NLO CORRECTIONS TO THE WANDZURA-WILCZEK, TWIST-3, NUCLEON DVCS AMPLITUDE FACTORIZE !

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Abstract

We computed the NLO corrections to twist-3, $L \to T$, flavor non-singlet amplitude in DVCS on a nucleon in the Wandzura-Wilczek approximation. Explicit calculation shows that factorization holds for NLO contribution to this amplitude, although the structure of the factorized amplitude at the NLO is more complicated than in the leading-order formula.

Deeply virtual Compton scattering (DVCS) [1]–[8] on a nucleon, $\gamma^* N \to \gamma N'$, is perhaps the cleanest hard reaction sensitive to the generalized parton distributions (GPD). According to celebrated factorization theorems [9, 10, 11] the leading term in the $1/Q^2$ expansion of the DVCS amplitude, where Q^2 is large virtuality of the hard photon, can be expressed in terms of twist-2 generalized parton distributions. Twist-2 GPD's are related to matrix elements of non-local twist-2 quark and gluon string operators. These matrix elements contain complete information about nucleon structure seen by a highly-virtual electromagnetic probe. For that reason in recent years DVCS has been the subject of extensive theoretical investigations. First experimental data have also became recently available (see e.g. [12, 13, 14, 15]) and much more data are expected from JLAB, DESY, and CERN in the future.

The LO contribution to the DVCS amplitude on the nucleon to the twist-3 accuracy has been calculated in [16, 17]. Twist-3 corrections to the DVCS amplitude arise in a twofold way. First, as usual for a hard exclusive process, the hard amplitude with an additional parton, the gluon, taking part in the hard collision is suppressed by one power of $1/Q$. Such a genuine twist-3 contribution involves matrix element of three-parton operator in a nucleon state. Second, there is a so-called Wandzura-Wilczek (WW) contribution which arises from a configuration with minimal number of partons involved in the hard collision. Formally, the WW contribution arises because operators with external derivatives w.r.t. total translation in a transverse direction give nonzero contribution in the DVCS kinematics. As the current phenomenology of power corrections is consistent with an assumption that matrix elements of three-parton operators in a nucleon are small [18], one can conjecture that the WW contribution can provide a rather accurate numerical description of twist-3 corrections.

Recently, we have computed the NLO contribution to the WW twist-3, $L \to T$ flavor non-singlet DVCS amplitude. Besides obvious phenomenological applications, there is a broader, theoretical interest in such a calculation. A factorization theorem for twist-3 DVCS amplitude has neither been considered nor proven in the literature. As a consequence, although the direct calculation showed that the LO $L \to T$ amplitude factorizes, there is no guarantee that factorization prevails in higher orders as well. At the same time there have been no direct calculations supporting or disproving factorization of twits-3 contribution to DVCS beyond the leading order. Although computation of one-loop, flavor non-singlet amplitude may seem trivial, based on experience with NLO corrections to twist-2 amplitudes, calculation of NLO twist-3 contribution has turned out to be technically quite involved, warranting a more detailed discussion. Our calculation demonstrates that the amplitude does factorize at the NLO. It is tempting to interpret it as a hint that the factorization holds for this particular twist-3 DVCS helicity amplitude to all orders.

Calculation of NLO corrections to the L→T amplitude requires knowledge of the nucleon matrix element of vector and axial-vector non-local quark string operators

$$\langle p'|\bar{\psi}(x)\gamma^{\sigma}\psi(y)|p\rangle \tag{1}$$

and

$$\langle p'|\bar{\psi}(x)\gamma^{\sigma}\gamma_5\psi(y)|p\rangle \tag{2}$$

to the twist-3 accuracy but for arbitrary x and y. In the Wandzura-Wilczek approximation the result is given in terms of distribution functions which parametrize matrix elements of string operators restricted to the light-cone:

$$F_{\mu}(x,\xi) = \int_{-\infty}^{\infty} \frac{d\lambda}{2\pi} e^{-ix\lambda} \langle p'|\bar{\psi}(\frac{1}{2}\lambda n)\gamma_{\mu}\psi(-\frac{1}{2}\lambda n)|p\rangle\,, \tag{3}$$

$$\widetilde{F}_{\mu}(x,\xi) = \int_{-\infty}^{\infty} \frac{d\lambda}{2\pi} e^{-ix\lambda} \langle p'|\bar{\psi}(\frac{1}{2}\lambda n)\gamma_{\mu}\gamma_5\psi(-\frac{1}{2}\lambda n)|p\rangle\,. \tag{4}$$

To simplify notation, we have omitted in the above formulae the path-ordered exponential connecting the quark fields.

Corresponding Feynman diagrams shown in Fig. 1 are the same as for the NLO contributions to twist-2 amplitude. Nevertheless, besides trivial technical complications due to derivatives of corresponding diagrams w.r.t. external momenta, some new subtleties appear here. It turns out that to twist-3 accuracy the $L \to T$ amplitude has formally the same structure as corresponding piece of the $L \to L$ amplitude which appears at the NLO and describes the twist-2 transition between longitudinally polarized initial and final photons. In the massless QCD the corresponding contribution to the hadronic tensor has logarithmic singularity $\sim \ln[q^2/q'^2]$ as the virtuality of the final photon tends to zero. Of course, the $L \to L$ scattering amplitude obtained by contraction with polarization vectors of initial and final photons vanishes in this limit. In order to obtain the NLO contribution to the $L \to T$ amplitude one has to subtract properly regulated $L \to L$ amplitude. A convenient method for regularizing loop integrals arising at the NLO is provided by dimensional regularization. We kept space-time dimension $d = 4 - 2\epsilon$ keeping virtuality of the final photon small but different from zero and applied the $\overline{\text{MS}}$ subtraction scheme. For the γ_5 matrix in d-dimensions we used the t'Hooft-Veltman definition in terms of four antisymmetric gamma-matrices. Powerful check of the resulting calculation is provided by

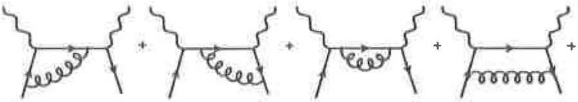

Figure 1: Feynmann diagrams for the NLO correction in WW approximation for $H(k,k',k'')$

the electromagnetic gauge-invariance of the final answer. We computed all possible contributions and checked that in the sum of all diagrams only such combination of momenta appears which is consistent with electromagnetic gauge-invariance.

In order to complete proof of factorization of the $L \to T$ amplitude at the NLO one has to demonstrate that the structure of singular terms is indeed such that they can be absorbed, following the standard procedure, into renormalization of the LO $L \to T$ amplitude.We have shown this by deriving explicitely one-loop evolution equations of the transverse components of the light-cone matrix elements (3) and (4). As it follows, the NLO correction to the $L \to T$ amplitude can be put into a factorisable, free of explicit IR singularities, self-consistent form.

To summarize, explicit calculation shows factorizability of the NLO correction to the twist-3, Wandzura-Wilczek, flavor non-singlet DVCS amplitude corresponding to scattering of longitudinal photon off nucleon. We have shown that, similarly to the LO, the singularity structure of the corresponding Wilson coefficients is such that the convolution integrals with GPD's are well defined. After the interference with the twist-2 LL amplitude is properly taken into account all IR singular terms arising in the calculation of the $L \to T$ amplitude can be absorbed into renormalization of the LO result in a usual manner. Besides the phenomenological applications our result strongly suggests that factorization holds for the twist-3, $L \to T$ DVCS amplitude beyond LO and possibly to all orders in the α_S expansion.

References

[1] D. Müller, D. Robaschik, B. Geyer, F.M. Dittes, J. Horejsi, Fortschr. Phys. **42** (1994) 101.

[2] X. Ji, Phys. Rev.**D55** (1997) 7114.

[3] M. Vanderhaegen, P.A.M. Guichon and M. Guidal, Phys. Rev. bf D60, (1999) 094017.

[4] M. Diehl *et al.*, Phys. Lett. **B 411**, (1997) 193; Eur. Phys. J. **C8**, (1999) 408; Phys. Lett. **B428** (1998) 359.

[5] M. Diehl, Eur. Phys. J. **C19**, (2001) 485.

[6] L. Frankfurt *et al.*, Phys. Lett. **B418**, (1998) 345.

[7] L. Frankfurt, A. Freund and M. Strikman, Phys. Rev. **D58**, (1998) 114001; Phys. Lett. **B460**, (1999) 417.

[8] K.J. Golec-Biernat and A.D. Martin, Phys. Rev. **D59**, (1999) 014029.

[9] A. V. Radyushkin, Phys. Rev. **D56** (1997), 5524.

[10] X. Ji and J. Osborne, Phys. Rev. **D58** (1998) 094018.

[11] J. C. Collins and A. Freund, Phys. Rev. **D59** (1999) 074009.

[12] P. R. Saull [ZEUS Collaboration], "Prompt photon production and observation of deeply virtual Compton scattering," hep-ex/0003030.

[13] Rainer Stamen [H1-Collaboration], " Measurement of the Deeply Virtual Compton Scattering at Hera", H1prelim-00-17, DIS 2000 and IHEP 2000.

[14] A. Airapetian [HERMES Collaboration], deeply-virtual Compton scattering," hep-ex/0106068.

[15] M. Amarian [HERMES collaboration], "DVCS and exclusive meson production measured by HERMES",
talk at workshop "Skewed Parton Distributions and Lepton - Nucleon Scattering", DESY, Sept. 2000, http://hermes.desy.de/workshop/TALKS/talks.html

[16] M. Penttinen, M. V. Polyakov, A. G. Shuvaev and M. Strikman, Phys. Lett. B **491** (2000) 96 [hep-ph/0006321].

[17] A. V. Belitsky and D. Muller, Nucl. Phys. B **589** (2000) 611 [hep-ph/0007031].

[18] D. V. Kiptily and M. V. Polyakov, arXiv:hep-ph/0212372.