The Q^2 dependence of the generalised GDH integral in the HERMES experiment

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- The GDH sum rule
- The generalized GDH sum rule (extension for virtual photons)
- Contribution of g_2
- 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
- Combination of the results in the resonance and DIS region for p, n and d
- 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 κ to the magnetic moment of the nucleon ($\kappa_{\rm p}$=1.79, $\kappa_{\rm n}$=$-$1.91) with the total absorption cross sections for circularly polarised real photons on polarised nucleons:

$$\int_0^\infty \left[\sigma_{1/2}(\nu) - \sigma_{3/2}(\nu)\right] \frac{d\nu}{\nu} = -\frac{2\pi^2\alpha}{M^2}\kappa^2$$

general dispersion relation for forward Compton scattering
+ low-energy theorem of Low
+ additional assumption that the spin-flip part of the Compton scattering amplitude goes to zero at infinite energy without any poles.

Theoretical predictions:
-204 μb p
-233 μb n

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 $-Q^2$:

$$I(Q^2) \equiv \int_{Q^2/2M}^{\infty} \left[\sigma_{1/2}(\nu, Q^2) - \sigma_{3/2}(\nu, Q^2)\right] \frac{d\nu}{\nu}$$

$$= \frac{8\pi^2\alpha}{M} \int_0^1 \frac{g_1(x, Q^2) - \gamma^2 g_2(x, Q^2)}{K} \frac{dx}{x}$$

g_1, g_2 polarised structure functions of the nucleon
x Bjorken variable
$K = \nu\sqrt{1+\gamma^2}$ flux factor of the virtual photons
$\gamma^2 = Q^2/\nu^2$

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

The Q^2 dependence of $I(Q^2)$ connects the static ground state properties of the nucleon with its helicity structure as measured in inelastic scattering in the resonance and deep inelastic regions

$$I(Q^2) \equiv \int_{Q^2/2M}^{\infty} \Delta\sigma(\nu, Q^2)\frac{d\nu}{\nu}$$

where :

$$\Delta\sigma(\nu, Q^2) = \sigma_{1/2}(\nu, Q^2) - \sigma_{3/2}(\nu, Q^2) = \frac{8\pi^2\alpha}{M}\frac{A_1 F_1}{K}$$

$F_1 = F_2 \frac{1+\gamma^2}{2x(1+R)}$

$F_2^{DIS} \rightarrow$ NMC parameterization

$R^{DIS} \rightarrow$ SLAC parameterization

F_2^{res} modification of F_2 for nucleon resonances
$R^{res} = 0.18$ (the choice don't affect the result)

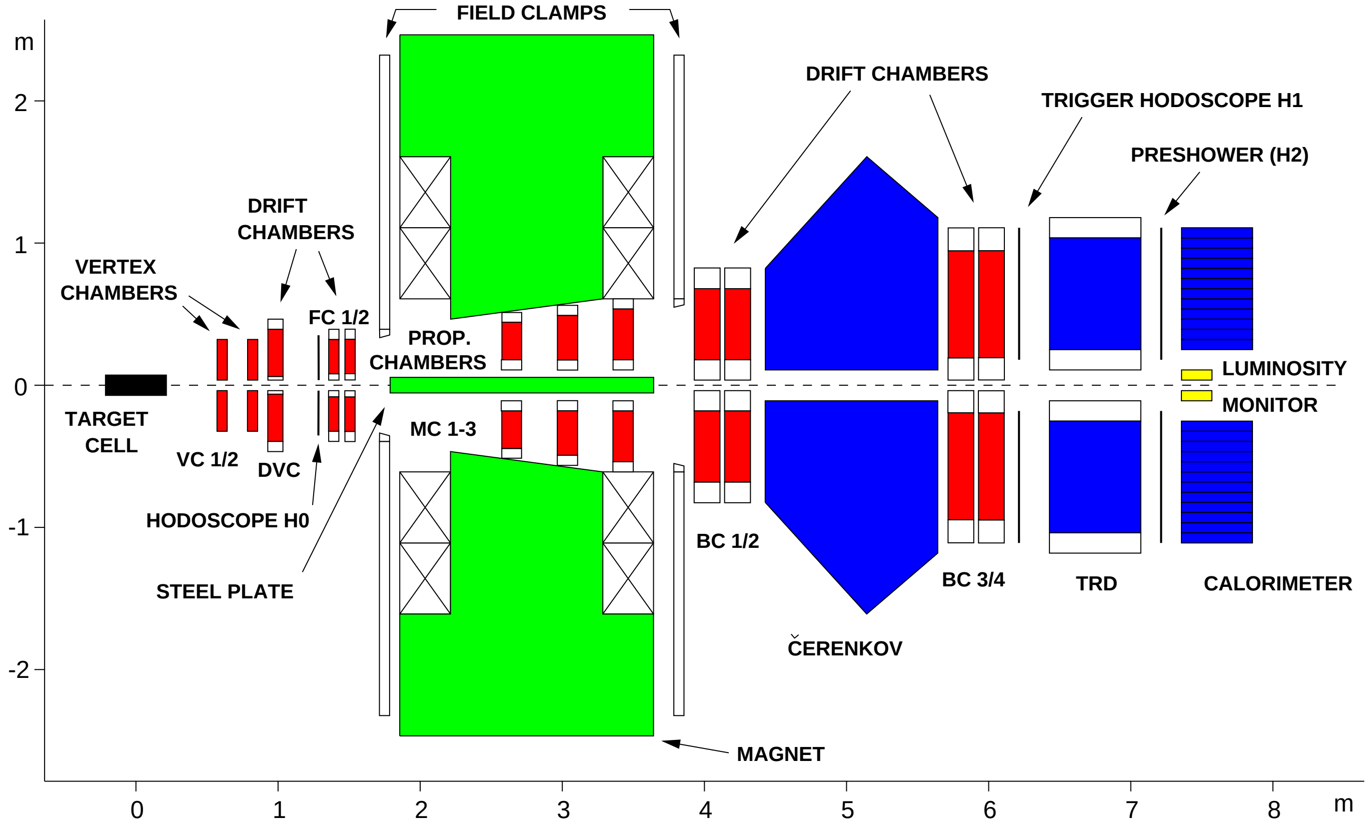
$A_1 = A_{\parallel}/D - \eta A_2$

$A_2^{DIS,p} = 0.06 \pm 0.16$ (SLAC at Q^2=3 GeV^2)

$A_2^{DIS,d} = \frac{0.05 M_p x}{\sqrt{Q^2}}$
$A_2^{res} = 0$ (almost unknown; effect of different values studied and included in systematic error)

$K = \nu\sqrt{1+\gamma^2}$ flux factor of the virtual photons

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

- Calorimeter: 840 lead-glass blocks,
  $\delta E/E \sim 5\%/\sqrt{E}$, $\delta\theta \sim 1$ mrad

- Particle identification:
  Threshold Čerenkov, TRD, Preshower, Calorimeter

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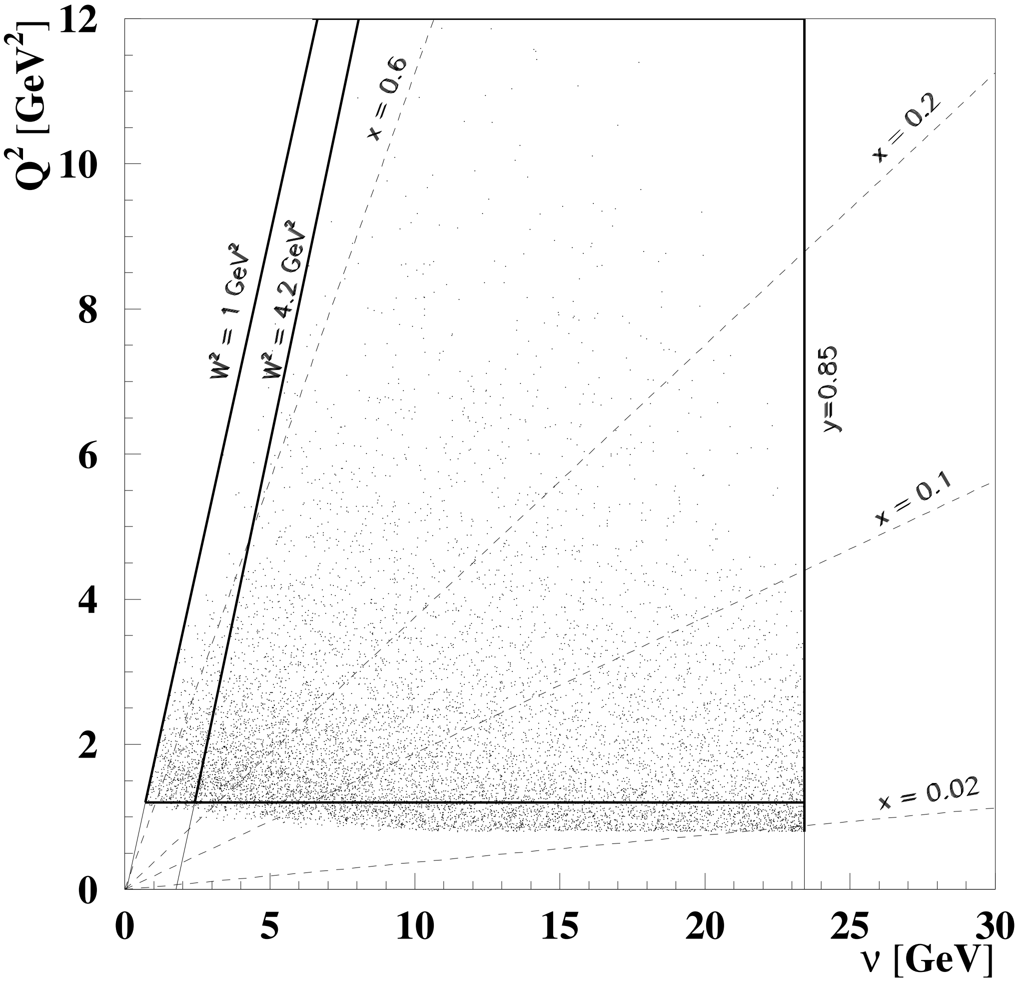
HERMES kin. plane

$E_{\rm beam}$=27.5 GeV

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

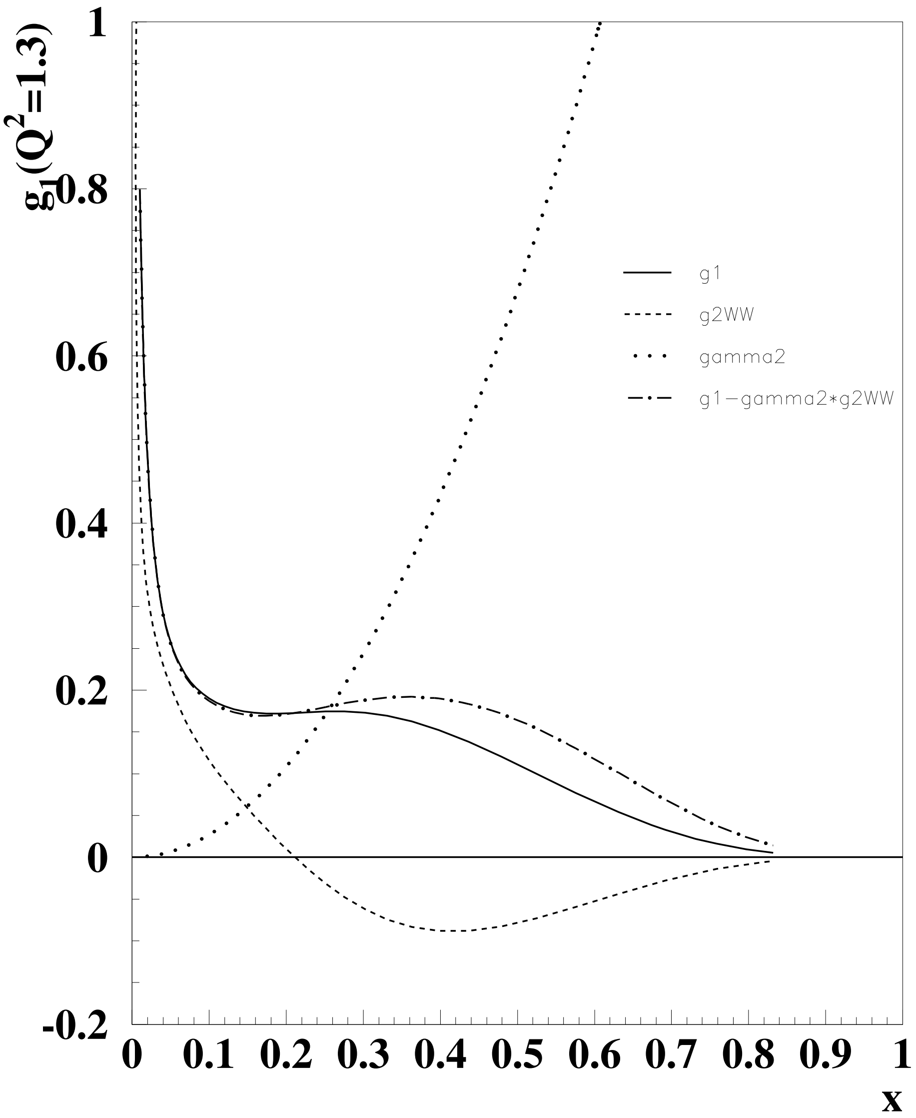


$1.2 < Q^2 < 12$ GeV^2

$1 \leq W^2 \leq 4.2$ GeV^2 (Resonance Region)
$4.2 \leq W^2 \leq 45$ GeV^2 (DIS Region)
$1 \leq W^2 \leq 45$ GeV^2 (Resonance + DIS Regions)

Contribution of g_2

$$g_2^{\rm WW}(x,Q^2) = -g_1(x,Q^2) + \int_x^1 g_1(y,Q^2)\frac{dy}{y}$$



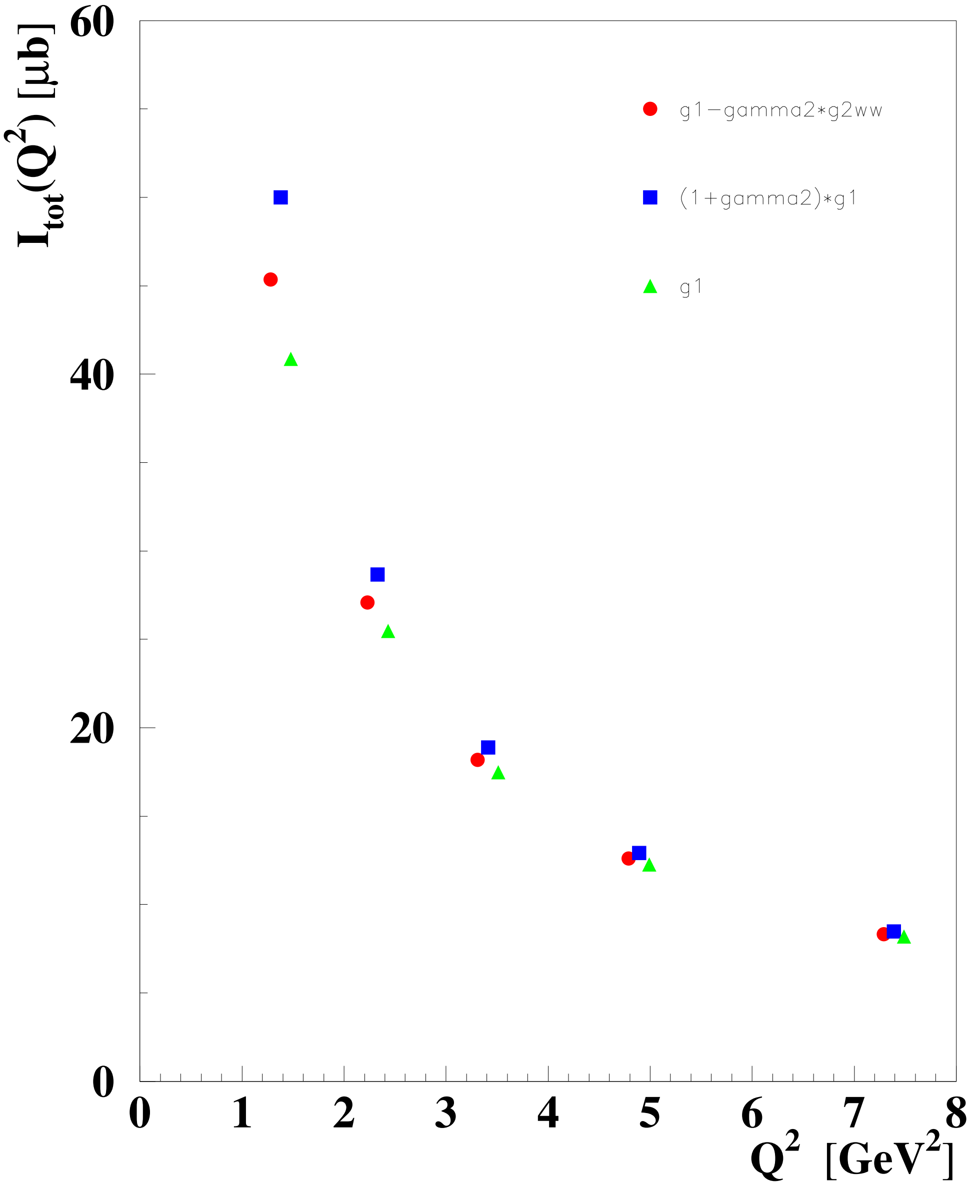
g_1^p from DGLAP NLO solution with G.S. parameterisation

T. Gehrmann and W.J. Stirling, Phys. Rev. **D 53** (1996) 267;

M. Hirai *et al.*, Comp. Phys. Comm. **108** (1998)

$$I(Q^2) \equiv \int_{Q^2/2M}^{\infty} \left[\sigma_{1/2}(\nu, Q^2) - \sigma_{3/2}(\nu, Q^2)\right] \frac{d\nu}{\nu}$$

$$= \frac{8\pi^2\alpha}{M} \int_0^1 \frac{g_1(x, Q^2) - \gamma^2 g_2(x, Q^2)}{K} \frac{dx}{x}$$



The effect of g_2 is decreasing with Q^2 increasing:

20 % effect at $Q^2 = 1.3$ GeV^2

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}

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

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

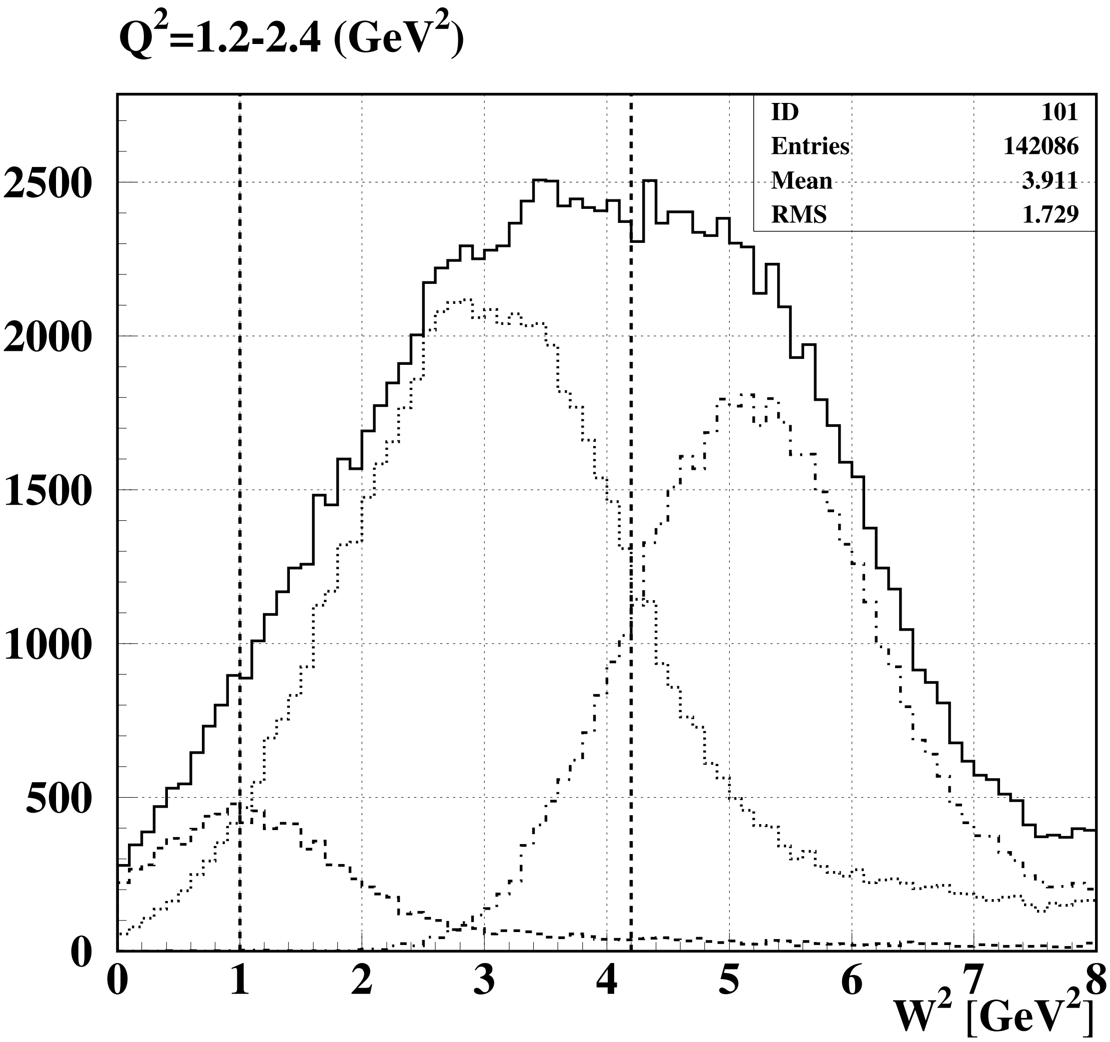
$$f_{el} = \frac{\#\,\text{Elastic events}\,(W^2 < 1.0)}{\#\,\text{total events in}\,W^2}$$

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

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

HERMES Analysis: Resonance region (2)

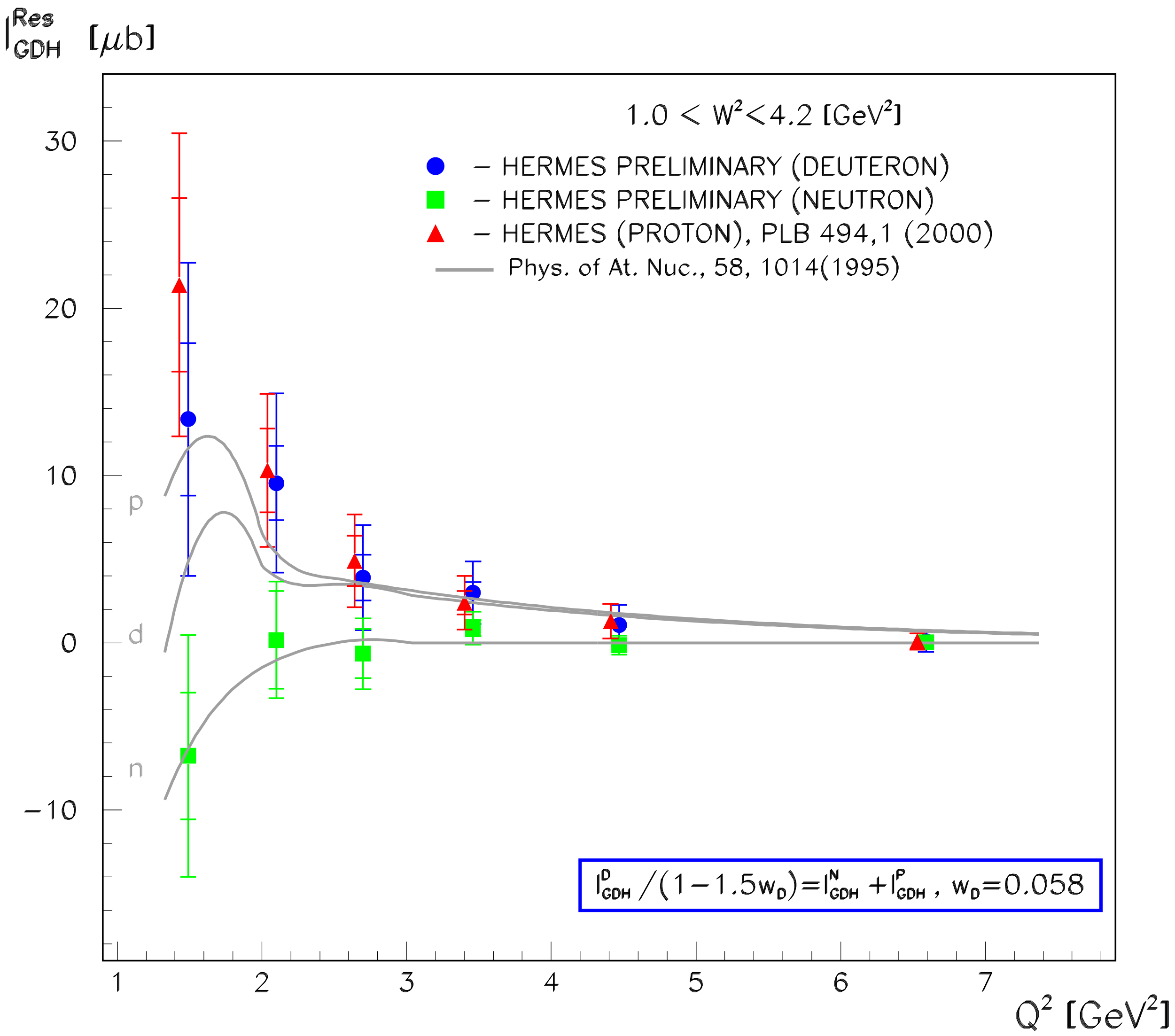
Contamination from Elastic and DIS



Elastic $\rightarrow$ from 10 to 2% with Q^2 increase

DIS $\rightarrow$ from 7 to 16% with Q^2 increase

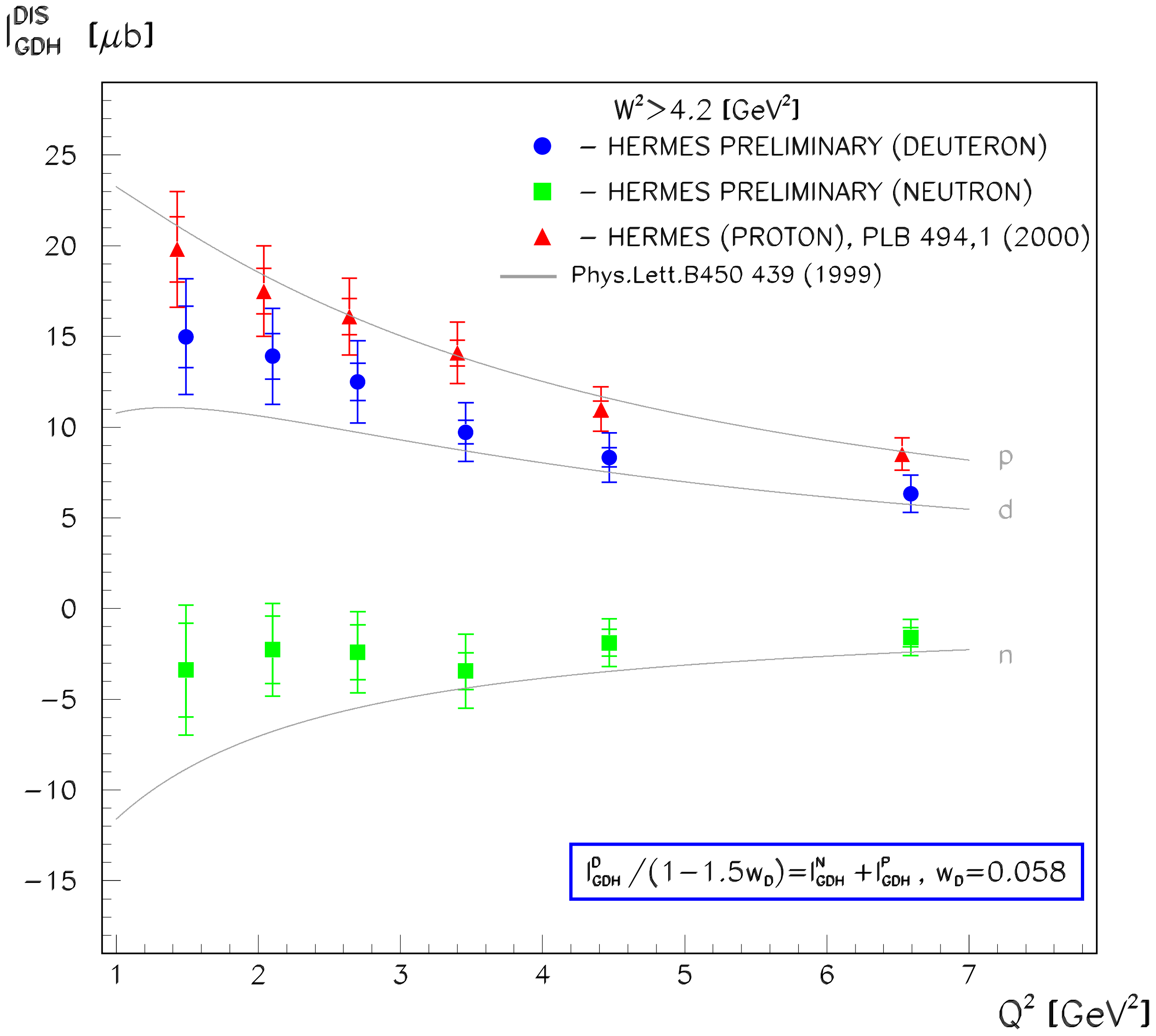
RES contribution to I_{GDH}



- 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

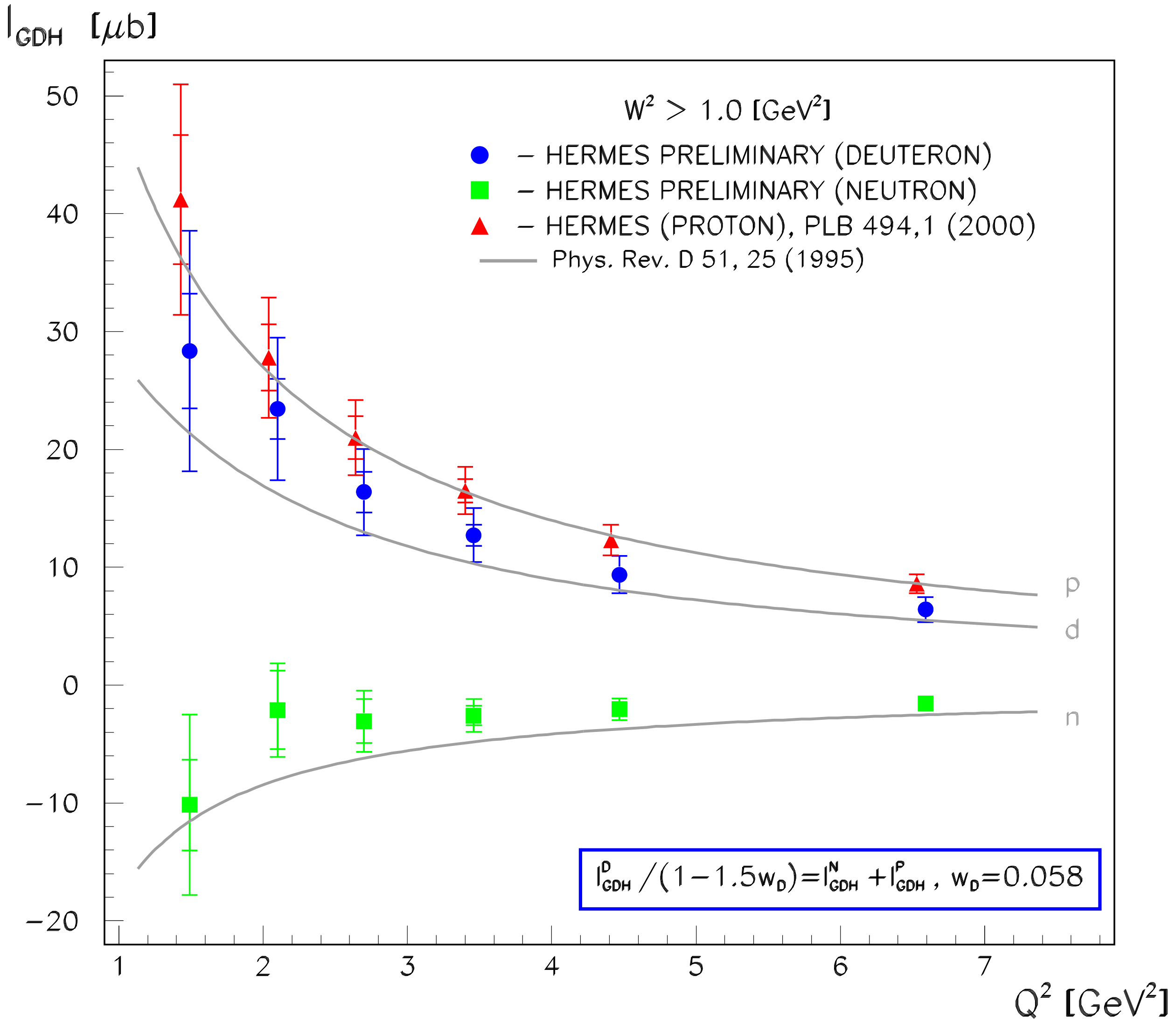
HERMES Collaboration, Phys. Lett. **B 494 (2000) 1**

DIS contribution to I_{GDH}



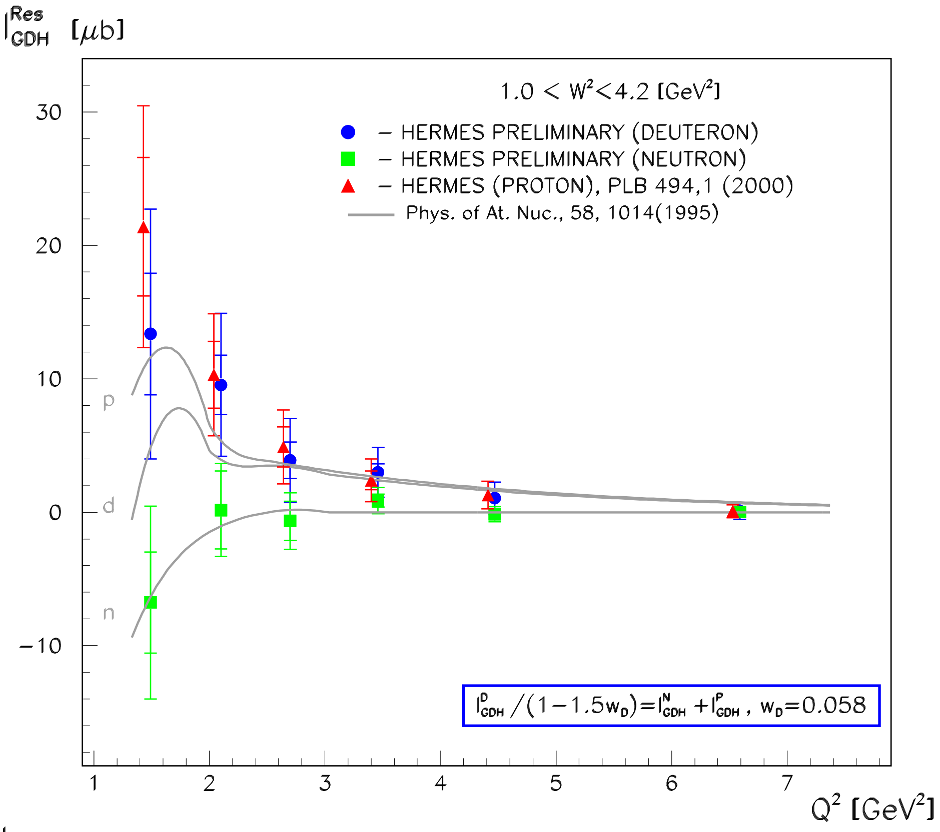
- I^{DIS}_{GDH} sizeable down to the lowest measured Q^2
- Agreement with parameterisation for Q^2 >3 GeV^2

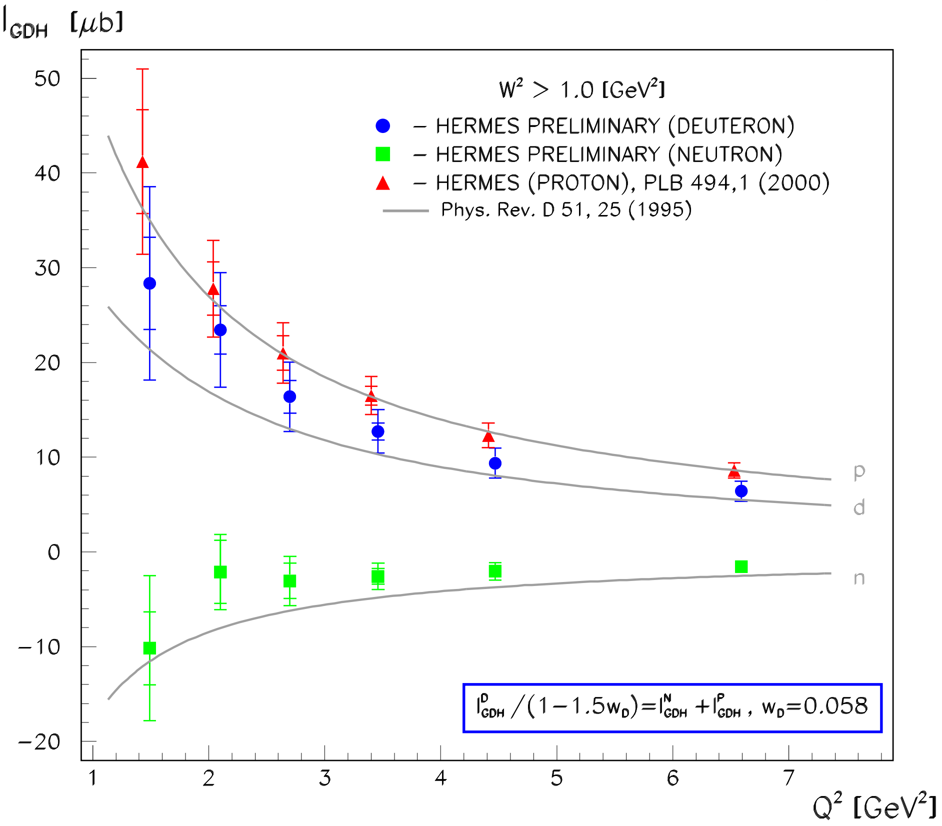
Combined results from RES and DIS to I_{GDH}



- 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^{DIS}_{GDH} dominant for Q^2 above 3 GeV^2 and remains sizeable down to the lowest measured Q^2
- $I^n_{GDH}<0$ and smaller in absolute value than I^p_{GDH}

$I^{p,d,n}_{GDH}$


I^{Res}_{GDH} [μb]
$1.0 < W^2 < 4.2$ [GeV^2]
– HERMES PRELIMINARY (DEUTERON)
– HERMES PRELIMINARY (NEUTRON)
– HERMES (PROTON), PLB 494,1 (2000)
Phys. of At. Nuc., 58, 1014(1995)
p
d
n
$I^D_{GDH}/(1-1.5w_D)=I^N_{GDH}+I^P_{GDH}$, w_D=0.058
Q^2 [GeV^2]


I_{GDH} [μb]
$W^2 > 1.0$ [GeV^2]
– HERMES PRELIMINARY (DEUTERON)
– HERMES PRELIMINARY (NEUTRON)
– HERMES (PROTON), PLB 494,1 (2000)
Phys. Rev. D 51, 25 (1995)
p
d
n
$I^D_{GDH}/(1-1.5w_D)=I^N_{GDH}+I^P_{GDH}$, w_D=0.058
Q^2 [GeV^2]

Conclusions

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

- For Q^2 >1.5 GeV^2, existing resonance-excitation models are not sufficient to fully explain the experimental results for I_{GDH}^{res}

- Above Q^2=3 GeV^2 the DIS contribution is dominant

- Total I_{GDH} shows a $1/Q^2$ behavior $\longrightarrow$ no large effects from either resonances or non-leading-twist

- The strong turn down of $I^p_{GDH}(Q^2)$ towards the real photon prediction of -204 μb should occur at Q^2 lower than 1.2 GeV^2