Constraints on gluon polarization in the nucleon at NLO accuracy

G. A. Navarro\textsuperscript{1,}\footnote{Partially supported by CONICET, Fundación Antorchas, UBACYT and ANPCyT, Argentina.} and R. Sassot\textsuperscript{1,}\footnote{Electronic address: gabin@df.uba.ar} \footnote{Electronic address: sassot@df.uba.ar}

\textsuperscript{1}Departamento de Física, Universidad de Buenos Aires
Ciudad Universitaria, Pab.1 (1428) Buenos Aires, Argentina

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We compare constraints on the gluon polarization in the nucleon obtained in next to leading order global QCD fits to polarized deep inelastic scattering data with those coming from observables more directly linked to the gluon polarization, such as the double spin asymmetry measured by PHENIX at RHIC, and high-\textit{p}_{\text{T}} hadron production studied by COMPASS at CERN.

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I. INTRODUCTION

The extent to which gluons are polarized in the nucleon, and consequently the origin of the nucleon spin, has persisted as an elusive question for almost two decades in spite of strenuous experimental efforts and theoretical activity \ cite{1}. Although the spin dependent gluon density in principle can be sized in inclusive deep inelastic scattering measurements, mainly through the scale dependence of the measured asymmetries, this dependence is rather mild in the kinematical range accessed by experiments, and conclusions about it are also veiled by our ignorance regarding the polarization of the other partonic species, which also contribute to the scale dependence, specially that of sea quarks. Therefore, even in the most ambitious scenario, inclusive deep inelastic scattering data can at most suggest mild constraints on the gluon polarization.

In a recent article \cite{2}, we have shown that the enduring efforts to measure less inclusive observables in deep inelastic scattering have finally begun to yield, allowing combined next to leading order global QCD fits to inclusive and semi-inclusive deep inelastic scattering data where sea quarks and gluons are much more definitely constrained. In the mean time, independent measurements of other less inclusive observables, such as pion production in polarized proton-proton collisions \cite{3}, and high transverse momentum hadron pair production in deep inelastic scattering have begun to provide more direct assessments of the gluon polarization with competing precision \cite{4,5}. It is therefore of great interest to compare the gluon polarization estimates coming from both the global analysis of deep inelastic scattering data and from the more direct measurements. In the following we perform such comparison and we find that although preliminary direct measurements still have a moderate impact in the fits, there is a remarkable agreement and complementarity between both approaches, what encourage us to incorporate the forthcoming data in future global analysis.

II. COMPARISON

In the case of inclusive and semi-inclusive polarized deep inelastic scattering (DIS), the next to leading order (NLO) QCD framework required to compute the respective observables have been available for some time \cite{8,9}, and indeed recent global analyses have demonstrated both the relevance of these corrections and also the non negligible impact of most recent semi-inclusive data \cite{2,10}. Specifically, in reference \cite{2} it has been found that the best global QCD fits to combined DIS data constrain the gluon polarization to be moderately positive with a first moment of this density $\delta g \equiv \int dx \Delta g$ of 0.680 at 10 GeV$^2$ with an uncertainty range given by [0.452, 0.771] for a one-unit increase in $\chi^2$ and by [$-0.107, 0.807$] allowing a more conservative 2% variation of $\chi^2$. In these constraints, both the requirement of positivity of the polarized parton densities relative to a modern set of unpolarized parton densities \cite{13}, and the correlation between gluon and sea quark polarization, are found to be crucial. Fits with a wide variation in the gluon polarization reproduce inclusive data equally well, however they are clearly differentiated because of their sea quark polarization by semi-inclusive data.
The cross section for single inclusive large $p_T$ pion production in longitudinally polarized proton-proton collisions, which is right now being measured at Brookhaven National Laboratory Relativistiv Heavy Ion Collider (BNL RHIC) have also been computed at NLO accuracy, and have been found to be significantly dependent on $\Delta g^{11,12}$. Recently, the PHENIX collaboration has presented preliminary results with considerably reduced errors which clearly disfavors scenarios with large gluon polarization and are in nice agreement with estimates of updated polarized fits. In Figure 1, we show the expectation for the double spin asymmetry computed with the best fit of reference 2, together with the data reported by PHENIX 3. We also plot the uncertainty band associated to a $\Delta \chi^2 = 2\%$ variation. The $\chi^2$ for PHENIX data obtained with the best fit of reference 2, which is previous to the latest set of

![Graph showing data and fit comparisons](image)

**FIG. 1:** (a) Data on $A_{\pi 0}^{0,LL}$ compared with the estimate coming from the the NLO fit of reference 2 and the uncertainty band allowing $\Delta \chi^2 = 2\%$; (b) the same but for estimates for $\Delta g/g$ from 5.

PHENIX data, and computed including the 40% scaling uncertainty in the nondiagonal covariance matrix, results to be 10.93, for $N = 8$ data points, which is well within the $\sqrt{2N}$ range expected for a given subset of data in global fit and therefore should be considered as consistent. The value for $\chi^2$ is comparable to the one obtained (11.2) in a recent fit 15 to both inclusive DIS data and the PHENIX measurement, although not including the scaling error in the computation.

Similar agreement is found comparing the expectation of the fit for $\Delta g/g$ at 1 GeV$^2$ against preliminary data from COMPASS 4, 5, and previous measurements 6, 7, as shown in Figure 1. In this case we include both the leading order (LO) and the NLO expectation because the reported values for $\Delta g/g$ correspond to a LO extraction improved with Monte Carlo higher order corrections. We include in the plot the uncertainty band coming from a 2\% variation in $\chi^2$, plus that coming from varying $Q^2$ up to 10 GeV$^2$, what again highlights the nice consistency between independent data set and the frameworks implemented for the corresponding analyses.

**III. COMBINED FIT**

Further insight on the interplay between DIS data and that coming from PHENIX can be obtained analyzing the profile of $\chi^2$ function for the different subsets of data in a combined fit, against the range of variation of the net gluon polarization, as it was done in 2. In Figure 2 we show the profile of the total $\chi^2(DIS + A_{\pi 0}^{0,LL})$ of a global fit to inclusive and semi-inclusive data along the lines of that of reference 2 but also including PHENIX data as a solid line. The curve has similar shape to the one found in 2 but shifted upwards between eleven and thirteen units, which is essentially the partial contribution of $A_{\pi 0}^{0,LL}$ to $\chi^2(DIS + A_{\pi 0}^{0,LL})$. In order to see the relevance of $A_{\pi 0}^{0,LL}$ data, this last contribution is also plotted as a dashed-dotted line with an offset 430.91 units, which the partial contribution of DIS data $\chi^2_0(DIS)$ for
the best fit. Notice the partial contribution of $A_{\pi}^{\theta}$ is almost flat around the minimum of $\chi^2(DIS + A_{\pi}^{\theta})$ and reaches its own minimum for slightly lower values of $\delta g$ but within the one-unit variation of $\chi^2(DIS + A_{\pi}^{\theta})$, what highlights the consistency between both data sets.

![Graph of contributions to $\chi^2$ of different sets of data against the gluon net polarization.](image)

**FIG. 2:** Profiles of contributions to $\chi^2$ of different sets of data against the gluon net polarization.

In Figure 2 we have plotted also the profile obtained for DIS data only in [2] as a dashed line, with an offset given by the partial contribution of $A_{\pi}^{\theta}$ at its minimum $\chi^2_0(A_{\pi}^{\theta})$, in order to see the net effects on the fit of PHENIX data. In Table I we show the partial contributions to $\chi^2$ at both minima.

| $\chi^2(DIS + A_{\pi}^{\theta})$ | $\chi^2(DIS)$ | $\chi^2(A_{\pi}^{\theta})$ | $\delta g$ |
|--------------------------------|----------------|-----------------|-------|
| $\chi^2_0(DIS + A_{\pi}^{\theta})$ | 441.84 | 430.91 | 10.93 | 0.680 |
| $\chi^2_0(A_{\pi}^{\theta})$ | 442.63 | 431.82 | 10.81 | 0.450 |

**TABLE I:** Partial contributions to $\chi^2$ values and first moment of $\Delta g$ at $Q^2 = 10$ GeV$^2$

Clearly, these effects are almost imperceptible around the minimum but can be noticed for $\chi^2(DIS + A_{\pi}^{\theta})$ variations between the one-unit and the 2% increase. Close to the minimum of $\chi^2(DIS + A_{\pi}^{\theta})$, the decrease of $\chi^2(A_{\pi}^{\theta})$ for decreasing $\delta g$ is overpowered by the increase of $\chi^2(DIS)$ and consequently, the position of the minimum remains that found for DIS data. Given the large number of DIS data included in the fit (478) compared to the rather limited set of $A_{\pi}^{\theta}$ available at present, the small impact in the fit is not surprising, nevertheless the consistency shown, and the possibility of increasing considerably the statistics in the future is encouraging.

**IV. CONCLUSIONS**

We have compared the constraints on the gluon polarization in the nucleon obtained in next to leading order global QCD fits to polarized deep inelastic scattering data with those coming the double spin asymmetry measured by
Phenix at RHIC. Although the relative statistical weight of $A_{LL}^{\pi_0}$ data in a global NLO fit including also DIS data is rather limited, we find a remarkable agreement and moderate improvement when combining both data sets. In the case of other direct measurements such as high-$p_T$ hadron production studied by COMPASS at CERN, the lack of a NLO framework for the computation of the corresponding asymmetries does not allow to include them yet in a combined NLO global analysis however we find preliminary agreement which hopefully will be checked at NLO accuracy in the near future.

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