

Constraints on polarized parton distributions from open charm and W production data

Emanuele Roberto Nocera*

Università degli Studi di Milano & INFN Milano - Via Celoria 16 Milano, Italy

E-mail: emanuele.nocera@unimi.it

We study the impact of new open charm muoproduction data from COMPASS and preliminary W^\pm production data from STAR on NNPDFpol1.0, the first unbiased set of polarized parton distributions recently delivered by the NNPDF Collaboration and based on inclusive Deep-Inelastic Scattering data only. The information contained in the new data sets is incorporated in our Monte Carlo parton determination via Bayesian reweighting, a method based on statistical inference which avoids the need for a global refitting. We explicitly show to which extent COMPASS and STAR data can improve our knowledge of gluon and antiquark polarized parton distributions respectively.

*XXI International Workshop on Deep-Inelastic Scattering and Related Subjects - DIS2013
22-26 April, 2013
Marseille, France*

*Speaker.

Introduction. In those last years an increasing effort has been devoted to the determination of helicity-dependent, or polarized, Parton Distribution Functions (PDFs), motivated by the role they play in understanding nucleon's spin in terms of its Quantum Chromodynamics (QCD) parton substructure [1]. Spurred by remarkable experimental progress, several next-to-leading order (NLO) studies were performed, showing which aspects of polarized PDFs are probed by the various pieces of available experimental information (see for example [2] and references therein).

The NNPDF Collaboration has recently presented the first unbiased determination of polarized PDFs from polarized inclusive Deep-Inelastic Scattering (DIS) world data, based on a methodology which uses Monte Carlo sampling of experimental data and Neural Networks as flexible interpolants [3]. In this analysis, they showed that available inclusive DIS data only weakly constrain the gluon PDF, probed by scaling violations in this process, unless one makes rather strong assumptions on its functional form. Furthermore, presently available neutral-current DIS data do not allow one to separately determine polarized quark and antiquark distributions in the nucleon.

In this contribution, we study to which extent recent measurements of open charm muoproduction data from COMPASS [4] and preliminary results on W^\pm production data from STAR [5] can improve our knowledge of the gluon and antiquark polarized PDFs, respectively. In order to include this new experimental information in our previous fit [3], we use the reweighting technique [6, 7], which consists of assigning to each replica in a prior PDF ensemble a weight proportional to the probability that this replica agrees with new data. The reweighted ensemble is then a representation of the probability distribution of PDFs conditional on both old and new data. The reweighting method has the main advantage of avoiding full refitting, which is typically a cumbersome and time consuming task.

COMPASS open charm data. The COMPASS Collaboration has recently presented new experimental results for the virtual photon-nucleon asymmetry $A_{LL}^{\gamma N \rightarrow D^0 X}$ obtained from open charm production tagged by D^0 meson decays in muon-nucleon scattering [4]. These data potentially provide a direct insight into the polarized gluon distribution. At leading-order (LO), open charm production is driven by the photon-gluon fusion (PGF) mechanism, $\gamma^* g \rightarrow c\bar{c}$ and the LO virtual photon-nucleon asymmetry $A_{LL}^{\gamma N \rightarrow D^0 X}$ can be expressed as

$$A_{LL}^{\gamma N \rightarrow D^0 X} \equiv \frac{d\Delta\sigma_{\gamma N}}{d\sigma_{\gamma N}} = \frac{\Delta g \otimes d\Delta\hat{\sigma}_{\gamma g} \otimes D_c^{D^0}}{g \otimes d\hat{\sigma}_{\gamma g} \otimes D_c^{D^0}}, \quad (1)$$

where Δg (g) is the polarized (unpolarized) gluon PDF, $\Delta\sigma_{\gamma N}$ ($\sigma_{\gamma N}$) is the spin-dependent (averaged) hard cross section, and $D_c^{D^0}$ is the non-perturbative fragmentation function of a produced charm quark into the observed D^0 meson, which is assumed spin independent. In this framework, COMPASS kinematics allows one to investigate the polarized gluon PDF in the momentum fraction region $0.06 \lesssim x \lesssim 0.22$ and at the energy scale $Q^2 = 4(m_c^2 + p_T^2) \sim 13 \text{ GeV}^2$, where m_c is the charm quark mass and p_T is the transverse momentum of the produced charmed hadron.

Theoretical predictions for the virtual photon-nucleon asymmetry $A_{LL}^{\gamma N \rightarrow D^0 X}$ are made following Ref. [8] by evaluating the analytical expression for both the numerator and the denominator in Eq. (1). In Fig. 1 we compare COMPASS measurements [4], separated into individual decay channels, with our predictions for different input parton sets and in three bins of the charmed hadron energy; the curve labelled as NNPDF is computed using the polarized (unpolarized) gluon PDF

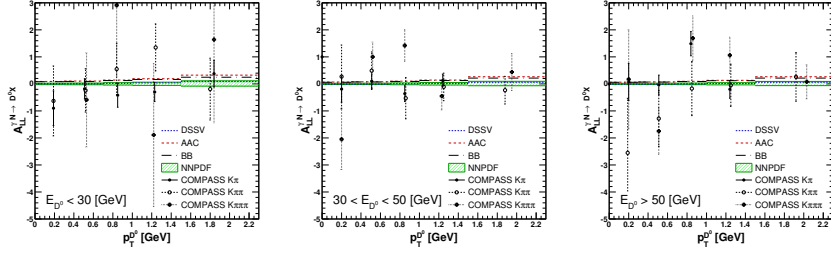


Figure 1: Experimental double-spin asymmetry for D^0 meson photoproduction $A_{LL}^{\gamma N \rightarrow D^0 X}$ measured by COMPASS [4] from three decay channels compared to LO predictions computed for different PDF sets in three bins of the charmed hadron energy E_{D^0} and in five bins of its transverse momentum $p_T^{D^0}$.

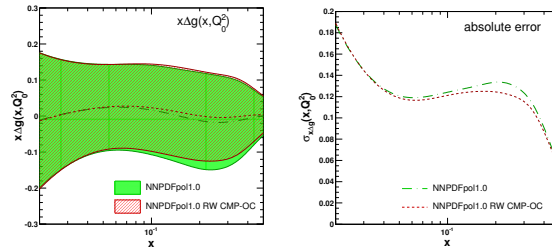


Figure 2: Comparison between the unweighted and the reweighted polarized gluon distribution at $Q_0^2 = 1 \text{ GeV}^2$ (left panel) and the improvement in its absolute error (right panel).

from the NNPDFpol1.0 [3] (NNPDF2.3 NLO [9]) parton set. We explicitly checked that the asymmetry, both mean value and error, mostly depend on the polarized gluon PDF and its uncertainty. Predictions do not change if we choose for the unpolarized gluon PDF a replica at random in the ensemble [9] or its mean value; also the dependence on the fragmentation function is moderate, as already pointed out in Ref. [10], for which we choose the Petersen parametrization as in Ref. [8].

We evaluate the χ^2 of the new data to the prediction from each replica in the prior PDF ensemble [3] according to Ref. [6] and obtain the value per data point $\chi^2/N_{\text{dat}} = 1.23$, which does not decrease after reweighting. We compare the polarized gluon PDF and its uncertainty before and after reweighting in Fig. 2. As expected from the present experimental errors shown in Fig. 1, which are large in comparison to the theoretical uncertainty due to the PDF, the impact of COMPASS open-charm data on the polarized gluon PDF is fairly small. The same conclusion was stressed in Ref. [10], where the longitudinal asymmetry was computed at NLO. Even though we computed this asymmetry at LO and its NLO corrections were shown not to be negligible (see Ref. [10]), we expect our conclusions will be unchanged when replacing the LO expression, Eq. (1), with its NLO counterpart. The knowledge on the polarized gluon distribution may be improved by inclusive jet production data from the Relativistic Heavy Ion Collider (RHIC), but only precise measurements at a high-energy Electron-Ion Collider (EIC) might reduce its uncertainty in a significant way [2].

STAR W^\pm data. Preliminary measurements on the longitudinal single-spin asymmetry for W^\pm boson production in polarized proton-proton collisions have been presented by STAR Collaboration recently [5]. Since this asymmetry arises from a purely weak interaction which couples left-

Experiment	Set	N_{dat}	χ^2/N_{dat}				$\chi_{\text{rw}}^2/N_{\text{dat}}$				$N_{\text{eff}}/N_{\text{rep}}$			
			1- σ	2- σ	3- σ	4- σ	1- σ	2- σ	3- σ	4- σ	1- σ	2- σ	3- σ	4- σ
STAR		12	2.16	2.21	2.10	2.05	1.80	1.33	1.06	1.06	0.42	0.40	0.38	0.32
	STAR W^+	6	1.44	1.58	1.58	1.57	1.25	1.12	1.04	1.04	0.76	0.65	0.60	0.50
	STAR W^-	6	2.89	2.85	2.62	2.53	2.35	1.54	1.08	1.07	0.27	0.30	0.30	0.27

Table 1: A summary of the reweighting with the W data from STAR experiment [5]: the number of available datapoints N_{dat} , the value of the χ per data point χ^2/N_{dat} ($\chi_{\text{dat}}^2/N_{\text{dat}}$) before (after) reweighting and the fraction $N_{\text{eff}}/N_{\text{rep}}$ of replicas left after reweighting ($N_{\text{rep}} = 300$), for the different priors discussed in the text.

handed quarks with right-handed antiquarks ($u_L \bar{d}_R \rightarrow W^+$ and $d_L \bar{u}_R \rightarrow W^-$), it provides an ideal tool to study individual polarizations of quarks and antiquarks inside the proton (see *e.g.* Ref. [2] for a wider discussion). These data are complementary, but independent, of those coming from Semi-Inclusive DIS (SIDIS), however their analysis does not require the usage of poorly known fragmentation functions.

As already discussed in Ref. [11], the available, DIS-only, NNPDF polarized parton set [3] cannot be directly used as a prior ensemble for reweighting with STAR- W data sets, since only the sum of quark and antiquark distributions was fitted there. In Ref. [11], we argued that suitable prior PDF ensembles may be constructed by supplementing the NNPDF_{pol1.0} analysis [3] with some reasonable assumption on the antiquark distributions, coming for example from existing fits to SIDIS data. If STAR data bring in sufficient amount of new information, the reweighted PDFs will be almost independent of the choice of the prior.

Following the method illustrated in Ref. [11], we construct four different prior ensembles, each made of $N_{\text{rep}} = 300$ PDFs, in which the $\Delta \bar{u}$ and $\Delta \bar{d}$ distributions are generated from a neural network fit to the DSSV08 [12] best fit plus 1- σ , 2- σ , 3- σ , 4- σ uncertainty. The idea is to enlarge the uncertainty until the reweighted observable becomes independent of the prior PDF set: we will find that the 3- σ and 4- σ prior sets accommodate our purpose, as discussed below. Using the CHE code [13], we then compute for each prior the electron (positron) longitudinal single-spin asymmetry $A_L^{e^-}$ ($A_L^{e^+}$) from $W^{-(+)}$ boson production at NLO and with STAR kinematics (center-of mass-energy $\sqrt{s} = 510$ GeV and integrated lepton transverse momentum $25 < p_T < 50$ GeV).

In Tab. 1 we show, for each prior, the χ^2 per data point χ^2/N_{dat} ($\chi_{\text{rw}}^2/N_{\text{dat}}$) before (after) reweighting and the fraction $N_{\text{eff}}/N_{\text{rep}}$ of replicas left after reweighting, as defined in Ref. [6]. The quality in the description of STAR data before reweighting is comparable for all prior sets, though it is far from being optimal, since the value of the χ^2 per data point is significantly above one. As expected, this value improves after reweighting, but different lowering is reached depending on the prior. A value of reweighted χ^2 per data point of order one, which reveals a good description of data, is reached only using the 3- σ or 4- σ prior PDF ensemble. Notice that no significant improvement in the description of data is reached moving from the 3- σ to the 4- σ prior, thus ensuring the independence of our results from any of these two choices (and from any other prior constructed assuming less stringent antiquark distributions). Of course, the latter is less efficient at representing the underlying PDF probability distribution, as shown by the lower value of the effective number of replicas (see Tab. 1), and a wider PDF ensemble would be needed.

In Fig. 3 we plot the longitudinal positron (electron) single-spin asymmetry $A_L^{e^+}$ ($A_L^{e^-}$) from production and decay of $W^{+(-)}$ bosons at STAR. The asymmetry is shown before and after reweight-

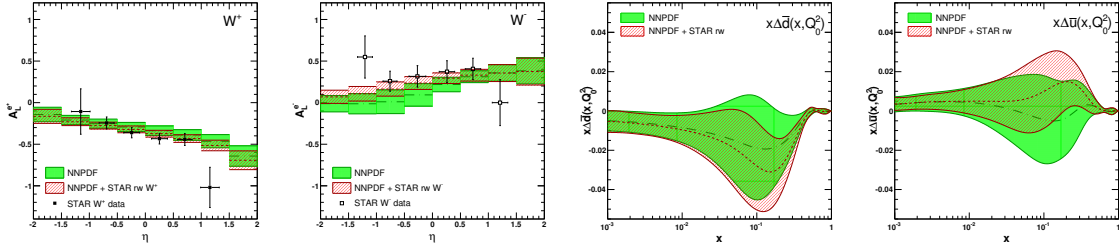


Figure 3: The longitudinal positron (electron) single-spin asymmetry $A_L^{e^+}$ ($A_L^{e^-}$) from production and decay of $W^{+(-)}$ bosons at STAR before and after reweighting of 3- σ prior, in bins of the lepton rapidity η and together with experimental data. The corresponding probed antiquark PDFs at $Q_0^2 = 1 \text{ GeV}^2$ are also shown.

ing of the 3- σ prior (boldface in Tab. 1), in bins of the lepton rapidity η and together with experimental data. The reweighted observable nicely agrees with experimental data and its uncertainty is reduced with respect to the prior. In Fig. 3 we also show the $\Delta\bar{d}$ and the $\Delta\bar{u}$ parton distributions before and after reweighting at $Q^2 = 1 \text{ GeV}^2$; other PDFs not shown here, including strangeness, are almost unaffected. All the results shown in Fig. 3 are obtained for the simultaneous reweighting with STAR W^\pm data; by reweighting with separate W^+ (W^-) data set, we have explicitly checked that $\Delta\bar{d}$ ($\Delta\bar{u}$) are separately probed, as expected.

In conclusion, our analysis, though based on a small preliminary set of W production data, clearly demonstrates their potential in constraining the polarized antiquark PDFs; further relevant insight is expected to be supplied by the ongoing analyses and runs from both STAR and PHENIX experiments in the forthcoming years.

Acknowledgments

I would like to thank the convenors of the spin working group for the opportunity to present this work. I am also grateful to M. Stratmann for useful discussions and to S. Forte and J. Rojo for a careful reading of the manuscript.

References

- [1] E. Leader, *Spin in Particle Physics*, *Camb. Monogr. Part. Phys. Nucl. Phys. Cosmol.*, **15:1**, 2001.
- [2] D. de Florian, R. Sassot, M. Stratmann and W. Vogelsang, *QCD Spin Physics: Partonic Spin Structure of the Nucleon*, *Prog. Part. Nucl. Phys.* **67** (2012) 251, [1112.0904].
- [3] [NNPDF Collaboration], R. D. Ball *et al.*, *Unbiased determination of polarized parton distributions and their uncertainties*, accepted for publication in *Nucl. Phys.* **B**, 1303.7236.
- [4] [COMPASS Collaboration], C. Adolph *et al.*, *Leading and Next-to-Leading Order Gluon Polarisation in the Nucleon and Longitudinal Double Spin Asymmetries from Open Charm Muoproduction*, 1211.6849.
- [5] J. R. Stevens, *The STAR W program at RHIC*, to appear in the proceedings of *QCD-N'12*, 1302.6639.

- [6] [NNPDF Collaboration], R. D. Ball *et al.*, *Reweighting NNPDFs: the W lepton asymmetry*, *Nucl. Phys.* **B849** (2011) 112, [1012.0836].
- [7] [NNPDF Collaboration], R. D. Ball *et al.*, *Reweighting and Unweighting of Parton Distributions and the LHC W lepton asymmetry data*, *Nucl. Phys.* **B855** (2012) 608, [1108.1785].
- [8] C. Simolo, *Extraction of characteristic constants in QCD with perturbative and nonperturbative methods*, PhD thesis, Milano 2006, 0807.1501.
- [9] [NNPDF Collaboration], R. D. Ball *et al.*, *Parton distributions with LHC data*, *Nucl. Phys.* **867** (2013) 244, [1207.1303].
- [10] J. Riedl, M. Stratmann, and A. Schafer, *Longitudinally Polarized Photoproduction of Heavy Flavors at Next-to-Leading Order of QCD*, *Eur. Phys. J.* **C73** (2013) 2360, [1212.1319].
- [11] E. R. Nocera, *Inclusion of W^\pm single-spin asymmetry data in a polarised PDF determination via Bayesian reweighting*, to appear in the proceedings of *QCD-N'12*, 1302.6409.
- [12] D. de Florian, R. Sassot, M. Stratmann and W. Vogelsang, *Extraction of Spin-Dependent Parton Densities and Their Uncertainties*, *Phys. Rev.* **D80** (2009) 034030, [0904.3821].
- [13] D. de Florian and W. Vogelsang, *Helicity Parton Distributions from Spin Asymmetries in W -Boson Production at RHIC*, *Phys. Rev.* **D81** (2010) 094020, [1003.4533].