MEASUREMENT OF THE GLUON POLARIZATION $\Delta G/G$ AT COMPASS

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One of the key objectives of the COMPASS experiment at CERN is the determination of the gluon contribution to the nucleon spin. The gluon polarization is measured via photon-gluon fusion in deep-inelastic scattering of 160 GeV/c polarized muons on a polarized ^{6}LiD solid-state target. Photon-gluon fusion is tagged by the observation of charmed mesons or the production of hadron pairs with large transverse momenta p_t. The status of the analysis of the D^0 and D^{0*} events and of the high-p_t hadron pairs is shown. The gluon polarization $\Delta G/G$ has been determined from the asymmetry of high-p_t hadron pairs with $Q^2 > 1$ (GeV/c)^2 in an analysis of the 2002/03 data as $\Delta G/G = 0.06 \pm 0.31(stat.) \pm 0.06(syst.)$.

1. Introduction

In an intuitive picture the spin of the nucleon is carried by its valence quarks. However, deep inelastic scattering (DIS) experiments (EMC, SMC, SLAC, HERMES) have shown that only a small fraction of the nucleon spin is carried by quarks. Since then, it has been one of the key questions in hadron physics, how the total spin of the nucleon $\hbar/2$ is composed. Candidates, which may contribute in addition to the quark spin $\Delta\Sigma$ are the helicity contribution of the gluon ΔG as well as the quark and gluon orbital angular momenta $L_{q,g}$:

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_{q,g} \tag{1}$$

One of the main goals of the COMPASS experiment[1] is a measurement of the helicity contribution ΔG of the gluon to the nucleon spin, via the photon-gluon fusion process. Photon-gluon fusion is tagged by the production of charmed mesons D^0 and D^{0*} or of hadron pairs with large transverse momenta p_t. In addition to the gluon polarization, the COMPASS experiment investigates a broad physics program[2] in polarized semi-inclusive deep inelastic scattering and hadron spectroscopy.

2. The COMPASS experiment

The COMPASS experiment uses a 160 GeV/c polarized muon beam of the CERN SPS scattering it off a polarized ^{6}LiD solid state target[3] at a high luminosity of about $4 \cdot 10^{32}$ cm^{-2}s^{-1}. From the counting rate difference in two oppositely polarized target cells, the photon-nucleon cross-section asymmetry $A^{\gamma^* d}$ can be determined:

$$A^{\gamma^* d} = \frac{\Delta\sigma^{\gamma^* d}}{\sigma^{\gamma^* d}} = \frac{1}{P_b P_t f D} \cdot \frac{N_1^{\leftrightarrows} - N_2^{\leftrightarrows}}{N_1^{\leftrightarrows} + N_2^{\leftrightarrows}}, \tag{2}$$

where the muon beam polarization is $P_b \approx 0.76$, the target polarization $P_t \approx 0.5$, and the fraction of polarized material in the target $f \approx 0.4$. The depolarization factor $D(y)$ of the virtual photon γ^* can be calculated as a function of the fractional energy transfer y.

The particles produced in the interaction are detected in a two-stage forward spectrometer with high momentum resolution, high rate capability and an excellent particle identification using hadronic and electromagnetic calorimeters and a large ring-imaging Čerenkov detector, which is able to identify kaons and pions from the charmed meson decay. A special quasi-real photo-production trigger allows to detect events with scattered muons down to $Q^2 = 10^{-4}$ (GeV/c)^2. Data have been taken from 2002 until 2004 so far.

3. Gluon polarization from open charm production

The "golden channel" to tag photon-gluon fusion events is the production of a $c\bar{c}$-quark pair, since the charm content of the nucleon is very small and the hard scale is set by the charm mass for this channel. One of the charm quarks fragments into a D^0 or a D^{0*} meson, which is detected in our experiment. The D^0 and D^{0*} mesons are reconstructed from their invariant mass in the decays $D^0 \to K^-\pi^+$ and $D^{0*} \to D^0 + \pi$ and the charge-conjugated decays (Fig. 1). The gluon polarization $\Delta G/G$ can then be determined from the experimental asymmetry in the open-charm production according to:

$$A^{\gamma^* d \to c\bar{c}} = \frac{\int d\hat{s} \Delta\sigma^{PGF}(\hat{s}) \Delta G(x_g, \hat{s})}{\int d\hat{s} \sigma^{PGF}(\hat{s}) G(x_g, \hat{s})} \approx \langle a_{LL} \rangle \frac{\Delta G}{G}, \tag{3}$$

where $\hat{s}$ is the invariant mass $m^2_{c\bar{c}}$ of the charm quark pair. The polarized photon-gluon cross section $\Delta\sigma^{PGF}$ has been calculated in NLO by two groups[4,5]. The analysis of the full 2002-2004 dataset is in progress, the projected statistical error on $\Delta G/G$ is 0.24.

4. Gluon polarization from hadron pairs with large p_t

Another approach to tag the photon-gluon fusion process is the detection of a hadron pair[6] with large transverse momenta p_t. The transverse momentum of each hadron relative to the virtual photon is required to be larger than 0.7 GeV/c and $(p_{t1}^2 + p_{t2}^2) > 2.5$ (GeV/c)^2. To ensure that the hadrons originate from the current fragmentation region cuts on $x_F > 0.1$ and $z > 0.1$ have been applied. Contributions from resonances are removed by a two hadron invariant mass cut $m(h_1h_2) > 1.5$ GeV/c^2. Requiring $Q^2 > 1$ (GeV/c)^2 suppresses a possible contribution from resolved photon processes, where the hadronic structure of the photon is probed, and requiring $x_{Bj} < 0.05$ selects a kinematic region, where the asymmetry from leading order DIS and QCD-Compton scattering is small. From the selected high-p_t sample of events in the 2002/2003 data we have measured:

$$A_{LL}^{\gamma^* d \to hhX} = -0.015 \pm 0.080(stat.) \pm 0.013(syst.) \tag{4}$$

The systematic uncertainty takes into account possible false asymmetries, the uncertainty in the measurement of the target and beam polarization and the knowledge of the depolarization D and dilution factor f. The gluon polarization is calculated from the asymmetry $A_{LL}^{\gamma^* d \to hhX}$ as:

$$A_{LL}^{\gamma^* d \to hhX} = \left\langle \frac{\hat{a}_{LL}^{PGF}}{D} \right\rangle \frac{\sigma^{PGF}}{\sigma^{tot}} \frac{\Delta G}{G}, \tag{5}$$

where $\hat{a}_{LL}^{PGF}$ is the analyzing power and $\sigma^{PGF}/\sigma^{tot}$ the fraction of photon-gluon fusion events. Background processes like QCD-Compton scattering and leading order DIS contribute only as a dilution to the measured signal: their asymmetry is proportional to $A_1^d(x)$, which is very small in the selected kinematic range $x_{Bj} < 0.05$. Their effect has been taken into account in the systematic uncertainty of the result. The analyzing power $\hat{a}_{LL}^{PGF} = -0.75 \pm 0.05(syst.)$ and the fraction $\sigma^{PGF}/\sigma^{tot} = 0.34 \pm 0.07(syst.)$ of photon-gluon fusion events were determined using a Monte-Carlo simulation (LEPTO) with a modified set of fragmentation parameters[7] and including radiative corrections (RADGEN). Our result for $\Delta G/G$ is (Fig. 1):

$$\Delta G/G = 0.06 \pm 0.31(stat.) \pm 0.06(syst.) \tag{6}$$

at a mean gluon momentum fraction $\langle x_g \rangle = 0.13 \pm 0.08$(RMS).

5. Outlook

The first COMPASS result on $\Delta G/G$ for high-p_t hadron pairs with $Q^2 > 1$ (GeV/c)^2 is shown in Fig.1 in comparison with other experiments[7,8].

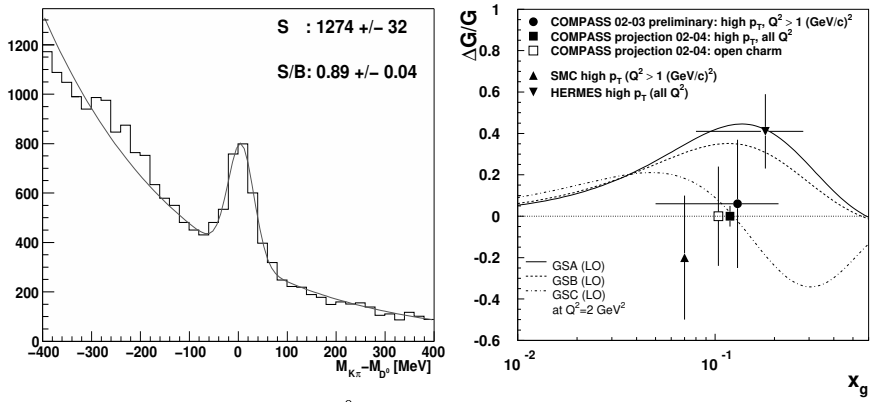

Figure 1. Left: Reconstructed D^0 in the $K\pi$ invariant mass spectrum tagged by their decay from D^* (2003 data). Right: COMPASS result for $\Delta G/G$ from high-p_t hadron pairs with $Q^2 > 1$ (GeV/c)^2 from 2002/03 data compared to SMC[7] ($Q^2 > 1$ $(GeV/c)^2$) and HERMES[8] (all Q^2) measurements. In addition, projections for the statistical accuracy in $\Delta G/G$ from open charm production and high-p_t hadron pairs for all Q^2 are shown for the full 2002-04 dataset. The curves show the parameterizations A - C of [9].

Including the 2004 run, the present data will be approximately doubled. There are about 10 times more events at $Q^2 < 1$ (GeV/c)^2. However, at low Q^2, a background of resolved photons enters as an additional theoretical uncertainty. The projected statistical accuracy on $\Delta G/G$ from open charm production and high-p_t hadron pairs for all Q^2 is shown in Fig.1. COMPASS will resume data taking in 2006 and will continue its physics program until at least 2010.

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