Improved TMD factorization for forward dijet production in pA collisions

Elena Petreska[1,2]

[1]Centre de Physique Théorique, École Polytechnique, CNRS, Université Paris-Saclay, F-91128 Palaiseau, France ,
[2]Departamento de Física de Partículas and IGFAE, Universidade de Santiago de Compostela, 15782 Santiago de Compostela, Spain

We study the production of forward dijets in proton-nucleus high-energy collisions. When both of the jets are produced in the forward rapidity direction, the collision probes the large-x parton distributions in the projectile and the small-x gluons in the target. We derive a factorization formula for this process valid for an arbitrary value of the momentum imbalance k_t of the jets [1][1]:

$$\frac{d\sigma^{pA\to \text{dijets}+X}}{d^2P_t d^2k_t dy_1 dy_2} = \frac{\alpha_s^2}{(x_1x_2s)^2}\sum_{a,c,d} x_1 f_{a/p}(x_1,\mu^2)\sum_{i=1}^{2} K^{(i)}_{ag^*\to cd}(k_t)\Phi^{(i)}_{ag\to cd}(k_t)\,\frac{1}{1+\delta_{cd}}\,. \tag{1}$$

The proton's large-x_1 partons are described with parton distributions functions of collinear factorization $f_{a/p}(x_1,\mu^2)$, while the target is represented with a total of six, two per channel, transverse momentum dependent (TMD) gluon distributions $\Phi^{(i)}_{ag\to cd}(k_t)$. The dependence on the transverse momentum k_t of the small-x_2 gluon is also explicitly present in the hard factors $K^{(i)}_{ag^*\to cd}(k_t)$ for the partonic subprocesses [2]. The factorization formula, Eq.(1), is therefore applicable for the whole range of k_t values between the saturation scale Q_s and the hard typical momentum of the jets P_t.

The new formula interpolates between the regions of validity of two factorization formulas for dijet production applicable for only certain limits of k_t values. The first framework is the high-energy factorization (HEF) [2–4] valid for large k_t on the order of the momentum of the jets, $Q_s \ll k_t \sim P_t$. The HEF formula has k_t dependent matrix elements, but only one gluon distribution for the target. It can be derived from the color glass condensate (CGC) cross section in the dilute target approximation [1]. The CGC formalism [5] captures the multi-gluon scatterings of the projectile parton with the saturated field of the target from first principles, but the CGC cross section for dijet production can not be written in a factorized form in the most general case. We

[1]The rapidities of the outgoing particles are y_1 and y_2, and s is the center of mass energy squared.
[2]The expressions for the hard factors can be found in Ref. [1].

show that by restricting the interactions to two gluon exchanges (dilute target limit) the CGC cross section involves only the HEF gluon distribution for the target, and complete equivalence with the HEF formula is achieved.

The second formalism is the TMD factorization [6,7] with on-shell hard factors and eight TMD gluon distributions for the target. It is valid for small k_t values, $k_t \sim Q_s \ll P_t$. The TMD distributions are the result of the resummation of collinear gluons from the target that couple to the hard part. We improve the TMD formula that was derived in Ref. [7] by including all finite-N_c corrections, reducing the number of independent distributions to two per channel, and restoring the k_t dependence in the hard part. The resulting formula, Eq. (1), encompasses both formalisms, the HEF and TMD factorization.

The TMD gluon distributions $\Phi^{(i)}_{ag\to cd}(k_t)$ are specific for this process and are determined by the color structure of the hard partonic scattering. For large-N_c they can be written as a convolution of only two fundamental distributions, the *dipole distribution*, and the *Weizsäcker-Williams gluon distribution*. We calculate the gluon densities in the large-N_c limit in the Golec-Biernat-Wusthoff model [8]:

$$\begin{aligned}
\Phi^{(1)}_{qg\to qg}(x_2,k_t) &= \frac{N_c S_\perp}{2\pi^3\alpha_s}\frac{S_\perp}{Q_s^2(x_2)}k_t^2\exp\left[-\frac{k_t^2}{Q_s^2(x_2)}\right],\\
\Phi^{(2)}_{qg\to qg}(x_2,k_t) &= \frac{N_c S_\perp}{2\pi^3\alpha_s}\exp\left[-\frac{k_t^2}{Q_s^2(x_2)}\right]\int_1^\infty\frac{dt}{t(t+2)}\exp\left[\frac{2k_t^2}{(t+2)Q_s^2(x_2)}\right],\\
\Phi^{(1)}_{gg\to q\bar q}(x_2,k_t) &= \frac{N_c S_\perp}{16\pi^3\alpha_s}\exp\left[-\frac{k_t^2}{2Q_s^2(x_2)}\right]\left(2+\frac{k_t^2}{Q_s^2(x_2)}\right),\\
\Phi^{(2)}_{gg\to q\bar q}(x_2,k_t) &= -\frac{N_c^3 S_\perp}{16\pi^3\alpha_s}\exp\left[-\frac{k_t^2}{2Q_s^2(x_2)}\right]\left(2-\frac{k_t^2}{Q_s^2(x_2)}\right),\\
\Phi^{(1)}_{gg\to gg}(x_2,k_t) &= \frac{N_c S_\perp}{8\pi^3\alpha_s}\exp\left[-\frac{k_t^2}{2Q_s^2(x_2)}\right]\left(\frac{1}{2}+\frac{k_t^2}{4Q_s^2(x_2)}+\int_1^\infty\frac{dt}{t(t+1)}\exp\left[\frac{k_t^2}{2(t+1)Q_s^2(x_2)}\right]\right),\\
\Phi^{(2)}_{gg\to gg}(x_2,k_t) &= \frac{N_c S_\perp}{4\pi^3\alpha_s}\exp\left[-\frac{k_t^2}{2Q_s^2(x_2)}\right]\left(\frac{1}{2}-\frac{k_t^2}{4Q_s^2(x_2)}+\int_1^\infty\frac{dt}{t(t+1)}\exp\left[\frac{k_t^2}{2(t+1)Q_s^2(x_2)}\right]\right)
\end{aligned}\quad(2)$$

We also obtain their high-k_t behavior in the McLerran-Venugopalan model [9]. To leading order all the distributions scale as Q_s^2/k_t^2.

The factorization formula in Eq. (1) can be used for phenomenological studies of dijet azimuthal correlations in dilute-dense collisions, with both, analytical input for the TMD gluons, Eq. (2), or numerical calculations that implement small-x evolution. The results will be presented in a forthcoming publication.

Acknowledgements

I thank my collaborators Piotr Kotko, Krzysztof Kutak, Cyrille Marquet, Sebastian Sapeta and Andreas van Hameren, with whom this work was completed. I also thank the European Research Council grant HotLHC ERC-2011-StG-279579, Ministerio de Ciencia e Innovación of Spain under project FPA2014-58293-C2-1-P and Xunta de Galicia (Consellería de Educación) within the Strategic Unit AGRUP2015/11.

References

[1] P. Kotko, *et al.*, "Improved TMD factorization for forward dijet production in dilute-dense hadronic collisions," *JHEP*, **09**(2015), 106, 1503.03421.

[2] S. Catani, M. Ciafaloni, and F. Hautmann, "High-energy factorization and small x heavy flavor production," *Nucl. Phys.*, **B366**(1991), 135.

[3] M. Deak, F. Hautmann, H. Jung, and K. Kutak, "Forward Jet Production at the Large Hadron Collider," *JHEP*, **09**(2009), 121, 0908.0538.

[4] Krzysztof Kutak and Sebastian Sapeta, "Gluon saturation in dijet production in p-Pb collisions at Large Hadron Collider," *Phys. Rev.*, **D86**(2012), 094043, 1205.5035.

[5] Francois Gelis, Edmond Iancu, Jamal Jalilian-Marian, and Raju Venugopalan, "The Color Glass Condensate," *Ann. Rev. Nucl. Part. Sci.*, **60**(2010), 463, 1002.0333.

[6] C. J. Bomhof, P. J. Mulders, and F. Pijlman, "The Construction of gauge-links in arbitrary hard processes," *Eur. Phys. J.*, **C47**(2006), 147, hep-ph/0601171.

[7] Fabio Dominguez, Cyrille Marquet, Bo-Wen Xiao, and Feng Yuan, "Universality of Unintegrated Gluon Distributions at small x," *Phys. Rev.*, **D83**(2011), 105005, 1101.0715.

[8] Krzysztof J. Golec-Biernat and M. Wusthoff, "Saturation effects in deep inelastic scattering at low Q**2 and its implications on diffraction," *Phys. Rev.*, **D59**(1998), 014017, hep-ph/9807513.

[9] Larry D. McLerran and Raju Venugopalan, "Computing quark and gluon distribution functions for very large nuclei," *Phys. Rev.*, **D49**(1994), 2233, hep-ph/9309289.