Experimental Studies of Spin Structure in Light Nuclei

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Why studying light nuclei spin structure ?

- Test of effective theories of strong interaction (χPT,...).
- Connection between hadronic and nuclear physics.
- Effective neutron target.

Why studying light nuclei spin structure ?

- Test of effective theories of strong interaction (χPT,...).

- Connection between hadronic and nuclear physics.

- (Effective neutron target.) ⟼ Source of the data available so far.

I will discuss two avenues of research:

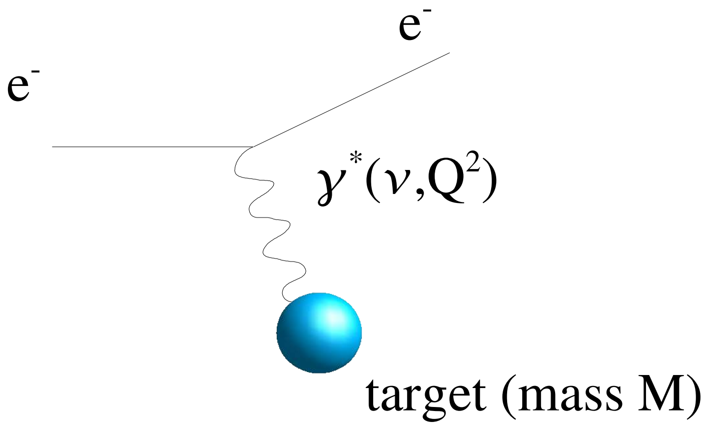
1) Moments of spin structure functions: Sum rules that helped testing QCD are also valid for nuclei.
   ⇒Powerful tools for nuclear structure study.

2) Polarized EMC effect.

I will be discussing JLab's research only.

Electron scattering at Jefferson Lab

- Probe nucleon and nuclei using electrons.



  - ν: energy transfer
  - Q^2:-(4-momentum transfer)^2
  - $W^2=M^2+2M\nu-Q^2$: (invariant mass)^2
  - $x=Q^2/(2M\nu)$: Bjorken scaling variable (momentum fraction carried by struck quark)

Sum rules

Sum rules are relations linking an integral over structure functions to quantities characterizing the target.

Examples of polarized sum rules (for nucleons):

Bjorken sum rule: $\int_0^1 [g_1^p(x)-g_1^n(x)]dx = \frac{1}{6} g_A$ stands at $Q^2 \rightarrow \infty$

(generalized version for finite Q^2 also exists. Versions for individual nucleons exist: Ellis-Jaffe SR. Have additional hypotheses beyond validity of pQCD.)

GDH sum rule: $\int_{\nu_{thr}}^{\infty} \sigma_{TT}(\nu)\frac{d\nu}{\nu} = \frac{-4\alpha\pi^2\kappa^2}{M^2}$ $Q^2=0$

where $\sigma_{TT} \equiv (\sigma^{1/2}-\sigma^{3/2})/2$ (can also be written as sum on g_1 and g_2)

Generalized GDH SR: $\int_{\nu_{thr}}^{\infty} \frac{K}{\nu}\sigma_{TT}(\nu,Q^2)\frac{d\nu}{\nu} = \frac{-4\alpha\pi^2}{M^2} I_{TT}(\nu,Q^2)$ any Q^2

Burkhardt–Cottingham sum rule: $\int_0^1 g_2(x,Q^2)dx=0$ Valid for any Q^2

Polarizabilities sum rules:

Generalized forward spin polarizability:

$$\gamma_0=\frac{4e^2M^2}{\pi Q^6}\int_{\nu_{thr}}^{\infty} x^2\left(g_1-\frac{4M^2}{Q^2}x^2g_2\right)dx$$

Longitudinal-Transverse polarizability:

$$\delta_{LT}=\frac{4e^2M^2}{\pi Q^6}\int_{\nu_{thr}}^{\infty} x^2(g_1+g_2)dx$$

Usefulness of sum rules

- Test of theory on which the sum rule is based:

  ex: (generalized) Bjorken SR:

$$\int[g_1^p\underbrace{(x,Q^2)-g_1^n(x,Q^2)}_{\text{measured (CERN, SLAC, DESY)}}]dx \underset{\text{theory}}{=} \underbrace{\frac{1}{6}g_A}_{\text{known}}.\underbrace{f(Q^2)}_{\text{calculated (pQCD)}}.$$

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$$\text{measured (CERN, SLAC, DESY)} \qquad \text{theory} \qquad \text{known} \quad \text{calculated (pQCD)}$$

- Test hypothesis entering the sum rule derivation.

  ex: Ellis-Jaffe SR: $\Delta S=0$, flavor SU(3) symmetry.

- Only known way to access observables.

  ex: generalized GDH sum rule, polarizability sum rules

  ⇒Test calculation methods: χPT, Lattice QCD,...

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⇒Sum rules are versatile approaches to investigate target structure and the interactions shaping it.

What sum rules are available for nuclear targets ?

Bjorken sum rule: For any mirror nuclei.

Ex. ^{3}He & ^{3}H: $\int [g_1^{3H}(x,Q^2)-g_1^{3He}(x,Q^2)]dx = g_A^{Tri}.f(Q^2)$.

GDH and Generalized GDH sum rules: Valid for any target.

$$\int_{\nu_{\gamma\text{-desint.}}}^{\infty} (\sigma(\nu)^A - \sigma(\nu)^P)\frac{d\nu}{\nu} = \frac{-4\alpha S\pi^2\kappa^2}{M^2}$$

BC sum rule: Valid for any target.

Nuclear effects in the GDH sum rule

$$\frac{-4\alpha S\pi^2\kappa^2}{M^2} = \begin{cases} -204\ \mu\text{b} & \text{(proton)} \\ -234\ \mu\text{b} & \text{(neutron)} \end{cases}$$

$^3\vec{\mathrm{He}} \sim \vec{n} + 2p$. Since GDH sum is insensitive to unpolarized target content, we expect: $\mathrm{GDH}_{3He} \sim \mathrm{GDH}_n$ +break-up

Similarly, $\vec{D} \sim \vec{p} + \vec{n}$. We expect $\mathrm{GDH}_D \sim \mathrm{GDH}_p + \mathrm{GDH}_n$ +break-up

We have:

$$\frac{-4\alpha S\pi^2\kappa^2}{M^2} = \begin{cases} -496\ \mu\text{b} & (^3\text{He}) \\ -0.65\ \mu\text{b} & \text{(deuteron)} \end{cases}$$

⇒Large contribution from nuclear structure

Available data on integrals of $g_{1,2}$ from JLab

- ^{3}He from $0.1<Q^2<0.9$ GeV^2. E94010. 1998, Hall A
  - M. Amarian *et al.* Phys.Rev.Lett. 89 (2002) 242301
  - M. Amarian *et al.* Phys.Rev.Lett. 92 (2004) 022301

Spokespersons: Z-E Meziani, G. Cates, J-P Chen

- Deuteron from $0.07<Q^2<3.$ GeV^2. EG1. 1998 and 2000, Hall B
  - J. Yun *et al.,* PRC, 67, 055204 (2003)
  - K.V. Dharmawardane *et al.,* PLB, 641, 11 (2006)
  - P.E. Bosted *et al.,* PRC, 75, 045203 (2007)

Spokespersons: S. Kuhn, G. Dodge, M. Taiuti

- Deuteron for Q^2~1 GeV^2. RSS. 2000, Hall C

Spokespersons: O. Randon, M. Jones

- ^{3}He from $0.02<Q^2<0.2$ GeV^2. E97110. 2003, Hall A.

Spokespersons: J-P Chen, A. Deur, F. Garibaldi

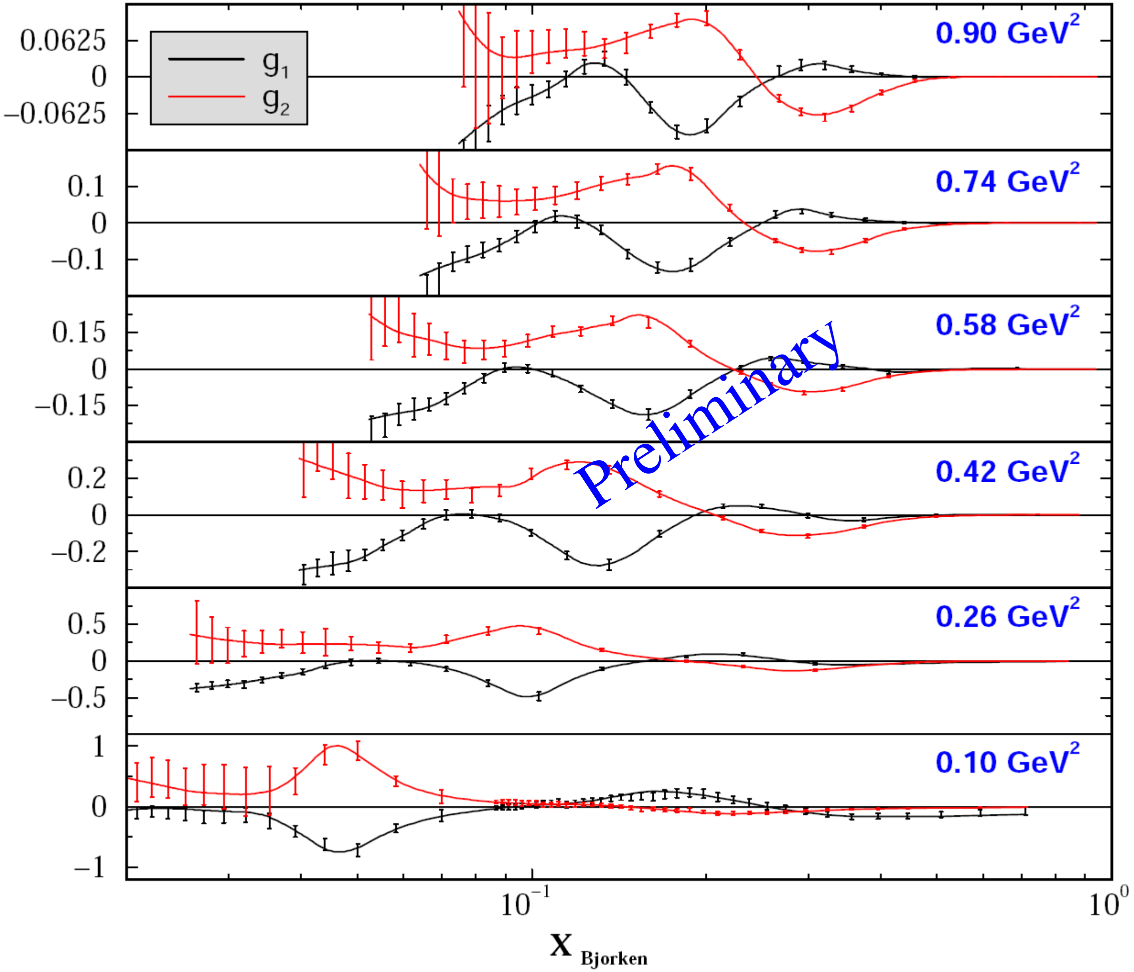
- Deuteron from $0.01<Q^2<0.3$. EG4. 2006, Hall B

Spokespersons: A. Deur, G. Dodge, K. Slifer

Results from E94010

Spin structure functions on ^{3}He

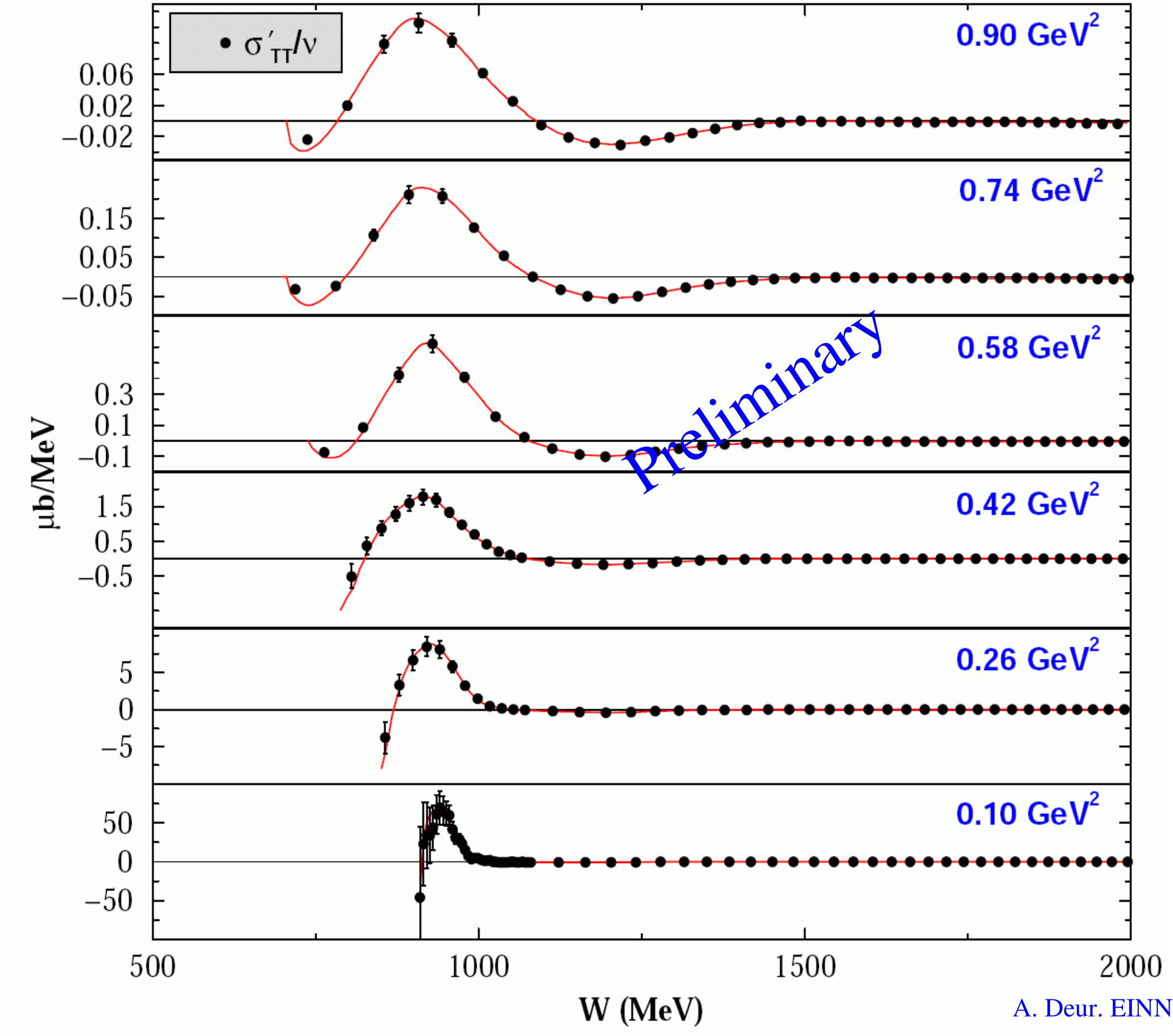
K. Slifer *et al.*, TBP



Results from E94010

GDH integrand (^{3}He)

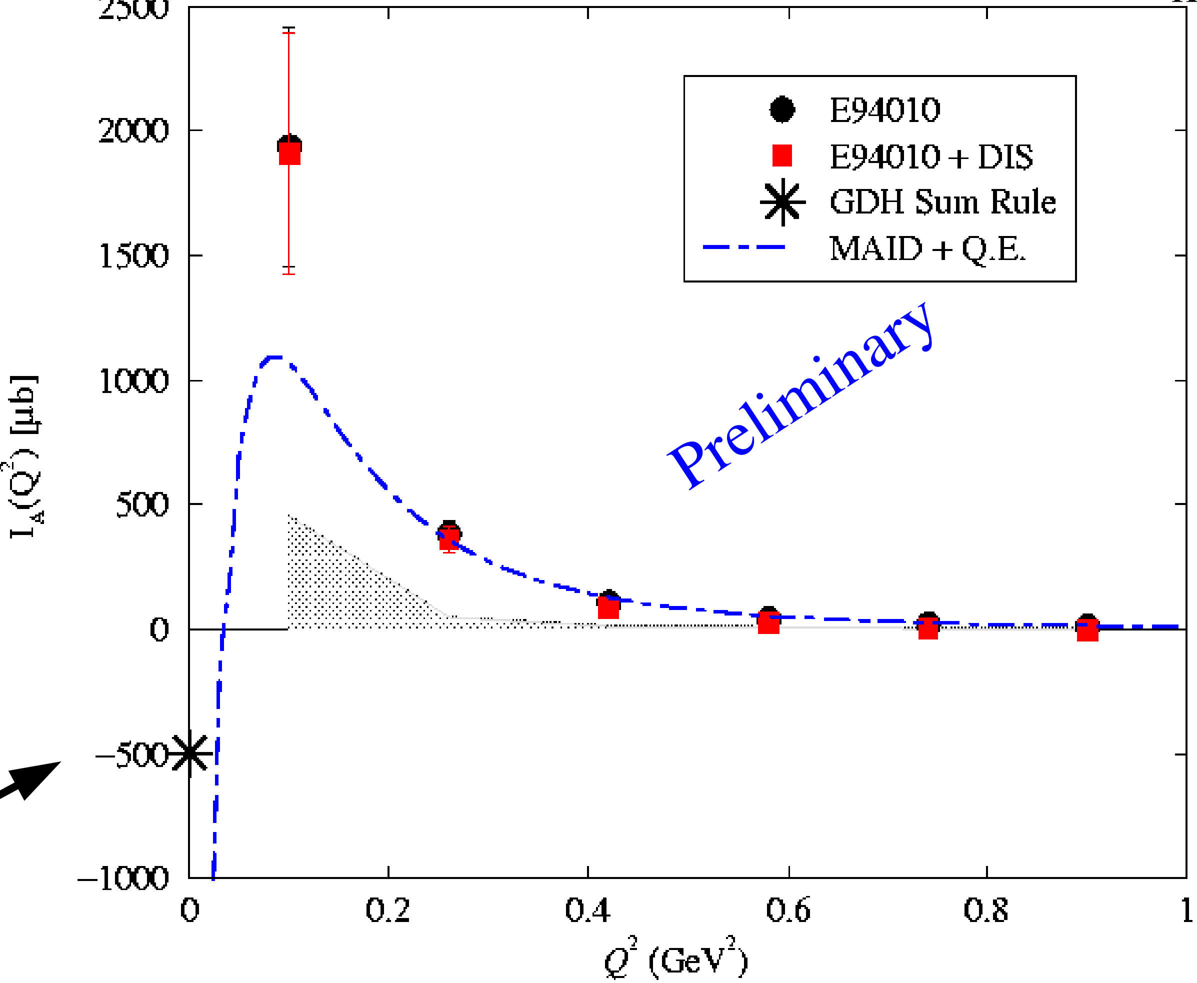
K. Slifer *et al.*, TBP



Results from E94010

GDH sum rule on ^{3}He

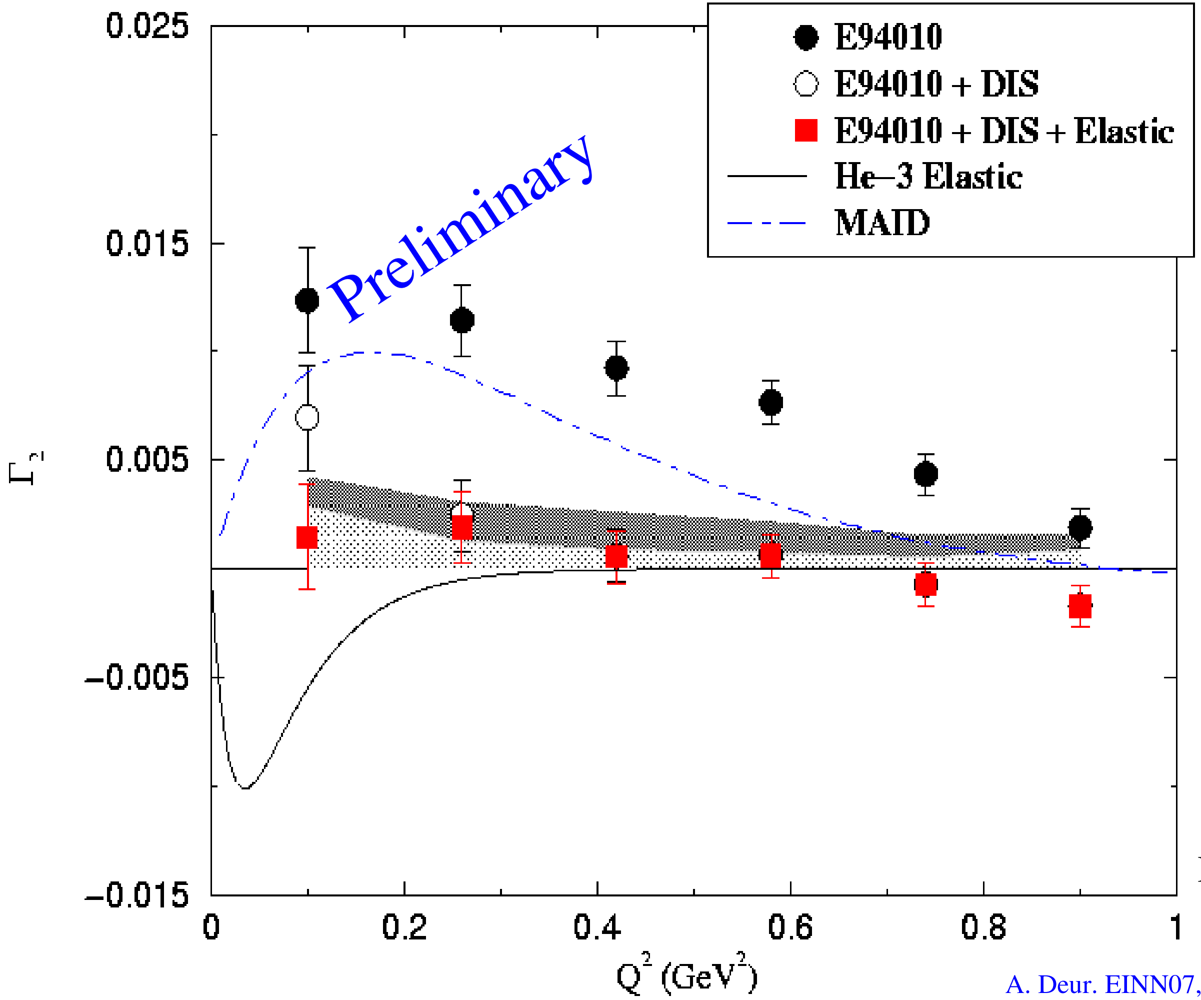
K. Slifer *et al.*, TBP



Note the large scale

Results from E94010

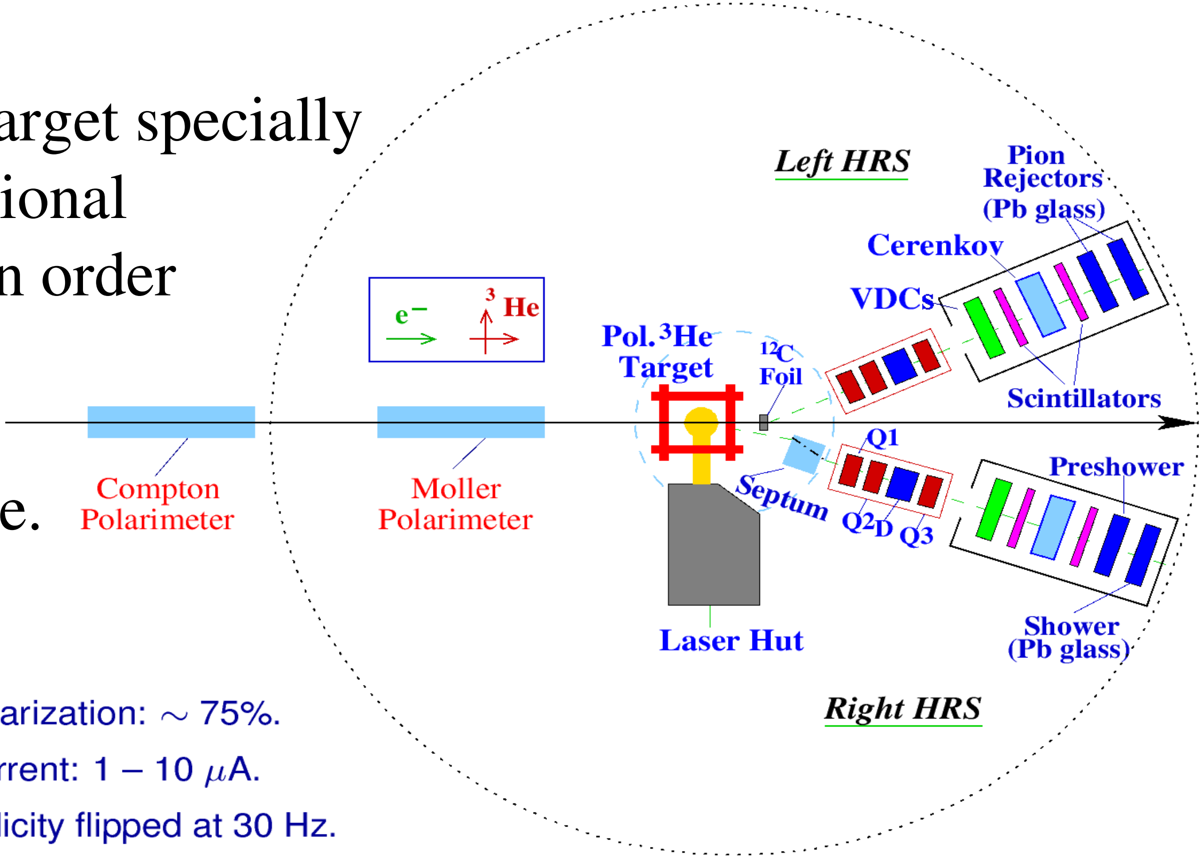
Burkhardt–Cottingham sum rule on ^{3}He $\int_0^1 g_2 dx=0$



K. Slifer *et al.*, TBP

Experiment E97110

- Continuation of E94010.
- Designed to extend low Q^2 coverage down to 0.02 GeV^2.
- Ran in Hall A with ^{3}He target specially designed target and additional magnet in spectrometer in order to access forward angles.
- Test of χPT for n and ^{3}He.

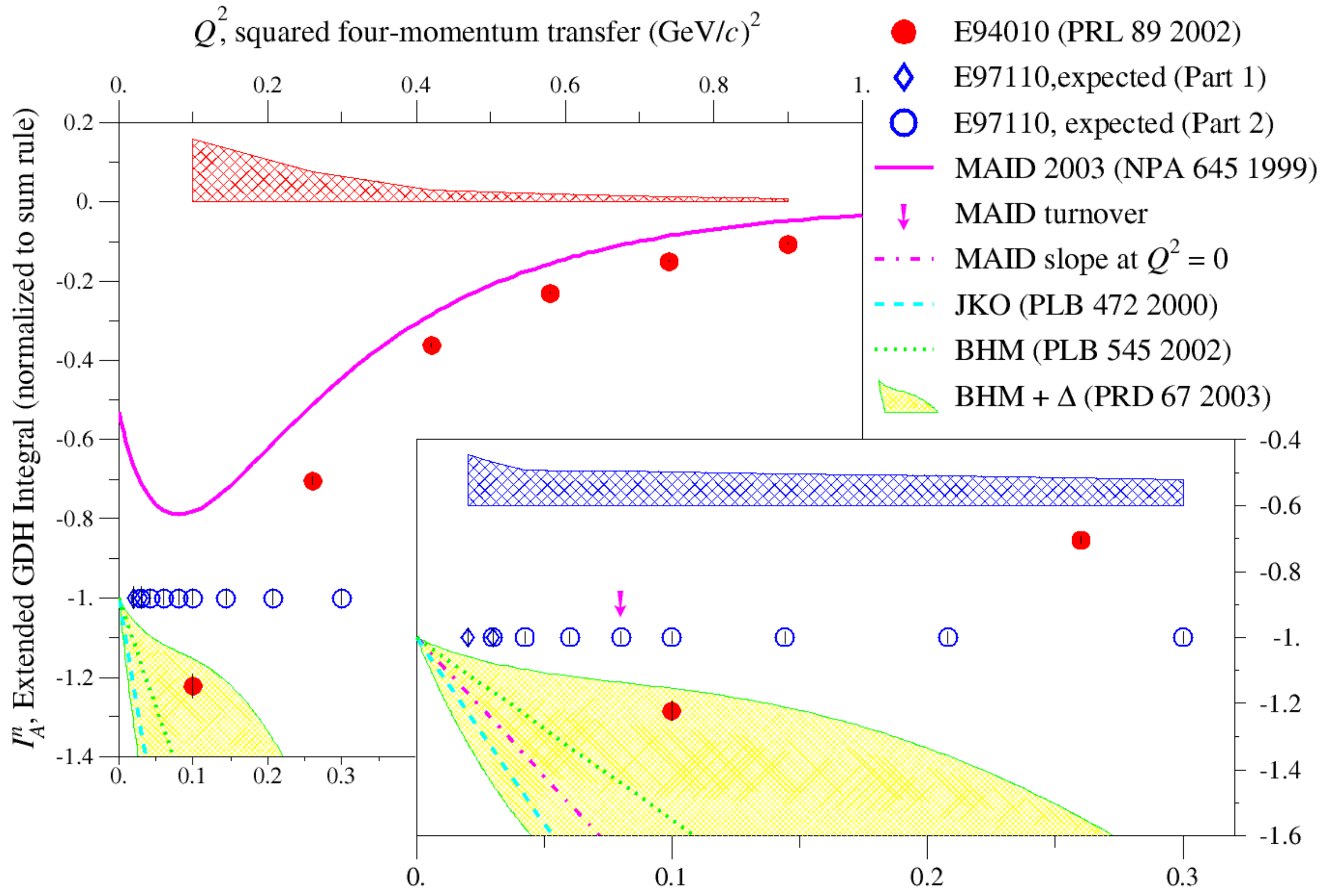


Beam Polarization: $\sim$ 75%.

Beam Current: 1 – 10 μA.

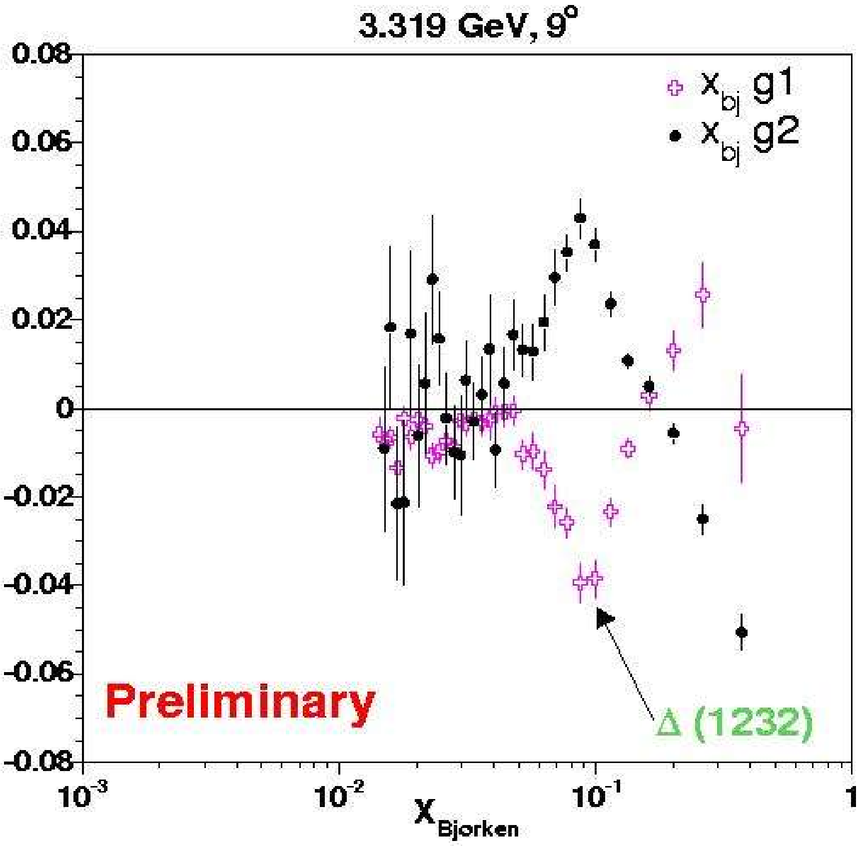
Beam Helicity flipped at 30 Hz.

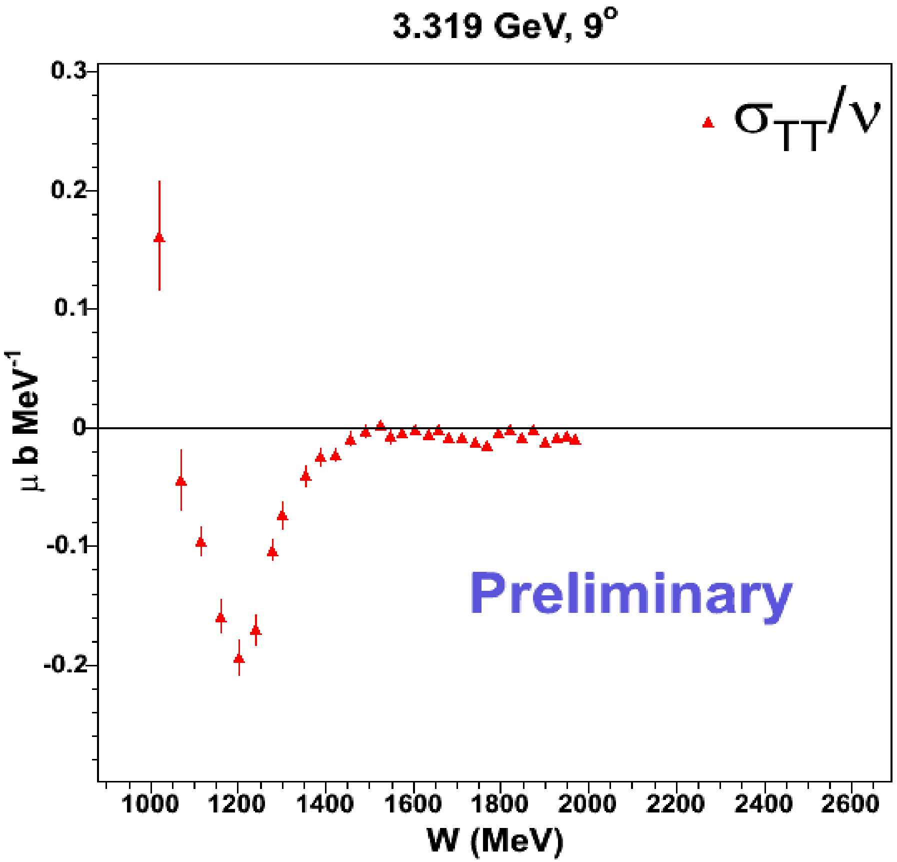
Expected Q^2 coverage and accuracy on GDH^n



Preliminary Results from E97110

Analysis by V. Sulkosky





7 other energies and angles (6° and 9°) also analyzed.

Perspectives on sum rules

- E94010 results on ^{3}He to be published soon.
- Extension at lower Q^2 to test χPT.
- From E94010 results, E97110 data at lower Q^2 should be very interesting. But analysis for ^{3}He is more challenging.
- Proposal to disentangle the breakup and q-elastic parts for deuteron in Hall C (complement CLAS EG4). JLab PR06-018

Spokespersons: K. Slifer, A. Deur

EMC effect in spin structure functions

EMC effect: never studied for spin distributions.

Expected to be large for spin distributions.

(I. Cloët, W. Bentz and A. W Thomas, PRL 95 052302 (2005).

(deuteron, light nucleus (^{6}Li). (Hall C) E07-011. To be run in 2008)

P. Bosted, X. Jiang, F. Wesselmann

proton, light nucleus (^{7}Li). (Hall B) Letter Of Intent LOI 06-003

V. Dharmawardane, P. Bosted, W. Brooks, D. Crabb, S. Kuhn

neutron, heavy nucleus (^{129}Xe, possibly ^{21}Ne).(Hall A): LOI 06-004

A. Deur, X. Zheng

EMC effect on g_1^n in ^{129}Xe and ^{21}Ne.

LOI 06-004,
A. Deur, X. Zheng

Experiment in Hall A with standard equipment, except target.

Established technology to polarize Xe and Ne (same as ^{3}He) but need to be pushed and adapted to target. Possible, but significant R&D required.

Uncertainty on shell model calculations makes it difficult to disentangle the trivial nuclear effects (effective polarization of the polarized valence nucleon) from interesting effect (modification of nucleon structure).

EMC effect on g_1^p in ^{7}Li.

LOI 06-003

V. Dharmawardane, P. Bosted, W. Brooks, D. Crabb, S. Kuhn

Experiment in Hall B with standard equipment.

Established technology for polarized ^{7}Li target.

Similar uncertainty as for Xe & Ne would make results hard to interpret.

Polarized EMC effect

⇒ - Experiments are possible.

- Calculations on polarized EMC effect available.

- Understanding of nuclear structure not good enough yet to disentangle nuclear structure effects from nucleon modification.

Situation may improve for light nuclei.
Maybe specific experiments can help for heavier ones
(ex. quasi-elastic scattering to constrain effective polarization).

Summary and perspectives

- JLab program on neutron spin structure is providing large amount of polarized data on D and ^{3}He.

- Sum rules on ^{3}He (generalized GDH, BC) were investigated.
  - BC sum rule holds.
  - GDH sum at $Q^2 \neq 0$ very large and opposite sign as for $Q^2=0$. lower Q^2 data available soon will help understanding the situation and will provide first check of GDH sum rule on ^{3}He.

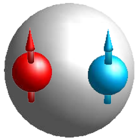
- Nuclear sum rules cannot be investigated yet on D due to lack of detector resolution. Experiment proposed to measure missing moiety.

- Extensive data set on D and ^{6}Li in DIS will be taken in 2008 (Hall C).

- Possibility of experiments on polarized EMC effect explored. Present uncertainty on nuclear structure would cloud interpretation.

Complementarity of ^{3}He and D

- Deuteron:
  - Neutron extraction:



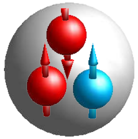
$$\Gamma_1^n = \left(\frac{2}{1-1.5\omega_d}\right)\Gamma_1^d - \Gamma_1^p$$

  - Simplest nucleus
  - Loosely bound nucleons

} uncertainty on the above equation: 2%

  - Large correction from proton → Uncertainty on input: $\Delta\Gamma_1^p = 8\%$

- Polarized ^{3}He:
  - Neutron extraction:



$$\Gamma_1^n = \frac{\Gamma_1^{He} - 2P_p\Gamma_1^p}{P_n}$$

  - More complex nucleus
  - Nucleons bound more tightly

} uncertainty on the above equation: 8%

  - Small nuclear correction: $P_p\Delta\Gamma_1^p = 0.2\%$, $\Delta P_n = 2\%$

Error on nuclear correction in both cases: ~8%. Different origin in both cases

→ excellent complementarity of Deuteron and $^3\overrightarrow{\mathrm{He}}$

(Numbers are for Q^2=0.1 GeV^2)