HERMES measurements of the generalised GDH integral

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on behalf of the HERMES Collaboration

Workshop on Compton Scattering from Low to High Momentum Transfer

ECT*, Trento March 31 - April 4, 2003

- The GDH sum rule
- The generalized GDH sum rule (extension for virtual photons)
- Analysis of HERMES data
- Results for the measurement of the resonance contribution to the GDH sum rule for p, n and d
- Results of first determination of DIS contribution to the generalized GDH sum rule for p, n and d
- Total GDH integrals for p, n and d
- Proton-Neutron Difference
- Conclusions

The GDH sum rule

The GDH sum rule, derived in the sixties by Gerasimov and independently by Drell and Hearn, relates the anomalous contribution to the magnetic moment of the nucleus(on) κ with the total absorption cross sections for circularly polarised real photons on polarised nucleus(on):

$$I_{\rm GDH} = \int_{\nu_0}^{\infty} [\sigma^{\overset{\rightarrow}{\Leftarrow}}(\nu) - \sigma^{\overset{\rightarrow}{\Rightarrow}}(\nu)] \frac{d\nu}{\nu} = -\frac{4\pi^2 I \alpha}{M_t^2} \kappa^2$$

$\sigma^{\overset{\rightarrow}{\Leftarrow}}, \sigma^{\overset{\rightarrow}{\Rightarrow}}$: photoabsorption cross sections for (anti)–parallel spin

$\Rightarrow$ Link between helicity–dependent dynamics and static ground property of the target nucleus

Theoretical predictions:
-204 μb p
-233 μb n
-0.65 μb d

Never been tested directly

The generalised GDH sum rule

The integral can be generalised to the absorption of virtual photons with energy ν and squared four-momentum $-Q^2$:

$$I_{GDH}(Q^2) = \int_{\nu_0}^{\infty} [\sigma^{\overleftarrow{\Leftarrow}}(\nu, Q^2) - \sigma^{\overrightarrow{\Rightarrow}}(\nu, Q^2)] \frac{d\nu}{\nu}$$

R. Pantförder, hep–ph/9805434

$\Rightarrow$ Tool to study transition of helicity–dependent dynamics from non–perturbative photoabsorption to perturbative DIS at high Q^2

TARGET WITH SPIN 1/2:

$$I_{GDH}(Q^2) = \frac{8\pi^2\alpha}{M} \int_0^{x_0} \frac{g_1(x, Q^2) - \gamma^2 g_2(x, Q^2)}{K} \frac{dx}{x}$$

g_1, g_2: polarised structure functions of the nucleon
K = flux factor of the virtual photons

$I(Q^2)$ connects the GDH expectation for real photon with the Ellis-Jaffe (or Bjorken in the case of p–n) in the asymptotic region:

$$I_{\mathrm{GDH}}(Q^2) \rightarrow \tfrac{16\pi^2\alpha}{Q^2}\Gamma_1(Q^2) \qquad \Gamma_1(Q^2) = \textstyle\int_0^1 g_1(x, Q^2)dx$$

GDH p-n difference

GDH $p-n$ difference $\Rightarrow$ Bjorken Sum Rule

$I^p_{\mathrm{GDH}}(Q^2) - I^n_{\mathrm{GDH}}(Q^2) \to \frac{16\pi^2\alpha}{Q^2}[\Gamma^p_1(Q^2) - \Gamma^n_1(Q^2)]$

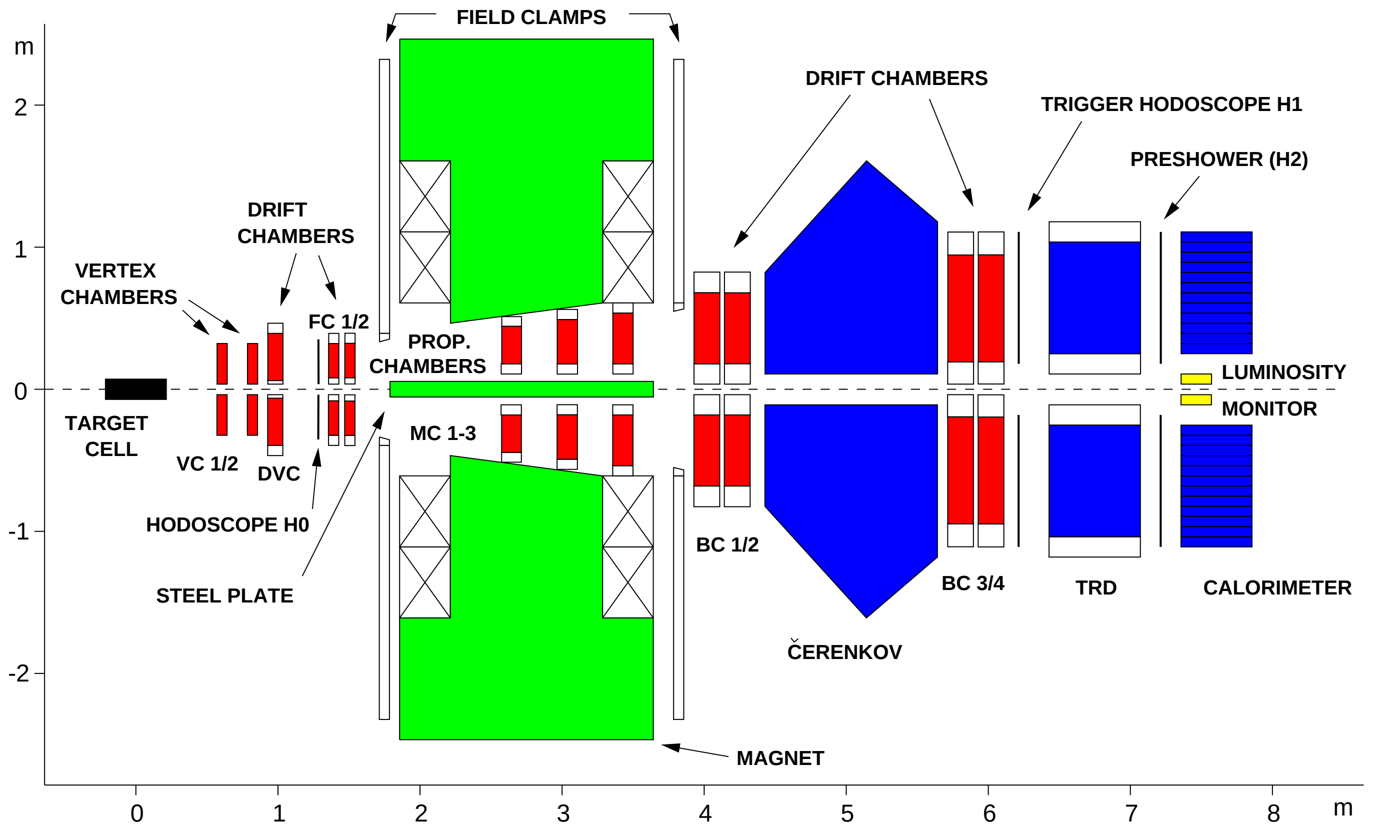
Fundamental Bjorken Sum Rule derived from current algebra and isospin symmetry

Bjorken SR relates the difference of first moments g_1^p and g_1^n at fixed Q^2 to the measured neutron β–decay coupling constant $g_a = |g_A/g_V| = 1.2670 \pm 0.0035$:

$$\Gamma^p_1 - \Gamma^n_1 = \frac{1}{6} \cdot g_a \cdot C_{ns}(\alpha_s(Q^2))$$

Experimental verification of the Bjorken SR at finite Q^2 provides a fundamental test of QCD

HERMES experiment



- Forward dipole spectrometer:
  1.5 Tesla·m , $40 < \theta < 220$ mrad
- Charge particle tracking: 57 tracking planes,
  $\delta P/P = (0.7 - 1.3)\%$, $\delta\theta < 0.6$ mrad
- Particle identification:
  Čerenkov/RICH, TRD, Preshower, Calorimeter
  e/h identification <0.4
- Calorimeter: 840 lead-glass blocks,
  $\delta E/E \sim 5\%/\sqrt{E}$, $\delta\theta \sim 1$ mrad

HERMES Collaboration NIM A417 (1998) 230

HERMES kinematic

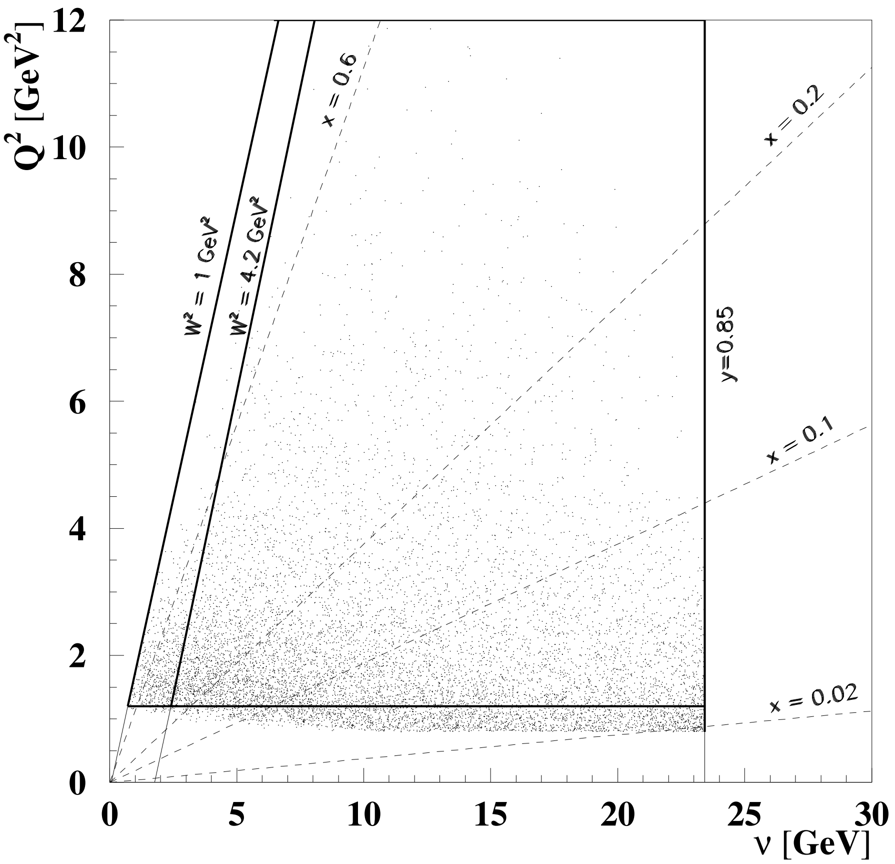
$e^{\pm}$ scattered on ^{2}H (^{1}H) $\quad E_{\rm beam}$=27.6 GeV

$< P_{\rm beam} >=0.55\pm0.01_{\rm syst}$ $(0.55\pm0.02_{\rm syst})$

$< P_{\rm target} >=0.85\pm0.03_{\rm syst}$ $(0.86\pm0.04_{\rm syst})$

Int. Luminosity / nucleon = 111 (70) pb^{-1}

$40 \leq \theta \leq 220$ mrad $\qquad$ y<0.85



$1.2 < Q^2 < 12$ GeV^2 in 6 bins

$1\leq W^2 \leq 4.2$ GeV^2	(RES)	0.55 (0.13) Mevents
$4.2\leq W^2 \leq 45$ GeV^2	(DIS)	7.7 (1.4) Mevents
$W^2 \geq 1$ GeV^2	(RES+DIS+extrapolation)	

extrapolation: N. Bianchi, E. Thomas, Phys. Lett. **B 450** (1999) 439

A. Fantoni, Trento 2003

HERMES Analysis

$$I_{GDH}(Q^2) = \frac{8\pi^2\alpha}{M_t}\int_0^{x_0} \frac{\tilde{A}_1(x,Q^2)F_1(x,Q^2)}{K}\frac{dx}{x}$$

$F_1 = F_2 \frac{1+\gamma^2}{2x(1+R)}$ $\quad$ F_1, F_2 unpol. struct. functions

$F_2^{\rm DIS} \rightarrow$ NMC fit [NMC Coll., PL **B 364** (1995) 107]
$R^{\rm DIS} \rightarrow$ SLAC fit [L.W. Whitlow *et al.*, PL **B 250** (1990) 193]
$F_2^{\rm res} \rightarrow$ Bodek fit [A. Bodek, Phys. Rev. **D8** (1973) 2331]
$R^{\rm res} = \sigma_L/\sigma_T = 0.18$
$K = \nu\sqrt{1+\gamma^2}$ (Gilman notation) = photon flux factor

$$\tilde{A}_1 = \frac{A_\parallel}{D} - \eta\tilde{A}_2 \qquad A_\parallel = \frac{1}{P_b P_t}\frac{N^{\stackrel{\rightarrow}{\Leftarrow}}L^{\stackrel{\rightarrow}{\Rightarrow}} - N^{\stackrel{\rightarrow}{\Rightarrow}}L^{\stackrel{\rightarrow}{\Leftarrow}}}{N^{\stackrel{\rightarrow}{\Leftarrow}}L^{\stackrel{\rightarrow}{\Rightarrow}} + N^{\stackrel{\rightarrow}{\Rightarrow}}L^{\stackrel{\rightarrow}{\Leftarrow}}}$$

$\tilde{A}_1$=photon-helicity asymmetry; spin 1/2 $\Rightarrow \tilde{A}_{1,2} \equiv A_{1,2}$
$A_\parallel$=measured longitudinal cross section asymmetry
$\tilde{A}_2^{\rm DIS,d(p)} = \frac{0.2(0.53)Mx}{\sqrt{Q^2}}$ $\quad \tilde{A}_2^{\rm res,d}=0$ $\quad A_2^{\rm res,p}=0.06\pm0.16$

$$I_{GDH}^n = \frac{I_{GDH}^d}{1-1.5\omega_d} - I_{GDH}^p$$

[C. Ciofi Degli Atti *et al.*, Phys. Lett. **B 376** (1996) 309]

$\omega_d = 0.050 \pm 0.010$: probability of d to be in D-state

HERMES Analysis: Resonance region (1)

Contamination from Elastic and DIS regions

Calculation done using Monte Carlo with parameterization for elastic cross section and DIS cross section and F_2^{Res}

$$A_{meas} = f_{el} A_{El} + f_{res} A_{Res} + f_{dis} A_{DIS}$$

$$A_{\parallel}(Res) = (A_{meas} - f_{el} A_{El} - f_{dis} A_{DIS}) / f_{el}$$

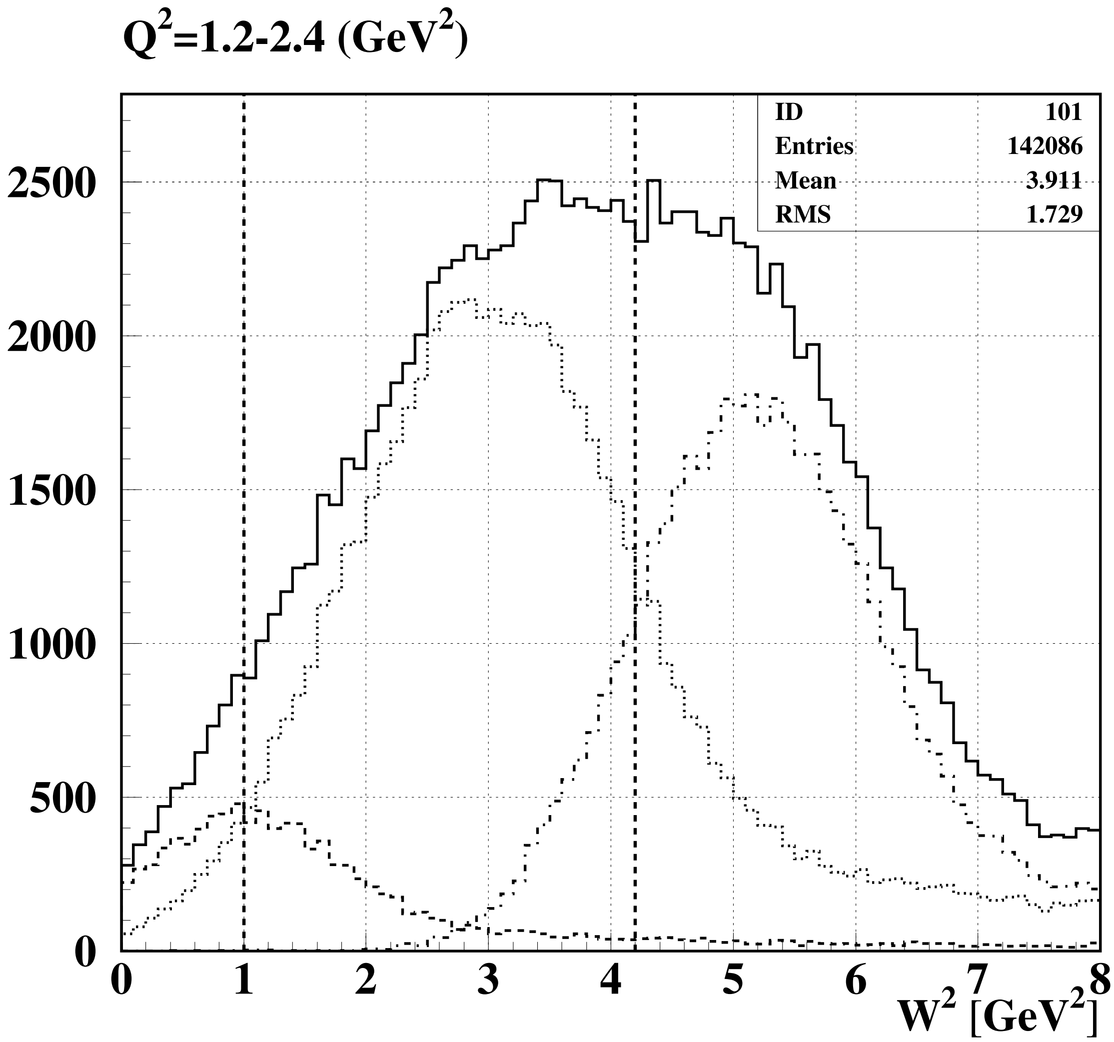
$$f_{el} = \frac{\#\,\text{Elastic events}\ (W^2 < 1.0)}{\#\,\text{total events in}\ W^2}$$

$$f_{res} = \frac{\#\,\text{Resonance events}\ (1.0 < W^2 < 4.2)}{\#\,\text{total events in}\ W^2}$$

$$f_{dis} = \frac{\#\,\text{DIS events}\ (W^2 > 4.2)}{\#\,\text{total events in}\ W^2}$$

HERMES Analysis: Resonance region (2)

Contamination from Elastic and DIS

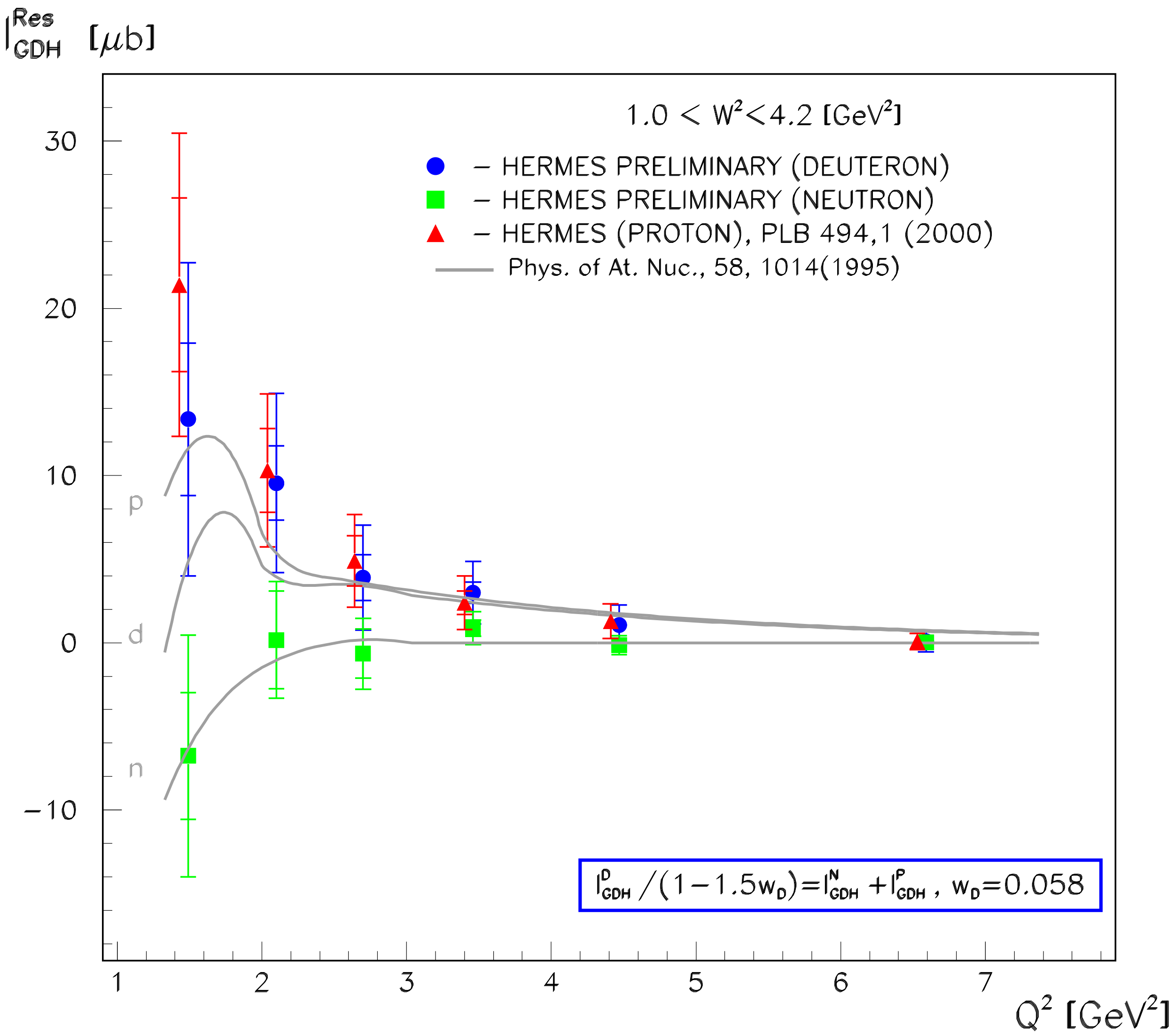


d (p):

Quasi-(elastic) → from 15(10) to 3(2)% with Q^2 increase

DIS → from 11(7) to 23(16)% with Q^2 increase

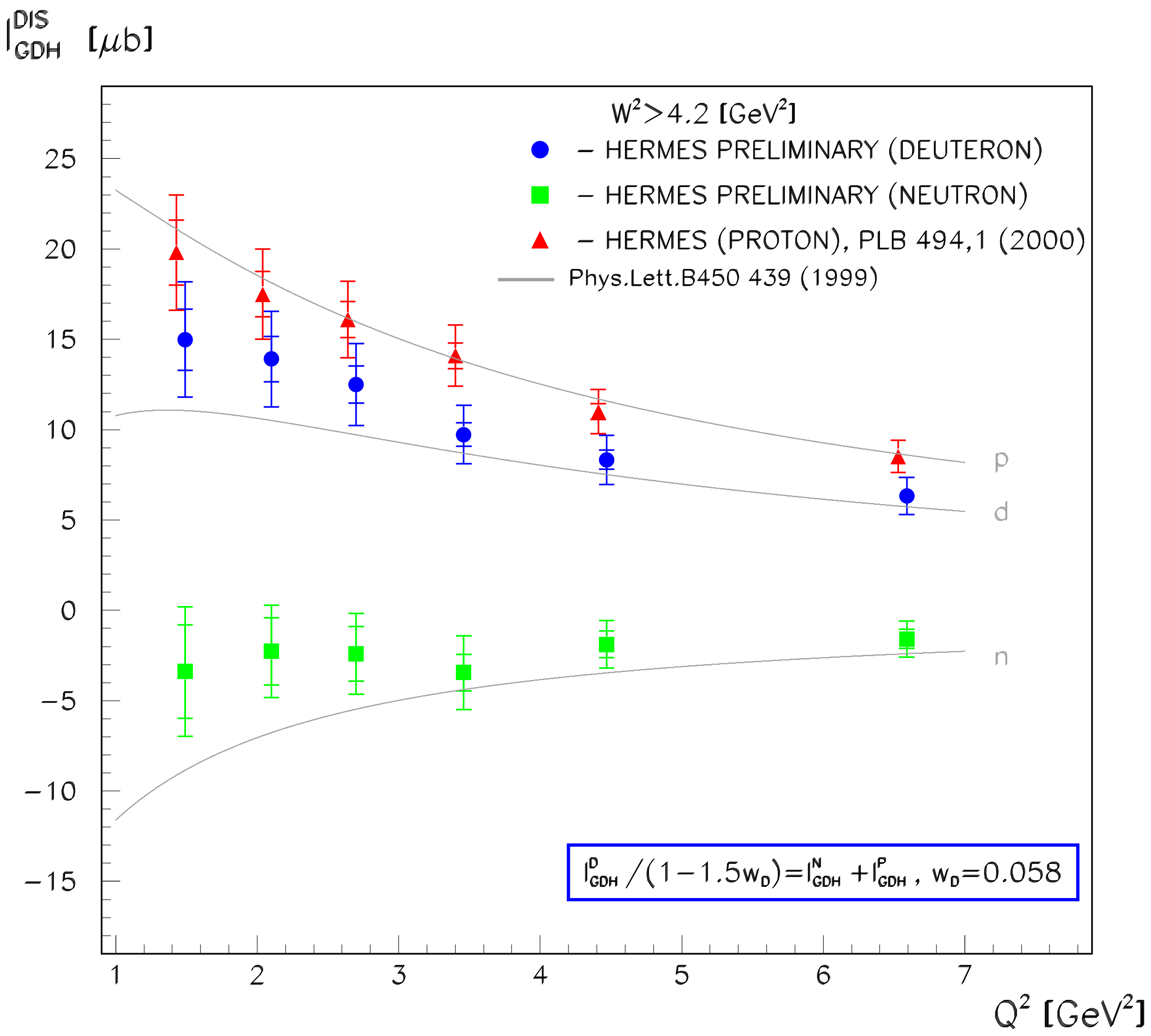
RES contribution to I_{GDH}



- I_{GDH}^{res} strongly decrease with Q^2 (strong reduction of the available x range for W^2 <4.2 GeV^2 as Q^2 increase)
- Comparison between models and data suggests that the resonance excitation models are not sufficient to well reproduce the experimental I_{GDH}^{res} for Q^2 <1.5 GeV^2 (n ok, p and d within total exp errors)

p: HERMES Collaboration, Phys. Lett. **B 494 (2000) 1**

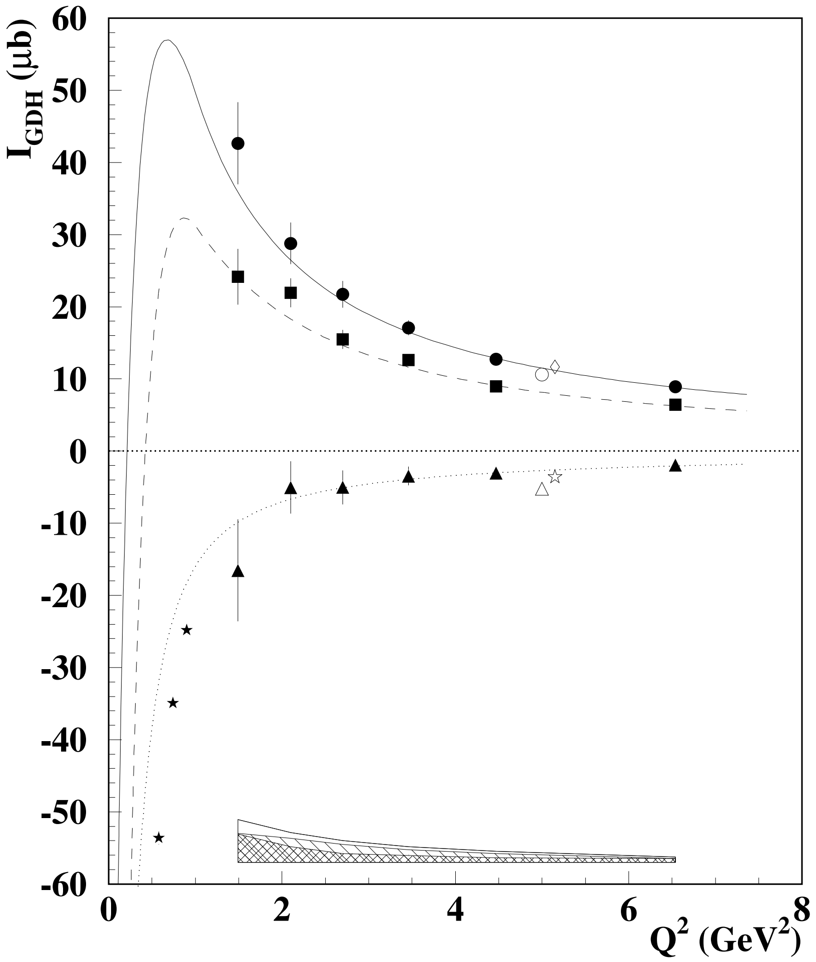
DIS contribution to I_{GDH}



- I^{DIS}_{GDH} sizeable down to the lowest measured Q^2
- Agreement with parameterisation for $Q^2 > 3$ GeV^2

p: HERMES Collaboration, Phys. Lett. **B 444 (1998) 531**

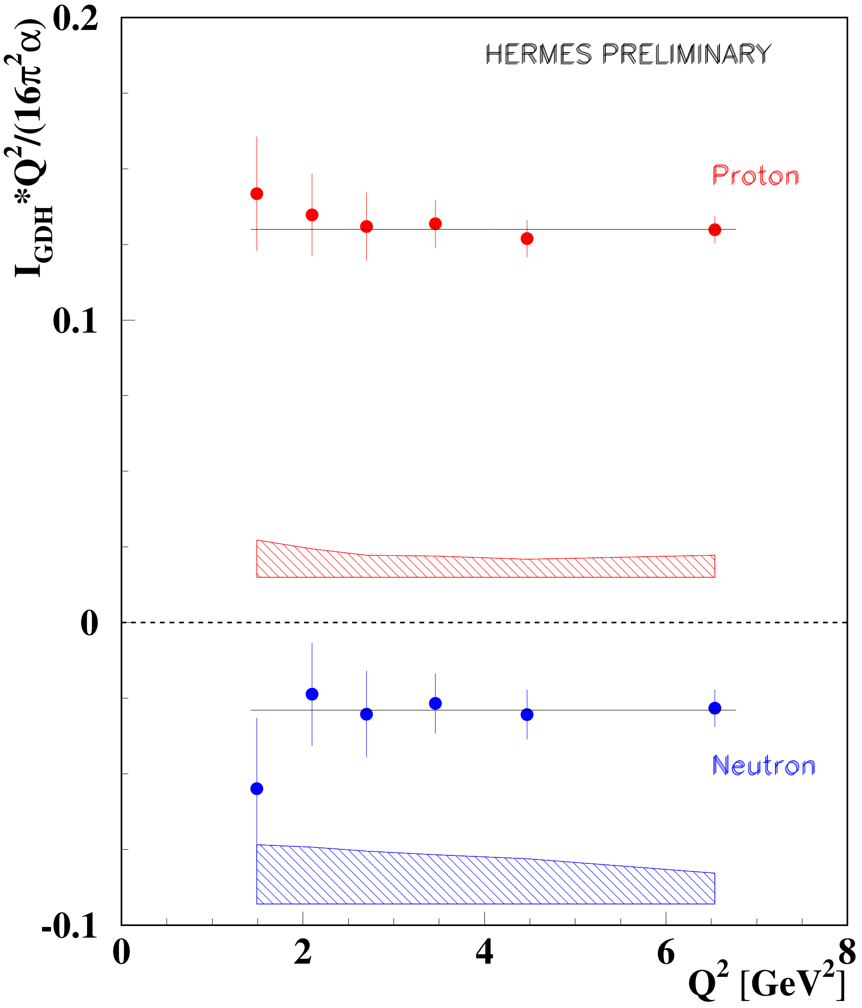
Combined results from RES and DIS to I_{GDH}



- I_{GDH} consistent with $1/Q^2$ law
- Q^2 behavior of I_{GDH} consistent with the pQCD evolution of the integral without considering any additional resonance or higher twist effect
- I_{GDH}^{DIS} dominant for Q^2 above 3 GeV^2 and remains sizeable down to the lowest measured Q^2
- $I_{GDH}^{n}<0$ and smaller in absolute value than I_{GDH}^{p}
- Agreement with SLAC data E143 (left) and E155 (right) at Q^2=5 GeV^2
- Agreement with Jlab data at low Q^2

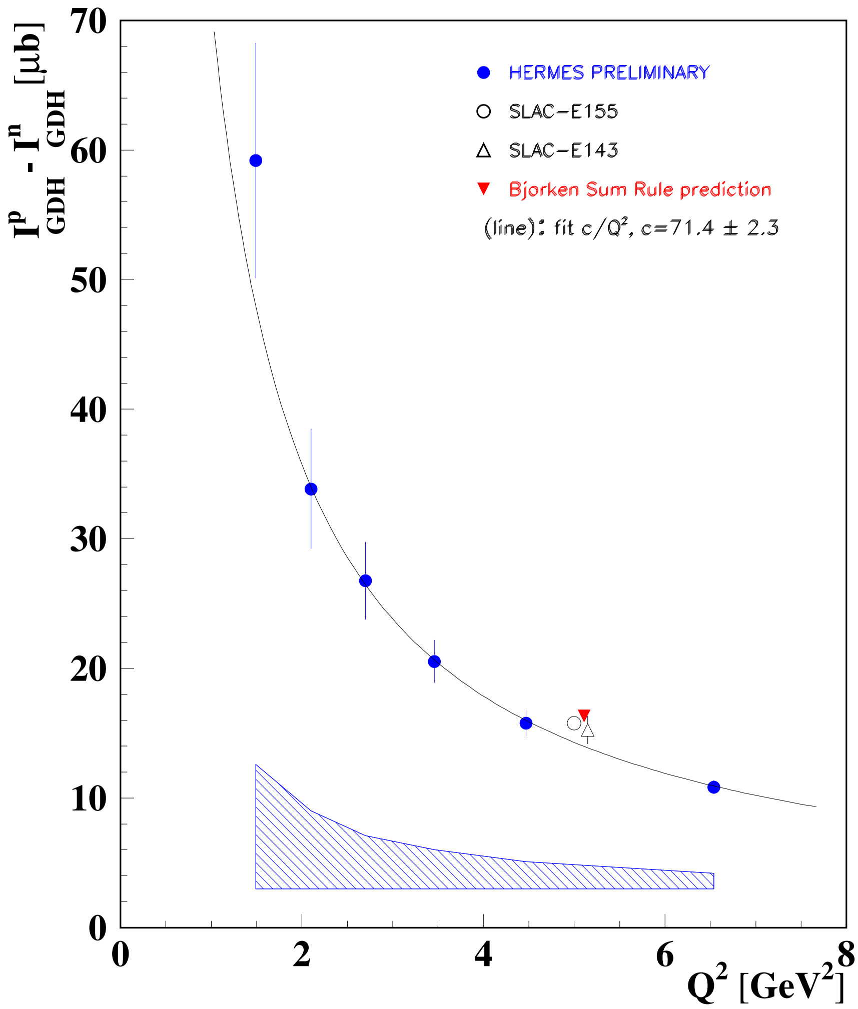
p: HERMES Collaboration, Eur. Phys. Journal **C 26 (2003) 527**

Q^2 dependence $\approx 1/Q^2$?



- Dividing out $\sim 1/Q^2$ dependence (leading-twist) $\longrightarrow$ flat Q^2 behavior for both p and n
- No indication for sizeable contributions from higher twists or nucleon-resonance form factors down to $Q^2 \simeq 1.5$ GeV^2

Proton-Neutron Difference



- Agreement with Bjorken sum rule prediction at Q^2=5 GeV^2: $I^p_{\rm GDH} - I^n_{\rm GDH} = (16.33 \pm 0.45)\ \mu b$
- Agreement with SLAC data at Q^2=5 GeV^2
- No turn-over observed in HERMES range to meet GDH SR prediction: $(I^p_{\rm GDH} - I^n_{\rm GDH})|_{Q^2=0} = 29\ \mu b$
- $I^p_{\rm GDH} - I^n_{\rm GDH} \propto 1/Q^2$ down to lowest meas. value

Conclusions

- Q^2-dependence of the generalised GDH integral for p, n and d determined for the first time in RES and DIS regions ($1.2 \leq Q^2 \leq 12$ GeV^2) simultaneously

  1. RES: small for $Q^2 > 3$ GeV^2
  2. DIS: sizeable over full range
  3. Total: $1/Q^2$ behavior $\longrightarrow$ no effects from resonances or non-leading-twist

- Turn-over of Proton and Deuteron GDH data towards the real photon prediction NOT observed in HERMES range

- GDH Proton-Neutron difference:
  1. good agreement with Bjorken SR prediction and SLAC data at Q^2=5 GeV^2
  2. LT ($1/Q^2$ behavior) until $Q^2 \simeq 1.5$ GeV^2