High-energy resummation in inclusive hadroproduction of Higgs plus jet

Francesco Giovanni Celiberto[1,2,3], Dmitry Yu. Ivanov[4], Mohammed. M. A. Mohammed[5⋆] and Alessandro Papa[5]

1 European Centre for Theoretical Studies in Nuclear Physics and Related Areas (ECT*), I-38123 Villazzano, Trento, Italy
2 Fondazione Bruno Kessler (FBK), I-38123 Povo, Trento, Italy
3 INFN-TIFPA Trento Institute of Fundamental Physics and Applications, I-38123 Povo, Trento, Italy
4 Sobolev Institute of Mathematics, 630090 Novosibirsk, Russia and Novosibirsk State University, 630090 Novosibirsk, Russia
5 Dipartimento di Fisica, Università della Calabria, and Istituto Nazionale di Fisica Nucleare, Gruppo collegato di Cosenza, I-87036 Arcavacata di Rende, Cosenza, Italy

⋆ mohammed.maher@unical.it

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Abstract

Using the standard Balitsky-Fadin-Kuraev-Lipatov (BFKL) approach, with partial inclusion of next-to-leading order effects, we propose the inclusive hadroproduction of a Higgs boson and of a jet, featuring large transverse momenta and well separated in rapidity, as a new channel to probe the BFKL dynamics. Predictions are presented for cross-sections and azimuthal angle correlations in different kinematics configurations for the final-state transverse momenta. We find that the large energy scales provided by the emission of a Higgs boson stabilize the BFKL series.

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1 Introduction

The Balitsky-Fadin-Kuraev-Lipatov (BFKL) [1–4] approach represents a suitable framework for the theoretical description of the QCD dynamics in the high energy-limit. During the last years, the investigation of semi-hard processes [5] to probe the BFKL dynamics has become a theoretical and experimental challenge. Typical BFKL observables at the LHC are the azimuthal-angle correlations of the tagged particles in the final state, which are separated in rapidity, here the experimental challenge being a good resolution in the azimuthal plane, while the theoretical challenge is the incorporation of NLO corrections to impact factors, so as to treat different processes with consistent accuracy, and make predictions to be compared with data. Recently, a number of probes for BFKL signals have been proposed for different collider environments: the diffractive leptoproduction of two light vector mesons [6–9], the total cross section of two highly-virtual photons [10], the inclusive hadroproduction of two jets with large transverse momenta and well separated in rapidity (Mueller-Navelet channel [11]), for which several phenomenological studies have carried out so far (for more details see [12] and references therein), the inclusive detection of two light-charged hadrons [13–15], three- and four-jet hadroproduction [16–21], J/Ψ-jet [22], hadron-jet [23–25], the inclusive production of rapidity-separated Λ-Λ or Λ-jet pairs [26], and recently, double Λ_c or of a Λ_c plus a light-flavored jet system [27], Drell-Yan–jet [28, 29] and heavy-quark pair photo- [30, 31] and hadroproduction [32, 33].

In this work the inclusive production at the LHC of a Higgs boson and of a jet, well separated in rapidity, is suggested as a further probe of the BFKL resummation [34]. For a Higgs boson with mass $M_H = 125$ GeV, the fraction of the longitudinal momentum of the parent proton carried by the struck gluon $x \sim M_H/\sqrt{s} \sim 0.008$ is rather small, making it describable within the BFKL approach.

2 Theoretical Set Up

The process of our consideration is the concurrent inclusive production of a Higgs boson and a jet (see Fig. 1):

$$\text{proton}(p_1) + \text{proton}(p_2) \to H(\vec{p}_H, y_H) + \text{X} + \text{jet}(\vec{p}_J, y_J)\,, \tag{1}$$

emitted with large transverse momenta, $|\vec{p}_{H,J}| \gg \Lambda_{\text{QCD}}$, and separated by a large rapidity interval, $\Delta Y = y_H - y_J$, while p_1 and p_2 are taken as Sudakov light cone base vectors. The cross section of the process can be presented as a Fourier series of the so-called azimuthal coefficients, and it reads

$$\frac{d\sigma}{dy_H dy_J\, d|\vec{p}_H|\, d|\vec{p}_J| d\varphi_H d\varphi_J} = \frac{1}{(2\pi)^2}\left[\mathcal{C}_0 + \sum_{n=1}^{\infty} 2\cos(n\varphi)\,\mathcal{C}_n\right], \tag{2}$$

where $\varphi = \varphi_H - \varphi_J - \pi$, with $\varphi_{H,J}$ the Higgs and the jet azimuthal angles, and C_0 gives the total cross section, while the coefficients $C_{n>0}$ determine their azimuthal-angle distribution.

3 Numerical results

The numerical analysis was preformed using JETHAD [12], a promising standard software under development in our group, suited for the analysis of inclusive semi-hard reactions. As for the renormalization For quarks and gluon PDFs, the MMHT2014 NLO PDF set [35] was employed. We considered three different kinematical configurations for the final-state transverse momentum of detected particles, and constrained the Higgs and jet inside the rapidity acceptances of CMS detector, $|y_H| < 2.5$ and $|y_J| < 4.7$, respectively. First, we studied the φ-summed cross section $C_0(\Delta Y, s)$, the azimuthal-correlation moments, $R_{n0} = C_n/C_0 \equiv \cos(n\phi)$, and their ratios, $R_{nm} = C_n/C_m$ as functions of the Higgs-jet rapidity distance ΔY. We considered the p_H-distribution for two different values of rapidity interval ($\Delta Y = 3, 5$). A detailed study on this observable covering all the high p_H regions would rely on a unified formalism where distinct resummations are concurrently embodied. We summarized our results in Figs. 2

and 3. We adopted the MSbar renormalization scheme, obtaining, for all the considered observables, that the NLA patterns are close to LLA ones. This indicates good stability of the perturbative series, with no need to use scale optimization procedures as for other semihard processes.

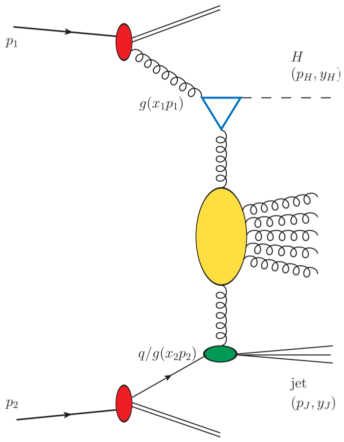

Figure 1: Higgs-jet hadroproduction process

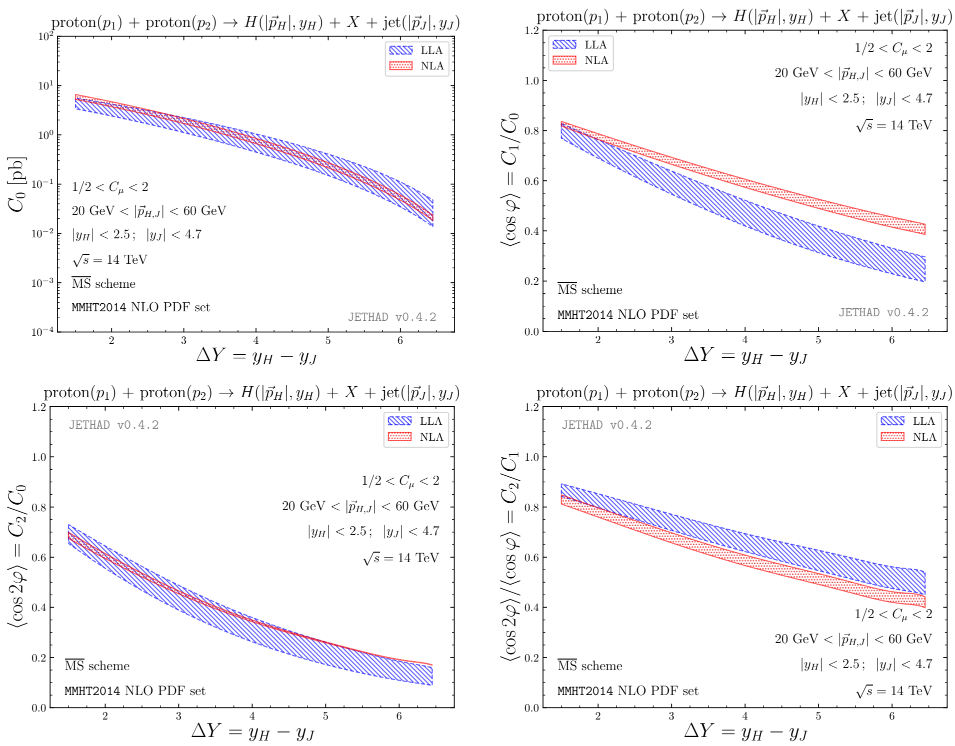

Figure 2: ΔY-dependence of the C_0 and several ratios $R_n m \equiv C_n/C_m$, for the inclusive Higgs-jet hadroproduction

4 Conclusions

In conclusion, the Higss-plus-jet process shows a fair stability under higher order corrections. The high energy resummation approach is valid and available in the symmetric and interme-

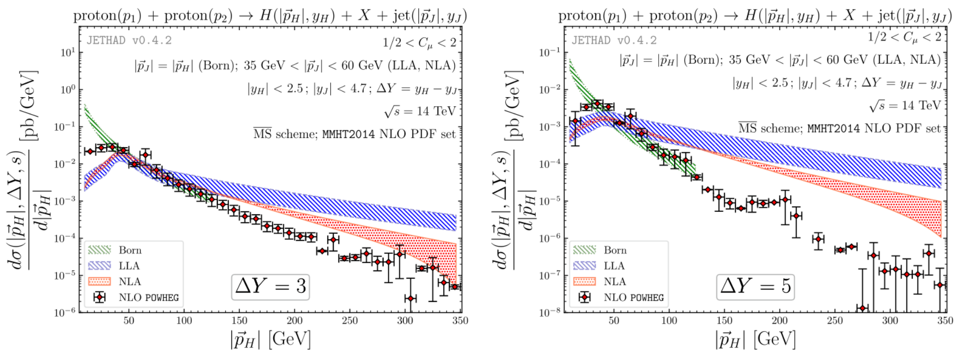

Figure 3: p_H-dependence of the cross section for the inclusive Higgs-jet hadroproduction

diate regions of the p_H values, beyond that, the description for Higgs momentum distribution would be relied on many-sided resummation formalism unifying different approaches.

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References

[1] V. S. Fadin, E. A. Kuraev and L. N. Lipatov, *On the pomeranchuk singularity in asymptotically free theories*, Phys. Lett. B **60**, 50 (1975), doi:10.1016/0370-2693(75)90524-9.

[2] E. Kuraev, L. Lipatov and V. S. Fadin, *Multi-reggeon processes in yang-milles theory*, Sov. Phys. JETP **43**, 443 (1976).

[3] E. A. Kuraev, L. N. Lipatov and V. S. Fadin, *The Pomeranchuk Singularity in Nonabelian Gauge Theories*, Sov. Phys. JETP **45**, 199 (1977).

[4] I. I. Balitsky and L. N. Lipatov, *The Pomeranchuk Singularity in Quantum Chromodynamics*, Sov. J. Nucl. Phys. **28**, 822 (1978).

[5] L. Gribov, *Semihard processes in QCD*, Phys. Rep. **100**, 1 (1983), doi:10.1016/0370-1573(83)90022-4.

[6] D. Yu Ivanov, M. I. Kotsky and A. Papa, *The impact factor for the virtual photonto light vector meson transition*, Eur. Phys. J. C **38**, 195 (2004), doi:10.1140/epjc/s2004-02039-4.

[7] D. Yu. Ivanov and A. Papa, *Electroproduction of two light vector mesons in the next-to-leading approximation*, Nucl. Phys. B **732**, 183 (2006), doi:10.1016/j.nuclphysb.2005.10.028.

[8] D. Yu. Ivanov and A. Papa, *Electroproduction of two light vector mesons in next-to-leading BFKL: study of systematic effects*, Eur. Phys. J. C **49**, 947 (2007), doi:10.1140/epjc/s10052-006-0180-8.

[9] R. Enberg, B. Pire, L. Szymanowski and S. Wallon, *Erratum to: BFKL resummation effects in $\gamma^* \gamma^* \to \rho\rho$*, Eur. Phys. J. C **51**, 1015 (2007), doi:10.1140/epjc/s10052-007-0375-7.

[10] D. Yu. Ivanov, B. Murdaca and A. Papa, *The $\gamma^*\gamma^*$ total cross section in next-to-leading order BFKL and LEP2 data*, J. High Energy Phys. **10**, 058 (2014), doi:10.1007/JHEP10(2014)058.

[11] A. H. Mueller and H. Navelet, *An inclusive minijet cross section and the bare pomeron in QCD*, Nucl. Phys. B **282**, 727 (1987), doi:10.1016/0550-3213(87)90705-X.

[12] F. G. Celiberto, *Hunting BFKL in semi-hard reactions at the LHC*, Eur. Phys. J. C **81**, 691 (2021), doi:10.1140/epjc/s10052-021-09384-2.

[13] F. G. Celiberto, D. Yu. Ivanov, B. Murdaca and A. Papa, *High energy resummation in dihadron production at the LHC*, Phys. Rev. D **94**, 034013 (2016), doi:10.1103/physrevd.94.034013.

[14] F. G. Celiberto, D. Yu. Ivanov, B. Murdaca and A. Papa, *Dihadron production at LHC: BFKL predictions for cross sections and azimuthal correlations*, AIP Conf. Proc. **1819**, 060005 (2017), doi:10.1063/1.4977161.

[15] F. G. Celiberto, D. Yu. Ivanov, B. Murdaca and A. Papa, *Dihadron production at the LHC: full next-to-leading BFKL calculation*, Eur. Phys. J. C **77**, 382 (2017), doi:10.1140/epjc/s10052-017-4949-8.

[16] F. Caporale, G. Chachamis, B. Murdaca and A. Sabio Vera, *Balitsky-Fadin-Kuraev-Lipatov Predictions for Inclusive Three Jet Production at the LHC*, Phys. Rev. Lett. **116**, 012001 (2016), doi:10.1103/PhysRevLett.116.012001.

[17] F. Caporale, F. G. Celiberto, G. Chachamis and A. Sabio Vera, *Multi-Regge kinematics and azimuthal angle observables for inclusive four-jet production*, Eur. Phys. J. C **76**, 165 (2016), doi:10.1140/epjc/s10052-016-3963-6.

[18] F. Caporale, F. G. Celiberto, G. Chachamis, D. Gordo Gómez and A. Sabio Vera, *BFKL azimuthal imprints in inclusive three-jet production at 7 and 13 TeV*, Nucl. Phys. B **910**, 374 (2016), doi:10.1016/j.nuclphysb.2016.07.012.

[19] F. Caporale, F. G. Celiberto, G. Chachamis, D. Gordo Gómez and A. Sabio Vera, *Inclusive four-jet production at 7 and 13 TeV: Azimuthal profile in multi-Regge kinematics*, Eur. Phys. J. C **77**, 5 (2016), doi:10.1140/epjc/s10052-016-4557-z.

[20] F. Caporale, F. G. Celiberto, G. Chachamis, D. Gordo Gómez and A. Sabio Vera, *Probing the BFKL dynamics in inclusive three jet production at the LHC*, EPJ Web Conf. **164**, 07027 (2017), doi:10.1051/epjconf/201716407027.

[21] F. Caporale, F. G. Celiberto, G. Chachamis, D. Gordo Gómez and A. Sabio Vera, *Stability of azimuthal-angle observables under higher order corrections in inclusive three-jet production*, Phys. Rev. D **95**, 074007 (2017), doi:10.1103/PhysRevD.95.074007.

[22] R. Boussarie, B. Ducloué, L. Szymanowski and S. Wallon, *Forward J/ψ and very backward jet inclusive production at the LHC*, Phys. Rev. D **97**, 014008 (2018), doi:10.1103/physrevd.97.014008.

[23] A. D. Bolognino, F. G. Celiberto, D. Yu. Ivanov, M. M. A. Mohammed and A. Papa, *Hadron-jet correlations in high-energy hadronic collisions at the LHC*, Eur. Phys. J. C **78**, 772 (2018), doi:10.1140/epjc/s10052-018-6253-7.

[24] A. D. Bolognino, F. G. Celiberto, D. Yu. Ivanov, M. M. A. Mohammed and A. Papa, *Inclusive Hadron-jet Production at the LHC*, Acta Phys. Pol. B Proc. Suppl. **12**, 773 (2019), doi:10.5506/APhysPolBSupp.12.773.

[25] F. G. Celiberto, A. D. Bolognino, D. Yu. Ivanov, M. M.A. Mohammed and A. Papa, *High-energy effects in forward inclusive dijet and hadron-jet production*, Proc. Sci. **352**, 049 (2019), doi:10.22323/1.352.0049.

[26] F. Giovanni Celiberto, D. Yu. Ivanov and A. Papa, *Diffractive production of Λ hyperons in the high-energy limit of strong interactions*, Phys. Rev. D **102**, 094019 (2020), doi:10.1103/PhysRevD.102.094019.

[27] F. G. Celiberto, M. Fucilla, D. Yu. Ivanov and A. Papa, *High-energy resummation in Λ_c baryon production*, Eur. Phys. J. C **81**, 780 (2021), doi:10.1140/epjc/s10052-021-09448-3.

[28] K. Golec-Biernat, L. Motyka and T. Stebel, *Forward Drell-Yan and backward jet production as a probe of the BFKL dynamics*, J. High Energy Phys. **12**, 091 (2018), doi:10.1007/jhep12(2018)091.

[29] M. Deak, A. van Hameren, H. Jung, A. Kusina, K. Kutak and M. Serino, *Calculation of the $z+$ jet cross section including transverse momenta of initial partons*, Phys. Rev. D **99**, 094011 (2019), doi:10.1103/physrevd.99.094011.

[30] F. G. Celiberto, D. Yu. Ivanov, B. Murdaca and A. Papa, *High-energy resummation in heavy-quark pair photoproduction*, Phys. Lett. B **777**, 141 (2018), doi:10.1016/j.physletb.2017.12.020.

[31] A. Papa, A. D. Bolognino, F. G. Celiberto, M. Fucilla, D. Yu. Ivanov and B. Murdaca, *Inclusive production of two rapidity-separated heavy quarks as a probe of BFKL dynamics*, Proc. Sci. **352**, 067 (2019), doi:10.22323/1.352.0067.

[32] A. D. Bolognino, F. G. Celiberto, M. Fucilla, D. Yu. Ivanov and A. Papa, *High-energy resummation in heavy-quark pair hadroproduction*, Eur. Phys. J. C **79**, 939 (2019), doi:10.1140/epjc/s10052-019-7392-1.

[33] A. D. Bolognino, F. G. Celiberto, M. Fucilla, D. Yu. Ivanov and A. Papa, *Inclusive production of a heavy-light dijet system in hybrid high-energy and collinear factorization*, Phys. Rev. D **103**, 094004 (2021), doi:10.1103/physrevd.103.094004.

[34] F. G. Celiberto, D. Yu. Ivanov, M. M. A. Mohammed and A. Papa, *High-energy resummed distributions for the inclusive Higgs-plus-jet production at the LHC*, Eur. Phys. J. C **81**, 293 (2021), doi:10.1140/epjc/s10052-021-09063-2.

[35] L. A. Harland-Lang, A. D. Martin, P. Motylinski and R. S. Thorne, *Parton distributions in the LHC era: MMHT 2014 PDFs*, Eur. Phys. J. C **75**, 204 (2015), doi:10.1140/epjc/s10052-015-3397-6.