PROCEEDINGS OF SCIENCE

Exclusive Double Drell-Yan factorization and GTMDs

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The factorization of exclusive processes can give access to generalized transverse momentum-dependent distributions (GTMDs). We consider here the case of the differential cross-section for the exclusive process $\pi N \to N'\gamma^*\gamma^* \to p(\ell^+\ell^-)(\ell^+\ell^-)$. We provide a factorization theorem for this process studying the gauge links that are involved and providing an expression of the cross-section factorized in terms of two GTMDs and two light-cone wave functions. Furthermore, we show that the soft radiation has a structure very similar to the one found in single parton scattering. Finally, the cancellation of rapidity divergences is also studied.

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1. Introduction

An important goal within the QCD community is to understand the inner structure of hadrons and hadronic structures in multiple dimensions. Generalized transverse momentum dependent distributions (GTMDs) are considered *mother distributions* of both GPDs and TMDs since they reduce to them in certain kinematical limits [1]. They give information on the five-dimensional parton structure and are relevant for understanding the origin of the proton spin.

In the present work, we consider an exclusive process, namely $\pi N \to N'\gamma^*\gamma^* \to N'(\ell^+\ell^-)(\ell^+\ell^-)$ and show that, thanks to the particular configuration of soft radiation and power ordering, the factorization of its cross-section using Soft Collinear Effective Theory (SCET) operators (see e.g. [2]) gives access to GTMDs and light-cone wave-functions. The choice of the process has been inspired by the recent work of [3]. To conclude, we have confirmed the cancelation of rapidity divergences in the final expression of our process at one-loop.

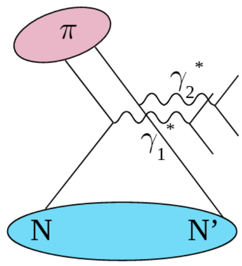

Figure 1: Exclusive Double Drell-Yan at leading power

2. All-order factorization procedure

In order to factorize the cross-section we start by writing the general expression of the hadronic tensor of the process shown in Figure (1):

$$W_{\mu\nu\alpha\beta} = \sum_X \int dz_{1,2,3} e^{-iq_1\cdot z_1 - iq_2\cdot z_2 + iq_1\cdot z_3} \langle \Pi N | J^\dagger_{\alpha,z_1} J^\dagger_{\beta,z_2} | N' \rangle \langle N' | J_{\mu,z_3} J_{\nu,0} | \Pi N \rangle \quad , \tag{1}$$

where the two hard scatterings are represented as two quark electromagnetic currents while the leptons in the final state are included in a leptonic tensor omitted here.

In SCET one can decompose four-vectors in light-like coordinates as $v^\mu = \bar{n}\cdot v \frac{n^\mu}{2} + n\cdot v \frac{\bar{n}^\mu}{2} + v_\perp = v^+ \frac{n^\mu}{2} + v^- \frac{\bar{n}^\mu}{2} + v_\perp$, with $n \cdot \bar{n} = 2$. The fields are divided into collinear, anti-collinear and soft fields based on the scaling of its momenta. With this, one can build SCET operators and match the corresponding QCD ones onto them. In the case of the quark electromagnetic current we define the corresponding effective current as:

$$J^{ad}_\mu = \sum_q e_q C(Q^2/\mu^2) \bar{\chi}^{q,d}_{\bar{n}} S^{\dagger dc}_{\bar{n}} \gamma_\mu S^{ca}_n \chi^{q,a}_n \quad , \tag{2}$$

where a, c, d are color indices. $C(Q^2/\mu^2)$ is the hard function and represents the high-energy contribution, the collinear and anti-collinear fermion fields are given by $\chi^a_{n(\bar{n})} = W^{\dagger,aa'}_{n(\bar{n})} \xi^{a'}_{n(\bar{n})} = W^{\dagger,aa'}_{n(\bar{n})} P_{+(-)} \psi^{a'}_{n(\bar{n})}$ and W_n and S_n are soft Wilson lines and represent the soft radiation of gluons.

After matching the four QCD currents to the effective ones we can obtain the factorized expression of the hadronic part of the cross-section. To this end, we assume that the momentum of the nucleon has a collinear scale while the momentum of the pion has an anti-collinear one. Taking into account the scaling of the photon momenta and the scaling of the fields, we do a multipole expansion to drop the power-suppressed dependence on the field's momenta. Schematically, the resulting factorized hadronic tensor is:

$$W_{\mu\nu\alpha\beta} \sim H\, w_{NN',\alpha} \otimes S_1 \otimes \phi_{\pi,\beta} \otimes w_{N'N,\mu} \otimes S_2 \otimes \phi_{\pi,\nu} \quad , \tag{3}$$

where $H = |C|^4$ is the hard factor, $w_{NN',\alpha}$ and $w_{N'N,\mu}$ have only collinear fields and are two GTMD correlators [1], S_1 and S_2 are soft functions with four Wilson lines each, and $\phi_{\pi,\beta}$ and $\phi_{\pi,\nu}$ have only anti-collinear fields and they are light-cone wave functions with two fermion fields each [4], [5]. This factorization, at leading twist, is valid for all combinations of polarization states. Furthermore, the obtained soft factors have the same structure as the one of Drell-Yan factorization [6]. In position space we have:

$$S(\vec{r}_\perp) = \frac{1}{N_c} \mathrm{tr}\langle 0|\bar{T}\{S_n^\dagger S_{\bar{n}}(\vec{r}_\perp)\}T\{S_{\bar{n}}^\dagger S_n(0)\}|0\rangle \quad . \tag{4}$$

When doing perturbative calculations of each of the obtained functions in the factorization theorem, we integrate over all momentum space. However, in the collinear and anti-collinear integrands, doing this would imply integrating over the soft region as well. To remove the overlap between regions it is necessary to perform the so-called zero-bin subtraction which, in summary, implies dividing the correlators of consideration by their associated soft function. Furthermore, it is also necessary to treat unwanted rapidity divergences that appear in all perturbative calculations in the soft and collinear limits of QCD.

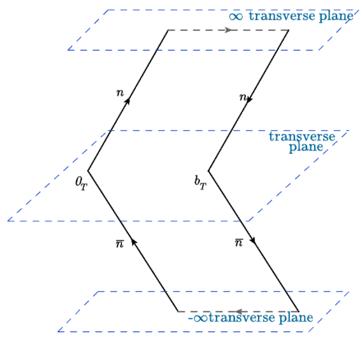

Figure 2: Single color loop in the Drell-Yan Soft Factor

The subtraction of rapidity divergences of the light-cone wave functions [7] and the GTMD correlators [8] need to be done by properly combining them with the relevant soft factors. It turns out that, since the collinear and anti-collinear functions have the same number of fields, both of them have the same procedure to remove the overlap with the soft region and absorb rapidity divergences. One can define GTMD and light-cone wave function correlators without rapidity divergences and in coordinate space as:

$$W_{N'N} = w_{N'N}\, S^{1/2} = \frac{w_{N'N}^{unsub}}{S}\, S^{1/2} \qquad\qquad \Phi_\pi = \phi_\pi\, S^{1/2} = \frac{\phi_\pi^{unsub}}{S}\, S^{1/2} \quad , \tag{5}$$

where $w_{NN'}$ and ϕ_π have included the zero-bin subtraction.
Finally, one should also contract the color indices to form color singlets in all the matrix elements. As a consequence, the soft factor of consideration is connected into a single Wilson color loop as shown in Figure (2). In general, multi-parton scatterings in inclusive processes are factorized into functions with a larger number of fields and the color structures will be more complex.

By including the square-roots of the soft factors within the definition of the collinear and anti-collinear functions one obtains a factorized cross-section without the soft factor:

$$W_{\alpha\beta\mu\nu} \sim H\, W_{NN',\alpha} \otimes \Phi_{\pi,\beta} \otimes W_{N'N,\mu} \otimes \Phi_{\pi,\nu} \quad . \tag{6}$$

In our future work, we detail this procedure and elaborate on the evolution kernels of the distributions that appear in the factorization theorem [9].

3. Conclusion

The present study shows that a factorized cross-section sensitive to the GTMD is also dependent on the product of two soft factors appearing in single parton scattering processes. The factorization theorem depends on several non-perturbative functions. The subtraction of rapidity divergences in the collinear and anti-collinear functions gives rise to an expression without soft radiation factor.

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