# Forward Drell-Yan plus backward jet as a test of BFKL evolution

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**DOI:** `http://dx.doi.org/10.3204/DESY-PROC-2012-02/115`

We study Drell-Yan plus jet events where the gauge boson is produced in the forward direction of one of the colliding protons and a jet is produced in the forward direction of the second proton. The resulting large rapidity difference between the final states then opens up the phase space for BFKL evolution. First numerical results on partonic level are provided.

## 1 Introduction

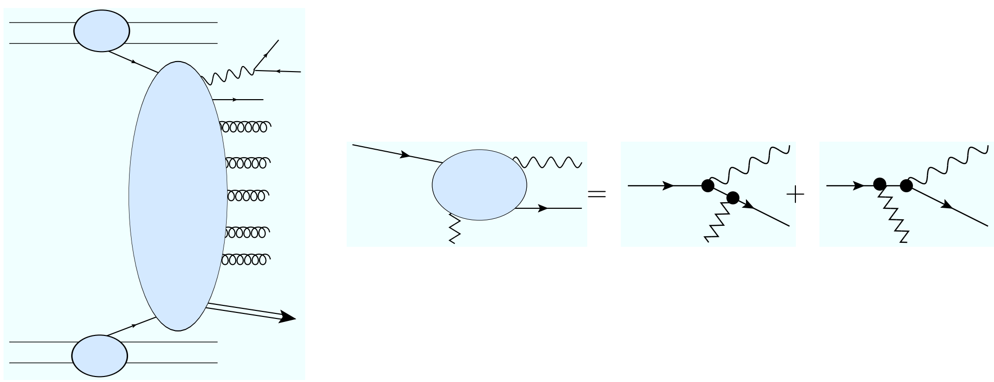
Due to its large center of mass energy the LHC allows for the study of forward physics using methods of perturbative QCD. Among them we find forward production of different systems such as high $p_T$ jets, heavy quark pairs [1] and Drell-Yan (DY) processes where a virtual photon or $Z$ boson decays into a pair of leptons [2, 3]. The study of these type of processes is interesting as they allow to probe parton distribution functions at very small values of $x$ which have not been reached in so-far collider experiments. It therefore provides a possibility to test formalisms which have been especially developed for the description of small $x$ processes and which go beyond the standard formulation in terms of collinear factorization by including additional small $x$ enhanced contributions. The starting point of such studies is given by BFKL evolution which resums small $x$ logarithms on the level of partonic scattering amplitudes at leading logarithmic (LL) [4, 5] and next-to-leading-logarithmic (NLL) [6, 7] accuracy. Extensions of BFKL evolution comprise on the one hand additional resummation of collinear logarithms [8, 9, 10, 11, 12] which cure the instability of pure NLL BFKL evolution and on the other hand the inclusion of saturation effects which refer to the presence of high parton densities at small $x$.

A proper identification of relevant effects at small $x$ seems almost impossible at the level of inclusive cross-sections. Cancellations between different final states minimize the sensitivity to the particular feature of the employed method and deviations from inclusive evolution equations due to small $x$ effects may be partly hidden into the chosen initial conditions. It is therefore necessary to turn to the study of more exclusive observables in order to distinguish different effects at small $x$ and to identify the correct description. Among these exclusive observables there is a class of events where the entire dependence of the process on the non-perturbative dynamics is factorized by conventional collinear factorization. These observables typically involve hard events in the forward region of both scattering protons, while the large difference in rapidity difference between the hard final states opens up the phase space for BFKL evolution.

Among the best explored processes of this type are 'Mueller-Navelet' jets which consist of a high $p_T$-jets in the forward regions of each proton. Currently this process is one of the little examples where a complete NLL description exists [13], with both BFKL evolution and impact factors at NLL [14, 15, 16, 17]. In contrast to naïve expectations, the result of [13] revealed a strong dependence t on the next-to-leading order corrections to the jet impact factors. At the same time, the numerical differences between the NLL resummed result and a pure collinear NLO result remain small for a large class of observables, once NLO corrections to impact factors are included.

This observation motivates the study of a new type of forward-backward observable, where a DY pair is produced in the forward direction of one of the particles instead of a jet. The hope is that this observable is able to better distinguish between standard NLO results and NLL BFKL resummed predictions. Even though the large virtuality of the photon and/or the mass of the $Z$ diminish at first the value of the strong coupling constant $\alpha_s$, the rapidity difference between lepton pair and backward jet remains large at the Large Hadron Collider, $\Delta Y < 7$ and a study of BFKL evolution seems meaningful. In particular with the DY final state in the color singlet, this observable can be expected to be less sensitive to hadronization effects. In addition, study of new final states may also trigger new theoretical efforts for an improved definition of impact factors and lead to the identification of new BFKL observables. In the following we present some partial results of our study, for details we refer to the paper in preparation [18].

## 2 The leading-order DY impact factor




(a) (b)

Figure 1: a) A large difference in rapidity between the forward gauge boson ($\gamma^*, Z$) and the backward jet opens up the phase space for BFKL evolution. b) The leading order DY impact factor is obtained as the sum of two effective diagrams where the $t$-channel gluon carries eikonal polarizations.

In the current study we restrict to the LO impact factor, where relevant diagrams can be found in Fig. 1.b. A complete NLO study seems possible using Lipatov's effective action [19] which is currently explored at NLO [20, 21, 22, 23]. The leading order impact factor reads

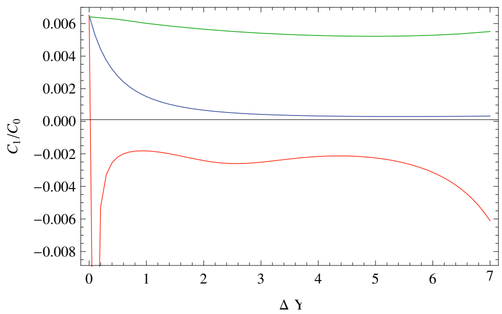
$$\Phi_{Zq} = \frac{c_f \alpha_s \sqrt{N_c^2 - 1}}{\pi \boldsymbol{k}^2 N_c} \left[ \frac{z\boldsymbol{k}^2\big((1-z)^2+1\big) + 2M^2(1-z)z}{D_1 D_2} - \frac{M^2 z(1-z)}{D_1^2} - \frac{M^2(1-z)z}{D_2^2} \right]$$

$$D_1 = (\boldsymbol{q} - z\boldsymbol{k})^2 + (1-z)M^2 \qquad D_2 = \boldsymbol{q}^2 + (1-z)M^2 \tag{1}$$

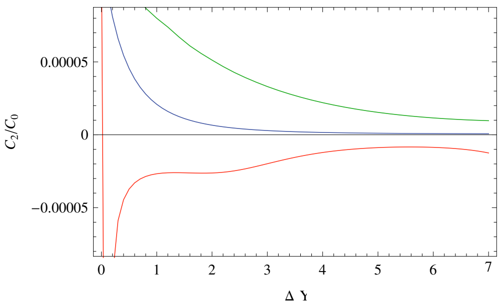
Here $M$ denotes the mass of the $Z$ boson and the virtuality of the photon respectively, while $c_f$ yields the corresponding coupling to the quark. $\boldsymbol{q}$ and $\boldsymbol{k}$ are the transverse momenta of the final state gauge boson and initial gluon, while $z$ is the momentum fraction of the initial quark momentum carried on by the gauge boson.

# 3 Preliminary numerical results at partonic level

The above impact factor carries a logarithmic singularity if the final state quark turns to be soft. To avoid this singularity we study ratios of angular coefficients $\mathcal{C}_n = \langle \cos n\phi \rangle$, where $\phi$ denotes the azimuthal angle between the jet and the gauge boson. In a preliminary study




(a)




(b)

Figure 2: Comparison on partonic level with fixed running coupling of LL (green), NLL (red) and NLL RG improved (blue) BFKL Green's function [12]. Both ratios $\mathcal{C}_1/\mathcal{C}_0$ (a) and $\mathcal{C}_2/\mathcal{C}_0$ are highly sensitive to the Green's function

which restricts to the partonic level and fixed coupling, we find a rather poor convergence of the BFKL evolution for the ratios $\mathcal{C}_n/\mathcal{C}_0$. It is notable that a similar effect occurs in the NLL jet study of [13] where the NLO impact factor corrections dominate the corresponding observable. The ratio $\mathcal{C}_1/\mathcal{C}_2$ shows on the other hand very good convergence and promises to be a good candidate for future phenomenological studies.

# Acknowledgments

We are grateful for financial support from the German Academic Exchange Service (DAAD), the MICINN under grant FPA2010-17747, the Research Executive Agency (REA) of the European Union under the Grant Agreement number PITN-GA-2010-264564 (LHCPhenoNet) and Comunidad de Madrid (HEPHACOS ESP-1473).

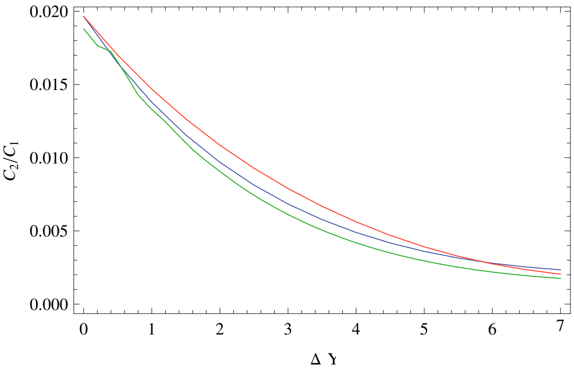



Figure 3: Comparison on partonic level with fixed running coupling of LL (green), NLL (red) and NLL RG improved (blue) BFKL Green's function [12]. The ratio $\mathcal{C}_2/\mathcal{C}_1$ reveals excellent convergence at this level of accuracy.

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