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Nuclear Physics B Proceedings Supplement

Nuclear Physics B Proceedings Supplement 00 (2011) 1–4

Longitudinal spin physics results from COMPASS

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Abstract

The COMPASS experiment at the CERN SPS has a broad physics program focused on the nucleon spin structure and hadron spectroscopy, using muon and hadron beams, respectively. Results from the COMPASS on the inclusive longitudinal double spin asymmetries $A_1^{d,p}$ measured in deep-inelastic polarized muon scattering off the polarized ^6LiD and NH_3 targets are presented. The new proton data cover the range $Q^2 > 1(\,\mathrm{GeV}^2/c)$, $0.004 < x < 0.7$ and improve the statistical precision of $g_1^p(x)$ by factor of two at $x < 0.02$ compared to previous measurements. The spin-dependent non-singlet function $g_1^{NS}(x, Q^2)$ extracted from the data allows to evaluate the isovector quark density $\Delta q_3(x, Q^2)$ and check the Bjorken sum rule prediction. The helicity distributions for the three lightest quark and antiquark flavours extracted from the measured double spin asymmetries for production of charged pions and kaons in semi-inclusive deep-inelastic scattering are also presented and discussed. The gluon polarization in the nucleon was determined using open charm production or high transverse-momentum hadron pairs production in polarized muon scattering off longitudinally polarized target.

Keywords: Inelastic muon scattering, spin, asymmetry, parton distribution function, gluon polarization

1. Introduction

COMPASS is an experiment at CERN aimed at the study of the spin structure of the nucleon and on the hadron spectroscopy [1]. This talk is dedicated to the results obtained by the COMPASS collaboration with polarized μ^+ beam of 160 GeV/c and longitudinally polarized deuteron and proton targets to study the gluon polarization and the polarized parton distribution functions (PDF) of the nucleon.

In 2002-2006 ^6LiD polarized target were used to measure spin-dependent asymmetry for the deuteron. In 2006 the spectrometer was upgrated. In particular, a new target solenoid was installed, which resulted in an increase of angular acceptance from 70 to 180 mrad. To reduce the systematic errors due to the different spectrometer acceptance for the upstream and downstream target cells, a 3-cells target configuration was installed. Also an improvement of the RICH photon detectors was performed. In 2007 data taking continued with an ammonia NH_3 polarized target to study polarized deep inelastic scattering (DIS) on the proton target.

The European Muon Collaboration (EMC) at CERN published in 1988 the result interpreted that the quarks are carrying only a small fraction of the nucleon spin, contrary to the naive quark-parton model expectation. This results has been confirmed by different experiments at CERN, DESY, SLAC and J-LAB. The contribution of the quarks to the spin of the nucleon is now well established to be about 30%. The nucleon spin can be decomposed as

$$S_z = \frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_z, \tag{1}$$

where $\Delta\Sigma$ and ΔG are the quarks and gluons helicity contributions and L_z is the contribution of their orbital angular momenta.

The purpose of the COMPASS experiment with longitu-

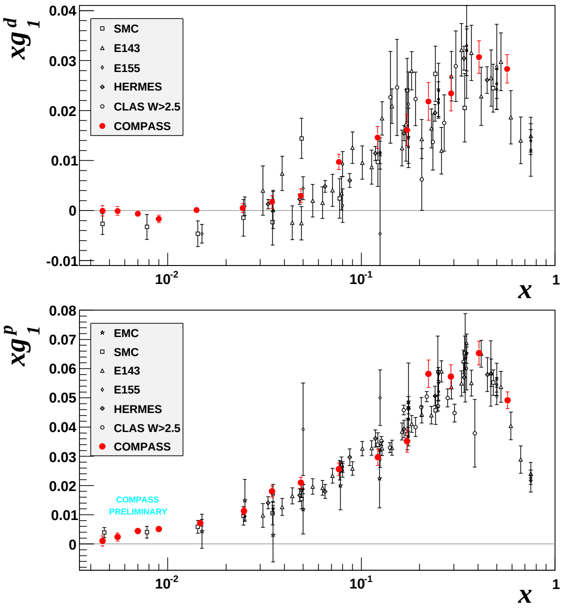

Figure 1: The spin dependent structure functions $g_1^{d(p)}$ obtained from COMPASS data 2002-2007 and the world data. For comparison all points have been evolved to $Q^2 = 3\,(\mathrm{GeV}/c^2)$.

dinally polarized targets is to get the value of $\Delta\Sigma$, measure of the gluon polarization, make a test of the Bjorken sum rule and extract helicity distributions for quarks and antiquarks of different flavors Δq.

2. COMPASS inclusive measurements

COMPASS results on the inclusive longitudinal spin dependent asymmetries A_1^d and A_1^p cover kinematical range $0.004 < x < 0.7$ and $Q^2 > 1(\mathrm{GeV}/c)^2$ [2, 3]. The longitudinal spin dependent structure functions $g_1^{p,d}$ can be obtained from asymmetries $A_1^{p,d}$ by the relation

$$g_1 = \frac{F_2}{2x(1+R)} A_1, \tag{2}$$

where F_2 is the spin independent structure function [5] and $R = \sigma_L/\sigma_T$ [6]. COMPASS results on g_1 are presented in Fig.1 in comparison with world data. All data are in a good agreement and COMPASS improves the statistical precision of the measurement in the low x region ($x < 0.01$) by factor of 2-3 compared to previous measurements.

COMPASS measurements with the deuteron target provide an accurate evaluation of the first moment of g_1 for the average nucleon N in an isoscalar target $g^N = (g_1^p + g_1^n)/2$ from which, assuming $SU(3)$ flavor symmetry, the first moment of the strange quark and antiquark distributions can be extracted if the value of the octet matrix element $a_8 = 3F - D$ is taken from the semi-leptonic hyperon decay. At NLO of QCD the strange quark polarization of the nucleon was found $(\Delta s + \Delta\bar{s})_{Q^2\to\infty} = -0.08 \pm 0.01(stat.) \pm 0.02(syst.)$[3]. The first moment of g_1^d(x) has also provided the value for the matrix element of the flavor singlet axial current $a_0 \equiv \Delta\Sigma = 0.33 \pm 0.03(stat.) \pm 0.05(syst.)$ at $Q^2 = 3\,(\mathrm{GeV}/c^2)$.

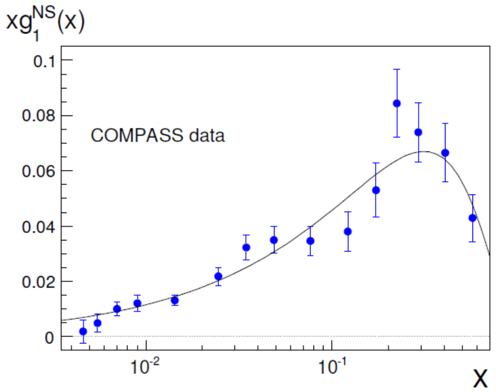

Figure 2: Values of $g_1^{NS}(x)$ at $Q^2 = 3(\mathrm{GeV}/c)^2$, derived from the COMPASS measurements of A_1^p and A_1^d and result of the three parameter QCD fit at NLO. The error are statistical only.

Having measured A_1^p and A_1^d COMPASS can construct so called non-singlet spin-dependent structure function $g_1^{NS}(x, Q^2) = g_1^p(x, Q^2) - g_1^n(x, Q^2)$ which is of special interest because its Q^2 dependence is decoupled from the singlet quark and gluon spin densities

$$g_1^{NS}(x, Q^2) = \frac{1}{6}\int_x^1 \frac{dx'}{x'} C^{NS}\left(\frac{x}{x'}, \alpha_s(Q^2)\right) \Delta q_3(x', Q^2), \tag{3}$$

where C^{NS} is a Wilson coefficient function and $\Delta q_3 = (\Delta u + \Delta\bar{u}) - (\Delta d + \Delta\bar{d})$ the isovector spin density. According to the Bjorken sum rule the integral of g_1^{NS} at any fixed Q^2 is proportional to the ratio g_A/g_V of the axial and vector coupling constants and given by the relation

$$\Gamma_1^{NS}(Q^2) = \frac{1}{6}\left|\frac{g_A}{g_V}\right| C_1^{NS}(Q^2), \tag{4}$$

where the coefficient $C_1^{NS}(Q^2)$ can be calculated in perturbative QCD up to 3d order in α_s [7]. The comparison of the value $|g_A/g_V| = 1.2694 \pm 0.0028$ [8] obtained from neutron β decay thus provides the clean test of the Bjorken sum rule. The value of g_1^{NS} (see Fig.2) were obtained as

$$g_1^{NS}(x,Q^2) = 2\left[g_1^p(x,Q^2) - \frac{g_1^d(x,Q^2)}{1-1.5\omega_D}\right], \qquad (5)$$

where the the deuteron D-state probability ω_D is 0.05 ± 0.01 [9].

The analysis has been done at $Q^2 = 3(\,\mathrm{GeV}/c)^2$. The integral of g_1^{NS} has been evaluated from the measured values in the range $0.004 < x < 0.7$ with additional low and high contributions taken from the NLO fit of g_1^{NS}. The performed test is mainly limited by systematic

$$|g_A/g_V| = 1.28 \pm 0.07(stat.) \pm 0.1(syst.), \qquad (6)$$

compared to 1.2694 ± 0.0028 derived from neutron β decay. The test is satisfied within one standard deviation of the statistical uncertainty.

3. COMPASS semi-inclusive measurements

Semi-inclusive DIS (SIDIS) asymmetries, where in addition to the scattered lepton, pions and kaons are detected, are sensitive to the individual quark and antiquark flavours. The first measurement of SIDIS asymmetries were performed by the EMC more than twenty years ago. The COMPASS measurements for the scattering of high-energy polarized muon off proton and deuteron polarized targets allowed to extract SIDIS $\pi^\pm$ and $K^\pm$ asymmetries which, together with inclusive asymmetries, allow to perform a full flavor decomposition in LO, thus accessing for the first time all u, d, s quark and anti-quark helicity distributions separately.

SIDIS asymmetry for the hadron h can be written as a sum of products of the quark Δq and anti-quark $\Delta\bar{q}$ helicity distributions with the corresponding fragmentation functions $D^h_{q,\bar{q}}$

$$A_1^h(x,z) = \frac{\Sigma_q e_q^2\left(\Delta q(x) D_q^h(z) + \Delta\bar{q}(x) D_{\bar{q}}^h(z)\right)}{\Sigma_q e_q^2\left(q(x) D_q^h(z) + \bar{q}(x) D_{\bar{q}}^h(z)\right)}. \qquad (7)$$

Eight measured semi-inclusive and two inclusive asymmetries provide a system of ten equations with six unknowns ($\Delta u, \Delta d, \Delta s, \Delta\bar{u}, \Delta\bar{d}, \Delta\bar{s}$). A least-square fit to the data were performed in each x-bin. The SIDIS analysis was limited to $x \leq 0.3$, and for $x > 0.3$ Δu and Δd were obtained from the inclusive data assuming $\Delta\bar{q}$ to be zero.

The fit results for the Δs and $\Delta\bar{s}$ distributions and for their difference show that in the measured x range both distributions are similar and compatible with zero. From here on the distributions of Δs and $\Delta\bar{s}$ will be assumed to be equal, an assumption which reduces the number of unknowns to five and improves the statistical precision with the DSSV fit results at least by factor 1.5. The COMPASS results [10] for the quark helicity distributions are shown in Fig.3. They are in a good qualitative agreement with the fit result. We also conclude that the antiquark distributions do not show variation in the x range and are consistent with zero. The first moments of the helicity distributions are listed in the Table 1. The unmeasured contributions at low and high x were estimated by extrapolating the data towards $x = 0$ and $x = 1$ and by using DSSV parametrization [11].

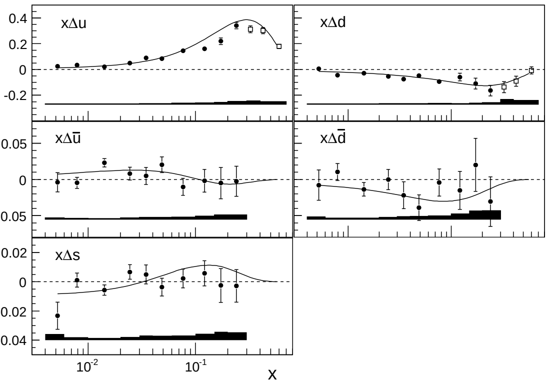

Figure 3: The quark helicity distributions $x\Delta u, x\Delta d, x\Delta\bar{u}, x\Delta\bar{d}, x\Delta s$ ($\Delta s = \Delta\bar{s}$) at $Q^2 = 3(GeV/c)^2$ as a function of x. The bands at the bottom of each plot show the systematic errors. The curves show the result of DSSV fit at NLO [11].

Table 1: Full first moment of the quark helicity distributions at $Q^2 = 3(\,\mathrm{GeV}/c)^2$. The first error is statistical, the second one systematic.

x range	Extrapolation	DSSV
Δu	$0.71 \pm 0.02 \pm 0.03$	$0.71 \pm 0.02 \pm 0.03$
Δd	$-0.34 \pm 0.04 \pm 0.03$	$-0.35 \pm 0.04 \pm 0.03$
$\Delta\bar{u}$	$0.02 \pm 0.02 \pm 0.01$	$0.03 \pm 0.02 \pm 0.01$
$\Delta\bar{d}$	$-0.05 \pm 0.03 \pm 0.02$	$-0.07 \pm 0.03 \pm 0.02$
$\Delta s(\Delta\bar{s})$	$-0.01 \pm 0.01 \pm 0.01$	$-0.05 \pm 0.01 \pm 0.01$
$\Delta\Sigma$	$0.32 \pm 0.03 \pm 0.03$	$0.22 \pm 0.03 \pm 0.03$

It is seen that, in contradiction with the inclusive analysis, the values of the strange quark helicity does not indicate that its first moment is negative.

The sum of the quark and antiquark contributions obtained in SIDIS analysis $\Delta\Sigma = 0.32 \pm 0.03 \pm 0.03$ is in agreement with inclusive analysis result.

4. The gluon polarization measurement

In polarized semi-inclusive DIS the polarization $\Delta g/g$ of the gluon carrying a fraction of the nucleon momentum x_g can be obtained from the asymmetry of

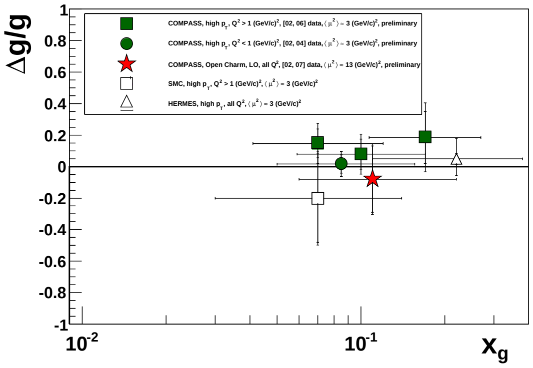

Figure 4: COMPASS measurements of $\Delta g/g$ in comparison with SMC [14] and HERMES [15] results.

spin-dependent cross-section of the photon-gluon fusion (PGF), $\gamma g \rightarrow q\bar{q}$. The COMPASS uses two procedures to tag this process. The first one consists in selecting events with charmed mesons D^0 and D^*, which provides the purest sample of PGF events, but at low rate. Another possibility is to select events with two hadrons which have high transverse momenta, p_T, with respect to the virtual photon. This procedure provides much larger statistics but leaves a significant fraction of background events in the selected sample. For estimation of the fraction of PGF events and of the contribution from the background in the measured asymmetry Monte-Carlo simulation has to be used [12].

COMPASS results on the $\Delta g/g$ measurement based on the analysis of data collected during 2002-2004, 2006 and 2007 years [12, 13] are presented in Fig.4. Our results obtained with two different procedures are compatible to each other within experimental uncertainties and give value of $\Delta g/g$ close to zero.

The COMPASS measurements of the gluon polarization in the nucleon, together with other measurements all situated around $x \sim 0.1$, point towards a small gluon polarization at that value of x. This is in agreement with a small value of the first moment $\Delta G = \int_0^1 \Delta g(x)dx$, of the gluon helicity distribution, although this in principle does not exclude a large value.

5. Conclusion

The COMPASS collaboration has performed precise measurements of the longitudinal spin asymmetries for the proton and the deuteron, covering a large range of x ($0.004 < x < 0.7$) in the region $Q^2 > 1(\mathrm{GeV}/c)^2$. The data increase the statistical precision in low x region by factor 2-3. COMPASS data improve the evaluation of the non-singlet spin structure function g_1^{NS} and provide a test of the Bjorken sum rule, which is satisfied within one standard deviation of the statistical uncertainty.

Longitudinal spin asymmetries for identified pions and kaons combined with inclusive asymmetries allow to evaluate the three lightest flavor quark and antiquark helicity distributions. No difference is observed between Δs and $\Delta\bar{s}$ distributions, which are both compatible with zero. The sum of the flavor-separated first moments, linearly extrapolated to $x = 0$ is in a good agreement with our previous determination of $\Delta\Sigma$ obtained in inclusive analysis.

The COMPASS measurements of the gluon polarization in the nucleon are compatible with zero. The shape of the $\Delta g/g$ is still unknown and the large value of the first moment ΔG can not be excluded.

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