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PROBING BFKL DYNAMICS WITH FORWARD DRELL–YAN LEPTON-PAIR AND BACKWARD JET*

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The forward Drell–Yan (DY) lepton-pair production together with a backward jet is proposed as a new way to study the BFKL effects due to a large rapidity gap between the two systems. The predictions for quantities to be measured are computed using the leading order DY impact factors and the BFKL kernel with a consistency condition which takes into account an important part of the next-to-leading order corrections.

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1. Introduction

The Drell–Yan lepton-pair production [1] is one of the most important processes which allow to study the QCD structure of the colliding hadrons. Of particular importance in this presentation are the high-energy QCD effects described by the Balitsky–Fadin–Kuraev–Lipatov (BFKL) formalism [2] which is complementary to the commonly used collinear resummation schemes. A classical process to study the BFKL effects in hadronic collisions, proposed by Mueller and Navelet (MN) [3], is a production of two jets with similar transverse momenta but separated by a large rapidity interval. In particular, it was proposed to look at the azimuthal decorrelation in the MN jets [4, 5]. Such studies were performed experimentally at the Fermilab [6, 7] and the LHC [8, 9] and analyzed theoretically in [10, 11] using the full NLO jet impact factors and NLL BFKL kernels.

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We propose to replace one of the MN jets by a forward Drell–Yan lepton pair, which has several advantages. *(i)* The experimental precision of DY measurements is usually very high. *(ii)* This process offers a broader range of parameters which may be scanned like the lepton-pair mass M or its transverse momentum $q_\perp$. *(iii)* The lepton-pair angular distribution allows to determine the DY structure functions [12] which show sensitivity to the underlying BFKL dynamics. *(iv)* Particularly interesting is the Lam–Tung combination of the DY structure functions [13].

The results presented in the forthcoming are based on an extended version of the paper [14].

2. Kinematics and cross sections

In Fig. 1, we show the relevant kinematic variables. The most important is the large rapidity distance $\Delta Y_{\gamma \mathrm{J}}$ between the forward DY boson q and the backward jet p_J to be measured experimentally. The rapidity distance ΔY_P is purely theoretical since it is an argument of the BFKL kernel, related to $\Delta Y_{\gamma \mathrm{J}}$ through kinematics. The DY+jet cross section reads

$$\begin{aligned}\frac{\mathrm{d}\sigma^{\mathrm{DY+j}}}{\mathrm{d}\mathit{\Pi}\,\mathrm{d}\Omega} &= \left(1-\cos^2\theta\right)\frac{\mathrm{d}\sigma^{\mathrm{L}}}{\mathrm{d}\mathit{\Pi}} + \left(1+\cos^2\theta\right)\frac{\mathrm{d}\sigma^{\mathrm{T}}}{\mathrm{d}\mathit{\Pi}} \\ &\quad + \left(\sin^2\theta\cos 2\phi\right)\frac{\mathrm{d}\sigma^{\mathrm{TT}}}{\mathrm{d}\mathit{\Pi}} + \left(\sin 2\theta \cos\phi\right)\frac{\mathrm{d}\sigma^{\mathrm{LT}}}{\mathrm{d}\mathit{\Pi}}\,, \end{aligned} \tag{1}$$

where (θ,ϕ) are lepton spherical angles, $\mathit{\Pi} = (M^2, \vec{q}_\perp, \vec{p}_{\mathrm{J}\perp}, \Delta Y_{\gamma\mathrm{J}})$ and

$$\begin{aligned}\frac{\mathrm{d}\sigma^{(\lambda)}}{\mathrm{d}\mathit{\Pi}} &= \frac{4\alpha_{\mathrm{em}}^2\alpha_{\mathrm{s}}^2}{(2\pi)^4}\,\frac{1}{M^2 p_{\mathrm{J}\perp}^2}\int_0^1 \mathrm{d}x_1 \int_0^1 \mathrm{d}x_2\, \theta(1-z)\, f_q(x_1,\mu) f_{\mathrm{eff}}(x_2,\mu) \\ &\quad \times \int \frac{\mathrm{d}^2 k_{1\perp}}{k_{1\perp}^2}\, \mathit{\Phi}^{(\lambda)}\left(\vec{q}_\perp, \vec{k}_{1\perp}, z\right)\, K\left(\vec{k}_{1\perp}, \vec{k}_{2\perp} = -\vec{p}_{\mathrm{J}\perp}, \Delta Y_\mathrm{P}\right)\end{aligned} \tag{2}$$

are the differential DY structure functions for the four polarizations $\lambda =$ L, T, LT, TT; $\mathit{\Phi}^{(\lambda)}$ are the DY impact factors and K is the BFKL kernel with kinematic constraint, given by the Fourier decomposition in the azimuthal angle ϕ between $\vec{k}_{1\perp}$ and $\vec{k}_{2\perp}$

$$K\left(\vec{k}_{1\perp}, \vec{k}_{2\perp}, \Delta Y_\mathrm{P}\right) = \frac{2}{(2\pi)^2\left|\vec{k}_{1\perp}\right|\left|\vec{k}_{2\perp}\right|}\left(I_0(\Delta Y_\mathrm{P}) + \sum_{m=1}^{\infty} 2\cos(m\phi) I_m(\Delta Y_\mathrm{P})\right). \tag{3}$$

More details on the choice of K is given in [14].

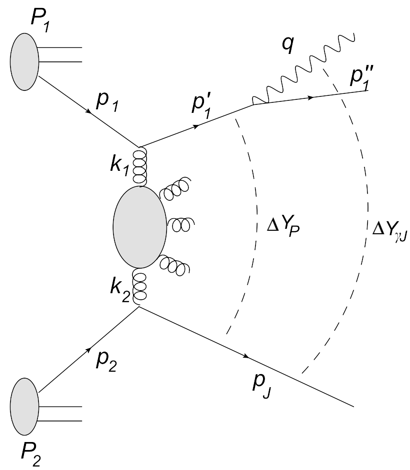

Fig. 1. Kinematic variables relevant for the DY+jet production.

In the forthcoming presentation, we will show the results for the helicity-inclusive cross section (1) integrated over the full spherical angle Ω

$$\frac{\mathrm{d}\sigma^{\mathrm{DY+j}}}{\mathrm{d}\Pi} = \frac{16\pi}{3}\left(\frac{\mathrm{d}\sigma^{\mathrm{T}}}{\mathrm{d}\Pi} + \frac{1}{2}\frac{\mathrm{d}\sigma^{\mathrm{L}}}{\mathrm{d}\Pi}\right) . \tag{4}$$

3. Azimuthal angle dependence

The first quantity to study is the dependence of (4) on the azimuthal angle $\phi_{\gamma\mathrm{J}}$ between the photon transverse momentum $\vec{q}_\perp$ and jet momentum $\vec{p}_{\mathrm{J}\perp}$, see Fig. 2 where the normalized formula (4) is shown as a function of $\phi_{\gamma\mathrm{J}}$. The BFKL effects in the DY+jet case (left) lead to stronger decorrelation in the azimuthal angle in comparison to the LO-Born (two gluon) exchange and also to the MN jet case (right).

In Fig. 3, we show the comparison between the DY+jet (solid lines) and MN jet (dashed lines) processes in terms of the mean cosine

$$\langle\cos(n\phi_{\gamma\mathrm{J}})\rangle = \frac{\int_0^{2\pi}\mathrm{d}\phi_{\gamma\mathrm{J}}\ \frac{\mathrm{d}\sigma^{\mathrm{DY+j}}}{\mathrm{d}M\mathrm{d}\Delta Y_{\gamma\mathrm{J}}\mathrm{d}q_\perp\,\mathrm{d}p_{\mathrm{J}\perp}\mathrm{d}\phi_{\gamma\mathrm{J}}}\cos(n\phi_{\gamma\mathrm{J}})}{\int_0^{2\pi}\mathrm{d}\phi_{\gamma\mathrm{J}}\ \frac{\mathrm{d}\sigma^{\mathrm{DY+j}}}{\mathrm{d}M\mathrm{d}\Delta Y_{\gamma\mathrm{J}}\mathrm{d}q_\perp\,\mathrm{d}p_{\mathrm{J}\perp}\mathrm{d}\phi_{\gamma\mathrm{J}}}} \tag{5}$$

for $n = 1$ and $n = 2$ as a function of the rapidity difference $\Delta Y_{\gamma\mathrm{J}}$. In both cases, we see stronger decorrelation for the DY+jet production than for the MN jet case. Note that the mean cosine values equal one for the MN jet process in the Born approximation when both jets have the same transverse momentum, which gives the strongest possible correlation.

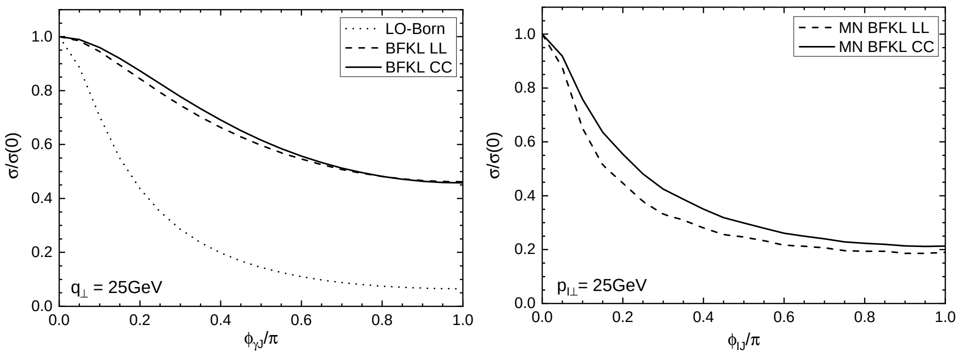

Fig. 2. The azimuthal angle dependence of the normalized helicity cross sections for the DY+jet (right) and MN jets (left) processes for $q_\perp = 25$ GeV, $p_{\mathrm{J}\perp} = 30$ GeV, $M = 35$ GeV and $\Delta Y_{\gamma \mathrm{J}} = \Delta Y_{\mathrm{IJ}} = 7$.

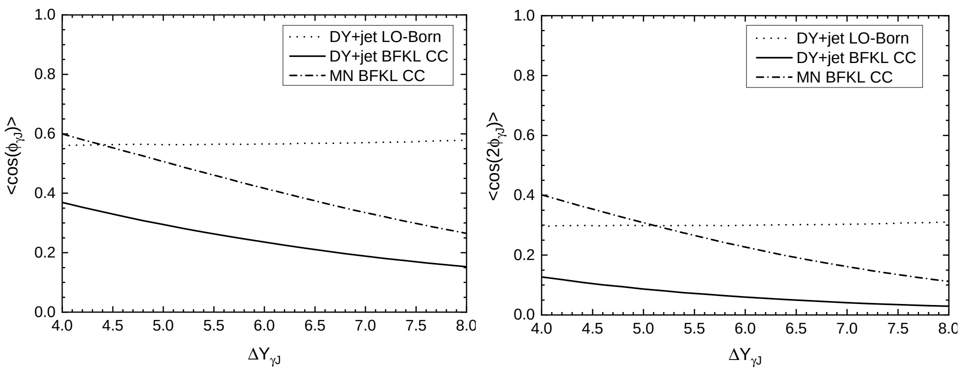

Fig. 3. The mean cosine $\langle \cos(n\phi_{\gamma \mathrm{J}})\rangle$ as a function of rapidity difference $\Delta Y_{\gamma \mathrm{J}}$ for $n = 1$ (left) and $n = 2$ (right) for the DY+jet (solid lines) and MN jets (dashed lines) processes with $q_\perp = p_{\mathrm{I}\perp} = 25$ GeV, $p_{\mathrm{J}\perp} = 30$ GeV and $M = 35$ GeV.

4. Angular coefficients

In the inclusive DY process, it is useful to define normalized structure functions. We follow this approach and define for the DY+jet process the following coefficients:

$$A_0 = \frac{\mathrm{d}\sigma^{\mathrm{L}}}{\mathrm{d}\sigma^{\mathrm{T}} + \mathrm{d}\sigma^{\mathrm{L}}/2}\,, \quad A_1 = \frac{\mathrm{d}\sigma^{\mathrm{LT}}}{\mathrm{d}\sigma^{\mathrm{T}} + \mathrm{d}\sigma^{\mathrm{L}}/2}\,, \quad A_2 = \frac{2\mathrm{d}\sigma^{\mathrm{TT}}}{\mathrm{d}\sigma^{\mathrm{T}} + \mathrm{d}\sigma^{\mathrm{L}}/2}\,. \tag{6}$$

Lam and Tung proved the following relation valid at the LO and NLO for the DY qg channel in the collinear leading twist approximation [1, 13]:

$$\mathrm{d}\sigma^{\mathrm{L}} - 2\mathrm{d}\sigma^{\mathrm{TT}} = 0 \quad \text{or} \quad A_0 - A_2 = 0\,. \tag{7}$$

As it was shown in [15], the combination $A_0 - A_2$ is sensitive to partons' transverse momenta. In Fig. 4, we show this combination as a function of the photon-jet azimuthal angle $\phi_{\gamma \mathrm{J}}$. We see a dramatic difference between the full BFKL result, which is almost independent of the angle, and the LO-Born approximation (two gluon exchange) in which we find a strong dependence on the angle. A similar pattern can be found for the coefficients A_0, A_1 and A_2 separately. This shows that for leptons' angular coefficients, the decorrelation coming from the BFKL emissions is almost complete.

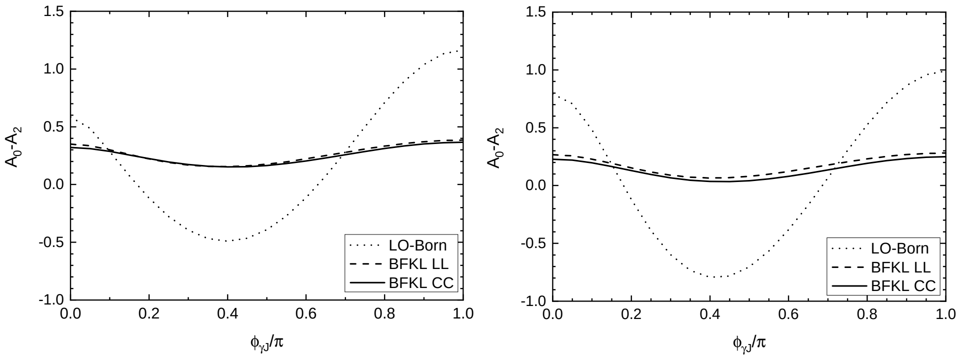

Fig. 4. The Lam–Tung difference of angular coefficients $A_0 - A_2$ as a function the azimuthal photon-jet angle $\phi_{\gamma \mathrm{J}}$ for $q_\perp = 25$ GeV (left) and $q_\perp = 60$ GeV (right) while $p_{\mathrm{J}\perp} = 30$ GeV, $\Delta Y_{\gamma \mathrm{J}} = 7$ and $M = 35$ GeV.

5. Conclusions

We proposed a new process to study the BFKL dynamics in high-energy hadronic collisions — the Drell–Yan plus jet production. In this process, the DY photon with large rapidity difference with respect to the backward jet should be tagged through the lepton pair. The presented numerical results show a significant angular decorrelation with respect to the Born approximation for the BFKL kernel. The found decorrelation is also stronger than for the Mueller–Navelet jets due to more complicated final state with one more particle, being the DY boson. We also presented numerical results on the angular coefficients of the DY lepton pair which provide an additional experimental opportunity to test the effect of the BFKL dynamics in the proposed process.

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REFERENCES

[1] C.S. Lam, Wu-Ki Tung, *Phys. Rev. D* **18**, 2447 (1978).

[2] L.N. Lipatov, *Phys. Rep.* **286**, 131 (1997).

[3] A.H. Mueller, H. Navelet, *Nucl. Phys. B* **282**, 727 (1987).

[4] V. Del Duca, C.R. Schmidt, *Phys. Rev. D* **49**, 4510 (1994).

[5] W.J. Stirling, *Nucl. Phys. B* **423**, 56 (1994).

[6] S. Abachi *et al.*, *Phys. Rev. Lett.* **77**, 595 (1996).

[7] B. Abbott *et al.*, *Phys. Rev. Lett.* **84**, 5722 (2000).

[8] G. Aad *et al.*, *Eur. Phys. J. C* **74**, 3117 (2014).

[9] V. Khachatryan *et al.*, *J. High Energy Phys.* **1608**, 139 (2016).

[10] B. Ducloue, L. Szymanowski, S. Wallon, *Phys. Rev. Lett.* **112**, 082003 (2014).

[11] F. Caporale, D.Yu. Ivanov, B. Murdaca, A. Papa, *Eur. Phys. J. C* **74**, 3084 (2014) [*Erratum ibid.* **75**, 535 (2015)].

[12] D. Brzemiński, L. Motyka, M. Sadzikowski, T. Stebel, *J. High Energy Phys.* **1701**, 005 (2017).

[13] C.S. Lam, Wu-Ki Tung, *Phys. Rev. D* **21**, 2712 (1980).

[14] K. Golec-Biernat, L. Motyka, T. Stebel, *J. High Energy Phys.* **1812**, 091 (2018) [`arXiv:1811.04361 [hep-ph]`].

[15] L. Motyka, M. Sadzikowski, T. Stebel, *Phys. Rev. D* **95**, 114025 (2017).