

MULTIPLE INTERACTIONS IN LOW x DIS AND HIGH ENERGY pp COLLISIONS*

GÖSTA GUSTAFSON

Department of Theoretical Physics, Lund University
Sölvegatan 14A, S-22362 Lund, Sweden

E-mail: gosta@thep.lu.se

(Received November 14, 2003)

The LDC formalism for DIS can describe HERA structure functions, and also agrees well with CTEQ and MRST gluon distributions. It is also suitable for hadronic collisions, and provides a strong connection between ep and pp reactions. Some preliminary results are presented.

PACS numbers: 13.60.-r, 13.85.Hd

1. Introduction

In hadron-hadron collisions *collinear factorization* works well for calculations of high- p_{\perp} jets. However, in this formalism the minijet cross section diverges with $\sigma_{\text{jet}} \sim 1/p_{\perp}^4$, which implies that also the total E_{\perp} diverges. This implies the need for a soft cutoff, and in PYTHIA [1] fits to experimental data give a cutoff $p_{\perp 0} \sim 2$ GeV. The cutoff is also growing with energy, which makes it difficult to extrapolate safely to the high energies at LHC.

In the k_{\perp} -factorization formalism the off shell matrix element does not blow up when the exchanged transverse momentum $k_{\perp} \rightarrow 0$. Assume that two incoming partons, with momenta k_1 and k_2 , scatter producing the outgoing partons (jets) q_1 and q_2 . When the momentum exchange k_{\perp}^2 is smaller than the incoming virtualities $k_{\perp 1}^2$ and $k_{\perp 2}^2$, the cross section does not diverge, and the total E_{\perp} stays finite.

When $\sigma_{\text{jet}} > \sigma_{\text{tot}}$ it implies that there are often several hard subcollisions in a single event. Therefore correlations become important, and the observed “pedestal effect” implies that the hard subcollisions are not independent, indicating an impact parameter dependence such that central collisions have many minijets, while peripheral collisions have fewer minijets [2]. In this talk I want to discuss connections between ep and pp collisions, and how experimental DIS data can improve predictions for high energy pp reactions. The results presented are obtained together with Leif Lönnblad and Gabriela Miu.

* Presented at the XXXIII International Symposium on Multiparticle Dynamics, Kraków, Poland, September 5–11, 2003.

2. DIS at small x

In the small x (BFKL) region non- k_\perp -ordered parton chains are important. We let k_i denote the virtual links and q_i the (quasireal) emitted partons in the chain, as indicated in Fig. 1(a). Then, if the link with transverse momentum $k_{\perp i}$ is a local maximum, it corresponds to a hard subcollision, where $q_{\perp i} \approx k_{\perp i} \approx q_{\perp i+1}$. A single local maximum corresponds to a resolved photon interaction, and with several local maxima there are several correlated hard subcollisions.

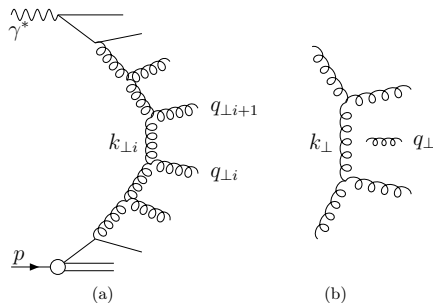


Fig. 1. (a) A large transverse momentum, $k_{\perp i}$, in the middle of the chain corresponds to a hard subcollision between a proton and a resolved photon. (b) In the BFKL and LDC formalisms a soft emitted gluon is treated as final state radiation, while in the CCFM model some of these gluons are treated as initial state radiation.

The BFKL equation describes only *inclusive* cross sections. A link in the ladder corresponds to a Reggeized gluon, where soft emissions are compensated by virtual corrections (*cf.* Fig. 1(b)). Therefore such soft emissions do *not* contribute to parton distribution functions. They *do* contribute, however, to the final state properties, where they have to be added associated with appropriate Sudakov form factors.

The CCFM model interpolates between BFKL and DGLAP. Here soft emissions are included in the initial state radiation, with an extra suppression from non-eikonal form factors. The Linked Dipole Chain (LDC) model [4] is a reformulation and generalization of CCFM. The separation between initial and final state radiation is here more similar to the BFKL formalism. Thus the parton with momentum q in Fig. 1(b) corresponds to final state radiation if $q_\perp < k_\perp$, and should thus not be included in the initial state ladder. An important consequence is that in LDC the ISR chain is fully symmetric between the photon end and the proton end of the ladder. To leading order in $\ln 1/x$ the structure function is given by

$$F \sim \sum_n \prod_i^n \int \int \frac{3\alpha_s}{\pi} \frac{dz_i}{z_i} \frac{dq_{\perp i}^2}{q_{\perp i}^2} \theta(q_{\perp i} - \min(k_{\perp i}, k_{\perp i-1})) \delta(x - \prod z_i). \quad (1)$$

As $\mathbf{q}_{\perp i} \equiv \mathbf{k}_{\perp i} - \mathbf{k}_{\perp i-1}$, the θ -function implies that $q_{\perp i}^2 \approx \max(k_{\perp i}^2, k_{\perp i-1}^2)$. Expressed in the virtual link momenta the product of the factors $dq_{\perp i}^2/q_{\perp i}^2$ then give corresponding factors $dk_{\perp i}^2/k_{\perp i}^2$, except for a local maximum or minimum $k_{\perp i}$. For a local maximum we get a factor $dk_{\perp i}^2/k_{\perp i}^4$, corresponding to a hard subcollision, while for a local minimum we just get $dk_{\perp i}^2$, with no singular factor. The LDC model is implemented in a MC event generator LDCMC [5], which well reproduces data on F_2 , and also agrees well with CTEQ and MRST parametrizations for the gluon distribution function [6].

3. Hadron collisions

The symmetry between the two ends of the parton chain implies that the LDC formalism also is applicable to hadron-hadron collisions. The fit to DIS data determines the cross section for a *chain* in pp collisions (which possibly may contain more than one hard subcollision). There is here a potential problem from the fact that with a running α_s a soft cutoff, Q_0 , is needed. Good fits to DIS data are possible with different cuts, if the input distribution $f_0(x, Q_0^2)$ is adjusted accordingly. If the cutoff Q_0 is increased the number of hard chains (with transverse momenta $q_{\perp} > Q_0$) decreases, which could cause uncertain results. However, at the same time the number of soft chains (for which all $q_{\perp} < Q_0$) increases, and as shown in Ref. [3], it turns out that the total number of chains is independent of the cutoff. Thus the total chain cross section $\sigma_{\text{chain}} = \sigma_{\text{hard chain}} + \sigma_{\text{soft chain}}$ is fixed by DIS data, and this implies evidently a very strong connection between DIS and pp scattering [3].

There are two sources for *multiple interactions*: It is possible to have two hard scatterings in the same chain, and there may be more than one chain in a single event. As described above, the LDC model can predict the correlations between hard scatterings within one chain, and also the average number of chains. If the different chains were uncorrelated, the number of chains in one event would be given by a Poissonian distribution. However, events with high p_{\perp} jets also have a higher background activity, the so called pedestal effect. This indicates that the parton subcollisions are correlated; central collisions have more and peripheral collisions fewer hard subcollisions. In PYTHIA comparisons with data favour a b -dependence described by a double Gaussian distribution. The result for the number of subcollisions turns out to be very close to a geometric distribution.

Some preliminary results from the LDC model are shown in Fig. 2. Here a geometric distribution is assumed for the number of chains in one event, with the tail of the distribution reduced to satisfy energy conservation. Fig. 2(a) shows the number of minijets in the “minimum azimuth region” $60^\circ < \phi < 120^\circ$ at $\sqrt{s} = 1.8$ TeV. The two LDC curves are obtained for soft cut-off values .99 and 1.3 GeV, showing the insensitivity to this cut-off. The

two PYTHIA curves correspond to default parameter values, and parameters tuned to CDF data [7]. We note that the LDC result agrees very well with the tuned PYTHIA result. Fig. 2(b) shows corresponding results for LHC. Also here the two curves correspond to different cut-off values, and for comparison the result for 1.8 TeV is also indicated. We see that the activity increases by a little more than a factor of 2 between the two energies.

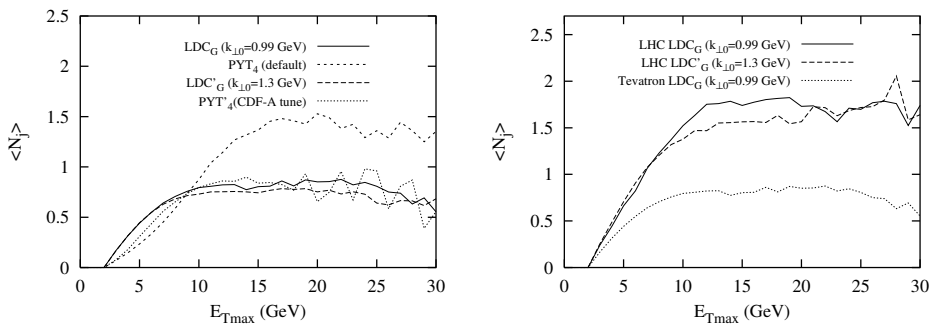


Fig. 2. The average number of minijets in the “minimum azimuth region” for $|\eta| < 2.5$ vs. E_{\perp} for the hardest jet. (a) For $\sqrt{s} = 1.8$ TeV. (b) For 14 TeV.

In conclusion we have shown that there is a strong connection between DIS and high energy pp collisions, and preliminary results for the number of minijets and the pedestal effect are presented.

The symmetry of our formalism implies that the chains join at one end at the same rate as they multiply at the other. The chain cross section grows like s^{λ} , and therefore the average chain multiplicity satisfies $\langle n_{\text{chain}} \rangle \propto s^{\lambda}/\sigma_{\text{tot}}$. Thus our results also may have implications for unitarization, saturation and diffraction. Work in these areas is in progress.

REFERENCES

- [1] T. Sjöstrand *et al.*, *Comput. Phys. Commun.* **135**, 238 (2001).
- [2] T. Sjöstrand, M. van Zijl, *Phys. Rev.* **D36**, 2019 (1987).
- [3] G. Gustafson, L. Lönnblad, G. Miu, *Phys. Rev.* **D67**, 034020 (2003).
- [4] B. Andersson, G. Gustafson, J. Samuelsson, *Nucl. Phys.* **B467**, 443 (1996);
B. Andersson, G. Gustafson, H. Kharraziha, *Phys. Rev.* **D57**, 5543 (1998).
- [5] H. Kharraziha, L. Lönnblad, *J. High Energy Phys.* **03**, 006 (1998).
- [6] G. Gustafson, L. Lönnblad, G. Miu, *J. High Energy Phys.* **0209**, 005 (2002).
- [7] R. Field, private communication at the workshop MC@LHC, CERN, July 2003.