The GDH Sum Rule in Few–Body Systems.

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For the Jefferson Lab Hall A GDH Collaboration.

Physics Framework

Late 70's, polarized beams and targets.

→
- Further checks of pQCD.
- Spin structure of the nucleons.

SLAC, CERN, DESY

Jefferson Lab:

- Continuous polarized electron beam.
- Low to intermediate Q^2 range.

→ Precise study of the pQCD–npQCD transition.

(pQCD: quarks & gluons; npQCD: nucleons & mesons)

A unique tool to study this transition: The extended GDH sum rule.

GDH Sum Rule: $Q^2=0$

- Spin ½ targets (nucleons, ^{3}He,...):

$$\int_{\nu_0}^{\infty} \sigma^{TT} \frac{d\nu}{\nu} = -\pi\alpha\frac{\kappa^2}{M^2}$$

S. Gerasimov. Yad. Fiz. 2 598 (1965)

S. D. Drell & A.C Hearn Phys. Rev. Lett. 16 908 (1966)

κ: anomalous magnetic moment

$$\sigma^{TT} = \frac{\sigma^{1/2} - \sigma^{3/2}}{2}$$ Photoproduction cross sections

- General case:

$$\int_{\nu_0}^{\infty} \sigma^{TT} \frac{d\nu}{\nu} = -4\pi^2\frac{\mu_a^2}{J}$$

Generalized GDH sum rule (GDH*)

"Generalized": From photoproduction to electroproduction

$Q^2=0$ $\qquad$ $Q^2>0$

Several ways to define the GDH* integral so that
$GDH^*(Q^2) \xrightarrow[Q^2\to 0]{} GDH$

D. Drechsel et al, Phys. Rev D63 (2001 114010)

One definition of GDH* stands out:

X. Ji & J. Osborn. J.Phys G27 (2001) 127

- Extends the sum rule.
- Connects to the Bjorken sum rule.

$$\int_{\nu_0}^{\infty} G_{1(2)} \frac{d\nu'}{\nu'} = \overline{S}_{1(2)}$$

$\overline{S}_{1(2)}$: forward Compton amplitudes.

Calculable on the full QCD spectrum (χpT, lattice, Higher Twist Expansion).

Connection between the sum rules

$Q^2=0$

$$\int_{\nu_0}^{\infty} \left[\sigma^{1/2}(\nu)-\sigma^{3/2}(\nu)\right] \frac{d\nu}{\nu} = -2\pi^2\alpha\frac{\kappa^2}{M^2}$$ → GDH sum rule

Photoproduction

↓

Electroproduction

$$\frac{M^2}{8\pi^2\alpha}\int_{\nu_0}^{\infty} \left[\sigma^{1/2}(\nu,Q^2)-\sigma^{3/2}(\nu,Q^2)\right] \frac{d\nu}{\nu}$$ → GDH* integral

$$= \frac{2M^2}{4\pi^2\alpha}\int_{\nu_0}^{\infty} \sigma^{TT} \frac{d\nu}{\nu}$$

$$= \frac{2M^2}{Q^2}\int_{0}^{1^-} g_1(x,Q^2) - 4M^2\frac{x^2}{Q^2} g_2(x,Q^2)\, dx$$ → Ji sum rules

↓

$$\frac{1}{Q^2} g_2(\nu,Q^2) \xrightarrow[\substack{Q^2\to\infty \\ \nu\to\infty}]{} 0$$

$$\int_0^1 g_1^p(x)\,dx - \int_0^1 g_1^n(x)\,dx = \frac{1}{6}a_1$$ → Bjorken sum rule

$Q^2 \to \infty$

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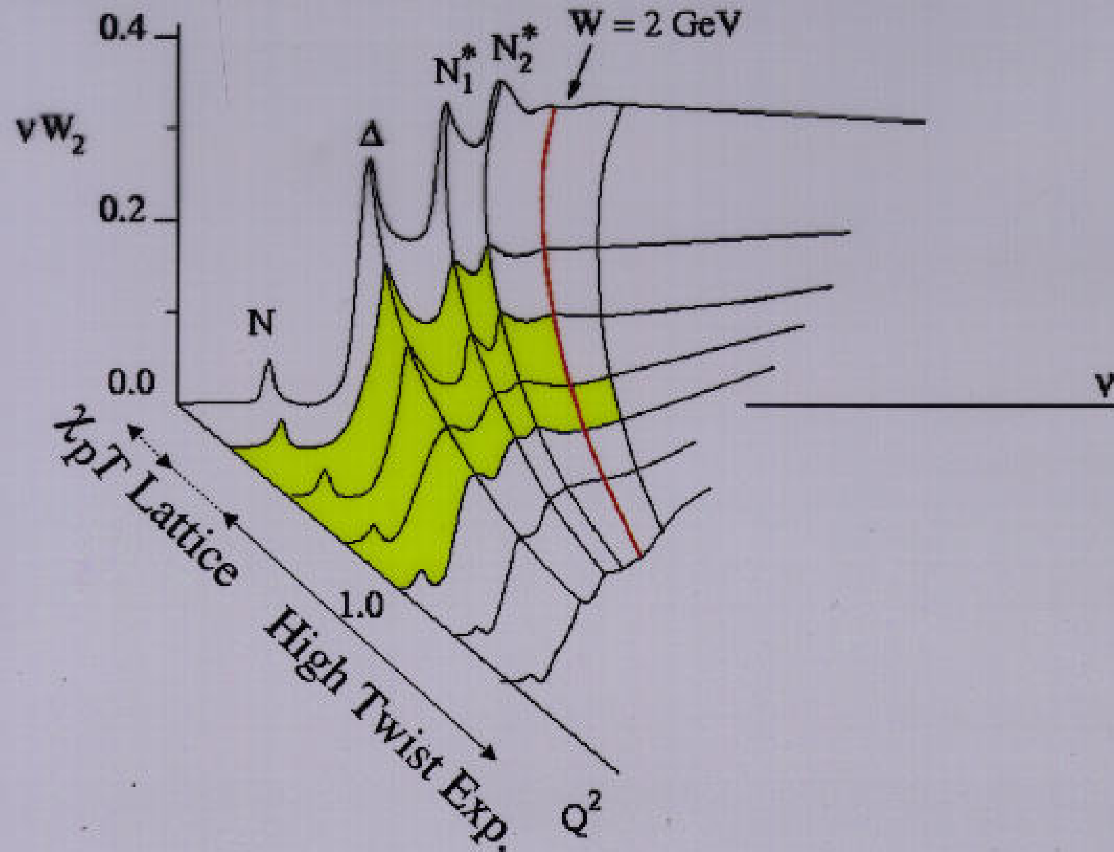
Transition from incoherent to coherent reactions

Experiment E94010, Hall A:



- RHS of the sum rule calculable on the full QCD spectrum
- LHS measured in: •the transition domain (JLab Hall A & B)
  •the DIS domain (E143, HERMES)

Nuclear Study on ^{3}He

GDH(^{3}He) ~ −496 μb

If $^3\overrightarrow{He} \sim \vec{n}$

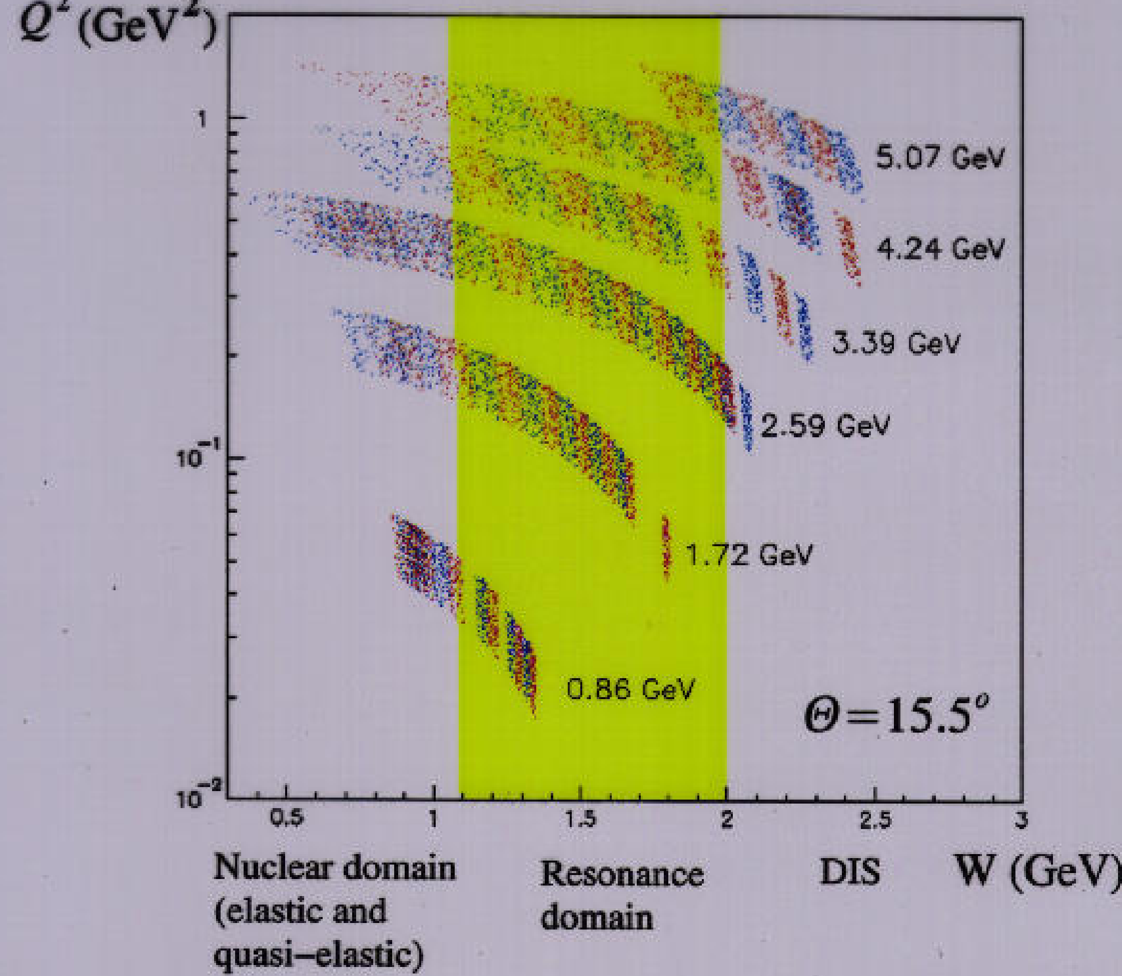
Then GDH(^{3}He) ~ GDH(n) + quasi−elastic contribution
(−233 μb) (−263 μb)

→ The measurement of the quasi−elastic part can be used as a check of our understanding of the ^{3}He nuclear description.

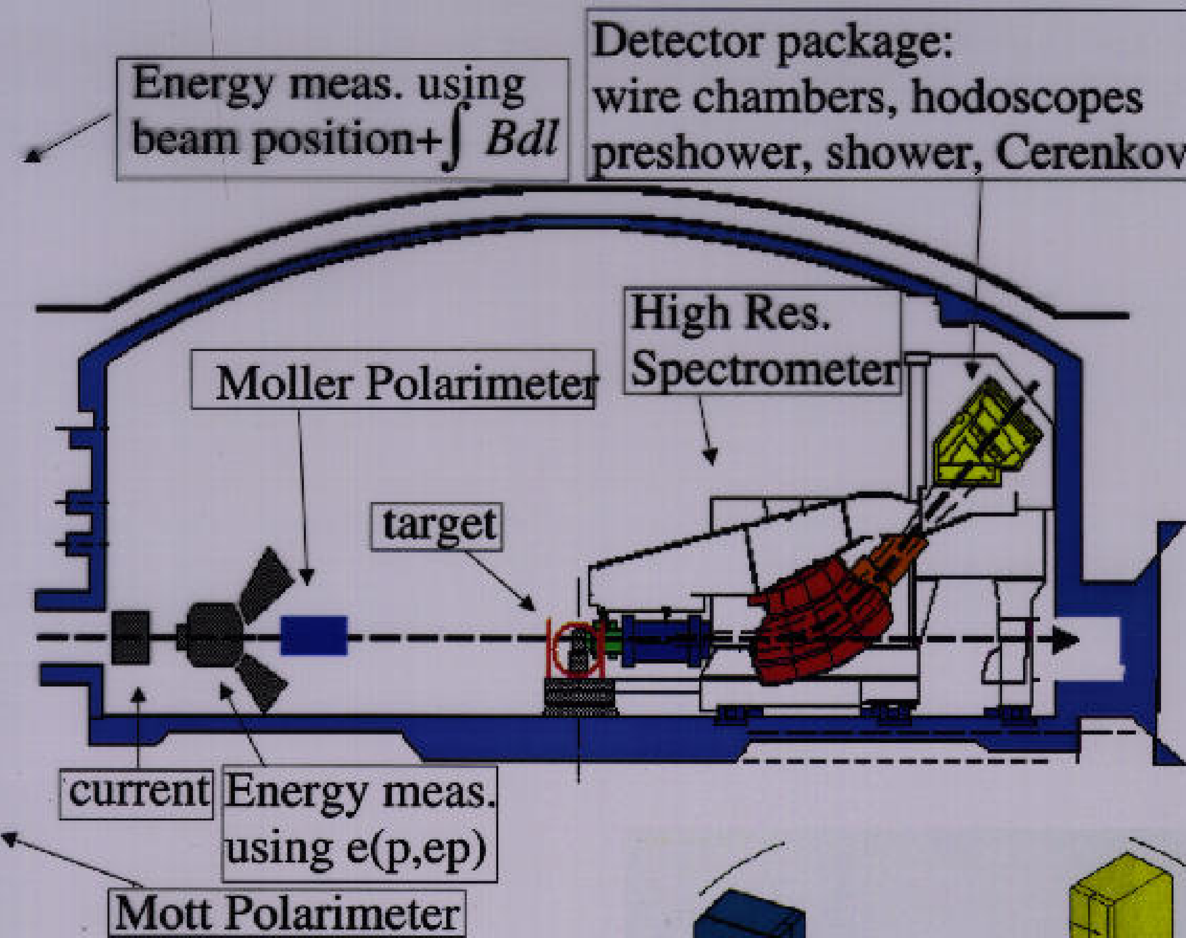
Experimental method and kinematics.

Experimentally, we have to obtain: $\sigma^{\uparrow\uparrow}, \sigma^{\uparrow\downarrow}, \sigma^{\rightarrow\uparrow}, \sigma^{\rightarrow\downarrow}$

in order to get g_1, g_2, σ^{TT} at fixed Q^2.

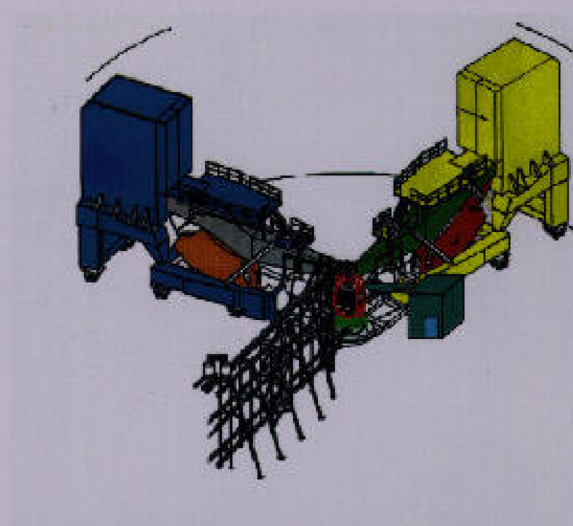


Jefferson Lab Hall A.



Beam characteristics:

- 1–15 μA
- 0.8–5.1 GeV
- 70% pol.



The ^{3}He polarized target

$\overrightarrow{^3He}$ at first order: $\vec{n}$ diluted by 2 p.

JLab target design: Similar to SLAC E142/E154.
Improvement: Optical pumping in any (in–plane) direction.

Successfully used in 4 experiments (GDH*, G_m^n, A_1^n, g_2^n).

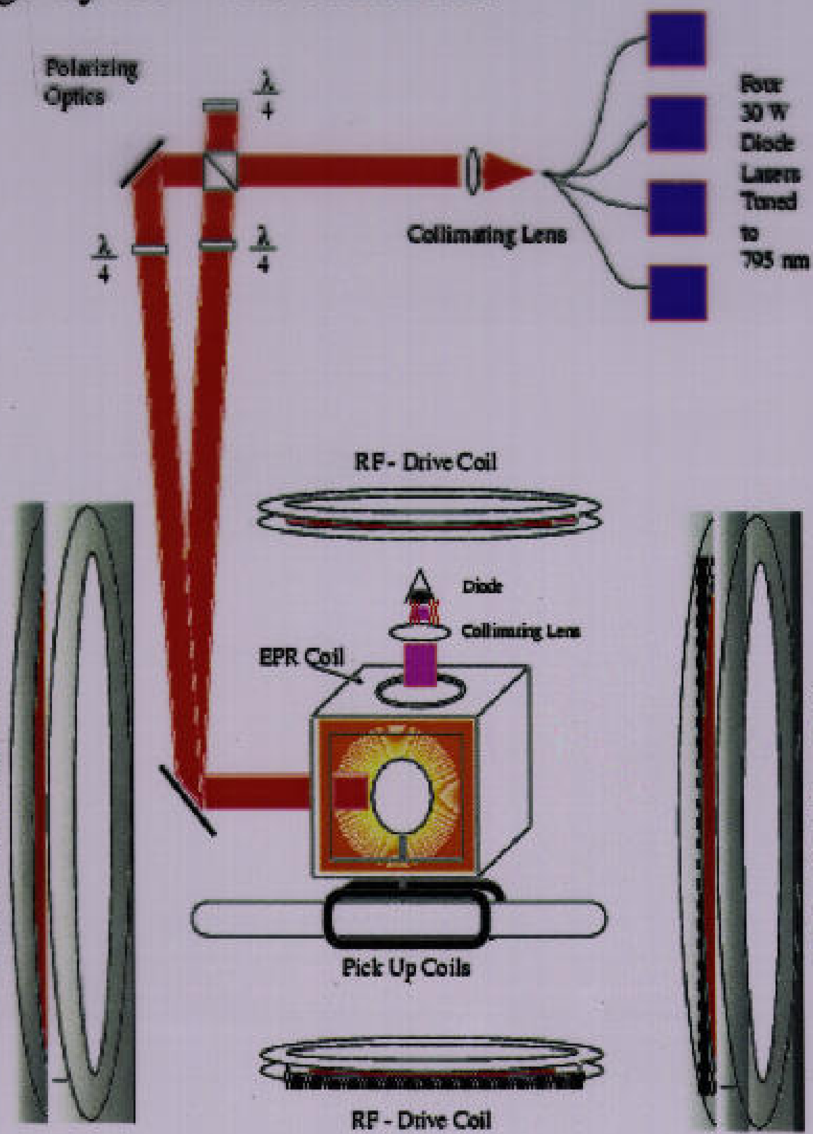
Polarization=35–40% (in running conditions).
Length=25 to 40 cm.

→ Luminosity 10^{36} cm^{-2}.s^{-1} (for 15 μA, 40 cm).

Polarimetry: NMR,EPR (and elastic).
$\Delta P/P$= 4% (GDH*)

^{3}He Target Setup

Basic principles: Optical pumping of Rb, then spin exchange by Rb–^{3}He collisions.



Collaboration: CalTech, Clermont–Ferrand, JLab, Univ. of Kentucky, MIT, Princeton, Temple, Univ. of Virginia, Col. of William & Mary.

From ^{3}He to Neutron

degli Atti et al
Phy Rev C48 968 (1993)
Phys Let B404 223 (1997)

^{3}He: not in a pure S wave. → The proton spins contribute to the nucleus spin.

$$g^{3He} = 2P_p g^p + P_n g^n$$

with: $P_p = -0.028$
$P_n = 0.86$

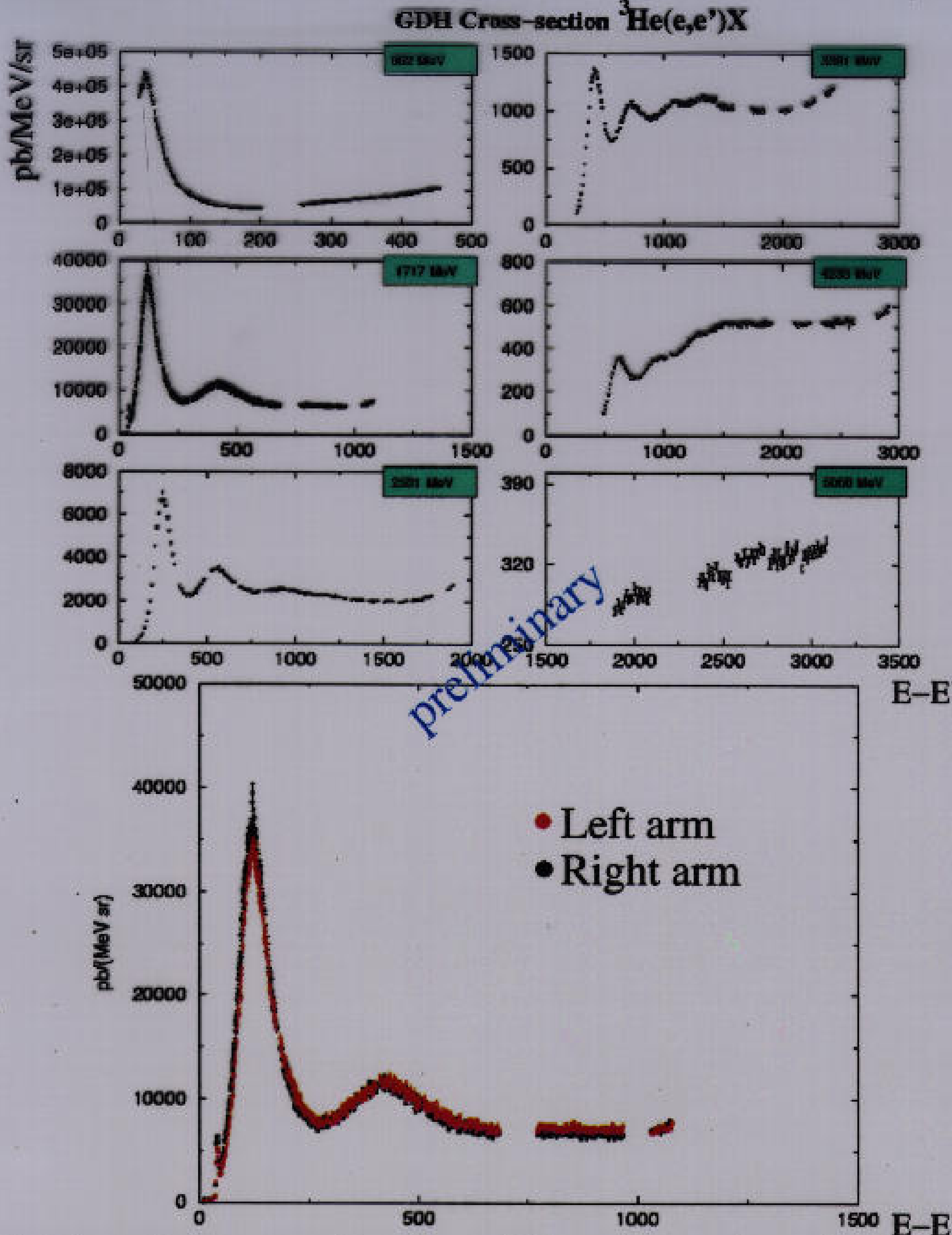
Further nuclear effects (Fermi motion and binding) are taken into account with a convolution model.

This method has proven reliable for:

- the DIS domain.
- the resonance and DIS domains (integrated quantities).

Our experiments: integrated quantities or DIS
→ The neutron extraction should be fine.

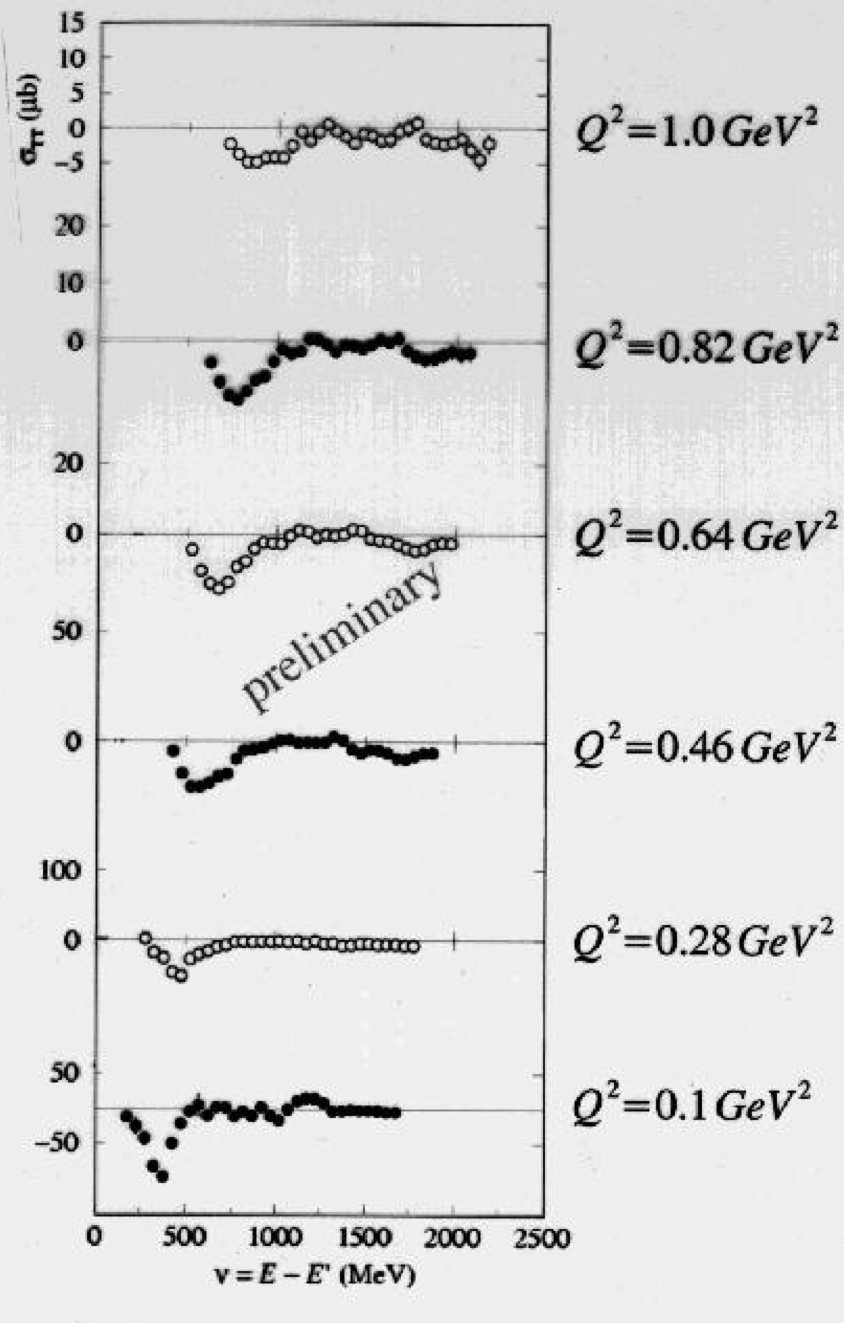
However, it is highly desirable to have an extraction procedure working everywhere for any quantities (open challenge for theorists !).



Note: No radiative corrections here. RC are done using polrad.

I. Akushevitch et al. Comput. Phys. Commun. 104, 201 (1997)

The GDH* integrand: σ^{TT}



Note: On ^3He. Statistical error only.

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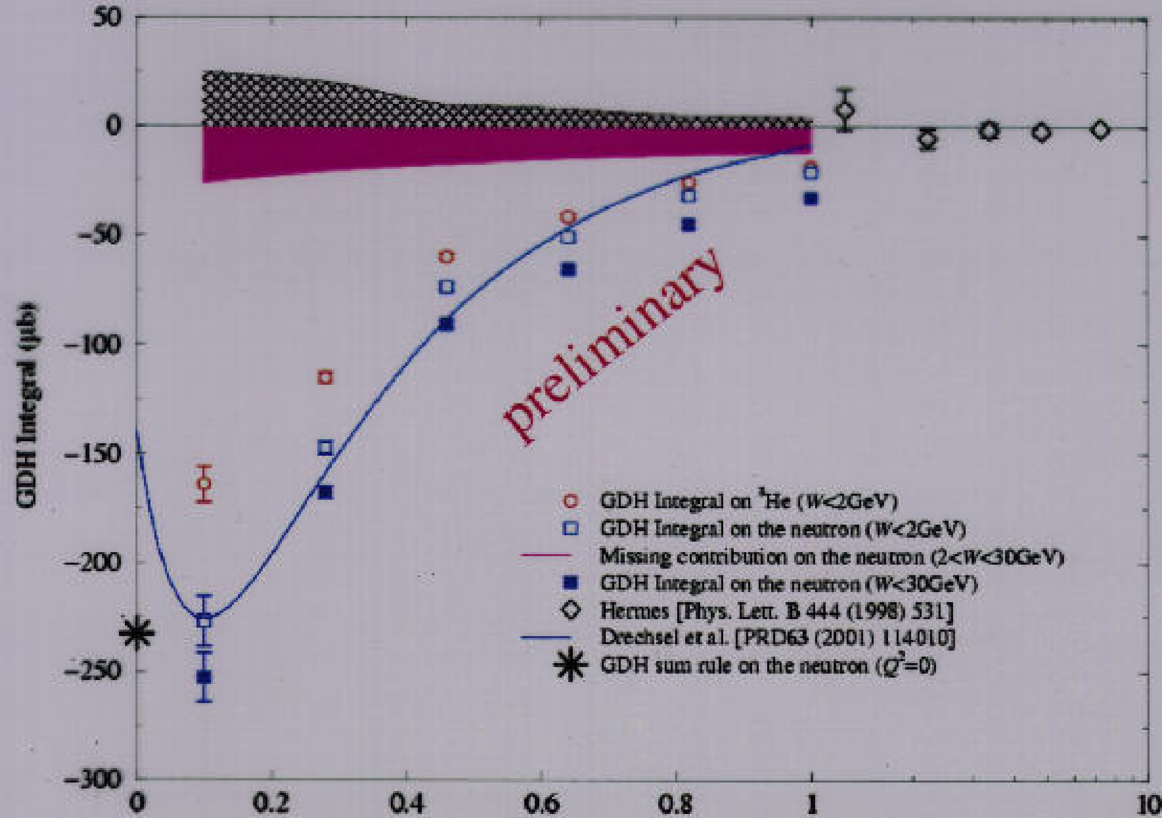
Evolution of the GDH*(Q^2) Integral



Note: The GDH integral on ^{3}He does not include here the quasi–elastic contribution.
Log scale for HERMES data.

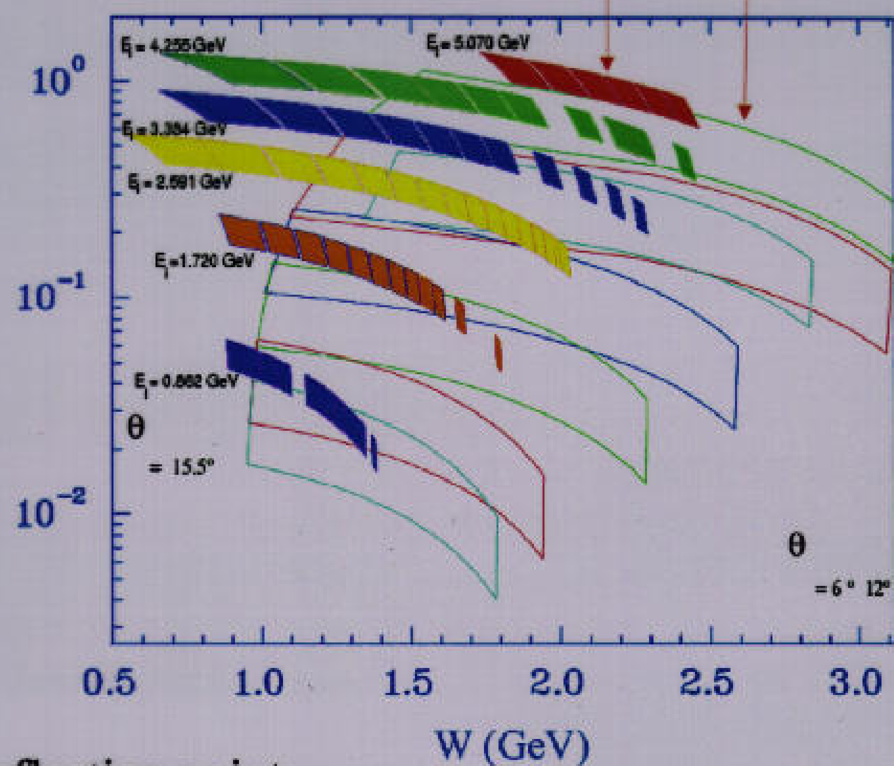
Small Q^2 GDH*

experiment E97110
J.P Chen, A. Deur, F. Garibaldi

- Our data are not conclusive with regards to:
  - The turn over at small Q^2.
  - The validity of the GDH sum rule at Q^2=0
- New septum magnets:

  data as low as <Q^2>=0.02 GeV^2 (scattering angles: 6 and 9 degrees).

Kinematic coverage of JLab E94-010 and E97-010



GDH* inflection point:

Strong constraint on calculations and models.
Allows extrapolation to the photon point.

Conclusion

- High precision data on the transition region.
- Benchmark measurement for Chiral perturbation theory and future lattice calculations.
- Check and refinement of models describing the transition from QCD to pQCD and the neutron structure.
- Test of Nuclear ^{3}He wave functions.
- low Q^2 sequel of the experiment.