# FIRST REGGE DESCRIPTION OF POLARISED PHOTON-NUCLEON ABSORPTION CROSS SECTION

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The first Regge description of the virtual photon absorption cross section difference $\Delta\sigma(\gamma^*,N) = \left[\sigma_{1/2}(\gamma^*,N) - \sigma_{3/2}(\gamma^*,N)\right]$ was obtained from a global fit of all the data collected by the experiments measuring spin asymmetries in polarized lepton - polarized nucleon deep inelastic scattering. This work present a phenomenological and a numerical description of all the polarized deep inelastic data ($\Delta\sigma(\gamma^*,N)$, $g_1$ spin structure function). The model also provide reliable predictions for the photo-production limit through a smooth $Q^2$-transition and allow to size the non resonant contribution to the Gerasimov-Drell-Hearn sum rule.

## 1 Introduction

The polarised photon nucleon absorption cross section asymmetry is already well described by NLO-QCD fits to world data [1]. However, these fits cannot be extrapolated unambiguously to the real photon case. One of the main interest of having a parameterisation extending up to $Q^2 = 0$ is that a fundamental sum rule have been derived by Gerasimov, Drell and Hearn[2] (GDH) for the real photon nucleon absorption polarised cross section. This sum rule relates the cross section difference $\Delta\sigma = [\sigma_{1/2} - \sigma_{3/2}]$, where $\sigma_{1/2}$ and $\sigma_{3/2}$ are the real photon-nucleon absorption cross section of total helicity 1/2 and 3/2 respectively, to the anomalous contribution $\kappa$ to the magnetic moment of the nucleon:

$$I = \int_0^\infty \Delta\sigma(\nu)\frac{d\nu}{\nu} = -\frac{2\pi^2\alpha}{m^2}\kappa^2, \qquad (1)$$

where $\nu$ is the photon energy. Due to the lack of suitable polarised beam facility, this sum rule as never been tested directly. The low energy contribution to the sum rule is expected to be the dominant one due to the $1/\nu$ weight in Eq. 1. However, phenomenological estimates of the low energy contribution from multipole analysis of single pion photo-production amplitudes and from the double pion contribution from the nucleon resonance decays [3] [4] are not in agreement with the sum rule expectations. The persisting discrepancy between these estimates and the sum rule expectations triggered some dedicated experiments [5] aiming to measure $\Delta\sigma(\nu)$ up to $\nu = 3$ GeV. Since the high energy contribution to the GDH sum rule will not be accessible to

forthcoming experiments and is missing in all the estimates, only a $Q^2 = 0$ extrapolation of deep-inelastic-scattering (DIS) measurements of $\Delta\sigma(\nu, Q^2)$ can be used to estimate it. In this work, the first parameterisation of polarised DIS world data extending to $Q^2 = 0$ through smooth $Q^2$ transition is presented. The parameterisation is based on Regge theory. Indeed, as shown for the unpolarised photon nucleon absorption cross section [6], Regge language can provide a similar description for real and virtual photon, taking into account the threshold effect arising from the virtual particle exchange [7]. It is also important to point out that, for the polarised case, such parameterisation will allow not only to size the high energy contribution to the sum rule, but can also provide a crude estimate of the low energy non resonant multi-hadron contribution which is also missing in actual estimates.

## 2 Data analysis and fitting procedure

A total of 511 spin asymmetries $A_1$ measurement for the proton, deuteron and neutron were used. The data were collected by six experiments at CERN (EMC[8], SMC[9]), SLAC (E142[10], E143[11], E154[12]) and DESY (HERMES[13]). The kinematic range covered by the data is 0.3 GeV$^2$ $< Q^2 <$ 70 GeV$^2$ and 4 GeV$^2$ $< W^2 <$ 300 GeV$^2$ for the proton and deuteron, and 1 GeV$^2$ $< Q^2 <$ 15 GeV$^2$ and 4 GeV$^2$ $< W^2 <$ 70 GeV$^2$ for the neutron. The cross section asymmetries $A_1$ were converted into cross section differences $\Delta\sigma$ by multiplying them by the total cross section using parameterisation of $F_2$ [14] and $R$ [15]. The $\Delta\sigma$ experimental data were reproduced by a global 3-D fit over the $Q^2$ and $W^2$ variables and the isospin dimension $T$:

$$\Delta\sigma = \Delta\sigma(T, W^2, Q^2) = \left[ 2aW^{2(\alpha^0_{a1}-1)}T + fW^{2(\alpha^0_{f1}-1)} + g\frac{lnW^2}{W^2} \right] F, \quad (2)$$

where the isovector contribution to $\Delta\sigma$ is provided by the $a_1(1260)$ meson trajectory and the isoscalar is provided by the $f_1(1285)$ meson trajectory and the two gluon exchange, the latter giving rise to a contribution of the form $\sim \frac{lnW^2}{W^2}$ [16]. Alternative models were also investigated: a model with a contribution from additional isovector Reggeon exchange (model III) a model with smooth $Q^2$ dependence of $\alpha^0_{a1}$ (model II). The different models and their results are extensively described in [17]. The threshold factor $F$ in 2 is similar to the ones used in the description of unpolarised cross section [7 6 18 19], it is given by

$$F = \left[ \frac{W^2 - W_\pi^2}{W^2 - W_\pi^2 + Q^2 + m_r^2} \right]^p, \quad \text{where } p = 1.5 \left( 1 + \frac{Q^2}{Q^2 + M^2} \right), \quad (3)$$

$W_\pi = 1.07$ GeV is the single pion electro-production threshold and $m_r = 1.26$ GeV is a common mass scale of the exchanged particles which is close to the $a_1$ and $f_1$ meson masses and to the two gluon exchange hadronic scale. $M$ a free parameter of the fit. Because Regge theory gives no indication about the relative weight and $Q^2$-dependence of the various contributions, the three coefficients in eq. 2 were parameterised with a simple and smooth $Q^2$-dependence, with two free parameters each :

$$a, f, g = p_1^{a,f,g} + p_2^{a,f,g} t \text{ where } t = log\frac{log\frac{Q^2+Q_0^2}{\Lambda^2}}{log\frac{Q_0^2}{\Lambda^2}}. \quad (4)$$

Here $\Lambda$ and $Q_0^2$ are the QCD cutoff and scale parameters, respectively. We used $\Lambda = 0.255$ GeV and $Q_0^2 = 0.278$ GeV$^2$ in agreement with the ALLM parameterisation for the unpolarised total transverse cross section $\sigma_T$[6]. The cross section difference for the proton and neutron were defined by eq. 2 with $T$=+1/2 and $T$=−1/2, respectively. The cross section difference for the deuteron was defined $\Delta\sigma^d = [\Delta\sigma^p + \Delta\sigma^n](1 - 1.5\omega_D)$ where $\omega_D = 0.05$ is the D-wave probability in the deuteron[20].

## 3 Results

The comparison between the results of the three models and the experimental data as function of the three variables ($T$, $W^2$ and $Q^2$) is shown in fig. 1. The numerical value of the free parameters are given in table 1. All the three models well reproduce the data. The difference between the fit and data normalised by the experimental error bar is shown at figure 2. The flatness of the distribution ensure the reliability of the extrapolation to $Q^2 = 0$. The comparison between expectations of model II for polarised structure functions $g_1$, NLO-QCD fit based on polarised parton density distributions [1] and the data is shown in fig. 2. Our Model and the QCD model are in good agreement at least for $x \geq 0.03$ and both well reproduce the experimental data. The very recent E155 [21] $g_1^d$ data displayed in fig. 2 were not included in the fit. These data seems to support a change of sign in the $g_1^d$ structure function around $x \approx 0.02$. If this change of sign if confirmed, it means that the minimal Regge model aiming to describe polarised photon-nucleon absorption cross section should have at least two isoscalar components, and of course one isovector component to match the very different $g_1^p$ and $g_1^n$ behavior.

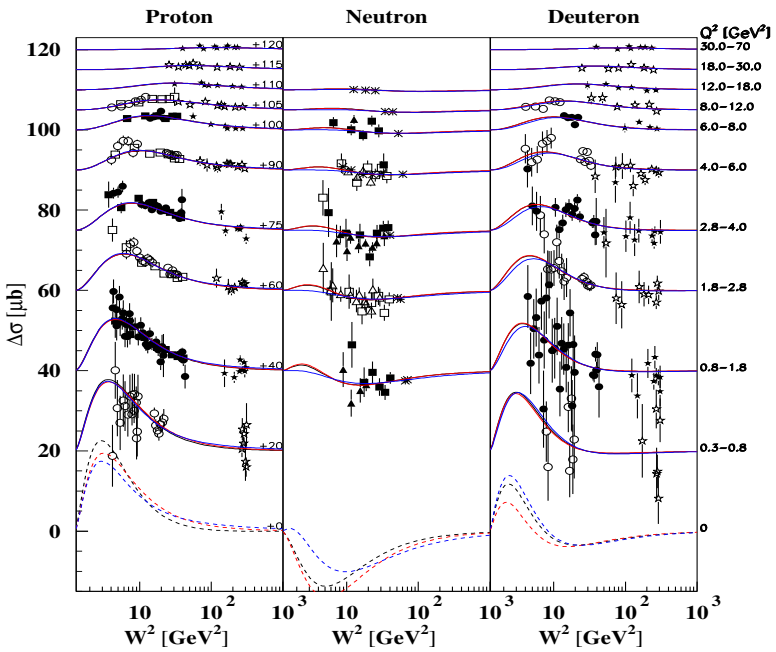


Figure 1. Cross section differences as a function of $W^2$ for different $Q^2$-bins (on the right scale). Data are from Refs. [8,9] (stars), [10] (triangles), [11] (circles), [12] (asterisks), and [13] (squares). For a better view, a $Q^2$-increasing constant value (on the right side of the proton panel) has been added to the data which are presented with open and close symbols alternatively. Only data with statistical error lower than 10 $\mu$b are shown. The solid curves are the results of the three models calculated for the average $Q^2$-values in each $Q^2$-bin. The dashed curves are the models predictions for $Q^2$=0.

## 4 Contributions to GDH sum rule

The high energy ($W \geq 2$ GeV) contribution as well as the low energy ($W < 2$ GeV) non resonance multi hadron contribution to GDH sum rule have been estimated, by integrating the the models from 2 pion photo production threshold ($W_{2\pi}$). The error was calculated by taking into account the differences between the three models considered, the statistical error of the data, the error on the fixed parameters and possible variation of the threshold parameterisation. As shown in table 2 if one take into account the non resonance contribution predicted by these models, the GDH sum rule is fulfilled.

| | Model I | Model II | Model III |
|---|---|---|---|
| $p_1^a$ [$\mu$b] | 107±6 | 133±4 | 45 ±27 |
| $p_2^a$ [$\mu$b] | -40±4 | -75±3 | 107 ±47 |
| $p_1^f$ [$\mu$b] | 83±25 | 112±21 | 119±15 |
| $p_2^f$ [$\mu$b] | 141±47 | 64±24 | 51±17 |
| $p_1^g$ [$\mu$b] | -22±3 | -28±3 | -34±2 |
| $p_2^g$ [$\mu$b] | 20±2 | 23±2 | 24±2 |
| $p_1^r$ [$\mu$b] | - | - | 36±2 |
| $p_2^r$ [$\mu$b] | - | - | -19±1 |
| $M^2$ [GeV$^2$] | 3.7±0.7 | 4.8±0.8 | 2.9±0.5 |
| $\alpha^0_{a_1}$ | 0.17±0.02 | $(0.21 \pm 0.02) \cdot t$ | -0.44±0.13 |
| $\alpha^0_{f_1}$ | -0.44±0.09 | -0.32±0.09 | -0.23±0.05 |
| $\alpha^0_r$ | - | - | 0.46±0.02 |
| $\chi^2/ndf$ | 1.14 | 1.12 | 1.13 |

Table 1. Parameter values provided by the fit of the data with the different models. The error estimates have been obtained from a MINOS analysis of the MINUIT program.

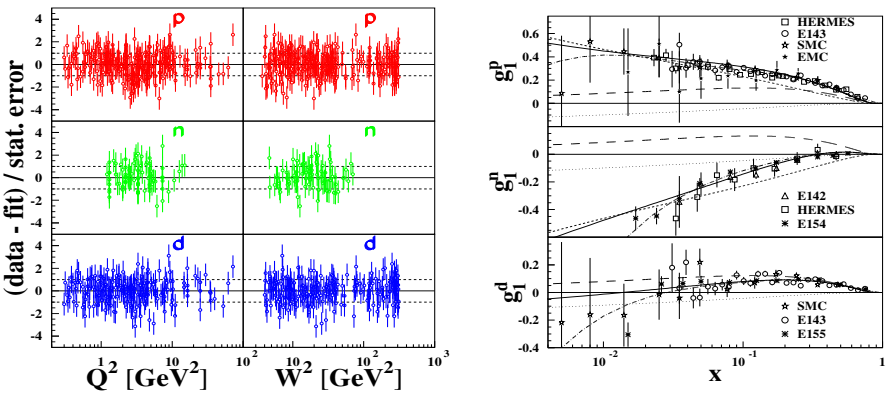


Figure 2. Left: difference between data and fit, normalised by the experimental statistical error. Right: spin structure functions $g_1(x)$ at $Q^2 = 3$ GeV$^2$. The solid curves are the results of Model II. The short-dashed, long-dashed and dotted curves are the $a_1$, $f_1$ and two-gluons contributions respectively. The predictions of a NLO-QCD fit [1] are indicated by the dot-dashed curves. The very recent E155 data for the deuteron were not included in the fit.

## References


1. M. Gluck et al., Phys. Rev. **D 53** (1996) 4775.

| | $I_p$ [$\mu$b] | $I_n$ [$\mu$b] | $I_{p-n}$ [$\mu$b] |
|---|---|---|---|
| Resonance and $1\pi$ | | | |
| $I_{N\pi}$(Drechsel[4]) | $-196$ | $-145$ | $-51$ |
| $I_{N^*\to N\pi\pi}$(Karliner[3]) | $-65$ | $-35$ | $-30$ |
| **Non resonance Multi-hadron** ($W_{2\pi}$) | | | |
| $I_{he}(W \geq 2GeV)$ | $+25 \pm 6$ | $-36 \pm 10$ | $+61 \pm 12$ |
| $I_{le}(W \leq 2GeV)$ | $+19 \pm 13$ | $-9 \pm 13$ | $+28 \pm 23$ |
| $I_{TOT}$ | $-217 \pm 18$ | $-220 \pm 22$ | $+8 \pm 32$ |
| GDH sum rule | $-204$ | $-233$ | $+29$ |

Table 2. Evaluation of the GDH integral ($I_{TOT}$) and its high energy ($he$) and low energy ($le$) non resonant contributions.


2. S.B. Gerasimov, Sov. J. Nucl. Phys. **2** (1966) 430; S.D. Drell and A.C. Hearn, Phys. Rev. Lett. **16** (1966) 908.
3. I. Karliner, Phys. Rev. **D 7** (1973) 2717.
4. D. Drechsel and G.Krein, Phys. Rev. **D 58** (1998) 116009.
5. N. Bianchi, Proc. Workshop on Electron Nucleus Scattering, Ed. O. Benhar, Elba, July 1-5, 1996, p.363 and references therein.
6. H. Abramowicz, E.M. Levin, A. Levy and U. Maor, Phys. Lett. **B 269** (1991) 465.
7. A. Levy and U. Maor, Phys. Lett. **B 182** (1986) 108.
8. EMC Collaboration, J. Ashman *et al.*, Nucl. Phys. **B 328** (1989) 1.
9. SMC Collaboration, B. Adeva *et al.*, Phys. Rev. **D 58** (1998) 112001.
10. E142 Collaboration, P.L. Anthony *et al.*, Phys. Rev. **D 54** (1997) 6620.
11. E143 Collaboration, K. Abe *et al.*, Phys. Rev. **D 58** (1998) 112003.
12. E154 Collaboration, K. Abe *et al.*, Phys. Rev. Lett. **79** (1997) 26.
13. HERMES Collaboration, K. Ackerstaff *et al.*, Phys. Lett. **B 444** (1998) 531; K. Ackerstaff *et al.*, Phys. Lett. **B 404** (1997) 383; A. Airapetian *et al.*, Phys. Lett. **B 442** (1998) 484.
14. NMC Collaboration, M. Arneodo *et al.*, Phys. Lett. **B 364** (1995) 107.
15. L.W. Whitlow *et al.*, Phys. Lett. **B 250** (1990) 193.
16. S.D. Bass and P.V. Landshoff, Phys. Lett. **B 336** (1994) 537.
17. N. Bianchi and E. Thomas, Phys. Lett. **B 450** (1999) 439.
18. A. Capella, et al., Van, Phys. Lett. **B 337** (1994) 358.
19. P. Desgrolard et al., hep-ex 9803286,
20. R. Machleidt *et al.*, Phys. Rep. **149** (1987) 1.
21. E155 Collaboration (P.L. Anthony et al.). SLAC-PUB-8041, Mar 1999.