Measurement of the Generalized GDH Integral for the Proton

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The GDH Sum Rule

The **GDH sum rule** relates the anomalous contribution k of the magnetic moment of the nucleon to an energy weighted integral of the difference of the nucleon's polarised total photoabsorption cross sections:

$$\int_{\nu_0}^{\infty} [\sigma_{1/2}(\nu) - \sigma_{3/2}(\nu)] \frac{d\nu}{\nu} = -\frac{2\pi^2\alpha}{M^2} k^2, \tag{1}$$

where $\sigma_{1/2(3/2)}$ are the photoabsorption cross sections for total helicity equal to 1/2(3/2), ν is the photon energy, ν_0 is the pion photoproduction energy threshold, M is the nucleon mass.

- For the proton ($k_p = +1.79$) the GDH sum rule prediction is -204μb.
- The sum rule arises from the combination of a general dispersion relation for forward Compton scattering and the low-energy theorem of Low , with the additional assumption that the spin-flip part of the Compton scattering amplitude goes to zero at infinite energy without any poles.
- It has never been experimentally measured, due to the need of both longitudinally polarised beam and longitudinally polarised target and a wide range of photon energies has to be covered

The Generalized GDH Integral

The GDH integral can be generalized for the case of absorption of virtual photons with squared four-momentum ($-Q^2$) :

$$I(Q^2) = \frac{8\pi^2\alpha}{M}\int_0^{x_0}\frac{g_1(x,Q^2)-\gamma^2 g_2(x,Q^2)}{\nu\sqrt{1+\gamma^2}}\frac{dx}{x} = \qquad (2)$$

$$\frac{8\pi^2\alpha}{M}\int_0^{x_0}\frac{A_1F_1}{\nu\sqrt{1+\gamma^2}}\frac{dx}{x},$$

where $g_{1(2)}$ are the polarised structure functions of the nucleon, $\gamma^2 = Q^2/\nu^2$, A_1 is a spin asymmetry, F_1 is a unpolarised structure functions of the nucleon, $x_0 = Q^2/2M\nu_0$.

- The generalization of the GDH integral to non–zero photon virtuality Q^2 allows to study the transition from the polarised real photon absorbtion on the nucleon (at low W^2) to the polarised inclusive lepton scattering on quarks (at large W^2).

- How these processes evolve with the spatial resolution scale which is given by Q^2. For $Q^2 >> 1$ GeV^2 and $\gamma^2 \to 0$

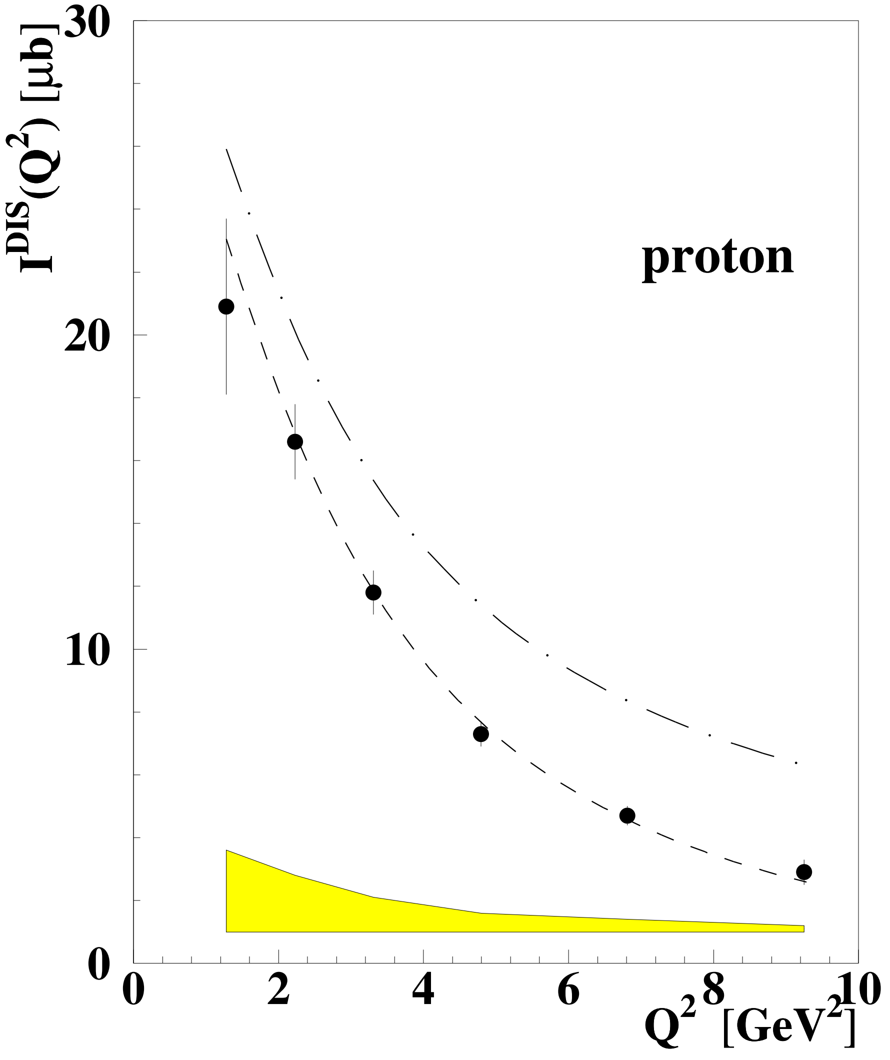
$$I_{GDH} = \frac{16\pi^2\alpha}{Q^2}\Gamma_1, \qquad (3)$$

  where $\Gamma_1 = \int_0^1 g_1(x)dx$ is predicted to be only weakly Q^2-dependent due to QCD corrections.

- Several models have been proposed to extend the GDH integral to finite Q^2. Some of these models predicted large effects of the nucleon resonance excitation or of higher twists for Q^2 up to few GeV^2.

GDH Integral in DIS region

The generalised GDH integral for the proton as a function of Q^2 in the deep inelastic region for the Q^2 range (8.0–12.0) GeV^2. HERMES, K. Ackerstaff *et al.*, Phys. Lett. B444 (1998) 531

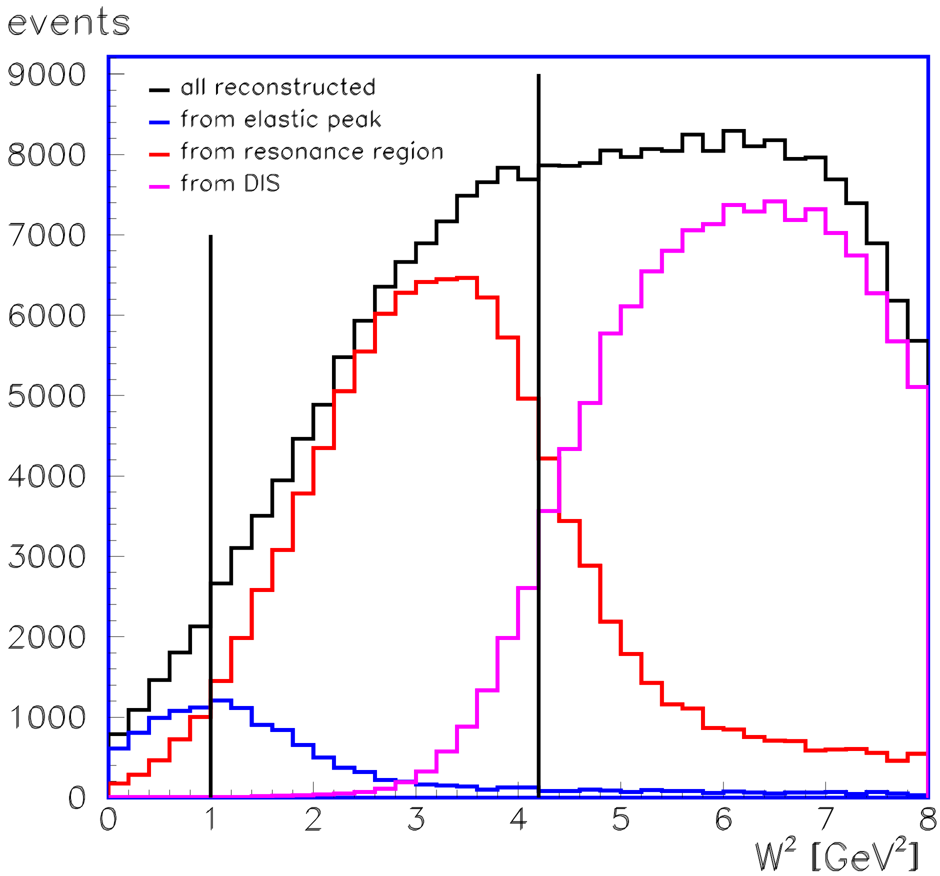


The dashed curves in Figures show the integrals for GRSV-96 parameterisation over the x range measured at HERMES for proton. The dash-dotted curves show the integrals of the NLO parameterisation from ν_0 to infinity, thus including in addition the low x (high ν) contribution, which for the proton is about 4μb.

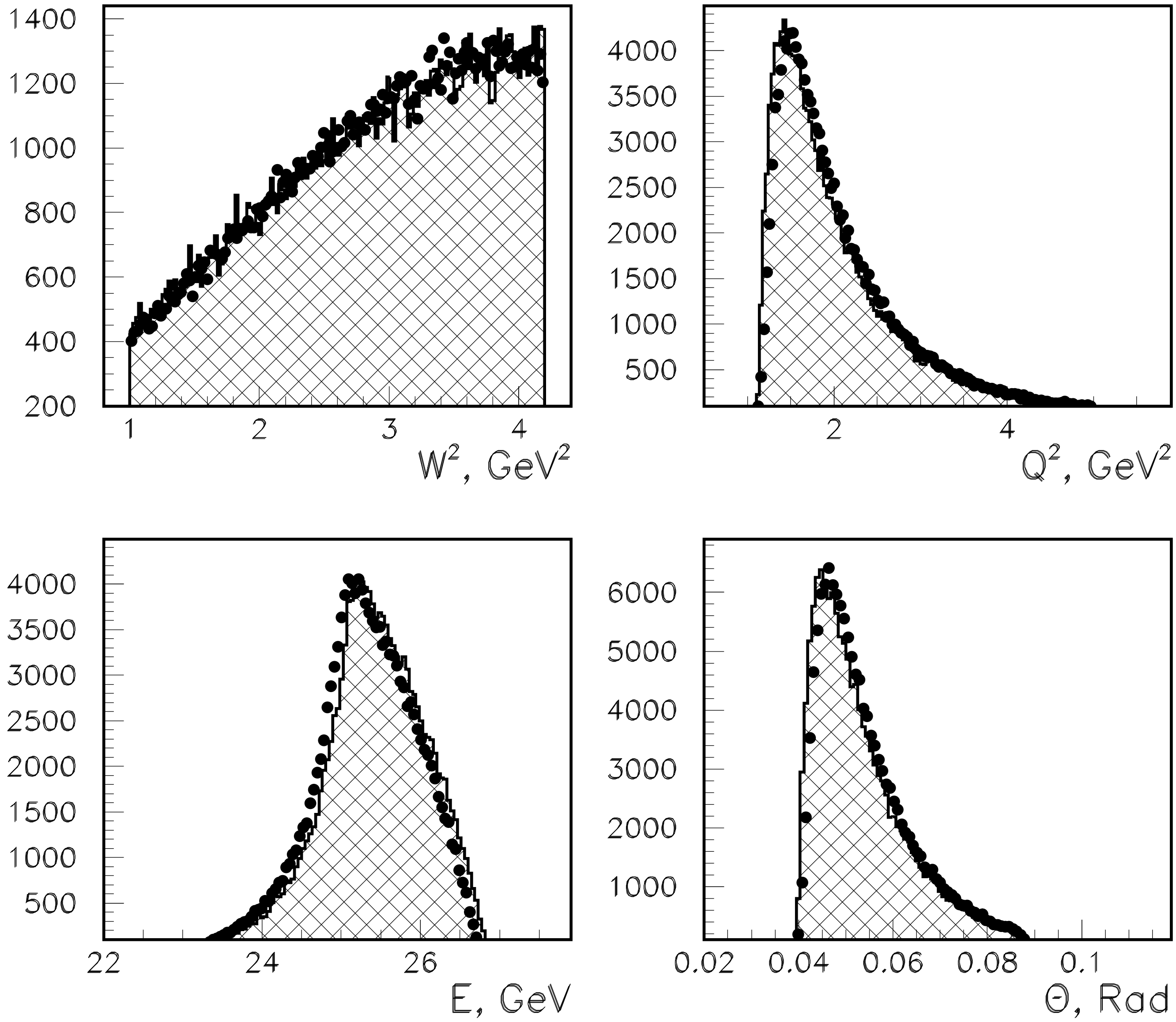
Monte-Carlo studies

- Using HERMES Monte-Carlo package (HMC) events were simulated with elastic, resonance and DIS cross sections.
- The structure function F_2 was calculated from modification of the parametrization: A.Bodek et al., Phys.Rev. D20 (1979) 1471, R=0.18 for whole resonance region.

- Good DATA–MC agreement.
- Resolutions for resonance region(1.0 GeV^2 $<$W^2 $<$4.2 GeV^2): $\Delta\theta/\theta$ is $\sim$ 1%, $\Delta Q^2/Q^2$ $\sim$ 2.2%, $\Delta W^2/W^2$ $\sim$ 25% $\Delta P/P$ $\sim$ 1.6% aside from bremsstrahlung tails.
- The relative contaminations from elastic and DIS amount in average to 8% and 9% , respectively.



DATA-MC Comparison for Resonance region



The DATA-MC comparison for W^2, Q^2, scattered energy (E) and scattered angle (θ) distributions. The DATA are marked as histogram, MC are marked as points.

Extraction of Spin Asymmetry

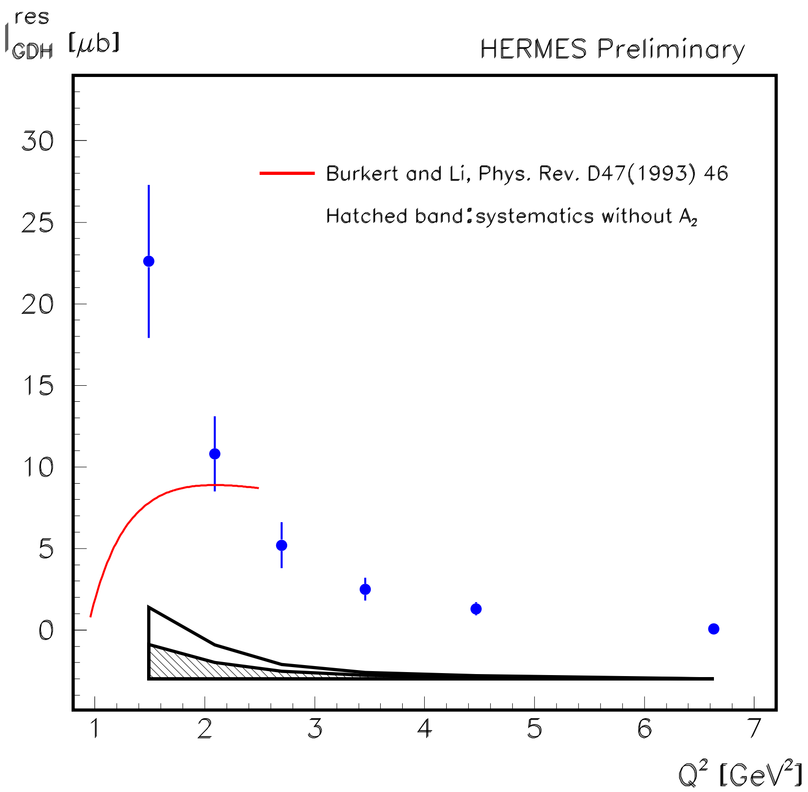
- The measurement was performed in 1997 with a 27.6 GeV beam of longitudinally polarised positrons incident on a longitudinally polarised ^{1}H gas target internal to the HERA storage ring.
- Data were divided into six bins in Q^2.
- The kinematic requirements on the detected scattered positrons:
  1.0 GeV^2 $<$W^2 $<$45.0 GeV^2,
  1.2 GeV^2 $<$Q^2 $<$12.0 GeV^2,
  $\theta > 0.04$ Rad and $y < 0.85$.
- The spin asymmetry A_1 is calculated with the following formula:

$$A_1 = \frac{A_{\|}}{D} - \eta A_2 \qquad \frac{A_{\|}}{D} = \frac{1}{D} \frac{N^- L^+ - N^+ L^-}{N^- L_p^+ + N^+ L_p^-} \tag{4}$$

  N is the number of detected scattered positrons,
  L is the integrated luminosity corrected for dead time,
  L_P is the integrated luminosity corrected for dead time and weighted by the product of beam and target polarisations,
  $+$ $(-)$ refers to the cases where the target spin axis was oriented parallel (anti-parallel) to the positron beam.
- $A_2 = 0.5x/\sqrt{Q^2}$ for DIS region and
  A_2=0 for resonance region.
- Radiative corrections (POLRAD 2.0) do not exceed 2% of the calculated spin asymmetry.
  I. Akushevich *et al.*, Comput. Phys. Commun. **104** (1997) 201
- After applying the data quality criteria, 1.52 M events were selected for analysis, including 0.13 M events in resonance region.
- The contribution from elastic peak was substructed on A_1 level (MC studies).

GDH Integral in Resonance region

The Resonance part of GDH Integral as function of Q^2 for W^2 range (1.0 – 4.2) GeV^2.



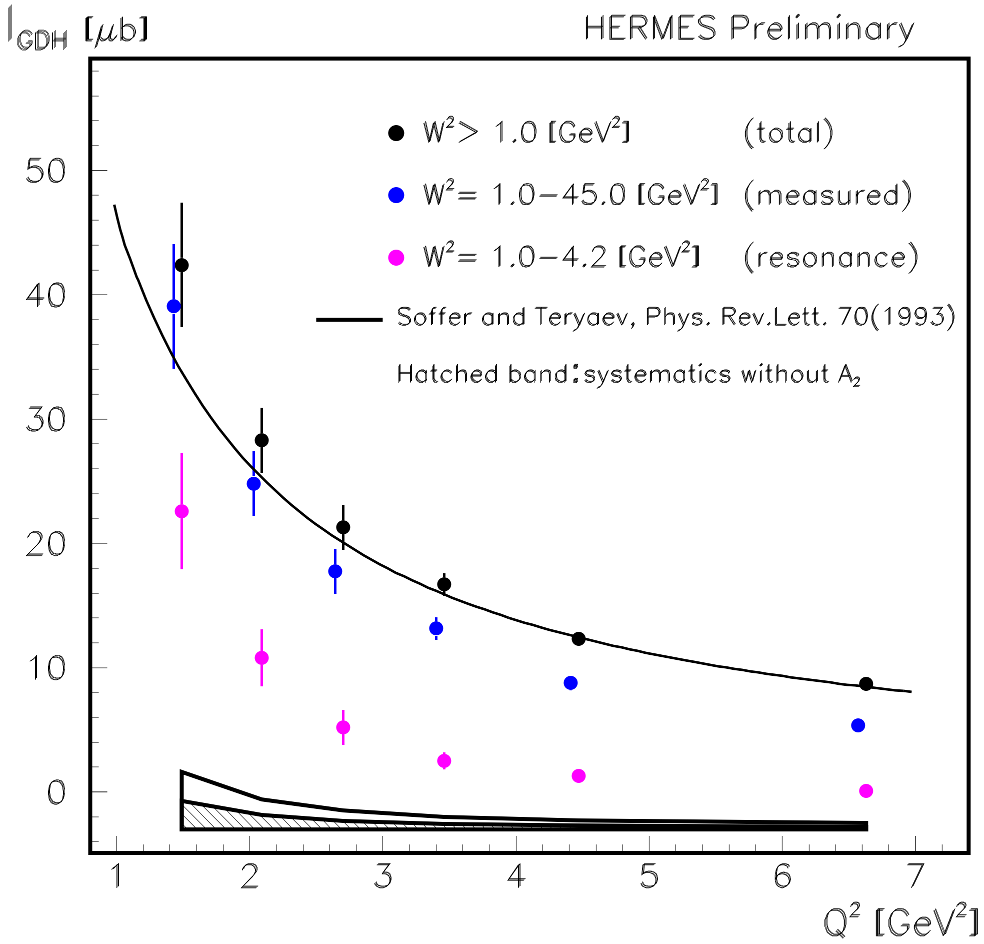
- Burkert and Li model parameterised the Q^2- evolution of main nucleon resonances (P_{33}(1232), P_{11}(1440), S_{11}(1535), D_{13}(1520), F_{15}(1680)) and assumed single quark transition to evaluate the contribution for less excited and higher mass resonances.
- Comparison of measured resonance part of the GDH integral with the Burkert–Li model shows significant excess of theoretical prediction for Q^2 <2.0 (GeV)^2.

The systematical uncertainties:

- Beam and target polarizations (5.3%).
- Smearing effects (up to 5.5%) and due to F_2 fit (2%).
- Due to A_2: for the resonance region the uncertainty due to the unknowledge of A_2 is dominant and exceed to 17%.

Q^2 dependence of the GDH Integral

The generalized GDH integral as function of Q^2.



- The contributions for unmeasured region ($W^2 > 45.0$ GeV^2) were estimated with parameterization from N.Bianchi and E.Thomas , Phys. Lett. B450 (1999), 439. , which were equal to 3.4–3.6 μbarn.
- A parameterization for A_1 (GRSV-96) based on a NLO-QCD analysis provided within 5% the same results. M. Glück *et al.*, Phys. Rev. **D 53** (1996), 4775.
- Results are in good agreement with the model prediction of Soffer-Teryaev.

Conclusions

- The Generalised Gerasimov–Drell–Hearn Integral for proton is experimentally measured for the first time in both the resonance and DIS regions for the Q^2 range (1.2–12.0) GeV^2.

- The measured resonance part of the GDH integral is not in agreement with the expectations of Burkert–Li model for $Q^2 < 2$ GeV^2.

- Combination of HERMES data for resonance and DIS regions allows to provide the first measurements of the Q^2 dependence of the Generalized GDH Integral for proton. Experimental results are in good agreement with the model prediction of Soffer-Teryaev.