Nucleon spin structure studies at COMPASS

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Abstract.
One of the main goal of the COMPASS experiment at CERN is the study of the spin structure of the nucleon in DIS, by scattering 160 GeV polarized muon beam on a longitudinally (or transversely) polarized ^{6}LiD target. Besides the scattered muon, the particles produced in the deep inelastic scattering are detected by a two stage magnetic spectrometer equipped with state of the art tracking and particle ID detectors.

The emphasis of COMPASS muon program is the direct determination of the gluon polarization $\Delta G/G$, accessed via asymmetries involving photon-gluon fusion mechanism (PGF). Both open charm production (detecting D^0's), as well as production of hight p_T hadron pairs are used to tag PGF. Preliminary results for $\Delta G/G$ based on the analysis of 2002 and 2003 data are shown. In addition, improved measurement of the deuteron structure function g_1^d at small x, as well as studies of transverse distribution functions in the deuteron by measuring Collins and Sivers azimuthal asymmetries, are reported.

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INTRODUCTION

The spin $1/2$ of the nucleon can be decomposed in the contributions from its constituents as:

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

where $\Delta\Sigma$ is the contribution from the quarks to the nucleon spin, ΔG the contribution from the gluons (which have spin 1), and L_{q+g} the contribution from orbital angular momentum of quarks and gluons.

The origin of the spin of the nucleon is a subject that draws great interest since 1988, when the EMC experiment found that only a small fraction of the nucleon spin seems carried by the quarks[1] ($\Delta\Sigma = 12 \pm 9 \pm 14\%$). This lead to the so called "spin-crisis", because it is in contrast with the naive quark-parton model, which predicts that 60% of the nucleon spin should come from the contribution of the valence quarks. This result has been confirmed since by a series of deep inelastic scattering (DIS) experiments at CERN[2], SLAC[3] and DESY[4], giving on average $\Delta\Sigma$ = 20 to 30%.

The remaining contributions to the nucleon spin must then come from the gluons spin ΔG, and(or) from quark and gluon orbital angular momenta. The direct measurement of the gluon polarization $\Delta G/G$ is presently the main focus of the COMPASS muon program.

THE EXPERIMENT

COMPASS is a fixed target experiment [5] located at the muon beam line of the CERN SPS, at the exact place of the previous SMC experiment[2]. Data have been collected in 2002, 2003 and 2004, and a muon run is also planned in 2006. Details of the experimental setup can be found in [6, 7], and I only indicate the major factors of improvements with respect to SMC:

- the muon luminosity is about 5 times larger
- a new ^6LiD target polarized up to 50%, with a packing factor of about .4, improving the factor of merit for measuring small asymmetries
- the trigger range in Q^2 has been extended down to quasi-real photo-production to be able to accumulate enough statistics for the very low cross section PGF events
- the vertical acceptance of the two stage spectrometer has been increased to ± 180 mrad, to be able to have full coverage of semi-inclusive DIS events
- new particle ID detectors , among which a RICH detector, and highly segmented and high flux capable tracking detectors to separate charm events from combinatorial backgrounds

POLARIZED DISTRIBUTION FUNCTIONS

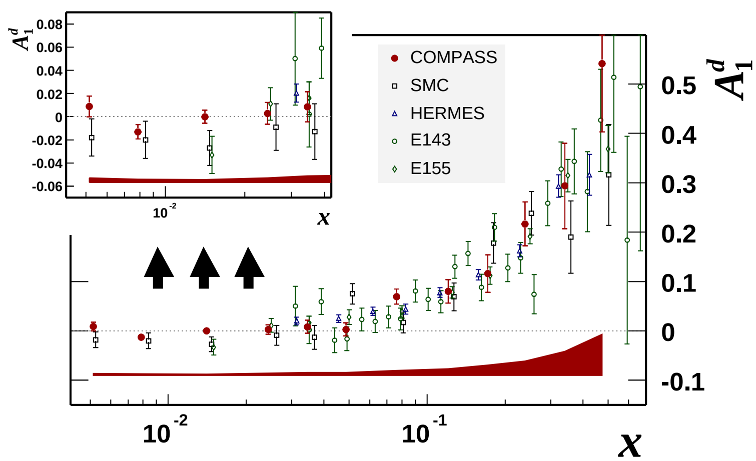

FIGURE 1. The virtual-photon deuteron asymmetry $A_1^d \approx g_1/F_1$ measured by COMPASS. The error bars represent the statistical error and the band the systematic error.

Thanks to the larger luminosity, and extended coverage of the trigger system, we were able to improve the measurement of the polarized asymmetry A_d^1 [8] for inclusive DIS (fig. 1), and hence the structure function g_d^1, in the low x range down to x=0.004.

Incorporating these data in a global QCD fit to world data on polarized DIS asymmetries [1, 2, 3, 4, 9, 10] helps to decrease the statistical error on the contribution from the quarks to the nucleon spin [11]: $\Delta\Sigma = 0.237 \pm 0.025$. This is easily understood by the fact that $\Delta\Sigma$ is derived from the moments of the distribution functions, where the low x data have non negligible weight.

These global QCD fits to the polarized asymmetries, in which DGLAP evolution equations are solved via numerical integration at NLO, allow an indirect determination of the helicity Parton Distribution Functions (PDF) of the quarks and gluons in the nucleon[12, 13, 14]. Although they fix quite well the polarized valence quark distributions, they only poorly constrain the polarized sea quark and gluon distributions, due to the limited accuracy and range in (x,Q^2) of the world data. This situation of course improves over time, with the inclusion of recent precise data from Jlab[9], Hermes[10] and our above cited result on A_d^1. But the obtained x dependence of the gluon distribution will always follow the functional form used in the fit, and remain the main systematic uncertainty of these fits.

GLUON POLARIZATION

Hence, a direct measurement of the polarized gluon distribution functions in semi-inclusive DIS is of crucial importance. This is the main goal of COMPASS muon program, where the gluon polarization $\Delta G/G$ is obtained by measuring the helicity asymmetry of the photon-gluon fusion (PGF) cross-section ($\gamma^* g \rightarrow q\overline{q}$). The fraction of PGF events in the data sample can be enhanced by selecting either open charm events or hadron pairs with high transverse momentum.

The cleanest tagging is provided by requiring the $q\,\overline{\ }q$ pair to be a $c\,\overline{\ }c$ pair, since the presence of c quarks inside the nucleon is negligible. The large mass of the c quark also sets a hard scale to ensure factorization of the “hard” PGF amplitude and the “soft” gluon distribution. The c quark is identified in the form of a D^0 meson which decays to $K\pi$. Due to multiple scattering inside the thick polarized target, the D^0 decay vertex cannot be distinguished from the primary vertex and the D^0 peak sits above a large combinatorial background. This background can be reduced by selecting D^0 coming from the decay $D^* \rightarrow D^0 \pi_s$. Due to the background and the small cross section, this channel is statistically limited. Using 2002 and 2003 data, we get[15]: $\Delta G/G = -1.08 \pm 0.73(stat)$.

An alternative tagging of PGF is obtained by requiring a pair of hadrons with large p_t. The hard scale is set by the condition $\Sigma(p_T^2) > 2.5 GeV^2$. The measured asymmetry can be written as $A_{\|} = R_{PGF}\, a_{LL}^{PGF}(\Delta G/G) + A_{bckg}$. Here R_{PGF} is the fraction of PGF events in the sample; a_{LL}^{PGF} is the analyzing power, i.e. the spin asymmetry of the PGF process which can be computed in perturbative QCD. A_{bckg} is the asymmetry of the physics background. It includes the QCD Compton process, $\gamma^* q \rightarrow qg$, and at low Q^2 the resolved photon processes where the photon fluctuates to a hadronic state and one of the partons from the photon interacts with one of the partons from the nucleon.

From the 2002 and 2003 data sample at $Q^2 < 1$ GeV^2 and using Pythia to estimate R_{PGF} and A_{bckg}, we obtain [16] :

$$\frac{\Delta G}{G}(x = 0.10) = 0.024 \pm 0.089(stat) \pm 0.057(syst). \tag{2}$$

At $Q^2 > 1$, the background is easier do deal with, but much less statistics is avalaible, and we obtain:

$$\frac{\Delta G}{G}(x = 0.13) = 0.01 \pm 0.31(stat) \pm 0.06(syst). \tag{3}$$

The high p_T results are presented in fig. 2, together with earlier measurements[17, 18].

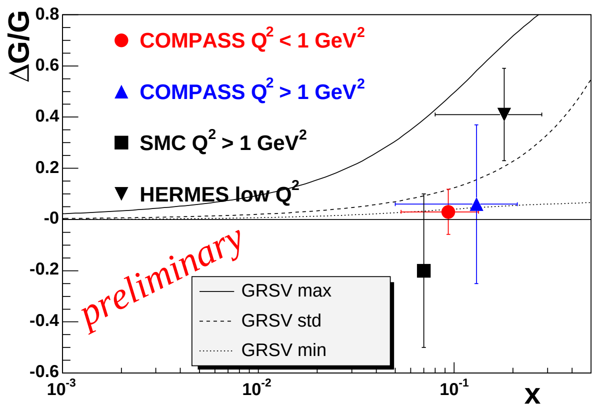

FIGURE 2. Various measurements of $\Delta G/G$ from high p_T events compared to three parametrisations from GRSV[12] corresponding to integrals $\Delta G = \int_0^1 \Delta G(x)dx$ =0.2, 0.6 and 2.5.

TRANSVERSE DISTRIBUTIONS

To completely describe the quark state of the nucleon at twist-two level, three distribution functions are neccessary: the momentum distribution of the partons $q(x)$, the helicity distribution $\Delta q(x)$ and the transverse spin distribution $\Delta_T q(x)$[19].

The transverse distribution $\Delta_T q(x)$ are difficult to measure, as they are chirally-odd and therefore absent in inclusive DIS. They can be accessed by measuring the single spin asymmetries (SSA) in semi-incusive DIS on transversely polarised nucleons, in which a hadron is detected in the final state.

Two kinds of polarized fragmentation have been used so far. The Collins fragmentation function tells how much the transverse spin of the fragmenting quark is reflected in the azimuthal distribution of the produced hadrons. It results in an azimuthal asymmetry in terms of the Collins angle, $\phi_{col} = \phi_h + \phi_s - \pi$, where ϕ_h is the azimuthal angle of the produced hadron and ϕ_s that of the target spin. An azimuthal asymmetry in terms of the Sivers angle, $\phi_{siv} = \phi_h - \phi_s$, is also possible. It is related to the quark momentum distribution in the plane transverse to the nucleon momentum. Our Collins and Sivers azimuthal asymmetries obtained on deuterium from 2002 data are reported in [20]. They are compatible with zero within the statistical error bars, in contrast to recent Hermes results on the proton[21]. This may indicate a possible cancellation between proton and neutron asymmetries.

The so-called interference fragmentation function is due to some interference effects in the production of two hadrons. It results in an azimuthal distribution in terms of the angle $\phi_{RS} = \phi_R + \phi_s - \pi$. The complete description of asymmetries, angles, and the asymmetry $A_{\phi_{RS}}$ obtained from 2002 and 2003 data as a function of the two hadron mass is discussed in ref.[22]. Again, it is compatible with zero within error bars.

CONCLUSION

COMPASS has collected from 2002 to 2004 new and precise informations about the spin structure of the nucleon[8, 16, 20, 22].

The most important result concerns the direct measurement of the gluon polarization. Our most precise result from events with high p_t hadrons at $Q^2 < 1$ GeV^2 clearly rules out values of $\Delta G > 1$, but is not yet precise enough to solve the “spin crisis”. The situation will improve by adding 2004 data (as much as 2002 and 2003 combined), and forthcoming 2006 run with improved factor of merit, thanks mainly to improvements in target solid angle and RICH performance. Also, precise direct measurements from polarized p-p collisions will show up soon from RHIC[23].

A complemenatry approach to the “spin crisis” is planned to be addressed after 2010 at COMPASS by the study of generalized parton distributions, from which some information about the angular momentum of the quarks can be extracted.

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