The Drell-Hearn-Gerasimov Sum-Rule at Polarized HERA

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Abstract

We discuss the potential of polarized HERA to measure the spin dependent part of the total photoproduction cross-section at large $\sqrt{s_{\gamma p}}$.

The Drell-Hearn-Gerasimov sum-rule [1] (for reviews see [2, 3]) for spin dependent photoproduction relates the difference of the two cross-sections for the absorption of a real photon with spin anti-parallel σ_A and parallel σ_P to the target spin to the square of the anomalous magnetic moment of the target nucleon,

$$(\mathrm{DHG}) \equiv -\frac{4\pi^2\alpha\kappa^2}{2m^2} = \int_{\nu_{th}}^{\infty} \frac{d\nu}{\nu}(\sigma_A - \sigma_P)(\nu). \tag{1}$$

Here ν is the (LAB) energy of the exchanged photon, m is the nucleon mass and κ is the anomalous magnetic moment.

The first direct test of the Drell-Hearn-Gerasimov sum-rule will be made in experiments which are planned or underway at the ELSA, GRAAL, LEGS and MAMI facilities. These experiments will measure $(\sigma_A - \sigma_P)$ up to a photon LAB energy $\nu = 3\mathrm{GeV}$ ($\sqrt{s_{\gamma p}} \leq 2.5\mathrm{GeV}$). They will make a precise measurement of nucleon resonance contributions to (DHG), thus testing multipole analyses of unpolarized single-pion photoproduction data [4], as well as the contributions from strangeness production and vector meson dominance. There is no elastic contribution to (DHG).

The high-energy part of $(\sigma_A - \sigma_P)$ is expected to be determined by Regge theory for $\sqrt{s_{\gamma p}} \geq 2.5\mathrm{GeV}$. In this note we briefly review possible Regge contributions to $(\sigma_A - \sigma_P)$ and summarise the present knowledge of these contributions from low Q^2 ($\simeq 0.45\mathrm{GeV}^2$) inclusive photoproduction. Finally, we discuss the contribution that polarized HERA could make to the measurement of these high $\sqrt{s}$ Regge contributions to the Drell-Hearn-Gerasimov sum-rule.

At large centre of mass energy squared ($s = 2m\nu + m^2$), soft Regge theory predicts [5, 6, 7]

$$\Big(\sigma_A - \sigma_P\Big) \sim N_3 s^{\alpha_{a_1}-1} + N_0 s^{\alpha_{f_1}-1} + N_g \frac{\ln\frac{s}{\mu^2}}{s} + N_{PP}\frac{1}{\ln^2\frac{s}{\mu^2}} \tag{2}$$

Table 1: A_1 at large s and low Q^2

Experiment	$\langle Q^2 \rangle$	$\sqrt{s}$	A_1^p	A_1^d
($Q^2 \leq 0.7\text{GeV}^2$, $\sqrt{s} \geq 2.5\text{GeV}$)				
E-143	0.45	3.5	0.077 ± 0.016	$+0.008 \pm 0.022$
SMC	0.45	16.7	0.064 ± 0.024	-0.013 ± 0.020

Here α_{a_1} and α_{f_1} are the intercepts of the isovector $a_1(1260)$ and isoscalar $f_1(1285)$ and $f_1(1420)$ Regge trajectories, which are usually taken between -0.5 and 0.0 [5]. (We note, however, that the isotriplet part of the deep inelastic structure function g_1 behaves like $x^{-0.5}$ in the range ($0.01 < x < 0.12$) in the SLAC data [10], corresponding to an effective Regge intercept $\alpha_{a_1}(Q^2) \simeq +0.5$ at the relatively low deep inelastic $Q^2 \simeq 3 - 5\text{GeV}^2$.)

The $\ln s/s$ term is induced by any vector component to the short range exchange potential [7] – for example, two nonperturbative gluon exchange [9]. The $1/\ln^2 s$ term represents any pomeron-pomeron cut contribution to $(\sigma_A - \sigma_P)$. The mass parameter μ is a typical hadronic $\sim 0.5\text{GeV}$. The coefficients N_3, N_0, N_g and N_{PP} in Equ.(2) are to be determined from experiment.

Besides their importance for a precise test of the DHG sum-rule, the soft Regge contributions to $(\sigma_A - \sigma_P)$ form a baseline for investigations of DGLAP and BFKL small x behaviour in g_1, the nucleon's first spin dependent structure function.

To estimate the Regge contribution to $(\sigma_A - \sigma_P)$ at $Q^2 = 0$ we take the low Q^2 data from the E-143 [11] and SMC [12] experiments ($0.25\text{GeV}^2 < Q^2 < 0.7\text{GeV}^2$) on

$$A_1 = \frac{\sigma_A - \sigma_P}{\sigma_A + \sigma_P} \tag{3}$$

This low Q^2 data has the following features. First, the spin asymmetries A_1^p and A_1^d show no significant Q^2 dependence in the range of each experiment. Secondly, the isoscalar deuteron asymmetry A_1^d is consistent with zero in both the E-143 and SMC low Q^2 bins. There is a clear positive proton asymmetry in the E-143 data, signalling a strong isotriplet term in $(\sigma_A - \sigma_P)$ at $s \simeq 12\text{GeV}^2$. The SMC A_1^p data is less clear: combining the SMC low Q^2 A_1^p data yields a positive value for A_1^p. However, the majority of these SMC points are consistent with zero.

In Table 1 we combine the low Q^2 data to obtain one point corresponding to each experiment. We impose the cut ($Q^2 \leq 0.7\text{GeV}^2$, $\sqrt{s} \geq 2.5\text{GeV}$), so that the mean Q^2 is less than 0.5GeV^2 for each experiments, and so that our data set is well beyond the resonance region.

We assume that the large $\sqrt{s}$ A_1 is approximately independent of Q^2 between $Q^2 = 0$ and $Q^2 \simeq 0.5$ GeV^2. For the total photoproduction cross-section we take

$$(\sigma_A + \sigma_P) = 67.7 s^{+0.0808} + 129 s^{-0.4545} \tag{4}$$

(in units of μb), which is known to provide a good Regge fit for $\sqrt{s}$ between 2.5GeV and 250GeV [8]. (Here, the $s^{+0.0808}$ contribution is associated with pomeron exchange and the $s^{-0.4545}$ contribution is associated with the isoscalar ω and isovector ρ trajectories.) Since the E-143 low

Q^2 data shows a clearly positive A_1^p with the smallest experimental error, we choose to normalise to E-143. We estimate

$$(\sigma_A - \sigma_P) \simeq 10\mu\text{b} \quad \text{at} \quad (Q^2 = 0, \sqrt{s} = 3.5\text{GeV}) \tag{5}$$

The small isoscalar deuteron asymmetry A_1^d indicates that the isoscalar contribution to A_1^p in the E-143 data is unlikely to be more than 30%. In Fig. 1 we show the asymmetry A_1^p as a function of $\sqrt{s}$ between 2.5 and 250 GeV for the four different would-be Regge behaviours for $(\sigma_A - \sigma_P)$: that the high energy behaviour of $(\sigma_A - \sigma_P)$ is given

1. entirely by the (a_1, f_1) terms in Equ.(2) with Regge intercept either (a) $-\frac{1}{2}$ (conventional) or (b) $+\frac{1}{2}$ (motivated by the observed small x behaviour of $g_1^{(p-n)}$),

2. by taking 2/3 isovector (conventional) a_1 and 1/3 two non-perturbative gluon exchange contributions at $\sqrt{s} = 3.5$GeV,

3. by taking 2/3 isovector (conventional) a_1 and 1/3 pomeron-pomeron cut contributions at $\sqrt{s} = 3.5$GeV.

Photoproduction cross-sections can be measured in ep collisions at HERA at high $\sqrt{s_{\gamma p}}$ energies. The dominant processes in ep collisions are γp interactions where the photon is on mass shell. The electron is scattered under approximately zero degrees with respect to the electron beam direction, which at HERA means that it remains in the beampipe. The energy of the scattered electron E'_e is however reduced to $E'_e = E_e - E_\gamma$, with E_e the incident electron energy and E_γ the emitted photon energy. The HERA machine magnets in the beamline, which steer the beam into a closed orbit, act as a spectrometer on these off-momentum electrons. The experiments H1 and ZEUS have installed calorimeters to detected these kicked out electrons along the beamline. In case of H1 calorimeters (stations) are installed at three locations: at 8 m , 30 m and 44 m distance from the interaction point [13]. The stations accept (tag) electrons from different momentum ranges, which correspond to $\sqrt{s_{\gamma p}}$ ranges of 280-290 GeV, 150-250 GeV and 60-115 GeV respectively. At the central energy value of each region the acceptance of these devices amounts to 15%, 85% and 70% respectively. The locations of the stations may change as a result of the HERA luminosity upgrade, and are presently under study.

Equ.4 shows that the γp cross section is large, of order of hundreds of microbarns. The photon energy spectrum emitted from an electron beam is given in the Weizsäcker-Williams approximation [14]. An integrated ep luminosity at HERA of 1 pb^{-1} can yield about $N = 1500$K γp events in each of the 30 m and 44 m stations, and about 10 times less in the 8 m station.

The collider experiments record presently unpolarized ep collisions. Around the year 2000, spin rotators will be installed for the electrons, converting the natural transverse polarization of the electron beam into a physics whise more useful longitudinal one. Studies are being made to have also the proton beam at HERA polarize [15] which would enable polarized ep and thus polarized γp collisions. Note however that the polarization of the photon beam will be reduced by a factor $D = y(2-y)/(y^2 + 2(1-y))$, the so called depolarization factor. Here $y = s_{\gamma p}/s_{ep}$. For the three stations the measurements are at $y = 0.09, 0.44$ and 0.90, leading to values of $D = 0.094, 0.52$ and 0.98. The measured asymmetries at HERA are correspondingly reduced by this factor.

If HERA is fully polarized, event samples of the order of 100 - 500 pb^{-1} will be collected, with expected beam polarizations $P_e = P_p = 0.7$. In the small asymmetry approximation the error on the asymmetries, δA_1 can be calculated as $1/(P_e P_p \sqrt{N})$. Due to data-taking bandwidths and

trigger problems presently not all tagged γp events are recorded. Assuming a data taking rate of 2 Hz for these events, also in future, leads to about 40 M events/year giving a reachable precision $\delta A_1 = 1/(P_e P_p \sqrt{N}) = 0.0003$. It is however not excluded that novel techniques in triggering, data-taking and data storage will become available and can be installed for the experiments, which would allow to collect all produced events, amounting to approximately 15,000M events in total for the three stations in a period of 3 to 5 years. This would lead to maximal reachable precisions of $\delta A_1 = 3.10^{-5}$ for a measurement at the 30m and the 44m station, and $\delta A_1 = 10^{-4}$ for a measurement at the 8m station. Note that when compared with the true asymmetries as shown in Fig. 1, the depolarization factor D reduces the effective sensitivities with the numbers given above.

Given the projected asymmetries, polarized HERA with $\delta A_1 = 0.0003$ would be sensitive at $\sqrt{s_{\gamma p}} = 50$GeV to a $(\sigma_A - \sigma_P)$ falling no faster than s^{-1}. Taking the conventional, $\alpha_{a_1} = -\frac{1}{2}$, it would be sensitive to a two non-perturbative gluon exchange contribution which is not less than 30% in the E-143 data and to a pomeron-pomeron cut contribution which is not less than 3% in the E-143 data. At $\sqrt{s_{\gamma p}} = 250$GeV, polarized HERA would be sensitive to $(\sigma_A - \sigma_P)$ which falls no faster than $s^{-0.6}$ and to a pomeron-pomeron cut contribution which is no less than 6% of the E-143 A_1^p. We note that a zero-result (no significant signal) would put an upper bound on the Regge contribution to the Drell-Hearn-Gerasimov integral.

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References

[1] S.D. Drell and A.C. Hearn, Phys. Rev. Lett. **162** (1966) 1520;
S.B. Gerasimov, Yad. Fiz. **2** (1965) 839.

[2] S. D. Bass, Mod. Phys. Lett. **A12** (1997) 1051 and Proc. Zeuthen Workshop: *Deep Inelastic Scattering off Polarized Targets: Theory Meets Experiment* (DESY, Zeuthen)

[3] D. Drechsel, Prog. Part. Nucl. Phys. **34** (1995) 181.

[4] I. Karliner, Phys. Rev. **D7** (1973) 2717;
R.L. Workman and R.A. Arndt, Phys. Rev. **D45** (1992) 1789;
A.M. Sandorfi, C.S. Whisnant and M. Khandaker, Phys. Rev. **D50** (1994) R6681.

[5] R.L. Heimann, Nucl. Phys. **B64** (1973) 429;
J. Ellis and M. Karliner, Phys. Lett. **B213** (1988) 73.

[6] S.D. Bass and M.M. Brisudová, Bonn preprint TK-97-10 (1997).

[7] F.E. Close and R.G. Roberts, Phys. Lett. **B336** (1994) 257.

[8] P.V. Landshoff, Proc. Zuoz Summer School, PSI Proceedings 94-01 (1994) 135, hep-ph/9410250.

[9] S.D. Bass and P.V. Landshoff, Phys. Lett. **B336** (1994) 537.

[10] The E-143 Collaboration (K. Abe et al.), Phys. Rev. Lett. **74** (1995) 346;
The E-154 Collaboration (K. Abe et al.), Phys. Rev. Lett. **79** (1997) 26.

[11] The E-143 Collaboration (K. Abe et al.), Phys. Lett. **B364** (1995) 61.

[12] The Spin Muon Collaboration (D. Adams et al.), Phys. Lett. **B396** (1997) 338 and (B. Adeva et al.), CERN preprint CERN-PPE-97-118 (1997).

[13] H1 Collab., I. Abt et al., Nucl. Instr. and Meth. **A386** (1997) 310 and **A386** (1997) 348.

[14] C.F. Weizsäcker, Z. Phys. **88** (1934) 612;
E.J. Williams, Phys. Rev. **45** (1934) 729.

[15] D.P. Barber et al., Proceedings of the Workshop Future Physics at HERA, Eds. G. Ingelman, A. De Roeck, R. Klanner, (1996) 1205.

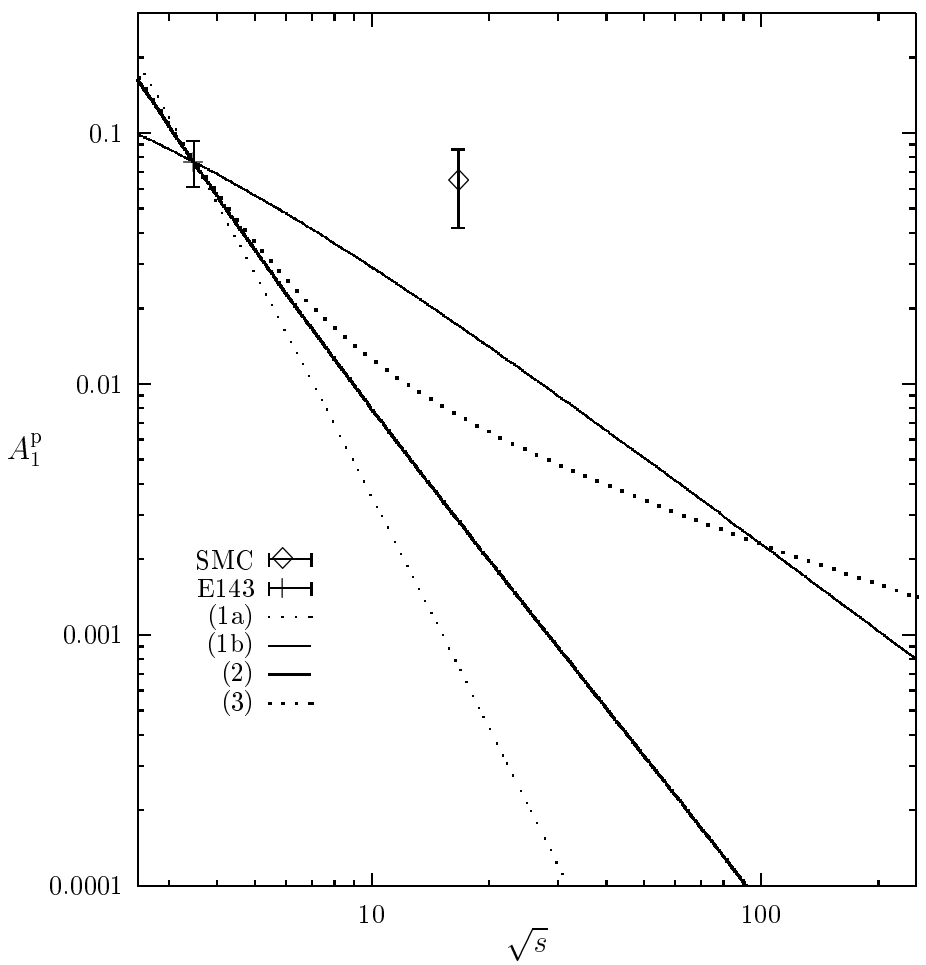

Figure 1: **The asymmetry A_1^p as a function of $\sqrt{s}$ for different Regge behaviours** for $(\sigma_A - \sigma_P)$: given entirely by (1a) the (a_1, f_1) terms in Equ.(2) with Regge intercept either $-\frac{1}{2}$ (conventional) or (1b) $+\frac{1}{2}$; (2) by 2/3 isovector (conventional) a_1 and 1/3 two non-perturbative gluon exchange contributions at $\sqrt{s} = 3.5$GeV; (3) by 2/3 isovector (conventional) a_1 and 1/3 pomeron-pomeron cut contributions at $\sqrt{s} = 3.5$GeV.