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The Linked Dipole Chain MC

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Abstract. We are working on a full-scale Monte Carlo simulation program [1] for describing e-p collisions. This MC is based on the Linked Dipole Chain (LDC) model which, in turn, is a modification and generalization of the CCFM model. Here I will start by explaining the basic model, then describe the MC-implementation and finish with some preliminary results.

INTRODUCTION

Generally in perturbative e-p DIS models one assumes that a parton is picked up from a proton parton distribution at low virtuality. After some perturbative emissions, called Initial State Bremsstrahlung (ISB), one ends up with a quark which interacts with the electron. More partons are then emitted from the initial ladder and those are called Final State Bremsstrahlung (FSB). In a realistic model one must also include a hadronization process where the partons become jets of colour singlet hadrons.

With the Linked Dipole Chain (LDC) model [2], one can perform both the ISB, to evaluate the structure function or the cross section, and the FSB to get a full description of the final state. The hadronization is then performed by the Lund fragmentation model [3]. In the MC-implementation one can also include corrections to the leading log approximation and use a running coupling.

The ISB part of the model is based on the CCFM [4] description which is a leading log approximation interpolating smoothly between the so called DGLAP [5] and BFKL [6] regions. Both DGLAP and BFKL have been shown to be asymptotically exact, though in different parts of phase space.

The original idea behind the LDC model is to incorporate CCFM into the Lund dipole picture [7]. This was shown to be a fruitful approach and, in the process, the CCFM scheme has become simpler and it has become possible to generalize the theory to handle a larger set of events. In addition some nonleading corrections are expected to be smaller in magnitude and more easily included in the formalism.

The dipole picture has previously been successful describing parton cascades in hadronic e^+e^- events and DIS. In the LDC model a direct connection between final state parton distributions and the evolution of the structure function is made possible, thus resulting in a theoretically more appealing picture.

LDC CROSS SECTIONS

The allowed phase space for the ISB in the LDC model is given by ordering of the positive and negative light cone momenta of the emitted partons, $\{q_{i+}\}$ and $\{q_{i-}\}$, with the outer limits set by the proton positive light cone momentum, P_+, and the photon negative light cone momentum, $p_{\gamma-}$. There is also an additional restriction that the transverse momentum, $q_{i\perp}$ of the emitted parton must be larger than the lower of the transverse momenta of the surrounding propagators, $k_{i\perp}$ and $k_{i-1\perp}$.

$$p_{\gamma-} > q_{n-} > \ldots > q_{1-}, \quad q_{n+} < \ldots < q_{1+} < P_+, \quad q_{i\perp} > \min(k_{i\perp}, k_{i-1\perp}) \quad (1)$$

For the weight distribution, dw of the initial chain, one has the nice factorization property: $dw = dw_1 dw_2 ... dw_n$, with one factor for each emission given by:

$$dw_i = \bar{\alpha} \frac{d^2 \bar{q}_{i\perp}}{\pi q_{i\perp}^2} \frac{dz_{i+}}{z_{i+}}, \tag{2}$$

where $z_{i+} = k_{i+}/k_{(i-1)+} < 1$ and $\bar{\alpha} = 3\alpha_s/\pi$.

By integrating the azimuthal angle it can be written approximately as:

$$dw_i = \bar{\alpha} \frac{dk_{i\perp}^2}{k_{i\perp}^2} \frac{dz_{i+}}{z_{i+}} \min\left(1, \frac{k_{i\perp}^2}{k_{i-1\perp}^2}\right). \tag{3}$$

It is instructive to look at three different possibilities for two succeeding emissions, specified by different orderings of the transverse momenta of the propagators, numbered k_1, k_2 and k_3 with k_1 closest to the proton end:

- $k_{1\perp} < k_{2\perp} < k_{3\perp}$: This is included in DGLAP and gives the same weight as there: $dw_2 dw_3 \propto \frac{1}{k_{2\perp}^2} \frac{1}{k_{3\perp}^2}$.
- $k_{1\perp} < k_{2\perp} > k_{3\perp}$: This gives the weight $dw_2 dw_3 \propto \frac{1}{k_{2\perp}^4}$ and resembles a hard sub collision with a momentum transfer $\hat{t} \simeq k_{2\perp}^2$.
- $k_{1\perp} > k_{2\perp} < k_{3\perp}$: Here $dw_2 dw_3 \propto \frac{1}{k_{1\perp}^2} \frac{1}{k_{3\perp}^2}$, which has no factor $\frac{1}{k_{2\perp}^2}$ and is thus infrared safe!

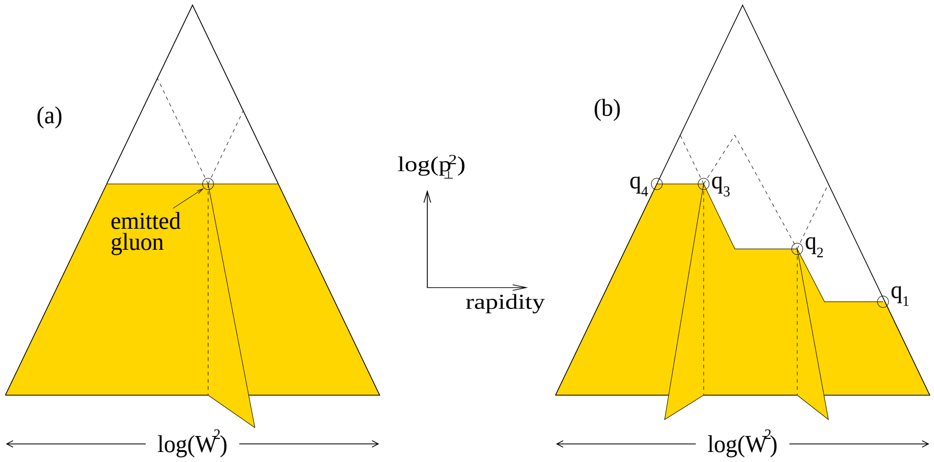

FIGURE 1. The phase space of parton emission from (a) a $q-\bar{q}$ pair and (b) in a DIS event.

THE DIPOLE MODEL

The Dipole model [7] was originally developed for parton cascades from a quark-antiquark system. The phase space for gluon emission from a $q-\bar{q}$ pair is given (in leading log) approximately by the triangular area in fig 1a. The gluons are assumed to be radiated from a $q-\bar{q}$ colour dipole and after each emission, the dipole is split into smaller dipoles, which continue to radiate independently under a $p_\perp$-ordering condition (shaded area). The size of the dipole triangle is determined by the $q-\bar{q}$ central mass energy W.

The momenta $\{q_i\}$ of the emitted ISB partons in DIS can of course also be plotted in a similar way (see fig 1b). Due to the ordering in positive and negative light cone momenta, one can insert the ISB into a triangle with a size determined by the photon's negative light cone momentum and the positive light cone momentum of the first perturbative gluon. After doing this, the FSB partons can be emitted in a similar way as for the $q-\bar{q}$ parton shower. The phase space of the FSB is the shaded area in fig 1b.

LEADING LOG RESULTS

The LDC model has been implemented in a MC program and some results within the leading log approximation have been achieved (for details of the implementation plus additional results see ref. [8]).

One result is that for a running coupling and very small x-Bjorken, the ISB chain seems to saturate around a constant $p_\perp$-level as it moves along the rapidity axis. The prediction from the BFKL model is that $\log p_\perp$ along the chain would be described by a Gaussian distribution with a growing width $\propto \log 1/x$. From the result of the LDC model one can clearly see that the BFKL prediction is indeed true for a constant coupling but not for a running coupling.

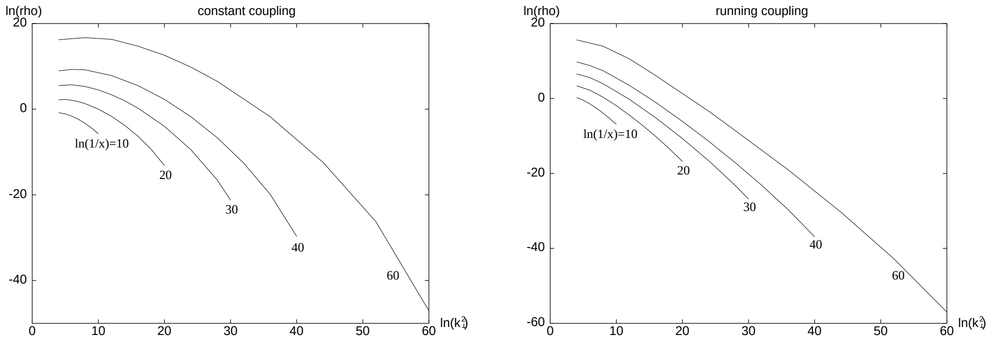

FIGURE 2. The decrease of the parton density with $p_\perp$ at a given rapidity, for different x-values, for constant vs. running coupling.

This is illustrated by the form of the decrease of the parton density with larger $p_\perp$-values, at a given rapidity. In fig 2 the parton density is plotted as a function of $\log p_\perp$ for different values of x-Bjorken, for constant vs. running coupling. The Gaussian behavior is observed for constant coupling, while for running coupling it appears to decay exponentially. It seems though that the exponential decay is significant only for events with very small x-values and might not be visible in available data.

THE REALISTIC MC

It is clear that we must include corrections to the leading log approximation, to be able to make proper quantitative predictions for the structure functions and final state properties of the experimental data. The necessary corrections are to require energy conservation, to include subleading terms in the splitting functions (including quarks) and to convolute the perturbative evolution with input parton distributions at low virtuality. Further, an $\mathcal{O}(\alpha_s)$ matrix element correction at the electroweak vertex is used.

The ISB emissions according to the LDC model together with the above corrections are implemented into the framework of the ARIADNE event generator [9]. The FSB emissions according to the Dipole model are performed by the ARIADNE event generator and the produced partons are hadronized by the JETSET MC [10] which uses the Lund fragmentation model.

RESULTS

As a preliminar result, the $E_\perp$ flow in the hadronic c.m.s. is plotted in fig. 3, together with experimental data from [11].

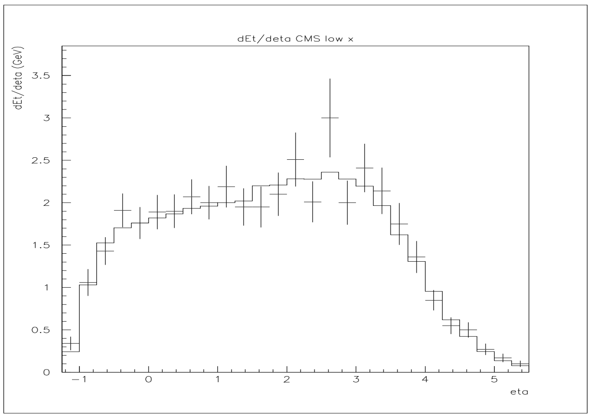

FIGURE 3. The $E_{\perp}$ flow as a function of pseudorapidity in hadronic c.m.s. compared with data from [11] (crosses)

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