Motivator: Measurement of G_E^n / G_M^n by the Double Polarised ^{2}H($\overrightarrow{e}$, e'$\overrightarrow{n}$) Reaction

Kieran Hamilton

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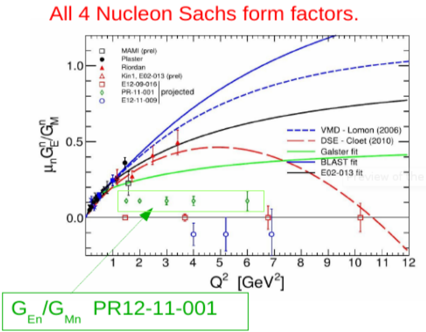
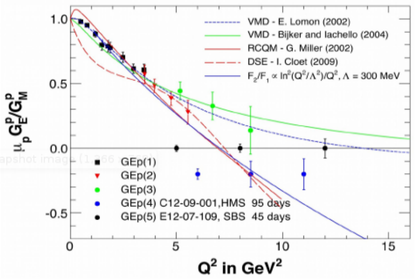
EMFF at Jefferson Lab - Hall A





Main points (as far as I'm considered):

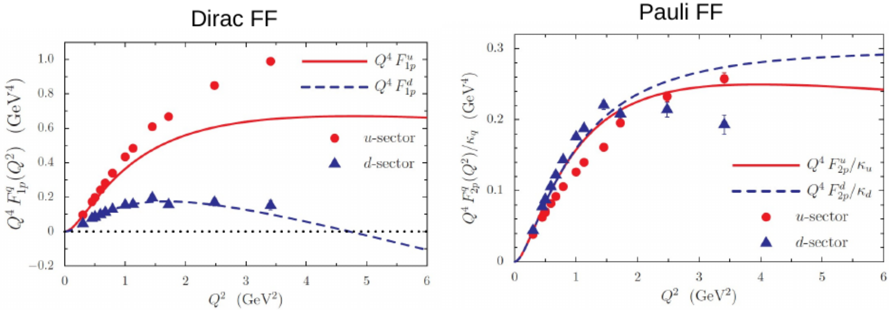
- DSE explicitly describe the dynamical generation of the mass of constituent quarks
- Zero crossing point (if any) of the G_E/G_M ratios affects the location and width of the transition region between constituent- and parton-like behavior of the dressed quarks.
- A more rapid transition from non-perturbative to perturbative behavior pushes the proton zero point to higher Q^2
- Conversely the neutron zero point is pushed to lower Q^2
- Neutron data completely lacking at high Q^2

SBS EMFFs:

- E12-09-019
- E12-09-016
- E12-07-109

EMFF and Diquark Correlations in Nucleons

Calculation: *I.Cloet et al., Phys. Rev. C 90, 045202 (2014)*



Dirac FF

Pauli FF

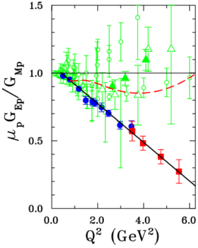
Separated data points: *G. D. Cates et al., Phys. Rev. Lett. 106, 252003 (2011).*

With *Proton & Neutron EMFF data* flavour decomposition possible
Assuming small strange component: $F^u_{1,2} = F^n_{1,2} + 2F^p_{1,2}$ $\quad F^d_{1,2} = 2F^n_{1,2} + F^p_{1,2}$

- Calculation using Nambu-Jona-Lassinio Model, Chiral Effective Field Theory of QCD Valid at low-intermediate energy “Parameter free” calculation. No. FF fit.
- “Soft” d Dirac FF: dominance of scalar diquark correlations
- Pauli FF: axial-vector diquark correlations and pion-cloud effects more important
- Q^2 range of decomposition set by availability of G^n_E data

The Need for Better G_E^n / G_M^n Data

- In terms of Q^2 range and precision, neutron measurements still lag way behind proton measurements
- For measurements in space-like domain at medium-high Q^2 JLab is the only viable lab. Quasi-elastic electron scattering from neutron in ^{2}H, ^{3}He...
- Double polarised experiments are the way to go (since ~ 1990). Relatively low sensitivity to two-photon exchange effects compared to Rosenbluth separation. Better access to relatively small G_E (compared to G_M)
- JLab: E12-09-016 G_E^n/G_M^n with polarized electron beam 3He target up to Q2 of 10 $(GeV/c)^2$ ...see S. Riordan for details.
- Neutron measurements extremely challenging...independent verification of results necessary. Alternative method with polarised electron beam and polarimeter to measure polarisation transfer to recoiling neutron. Unpolarised ^{2}H target - QE signal much cleaner
- ^{2}H experiment should, as far as possible, match kinematic range and precision of ^{3}He experiment.
- No recoil polarimetry measurement at $Q^2 > 1.5$ $(GeV/c)^2$



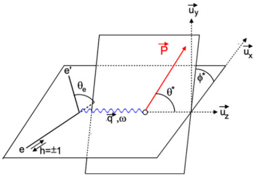


Fig. 15. Polarized electron scattering from a polarized target.

Summary of Experimental Technique

Question: Obtain G_E^n/G_M^n for Q^2 of 2.0 - 9.3 ? $(GeV/c)^2$

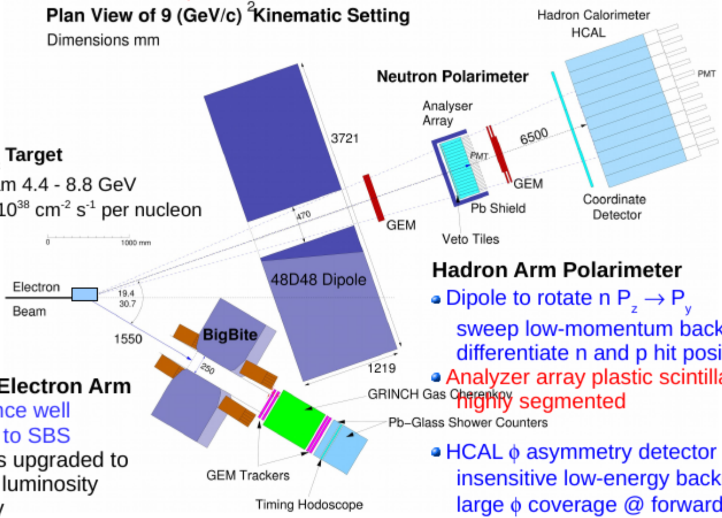
Measure double-polarised $^2H(\vec{e}, e'\vec{n})p$

As opposed to E12-09-016 $^3\vec{He}(\vec{e}, e'n)pp$

- Final-state neutron $P_x/P_z \longrightarrow G_E^n / G_M^n$ (precess $P_z \longrightarrow P_y$ in dipole magnetic field)
- Cryogenic D_2 Target 10 cm long
- 40μA 80% polarized electron beam
- $L = 1.26 \times 10^{38}$ cm^{-2}s^{-1}
- BigBite e' detector (same configuration as E12-09-019 G_M^n/G_M^p). Large acceptance ($\sim$ 55 msr), adequate momentum resolution ($\delta p/p \sim 1\%$)
- SBS Neutron polarimeter: acceptance well matched to electron arm. Dipole magnet, integrated field $\sim$ 2 Tm. Hadron calorimeter, high n efficiency, effective suppression soft background. Active organic-material analyzer. High rate charged-particle tracking systems
- Still examining polarimeter configurations...active/passive analyser? Geant-4 simulation

G_E^n Apparatus $e + d \longrightarrow e' + n + p$

Explore possibility to use G_{Ep} polarimeter charge-exchange n-p



10cm LD_2 Target

40 µA beam 4.4 - 8.8 GeV

$\mathfrak{L}$: 1.26 × 10^{38} cm^{-2} s^{-1} per nucleon

BigBite Electron Arm

Acceptance well matched to SBS

Detectors upgraded to increase luminosity capability

Hadron Arm Polarimeter

- Dipole to rotate n $P_z \rightarrow P_y$
  sweep low-momentum background
  differentiate n and p hit positions
- Analyzer array plastic scintillator
  highly segmented
- HCAL ϕ asymmetry detector
  insensitive low-energy background
  large ϕ coverage @ forward θ

G_E^n / G_M^n Using Recoil Polarimetery

R.G.Arnold, C.E.Carlson and F.Gross, Phys.Rev. C23(1981),363
A.I.Akhiezer et al., JEPT 33 (1957),765

$$\begin{aligned}
P_x &= -hP_e\frac{2\sqrt{\tau(1+\tau)}\tan\frac{\theta_e}{2}G_EG_M}{G_E^2+\tau G_M^2(1+2(1+\tau)\tan^2\frac{\theta_e}{2}} \\
P_y &= 0 \\
P_z &= hP_e\frac{2\tau\sqrt{1+\tau+(1+\tau)^2\tan^2\frac{\theta_e}{2}}\tan\frac{\theta_e}{2}G_M^2}{G_E^2+\tau G_M^2(1+2(1+\tau)\tan^2\frac{\theta_e}{2})} \\
\frac{P_x}{P_z} &= \frac{1}{\sqrt{\tau+\tau(1+\tau)\tan^2\frac{\theta_e}{2}}}\cdot\frac{G_E}{G_M}
\end{aligned}$$

Recoil Polarimetry...
N-N scattering $V_{so}(\boldsymbol{l.s})\rightarrow$
ϕ dependence of cross section relates to transverse polarisation components

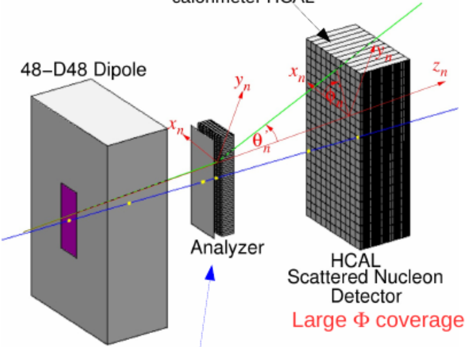
$$\sigma(\theta'_n,\phi'_n)=\sigma_\circ\left(1+P_e\alpha_{eff}\left[P_x^n\sin\phi'_n+P_y^n\cos\phi'_n\right]\right)$$

Precession angle of nucleon P_z through dipole

$$\chi = \frac{2\mu_N}{\hbar c\beta_N}\int_L B.dl$$

Integrated Field ~2 Tm: $\chi\rightarrow 70°$ as $\beta_n\rightarrow 1$

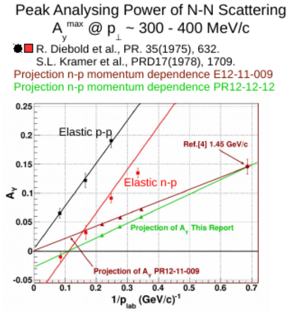
Scattering asymmetry blocks detect neutrons or protons...
Here: Fe/Plastic segmented calorimeter HCAL

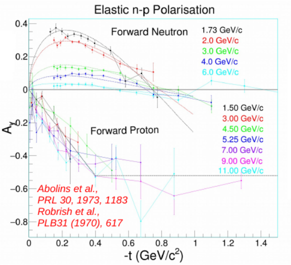


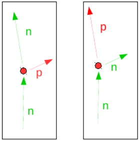
Analyser block for neutrons active (e.g. plastic scintillator) and position sensitive. Use both elastic n-p and quasi-elastic n-p from ^{12}C

Elastic N - N Scattering

- Elastic n-p or p-p for highest A_y value. LH_2 analyser possibly not feasible technically at JLab
- Proton A_y measurements C, CH_2 : detect forward proton + X undetected. This does not select elastic or quasi-elastic exclusively
- Empirical p+C value of $A_y \sim 0.5$ of free elastic p-p scattering. Partially fermi-motion smearing of the elastic signal. Partially inelastic contamination.
- Advantageous to detect forward scattered nucleon. Smaller spread in angles. High energy...threshold can be set to reject low-energy background







- A_y for n-p (or p-n) falling rapidly with increasing neutron momentum.
- A_y for charge-exchange n-p large at sufficiently large t ($\theta_p \sim$ few deg.). No apparent strong incident momentum dependence of A_y
- Charge-exchange cross section factor ∼ 10 lower than n-p. SAID PWA over estimates this cross section by a factor ∼6.

G_E^n / G_M^n Methods ... Pros and Cons

Polarized Target Neutron or Polarized Recoiling Neutron?

Advantages Recoil Polarimetry

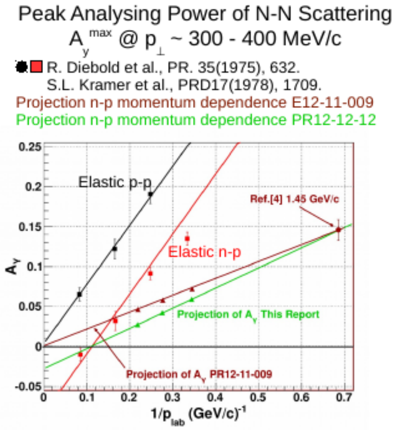
- ^{3}He target is complex and expensive
- ^{2}H (liquid) target offers higher luminosity (if detectors will stand the radiation load)
- Quasi-elastic scattering on ^{2}H gives a cleaner signal than ^{3}He...less non-elastic contamination
- Bound-nucleon effects smaller for ^{2}H

Disadvantages Recoil Polarimetry

- For n-p analysing power A_y prop $1/p_N$ Experiment FOM prop A_y^2 (or P_{target}^2) $A_y \sim 0.05$, $P_{target} \sim 0.6$
- Nucleon polarimeter has relatively low detection efficiency (n scattering)
- Up to now no recoil-polarimetry measurement beyond $Q^2 = 1.5$ (GeV/c)^2 Hall-C *Plaster et al, PRC 73,(2006), 025205*

Take home message from the plot:

- Hydrogen in principle the best analyser
- C, CH_2 used in practice
- For neutrons can use plastic scintillator or Cherenkov ...active analyzer highly desirable to reconstruct scattering kinematics



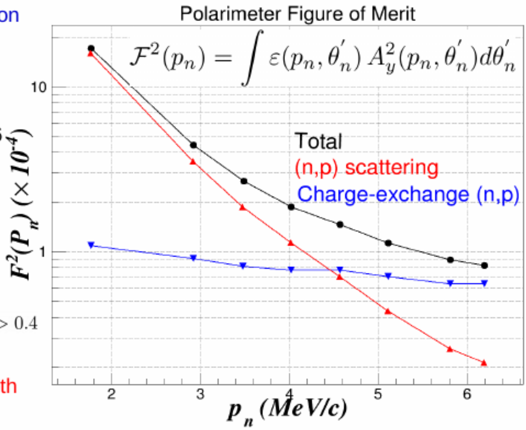
Preliminary: Polarimeter Figure of Merit

Neutron Scattering in Analyzer Material

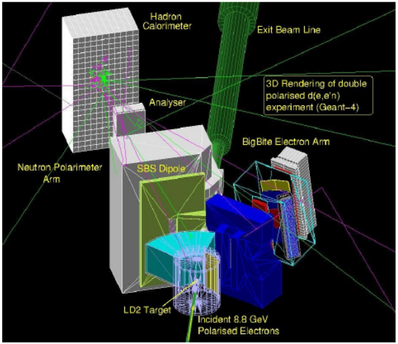
$$\sigma(\theta_n^{'}, \phi_n^{'}) = \sigma(\theta_n^{'}) \left[1 + A_y(\theta_n^{'}) \left\{ P_x^n \sin\phi_n^{'} + P_y^n \cos\phi_n^{'} \right\} \right]$$

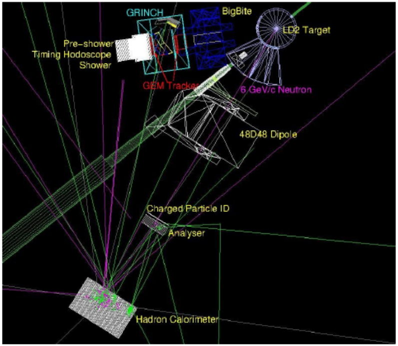
Monte Carlo: ROOT & G4

- Generate elastic n(e,e'n)
  produce n-momentum distribution
  n scatters from analyzer block
  into HCAL
- n-p cross section SAID PWA.
  × [1 + (effective# protons in C)]
  Scale charge-exchange by 0.16
  Efficiency ~ 7-8%
- Efficiency from G4 ~ 12-13%
- A_y for n-p scatter (forward n)
  Ladygin (JINR) fit to p_n and t
  dependence
- A_y charge-exch. n-p (forward p)
  $A_Y^H = t, -t < 0.4;\ A_Y^H = -0.52, -t > 0.4$
  $A_Y^C = 0.5 \times A_Y^H$
- SBS polarimeter sensitive to both
  n-p and charge-exchange n-p



The Geant4 Model





- Geant4.10.01: add ϕ dependence polarised nucleon elastic and QE scattering
- Record signal amplitude and time from each detector element.
- Analyse simulated data as in real experiment.
- Calculate element rates 8.8 GeV, 40 μ A on 10 cm LD_2 ($L = 1.26 \times 10^{38}$ cm^{-2}s^{-1})
- Concentrating on polarimeter arm. Cluster analysis, energy-weighted mean hit position
- Reconstruct angle in analyser and scattering angle analyser to calorimeter. Extract ϕ dependence.


THANKS
FOR WATCHING
ANY
QUESTIONS ?