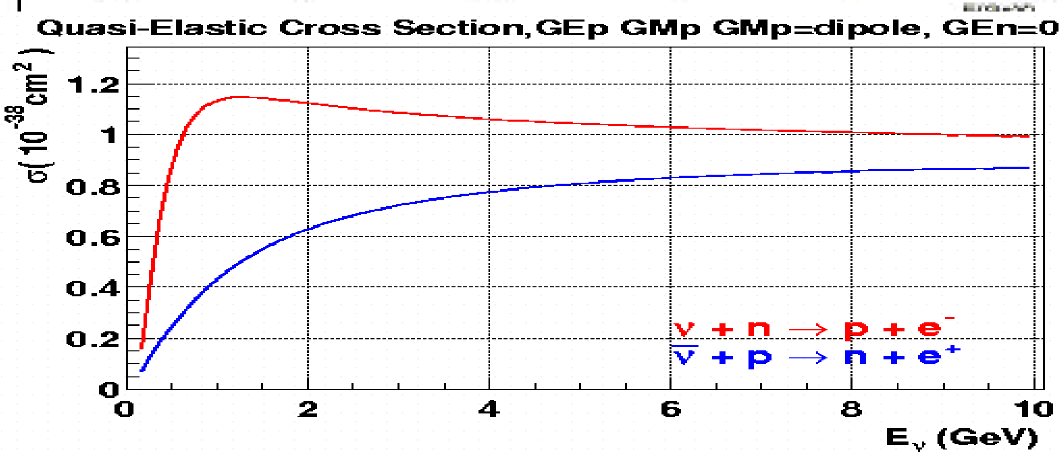


Note more recent
M_A is more reliable-
Better known flux

Examples of Low Energy Neutrino Data: Quasi-elastic cross sections-Absolute



$\sigma_{\text{quasi-elastic}}$ neutrinos On Neutrons From MINOS Paper and MINOS dipole MC



$\sigma_{\text{quasi-elastic}}$ neutrinos on Neutrons-Dipole

$\sigma_{\text{quasielasti}}$ Antineutrinos on Protons -Dipole

elas_D0DD.pict

By C.H. Llewellyn Smith (SLAC). SLAC-PUB-0958 Phys.Rept.3:261,1972

$$F_A(q^2) = -1.23/\left(1 - \frac{q^2}{M_A^2}\right)^n \quad (.24)$$

Old g_A

Replace by

New g_A

(5) Isotriplet current

$$F_V^1(q^2) = \left[F_1^p(q^2) - F_1^n(q^2)\right] = \text{Dirac electromagnetic isovector form factor.} \quad (3.15)$$

$\xi = \mu_p - \mu_n = 3.71$ (μ = anomalous magnetic moment)

$$F_V^2(q^2) = \frac{\mu_p F_2^p(q^2) - \mu_n F_2^n(q^2)}{\mu_p - \mu_n} = \text{Pauli electromagnetic isovector form factor.}$$

In terms of the Sachs form factors

$$F_V^1(q^2) = \left(1 - \frac{q^2}{4M^2}\right)^{-1}\left[G_E^V(q^2) - \frac{q^2}{4M^2} G_M^V(q^2)\right] \quad (3.16)$$

$$\xi F_V^2(q^2) = \left(1 - \frac{q^2}{4M^2}\right)^{-1}\left[G_M^V(q^2) - G_E^V(q^2)\right]$$

UPDATES this talk

Experimentally, the G's are described to within ± 10% by:

$$G_E^V(q^2) = \frac{1}{\left(1 - \frac{q^2}{0.71\ \text{GeV}^2}\right)^2}$$

$$G_M^V(q^2) = \frac{1 + \mu_p - \mu_n}{\left(1 - \frac{q^2}{0.71\ \text{GeV}^2}\right)^2}$$

This assumes

Dipole form factors

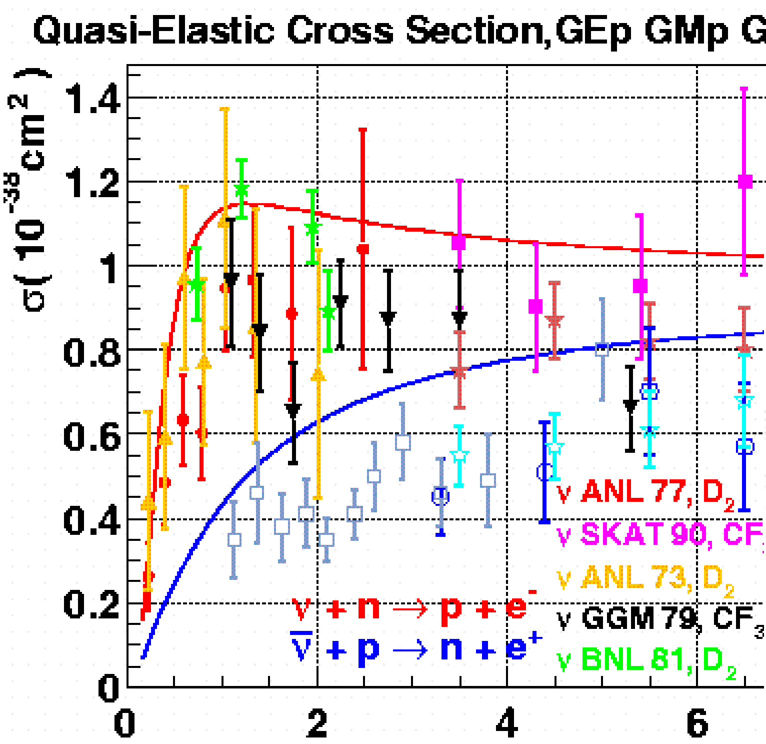
$G_E^N=0$

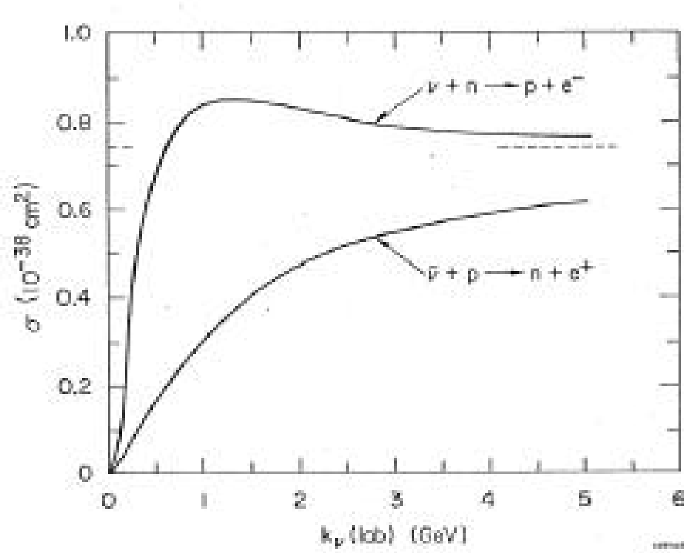
Replace by $G_E^V = G_E^P - G_E^N$

-->note G_E^N is POSITIVE

Replace by $G_M^V = G_M^P - G_M^N$

-->note G_M^N is NEGATIVE





10. Cross sections for the quasielastic process in the conventional theory with $m = 0$ and dipole forms

$$\frac{F(0)}{\left(1 - \frac{q^2}{0.73\ \mathrm{GeV}^2}\right)^2}$$

for the form factors F_A and $F_V^{1,2}$ L12 (the dotted line is the limit of σ_ν and $\sigma_{\bar{\nu}}$ as $E \to \infty$).

Old LS results with
Old ga=-1.23 and
MA below)

Compare to Original Llewellyn Smith Prediction