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From LHC to LHeC the issue of forward jets.

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In this note we outline problems which LHeC has potential to solve. Although in this study we do not address them directly we presented results obtained for LHC which we believe may be relevant also for LHeC. In particular we compare predictions for energy flow associated with forward jets in two scenarios: with and without multiple interactions.

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1. Introduction

Experiments at the Large Hadron electron Collider (LHeC) will allow to test the structure of the proton at very small values of longitudinal momentum fraction. This experiment will be a natural extension of HERA physics and it will hopefully allow to answer such questions as: do gluons saturate? what is the amount of multiple interactions at very low x and large Q^2 at DIS. The first of asked question is related to prediction of QCD evolution equations based on high energy factorization considered in high energy limit of QCD. In this limit in order for the unitarity evolution of the gluon density to be satisfied gluons apart from splitting have to recombine, for review see [1]. The second problem not clearly answered at HERA collider is the amount of multiple interactions at large Q^2 and low x in DIS. The need for multiple interactions comes from the need to regularize matrix elements contributing to exclusive process when it becomes larger then the total cross section. The physical picture behind that is provided by a statement that actually interacting photon can itself develop a hadronic structure and these constituents may interact with the partons coming from the proton to produce hadronic final states. This issue has been studied in [5] and the conclusion was that at lowest accessible x_{Bj} at HERA the amount of multiple interactions is substantial.

In this note we will not address these questions directly. We however, present aspects of forward jet phenomenology which we believe are relevant also for the LHeC physics and will shed light on the second of asked questions above. Namely we will calculate energy flow in collision of protons associated with production of two jets where one is in the central region of the detector while the other one is in the forward [4, 5] region. We will compare predictions based on high energy factorization approach to the one based on assumption of multiple interactions. This process is of particular interest since it will allow for better understanding of partonic structure of the proton at extreme energies. The large center of mass energy at the LHC will require application of QCD resummation approaches capable to account for multiple scales in the problem [6, 7]. Namely, one has to account for logarithms of type $\alpha_s^n \ln^m p_\perp/\Lambda_{QCD}$ where $p_\perp$ is a transversal momentum of produced jet and another type of logarithms: $\alpha_s^n \ln^m 1/x$ [8, 9] due to the fact that one of the incoming proton will be probed at very small longitudinal momentum fraction. The theoretical framework to resume consistently both kinds of logarithmic corrections in pQCD is based on high-energy factorization at fixed transverse momentum [10]. This formulation depends on unintegrated parton distributions, obeying appropriate evolution equations, and short-distance, process-dependent matrix elements.

2. Factorization kinematics and matrix elements relevant for forward jets

Forward jet associated with central jet is a process where after collision of two protons one collimated group of high $p_\perp$ hadrons continues along the direction of one of colliding protons - forward detector region, while another group heads toward central region. The high $p_\perp$ production at microscopic level can be understood as originating from collision of two partons where one of them which is almost on-shell carries large longitudinal momentum fraction $\xi_1 p_1$ of mother proton (p_1) while the other one carries small longitudinal momentum fraction $\xi_2 p_2$ of the other proton (p_2) and is off-shell, where k_1, k_2, are the four momenta of initial state partons and p_3 and p_4 are

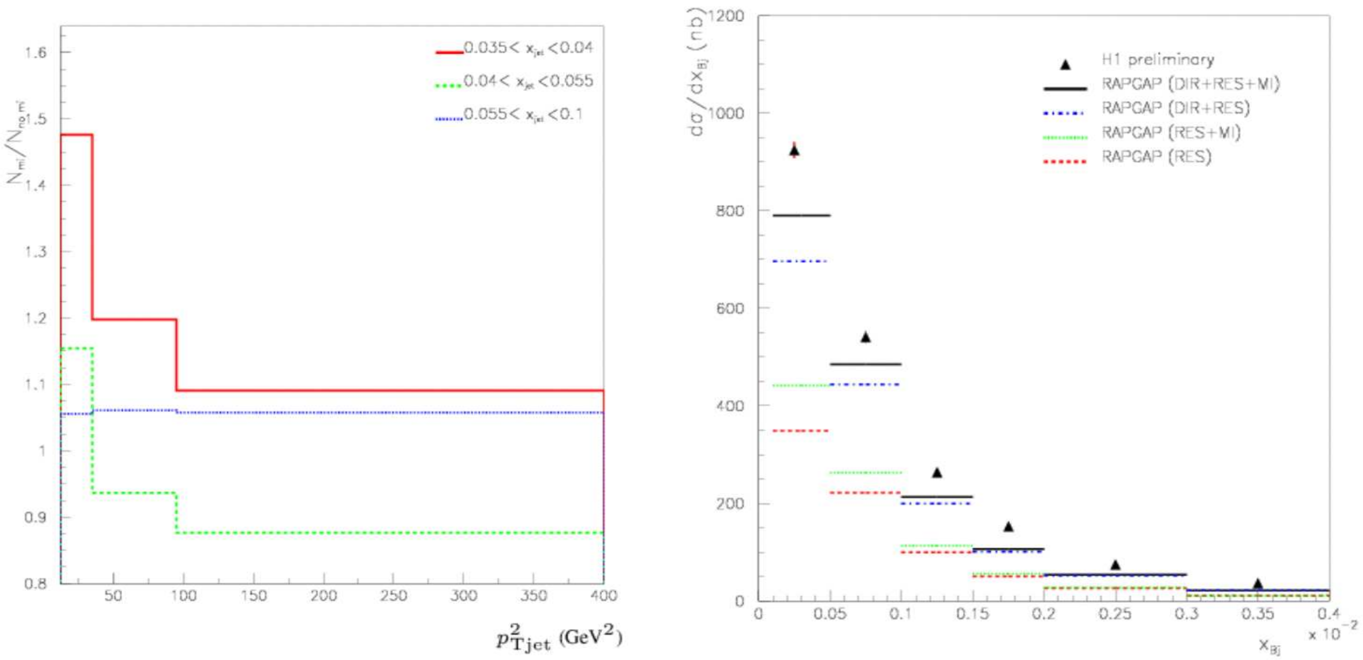

Figure 1: *Taken from [5]. The ratio of forward jets with and without multiple interactions as e function of jet transverse momentum squared for three regions of proton momentum fraction carried by jet(left). The H1 forward jet cross section data compared with RAPGAP 3.1 simulation. Multiple interactions are included (right).*

four-momenta of final state partons.

The framework to describe forward jets is provided by high-energy factorization which was derived after observation of gluon exchange dominance at high energies [10]. Similarly to collinear factorization it decomposes cross-section into parton density functions characterizing incoming hadrons $\phi(\xi, k_\perp)$ at fixed transverse momentum, and perturbatively calculable matrix elements $\widehat{\sigma}$. However, it resumes apart from large logarithms of hard scale also large logarithms coming from energy ordering. In high-energy factorization framework the parton densities are solutions to integro-differential evolution equations summing up perturbative terms with strong ordering condition in rapidity or angle of subsequently emitted partons. Such equations should be supplemented with some nonperturbative input distribution at initial value of ordering parameter which then is evolved with the evolution equation towards larger value of ordering parameter. The matrix elements relevant for high energy factorization describe hard subprocess where at least one of incoming partons is off mass shell. They are calculated by applying to scattering amplitudes $\mathscr{M}$ the high-energy eikonal projectors. In reference [11] matrix elements relevant for forward jets phenomenology have been calculated, in fully exclusive form.

3. Forward jet phenomenology at the LHC

We calculate transversal energy flow end energy flow associated with production of forward jet for a typical experimental scenario at LHC. We require at least two jets with $\mathrm{E}_\perp > 10$ GeV, where one jet has to be detected in the central region defined by $|\eta_c| < 2$ and the other jet is reconstructed in the forward region defined by $3 < |\eta| < 5$. The jets are reconstructed using the invariant $anti-k_t$-algorithm. We compare predictions from running the CASCADE Monte Carlo event generator

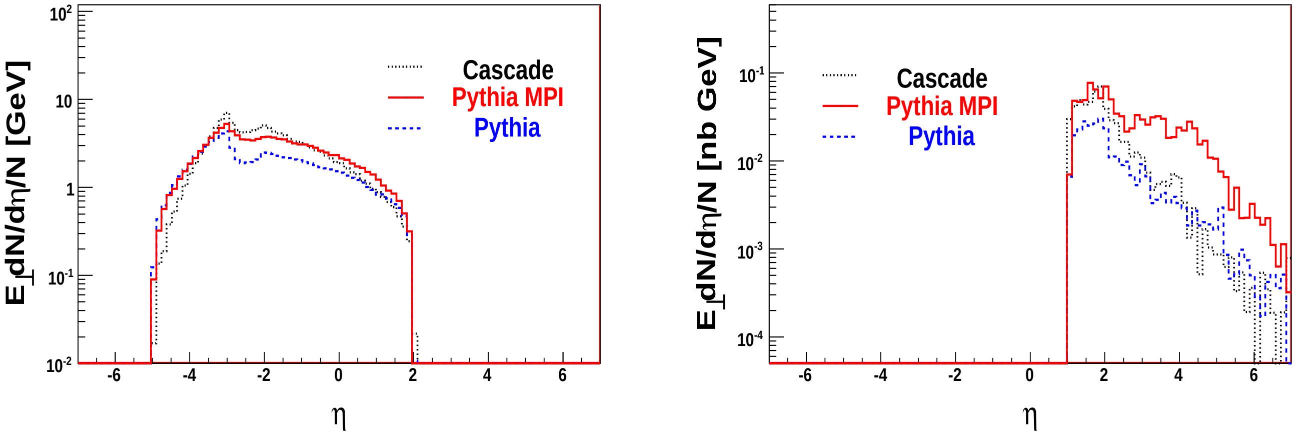

Figure 2: *Left: transversal energy in the inside region associated with forward and central jets at energy of collision 7 TeV. The minimal E_T of either of two jets is 10 GeV. Right: transversal energy in the outside region associated with forward and central jets the minimal E_T of either of two jets is 10 GeV.*

with the PYTHIA [13] Monte Carlo event generator running in two modes: with and without multi-parton interactions. Both Monte Carlo generators simulate higher order QCD corrections with parton showers: CASCADE uses parton showers according to the CCFM evolution equation whereas PYTHIA uses DGLAP based parton showers. In fig 2 we see that there is higher activity activity in the inter-jet region from corrections to collinear ordering. In the outside region at large rapidities we see that full branching is well approximated by collinear shower. However, we also see that multiple interactions scenario predicts considerably larger energy flow.

4. Conclusions

In this note we outlined some problems which LHeC has potential to solve. Although in this study we did not address them directly we presented results obtained for LHC which we believe may be relevant also for LHeC. In particular we have compared predictions for energy flow associated with forward jets in two scenarios: with and without multiple interactions. Similar study can be done for LHeC and can be used to study the amount of multiple interactions in DIS.

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References

[1] J. Jalilian-Marian and Y. V. Kovchegov, Prog. Part. Nucl. Phys. **56** (2006) 104 [arXiv:hep-ph/0505052].

[2] H. Kowalski, L. N. Lipatov, D. A. Ross and G. Watt, arXiv:1005.0355 [hep-ph].

[3] Z. J. Ajaltouni *et al.*, “Proceedings of the workshop: HERA and the LHC workshop series on the arXiv:0903.3861 [hep-ph].

[4] X. Aslanoglou *et al.*, “Performance Studies of Prototype II for the CASTOR forward Calorimeter at Eur. Phys. J. C **52**, 495 (2007).

[5] Z. J. Ajaltouni *et al.*, “Proceedings of the workshop: HERA and the LHC workshop series on the arXiv:0903.3861 [hep-ph].

[6] W. J. Stirling, “Production Of Jet Pairs At Large Relative Rapidity In Hadron Hadron Nucl. Phys. B **423**, 56 (1994).

[7] V. Del Duca, M. E. Peskin and W. K. Tang, Phys. Lett. B **306**, 151 (1993).

[8] L. N. Lipatov, “Reggeization Of The Vector Meson And The Vacuum Singularity In Nonabelian Sov. J. Nucl. Phys. **23**, 338 (1976) [Yad. Fiz. **23**, 642 (1976)].

[9] E. A. Kuraev, L. N. Lipatov and V. S. Fadin, Sov. Phys. JETP **45**, 199 (1977) [Zh. Eksp. Teor. Fiz. **72**, 377 (1977)].

[10] S. Catani, M. Ciafaloni and F. Hautmann, Phys. Lett. B **242**, 97 (1990).

[11] M. Deak, F. Hautmann, H. Jung and K. Kutak, JHEP **0909** (2009) 121.

[12] H. Jung, Comput. Phys. Commun. **143**, 100 (2002).

[13] T. Sjostrand, S. Mrenna and P. Z. Skands, JHEP **0605** (2006) 026