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A new LO extraction of gluon polarization from COMPASS DIS data

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A new LO evaluation of the gluon polarization in the nucleon is presented. The COMPASS data from 2002-2006 years from DIS region were re-analysed and gluon polarization was extracted using a so called all-p_T method. In this new method gluon polarization and leading process asymmetry are extracted simultaneously from the same data set using a Neural Network approach. Reduction of both systematic and statistical uncertainties by more than 50% is achived compared to the published result PLB 718 (2013) 922. The preliminary value of gluon polarization is $\Delta g/g$ = $0.113 \pm 0.038 \pm 0.035$ at average gluon momentum fraction $x_g = 0.10$ and scale of $\mu^2 = 3$ (GeV/c)^2.

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1. Introduction

The observation by EMC [1] that only a small fraction of the nucleon spin is carried by quark spins still strongly influences recent developments of spin physics. With all undertaken effort the spin fraction carried by gluons, ΔG, is still not measured precisely. In this work a re-analysis of COMPASS deuteron data from DIS region, published in [2], using new all-p_T method is presented A related analysis of COMPASS data in the photo-production regime can be found in [3].

2. Gluon Polarization extraction

The longitudinal double-spin asymmetry for the production of high-p_T hadron in the DIS regime can be expressed in therms of three processes a leading-order photo absorption process, the QCD Compton scattering processes (QCDC) and Photon-Gluon Fusion (PGF).

$$A^{\mathrm{h}}_{\mathrm{LL}}(x_{Bj}) = R_{\mathrm{PGF}}\, a^{\mathrm{PGF}}_{\mathrm{LL}} \frac{\Delta g}{g}(x_g) + R_{\mathrm{LP}}\, D A^{\mathrm{LO}}_1(x_{Bj}) + R_{\mathrm{QCDC}}\, a^{\mathrm{QCDC}}_{\mathrm{LL}} A^{\mathrm{LO}}_1(x_C) \ , \tag{2.1}$$

The leading order (LO) inclusive asymmetry A_1^{LO} is given by the ratio of spin-dependent and spin-averaged quark distribution functions (PDFs), weighted by the squared quark electric charges; R_i is the fraction of process i and a^i_{LL} the corresponding analysing power (*i.e.* the asymmetry of the partonic cross-section) [4]. The depolarization factor D is the fraction of the muon beam polarization transferred to the virtual photon and depends mainly on y. The variables x_{Bj}, x_g and x_C are the quark momentum fraction, the gluon momentum fraction in the PGF process and the quark momentum fraction in the QCDC process, respectively.

The evaluation of $\Delta g/g$ using Eq.(2.1) is done on the event by event basis and is possible if contribution from background processes can be subtracted. The R_i and a^i_{LL} are obtained by Neural Network parametrization of LEPTO MC, [5]. In previous work, the A_1^{LO} was evaluated from the inclusive lepton–nucleon asymmetry $A^{\mathrm{incl}}_{\mathrm{LL}}$, which can be decomposed in similar way as in Eq.(2.1). To reduce systematic uncertainties in this work we extract simultaneously $\Delta g/g$, $A_1^{\mathrm{LO}}(x_{Bj})$ and $A_1^{\mathrm{LO}}(x_C)$ from the same data set. The mathematical details of the simultaneous extraction of asymmetries are given in [6] and [7].

Comparing to the method used in [2], the proposed method gives several advantages. There is no more x'_C, x'_g, see Eq.(3) of [2] and therefore no simplifying assumptions and systematic error related to them. Similarly the systematic related to the parametrization of A_1^d is not needed. Finally in the new method it is possible to verify the underlying model (here LEPTO MC) by studying to so called A1 compatibility test, which is described in section 6.

3. Data Selection

COMPASS deuteron data were used in the analysis (2002-2006). Whenever possible the data selection follows the published analysis. But there are two important exceptions. At least one good hadrons in the final state is required instead of at least two. The low p_T events are kept in the analysis, as clear source of LP events is needed. Only data with p_T of the hadron lower than 2.5 GeV/c are used, because GEISHA and FLUKA, programs used to simulate secondary interactions in the target, do not agree in the high p_T region. Selected events have an interaction vertex located in the target fiducial volume and contain both a beam muon and a scattered muon. The DIS region is selected by the requirement that negative four momentum transfer Q^2 is larger than 1 $(\mathrm{GeV}/c)^2$. Events with $y < 0.1$ and with $y > 0.9$ are rejected.

4. Monte Carlo and Neural Network

The extraction of $\Delta g/g$ is based on the information taken from MC. Therefore the quality of information obtained from MC is crucial for this analysis. There was a considerable effort undertaken for the previous publication to improve the description of the apparatus as well as to tune fragmentation parameters so that the MC well describe data. In this analysis we use the same MC tuning and the apparatus description as in the previous analysis. Observe that the tuning was performed for a sub-sample having previous p_T cuts, about 6% of the current sample. It is not guaranteed that the tuning which describes well 6% of the sample will describe as good 100% of it. However, while data to MC comparison could be better, the description of data by MC with the high-p_T tuning is reasonable. The comparison is presented in Fig. 1, where data and MC are compared for several hadronic variables. To parametrize R_i, a^i_{LL}, x_g and x_C the NN package from Ref. [8] is used. Similar tests as in [2] where performed to guarantee correctness of the NN parametrizations.

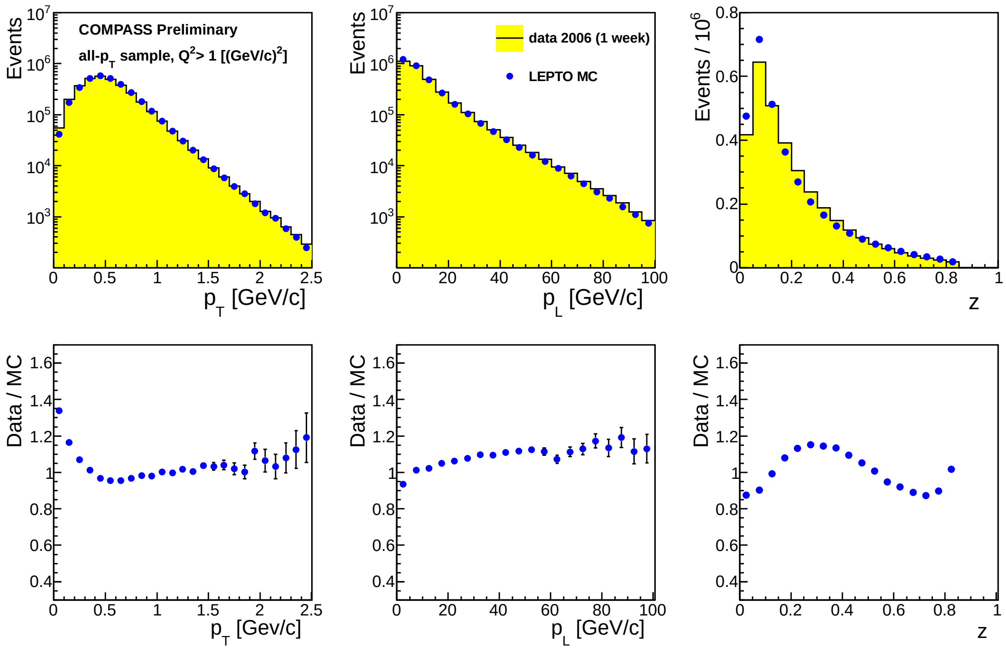

Figure 1: Comparison of data and MC for p_T, p_l and z.

5. Results

The preliminary result for $\Delta g/g$ and it statistical and systematic uncertainty is

$$\Delta g/g = 0.113 \pm 0.038 \pm 0.035, \tag{5.1}$$

at average value of $< x_g > \approx 0.10$ and average scale $\mu^2 =< Q^2 >= 3$ (GeV/c)^2. A correction for the probability of the deuteron to be in a D-wave state [9] was applied. The final $\Delta g/g$ value is almost $3\sigma_{stat}$ from zero, giving hints that $\Delta g/g$ might be positive in the region of the measurement. Similar conclusion is reached in NLO QCD fits when pp RHIC data are included, see *e.g.* [10]. The presented result agrees very well with previously published $\Delta g/g$ value, $\Delta g/g = 0.125 \pm 0.060 \pm 0.065$, [2]. The values of $\Delta g/g$ were extracted in three intervals of x_g. The comparison of the current results with that of [2] is presented on the left panel of Fig. 2. The central values are in agreement, the uncertainties are reduced by 50% in the all-p_T method. However, it has to be noted that for the new method, due to the fitting procedure, there is a 30% correlation between results obtained in 1st and 2nd x_g bin. On the right panel of Fig. 2 comparison of $\Delta g/g$ results with world LO extraction of $\Delta g/g$ is presented. The current result agrees well with all previous measurements [11], [12], [7] and [13].

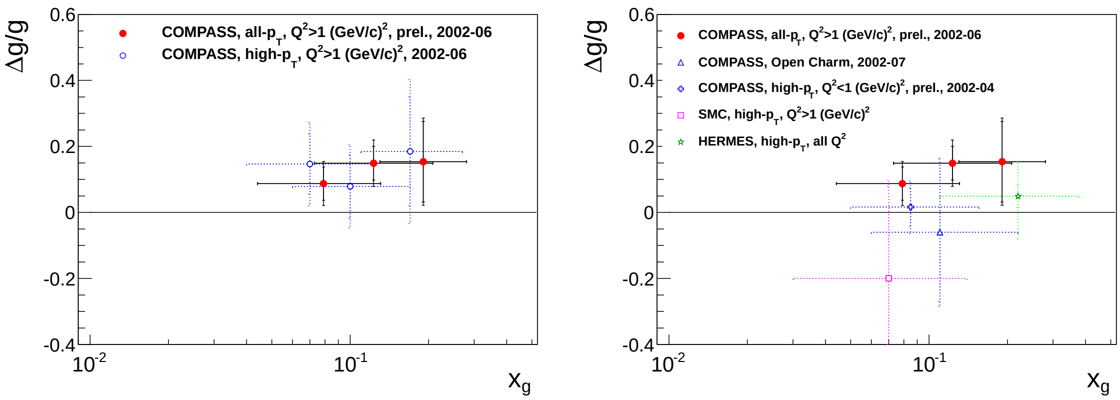

Figure 2: Left Panel: Comparison of the new preliminary results with published [2]; Right Panel: Comparison of new preliminary results with world LO $\Delta g/g$ extractions.

6. Systematic Studies

The new method is basically a mathematical reformulation of the $\Delta g/g$ extraction used in [2]. Therefore we assume that the conclusions reached concerning *e.g.* radiative corrections, resolved photon contribution, non-pion contamination, are valid. The remaining major contributions to the systematic error were re-valuated in the current analysis. This include: impact of NN on the $\Delta g/g$ results ($\Delta g/g_{NN} = 0.007$), uncertainty of the beam and target polarization as well as uncertainty of the dilution factor of the target ($\Delta g/g_{f,P_b,P_t} = 0.008$), the limit for experimental false asymmetries ($\Delta g/g_{false} = 0.029$) and finally $\Delta g/g$ uncertainty related with usage of MC in the analysis ($\Delta g/g_{MC} = 0.017$).

The presented analysis is model dependent. Therefore low value of $\Delta g/g_{MC} = 0.017$ needs to be explained in more details. To explore parameter space of the model dependence, 8 different MC samples are used. The MCs differs by usage of different tuning of fragmentation functions (default or COMPASS High-p_T, [2]) and usage or not parton shower mechanism. In addition impact of different PDFs, longitudinal structure function F_L and finally usage of GEISHA or FLUKA in MC were also tested. The results of $\Delta g/g$ obtained using different MCs are presented in Fig. 3.

The obtained results are very stable, the RMS is only 0.017, while at the same time the difference in statistical error of $\Delta g/g$ reaches up to a factor 2. The observed low model dependence can be understood, by the fact, that for low positive values of $\Delta g/g$ the systematic error is dominated by the ratio of $R_{\mathrm{QCDC}}/R_{\mathrm{PGF}}$. Both QCDC and PGF are higher order processes so the α_S cancels in the cross-section ratio. In addition the hadron p_T in both processes is dominated by the partonic cross section calculable in LO pQCD, and not by the fragmentation process, of which parameters are tuned. Thus the ratio of $R_{\mathrm{QCDC}}/R_{\mathrm{PGF}}$ is known more precisely than *e.g.* ratio $R_{\mathrm{LO}}/R_{\mathrm{PGF}}$ or R_{PGF} itself on which the error of $\Delta g/g$ depends.

In the new method it is possible to perform the so called A_1 compatibility test to verify the underlying model. Namely, The A_1^{LO} is known to be x dependent. Therefore the analysis of is performed in 12 bins of x_{Bj} for LP and 6 bins of x_C for QCDC process (In COMPASS: $x_{Bj} > 0.004$ while $x_C \gtrapprox 0.06$), The extracted asymmetries are called $A_1^{\mathrm{LP}}(x_{Bj})$ and $A_1^{\mathrm{QCDC}}(x_C)$ respectively. In the analysis 6 values of asymmetries measured for QCDC and LP which corresponds to the same x will be obtained. However,

$$A_1^{\mathrm{QCDC}}(x_C) = A_1^{\mathrm{LP}}(x_{Bj}) = A_1^{\mathrm{LO}}(x_{Bj});\ \text{ for } x_C = x_{Bj}. \tag{6.1}$$

We can verify equality of the asymmetries performing standard χ^2 test. The simplest explanation for the χ^2 test to eventually fail is because incorrect values of R_i and a^i_{LL} are used. This could happen when the MC tuning used in the analysis is wrong, or *e.g.* higher order corrections are substantial. In case the A_1 compatibility test is passed one can assume in the analysis that the asymmetries for QCDC and LP are equal. As more constraints are used in the fit, the uncertainties of the fitted parameters (including $\Delta g/g$) are reduced. This is the way the final analysis is being performed.

The results of the A_1 compatibility test for different MC samples varies between 3.9 and 13.1, with 8.1 obtained for the MC sample which is used for the presented preliminary $\Delta g/g$ value. With 6 degrees of freedom on 95% CL the A_1 compatibility fails if χ^2 is larger than 12.6. One of the tuning has indeed larger χ^2 than this limit and could be rejected.

The A_1 compatibility test can also be used to gain some knowledge concerning value of $a_{\mathrm{LL}}^{\mathrm{QCDC}} R_{\mathrm{QCDC}}$ directly from data. In the simplest case obtained from MC value of $a_{\mathrm{LL}}^{\mathrm{QCDC}} R_{\mathrm{QCDC}}$ can be multiplied by a factor η_{QCDC}. The χ^2 value of the A_1 compatibility test can be studied as a function of η_{QCDC}. The results of such studies are presented in Fig 3 as red circles (for blue circles the χ^2 includes also comparison of $\Delta g/g$ obtained with/without using constrain in Eq.(6.1)). In both cases the χ^2 minimum is obtained for values η_{QCDC} comparable to 1.0, giving more confidence in the MC model used in the analysis.

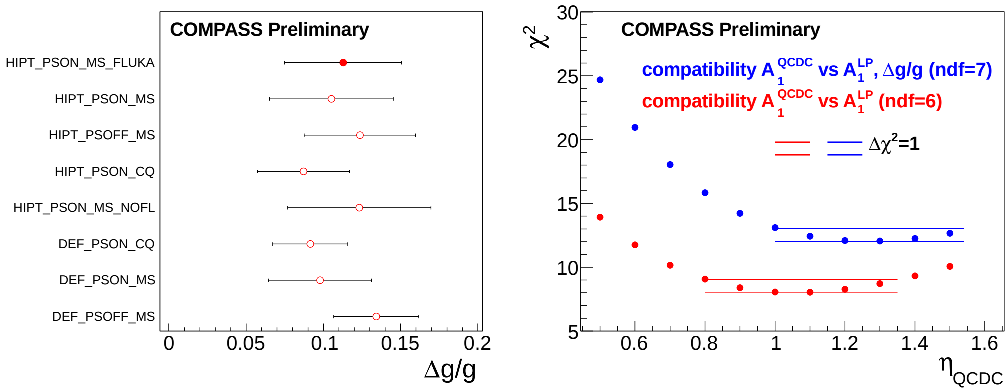

Figure 3: Left panel: Extracted values of $\Delta g/g$ for 8 different MCs, see text for details; Right panel: The results of the χ^2 scan of η_G, see text for details.

7. Summary

The re-evaluation of $\Delta g/g$ from COMPASS DIS data using the all-p_T method was presented. The new method allows for simultaneous extraction of $\Delta g/g$ and A_1^{LO}. Comparing with the previous method, both statistical and systematic uncertainties are reduced. In addition, in the new method it is possible to perform the A_1 compatibility test, and rejected wrong MC tunings. The obtained preliminary value of the gluon polarization in the nucleon at LO in pQCD is: $\Delta g/g = 0.113 \pm 0.038 \pm 0.035$, for $< x_g >= 0.10$ and scale $\mu^2 = 3$ (GeV/c)^2 This result has the lowest combined systematic and statistical uncertainties compared to the world direct extractions of $\Delta g/g$ in LO.

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