

JETS AT HIGH ENERGIES, FACTORIZATION AND JET VERTEX IN NL $\ln(s)^*$

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(Received August 5, 2002)

The next-to-leading corrections to the jet vertex which is relevant for the Mueller–Navelet jets production in hadronic collisions and for the forward jet cross section in lepton–hadron collisions are presented in the context of a k_t factorization formula which resums the leading and next-to-leading logarithms of the energy. Both the quark- and gluon-initiated contribution are now computed. This completes the framework for a full phenomenological analysis of Mueller–Navelet jets in NL $\log(s)$ approximation. Forward jets phenomenology still requires the NL photon impact factor.

PACS numbers: 12.38.Bx, 12.38.Cy, 11.55.Jy

1. Introduction

In recent works [1, 2] a novel element, relevant in the study of QCD in the Regge limit, has been defined and computed at the NLO level. It is the jet vertex, which represents one of the building blocks in the production of Mueller–Navelet jets [3] at hadron hadron colliders and of forward jets [4] in deep inelastic electron proton scattering. Such processes should provide a kinematical environments for which the BFKL Pomeron [5] QCD analysis could apply, since the transverse energy of the jet fixes a perturbative scale and the large energy yields a large rapidity interval.

We briefly remember here that in a strong Regge regime important contributions, or even dominant, come, in the perturbative language, from diagrams beyond NLO and NNLO at fixed order in α_s . This is the main reason for considering a resummation of the leading and next-to-leading logarithmic

* Presented at the X International Workshop on Deep Inelastic Scattering (DIS2002) Cracow, Poland, 30 April–4 May, 2002.

contributions as computed in the BFKL Pomeron framework. Such approach is lacking of unitarity so that, if the related corrections are not taken into account, one must consider an upper bound on the energy to suppress them. It is already known that the LL analysis is not accurate enough [6], being the kinematics selected by experimental cuts far from any asymptotic regime. Moreover at this level of accuracy there is a maximal dependence in the different scales involved (renormalization, collinear factorization and energy scales). For the Mueller–Navelet jet production process the only element still not known at the NLO level was the “impact factor”, which describes the hadron emitting one inclusive jet when interacting with the reggeized gluon which belongs to the BFKL ladder, accurate up to NLL [7,8]. The jet vertex, now computed, is the building block of this interaction. For the so called forward jet production in DIS the extra ingredient necessary is the photon impact factor, whose calculation is currently in progress [9,10]. Let us also remind that NLL BFKL approach has recently gained more theoretical solidity since the bootstrap condition in its strong form, which is the one necessary for the self-consistency of the assumption of Reggeized form of the production amplitudes, has been stated [11] and formally proved [12]. This relation is a very remarkable property of QCD in the high energy limit.

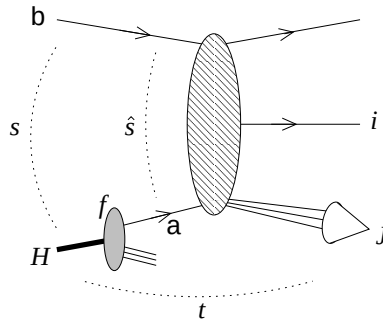


Fig. 1. High energy process with jet production. H is the incoming hadron providing a parton a (gluon g /quark q) with distribution density f_a which scatters with the parton b , J denotes the jet produced in the forward direction (w.r.t H) and i is the generic label for outgoing particles.

A particular theoretical challenge, interesting by itself and appearing in the calculation, is related to the special kinematics. The processes to be analyzed is illustrated in Fig.1: the lower parton emitted from the hadron H scatters with the upper parton q and produces the jet J . The gluon is hard, because of the large transverse momentum of the jet, and obeys the collinear factorization, *i.e.* its scale dependence is described by the DGLAP evolution equations [13]. Above the jet, on the other hand, the kinematics chosen requires a large rapidity gap between the jet and the outgoing par-

ton q : such a situation is described by BFKL dynamics. Therefore the jet vertex lies at the interface between DGLAP and BFKL dynamics, a situation which appears for the first time in a non trivial way. As an essential result of our analysis we find that it is possible to separate, inside the jet vertex, the collinear infrared divergences that go into the parton evolution of the incoming gluon/quark from the high energy gluon radiation inside the rapidity gap which belongs to first rung of the LO BFKL ladder.

2. Jet vertex and cross sections

Let us consider the kinematic variables $p_H = (\sqrt{s/2}, 0, \mathbf{0})$, $s := (p_H + p_q)^2$, $p_b = (0, \sqrt{s/2}, \mathbf{0})$, $p_i = E_i (e^{y_i}/\sqrt{2}, e^{-y_i}/\sqrt{2}, \phi_i)$, $p_a = x p_H$. In our analysis we study the partonic subprocess $a+b \rightarrow X + jet$ in the high energy limit

$$A_{\text{QCD}}^2 \ll E_J^2 \sim -t \text{ (fixed)} \ll s \rightarrow \infty. \quad (1)$$

According to the parton model, we assume the physical cross section to be given by the corresponding partonic cross section $d\hat{\sigma}$ (computable in perturbation theory) convoluted with the parton distribution densities (PDF) f_a of the partons a inside the hadron H . A jet distribution S_J , with the usual safe infrared behaviour, selects the final states contributing to the one jet inclusive cross section that we are considering. In terms of the jet variables — rapidity, transverse energy and azimuthal angle — the one jet inclusive cross section initiated by quarks and gluons in hadron H can be written as

$$\frac{d\sigma}{dJ} := \frac{d\sigma_{bH}}{dy_J dE_J d\phi_J} = \sum_{a=q,g} \int dx d\hat{\sigma}_{ba}(x) S_J(x) f_a^{(0)}(x). \quad (2)$$

One can easily see [1, 2] that at the *lowest order* the jet cross section, dominated by a t -channel gluon exchange, can be written as

$$\frac{d\sigma^{(0)}}{dJ} = \sum_{a=q,g} \int dx \int d\mathbf{k} h_b^{(0)}(\mathbf{k}) V_a^{(0)}(\mathbf{k}, x) f_a^{(0)}(x), \quad (3)$$

where $V_a^{(0)}(\mathbf{k}, x) = h_a^{(0)}(\mathbf{k}) S_J^{(2)}(\mathbf{k}, x)$ is the jet vertex induced by parton a , $h_a^{(0)}(\mathbf{k})$ is the partonic impact factor and $f_a^{(0)}(x)$ is the parton distribution density (PDF). The jet distribution is in this case trivial, $S_J^{(2)}(\mathbf{k}, x) = \delta(1 - x_J/x) E_J^{1+2\epsilon} \delta(\mathbf{k} - \mathbf{k}_J)$ with $x_J := E_J e^{y_J} / \sqrt{s}$.

At the *NLO approximation* virtual and real corrections enter in the calculation of the partonic cross section $d\hat{\sigma}_{ba}$. The three partons produced in the real contributions, in the upper, and lower rapidity region are denoted by

2 and 1, while the third, which can be emitted everywhere, by 3. Moreover we shall call $k = p_b - p_2$ and $k' = p_1 - p_a$ and $q = k - k'$. Bold letters as before indicate the trasverse part. The infrared and ultraviolet divergences can be, as usual, treated by dimensional regularization ($d = 4 + 2\varepsilon$). Taking into account the I.R. properties of the jet distribution $S_J^{(3)}$ the following structure is matched exactly up to NLO (*i.e.* α_s^3) [1,2]

$$\frac{d\sigma}{dJ} = \sum_{a=q,g} \int dx \int d\mathbf{k} d\mathbf{k}' h_b(\mathbf{k}) G(xs, \mathbf{k}, \mathbf{k}') V_a(\mathbf{k}', x) f_a(x), \quad (4)$$

where $h = h^{(0)} + \alpha_s h^{(1)} + \dots$, $V = V^{(0)} + \alpha_s V^{(1)} + \dots$, $f = f^{(0)} + \alpha_s f^{(1)} + \dots$ and $G(xs, \mathbf{k}, \mathbf{k}') := \delta(\mathbf{k} - \mathbf{k}') + \alpha_s K^{(0)}(\mathbf{k}, \mathbf{k}') \log \frac{xs}{s_0} + \dots$. The partonic impact factor correction in forward direction $h^{(1)}$ is well known [14], the PDF's f_a are the standard ones satisfying the LO DGLAP evolution equations and the BFKL Green function G is defined by the LO BFKL kernel $K^{(0)}$. The new element is the correction to the jet vertex $V^{(1)}$ whose expression, for the quark and gluon initiated case, is given in [1,2].

Another element, crucial in the derivation of the representation given above, is the energy scale s_0 associated to the BFKL rapidity evolution. The calculations show a natural choice, due to angular ordered preferred gluon emission and the presence of the jet defining distribution, which is also crucial to obtain the full collinear singularities which factorize into the PDF's. We give the expression of the jet vertex for the case $s_0(\mathbf{k}, \mathbf{k}') := (|\mathbf{k}'| + |\mathbf{q}|)(|\mathbf{k}| + |\mathbf{q}|)$. A mild modification of such a scale can be performed without introducing extra singularities, but in general this is not true. In any case using a different scale requires the introduction of modifying terms. For the symmetric Regge type energy scale $s_R = |\mathbf{k}||\mathbf{k}'|$, one has

$$G(xs, \mathbf{k}, \mathbf{k}') = (1 + \alpha_s H_L) \left[1 + \alpha_s K^{(0)} \log \frac{xs}{|\mathbf{k}||\mathbf{k}'|} \right] (1 + \alpha_s H_R), \quad (5)$$

where $H_L(\mathbf{k}, \mathbf{k}') = -K^{(0)}(\mathbf{k}, \mathbf{k}') \log(|\mathbf{k}| + |\mathbf{q}|/|\mathbf{k}|) = H_R(\mathbf{k}', \mathbf{k})$.

To obtain the jet cross section with accuracy up to NLL terms, one has to consider the NLL BFKL kernel $K = \alpha_s K^{(0)} + \alpha_s^2 K^{(1)}$, which has been computed with the scale $s_R = |\mathbf{k}||\mathbf{k}'|$. The corresponding Green function, to be used in (4), is given by

$$G(xs, \mathbf{k}_1, \mathbf{k}_2) = \int \frac{d\omega}{2\pi i} \left(\frac{xs}{s_R} \right)^\omega \langle \mathbf{k}_1 | (1 + \alpha_s H_L) [\omega - K]^{-1} (1 + \alpha_s H_R) | \mathbf{k}_2 \rangle. \quad (6)$$

The formula for the Mueller–Navelet jets [2] can be easily derived symmetrizing the formula (4) for the two jet case.

3. Conclusions

The calculations at the NLO accuracy for the jet vertex which lies at the interface between DGLAP and BFKL dynamics are completed. Therefore a phenomenological analysis of the Mueller–Navelet jets at NLL is now possible.

The results discussed have been obtained in collaboration with J. Bartels and D. Colferai [1, 2].

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