Nucleon Longitudinal Spin Structure- Experimental overview

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Abstract. We review here the results on the gluon and quark helicities obtained by HERMES, COMPASS, PHENIX and STAR. In the last section we give a brief outlook on future projects.

Keywords: Spin of the Nucleon; gluon and quark helicity, transversity, polarization
PACS: 13.88.+e

INTRODUCTION

One of the main goals of the current experiments studying nucleon spin structure is to determine how the total longitudinal spin projection of the nucleon, 1/2, is distributed among its constituents: quarks, gluons and orbital angular momentum. This is summarized in the equation $1/2 = (1/2)\Delta\Sigma+\Delta G+L_z$, where $\Delta\Sigma$ is the contribution of the spin of all quarks and antiquarks. Old estimations from the naive quark parton model as well as from a QCD approach neglecting strange quark polarization, have predicted a large polarization of the quarks $\Delta\Sigma=0.6$. When EMC first measured a value of $\Delta\Sigma$ compatible with zero in 1987, this led to the nucleon "spin crisis". Extensive measurements during the last decades have shown that the singlet axial matrix element a_0, which is related to $\Delta\Sigma$, is small, of the order of 0.3, but not zero. In some QCD schemes, $a_0 = \Delta\Sigma-(3\alpha_s/2\pi)\Delta G$. Thus a very large value of ΔG, several times the value of the nucleon spin, had been advocated to restore $\Delta\Sigma = 0.6$ when $a_0=0.3$. Today, first results from lattice QCD indicate in the contrary that the valence quark contributions to the nucleon spin could add up to a lower value of $\Delta\Sigma$ (u and d only) compatible with the latest measurements (0.3). They also indicate sizable quark contributions $L_z(u)$ and $L_z(d)$ to the angular momentum L_z however opposite thus canceling in L_z. Not much is known theoretically on ΔG, and in the last 15 years a large experimental effort has been undertaken for its measurement by various collaborations: HERMES at DESY, COMPASS at CERN, STAR and PHENIX at RHIC.

GLUON POLARIZATION

The gluon polarization can be determined by three different methods: (i) in polarized lepton nucleon SIDIS reactions, (ii) in polarized pp hard collisions, by choosing channels sensitive to the gluon distribution and measuring spin asymmetry

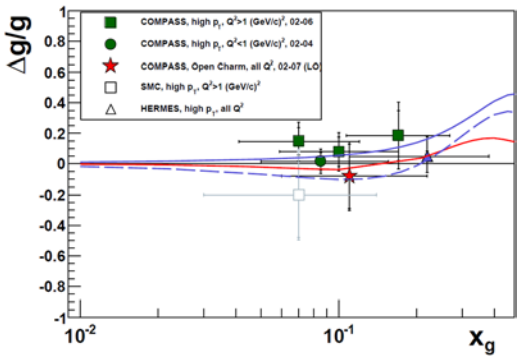

FIGURE 1. World direct measurements of the gluon polarization $\Delta g/g(x)$: COMPASS (4 green points from high p_T hadron pairs and red star from open charm channel), HERMES and SMC. All points are extracted at leading order (LO) in QCD. The curves are DSSV (lower red line) [4] and LSS (dashed and upper blue lines) [5] QCD fits at LO not including the data.

of cross-sections, or (iii) through global QCD fits of polarized inclusive DIS data.

(i) By using polarized lepton beams, 27 GeV e^- at HERMES or 160 GeV μ at COMPASS, scattered on polarized nucleons, direct measurements of $\Delta G/G$ are performed via a double spin asymmetry of cross sections for the photon gluon fusion (PGF) process $gg \rightarrow qq$. PGF events are searched for in two channels: the "open charm channel" where a cc pair is produced and a c quark is identified via the production of a D^0 meson, and the "high p_T hadron" channel, where outgoing lighter quarks hadronize into pions, with high transverse momentum p_T . The open charm channel is only accessible at COMPASS thanks to the high energy of the CERN polarized muon beam. It provides a clean signature of the PGF but is a difficult channel requiring to count events with D^0 production over a large combinatorial background of πK pairs, leading to limited statistics. On the contrary, the high p_T channel, used at both COMPASS and HERMES, benefits from high statistics but suffers from competing background processes which have to be simulated and accounted for. Fig.1 shows all existing direct measurements of the gluon polarization $\Delta G/G(x)$ extracted at leading order (LO) in QCD from the measured spin asymmetries. COMPASS results [1] from the open charm (star) and high p_T (closed squares and circle) channels are shown together with HERMES (triangle)[2] and SMC (open square) results. The measurements probe x_g values of the gluon momentum fraction around 0.1 and give results compatible with zero. The curves show parametrizations from QCD analyses which do not include these data and which are discussed later.

(ii) The other experimental studies of the gluon polarization are performed at the RHIC collider[3]. Collisions of protons polarized longitudinally in opposite directions have been realized mainly at $s^{1/2}$ = 200 GeV, but also at 62 GeV and more recently 500 GeV, covering various kinematical ranges. Several channels are used to pin down the gluon polarization. The most abundant channels in term of statistics are the production of π^0 at PHENIX and of single jets at STAR) [6].

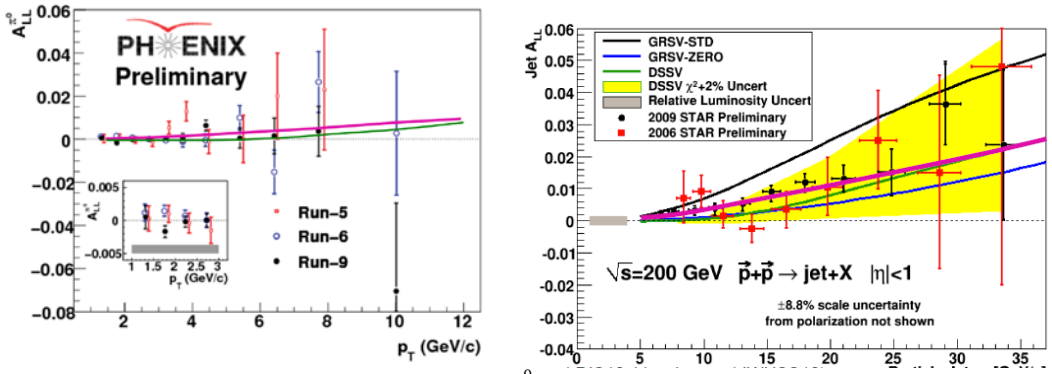

FIGURE 2. Double spin asymmetry $A_{LL}(p_T)$ for π^0 production at PHENIX *(left)* and for single jet production at STAR *(right)* [3] including run 9 data. New 'DSSV+' fit (in fuschia) give the value of the integral $\Delta G = +0.10$ in the restricted interval $0.05 < x_g < 0.2$.

In both cases, three different elementary processes (gg, gq and qq) contribute to the cross-section, so that the measured double spin asymmetries A_{LL} are sensitive to a combination of three quantities: $\Delta G(x_1).\Delta G(x_2)$, $\Delta G(x_1).\Delta q(x_2)$ and $\Delta q(x_1).\Delta q(x_2)$, where x_1 and x_2 are the fractions of momentum carried by the two colliding partons. For each channel (π^0, jets, etc.) the measured double spin asymmetry A_{LL} (p_T) is compared to calculations where a given parametrization of $\Delta G(x)$ is assumed. The results [3,6] are presented in Fig.2 *left* for the π^0 channel and in Fig.2 *right* for the single jet channels The data provide a strong constrain on the mean value of ΔG in the measured range $0.05 < xg < 0.2$. The new DSSV fit, including these latest data from RHIC run 9, give $\Delta G = +0.10$ in the interval $0.05<x<0.2$. Data taken at higher energy (500 GeV), not yet included here, will constrain a lower x_g region.

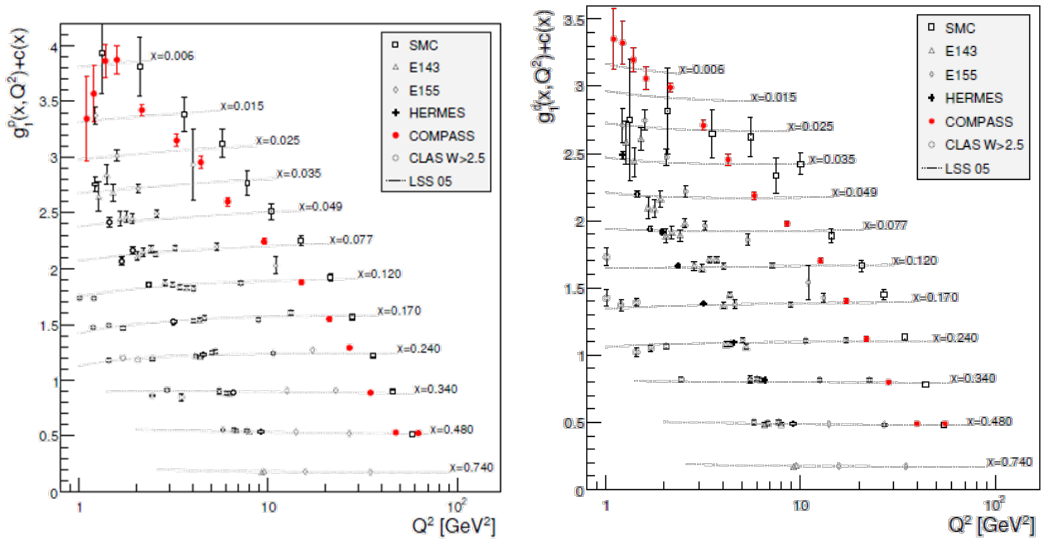

FIGURE 3. World data on longitudinal spin structure function g1: proton (left) and deuteron (right)

(iii) The third way to determine -indirectly- the gluon contribution to the nucleon spin is to perform a global fit of polarized data, making use of the QCD Q^2 evolution

equations which correlate g_1 and ΔG. Data on the longitudinal spin structure function g_1 exist for the proton, deuteron and neutron (^{3}He). They cover three decades in x and three in Q^2 (Fig.3). This is not sufficient to constrain severely enough $\Delta G(x,Q^2)$, however first results from global fits exist. To further constrain the fit, polarized pp data can be added [4]. As a result the polarized gluon distribution is severely constrained in the range $0.05 < x_g < 0.2$, as explained above. For the future, precise g_1 data taken at COMPASS at 200 GeV incident muon energy will improve the quality of data at low x values.

QUARK HELICITIES

In parallel to the polarized inclusive DIS measurements, semi inclusive (SIDIS) events where an additional hadron tags the flavor of the struck quark, were recorded both at HERMES and COMPASS. The data from this reaction, $\mu\, p \rightarrow \mu h X$, are used to extract at LO the helicity quark distributions for each quark flavor separately down to x = 0.004. This provides a broader picture of the nucleon spin, however requiring an additional input, the quark fragmentation functions (FF). COMPASS results [7] obtained using FFs from DSS [9] are shown in Fig.4 together with HERMES results[8] where FFs are extracted from the same HERMES data. The curve shows the global QCD fit of DSSV [4] at LO. Sea quark polarized distributions are found to be compatible with zero within the statistical errors. Concerning the strange quarks, note that the DSSV fit accommodates both the SIDIS data (COMPASS and HERMES data, shown here and compatible with zero), and the results from analyses of inclusive DIS

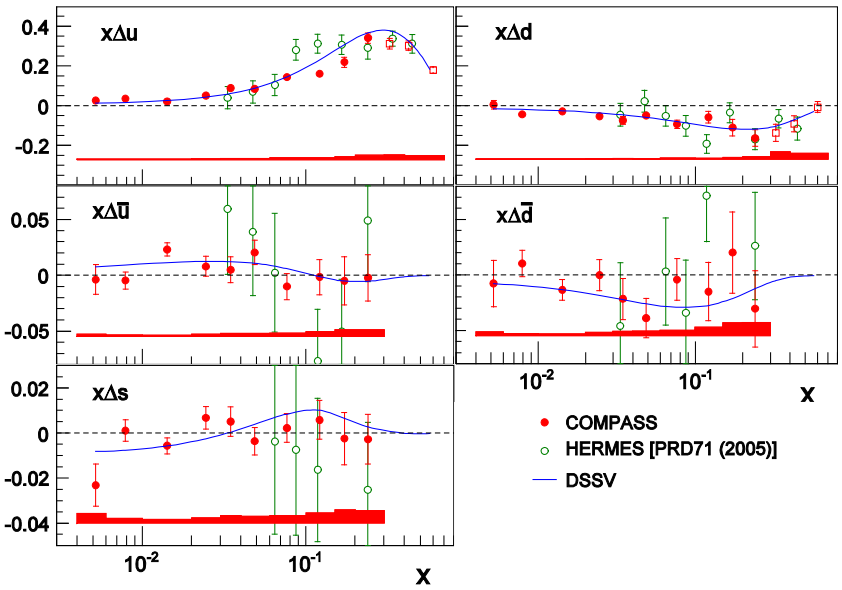

FIGURE 4. COMPASS (closed red points) and HERMES (open green points) results for the helicity quark distribution $x\Delta q(x)$ for five flavors compared to the global fit at NLO from DSSV[4].

data, which lead to a negative first moment for Δs (suggesting a negative contribution at low x). In the future, the SIDIS sector will benefit from more precise determination of quark FFs. At RHIC, in a short exploratory run, first collisions at 500 GeV were performed. By studying the parity violating reaction u d-bar $\rightarrow W^+ \rightarrow e^+ \nu$ the quantity Δd-bar/d-bar $-$ Δu/u is probed (similarly Δu-bar/u-bar $-$ Δd/d via W^-). First results from PHENIX and STAR reporting asymmetries with signs as expected from SIDIS results, are very encouraging [10]. The advantage of this channel is that no FF are needed for the extraction of quark helicities.

OUTLOOK

After the current program, RHIC prepares upgrades both on the accelerator and on the detectors. On the machine side, higher polarization (0.65 instead of 0.50) and higher luminosity (3. $10^{31}cm^{-1}s^{-1}$, *i.e.* three times higher than today) are foreseen for 2014. STAR and PHENIX upgrades [11] should be completed already by 2012 for the measurement of helicity distributions in polarized W production and the measurement of the gluon polarization at lower x from di-jets and di-hadrons. At COMPASS, from 2014 onwards, two new sectors will be studied: the transverse imaging of the nucleon with the measurement of Generalized Parton Distributions (GPDs) via exclusive processes [12], and the Transverse Momentun Dependent (TMD) distributions via polarized Drell-Yan reactions. In parallel to the GPD program, high statistics on SIDIS reactions μ p$\rightarrow$ μ' h will be recorded both to access several TMDs and to perform a full mapping of pion and kaon multiplicities which will serve as input to global QCD analyses of quark FF on one side and on PDFs on the other one. Future projects, described in dedicated contributions to this conference, like JLab-12 GeV and the long term project of an electron ion collider EIC or ENC, will contribute to the common effort to study nucleon spin, opening new kinematical ranges.

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