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A second update on double parton distributions

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ABSTRACT

We present two equivalent consistency checks of the momentum sum rule for double parton distributions and show the importance of the inclusion of the so-called inhomogeneous term in order to preserve correct longitudinal momentum correlations. We further discuss in some detail the kinematics of the splitting at the basis of the inhomogeneous term and update the double parton distributions evolution equations at different virtualities.

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1. Introduction

The hadron internal structure is presently encoded, thanks to the QCD factorisation theorem, in process-independent parton distribution functions (PDFs). The latter allow to predict cross sections for high-mass systems and high transverse-momentum jets in hadronic collisions in terms of binary partonic interactions. There are, however, increasing experimental evidences (for recent analyses see Ref. [1]) that hard double parton scattering (DPS) may occur within the same hadronic collision. The experimental and theoretical efforts to identify and quantify DPS contributions aim to understand and control this additional QCD background in new physics searches, especially in the multi-jet channel. At a more fundamental level, DPS could unveil parton correlations in the hadron structure not accessible in single parton scattering (SPS) and encoded in novel distributions, *i.e.* double parton distributions (DPDs). So far, measurements have only provided informations on σ_{eff}. This dimensionful parameter controls the magnitudo of DPS contribution under the simplifying assumptions of two uncorrelated hard scatterings and full factorisation of DPDs in terms of ordinary PDFs and model-dependent distribution in transverse position space. Many theoretical analyses have predicted QCD evolution effects on DPDs relaxing some or all the above assumptions [2–6]. A part of recent progress in this direction reported in Ref. [7], the experimental observation of the expected mild scaling violations induced by DPDs evolution is not yet possible given the accuracy of the present data. Nonetheless, a good theoretical control of the latter is mandatory if the whole DPS formalism has to be properly validated against data. A first attempt to calculate the scale dependence of longitudinal DPDs (hereafter called lDPDs) has been presented long ago in Ref. [2] under the assumption of factorisation in transverse space. With respect to standard single-parton distributions [8], lDPDs evolution equations do contain an additional term which is responsible for perturbative longitudinal correlation between the interacting partons. This result has stimulated in the recent past an increasing activity in the field and has generated some constructive criticism in the literature. A first critical point is that the relative transverse momentum of the interacting parton pair is not conserved between amplitude and its conjugate [9]. This implies that one should consider new distributions, addressed as two-particle generalised parton distributions, $_2$GPDs, which have an additional dependence on a transverse momentum vector Δ which parametrises this imbalance [9]. They reduce to lDPDs addressed in this paper when this vector is set to zero or, in position space, if they are integrated over the relative distance b of the parton pair. This additional dependence affects the evolution of the correlated and uncorrelated terms in rather different way [6] and give rise to inconsistencies with respect to the formalism of Refs. [2,3]. More importantly, $_2$GPDs enter the DPS cross sections rather than their b-integrated or $\Delta = 0$ counterparts, *i.e.* longitudinal DPDs, and moreover the integral over the imbalance Δ of the product of $_2$GPDs is directly proportional to the value of σ_{eff}^{-1} [9,10]. A second critical point is that the inclusion of single splitting contributions, according to the formalism of Ref. [2], poses a problem of consistency with SPS loop corrections when DPDs are used to evaluate DPS cross sections, a problem which is solved if one considers two-particle generalised parton distributions, $_2$GPDs [11]. From these observations, it appears that $_2$GPDs offer a natural solution to this class of problems and are

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a good candidate to focus on when addressing the issues related to QCD evolution. On the other hand, as we shall describe in the following, the presence of the inhomogeneous term in the evolution equations appearing Ref. [2] is crucial if one demands that longitudinal DPDs satisfy QCD consistency check for the momentum sum rule. It appears therefore that the road towards a consistent treatment of QCD evolution effects on DPDs is quite narrow as it must reconcile all these requirements at once.

This paper is organised as follows. In Section 2 we collect some definitions and formulas pertinent to the Jet Calculus formalism [12] and frequently used thereafter. In Section 3 we present two equivalent derivations of the momentum sum rule for lDPDs, paying particular attention to some delicate steps occurring in the calculation. In Section 4 we discuss in some detail the kinematics of the splitting in the inhomogeneous term and update the lDPDs evolution equations at different virtualities in light of the results obtained for the momentum sum rule. We summarise our results in Section 5.

2. Preliminaries

We recall briefly the main ingredients which we will use in our calculations. The longitudinal double-parton distributions $D_h^{j_1,j_2}(x_1,Q_1^2,x_2,Q_2^2)$ are interpreted as the two-particle inclusive distribution to find in a target hadron a couple of partons of flavour j_1 and j_2 with fractional momenta x_1 and x_2 and virtualities up to Q_1^2 and Q_2^2, respectively. The distributions at the final scales, Q_1^2 and Q_2^2, are constructed through the parton-to-parton functions, E, which themselves obey DGLAP-type [8] evolution equations:

$$Q^2\frac{\partial}{\partial Q^2}E_i^j\big(x,Q_0^2,Q^2\big) = \frac{\alpha_s(Q^2)}{2\pi}\int_x^1\frac{du}{u}P_k^i(u)E_i^k\big(x/u,Q_0^2,Q^2\big), \tag{1}$$

with initial condition $E_i^j(x,Q_0^2,Q_0^2)=\delta_i^j\delta(1-x)$ and $P_k^i(u)$ the Altarelli–Parisi splitting functions. The functions E provide the resummation of collinear logarithms up to the accuracy with which the $P_k^i(u)$ are specified. We may therefore express $D_h^{j_1,j_2}(x_1,Q_1^2,x_2,Q_2^2)$ as

$$\begin{aligned}
D_h^{j_1,j_2}\big(x_1,Q_1^2,x_2,Q_2^2\big)
&= \int_{x_1}^{1-x_2}\frac{dz_1}{z_1}\int_{x_2}^{1-z_1}\frac{dz_2}{z_2}\bigg[D_h^{j_1',j_2'}\big(z_1,Q_0^2,z_2,Q_0^2\big)E_{j_1'}^{j_1}\\
&\quad\times\left(\frac{x_1}{z_1},Q_0^2,Q_1^2\right)E_{j_2'}^{j_2}\left(\frac{x_2}{z_2},Q_0^2,Q_2^2\right)\\
&\quad+\int_{Q_0^2}^{\mathrm{Min}(Q_1^2,Q_2^2)}d\mu_s^2\,D_{h,corr}^{j_1',j_2'}\big(z_1,z_2,\mu_s^2\big)E_{j_1'}^{j_1}\\
&\quad\times\left(\frac{x_1}{z_1},\mu_s^2,Q_1^2\right)E_{j_2'}^{j_2}\left(\frac{x_2}{z_2},\mu_s^2,Q_2^2\right)\bigg].
\end{aligned}\tag{2}$$

The first term on r.h.s., usually addressed as the homogeneous term, takes into account the uncorrelated evolution of the active partons found at a scale Q_0^2 in $D_h^{j_1',j_2'}$ up to Q_1^2 and Q_2^2, respectively. The second term, the so-called inhomogeneous one, takes into account the probability to find the active partons at Q_1^2 and Q_2^2 as a result of a splitting at a scale μ_s^2, integrated over all the intermediate scale at which such splitting may occur. The distribution $D_{h,corr}^{j_1',j_2'}$ is given by

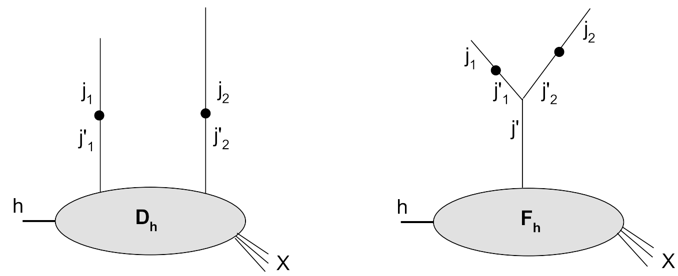

Fig. 1. Pictorial representation of both terms on right-hand side of Eq. (2). Black dots symbolise the parton-to-parton evolution function, E.

$$D_{h,corr}^{j_1',j_2'}\big(z_1,z_2,\mu_s^2\big) = \frac{\alpha_s(\mu_s^2)}{2\pi\,\mu_s^2}\frac{F_h^{j'}(z_1+z_2,\mu_s^2)}{z_1+z_2}\widehat{P}_{j'}^{j_1',j_2'}\left(\frac{z_1}{z_1+z_2}\right). \tag{3}$$

In Eq. (3), $F_h^{j'}$ are single parton distributions and $\widehat{P}_{j'}^{j_1',j_2'}$ are the real Altarelli–Parisi splitting functions [12]. Both terms in Eq. (2) are shown in Fig. 1. The scale Q_0^2 is in general the (low) scale at which lDPDs are usually modelled, in complete analogy with the single-parton distributions case. In the present context it also acts as the factorisation scale for the correlated term, since all unresolved splittings, for which $\mu_s^2<Q_0^2$, are effectively taken into account in the parametrisation of $D_h^{j_1',j_2'}(z_1,Q_0^2,z_2,Q_0^2)$. In the "equal scales" case, taking the logarithmic derivative with respect to Q^2 in Eq. (2), we recover the result presented in Ref. [2]:

$$\begin{aligned}
Q^2\frac{\partial D_h^{j_1,j_2}(x_1,x_2,Q^2)}{\partial Q^2}
&= \frac{\alpha_s(Q^2)}{2\pi}\int_{\frac{x_1}{1-x_2}}^1\frac{du}{u}P_k^{j_1}(u)D_h^{j_2,k}\big(x_1/u,x_2,Q^2\big)\\
&\quad+\frac{\alpha_s(Q^2)}{2\pi}\int_{\frac{x_2}{1-x_1}}^1\frac{du}{u}P_k^{j_2}(u)D_h^{j_1,k}\big(x_1,x_2/u,Q^2\big)\\
&\quad+\frac{\alpha_s(Q^2)}{2\pi}\frac{F_h^{j'}(x_1+x_2,Q^2)}{x_1+x_2}\widehat{P}_{j'}^{j_1,j_2}\left(\frac{x_1}{x_1+x_2}\right).
\end{aligned}\tag{4}$$

The first and second terms on the right-hand side are obtained through the Q^2 dependence contained in the E functions, while the last is obtained from the Q^2 dependent limit in the μ_s^2 integration in the correlated term. The lDPDs evolution equations therefore resum large contributions of the type $\alpha_s\ln(Q^2/Q_0^2)$ and $\alpha_s\ln(Q^2/\mu_s^2)$ appearing in the uncorrelated and correlated term of Eq. (2), respectively.

3. Momentum sum rule

A number of sum rules for lDPDs has been already discussed and used to constrain initial conditions for lDPDs evolution in Ref. [13]. Sum rules are in general expected to hold on the basis of unitarity of the relevant cross sections [14]. In the following we show that the momentum sum rule for DPDs satisfies the necessary, but not sufficient for it to hold, condition of being preserved

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