Spin Asymmetries in Photoproduction of High-p_T Hadron Pairs

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Experimental results from HERMES are presented on the longitudinal spin asymmetry in photoproduction of pairs of oppositely charged hadrons with high momentum transfer p_T. For h^+h^- pairs with $p_T^{h_1} > 1.5$ GeV/c and $p_T^{h_2} > 1.0$ GeV/c, a negative spin asymmetry $A_{||} = -0.28 \pm 0.12$ (stat.) $\pm\, 0.02$ (syst.) is observed. Monte Carlo studies with the PYTHIA [1] event generator suggest that in the kinematical domain of the measurement, photon-gluon fusion (PGF) dominates over other underlying background subprocesses. Using this model, the measured asymmetry may be interpreted in terms of a positive gluon polarization in the nucleon.

1. PHYSICS MOTIVATION

Understanding how the spin of the nucleon is shared among its constituents is among the most urgent tasks in the current experimental agenda. Violation of the Ellis-Jaffe sum rule in polarized inclusive leptoprocesses measured at SLAC, SMC, and HERMES [2] clearly demonstrates our lack of knowledge about the spin decomposition of the nucleon. Within models assuming exact SU(3) symmetry, the quark spins have been found to account for only around 30% of the nucleon spin[3]. Possible interpretations of such a low value of quark polarization are based either on a large negative strange quark polarization, or on a large positive gluon polarization which lowers total quark contribution due to the axial anomaly term [4]. For completness it has to be mentioned that the unknown orbital angular momentum of partons inside the nucleon also contributes to the nucleon spin. Up to now the Q^2 evolution of polarized structure functions has provided only very weak constraints on the gluon polarization; even the sign of ΔG is not known. Experimental programs to access gluon polarization more directly through the detection of final state hadrons have been developed during recent years [5], [6], [7]. In this paper we present experimental results of photoproduction of two oppositely charged hadrons from polarized hydrogen data at HERMES.

2. EXPERIMENTAL DATA

The experiment was carried out at the HERA storage ring using a 27.5 GeV positron beam with an average polarization of (55±3.4)%, incident on a pure hydrogen target with a polarization of (86±4)%. In the HERMES spectrometer [8], particle identification is accomplished using an electromagnetic calorimeter, a scintillator hodoscope preceded by two radiation lengths of lead, a transition radiation detector, and a gas threshold C_4F_{10}/N_2(70:30) Čerenkov counter. The luminosity is measured in a pair of $NaBi(WO_4)_2$ electromagnetic calorimeters that detect Bhabha-scattering from target electrons.

The longitudinal cross section asymmetry $A_{||}$ was determined using the formula:

$$A_{\|} = \frac{N^{\uparrow\downarrow}L^{\uparrow\uparrow} - N^{\uparrow\uparrow}L^{\uparrow\downarrow}}{N^{\uparrow\downarrow}L_P^{\uparrow\uparrow} + N^{\uparrow\uparrow}L_P^{\uparrow\downarrow}}\,, \tag{1}$$

Here $N^{\uparrow\uparrow}(N^{\uparrow\downarrow})$ is the number of oppositely charged hadron pairs observed for target spin parallel (anti-parallel) to the beam spin orientation. The luminosities for each target spin state are $L^{\uparrow\uparrow(\uparrow\downarrow)}$ and $L_P^{\uparrow\uparrow(\uparrow\downarrow)}$, the latter being weighted by the product of the beam and target polarization values for each spin state.

Events were selected that contained at least two oppositely charged hadrons. The observation of the scattered positron was not required. The highest momentum hadrons of each charge were required to have a momentum above 4.5 GeV/c and a transverse momentum p_T above 0.5 GeV/c. Here p_T is defined as the momentum transverse to the positron beam direction. In order to suppress contributions from low lying prominent vector meson resonances, a cut on a minimum value of the two-hadron invariant mass (assuming both to be pions) $M(2\pi) > 1.0$ GeV/c^2 was imposed. In addition both hadrons were required to originate from a common vertex in the target.

In Fig.1, the measured value of $A_{||}$ is presented. In the top (bottom) panel the positive (negative) hadron was required to have a p_T greater than 1.5 GeV/c and the asymmetry $A_{||}$ is plotted as a function of the p_T of the hadron of opposite charge. Although the two measurements are statistically consistent, the data suggest a larger asymmetry when the transverse momentum of the negative hadron is larger than that of the positive hadron. Averaging over both measurements, a negative asymmetry $A_{||} = -0.28 \pm 0.12$ (stat.)$\pm$ 0.02 (syst.) is observed for $p_T^{h_1} > 1.5$ GeV/c and $p_T^{h_2} > 1.0$ GeV/c. This negative value is in contrast to the positive asymmetries typically measured in DIS from protons.

A possible background from misidentification of the scattered positron as a positive hadron in the kinematical range of this analysis was determined to be less than 0.1%. Contributions from high-p_T hadrons and muons from charm decay were found to be small from Monte Carlo studies.

The systematic uncertainty of the measured asymmetry coming from the beam and target polarization is about 6% of $A_{||}$. Resolution effects, alignment uncertainties, and radiative corrections were found to be negligible for the kinematics of this measurement.

The measured asymmetry was interpreted assuming that five different processes could contribute to the cross section: lowest order deep inelastic scattering, interaction via the hadronic structure of the photon – described by the vector meson dominance model (VMD) and by non-resonant hadronic "anomalous" photon structure, and two first order QCD processes which describe the interaction of a pointlike photon, called "direct" processes. These are photon gluon fusion (PGF) and the QCD Compton effect (QCDC).

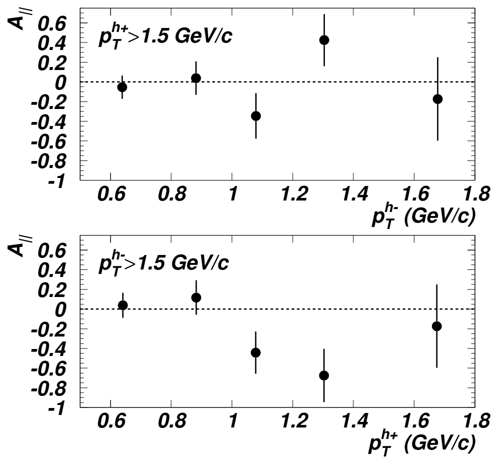

Figure 1. $A_{||}(p_T^{h^+}, p_T^{h^-})$ for $p_T^{h^+} > 1.5$ GeV/c (top) and for $p_T^{h^-} > 1.5$ GeV/c (bottom). Note that the rightmost data point is identical in both plots.

The contribution from lowest order DIS was confirmed to be negligible by a simulation based on the LEPTO Monte Carlo generator [9]. Contributions from other processes were estimated using the PYTHIA Monte Carlo generator. The minimum transverse momentum of the outgoing partons ($\hat{p}_T^{\min}$) was chosen following Ref. [10] to be $\hat{p}_T^{\min} = 0.5$ GeV/c. The contribution from VMD processes was found to be small in this model, and the contribution from "anomalous" photon structure at the CM energies of this experiment is assumed to be negligible [10].

Under the assumptions described above, only two of the five possible spin asymmetries A_i contribute significantly to the measured asymmetry:

$$A_{||} \approx (A_{\mathrm{PGF}} f_{\mathrm{PGF}} + A_{\mathrm{QCDC}} f_{\mathrm{QCDC}}) D \qquad (2)$$

where f_i is the unpolarized fraction of events from subprocess i, and D is the virtual photon depolarization factor. The subprocess asymmetries $\hat{a}_{\mathrm{PGF}} = \hat{a}(\gamma G \to q\bar{q})$ and $\hat{a}_{\mathrm{QCDC}} = \hat{a}(\gamma q \to qG)$

are directly calculable in LO QCD. For the photon gluon fusion process, $\hat{a}_{\mathrm{PGF}} = -1$ (exactly) for real photons and massless quarks, while for the QCD Compton effect, $\langle \hat{a}_{\mathrm{QCDC}} \rangle$ is roughly $+0.5$ (averaged over the kinematics selected by this analysis) and is independent of the quark flavor. The measured asymmetry can therefore be expressed as follows:

$$A_{||} \approx \left(\hat{a}_{\mathrm{PGF}} \frac{\Delta G}{G} f_{\mathrm{PGF}} + \hat{a}_{\mathrm{QCDC}} \frac{\Delta q}{q} f_{\mathrm{QCDC}} \right) D. (3)$$

This equation can be solved for $\Delta G/G$ after appropriate averaging over the selected kinematics.

A significant normalization difference is found between the measured yield and the simulation, although the dependences on the transverse momentum and other kinematic variables are reasonably well described.

In Fig.2, the measured $A_{||}$ (i.e. the average of the two panels of Fig.1) is compared with Monte Carlo predictions for different distributions of $\Delta G/G$. Since the measurements probed essentially the same range of $x_G = 0.06$-0.28 (yielding an average $\langle x_G \rangle = 0.17$), the results for $\Delta G/G$ were averaged. Using the PYTHIA model and the assumptions described above, a value for $\Delta G/G$ at the scale $\langle p_T^2 \rangle = 2.1$ (GeV/c)^2 was determined in LO QCD to be 0.41 ± 0.18 (stat.) ± 0.03 (syst.). The quoted systematic uncertainty represents the experimental systematic uncertainty only.

A large unknown theoretical uncertainty arises from the observed difference between the measured and simulated cross sections. At the kinematics of this measurement, no spin-dependent analyses of higher order QCD processes or contributions from anomalous photon structure are available; these processes have therefore been neglected in the model presented here. To alter the principal conclusion of this analysis, i.e., that $\langle \Delta G/G \rangle$ at $\langle x_G \rangle = 0.17$ is positive, a significant contribution from a neglected process with a large negative spin asymmetry would be needed.

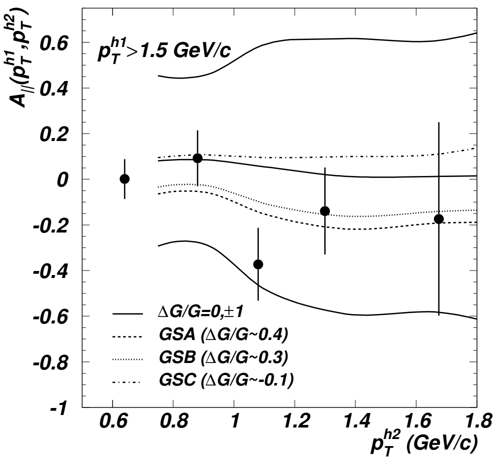

Figure 2. $A_{||}$ for high-p_T hadron pair production mesured at HERMES compared with with Monte Carlo predictions for ΔG/G $= \pm 1$ (lower/upper solid curves), ΔG/G $= 0$ (middle solid curve), and the phenomenological LO QCD fits of Ref. [11] (dashed, dotted, and dot-dashed curves).

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