QCD Evolution Workshop 2014
International Journal of Modern Physics: Conference Series
Vol. 37 (2015) 1560062 (9 pages)

DOI: 10.1142/S2010194515600629

Phenomenological Extraction of Transversity from COMPASS SIDIS and Belle e^+e^- Data

Franco Bradamante*

Dipartimento di Fisica, Trieste University, and INFN,
Sezione di Trieste, via A. Valerio 2, I-34127 Trieste, Italy
Franco.Bradamante@ts.infn.it

Published 25 February 2015

The valence transversity distributions of the u- and the d-quarks have been extracted point-by-point from single-hadron production and dihadron production data measured in semi-inclusive deep inelastic scattering and in e^+e annihilation. The extraction is based on some simple assumptions and does not require any parametrization. The transversity distributions are found to be compatible with each other and with previous analyses.

Keywords: Nucleon spin structure; transversity; COMPASS; BELLE.

PACS numbers: 13.60.−r, 13.88.+e, 14.20.−c, 14.65.−q

1. Introduction

The first evidence that the transversity parton distribution function (PDF) is different from zero came exactly 10 years ago, at the XVI International Spin Physics Symposium SPIN2014, where the HERMES Collaboration presented convincing evidence that the Collins asymmetry in $e^-p \to e^-hX$ semi-inclusive deep inelastic scattering (SIDIS) of 27 GeV electrons on transversely polarized protons is different from zero.[1] At the same conference the COMPASS Collaboration showed that the Collins asymmetry measured by scattering 160 GeV muons off transversely polarized deuterons was compatible with zero,[2] an indication that there could be cancellation between the u and d-quark transversity. One year after, an independent assessment that the Collins fragmentation function (FF) is different from zero came from the Belle Collaboration which measured, event by event, a non-zero correlation between the azimuthal angles of the hadrons in opposite jets in $e^+e^- \to h_1h_2X$ processes.[3] At this point it was possible to carry on first extractions[4] of the transversity PDF h_1 and of the Collins FF H_1 combining in a global fit the SIDIS experimental data from HERMES[5] and COMPASS,[6,7] with the Belle data.[3] In the past 10 years the

*In collaboration with Anna Martin and Vincenzo Barone.

experiments have produced more results,[8–10] reducing considerably the experimental errors, a JLab experiment has produced first results on a transversely polarized neutron target,[11] and several extractions of the transversity PDF and of the Collins FF have been performed by the Torino group.[12] Moreover a different method to address transversity has also been pursued,[13] based on the expected transverse spin asymmetry of the plane defined by two hadrons produced in the SIDIS process. These dihadron asymmetries were indeed measured by HERMES on a proton target[14] and by COMPASS, first on a deuteron target,[15] where the effect was small, compatible with zero, and later on a proton target.[15,16] The observables measured in these processes contain, besides the transversity, two unknown dihadron fragmentation functions (DiFFs), D_q and $H_q^{\angle}$. Very much as for the Collins asymmetry, also in this case independent information on the DiFF's came from the Belle Collaboration, which measured the correlations between the azimuthal angles of the planes containing two hadrons belonging to two back to back jets in $e^+e^- \to q\bar{q} \to j\bar{j}$ [22]. A global fit using SIDIS and e^+e^- data was performed, by the Pavia group,[17] and indeed the extracted transversity distributions are in rather good agreement with the corresponding quantities determined by the Torino group.

In this work we adopted a different approach with respect to that of Refs. [12] and [17]. Our goal was to extract the transversity PDF directly from the 1-h and 2-h SIDIS and e^+e^- data, without any parametrization of PDFs and FFs, and consequently without performing any global fit. The strategy was to extract from the e+e data the analyzing power of 1-h and 2-h production from a transversely polarized target, and then use this information to obtain point-by-point the transversity distributions from the SIDIS data. The main purpose of the exercise was to show that the transversity distributions could be obtained in a simple and straightforward way. As a consequence of this approach

i) having no parametrization for the PDFs nor for the FF we could not take care of evolution,
ii) the need to dispose of both proton and deuteron data measured at the same Q^2 value limited the data set to the COMPASS data.

In the following, we first discuss the 2-h case, which is simpler, and move to the 1-h case afterwards.

2. Dihadron Asymmetries

2.1. *Dihadron asymmetries in SIDIS*

After correcting for the spin transfer parameter and with the COMPASS azimuthal angle convention, the transverse spin asymmetry (differential in $x, z, M_{2h}, \ldots$) is given by[18,19]

$$A^{2h} = \frac{R}{M_{2h}} \frac{\sum_{q,\bar{q}} e_q^2 x h_1^q H_q^{\angle}}{\sum_{q,\bar{q}} e_q^2 x f_1^q D_q} = \frac{\sum_{q,\bar{q}} e_q^2 x h_1^q H_q}{\sum_{q,\bar{q}} e_q^2 x f_1^q D_q}. \tag{1}$$

where M_{2h} is the invariant mass of the hadron pair, $z = z_1 + z_2$ and we have defined

$$H_q(z, M_{2h}) = \sin\theta_q \cdot R/M_{2h} \cdot H_q^{\angle}(z, M_{2h}). \tag{2}$$

with θ the usual angle in the two hadron center of mass system, $\vec{R} = (\vec{P}_1 - \vec{P}_2)/2$, with $\vec{R}_T = \vec{R}\sin\theta$ and $R/M_{2h} = \sqrt{1 - 4m_\pi^2/M_{2h}^2}/2$.

With very reasonable assumptions,[18, 20] namely:
- for the polarised part:

$$H_q = -H_{\bar{q}}, \quad H_u = -H_d, \quad H_s = H_c = 0 \tag{3}$$

- for the unpolarised FFs:

$$D_u = D_d = D_{\bar{u}} = D_{\bar{d}}, \quad D_s = D_{\bar{s}}, \quad D_c = D_{\bar{c}} \tag{4}$$

and,

$$D_s \simeq D_c \simeq 0.5 D_u \tag{5}$$

which is close the the usual relation between favored and unfavored FFs and gives a c yield $\simeq 0.2$ the uds yield neglecting the s and c quarks contributions, and integrating over z and M. The asymmetries measured in COMPASS in the different x bins can then be written as:

$$A_p^{2h}(x) \simeq \frac{4xh_1^{u_v} - xh_1^{d_v}}{4xf_1^{*u} + xf_1^{*d}} \frac{\langle H_u \rangle}{\langle D_u \rangle}, \quad A_d^{2h} \simeq \frac{3}{5} \frac{xh_1^{u_v} + xh_1^{d_v}}{xf_1^{*u} + xf_1^{*d}} \frac{\langle H_u \rangle}{\langle D_u \rangle}. \tag{6}$$

The values of the COMPASS asymmetries we have used in this analysis are taken from Refs. [15, 16]. We use the h^+h^- results, assuming they are pions, which is a good approximation.

2.2. *Dihadron asymmetries at Belle*

The extraction of the analysing power described here is very similar to what has been done by the Pavia group in their early paper on this subject.[18]

In $e^+e^- \to q\bar{q} \to j\bar{j}$ the asymmetry (differential in z, $\bar{z}$, M_{2h} and $\overline{M}_{2h}$) can be written as[20, 21]

$$a_{12} = \frac{s^2}{1 + c^2} \frac{\sum_q e_q^2 H_q H_{\bar{q}}}{\sum_q e_q^2 D_q D_{\bar{q}}}. \tag{7}$$

where:
- the "bar" quantities refer to the jet initiated by the $\bar{q}$;
- $s^2 = \sin^2\theta_2$ and $c^2 = \cos^2\theta_2$, with θ_2 the angle between the e^+ and the pair direction;

The terms $\sin\theta_q$ ($\sin\theta_{\bar{q}}$) and R/M_{2h} ($\bar{R}/\overline{M}_{2h}$) are included in $H_q^{\angle}$ ($H_{\bar{q}}^{\angle}$) as from Eq. (2).

The fully integrated asymmetry measured by Belle[21] is $a^I_{12} = -0.0196 \pm 0.0002 \pm 0.0022$. With the previous assumptions on the FFs and D_c fixed in order to reproduce the Belle charm yield ($4\,D_c^2 \simeq 2.6 D_u^2$ [21]), it is

$$a^I_{12} \simeq -\frac{5}{8}\frac{s^2}{1+c^2}\left(\frac{\langle H_u \rangle}{\langle D_u \rangle}\right)^2 \tag{8}$$

where $\langle ... \rangle$ stays for integral over z_i, M_i, and the analysing power is

$$\langle a_P \rangle = \frac{\langle H_u \rangle}{\langle D_u \rangle} = \sqrt{-\frac{8}{5}\frac{(1+c^2)}{s^2} a^I_{12}} = 0.203, \tag{9}$$

with negligible statistical error and a systematic uncertainty of about 5%. The value has been taken as negative in order to get a positive transversity for the u quark.

This value for the analysing power will be used for the extraction of the transversity PDFs from the COMPASS data without any correction because:

- in spite of the different Q^2 values, the mean values of the relevant kinematic variables in COMPASS and BELLE are quite close.
- we have neglected the Q^2 evolution of the FFs which can be different for spin dependent and independent part. In Ref. [18], it has been evaluated as a -8% effect.

2.3. *Transversity PDFs from dihadron asymmetries*

Using the previous expressions and experimental values one can extract the transversity PDF from the COMPASS and BELLE results.

To this aim it is useful to introduce the quantities

$$c_p = 4xf_1^{*u} + xf_1^{*d}, \quad c_d = 5(xf_1^{*u} + xf_1^{*d})/3, \tag{10}$$

where $f_1^{*q} = f_1^q + f_1^{\bar{q}}$. They are obtained from CTEQ5D PDF and DSS LO FF parametrisations.

From the measured SIDIS asymmetries one can thus evaluate the quantities

$$4h_1^{u_v} - h_1^{d_v} = A_p^{2h} \cdot \frac{c_p}{\langle a_P \rangle}, \quad h_1^{u_v} + h_1^{d_v} = A_d^{2h} \cdot \frac{c_d}{\langle a_P \rangle}. \tag{11}$$

The preliminary results are shown in Fig. 1.

The transversity PDFs are then given by

$$\begin{aligned} xh_1^{u_v} &= \frac{1}{5}\frac{1}{\langle a_P \rangle}(c_p \cdot A_p^{2h} + c_d \cdot A_d^{2h}), \\ xh_1^{d_v} &= \frac{1}{5}\frac{1}{\langle a_P \rangle}(-c_p \cdot A_p^{2h} + 4c_d \cdot A_d^{2h}). \end{aligned} \tag{12}$$

The preliminary values are shown as closed squares in Fig. 3 together with the corresponding quantities extracted from the Collins asymmetries as described in the next section.

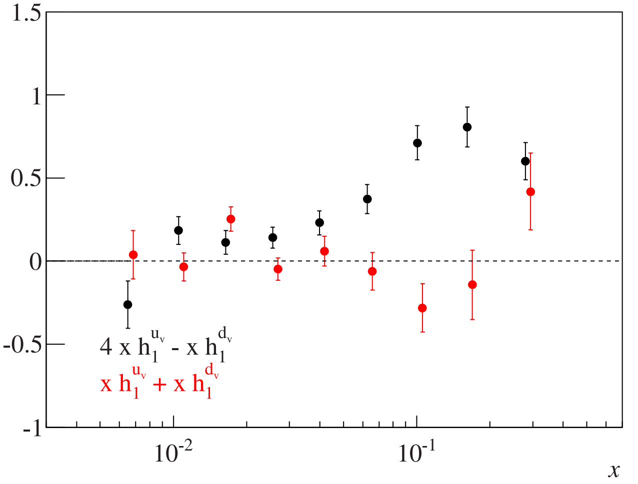

Fig. 1. Preliminary values of $4xh_1^{u_v} - xh_1^{d_v}$ (p) and $xh_1^{u_v} + xh_1^{d_v}$ (d).

3. Collins Asymmetries

The notation we use is the same as in Refs. [25, 23]. For convenience we introduce

$$H_{1q}^{\pm} = H_{1(q\to\pi^{\pm})}^{\perp(1/2)}, \quad D_{1q}^{\pm} = D_{1(q\to\pi^{\pm})},$$

and we consider only π^+ and π^- in the final state. We use in the following the experimental SIDIS asymmetries for charged hadrons from the entire data set of COMPASS, from the 2002, 2003 and 2004 runs with the deuteron target[6,7] and 2007 and 2010 runs with the proton target.[9,10]

As in the previous case, from the Belle data one has to calculate the analysing power to be used for the SIDIS asymmetries to extract transversity.

3.1. e^+e^- *annihilation into pions*

In $\mathrm{e}^+\mathrm{e}^- \to q\bar{q} \to j\bar{j}$ several azimuthal asymmetries have been measured by Belle.[22] Here we will use the so-called A_{12}^{UL} asymmetry (here the dependence on $M_{1,2}$ is not written explicitly) which can be written as[4,23]

$$A_{12}^{UL}(z_1, z_2) = \frac{\langle s^2 \rangle}{\langle 1 + c^2 \rangle} \left[P_U(z_1, z_2) - P_L(z_1, z_2) \right] \tag{13}$$

where z_1 and z_2 are the relative energies of the two pions, $s^2 = \sin^2\theta$, $c^2 = \cos^2\theta$ and

$$\begin{aligned} P_U(z_1, z_2) &= \frac{\sum_q e_q^2 [H_{1q}^+(z_1) H_{1\bar{q}}^-(z_2) + H_{1q}^-(z_1) H_{1\bar{q}}^+(z_2)]}{\sum_q e_q^2 [D_{1q}^+(z_1) D_{1\bar{q}}^-(z_2) + D_{1q}^-(z_1) D_{1\bar{q}}^+(z_2)]}, \\ P_L(z_1, z_2) &= \frac{\sum_q e_q^2 [H_{1q}^+(z_1) H_{1\bar{q}}^+(z_2) + H_{1q}^-(z_1) H_{1\bar{q}}^-(z_2)]}{\sum_q e_q^2 [D_{1q}^+(z_1) D_{1\bar{q}}^+(z_2) + D_{1q}^-(z_1) D_{1\bar{q}}^-(z_2)]}. \end{aligned} \tag{14}$$

The assumptions on the FFs are the usual ones, namely the favored and disfavored FFs are

$$\begin{aligned} H_1^{fav} &= H_{1u}^{+} = H_{1d}^{-} = H_{1\bar{u}}^{-} = H_{1\bar{d}}^{+}, \\ H_1^{dis} &= H_{1u}^{-} = H_{1d}^{+} = H_{1\bar{u}}^{+} = H_{1\bar{d}}^{-}, \end{aligned} \tag{15}$$

and correspondingly for the $D_{1q}^{\pm}$ FFs. Here we ignore the s-quark contribution putting equal to zero both $H_{1s(\bar{s})}^{\pm}$ (see also Eq. (45) of Ref. [23]) and $D_{1s(\bar{s})}^{\pm}$.

In the case $z_1 = z_2 = z$, namely when using only the "diagonal" measurements, it is

$$A_{12}^{UL}(z) = \frac{\langle s^2 \rangle}{\langle 1 + c^2 \rangle} \left[\frac{H_1^{fav}(z)}{D_1^{fav}(z)} \right]^2 B(z) \tag{16}$$

where

$$B(z) = \frac{b(z)[1 + a^2(z)] - [1 + b^2(z)]a(z)}{b(z)[1 + b^2(z)]} \tag{17}$$

and

$$a(z) = \frac{H_1^{dis}(z)}{H_1^{fav}(z)}, \quad b(z) = \frac{D_1^{dis}(z)}{D_1^{fav}(z)}. \tag{18}$$

In the right hand term, only the $b(z)$ function can be obtained by standard parametrisations, and the z dependence of $a(z)$ is not known.

We have done two alternative assumptions:

I1 $a(z) = -1$, *i.e.* $H_1^{dis}(z) = -H_1^{fav}(z)$
I2 $a(z) = -b(z)$, *i.e.* $H_1^{dis}(z)/D_1^{dis}(z) = -H_1^{fav}(z)/D_1^{fav}(z)$,

both in agreement with the finding that the asymmetries for positive and negative hadrons have approximately the same size and opposite sign, and with the strong application[23] of the Schäfer-Teryaev sum rule.[24] These assumptions allow to evaluate the ratio $H_1^{fav}(z)/D_1^{fav}(z)$ in the 4 z bins of the Belle data.

The measured values fitted with a function of z are shown in Fig. 2.

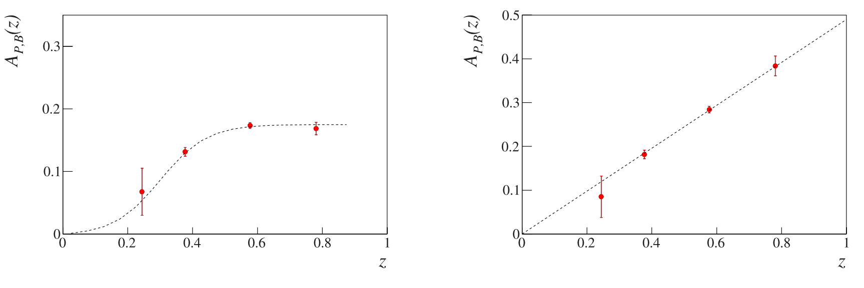

Fig. 2. The analysing power $A_P(z) = H_1^{fav}(z)/D_1^{fav}(z)$ as function of z for $a = -1$ (right) and $a = -b$ (left).

To obtain the analysing power the function are integrated over z giving

I1 $H_1^{fav}(z)/D_1^{fav}(z) \simeq 0.10$,
I2 $H_1^{fav}(z)/D_1^{fav}(z) \simeq 0.18$

with a weak x dependence if the evolution of H_1^{fav} is negligible. If the evolution of H_1^{fav} is the same as that of D_1^{fav} the analysing powers decrease in both cases by about 10% .

3.2. *Pion production in SIDIS*

The Collins asymmetry for $\pi^{\pm}$ in SIDIS can be written as

$$A^{\pm}_{Coll}(x,z) = \frac{\sum_{q,\bar{q}} e_q^2 x h_1^q(x) \otimes H^{\pm}_{1q}(z)}{\sum_{q,\bar{q}} e_q^2 x f_1^q(x) \otimes D^{\pm}_{1q}(z)} \tag{19}$$

Using the "Gaussian ansatz" [25] for the PDFs and the FFs, it can be re-written as

$$A^{\pm}_{Coll}(x,z) == C_G \cdot \frac{\sum_{q,\bar{q}} e_q^2 x h_1^q(x) H^{\pm}_{1q}(z)}{\sum_{q,\bar{q}} e_q^2 x f_1^q(x) D^{\pm}_{1q}(z)} \tag{20}$$

where

$$C_G = \frac{1}{\sqrt{1 + z^2 \langle p^2_{h_1} \rangle / \langle p^2_{H_1} \rangle}} \tag{21}$$

In the following we will assume $C_G = 1$, since $(z^2 \langle p^2_{h_1} \rangle / \langle p^2_{H_1} \rangle) \ll 1$. This assumption is expected to be reasonable in particular at low z, where the statistics is highest.

When only the x dependence of $A^{\pm}_{Coll}$ is considered the previous expression becomes

$$A^{\pm}_{Coll}(x) = \frac{\sum_{q,\bar{q}} e_q^2 x h_1^q(x) \langle H^{\pm}_{1q} \rangle}{\sum_{q,\bar{q}} e_q^2 x f_1^q(x) \langle D^{\pm}_{1q} \rangle} \tag{22}$$

where, for the COMPASS published data

$$\langle H^{\pm}_{1q} \rangle = \int_{0.2}^{1} H^{\pm}_{1q}(z) dz, \quad \langle D^{\pm}_{1q} \rangle = \int_{0.2}^{1} D^{\pm}_{1q}(z) dz. \tag{23}$$

Neglecting the s and c contributions, one gets

$$\begin{aligned}
A^{+}_{Coll,p} &= \frac{\langle H_1^{fav} \rangle}{\langle D_1^{fav} \rangle} \frac{4(xh_1^u + \alpha x h_1^{\bar{u}}) + (\alpha x h_1^d + x h_1^{\bar{d}})}{d_p^+} \\
A^{-}_{Coll,p} &= \frac{\langle H_1^{fav} \rangle}{\langle D_1^{fav} \rangle} \frac{4(\alpha xh_1^u + x h_1^{\bar{u}}) + (x h_1^d + \alpha x h_1^{\bar{d}})}{d_p^-} \\
A^{+}_{Coll,d} &= \frac{\langle H_1^{fav} \rangle}{\langle D_1^{fav} \rangle} \frac{(xh_1^u + xh_1^d)(4+\alpha) + (xh_1^{\bar{u}} + xh_1^{\bar{d}})(1+4\alpha)}{d_d^+}. \\
A^{-}_{Coll,d} &= \frac{\langle H_1^{fav} \rangle}{\langle D_1^{fav} \rangle} \frac{(xh_1^u + xh_1^d)(4\alpha+1) + (xh_1^{\bar{u}} + xh_1^{\bar{d}})(4+\alpha)}{d_d^-}.
\end{aligned} \tag{24}$$

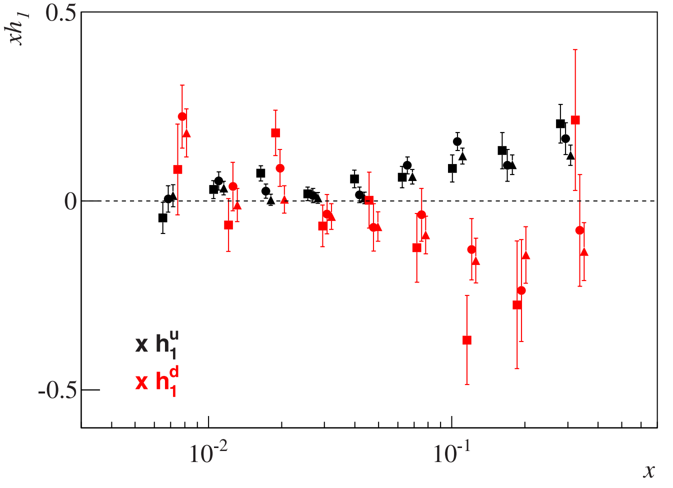

Fig. 3. Preliminary results for the transversity PDFs for u-quark (black points) and d-quark (red points) from dihadron (squares) and Collins asymmetries (circles for I1, triangles for I2).

where $\alpha = \langle H_1^{dis} \rangle / \langle H_1^{fav} \rangle$, the quantities $d_{p,d}^{\pm}$ correspond to the numerators when evaluated with unpolarised PDFs and FFs, and $\langle H_1^{fav} \rangle / \langle D_1^{fav} \rangle$ is taken from the previous section in the two different hypothesis.

Neglecting $\bar{q}$ transversity and solving the equations, in the two assumptions for $a(z)$ and α, one gets the preliminary values for the valence quarks transversity PDFs given in Fig. 3.

4. Conclusions

In spite of the large difference in the analysing power in the two hypothesis I1 and I2, the extracted transversity values from the Collins asymmetries are remarkably close and in very good agreement with the corresponding quantities evaluated from the dihadron asymmetries.

As a conclusion it can be safely stated that the Q^2 evolution affects in a similar way the Collins and the dihadron asymmetries.

Also, the effect of the convolution over the transverse momenta, which is present in the Collins asymmetry, seems to be small.

Finally the method looks powerful and in our opinion it can be safely applied also in the case of the Sivers and Boer-Mulder asymmetries.

References

1. G. Schnell [HERMES Collaboration], DESY-HERMES-04-40 (2004).
2. P. Pagano [COMPASS Collaboration], hep-ex/0501035 (2005).
3. K. Abe *et al.* [Belle Collaboration], *Phys. Rev. Lett.* **96**, 232002 (2006).

4. M. Anselmino, M. Boglione, U. D'Alesio, A. Kotzinian, F. Murgia, A. Prokudin and C. Turk, *Phys. Rev. D* **75**, 054032 (2007).
5. A. Airapetian *et al.* [HERMES Collaboration], *Phys. Rev. Lett.* **94**, 012002 (2005).
6. V. Y. Alexakhin *et al.* [COMPASS Collaboration], *Phys. Rev. Lett.* **94**, 202002 (2005).
7. E. S. Ageev *et al.* [COMPASS Collaboration], *Nucl. Phys. B* **765**, 31 (2007).
8. A. Airapetian *et al.* [HERMES Collaboration], *Phys. Lett. B* **693**, 11 (2010).
9. M. G. Alekseev *et al.* [COMPASS Collaboration], *Phys. Lett. B* **692**, 240 (2010).
10. C. Adolph *et al.* [COMPASS Collaboration], *Phys. Lett. B* **717**, 376 (2012).
11. X. Qian *et al.* [Jefferson Lab Hall A Collaboration], *Phys. Rev. Lett.* **107**, 072003 (2011).
12. M. Anselmino, M. Boglione, U. D'Alesio, S. Melis, F. Murgia and A. Prokudin, *Phys. Rev. D* **87**, 094019 (2013).
13. J. C. Collins, S. F. Heppelmann and G. A. Ladinsky, *Nucl. Phys. B* **420**, 565 (1994).
14. A. Airapetian *et al.* [HERMES Collaboration], *JHEP* **0806**, 017 (2008).
15. C. Adolph *et al.* [COMPASS Collaboration], *Phys. Lett. B* **713**, 10 (2012).
16. C. Adolph *et al.* [COMPASS Collaboration], *Phys. Lett. B* **736**, 124 (2014).
17. A. Bacchetta, A. Courtoy and M. Radici, *JHEP* **1303**, 119 (2013).
18. A. Bacchetta, A. Courtoy and M. Radici, *Phys. Rev. Lett.* **107**, 012001 (2011).
19. M. Radici, A. Bacchetta and A. Courtoy, *Int. J. Mod. Phys. Conf. Ser.* **25**, 1460045 (2014).
20. A. Courtoy, A. Bacchetta, M. Radici and A. Bianconi, *Phys. Rev. D* **85**, 114023 (2012).
21. A. Vossen *et al.* [Belle Collaboration], *Phys. Rev. Lett.* **107**, 072004 (2011).
22. R. Seidl *et al.* [Belle Collaboration], *Phys. Rev. D* **78**, 032011 (2008) [Erratum-ibid. **D86**, 039905 (2012)].
23. A. Bacchetta, L. P. Gamberg, G. R. Goldstein and A. Mukherjee, *Phys. Lett. B* **659**, 234 (2008).
24. A. Schafer and O. V. Teryaev, *Phys. Rev. D* **61**, 077903 (2000).
25. A. V. Efremov, K. Goeke and P. Schweitzer, *Phys. Rev. D* **73**, 094025 (2006).