Direct Measurement of the Gluon Polarization from Open Charm Events at COMPASS

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The gluon polarization, $\Delta g/g$, in the nucleon was measured using COMPASS data taken between 2002 and 2006. The analysis relies on the search for open-charm events with the production of D-mesons in order to isolate photon-gluon fusion processes. This method is characterized by the absence of physical backgrounds, offering a very clean extraction of $\Delta g/g$. It is however statistically limited, that is why a weighted method was developed to minimize the statistical error. The preliminary result is : $\langle\frac{\Delta g}{g}\rangle = -0.49 \pm 0.27 \pm 0.11(\text{syst.})$.

1 Introduction

In 1988 the EMC Collaboration [2] reported a small contribution from the quark spins, $\Delta\Sigma$, to the nucleon spin, S_N. Recent measurements show that $\Delta\Sigma \simeq 30\%$, the remaining fraction being carried by the gluon spin, ΔG, as well as by the orbital angular momenta of quarks and gluons $L_{q,g}$:

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

Nowadays, efforts are made to measure the gluon helicity distribution $\Delta g(x)$ whose first moment is ΔG. With lepton beam experiments, a direct measurement can be performed by using photon-gluon fusion processes (PGF) where the virtual photon interacts with a gluon *via* a quark resulting in a quark/anti-quark pair in the final state. First results were obtained by the HERMES [3], SMC [4] and COMPASS [5] experiments which tagged such events by requiring hadrons with high transverse momenta. However, this anlysis method suffers from contributions of physical backgrounds that have to be evaluated. The COMPASS experiment aims at isolating PGF events in a different way which consists in restricting the search to the production of charm only. Neglecting the intrinsic charm content of the nucleon, this method ensures a selection with no background from other physical processes. The main limitation comes from the statistics which is reduced due to a small charm production cross-section. Therefore this analysis is based on a weighted approach in order to minimize the statistical error of the final result.

2 The $\Delta g/g$ Measurement at COMPASS

2.1 Asymmetry Measurement

Between 2002 and 2006, the CERN based COMPASS experiment took data from a longitudinally polarized muon beam scattered off a ^{6}LiD target which is divided into two cells with opposite polarizations. The goal of this setup is to measure a spin asymmetry, $A_{\mu N\rightarrow\mu c\bar{c}X}$, which is directly related to the gluon polarization through the analyzing power a_{LL}^{PGF} :

$$A_{\mu N\rightarrow\mu c\bar{c}X} = \frac{N^{\overset{\leftarrow}{\Rightarrow}} - N^{\overset{\leftarrow}{\Leftarrow}}}{N^{\overset{\leftarrow}{\Rightarrow}} + N^{\overset{\leftarrow}{\Leftarrow}}} = f P_{targ} P_{\mu} a_{LL}^{PGF} R_S \frac{\Delta g}{g} + A_{BG}.$$

The $\Delta g/g$ measurement is diluted by experimental factors such as the beam polarization P_μ, the target polarization P_{targ} and its dilution factor f. The PGF signal is accompanied by a combinatorial background which might be a source of an additionnal asymmetry, A_{BG}. Moreover the fraction of signal R_S has also to be taken into account. $N^{\overset{\leftarrow}{\Leftarrow}}$ and $N^{\overset{\leftarrow}{\Rightarrow}}$ are obtained by counting the number of events where the spins of the muon and the nucleon are parallel and anti-parallel.

2.2 The D-meson Reconstruction

More than half of the time, the charm quark hadronizes into a D^0 meson and the COMPASS experiment was designed to detect their $K\pi$ decay. The procedure consists in reconstructing the invariant mass of all combinations of two outgoing tracks with opposite charge. The D^0 signal should appear as a peak centered on the D^0 mass. At this stage the combinatorial background is high and masks the signal so it has to be reduced by applying cuts. The most effective selection comes from the particle identification provided by the RICH detector. A maximum likelihood method is used to test different mass hypotheses and to reject wrong combinations such as $\pi\pi$, $p\pi$ or KK. The selection is completed with kinematical cuts on z_D, the fraction of the photon energy carried by the meson, and $|\cos(\theta^*)|$ where θ^* is the angle between the D^0 flight direction and the kaon momentum in the D^0 rest frame. The actual cuts are : $z_D > 0.2$ and $|\cos(\theta^*)| < 0.65$.

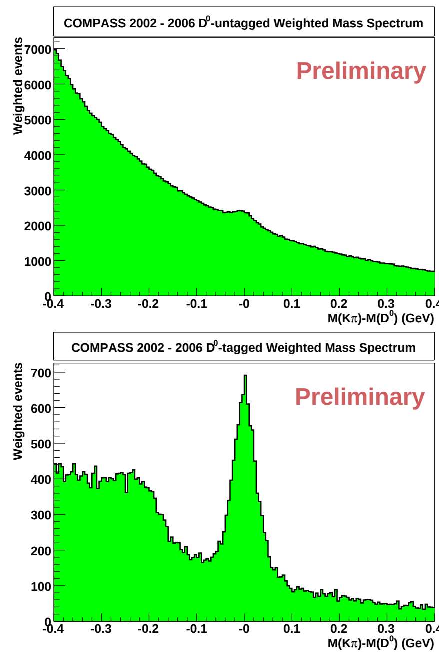

Figure 1: Invariant mass spectra for D^0 events (top) and for D^0 tagged by D^* events (bottom). Events are weighted by the parameterization of signal purity R_S.

To further reduce the background, a specific channel is studied where the D^0 comes from a D^* meson : $D^* \rightarrow D^0\pi$, where a low momentum pion is emitted. One can take advantage of the small mass difference between the D^* and the D^0 which offers a strict selection criterium : 3.2 MeV $< M(K\pi\pi) - M(K\pi) - m_\pi <$ 8.9 MeV. With the D^* tag, the kinematical cut on $|\cos(\theta^*)|$ can be relaxed : $|\cos(\theta^*)| < 0.9$. Moreover, due to its low momentum, the second pion sample is mostly contaminated by electrons so the RICH is used to suppress this false contribution. Figure 1 shows the resulting mass spectra for both channels where events are weighted by a parameterization of R_S (see later in Sec. 4). About 8,700 D^0 with a D^* tag and 37400 D^0 untagged are reconstructed and are analyzed separately.

3 A Weighted Extraction of $\Delta g/g$

Equation 1 is not statistically optimal since it uses each event regardless of its sensitivity to $\Delta g/g$. For example events with a large a_{LL}^{PGF} should prevail over events with a small a_{LL}^{PGF}. To take this into account, events are weighted according to their relevance to the measurement. It can be shown that the optimal weight w corresponds to the factors[a] in front of $\Delta g/g$ in Eq. 1 : $w = fP_\mu a_{LL}^{PGF} R_S$. The statistical gain is then given by the factor $1 + \frac{\sigma_w^2}{\langle w \rangle^2}$ showing that the error is reduced when the dispersion of the weights increases. To be applicable, this method requires the knowledge of the weight on an event-by-event basis. Experimental factors P_μ and f depend on measured kinematics so they are computable for each event. However, those factors have a rather low dispersion so their use in the weighting is quite limited. The situation is different for the analyzing power a_{LL}^{PGF} and the fraction of signal R_S. Indeed, the kinematical range of COMPASS allows for a wide range of a_{LL}^{PGF} values, from -0.5 to 0.8. Such a dispersion makes the weighting quite efficient. The fraction R_S can be interpreted as the probability for an event to be a signal event and again a large spectrum of values is possible, from 0 to 1. In this analysis, both quantities have been parameterized in terms of observables and the next section details how to obtain them.

4 Parameterizations of a_{LL}^{PGF} and R_S

Only one D^0 meson is requested, which does not allow to reconstruct the partonic kinematics of the hard subprocess $\mu g \to c\bar{c}$, required to compute exactly a_{LL}^{PGF}. However, a_{LL}^{PGF} can be parameterized in terms of measured kinematical variables using a neural network trained on events generated with AROMA, tuned with LO settings, and propagated through a GEANT simulation of the spectrometer. A correlation of 82% is obtained between the parametrized and generated a_{LL}^{PGF}.

In this analysis a parameterization of R_S was built taking into account the kinematics of the event, the RICH response and the invariant mass $M(K\pi)$. This information provides a large range of variation for R_S resulting in a gain in statistics. A second advantage of this method is that the selection cuts can be relaxed sparing some signal events. By doing that, a large amount of background events is introduced but these events are given a small value of R_S and therefore a low weight. A separate parameterization of R_S was built for each year of data taking and for the D^0 tagged and not tagged by D^*. The real data were used recursively by treating one variable at a time and the final parameterization was checked to make sure that no bias is introduced. The invariant mass spectra of Figure 1 are weighted by R_S to illustrate the effective signal used to compute $\Delta g/g$. The resulting gains in statistics are 15% and 45% for the D^0 tagged and not tagged sample, respectively.

[a]Time-dependant factors can introduce a bias if in the weight, that is why the target polarization is not included.

5 Results

The weighted extraction of $\Delta g/g$ from COMPASS open-charm events collected between 2002 and 2006 results in :

$$\langle \frac{\Delta g}{g} \rangle = -0.49 \pm 0.27(\text{stat.}) \pm 0.11(\text{syst.}),$$

corresponding to $x_g = 0.11^{+0.11}_{-0.05}$ and a scale $\mu^2 = 13$ GeV^2. The largest contributions to the systematic uncertainty come from the determination of a_{LL}^{PGF} and R_S. For the first one, it is given by the sensitivity to the charm mass which was chosen to be 1.5 GeV in AROMA, resulting in a 0.05 error. Due to the high background level, the parameterization of R_S, in the case where the D^0 is not tagged, leads to an uncertainty of 0.07 on $\Delta g/g$. No visible effect of false asymmetries due to detector inefficiencies and spectrometer instabilities was found, an upper limit was however set at the level of 0.05. In parallel to $\Delta g/g$, the background asymmetry was found to be compatible with zero for both channels.

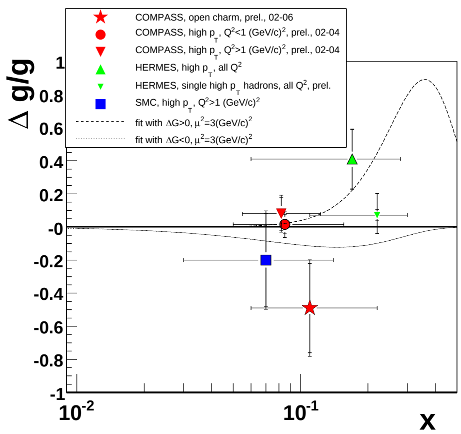

Figure 2: Comparison of $\Delta g/g$ measurements obtained from open-charm and high-p$_t$ analyses. The curves corresponds to parameterizations at 3 GeV^2 in the $\overline{\text{MS}}$ scheme obtained from [6]

6 Summary

The $\Delta g/g$ resulting from the open-charm analysis tends to favor negative values but is still less than two sigma away from zero. Figure 2 shows other results from analyses using the production of hadrons with high transverse momenta. The open-charm measurement offers an alternative method to extract $\Delta g/g$ which is much less model-dependent. For this analysis, large efforts have been made to optimize the limited statistics provided by the open-charm events. Some further improvements are however expected along with some new data taken in 2007.

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