Measuring the Gluon Helicity Difference Distribution Function of the Proton using Photoproduction Processes

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Abstract

Little information is known about the polarization of gluons inside a longitudinally polarized proton. I report on the sensitivity of photoproduction experiments to it. Both jet and heavy quark production are considered.

Introduction

Since the so-called EMC spin crisis has emerged,[1] much experimental and theoretical work has been done.[2] One remaining question is the size of the gluon helicity difference distribution function ($\Delta g$). In this contribution, the sensitivity to $\Delta g$ is studied in photoproduction experiments where both the photon and the proton are longitudinally polarized. The photoproduction of jets and heavy quarks is considered. As is well know, photoproduction processes receive contributions from two classes of subprocesses. In the first

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class, the photon interacts directly with the constituents of the proton (the “direct” contribution). In the second class, the photon interacts through its distribution functions (the “resolved” contribution). For the unpolarised distribution functions of the proton (photon), the set DO1.1 [5] (D0 [6]) is used. For the helicity difference distribution functions of the proton the three sets (set 1, 2, and 3) developed in Ref. 3 are used. At the initial $Q_0^2 = 4 \text{ GeV}^2$, the three sets have identical quark helicity difference distribution function, but different $\Delta g$, see Fig. 1. Clearly, the three sets can be used to study the sensitivity of an observable to $\Delta g$. The parametrization of Ref. 4 is used for the helicity difference distribution function of the photon.

**Two-jet production**

One observable sensitive to $\Delta g$ is the longitudinal asymmetry, defined as:

$$A_L = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}}. \quad (1)$$

where $\sigma^{++}$ ($\sigma^{+-}$) is the cross section for same (opposite) sign helicity of the photon and proton. The asymmetry for the direct contribution is presented in Table I, at $E_\gamma = 200 \text{ GeV}$ and $p_T(jet) \geq 3 \text{ GeV}$, for set 1 and 3 (smallest and largest $\Delta g$). $E_\gamma = 200 \text{ GeV}$ corresponds to the average value for $E_\gamma$ of present unpolarized experiments and $p_T(jet) = 3 \text{ GeV}$ is the lowest value at which jets have been observed in fixed target experiments[7]. Also shown in Table I are the asymmetries for the quark and gluon contributions corresponding to subprocesses involving a quark or a gluon inside the proton, respectively. The quark contribution gives a positive asymmetry and there is no difference between the two sets. The gluon contribution is negative and, as expected, the difference between the two sets is large, of the order of 85%. The cross

|       | quark | gluon | direct |
|-------|-------|-------|--------|
| set 1 | 25.   | -8.3  | 7.8    |
| set 3 | 25.   | -93.  | -36.   |

Table 1: Asymmetries (%) of the direct contribution for dijet production for set 1 and 3, $E_\gamma = 200 \text{ GeV}$, and $p_T(jet) \geq 3 \text{ GeV}$. 
Figure 1: Gluon helicity sum (solid) and helicity difference (dashes) distribution functions of the proton at $Q^2_0 = 4 \text{GeV}^2$ for set 1 (lower), 2 (middle) and 3 (upper).

| set 1 | diret | res  | total |
|-------|-------|------|-------|
|       | 7.8   | 2.7  | 5.3   |
| set 3 | -36.  | 17.  | -10.  |

Table 2: Asymmetries (%) for dijet production for set 1 and 3, $E_\gamma = 200 \text{GeV}$, and $p_T(jet) \geq 3 \text{GeV}$.

section of the quark and gluon contribution are about equal at this energy, such that the difference between the two sets for the direct contribution is about half of the difference for the gluon contribution, $\sim 40\%$. The total asymmetry is presented in Table 2, along with the asymmetry of the direct and resolved contribution. The difference between the two sets in the total asymmetry is only about 15\%. The problem stems from the fact that the gluon contribution is negative in the direct case and positive in the resolved case, such that the two contributions partially cancel each other. An obvious way to improve upon this is to separate the direct and resolved contributions, and then use the direct contribution to measure $\Delta g$, as it is the most sensitive contribution. The same techniques developed for the unpolarized case can be implemented to separate the direct and resolved contributions [8].

More detailed information can be obtained by looking at the longitudinal
asymmetry of the differential cross sections. In Fig. 2 the $x_p$-distribution of the direct contribution is presented as a representative example.

**Heavy Quark production**

As is well known, the resolved contribution for the photoproduction of heavy quarks for the energy range considered here is of the order of a few percent, and can be neglected. It turns out that the asymmetry is positive in some regions of phase space and negative in others [9]. Therefore, care must be taken when trying to evaluate the sensitivity of heavy quark production to $\Delta g$; it is bigger than suggested by the integrated asymmetry.

**Conclusions**

Considering the total asymmetry, one can show that two jet and heavy quark production have similar sensitivities to $\Delta g$. The best way to measure the gluon helicity difference distribution function is by using two jet production at low $p_T(jet)$, with separation of direct and resolved contribution, and then to use the direct contribution which has the biggest sensitivity.
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[9] see Fig. 8 in Ref. 3.
