PROCEEDINGS OF SCIENCE

TMD cross-section factorization for dijet production at the EIC

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We use soft collinear effective theory (SCET) to study a dijet production process in deep-inelastic-scattering (DIS), measuring the imbalance of the two hard probes in the Breit frame. In order to achieve factorization of the transverse momentum dependent (TMD) cross-section, we need to introduce a new dijet soft function that we calculate at one-loop, regulating rapidity divergencies with the δ-regulator and that is consistent with the ζ-presciption of TMDs. We also provide phenomenological discussion and plots for this process, which is expected to be measured at the future EIC. The study of these processes could provide new knowledge of the TMD gluon distributions, to which they are sensitive.

**** Particles and Nuclei International Conference - PANIC2021 ****
**** 5 - 10 September, 2021 ****
**** Online ****

https://pos.sissa.it/

PoS(PANIC2021)373

1. Introduction

The main objective of this work is to describe a factorization framework for dijet production in an electron-proton collider measuring the transverse momentum imbalance of the two hard probes and working in the Breit frame. To achieve factorization we use SCET. This process requires the introduction of a new dijet soft function that we compute at one-loop order and its anomalous dimension up to three-loops using consistency relations [1].

Dijet production is relevant as it is sensitive to both unpolarized and polarized gluon TMDs. Gluon TMDs are difficult to access due to the lack of clean processes where factorization holds and incoming gluons constitute the dominant effect. An example of that process is the Higgs production in hadronic colliders [2]. However, extractions from this process is challenging due to the nature of the scalar boson and its large mass. These complications has driven attention to quarkonium production in SIDIS at EIC and LHC, in particular dijet production in DIS. The experimental observation should be possible in the future EIC. [3].

2. Cross-section factorization

We consider the DIS process $\ell + h \to \ell' + J_1 + J_2 + X$. Jets here described have transverse momentum between 2 and 40 GeV in the Breit frame. There are two channels for the dijet process that we need to consider: a) the gluon-photon fusion channel which corresponds to the partonic process, $\gamma^* g \to f\bar{f}$, and b) the incoming quark or antiquark channel from the partonic process, $\gamma^* f \to g f$. The factorization that we propose holds when $|\boldsymbol{r}_T| \ll p_T$ and we treat the cross-sections only at leading power in an $|\boldsymbol{r}_T|/p_T$ or $|\boldsymbol{r}_T|/Q$ expansion, with $\boldsymbol{r}_T = \boldsymbol{p}_{1T} + \boldsymbol{p}_{2T}$ and $p_T = \frac{|\boldsymbol{p}_{1T}|+|\boldsymbol{p}_{2T}|}{2}$ being the transverse momentum imbalance and average transverse momentum imbalance.

For the factorization theorem to hold we require that no hierarchies exist among the parsonic Mandelstam variables. If such hierarchies exist, they will induce large logarithms in the hard factor of the cross-section and can potentially ruin the convergence of perturbative expansion. We also require Q to be of the same order as p_T in order to avoid contributions from the resolved photon processes. This leads to the jets being in the central rapidity region.

We compare the kinematic region where our factorization holds vs. the EIC coverage for different center of mass energies in fig. 1. We construct the x and Q values relevant for our process by taking p_T and ξ, longitudinal fraction of momentum, between this values and in the central rapidity region. We can see that overlap increases with the higher beam energies but we see that for all three energies the overlap is significant.

Within this constraints, the factorized cross-section is given by

$$\frac{d\sigma(\gamma^* g)}{dx d\eta_1 d\eta_2 dp_T d\boldsymbol{r}_T} = \sum_f H^{\mu\nu}_{\gamma^* g \to f\bar{f}}(\hat{s},\hat{t},\hat{u},\mu) \int \frac{d^2\boldsymbol{b}}{(2\pi)^2} \exp(i\boldsymbol{b}\cdot\boldsymbol{r}_T)\, F_{g,\mu\nu}(\xi,\boldsymbol{b},\mu,\zeta_1)$$
$$\times S_{\gamma g}(\boldsymbol{b},\eta_1,\eta_2,\mu,\zeta_2)\Big(C_f(\boldsymbol{b},R,\mu)J_f(p_T,R,\mu)\Big)\Big(C_{\bar{f}}(\boldsymbol{b},R,\mu)J_{\bar{f}}(p_T,R,\mu)\Big)\,, \quad (1)$$

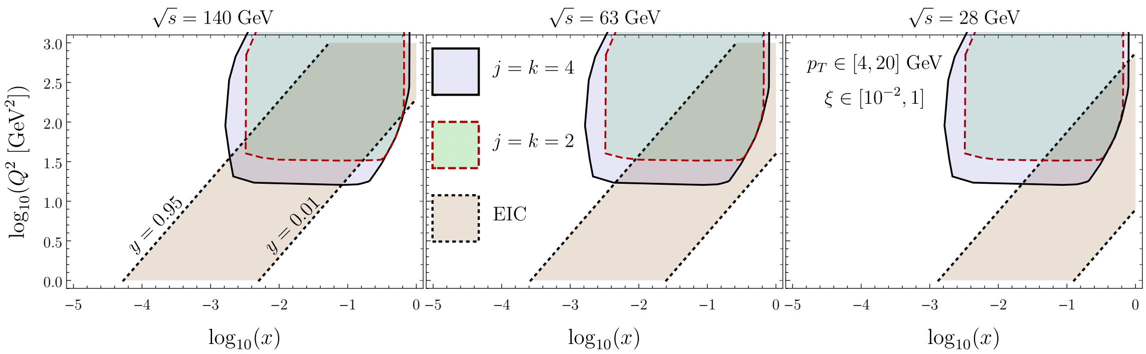

Figure 1: The (x, Q^2) coverage of EIC (brown/dashed) compared to the dijet events with $j = k = 4$ factorization regime (blue-solid) and with $j = k = 2$ (green-dashed), with j and k being the ratio between the Mandelstam variables and p_T and Q respectively. The factorization regime has been constructed assuming $p_T \in [4, 20]$ GeV, $\xi \in [10^{-2}, 1]$, and jet rapidities in the central rapidity region.

$$\frac{d\sigma(\gamma^* f)}{dx d\eta_1 d\eta_2 dp_T d\boldsymbol{r}_T} = \sum_f H^U_{\gamma^* f \to g f}(\hat{s}, \hat{t}, \hat{u}, \mu) \int \frac{d^2\boldsymbol{b}}{(2\pi)^2} \exp(i\boldsymbol{b}\cdot\boldsymbol{r}_T)\, F_f(\xi, \boldsymbol{b}, \mu, \zeta_1)$$
$$\times S_{\gamma f}(\boldsymbol{b}, \zeta_2, \mu)\Big(C_g(\boldsymbol{b}, R, \mu) J_g(p_T, R, \mu)\Big)\Big(C_f(\boldsymbol{b}, R, \mu) J_f(p_T, R, \mu)\Big), \quad (2)$$

for both gluon and quark channel respectively. Notice that while the gluon channel have contributions from both unpolarized and linearly polarized gluon TMDs, which are encoded in the tensorial structure of $F_{g,\mu\nu}$, the quark channel only have unpolarized contribution, F_f. The sum runs over all light quark and antiquark flavours f. Here we consider jets with their momentum reconstructed with the so called E-scheme, that is, the momentum of the jets is given by the sum of all jet-constituents. For these jets and for small jet radius ($R \ll 1$) the cross-section can be factorized in terms of the collinear-soft function $C_i(\boldsymbol{b}, R)$, that describes the soft radiation close to the jet boundary and the exclusive jet functions J_i, that describe the collinear and energetic radiation confined within the jet. These functions are calculated up to NLO for generic k_T-type and cone jet algorithms in [4, 5]. In addition, the factorization theorem contains the dijet soft function $S_{\gamma(g,f)}$.

2.1 Dijet soft function and ζ-prescription

The only new matrix element in the previous section is the soft function. Here we give the operator matrix element definition of the soft function

$$\hat{S}_{\gamma g}(\boldsymbol{b}) = \frac{1}{C_F C_A}\langle 0|\mathcal{S}_n^\dagger(\boldsymbol{b}, -\infty)_{ca'}\mathrm{Tr}\Big[S_{v_2}(+\infty, \boldsymbol{b}) T^{a'} S^\dagger_{v_1}(+\infty, \boldsymbol{b})$$
$$\times S_{v_1}(+\infty, 0) T^a S^\dagger_{v_2}(+\infty, 0)\Big]\mathcal{S}_n(0, -\infty)_{ac}|0\rangle. \quad (3)$$

The soft function corresponding to the case of incoming quark or antiquark is obtained with the exchange

$$\hat{S}_{\gamma f} = \hat{S}_{\gamma g}(n \leftrightarrow v_2)\,. \quad (4)$$

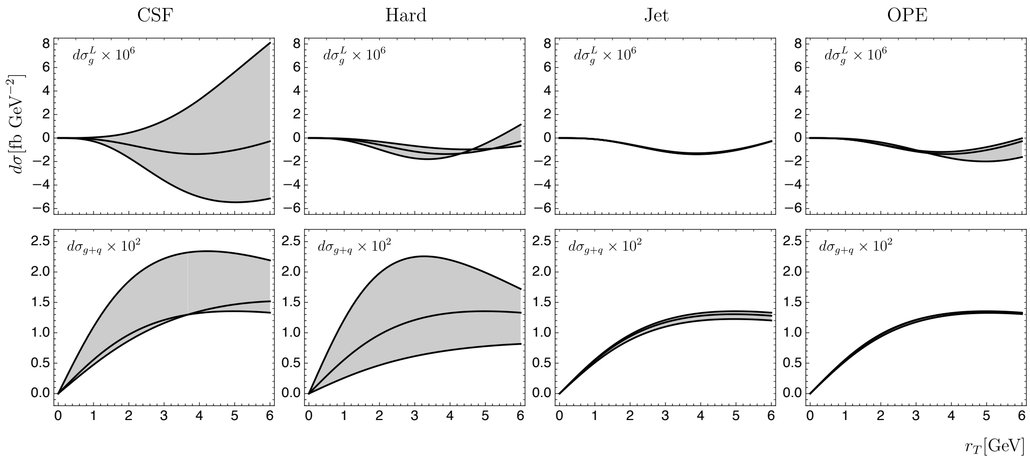

Figure 2: Cross-sections for dijet production at EIC with error-bands coming from scale dependence in collinear-soft factor (CSF), hard factor (Hard), jet distributions (Jet) and Wilson coefficients (OPE). Rows correspond to contributions from linearly polarized gluons (top) and total cross-section (bottom).

We also distinguish Wilson lines in the adjoint and fundamental SU(N_c) representations using $\mathcal{S}$ and S respectively. Note that the δ-regulator is introduced only in $S_n(\mathcal{S}_n)$. The dijet soft function is discussed and calculated at one-loop in [1].

We notice at this point that both the dijet soft function and TMDPDF in the factorized cross-section have an intricate interplay detailed in [1] due to the rapidity divergences, which introduces the rapidity scale dependence, $\zeta_{1,2}$, in the corresponding functions.

Finally, following the ζ-prescription and fixed-μ evolution, the evolution kernel that provides the evolution from the null-evolution ζ-line and that passes through the saddle-point to the final ζ point is given by

$$\mathcal{R}_S(\{\mu_0, \zeta_0\} \to \{\mu_f, \zeta_f\}) = \left(\frac{\zeta_f}{\zeta_\mu(b, \mu_f)}\right)^{-\mathcal{D}(b,\mu_f)}, \tag{5}$$

where ζ_μ is the parameterized null-evolution ζ-line that is given by the differential equation

$$\gamma_S(\mu, \zeta_\mu(b)) = 2\mathcal{D}_S(\mu, b)\frac{d\ln\zeta_\mu(b)}{d\ln\mu^2}, \tag{6}$$

and γ_S and $\mathcal{D}_S$ are the anomalous dimension and rapidity anomalous dimension respectively for the dijet soft function. The ζ-prescription for the dijet soft function is completely analogous to what was described for TMDs in [6].

3. Results

In fig. 2, the results for the cross-section including quark and gluon channels is shown. Plots are obtained considering $p_T = 20$ GeV and jets in the central rapidity region. We consider the contribution of linearly polarized gluons in a separate panel to show that their contribution is completely negligible, being a factor 10^3-10^4 smaller. This leads to the conclusion that the contribution from the linearly polarized gluons can be neglected when considering the unpolarized cross-section. More detailed analysis of the effect of non-perturbative models and the impact of jet radius in the results as well as plots for angular modulation and heavy hadron pair production can be found in [7].

4. Conclusions

Dijet production in SIDIS experiments present an opportunity to study the gluon TMD. In this work we have considered the case of the Electron Ion Collider (EIC), as an example. The processes have been proven to factorize consistently and this result has been checked at least at one loop. Nevertheless the evolution of the functions that appear in the factorization theorem is non-trivial and we propose an original solution, which is generic and independent of the resummation framework. We also note that it is consistent with the ζ-prescription of TMD [6] which we implement in this work.

The influence of this new soft function is certainly an element that should be studied in the future. In particular one should understand how large is its non-perturbative contribution to the cross-section and whether it appears in multiple processes

As a result of this study we can see that the extraction of gluon TMDs from dijet production at the EIC is conditioned yet by the possible theoretical and experimental precision. In particular, the linearly polarized gluon TMD appears generally too suppressed and hardly accessible if one uses the usual matching of TMDs onto their collinear counterpart distributions. Nevertheless, the discussed theoretical issues can potentially be solved or improved in future studies.

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