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Extraction of the worm-gear TMD g_{1T} from COMPASS, HERMES and JLab data on semi-inclusive DIS

Shohini Bhattacharya,[a,b,*] **Zhong-Bo Kang,**[c,d,e] **Andreas Metz,**[b] **Gregory Penn**[f,b] **and Daniel Pitonyak**[g]

[a] *Physics Department, Brookhaven National Laboratory, Bldg. 510A, Upton, NY 11973, USA*
[b] *Department of Physics, Temple University, Philadelphia, PA 19122, USA*
[c] *Department of Physics and Astronomy, University of California, Los Angeles, CA 90095, USA*
[d] *Mani L. Bhaumik Institute for Theoretical Physics, University of California, Los Angeles, CA 90095, USA*
[e] *Center for Frontiers in Nuclear Science, Stony Brook University, Stony Brook, NY 11794, USA*
[f] *Department of Physics, Yale University, New Haven, CT 06511, USA*
[g] *Department of Physics, Lebanon Valley College, Annville, PA 17003, USA*

E-mail: sbhattach@bnl.gov

Transverse momentum dependent parton distributions (TMDs) are an important class of functions required to understand the 3D structure of hadrons in terms of their underlying partons. One of the least known TMDs in terms of a global QCD analysis is the worm-gear TMD g_{1T}. It carries the probabilistic interpretation of finding longitudinally polarized quarks inside transversely polarized hadrons. In this proceedings, we present the first-ever global QCD analysis of the semi-inclusive DIS $A_{LT}^{\cos(\phi_h-\phi_S)}$ data using Monte Carlo techniques to extract the worm-gear TMD g_{1T}. The relevant data are available from COMPASS, HERMES and JLab. We compare our results for g_{1T} with different theoretical approaches, including the large-N_c approximation, the Wandzura-Wilczek-type approximation, and lattice QCD.

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[*] Speaker

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1. Theoretical background

There are two important theoretical predictions for $g_{1T}(x, \vec{k}_\perp^2)$: 1) Large-$N_c$ prediction: In the limit of large number of colors (N_c), $g_{1T}(x, \vec{k}_\perp^2)$ for up and down quark distributions can be related as [1] $g_{1T}^u(x, \vec{k}_\perp^2) \approx - g_{1T}^d(x, \vec{k}_\perp^2)$. 2) Wandzura-Wilczek-type (WW) approximation: By using the QCD equation of motion and neglecting certain quark-gluon correlations, the first $\vec{k}_\perp$ moment of $g_{1T}(x, \vec{k}_\perp^2)$ can be approximated in terms of the helicity PDF $g_1(x)$ as (see for instance Ref. [2]) $g_{1T}^{(1)}(x) \equiv \int d^2\vec{k}_\perp (k_\perp^2/2M^2) g_{1T}(x, \vec{k}_\perp^2) \approx x \int_x^1 dy g_1(y)/y$. While quite some work is available from lattice QCD [3, 4] and models [5], to date there has been no experimental extraction of g_{1T} and as such the validity/violation of these theoretical predictions have never been reported. In Ref. [6] we provided the *first-ever* extraction of g_{1T} from semi-inclusive data available from COMPASS [7], HERMES [8], and JLab [9] and tested the theoretical predictions. Here we summarize our main findings. (We refer to Ref. [6] for an overview of the experimental data and the fitting methodology which is based on Monte-Carlo replicas.)

2. Phenomenological results

2.1 Final fit results

Our final fit results are shown in Figure 1. These results indicate that g_{1T} for up quarks (down quarks) is positive (negative). The error band for the down quarks is relatively larger because of the lack of precise data for π^+ production from JLab, which used a neutron (^{3}He) target. The first prominent qualitative feature that we observe is the compatibility with the large-N_c approximation, for sure in terms of the relative signs (if not the relative sizes) of the two distributions.

2.2 Comparison with Large-N_c and WW-type approximations

Here we check the compatibility of experimental data with the large-N_c and the WW-type approximation. From Figs. 2 and 3 we observe a qualitative agreement of our final fit results with both these approximations. However, there are indications of (slight) violation in both the

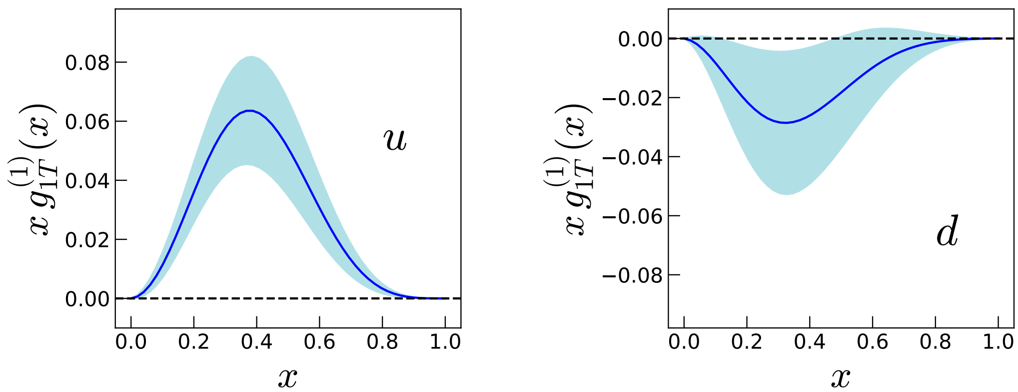

Figure 1: Main global fit results for $xg_{1T}^{(1)}(x)$ at $Q^2 = 4$ GeV^2 for up quarks (left) and down quarks (right) obtained in the weighted χ^2 method.

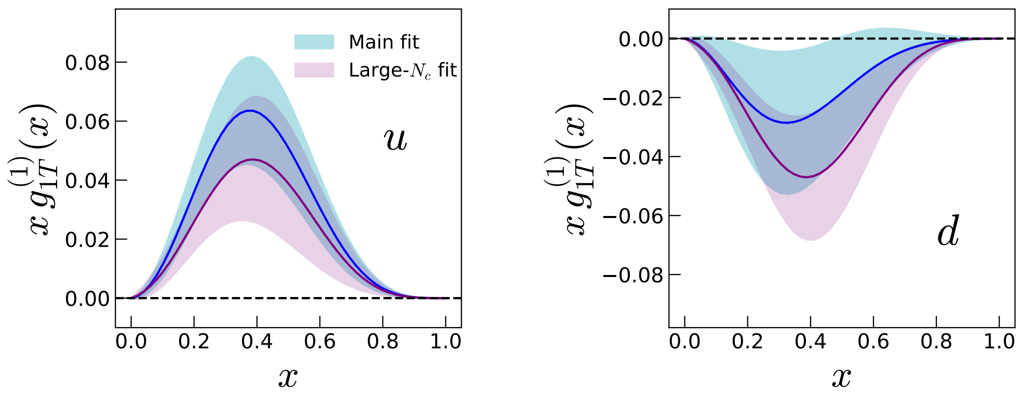

Figure 2: Comparison of our main extraction of $xg_{1T}^{(1)}(x)$ at $Q^2 = 4$ GeV^2 for up quarks (left) and down quarks (right) with the results obtained by imposing the large-N_c approximation on the fit.

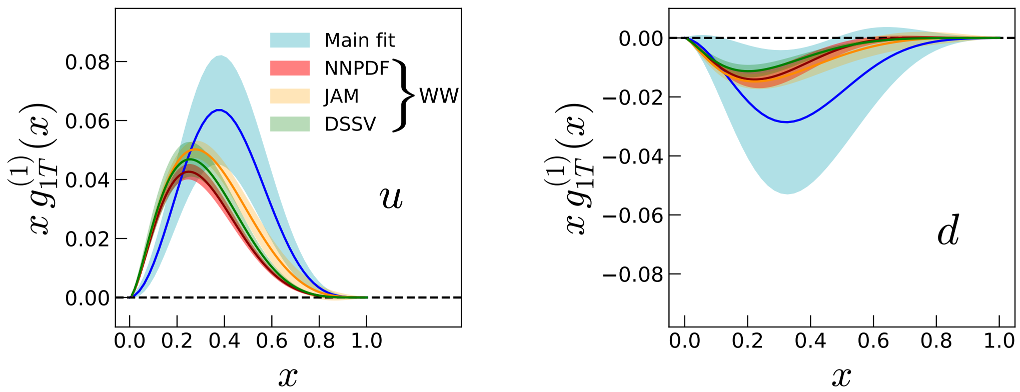

Figure 3: Comparison of our main extraction of $xg_{1T}^{(1)}(x)$ at $Q^2 = 4$ GeV^2 for up quarks (left) and down quarks (right) with the results obtained from the calculation of $xg_{1T}^{\rm WW}(x)$ using $g_1(x)$ taken from NNPDF [10], JAM [11], and DSSV [12].

cases. We also find that the global (weighted) chi-squared for our final fit is consistently better — $\chi_w^2/N_{\rm pts.}|_{\rm Main} = 0.86$ versus $\chi_w^2/N_{\rm pts.}|_{\text{Large-}N_c} = 0.99$ and $\chi_w^2/N_{\rm pts.}|_{\rm NNPDF} = 0.95$ (and similar values from JAM and DSSV). Still, these single values of chi-squared are insufficient to rule out the theoretical predictions. The reason is because these values correspond to the mean value from the replicas. So in Fig. 4 we show a direct comparison of the distribution of chi-squared values of our final fit replicas with those obtained in the large-N_c and the WW-type approximations. From such an analysis it is clear that the statistical spread of the chi-squared values for our results is so large that they overlap rather well with both the theoretical approximations. Therefore, we conclude that the presently available data is actually compatible with both the theoretical approximations.

2.3 Comparison with lattice QCD results for worm-gear shift

In this section, we calculate the so-called worm-gear shift $\langle k_x\rangle_{TL}$ for g_{1T} which is defined as, $\big[\langle k_x\rangle_{TL}\big](Q^2) \equiv M\int_0^1 dx\,\big(g_{1T}^{(1)u}(x,Q^2) - g_{1T}^{(1)d}(x,Q^2)\big)/\int_0^1 dx\,\big(f_1^u(x,Q^2) - f_1^d(x,Q^2)\big)$, with our fit results and in the WW-type approximation, and compare with the corresponding results from

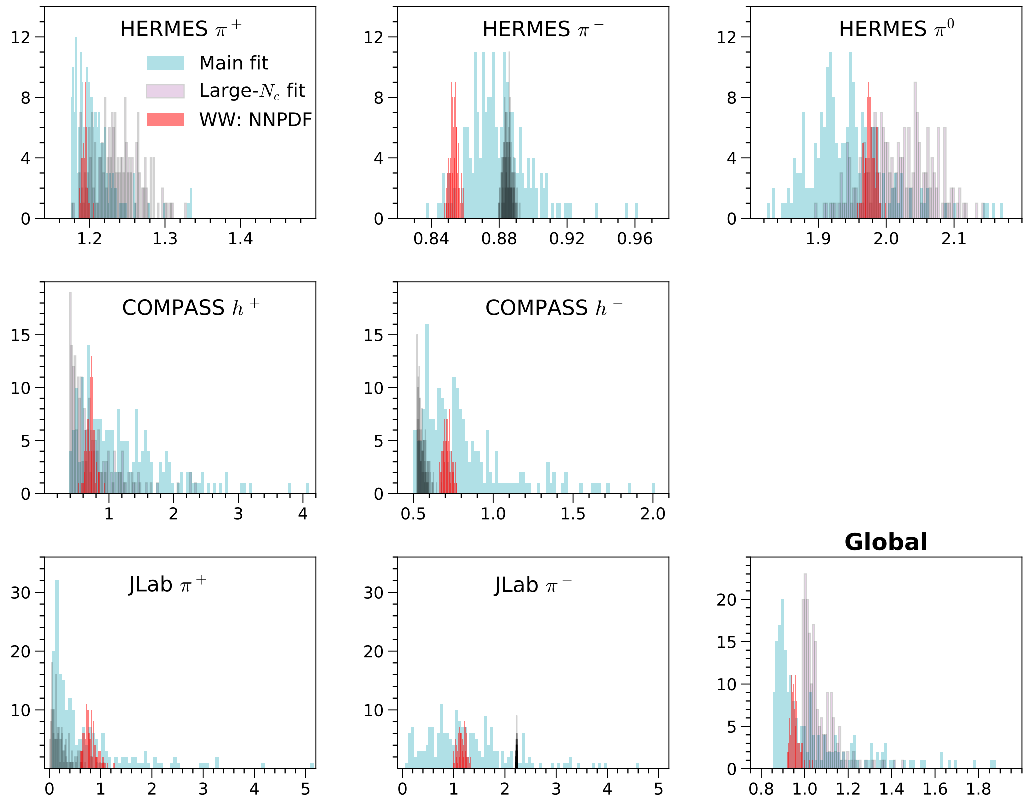

Figure 4: Distribution of $\chi^2_w/N_{\text{pts.}}$ for our main fit results with those obtained in the large-N_c and the WW-type approximations. For the latter, we have shown as the representative case results using NNPDF.

lattice QCD [13]. From Fig. 5 we observe a good compatibility between the results from these three methods. In particular, the agreement with lattice QCD results can be considered to be very encouraging given that there are several caveats present in those calculations.

3. Conclusion

We have shown the first results for g_{1T} extracted from semi-inclusive DIS data from COMPASS, HERMES and JLab data. Our results indicate that g^u_{1T} is positive and g^d_{1T} is negative and the magnitude of g^u_{1T} is somewhat larger than that of g^d_{1T}. Furthermore, we have provided the first quantitative comparison of g_{1T} from the experimental data with the large-N_c approximation, the WW-type approximation and a lattice QCD calculation. Our results indicate that while there seems to be a slight preference for a violation of both the large-N_c and the WW-type approximations, they are still compatible with the experimental data and more precise data will be needed to reliably validate or rule out (if at all) these approximations. We also find a decent compatibility of our results for worm-gear shift for g_{1T} with those from lattice QCD calculations.

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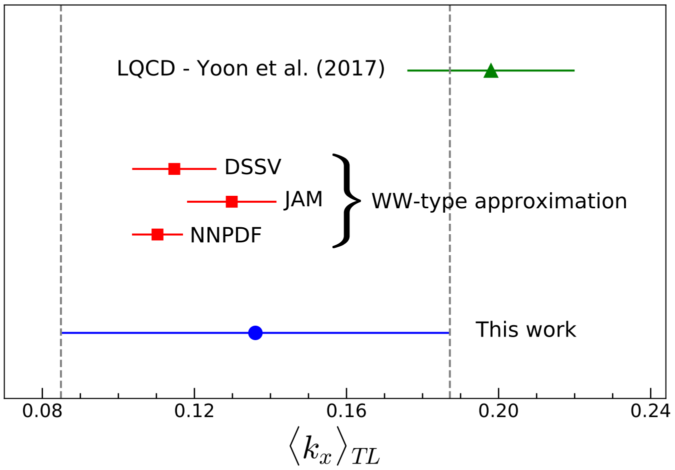

Figure 5: Comparison of the worm-gear shift $\langle k_x \rangle_{TL}$ calculated using our main fit with those obtained in the WW-type approximation as well as lattice QCD. The phenomenological results are at $Q^2 = 4$ GeV^2.

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