PROCEEDINGS OF SCIENCE

Updates on transversity extractions

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We give a brief overview on some of the latest results on the transversity function. We focus on some recent extractions from azimuthal asymmetries data measured in semi-inclusive deep-inelastic scattering processes, and on the impact of transverse single-spin asymmetry data measured in polarised proton-proton collisions on these extractions.

7th International Workshop on "Transverse phenomena in hard processes and the transverse structure of the proton (Transversity2024)
3-7 June 2024
Trieste, Italy

*Speaker

 https://pos.sissa.it/

PoS(Transversity2024)010

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1. Introduction

The transversity function, $h_1^q(x)$, is one of the three independent functions describing the collinear structure of spin-$\frac{1}{2}$ hadrons at leading twist. Being a chiral-odd quantity, it is not accessible in deep-inelastic scattering (DIS) processes. Thus, it has to be coupled with another chiral-odd quantity. In the context of collinear perturbative QCD, $h_1^q(x)$ is accessed together with di-hadron fragmentation functions (FFs) in two-hadron production in proton-proton and lepton-proton collisions [1–4], or in the framework of transverse momentum dependent distributions (TMDs), together with the Collins FF in semi-inclusive DIS (SIDIS) processes [5–7].

h_1^q is related to the two other independent collinear distributions (unpolarised and helicity PDFs) by the bound derived by Soffer [8]:

$$|h_1^q(x, Q^2)| \leq \frac{1}{2}\left[f_{q/p}(x, Q^2) + g_{1L}^q(x, Q^2)\right] \equiv \mathrm{SB}^q(x, Q^2)\,. \tag{1}$$

The Soffer bound (SB) was shown to be preserved by Q^2 evolution up to next-to-leading order in QCD [9, 10], and it represents a useful constraint for phenomenological analyses.

The interest in transversity extractions goes beyond the description of hadron structure. Indeed, quarks contribute to the nucleon tensor charge via the first Mellin moment of the non-singlet quark combination, defined as:

$$\delta q = \int_0^1 \left[h_1^q(x) - h_1^{\bar{q}}(x)\right] dx\,, \tag{2}$$

and the isovector combination of tensor charges

$$g_T = \delta u - \delta d \tag{3}$$

represents also an interesting quantity for beyond Standard Model (BSM) effects [11–13]. δq and g_T are also intensively studied within lattice QCD [14]. Therefore, transversity-related studies represent a bridge between QCD phenomenology, lattice QCD and BSM physics.

Here, we will concentrate on the latest results on transversity extractions within the TMD framework, touching upon different issues such as the usage of the SB and the compatibility of h_1^q extractions with complementary data from $p^\uparrow p$ collisions.

2. Latest results from SIDIS data

We start by summarising the results of Ref. [7], where the issue of the usage of the SB in the transversity extraction was thoroughly investigated. When extracting the transversity function, it is customary to adopt, at the initial scale Q_0^2, a parametrisation proportional to the SB [1, 3, 5, 6]

$$h_1^q(x, Q_0^2) \propto \mathrm{SB}(x, Q_0^2)\,. \tag{4}$$

The functional forms are written in a way such that the SB is automatically fulfilled for every x and Q^2 values throughout the fit. This choice represents a potential extra bias for the extraction: the amount of data available for the fit is not always large enough, and is usually not covering a sufficiently wide x-region. Therefore, when computing δq and g_T, their value mostly results from an extrapolation that depends on the selected functional form for h_1^q.

In Ref. [7] we proposed to avoid the automatic fulfillment of the SB in the parametrisation, but to apply it *a posteriori* on the extracted transversity functions. To illustrate the new method, we updated the extraction of Ref. [15], where the transversity function is parametrised as:

$$h_1^q(x, Q^2, k_\perp^2) = h_1^q(x, Q^2)\frac{e^{-k_\perp^2/\langle k_\perp^2\rangle}}{\pi\langle k_\perp^2\rangle}\,, \tag{5}$$
$$h_1^q(x, Q_0^2) = N_q^T x^\alpha (1-x)^\beta \frac{(\alpha+\beta)^{\alpha+\beta}}{\alpha^\alpha \beta^\beta}\mathrm{SB}^q(x, Q_0^2)$$

for $q = u_v, d_v$. Upon constraining $|N_q^T| \le 1$ the SB is automatically fulfilled. Within the new approach, such a constraint is no longer adopted on the parametrisation, but rather imposed on the Monte Carlo (MC) sets generated for estimating the uncertainty on h_1^q. In doing so, we removed this extra bias, and we are able to check if the extracted transversity PDFs are compatible with the SB.

The results are presented in Fig. 1, where we dubbed as “using SB” and “no SB” respectively the cases in which we apply the SB a posteriori and the one in which the SB is not applied at all. We note that: (a) the two extractions have almost the same $\chi^2_{\mathrm{dof}} \approx 0.93$; (b) the application of the SB a posteriori allows to properly estimate the size of the d_v transversity function and its uncertainty (cfr. *e.g.* Fig. 7 of Ref. [15]); (c) when relaxing the SB constraint, while the extracted $h_1^{u_v}(x)$ does not change very much, $h_1^{d_v}$ apparently violates the SB; (d) the violation has a statistical significance smaller than 1σ where data is available (white background in the plots of Fig. 1).

Later, in Ref. [16], we updated again the extraction of the transversity functions by including the latest data from the HERMES Collaboration [17]. A comparison of the two extractions of Ref. [7] (dubbed as “fit 2020”, “using SB” case) and of Ref. [16] (“fit 2023”) is presented in Fig. 2. Note that the two extractions adopted a different collinear PDF set, namely the CTEQ66 [18] and the MSHT20nlo [19] sets, respectively. On the other hand, we used the same collinear helicity PDF set from DSSV [20] and the same collinear FFs for pions and kaons from DEHSS [21, 22][1]. The main difference between the two extraction is in the magnitude of $h_1^{u_v}$, whose corresponding normalization value is, on average, larger than the one of the previous extraction, as shown in the right panel of Fig. 2. Nevertheless, the two extractions are compatible with each other. In the

[1] We guide the reader to [7, 16] for all the details about the adopted parametrisations.

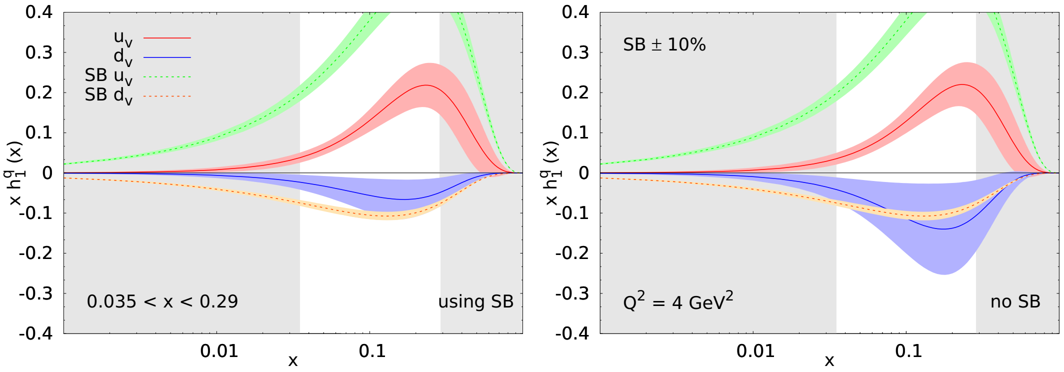

Figure 1: Comparison of extracted transversity functions for u_v and d_v with the application of the SB a posteriori (left) or without applying the SB (right). Figure taken from Ref. [7].

future, the new COMPASS measurements [23] are expected to further reduce the uncertainties on the extracted transversity functions.

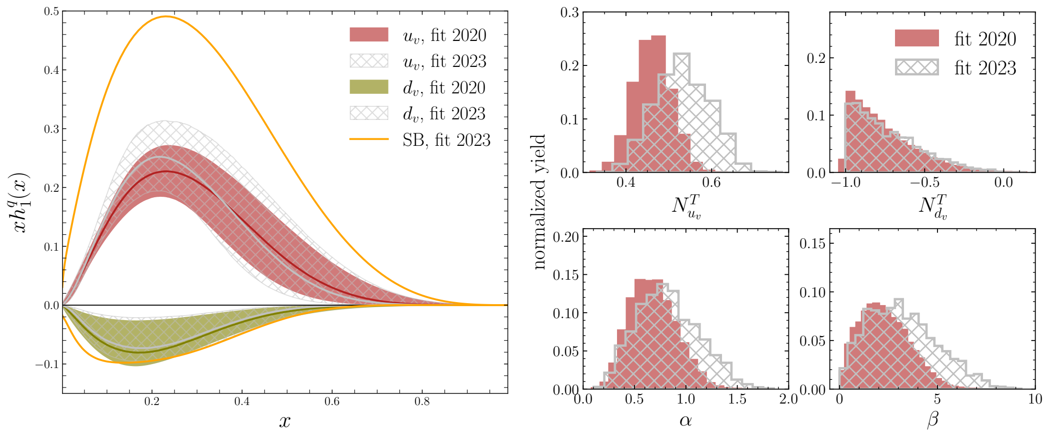

Figure 2: Left: comparison of extracted transversity functions from Ref. [7] ("fit 2020") and Ref. [16] ("fit 2023") and corresponding Soffer bound for the extraction of Ref. [16] . Right: comparison of parameter distributions for the two extractions.

3. Impact of A_N data

As previously mentioned, SIDIS data are limited in their kinematical coverage. Hence, complementary data are needed to reduce the extent to which the extrapolation for δq and g_T is performed.

Another proxy to the transversity function are the transverse single-spin asymmetries (TSSA or A_N) measured in $p^{\uparrow}p \to hX$ processes. These reactions can be described within the Generalised Parton Model (GPM) [24], where a factorised formulation in terms of TMDs is assumed as a starting point for the cross section, or within the Colour Gauge Invariant extension of the GPM (CGI-GPM) [25][2].

[2]This extension allows to recover the Sivers sign change through a one gluon exchange approximation.

The TSSA is defined as:

$$A_N = \frac{d\sigma^{\uparrow} - d\sigma^{\downarrow}}{d\sigma^{\uparrow} + d\sigma^{\downarrow}} = \frac{d\Delta\sigma}{2d\sigma} \simeq \frac{d\Delta\sigma_{\rm Siv} + d\Delta\sigma_{\rm Col}}{2d\sigma}\,, \tag{6}$$

where $d\sigma^{\uparrow}(\downarrow)$ is the polarised cross section for upward (downward) proton transverse polarisation, and where in the last equality we explicitly assume the (CGI-)GPM. The two terms at the numerator of Eq. (6) are related to the Sivers and Collins effects respectively. The latter is proportional to the convolution of the TMD transversity and the Collins FF:

$$d\Delta\sigma_{\rm Col} \propto \sum_{a,b,c,d} h_1^a(x_a, k_{\perp a}) \otimes f_{b/p}(x_b, k_{\perp b}) \otimes d\Delta\sigma^{a^{\uparrow}b\to c^{\uparrow}d} \otimes H_1^{\perp c}(z, k_{\perp h})\,, \tag{7}$$

and is sensitive to the large-x behaviour of h_1^q.

In Ref. [16] a Bayesian simultaneous reweighting was applied on the Sivers, transversity and Collins extractions from SIDIS and e^+e^- data, using A_N data measured by the BRAHMS and STAR Collaborations at RHIC. The results for the reweighted transversity functions and parameter distributions are presented in Fig. 3. Some comments are in order: (a) A_N data mostly impact on the transversity distribution; (b) the reweighted transversity distributions in the (CGI-)GPM formalism follow the SB shape rather closely at large x (see also the α and β distributions on the right panel of Fig. 3); (c) the uncertainty reduction is up to 80-90% for h_1^q at large x; (d) the Collins mechanism turned out to be the dominant contribution to A_N[3].

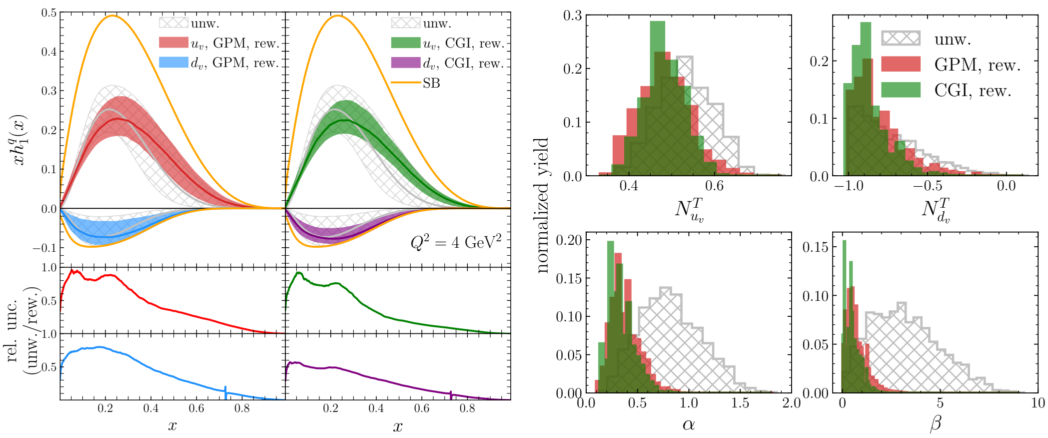

Figure 3: Unweighted and reweighted transversity functions from Ref. [16] (left) and comparsion of unweighted and reweighted parameter distributions (right) in the GPM and the CGI-GPM models.

4. Tensor charges

Through Eq. (2) and Eq. (3) we can compute the tensor charges at $Q^2 = 4$ GeV^2 for the two transversity extractions [7, 16] we have presented here. We summarise the results below in Table 1.

[3]In the (CGI-)GPM this was never seen before applying the SB a posteriori on the MC sets, finding now consistency with the observations in the collinear twist-3 formalism [26].

	$Q^2 = 4$ GeV^2				
	using SB Ref. [7]	no SB Ref. [7]	unw. Ref. [16]	GPM rew. Ref. [16]	CGI rew. Ref. [16]
δu	0.42 ± 0.09	0.40 ± 0.09	$0.46^{+0.10}_{-0.09}$	$0.47^{+0.09}_{-0.07}$	$0.47^{+0.08}_{-0.05}$
δd	-0.15 ± 0.11	-0.29 ± 0.22	$-0.15^{+0.10}_{-0.07}$	$-0.18^{+0.10}_{-0.06}$	$-0.19^{+0.07}_{-0.05}$
g_T	0.57 ± 0.13	0.69 ± 0.21	$0.60^{+0.13}_{-0.11}$	$0.64^{+0.11}_{-0.09}$	$0.65^{+0.10}_{-0.07}$

Table 1: Tensor charges computed for the extractions of Ref. [7] and Ref. [16], respectively with symmetric and asymmetric uncertainties at 2σ confidence level.

Finally, in Fig. 4 we present a comparison of the results of Refs. [7, 16] and various estimates of the tensor charges from phenomenological analyses. All of these analyses yield consistent values for g_T , δu, and δd. This corroborates the consistency of different extractions of transversity within different approaches exploiting a variety of experimental data.

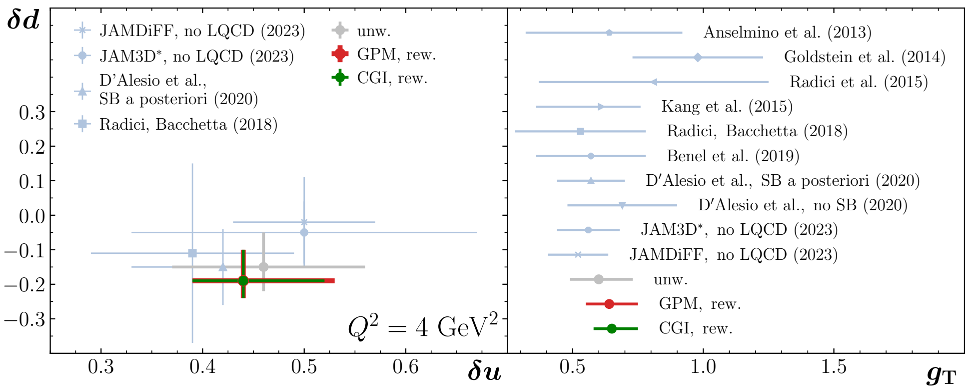

Figure 4: Comparison of u and d tensor charges (left panel) and the iso-vector combination g_T (right panel) from Ref. [16] with other phenomenological estimates at $Q^2 = 4$ GeV^2. Figure taken from Ref. [16]. See references therein for the different results from other phenomenological extractions.

5. Conclusions

We have presented here the latest updates on transversity extractions within the TMD framework. We have studied the role of the Soffer bound in the determination of transversity and the tensor charges, proposing a new approach for the application of positivity bounds in phenomenological analyses. This procedure allows to properly explore the parameter space and to test whether theoretical expectations are met by experimental data. Furthermore, we have presented the results of a simultaneous Bayesian reweighting of the transversity function using A_N data for polarised pp scattering. A_N data give further constraints on the large-x behaviour of the transversity functions, and the corresponding tensor charge results corroborate the consistency of several extractions within different formalisms that probe h_1^q in a variety of processes.

Acknowledgments

C.F. is supported by the European Union ”Next Generation EU" program through the Italian PRIN 2022 grant n. 20225ZHA7W.

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