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Search for a 2-Photon Exchange in Inclusive DIS on a Transversely Polarized Hydrogen Target at HERMES

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Abstract. Left-right single-spin asymmetries are measured in inclusive deep inelastic scattering at HERMES, with the goal of searching for a 2-photon exchange signal in the range $0.004 < x < 0.9$, $0.1 < Q^2 < 20$ GeV^2. In two separate regions, for $Q^2 > 1$ GeV^2 and $Q^2 < 1$ GeV^2, and for both electron and positron beams, the asymmetries are found to be consistent with zero showing that within the uncertainties no signal is detected.

Keywords: photon, DIS, inclusive
PACS: 13.60.Hb, 13.88.+e, 14.70.Bh

INTRODUCTION

In recent years the contribution of 2-photon-exchange to the cross section in electron-nucleon scattering has received increased attention. In elastic scattering it can be used to explain the different results obtained by the Rosenbluth and polarization transfer methods for the measurement of the electromagnetic proton form factors [1]. In inclusive Deep Inelastic Scattering (DIS) it is expected [2] to give rise to single-spin azimuthal asymmetries.

Little is known about the 2-photon exchange cross-section in DIS, other than the expected dependence on $\varepsilon_{\mu\nu\rho\sigma}S^{\mu}p^{\nu}k^{\rho}k'^{\sigma} \propto \vec{S}\cdot(\vec{k}\times\vec{k'})$, where k and k' are the initial and final lepton four-momenta, p is the initial four-momentum of the target nucleon, and S may be the polarization vector of either the lepton or the nucleon. The largest value of the cross section is thus obtained when the three vectors $\vec{S}$, $\vec{k}$ and $\vec{k'}$ are perpendicular to each other; so, for transverse target polarization, an asymmetry can be obtained between the number of leptons scattered to the left and those scattered to the right with respect to $\vec{S}$. Such an asymmetry is expected to be of the order of $\alpha_{em}M/Q$ [2], where M is the nucleon mass for transversely polarized target nucleons, while it is the lepton mass for the case of a transversely polarized lepton beam, thus showing that the effect is larger in the case of transversely polarized targets, where it is expected to be of the order of 10^{-2} for $Q^2 \simeq 1$ GeV^2.

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DATA ANALYSIS

The HERMES experiment at DESY has taken data with a transversely polarized proton target between 2002 and 2005 collecting a total of 3.5 M events with a positron beam in 2002 and 2004, and 6.1 M events with an electron beam in 2005, in the kinematic region $0.004 < x < 0.9$, $0.1 < Q^2 < 20$ GeV^2 and $W^2 > 3.24$ GeV^2, where, in the one-photon exchange approximation, $-Q^2$ is the squared four-momentum transfer, W is the invariant mass of the photon-nucleon system, and x is the Bjorken scaling variable, . For this analysis the Q^2 region was separated into a 'DIS' region ($Q^2 > 1$ GeV^2) and a 'low-Q^2' region ($Q^2 < 1$ GeV^2). Data were collected with the target polarized both in the 'up' ($P^{\uparrow}$) and 'down' ($P^{\downarrow}$) directions, with the polarization flipping every 90s to minimize systematic effects. The yields can be expressed as:

$$\begin{aligned} N_R^{\uparrow} &= (L^{\uparrow}\sigma_0 + L_P^{\uparrow}\Delta\sigma)\chi_R/2 \\ N_L^{\uparrow} &= (L^{\uparrow}\sigma_0 - L_P^{\uparrow}\Delta\sigma)\chi_L/2 \\ N_R^{\downarrow} &= (L^{\downarrow}\sigma_0 - L_P^{\downarrow}\Delta\sigma)\chi_R/2 \\ N_L^{\downarrow} &= (L^{\downarrow}\sigma_0 + L_P^{\downarrow}\Delta\sigma)\chi_L/2 \end{aligned} \tag{1}$$

where $L^{\uparrow,\downarrow}$ are the total luminosities in the two polarization states, $L_P^{\uparrow,\downarrow}$ are the polarization-weighted luminosities, $\chi_{L,R}$ are the left and right detector acceptances, and the 'true' asymmetry in the detector acceptance is $A_{true}^{meas} = \Delta\sigma/\sigma_0$. The measured asymmetry was calculated as:

$$A_N^{meas} = \left[\sqrt{\frac{N_L^{\uparrow}}{L_P^{\uparrow}}\frac{N_R^{\downarrow}}{L_P^{\downarrow}}} - \sqrt{\frac{N_R^{\uparrow}}{L_P^{\uparrow}}\frac{N_L^{\downarrow}}{L_P^{\downarrow}}} \right] \Bigg/ \left[\sqrt{\frac{N_L^{\uparrow}}{L^{\uparrow}}\frac{N_R^{\downarrow}}{L^{\downarrow}}} + \sqrt{\frac{N_R^{\uparrow}}{L^{\uparrow}}\frac{N_L^{\downarrow}}{L^{\downarrow}}} \right], \tag{2}$$

which has the advantage that effects coming from left and right acceptances cancel in the ratio [3], leaving no dependence on χ_L or χ_R. It can be approximated to $A_N^{meas} \simeq A_{true}^{meas}\left(1 + \frac{1}{2}\varepsilon_P^2\right)$ with $\varepsilon_P = (P^{\uparrow} - P^{\downarrow})/(P^{\uparrow} + P^{\downarrow})$. The measured asymmetry is equal to the true asymmetry if the two polarizations $P^{\uparrow}$ and $P^{\downarrow}$ are the same, which is true to a very good approximation, since they differ at most by 0.4%.

For a perfect detector, with a full 2π coverage in the azimuthal angle ϕ around the beam direction between the electron scattering plane and the upwards pointing direction of the target spin vector, and assuming that any underlying 2-photon asymmetry will behave in the simplest possible way, namely a $sin\phi$ modulation which is also anticipated from the dependence $\vec{S}\cdot(\vec{k}\times\vec{k}')$, the expected measurement of a left-right asymmetry of amplitude $A^{\sin\phi}$ would lead to:

$$A_N^{2\pi} = \frac{\int_0^{\pi} d\phi\ \sigma_0\, A^{\sin\phi} sin(\phi)}{\int_0^{\pi} d\phi\ \sigma_0} = \frac{2}{\pi}A^{\sin\phi} = 0.64\, A^{\sin\phi}. \tag{3}$$

The HERMES detector is top-bottom symmetric [4], with a gap in the horizontal direction, and thus it does not cover the full 2π range in ϕ. In order to get an estimate of the *acceptance scaling-factor* because of this incomplete ϕ-coverage, an asymmetry was introduced in a Monte Carlo sample containing a full detector simulation and later

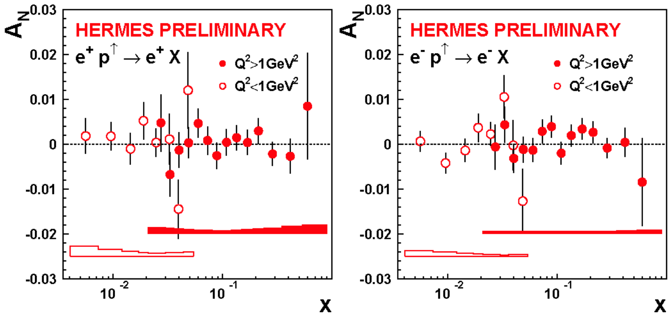

FIGURE 1. Normal asymmetry obtained from data taken with a positron beam (left) and with an electron beam (right). The open (closed) circles identify the data from $Q^2 < 1$ GeV^2 ($Q^2 > 1$ GeV^2).

extracted in the same way as done for real data. The ratio between the measured asymmetry A_N^{meas} and the input value $A^{\sin\phi}$ will be referred to as the acceptance scaling-factor χ: $A_N^{meas} = \chi A^{\sin\phi}$. The input amplitude $A^{\sin\phi}$ was varied between 0 and 0.5 and the stability of the resulting scaling factor was verified.

The final results for the measured asymmetries are shown in Figure 1 for positrons and electrons. In both cases the asymmetries are consistent with zero within uncertainties. The systematic bands include contributions from particle identification, trigger efficiencies, transverse magnet correction, target polarization and a Monte Carlo simulation used to estimate the effect of misalignment and beam curvature due to the transverse magnetic target field and beam shifts in position and angle. The acceptance factor χ is between 20% and 60% and is shown as a function of x in the middle panel of Figure 2. The results were not corrected for smearing and radiative effects, since at the moment there is no knowledge of the main background coming from the elastic 2-photon asymmetry. For this reason the estimated contribution coming from elastic events is shown as a panel in Figure 2. The overall asymmetries, obtained without binning in x and Q^2 but only separating the $0.004 < x < 0.9$ region into low and high Q^2, are shown in Table 1 together with statistical and systematic uncertainties. They are negligible within their uncertainties of the order of 10^{-3}. The average acceptance factors are 0.37 for the lower Q^2 region (58% of the value for full 2π acceptance) and 0.42 for the higher Q^2 region.

TABLE 1. Total asymmetry separated in the two Q^2 ranges under study.

beam	central $\times 10^{-3}$	stat $\times 10^{-3}$	total syst $\times 10^{-3}$
$Q^2 < 1$ GeV^2, $<x>= 0.02$, $<Q^2>= 0.6$ GeV^2			
e^+	1.28	1.47	1.35
e^-	1.35	1.29	0.73
$Q^2 > 1$ GeV^2, $<x>= 0.14$, $<Q^2>= 2.4$ GeV^2			
e^+	0.21	0.90	0.74
e^-	0.87	0.76	0.41

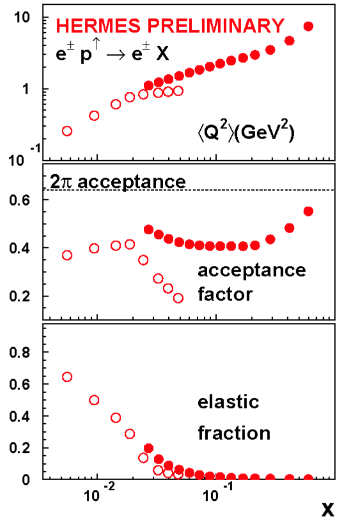

FIGURE 2. Top panel: Q^2 range of the data presented in Figure 1. Middle panel: acceptance factor under the assumption of a $\sin\phi$ asymmetry modulation. Bottom panel: percentage of elastic background events.

In conclusion, inclusive single spin asymmetries have been measured at HERMES on a transversely polarized proton target with the goal of searching for a signal coming from 2-photon exchange. No signal has been found within the uncertainties. At JLAB the proposed experiment JLAB-07-013 [5] will soon start taking data. Numerical estimates [6] for the kinematic range covered by this experiment result in expectations for the asymmetry of the order of 10^{-4}, the same order of magnitude of its anticipated precision.

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