The LDC Event Generator

Gösta Gustafson[a], Hamid Kharraziha[a], Leif Lönnblad[c]

[a] Dept. of Theoretical Physics, Sölvegatan 14a, S-223 62 Lund, Sweden, gosta@thep.lu.se, hamid@thep.lu.se
[b] NORDITA, Blegdamsvej 17, DK-2100 Copenhagen Ø, Denmark, leif@nordita.dk

Abstract: We describe briefly a Monte Carlo implementation of the Linked Dipole Chain model and an interface of it to the ARIADNE program for simulation of complete DIS events at HERA. Using this new tool we make some preliminary comparisons to HERA data and find reasonable agreement.

The Linked Dipole Chain model

We here give a brief sketch of the properties of the Linked Dipole Chain (LDC) model, developed by the Lund group. A more detailed description is presented in Refs. [1, 2]. The model is a reformulation and generalization of the formalism developed by Ciafaloni, Catani, Marchesini and Fiorani (CCFM) [3], which interpolates smoothly between the DGLAP and BFKL regions. In the CCFM model there is a specific recipe, which for each possible final state specifies a separation of the produced gluons in what can be called initial-state and final-state radiation. The initial state radiation can be described by a ladder diagram as in Fig. 1. Each set of final states, specified by a definite ladder (but with arbitrary fina-state radiation within the allowed kinematic region), gives a contribution to the cross section, or to the structure function F_2, with a specific weight which includes a non-eikonal form factor.

In the LDC model more of the produced gluons are treated as final-state radiation. This means that the possible final states are grouped in fewer but larger sets. Each set is specified by a chain as in Fig. 1 where the produced (pseudo-real) gluons q_i satisfy the constraint

$$q_{+,1} > q_{+,2} > \dots q_{+,n}; \qquad q_{-,1} < q_{-,2} < \dots q_{-,n}; \qquad q_{\perp,i} > \min(k_{\perp,i}, k_{\perp,i-1}). \tag{1}$$

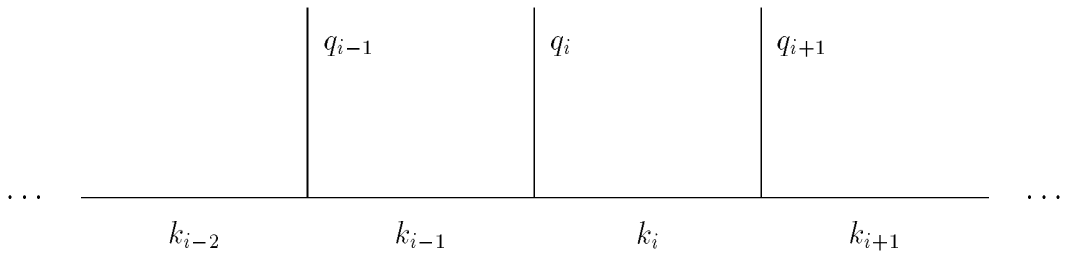

Figure 1: *The notation used for the links and rungs in the ladder.*

To leading order each gluon chain of this type contributes to the cross section, or to F_2, with a weight of the simple form ($z_i = k_{+,i}/k_{+,i-1}$; $\bar{\alpha} = 3\alpha_S/\pi$)

$$(\prod_i \bar{\alpha} \frac{d^2 q_{\perp,i}}{dq^2_{\perp,i}} \frac{dz_i}{z_i}) \cdot \delta(\sum_i q_i - P_{\mathrm{tot}}). \tag{2}$$

The non-eikonal form factors are exactly cancelled. The constraint in Eq. 1 means that any gluon with $y_i < y < y_{i+1}$ and $q_\perp < \min(k_{\perp,i}, k_{\perp,i-1})$ will be regarded as final-state radiation. They affect the properties of the final state and can be treated by means of Sudakov form factors, but they can be disregarded in the calculation of the γp cross section or F_2.

To generate events with the weights given in Eq. 2, or to calculate F_2, it is convenient to express the result in terms of the propagators k_i rather than the real momenta q_i. Equation 1 implies that $q^2_{\perp,i} \approx \max(k^2_{\perp,i}, k^2_{\perp,i-1})$, and thus the weight in Eq. 2 can be rewritten as

$$\prod_i \bar{\alpha} \frac{d^2 k_{\perp,i}}{k^2_{\perp,i}} \frac{dz_i}{z_i} \min(1, \frac{k^2_{\perp,i}}{k^2_{\perp,i-1}}) \tag{3}$$

If Q^2 is large, the dominant contribution is obtained for the ordered region $k_{\perp,1} < k_{\perp,2} < \ldots < k_{\perp,n}$, and the DGLAP result is recovered. If x is very small for moderate Q^2, also non-$k_\perp$-ordered chains give important contributions, and F_2 increases as a power $x^{-\lambda}$.

In the LDC model it is possible to study both a constant and a running α_S (in the latter case the result is sensitive to a necessary cutoff at small $q^2_\perp$, where α_S is very large). It is also possible to include quark lines and some non-leading contributions by replacing the pole term $1/z_i$ by appropriate splitting functions.

The LDC model is a general scheme, which within the same formalism describes what is often called "normal" DIS events, boson–gluon fusion and hard resolved photon–proton (or photon–photon) scattering. It is symmetric with respect to an exchange of the photon and proton ends of the ladder, and provides, for example, automatically the correct $1/k^4_\perp$ dependence for hard sub-collisions.

Generation of the initial chain

The objective is to produce the initial dipole chain by perturbative initial-state emission of partons, given the momentum fraction x_0 and flavour of the first perturbative incoming parton, the momentum fraction x and flavour of the struck quark and the virtuality Q^2 of the probing photon. For the probability distribution of the chain we use the result from the LDC model. Also quark emissions with the full splitting functions are considered.

The generation is done in three steps. We start out with the leading-log approximation probability for the production of a gluon jet. Also further simplifications are made, at this level, by using constant coupling, allowing the propagators to be below the non-perturbative limit ($Q_0 = 0.6$ GeV) and by neglecting the exponential suppression of emissions where the virtuality of the propagator decreases. These simplifications are corrected for later on, together with corrections to the leading-log approximation.

The path of the chain inside the phase space is specified by choosing the $k^2_\perp$ and k_- for the propagators. With the above simplifications and with logarithmic variables, the probability distribution for these points becomes flat inside a rectangular area specified by the available phase space and the ordering of k_+ and k_-.

The next step is to throw away all the chains which crawl under the perturbative level since these partons are included in the non-perturbative initial parton density. The surviving chains are then kept with a probability proportional to the suppression of the "going down" steps as in Eq. 3. The ones which are left, about one percent, are now distributed correctly within the leading-log approximation.

The remaining corrections are made in a similar manner: A weight is calculated which is proportional to the probability to keep the chain. Using this weight we are left with a set of chains which are properly distributed. The corrections included at this level are the running of α_s, the full splitting functions and a suppression factor, which is obtained from the integration over azimuthal angles, when the virtuality of two succeeding propagators are almost equal.

Interfacing to ARIADNE

The interface between the C++ code generating the dipole chains and the FORTRAN code of ARIADNE is hidden from the end user so that changing from the standard DIS scheme in ARIADNE [4] to using the LDC model is done by a simple switch in a common block, leaving the current interface to the Lepto generator [5] for generating the electro–weak interaction intact.

The interface consists of three main parts. One for giving the initial parton distributions to the LDC to determine at which x_0 the chain starts. Another deals with converting the initial chain of partonic links to final state on-shell partons, taking care of energy and momentum conservation and the $p_\perp$ limits of subsequent final-state dipole emissions in ARIADNE. The third part is a procedure to correct the emission closest to the electro–weak vertex so that the $\mathcal{O}(\alpha_S)$ matrix elements (taken from Ref. [6]) is reproduced.

The latter turns out to be a minor correction as the main difference as compared to the leading-log splittings is that the matrix elements behaves like $\propto Q^2/k_\perp^4$ when the $k_\perp$ of the first link is much larger than Q^2, which is already taken into account in the LDC part.

The initial parton densities are given as a simple parametrization:

$$xf_i(x) = A_i x^{\alpha_i}(1-x)^{\beta_i}(1+\gamma_i\sqrt{x}+\delta_i x) \tag{4}$$

And for the preliminary results below, we have simply taken the values presented in [7]. The correct procedure would, of course, be to adjust the parameters in Eq. 4 to fit available data on structure functions using the LDC evolution. This is a future project, which will result in an LDC set of parton density functions which should then, for consistency, also be used to calculate the electro–weak vertex in LEPTO.

The final part, which contains the actual FORTRAN/C++ interface, is a basically straight forward conversion from the momenta k of the generated links, to the momenta q of the (quasi-) real emitted gluons which make up the dipoles and may emit further final-state radiation. There are, however, some ambiguities. First we have to decide how to interpret the $k_\perp$ which in the leading log approximation determines the virtuality of the link. In the original, purely gluonic, formulation we used the relation $dk_\perp^2/k_\perp^2 = d\kappa$ where $\kappa \equiv \ln k_\perp^2/\Lambda^2$. In the $z \to 0$ limit the virtuality $-k^2 \approx k_\perp^2/(1-z)$ is the same as $k_\perp^2$. When quarks are introduced, they are massive, and z is not necessarily close to zero. Here we have used $\kappa = \ln\frac{m^2+k_\perp^2}{\Lambda^2} \equiv \ln\frac{m_\perp^2}{\Lambda^2}$ for simplicity, although a more correct choice might be the "off-shellness", $\kappa = \ln\frac{m^2-k^2}{\Lambda^2} \approx \ln\frac{m_\perp^2}{(1-z)\Lambda^2}$.

The $q_\perp$ of the real emissions are fully determined by the $k_\perp$ of the virtual links only in the leading log approximation, where the dependence upon the azimuthal angles can be neglected. This fact causes some problems with energy–momentum conservation. We have chosen to replace the phase-space factor $dz/z = dk_+/k_+$ in Eq. 3 by dk_-/k_-, and generate the chain from the photon rather than the proton end. Imposing energy–momentum conservation by hand implies that the value x_0' obtained when reaching the proton is not necessarily the same as the x_0 put in from the beginning. Starting from the proton end would give the corresponding, but more serious problem in the photon end.

The final problem arises when we have gluon links, where the outgoing partons must be associated with either the colour or the anticolour flow in the diagram in order to construct the final-state dipoles. This association is simply made randomly, but a complication occurs since two outgoing partons forming a dipole may be connected by more than a single link, in which case the correct limit for the final-state emission depends on the rapidity. In this first version of the LDC generator we have made the simplification that this limit is constant and given by the smallest $k_\perp$ of the connecting links.

Preliminary results

The following results are preliminary in the sense that there are, as mentioned above, still some ambiguities which have not been fully explored, and that the input parton densities may be more or less incompatible with the ones used at the electro–weak vertex and with the LDC evolution.

Besides the parameters in Eq. 4, which should be well constrained by inclusive structure function data, there are no new parameters introduced in the LDC generator. There is, of course, the Λ and cutoff in $k_\perp$ of the links, but these are taken to be the same as in the final-state emissions where they are constrained by LEP data [8]. In principle the $k_\perp$ cutoff should match the virtuality in the input parton densities $f_0(x_0, Q_0^2)$, but we may have a problem as long as no such parton densities satisfying the LDC evolution are available. The only other parameters deal with the fact that the LDC model in principle produces weighted events, which are then normalized to one using a veto. This is a very ineffective procedure and may be speeded up by varying the $\bar{\alpha}$ used internally and a global weight factor. Nevertheless, there is a possibility to have weights bigger than one, in which case the same initial chain may be given several times (although with different final-state radiation), and it is important to check that the distributions studied are insensitive to the choices of these parameters.

Due to lack of space, all distributions available in the HZTOOL [10] package are not presented here. Instead we only show two distributions in Fig. 2 to indicate how sensitive the result is to the input parton densities. The MRS-like input distributions used behaves like x^α for small x, where $\alpha = -0.17$, and for comparison we have used the same distributions but set α to 0. The result is that in the former case, the generated x_0 is generally smaller, resulting in shorter evolution in x which lowers the $E_\perp$ flow.

Besides these uncertainties, Fig. 2 shows that the LDC generator is working and is giving sensible results, although much more work is needed to get the input parton densities consistent

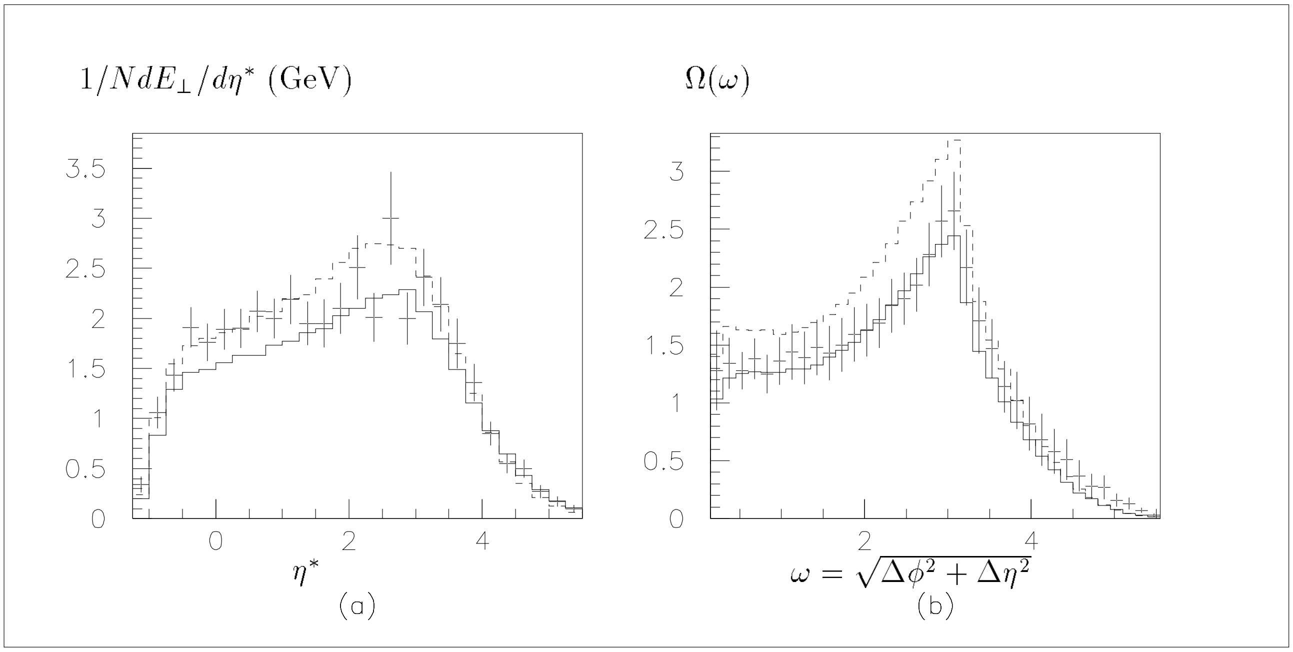

Figure 2: *(a) the $E_\perp$ flow as a function of pseudorapidity in the hadronic c.m.s. and (b) the transverse energy–energy correlations for $x < 0.001$ for the LDC generator compared with data from Ref. [9]. Full line is with input parton density behaving like $x^{-0.17}$ at small x while for dashed they behave like x^0.*

with structure function data and with the LDC evolution before quantitative predictions can be made.

References

[1] B. Andersson, G. Gustafson, J. Samuelsson, *Nucl. Phys.* **B463** (1996) 217.

[2] B. Andersson, G. Gustafson, H. Kharraziha, J. Samuelsson, Lund Preprint LU-TP-95-34, December 1995.

[3] M. Ciafaloni, *Nucl. Phys.* **B296** (1988) 49;
S. Catani, F. Fiorani, G. Marchesini, *Phys. Lett.* **B234** (1990) 339; *Nucl. Phys.* **B336** (1990) 18.

[4] L. Lönnblad, *Comp. Phys. Comm.* **71** (1992) 15.

[5] G. Ingelman, in Proc. HERA workshop, Eds. W. Buchmüller and G. Ingelman, Hamburg (1991) vol. 3, 1366.

[6] R.D. Peccei, R. Rückl, *Nucl. Phys.* **B162** (1989) 125.

[7] A.D. Martin, W.J. Stirling, R.G. Roberts, *Phys. Lett.* **B354** (1995) 155.

[8] I.G. Knowles, et al., 'QCD Event Generators', in Proc. LEP2 workshop, CERN report 96-01, Eds. G. Altarelli, T. Sjöstrand, F. Zwirner.

[9] H1 Collaboration, I. Abt et al., *Phys. Lett.* **B356** (1995) 118.

[10] J. Bromley, et al., "HZTOOL: A package for Monte Carlo – data comparison at HERA", these proceedings.

[11] N. Brook, et al., "Tuning Monte Carlo event generators to HERA data", these proceedings.