Parton shower contributions to jets from high rapidities at the LHC

M. Deák[1], *F. Hautmann*[2], *H. Jung*[3,4], *K. Kutak*[5]

[1]Universidade de Santiago de Compostela, E-15782 Santiago de Compostela
[2]Theoretical Physics, University of Oxford, Oxford OX1 3NP
[3]Deutsches Elektronen Synchrotron, D-22603 Hamburg
[4]CERN, Physics Department, CH-1211 Geneva 23
[5]Instytut Fizyki Jadrowej im H. Niewodniczanskiego, PL 31-342 Krakow

DOI: `http://dx.doi.org/10.3204/DESY-PROC-2012-02/271`

We discuss current issues associated with the dependence of jet distributions at the LHC on the behavior of QCD parton showers for high rapidities.

At the LHC, due to the phase space opening up at high center-of-mass energy, hadronic jets are accessed for the first time in a region sensitive to contributions of high rapidities [1], in which the forward kinematics forces the hard process into a regime characterized by multiple hard scales [2]. In this multi-scale region the production cross section is affected by high-energy logarithmically-enhanced corrections to all orders in the strong coupling, requiring resummation methods [3] to go beyond finite-order perturbation theory. Moreover, with increasing center-of-mass energies and rapidities the nonperturbative parton distributions are probed for smaller longitudinal momentum fractions. This implies that effects on jet distributions from multiple parton collisions [4] become more pronounced [5] due to the increase in the parton density.

Measurements of inclusive jet production are being carried out at the LHC [6, 7] over a kinematic range in transverse momentum and rapidity much larger than at the Tevatron and previous colliders. Comparisons with standard model theoretical predictions are based either on next-to-leading-order (NLO) QCD calculations, supplemented with nonperturbative (NP) corrections [6, 7] estimated from Monte Carlo event generators, or on NLO-matched parton shower event generators of the kind described in [8].

This article considers effects of QCD parton showers on jet production for increasing rapidity. As discussed in [2, 9] such multi-scale processes are sensitive to effects of the finite transverse-momentum tail of QCD multi-parton matrix elements. The theoretical framework to take these effects into account is based on using partonic matrix element and initial-state distributions unintegrated in both longitudinal and transverse momenta [10, 11, 12]. On the other hand, in NLO event generators finite-$k_\perp$ terms are taken into account only partially, through the higher-order correction at fixed α_s order. Parton shower generators based on collinear evolution, which are either matched to NLO calculations [8] or used to extract the NP corrections [6, 7], do not include finite-$k_\perp$ terms, as these terms correspond to modifications to angular or transverse-momentum ordering [10, 11, 12]. In what follows we illustrate parton showering effects using three Monte Carlo event generators: the $k_\perp$-shower CASCADE generator [13], the NLO matched POWHEG generator [14], and PYTHIA shower Monte Carlo [15], used in two different modes: with the tune P1 [15] including multiple parton collisions, and with single parton collision (PYTHIA-nompi). As emphasized in [16], effects coming from noncollinear multi-parton emission influence jets at large rapidities as well as jets produced centrally but in association with observed forward final states.

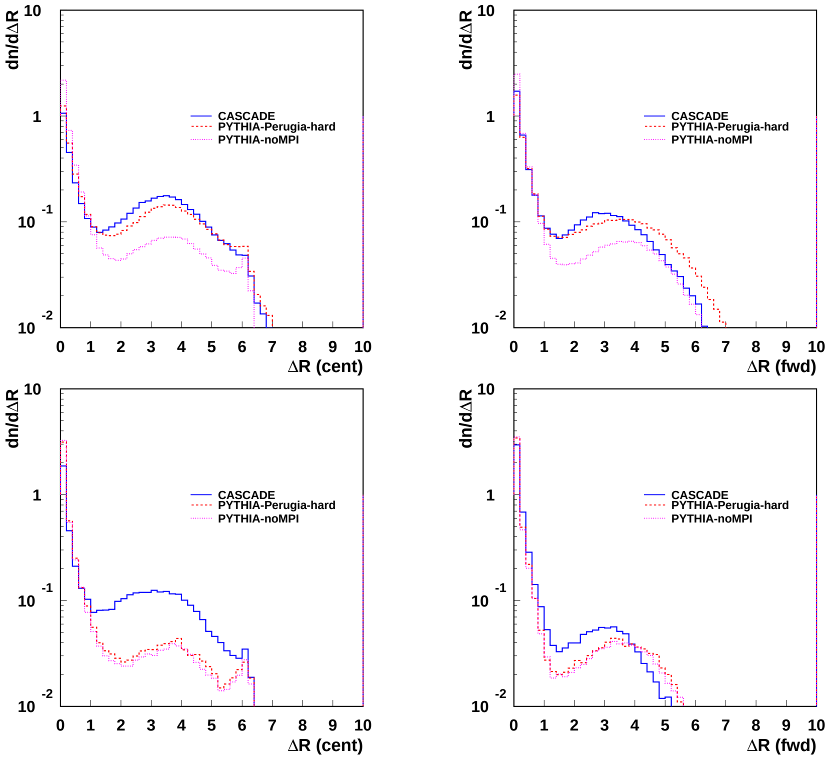

Figure 1: ΔR distribution of central ($|\eta_c| < 2$, left) and forward jets ($3 < |\eta_f| < 5$, right) for $E_T > 10$ GeV (upper row) and $E_T > 30$ GeV (lower row) [16]. The curves correspond to the $k_\perp$-shower Monte Carlo generator CASCADE and to the PYTHIA shower Monte Carlo generator used in two modes, one in which multiple parton interactions are included and one in which they are switched off.

In Fig. 1 we consider final states associated with production of a forward and a central jet [16] reconstructed via the Siscone algorithm [17] ($R = 0.4$) and report the $\Delta R = \sqrt{\Delta\phi^2 + \Delta\eta^2}$ distribution, where $\Delta\phi = \phi_{jet} - \phi_{part}$ ($\Delta\eta = \eta_{jet} - \eta_{part}$) is the azimuthal (rapidity) difference between the jet and the corresponding parton from the matrix element. This distribution probes to what extent jets are dominated by hard partons in the matrix element or originate from the showering. The large-ΔR region, corresponding to sizeable contributions to jets from showers, is seen to be enhanced by noncollinear corrections. While this effect can be also produced by multi-parton interactions for low E_T jets, this no longer applies as E_T increases. It is noteworthy that as a consequence of high-rapidity correlations the enhanced dependence of jet distributions on features of the parton showers is especially pronounced for central jets.

In Fig. 2 this issue is examined using the NLO event generator POWHEG matched with parton showers PYTHIA and HERWIG. We show the central jet transverse energy spectrum for the two cases, normalized to the result obtained by switching off parton showering. The marked differences between the two cases are consistent with the findings in [18], and with the large contribution to jets from showering indicated by Fig. 1. In particular this suggests that high-rapidity correlations affect the behavior of jet distributions in the central region.

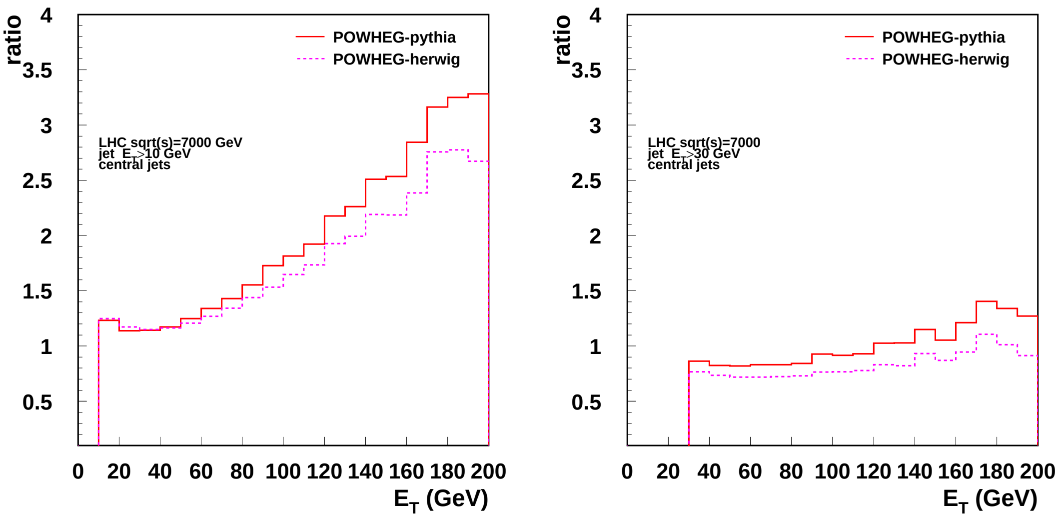

Figure 2: Ratio of central jet transverse energy spectra from the NLO-matched Monte Carlo generator POWHEG, interfaced with PYTHIA and HERWIG parton showers, to the no-showering result. (left) $E_T > 10$ GeV; (right) $E_T >30$ GeV.

We observe that while first measurements of forward jet spectra [18] are roughly in agreement with Monte Carlo simulations, detailed aspects of production rates and correlations [18, 19] are not well understood yet. Also, hadronic event shapes measured at the LHC [20] suggest that parton showering effects dominate contributions of hard matrix elements evaluated at high multiplicity. The numerical results [16] for the large rapidity region underline especially the significance of contributions to showering from transverse momentum dependent branching [21] and parton distributions [22]. This region is relevant to many aspects of LHC physics, including studies of jets from decays of highly boosted new particles [23], new particle searches using vector boson fusion channels [24], relationship of forward particle production and cosmic ray physics [25], high-density QCD and heavy ion collisions [26]. The treatment in terms of unintegrated distributions may in particular be useful to investigate effects of gluon rescattering [27] within parton branching approaches.

Acknowledgments. We thank the conveners for the invitation and excellent organization of the meeting.

References

[1] S. Baranov et al., in Z. Ajaltouni et al., Proc. *HERA and the LHC*, arXiv:0903.3861 [hep-ph] (CERN/DESY 2008).

[2] M. Deak, F. Hautmann, H. Jung and K. Kutak, JHEP **0909** (2009) 121; arXiv:0908.1870.

[3] S. Catani, M. Ciafaloni and F. Hautmann, Nucl. Phys. B**366** (1991) 135.

[4] N. Paver and D. Treleani, Nuovo Cim. **A**70 (1982) 215.

[5] P. Bartalini and L. Fanò (eds.), arXiv:1003.4220 [hep-ex], Proc. 1st Workshop on Multiple Parton Interactions (Perugia, 2008); P. Bartalini et al., arXiv:1111.0469 [hep-ph].

[6] ATLAS Coll. (G. Aad et al.), arXiv:1112.6297 [hep-ex].

[7] CMS Coll., preprint CMS PAS QCD-11-004.

[8] P. Nason and B.R. Webber, arXiv:1202.1251 [hep-ph].

[9] F. Hautmann and H. Jung, JHEP **0810** (2008) 113.

[10] G. Marchesini and B.R. Webber, Nucl. Phys. **B386** (1992) 215.

[11] M. Ciafaloni, Nucl. Phys. B**296** (1988) 49.

[12] S. Catani et al., Phys. Lett. B**242** (1990) 97; Nucl. Phys. B Proc. Suppl. **29A** (1992) 182; Phys. Lett. B**307** (1993) 147; S. Catani and F. Hautmann, Phys. Lett. B**315**(1993)157; Nucl. Phys. B**427** (1994) 475.

[13] H. Jung et al., Eur. Phys. J. C **70** (2010) 1237.

[14] S. Alioli, P. Nason, C. Oleari and E. Re, JHEP **1104** (2011) 081.

[15] P. Skands, Phys. Rev. D**82** (2010) 074018.

[16] M. Deak, F. Hautmann, H. Jung and K. Kutak, arXiv:1012.6037 [hep-ph]; arXiv:1112.6386 [hep-ph]; Eur. Phys. J. C **72** (2012) 1982; arXiv:1206.1745 [hep-ph].

[17] M. Cacciari and G.P. Salam, Phys. Lett. B **641** (2006) 57; M. Cacciari, G.P. Salam and G. Soyez, http://fastjet.fr; G.P. Salam and G. Soyez, JHEP **0705** (2007) 086.

[18] CMS Coll. (S. Chatrchyan et al.), JHEP **1206** (2012) 036.

[19] ATLAS Coll. (G. Aad et al.), JHEP **1109** (2011) 053; CMS Coll. (S. Chatrchyan et al.), arXiv:1204.0696 [hep-ex].

[20] CMS Coll. (V. Khachatryan et al.), Phys. Lett. B**699** (2011) 48.

[21] F. Hautmann and H. Jung, arXiv:0712.0568; arXiv:0808.0873; arXiv:1206.1796; F. Hautmann, Acta Phys. Polon. B **40** (2009) 2139; F. Hautmann, M. Hentschinski and H. Jung, arXiv:1205.6358 [hep-ph].

[22] F. Hautmann, Phys. Lett. B**655**(2007)26; arXiv:0708.1319; Nucl. Phys. B**604**(2001)391; hep-ph/0011381; hep-ph/0101006; J.C. Collins and F. Hautmann, JHEP **0103** (2001) 016; Phys. Lett. B**472** (2000) 129.

[23] A. Altheimer et al., arXiv:1201.0008 [hep-ph].

[24] CMS Coll. (S. Chatrchyan et al.), Phys. Lett. B**713** (2012) 68; Phys. Lett. B**710** (2012) 403; ATLAS Coll. (G. Aad et al.), Phys. Rev. Lett. **108** (2012) 111803; arXiv:1206.5971 [hep-ex].

[25] M. Grothe et al., arXiv:1103.6008 [hep-ph].

[26] D. d'Enterria, arXiv:0911.1273 [hep-ex].

[27] F. Hautmann and D.E. Soper, Phys. Rev. D**75** (2007) 074020; Phys. Rev. D**63** (2000) 011501; F. Hautmann et al., hep-ph/9906284; hep-ph/9806298; F. Hautmann, Phys. Lett. B**643** (2006) 171.