Rapidity Gaps and Other Final State Properties in the Colour Dipole Model for Deep Inelastic Scattering

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Abstract

In the light of recent results from the experiments at HERA, the treatment of DIS in the Colour Dipole Model is reviewed and improved. A procedure where the first emission in the dipole cascade is matched onto the exact $\mathcal{O}(\alpha_s)$ matrix element is introduced, giving a more correct dependence of the three-jet rate on Q^2 . Also a new treatment of the proton remnant is introduced assuming a pomeron-like part of the proton structure function, resulting in an, at least qualitatively, good description of the rapidity gap events found by the HERA experiments.

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1 Introduction

After the start of HERA a new kinematical region has been opened up for studies of Deep Inelastic Scattering (DIS) of electrons on protons. The perhaps most important result so far has been the dramatic increase of the F_2 structure function at small x found by both the H1 [1] and ZEUS [2] experiments. Although this could be taken as an indication of the importance of the BFKL-like [3,4] evolution, it turns out that F_2 as measured at HERA and at lower energy experiments can easily be reproduced [5] using the conventional DGLAP-like [6-9] evolution.

The relative importance of the two kinds of evolution can however also be studied by looking into details of the hadronic final states of DIS events. One such measurement could be to look at jets with large x_{jet} and $E_{jet} \approx Q^2$ in small x events [10,11]. This would in some sense select events with BFKL-like dynamics, which basically describe the evolution in x of the structure function for fixed Q^2 . The DGLAP equation, which requires evolution in Q^2 , should not contribute much to such events. A more inclusive measurement could be to simply measure the transverse energy flow in the proton direction in small x events. Here an increasing E_T flow with decreasing x would be a sign of BFKL dynamics [12].

Studying details of hadronic final states and comparing them with analytical predictions on the parton level requires, however, a good understanding of the non-perturbative hadronization process, which presently can only be described in terms of phenomenological models implemented in Monte Carlo event generators. Also the effects of partonic showers are best described by event generators.

Results for the E_T flow have been reported by both experiments at HERA [13,14], comparing them with different event-generator programs. Both analyses find that the E_T flow is very poorly described by the LEPTO [15] program, which implements a parton shower based on standard DGLAP evolution. In contrast, the ARIADNE [16] program, which uses the Colour Dipole Model (CDM) [17-20] for the QCD shower evolution, reproduces data fairly well.

On the other hand, the measurements of jet rates at HERA [21] are very well reproduced by LEPTO, while ARIADNE in particular fails to describe the dependence of the three-jet rate on Q^2 . In addition there is the observation of large rapidity gaps in DIS [22] which cannot be reproduced by either of the two programs.

In this paper the CDM and the ARIADNE program are reviewed and improved in the light of the studies of hadronic final states at HERA. The CDM for DIS [20] differs dramatically from the standard initial-state parton shower model [23] built into LEPTO. Instead of an explicit initial-state evolution, it is assumed in the CDM that all gluon emissions can be described by radiation from a *colour dipole* stretched between the struck quark and the proton remnant. This is similar to the case of e^+e^- annihilation, where bremsstrahlung

can be described in terms of gluon radiation from the colour dipole between the initial quark and anti-quark [19] with one important modification: in the latter case both quarks can be considered point-like, while in the DIS case only the struck quark is point-like whereas the proton remnant is an extended object. This assumption implies coherence conditions, which effectively restricts the available phase space for gluon emission in DIS.

With these simple assumptions the CDM successfully reproduces final-state properties measured at lower energy experiments like the EMC [20, 24]. The model has however one obvious shortcoming in that it only describes gluon radiation, while the process where the virtual photon interacts with an incoming gluon, creating a $q\bar{q}$ -pair, is completely neglected.

In ARIADNE this has so far been taken care of by using the $\mathcal{O}(\alpha_s)$ matrix element for this so-called boson-gluon fusion (BGF) process, as implemented in LEPTO. Here LEPTO is made to generate either a zeroth order quark-photon interaction or an $\mathcal{O}(\alpha_s)$ BGF interaction according to the matrix elements, which is cut off at a minimum $k_{\perp}$ to avoid divergences [16].

In this paper an alternative approach is introduced where, instead, the dipole cascade as such is corrected to match the exact $\mathcal{O}(\alpha_s)$ matrix element in the first emission. In this way the divergences in the matrix elements are cured by introducing a competition between the gluon emission and BGF processes using a Sudakov form factor.

The CDM assumes that the radiating colour dipole connects colour-3 (3) charge of the struck (anti) quark with the colour-3 (3) of the proton remnant. Exactly how the remnant is connected depends on whether a valence- or a sea-quark is struck; it is described in [20] briefly below. In any case, the colour-3 (3), takes a large fraction of the protons momentum, and since this will also become the endpoint of the fragmenting string after the dipole cascade, hadrons will be distributed more or less uniformly in rapidity far out in the proton direction. This is consistent with most events in DIS. However the existence of large rapidity gaps indicates that this remnant treatment is not quite correct. It seems that sometimes the struck quark belongs to a colour singlet object taking only a small fraction of the proton momentum [22].

In this paper the treatment of the proton remnant in the CDM is modified assuming that there is a pomeron-like part of the proton structure function, in the spirit of [25]. This means that in some events the radiating dipole will be connecting the struck quark with a *pomeron* remnant, taking only a small fraction of the proton momentum, leaving a diffracted proton retaining most of its original momentum. These events will then have large rapidity gaps consistent with those found at HERA.

The layout of this paper is as follows. In section 2 the gluon emission in the CDM is presented and compared with the $\mathcal{O}(\alpha_s)$ matrix element. In section 3 the BGF process is introduced into the dipole shower, together with the matching of the first emission in the dipole model to the full matrix element. The treatment of the proton remnant and the procedure for creating large rapidity gaps in the CDM are discussed in section 4. In

section 5 the results from the improved CDM are compared with the “old” dipole model, the conventional parton shower approach as implemented in LEPTO and, where available, with experimental data. Finally, section 6 contains some conclusions.

2 The QCD-Compton process

In the colour dipole model, gluon bremsstrahlung is described in terms of dipole radiation from colour dipoles. In e^+e^- annihilation the first gluon is then emitted by the dipole between the initial quark and antiquark, and further emissions are described as radiation from two independent dipoles, one between the quark and the gluon, and one between the gluon and the antiquark. In terms of the final energy fractions $x_i = 2E_i/W$ of the $q(1)$ and $\bar{q}(3)$ the matrix element used in the first emission can be written (integrated over an azimuthal angle):

$$\frac{d\sigma_g}{\sigma} = \frac{2\alpha_s}{3\pi} \frac{x_1^2 + x_3^2}{(1-x_1)(1-x_3)} dx_1 dx_3, \quad (1)$$

in terms of the variables $p_{\perp}^2 = W^2(1-x_1)(1-x_3)$ and $y = \frac{1}{2} \ln \frac{1-x_1}{1-x_3}$, corresponding to transverse momentum squared and rapidity respectively, this has a particularly simple approximate form

$$\frac{d\sigma_g}{\sigma} \approx \frac{4\alpha_s}{3\pi} \frac{dy_{\perp}^2}{p_{\perp}^2} dy. \quad (2)$$

In the dipole model for DIS [20] it is assumed that the gluon emission from the dipole between the struck quark and the proton remnant has the same form and differs from the e^+e^- annihilation case only in that the remnant is an extended object. If the remnant has a transverse extension $1/\mu$ it is then postulated, using simple coherence arguments, that a gluon radiated with a transverse momentum $p_{\perp}$ can resolve only a fraction $(\mu/p_{\perp})^\alpha$ of the remnant and hence at most carry away that fraction of the remnant momentum. Here, α corresponds to the dimensionality of the remnant, which is assumed to be one-dimensional in the following, i.e. $\alpha = 1$.

Looking at the available phase, limited by

$$p_{\perp} < \frac{W}{e^y + e^{-y}}, \quad (3)$$

the simple coherence condition above then corresponds to an extra cutoff

$$p_{\perp} < \frac{W}{e^y + p_{\perp} e^{-y}/\mu}, \quad (4)$$

giving a matrix element of the form

$$\frac{d\sigma_g}{\sigma} \approx \frac{4\alpha_s}{3\pi} \Theta(p_{\perp}^2, y, W, \mu) \frac{dp_{\perp}^2}{p_{\perp}^2} dy, \quad (5)$$

Figure 1: The diagrams contributing to the QCD-Compton process

where Θ is a theta-function corresponding to eq. (4).

This should be compared with the exact $\mathcal{O}(\alpha_s)$ form for the gluon emission (or QCD-Compton) diagrams in fig. 1 for a given x and Q^2 , again integrated over an azimuthal angle (see e.g. [26] and [27]):

$$\frac{d\sigma_g}{\sigma} = \frac{2\alpha_s}{3\pi} \frac{f_q(x', Q^2)}{f_q(x, Q^2)} \left(\frac{z_q^2 + x_p^2}{(1 - z_q)(1 - x_p)} + 2(x_p z_q + 1) + \frac{8x_p z_q(1 - v)}{1 + (1 - v)^2} \right) \frac{dx_p}{x_p} dz_q, \quad (6)$$

where x is the usual Bjorken- x , x' is the momentum fraction of the incoming quark, $x_p = x/x'$, z_q is the energy fraction of the outgoing quark, f_q is the parton density function of the struck quark and v is the scaling variable $P \cdot q / P \cdot l$ with q , P and l the four-momenta of the virtual photon and the incoming proton and electron respectively. These variables are related to the variables in eq. (1) through

$$x_p = \frac{Q^2}{W^2(1 - x_3) + Q^2}, \quad z_q = 1 - \frac{1 - x_1}{x_3} \quad \text{and} \quad W^2 = \frac{Q^2(1 - x)}{x}. \quad (7)$$

In the limit of small p_1^2 eq. (6) reduces to something very similar to eq. (5):

$$\frac{d\sigma_g}{\sigma} = \frac{4\alpha_s}{3\pi} \frac{f_q(x', Q^2)}{f_q(x, Q^2)} \frac{dp_1^2}{p_1^2} dy. \quad (8)$$

Comparing this to the matrix element used in the CDM, it is clear that the extra cutoff in the phase space due to the extension of the remnant in the dipole model corresponds to the ratio of structure functions in eq. (6). Hence the sharp theta-function in eq. (5) is an oversimplification and should strictly speaking be replaced by a smooth suppression. It turns out, however, that the results are largely independent of whether a sharp or smooth function is used [20]. The main difference between eqs. (5) and (8) is instead how the suppression sets in as is shown in fig. 2, where lines of equal suppression are shown in the $(\ln p_1^2, y)$ plane.

It should also be noted that the gluon radiation in the CDM only depends on W^2 , whereas the full matrix element depends on both x and Q^2 . This could explain why the description of the Q^2 dependence of the three-jet rate in the dipole model does not agree with data [21].

Figure 2: The available phase space of gluon emission (full line) and lines of equal suppression for eqs. (5) and (8) (dashed and dotted respectively)

Figure 3: The diagrams contributing to the BGF process

It is of course possible to actually use the exact matrix element of eq. (6) in the first emission in the dipole cascade. This would then probably improve the description of the three-jet rate. In the following this will be done with the exception that the ratio of structure functions in eq. (6) is replaced by the theta-function of eq. (5), to keep the simple description of the coherence effects due to the extension of the remnant.

3 The boson-gluon fusion process

In the small x regime the QCD-Compton diagram is, however, not as important as the boson-gluon fusion (BGF) diagram, which dominates because of the rapid increase of the gluon density with decreasing x . The BGF process is not at all described by the CDM, as the initial-state splitting of the incoming gluon cannot be translated into a corresponding final-state emission in the CDM.

Figure 4: The colour flow in the BGF process in the diagrams contributing to subsequent gluon emission from one of the dipoles.

Looking only at the $\mathcal{O}(\alpha_s)$ matrix element for the BGF diagrams in fig. 3,

$$\frac{d\sigma_{\text{BGF}}}{\sigma} = \frac{\alpha_s f_g(x', Q^2)}{4\pi f_q(x, Q^2)} \times \left(\frac{(x_p^2 + (1-x_p)^2)(z_q^2 + (1-z_q)^2)}{z_q(1-z_q)} + \frac{16x_p(1-x_p)(1-v)}{1+(1-v)^2} \right) \frac{dz_p dz_q}{x_p} \quad (9)$$

with the same notation as in eq. (6), it can of course be interpreted as, given a dipole between the struck quark and the proton remnant, the cross section for “emitting a corresponding antiquark” from this dipole. This process can then be added to the QCD-Compton one in the first step of the dipole shower, so that the dipole can either emit a gluon in the standard fashion or “emit” an (anti) quark according to eq. (9).

As usual in a shower evolution scenario the notion of what happens “first” is handled by the Sudakov form factor, where the evolution variable defines the concept of “time”. In the CDM the evolution variable is taken to be the Lorentz-invariant transverse momentum $p_\perp^2$ as defined above. This is however not suitable for the BGF process where, instead, the true $k_\perp^2 = z_q(1-x)Q^2/x_p$ of the emitted quark in the gamma-proton centre-of-mass frame is used. In this way, the probability that the “first” emission is a gluon emission or a BGF at some scale $p_\perp^2$ for a given x and Q^2 is given by

$$\frac{dP_g(k_\perp^2, y)}{dk_\perp^2 dy} = \frac{1}{\sigma} \frac{d\sigma_g(k_\perp^2, y)}{dk_\perp^2 dy} I(k_\perp^2) \quad (10)$$

$$\frac{dP_{\text{BGF}}(k_\perp^2, y)}{dk_\perp^2 dy} = \frac{1}{\sigma} \frac{d\sigma_{\text{BGF}}(k_\perp^2, y)}{dk_\perp^2 dy} I(k_\perp^2) \quad (11)$$

with

$$I(k_\perp^2) = \exp - \left[\frac{1}{\sigma} \int_{k_\perp^2}^{k_\perp^{2, \text{max}}} dk_\perp'^2 \int dy \left(\frac{d\sigma_g(k_\perp'^2, y)}{dk_\perp'^2 dy} + \frac{d\sigma_{\text{BGF}}(k_\perp'^2, y)}{dk_\perp'^2 dy} \right) \right]. \quad (12)$$

If a quark is “emitted” in this way in the first step of the dipole cascade, the proton remnant will be in a colour-8 state, and the procedure is to split this remnant into two parts carrying colour-3 and $\bar{3}$ charge respectively. This gives two dipoles, one between the struck quark and the corresponding oppositely coloured remnant, and one between the emitted (anti)

quark and the other part of the remnant, which then continue to radiate independently according to the conventional dipole model for DIS. Just as the gluon emission in the first step of the shower corresponds to coherent radiation of a gluon from the incoming and outgoing quark as in fig. 1, the emission from each dipole in the BGF process corresponds to coherent radiation of a gluon from one of the outgoing quarks and one of the colour lines of the incoming gluon, as shown in fig. 4. This should be a good approximation in the large- N_c limit.

Note that if a QCD-Compton emission is chosen in the first step of this scenario, the incoming quark cannot be said to have come from a gluon split into a $q\bar{q}$ -pair in a BGF-like way in the subsequent cascade, as is the case in a conventional initial-state parton shower. This means that the Sudakov form factor procedure introduced in eqs. (10)–(12) is not quite valid, as the notion that the gluon emission happens “before” the BGF of course assumes that a BGF-like emission actually can occur “after”. But at least for small x , where the BGF diagram dominates in the first step, this should only be a small correction.

4 Remnant treatment and rapidity gaps

As mentioned briefly in the introduction, the gluon emission in the CDM is sensitive to the way the dipole connects the struck quark and the proton remnant. If only a fraction of the remnant is connected by the dipole, the total energy available for gluon radiation is reduced.

In [20] a procedure was introduced, in which a clear distinction was made between the case where the virtual photon couples to a valence quark and the case where it couples to an (anti) sea-quark. In the former case the colour-3 charge is assumed to be carried by the whole remnant, which is treated as a simple diquark. In the case of a struck sea-quark, however, the remnant is not a simple diquark, but rather it contains all original flavour quantum numbers of the proton, plus the antifavour corresponding to the struck sea-quark. It is therefore assumed that the dipole connects the struck quark with a (valence) diquark leaving a colour-less meson containing the remaining valens quark and the anti-sea-quark. (In the case of a struck anti-sea-quark the dipole connects a valence quark and leaves a baryon.) The hadron is given a fraction z of the original proton momentum, where z is given by the Lund symmetric fragmentation function [28].

In the sea-quark case the available phase space for gluon emission is thus reduced either by scaling W in eq. (3) with $W \rightarrow W\sqrt{1-z}$ or, equivalently, assuming that the transverse extension of the remnant is unchanged, by reducing μ in eq. (5) by $\mu \rightarrow \mu(1-z)$. Note that this effectively introduces a smoothing of the theta-function in eq. (5).

In the case of BGF there is also a need to split the remnant into two parts, as described in section 3. Here the strategy is to have the same distribution between the valence quark

and diquark as the above procedure gives for the meson and baryon respectively.

Since the Lund string fragmentation governs the kinematics of the meson and baryon in the remnant treatment of sea-quark interaction events, large rapidity gaps (corresponding to z close to 1) will be very rare. It could however be assumed that the struck quark in some cases belonged to a colourless state taking only a small fraction of the proton momentum. This state could be a meson or, which will be assumed here, a pomeron produced diffractively by the proton in the spirit of [25] and the PomPYT program [29].

Assuming a “flux” of pomerons $f_P^P(x, t)$ taking a fraction x_P of the proton momentum at some small momentum transfer t , with the density of quarks $f_q^P(z, Q^2)$ within the pomeron, the “pomeron-included” part of the total parton density $f_q^P(x, Q^2)$ in the proton is given by a simple convolution:

$$f_q^P(x, Q^2) = \int dt \int dz \int dx_P f_P^P(x_P, t) f_q^P(z, Q^2) \delta(zx_P - x). \quad (13)$$

For each event there is then a probability $f_q^P(x, Q^2)/f_q^P(x, Q^2) < 1$ that the struck quark be part of a pomeron, in which case the x_P and t are generated according to the distributions f_P^P and f_q^P . This results in a dipole between the struck quark and the pomeron remnant with an invariant mass squared $M_x^2 = x_P W^2$, which is small since f_P^P typically is proportional to $1/x_P$.

The pomeron remnant in this scenario is always the antipartner of the struck quark, which is assumed to have a transverse extension $1/\mu_P$. This extension is not necessarily the same as the proton one, but in the following they will be set equal.

Assuming that a pomeron, which by definition is a “gluonic” object, contains quarks might seem strange at first, but since the virtual photon cannot couple directly to a gluon, it always makes sense to define a quark density f_q^P . It can of course be argued that the BGF diagram dominates and that the remnant therefore should be an extended gluon connecting both the quark and the corresponding antiquark with one dipole each. In the following, however, it is assumed that the energy sharing between the quark and antiquark in this case is sufficiently asymmetric (cf. the $1/(z_q(1-z_q))$ pole in eq. (9)) that one of them always can be considered a part of the remnant. This should be a good approximation, as long as M_x is not too large.

5 Comparisons

In this section results for the improved CDM as implemented in ARIADNE version 4.05 is compared with those from an older version (4.04) of ARIADNE and those from LEPTO version 6.1.

Figure 5: The mean p_T^1 as a function of x_F (a) and the p_T -balance as a function of rapidity for a backward trigger (b) (see [24] for definitions). The error bars correspond to EMC data, the solid line to ARIADNE-4.05, the dashed line is ARIADNE-4.04 and the dotted line is LEPTO-6.1, all using CTQ2L [31] structure functions.

ARIADNE version 4.05 can use any form of the pomeron-related functions f_P^P and f_q^P , but the following results are for the default choice of

$$f_P^P(x_P, t) = \frac{(1-x_P)^3}{x_P} (6.38e^{6t} + 0.424e^{3t}), \quad (14)$$

corresponding to the form in [30] with an extra suppression for large x_P to avoid situations with $f_q^P(x_P)/f_P^P > 1$ at large x , and

$$zf_i^P(z, Q^2) = \begin{cases} \frac{3}{2} z(1-z) & i = d, \bar{d}, u, \bar{u} \\ 0 & \text{otherwise.} \end{cases} \quad (15)$$

For low energy data such as those from the EMC [24], the old CDM already gave a satisfactory description. ARIADNE-4.05 improves this description slightly, as seen in fig. 5 where the results for the “seagull” plot and the p_T balance for a “backward trigger” are shown. The improved description of data is both due to the new implementation of BGF and the new pomeron scattering. The addition of the BGF process, although not as dominating since the x -values are higher than at HERA, increases the activity mostly in the positive x_P direction. In addition the pomeron scattering events, although not giving rise to very large rapidity gaps, again due to higher x -values, decrease the activity in the negative x_P .

At HERA, there is so far no published data corrected for detector efficiencies. However since, in the case of jet rates, the data are known to be reproduced by LEPTO [21], results from this program are a good reference. As is shown in fig. 6, ARIADNE-4.05 is in better agreement with LEPTO (data) than the old version. Although the rate is still too high for low Q^2 and small y_{cut} , the Q^2 -dependence is much better. It should be noted that the jet rates are sensitive to the choice of structure functions; however, the difference in Q^2

Figure 6: The three-jet rate (a) as a function of the jet-cut y_{cut} for $12 \text{ GeV}^2 < Q^2 < 80 \text{ GeV}^2$ and (b) as a function of Q^2 for $y_{\text{cut}} = 0.02$. Kinematical cuts are as in [21]. Full line is ARIADNE-4.05 using CTEQ2L structure functions. Dashed and dotted lines are ARIADNE-4.04 and LEPTO-6.1 respectively, with parameter settings and structure functions as in [21].

dependence for the old and new ARIADNE versions is due to the treatment of the matrix element.

In [14] it was found that ARIADNE-4.04 reproduced data for transverse energy flows fairly well and, as is shown in fig. 7, the new version is close to the old one and can be expected to give an equally good description of data. It is interesting that ARIADNE gives more “activity” than LEPTO, both in the jet rates and in the $E_{\perp}$ flow. The fact that ARIADNE describes the $E_{\perp}$ flow, but not the jet rates, indicates that the measured $E_{\perp}$ activity at HERA is less jet-like and, instead, look more like a soft underlying event found in hadron-hadron collisions. The only available event generator which implements an underlying-event mechanism for DIS is HERWIG [32] which, however, also fails to describe the $E_{\perp}$ flow.

For the rapidity-gap events there is again no corrected data published, and in fig. 8 is only shown the new version of ARIADNE, where the number of events with large rapidity gaps is of course very sensitive to the choice of the structure functions f_P^F and f_f^F . Also shown in fig. 8 is the distribution of M_x for events with large rapidity gaps, which shows the expected $1/M_x^2$ falloff for pomeron scattering events. Both results agree qualitatively with the corresponding measurements in [22].

6 Conclusions

It is important to have Monte Carlo event generators that reproduce as closely as possible experimental data, to be able to correct for detector deficiencies and hadronization effects before comparing them with theoretical predictions. The main goal of this paper

Figure 7: The transverse energy flow $E_{\perp}$ in the laboratory system as a function of the pseudo-rapidity distance to the “current quart” as defined in [14] for (a) $x < 0.001$ and (b) $x > 0.001$. Kinematical cuts are as in [14]. Full line is ARIADNE-4.05 using CTEQ2L structure functions. Dashed and dotted lines are ARIADNE-4.04 and LEPTO-6.1 respectively, with parameter settings and structure functions as in [14].

Figure 8: The distribution of (a) η_{max} as defined in [22] and (b) M_x for events with $\eta_{\text{max}} > 1.5$. Kinematical cuts are as in [22]. Full and dashed lines are ARIADNE-4.05 with and without pomeron scattering, both using CTEQ2L structure functions.

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was to improve this description for the Colour Dipole Model and the ARIADNE program. But different event generators also implement different theoretical assumptions, and some things could also be learned from the more direct comparison between event generator and experiment.

The fact that the Lepto program, which implements a conventional DGLAP-like evolution, does not reproduce the increased $E_{\perp}$ flow with decreasing x in the proton direction, indicates that the DGLAP equation is not suited to describe small- x physics at HERA. The ARIADNE program does reproduce the $E_{\perp}$ flow and, although it does not exactly implement BFLK-dynamics, it is sufficiently close to the dipole inspired description of the BFLK pomeron in [33] to indicate that this is indeed the relevant dynamics for small x events.

There are however more differences between the two programs, apart from the QCD shower evolution. While they both use the Lund string fragmentation [34, 35] as implemented in JETSET [36-38], they differ in the treatment of the hard interaction. In Lepto the parton shower is added onto states generated with zeroth or first-order α_s matrix elements where the divergences in the latter are regulated with a simple cutoff. This is not quite consistent with the Sudakov form factor prescription in the subsequent shower, but should be a good approximation for describing, for instance, the three-jet rates. A more correct procedure would be to use an approach like the one described in this paper where, instead, the $O(\alpha_s)$ matrix elements are corrected for in the first emission of the cascade. However, since the change of matrix element treatment in ARIADNE did not influence the $E_{\perp}$ flow very much, as seen in fig. 7, it is more likely that the inability to describe this feature in Lepto is due to the DGLAP-like shower evolution.

The introduction of pomeron-like scattering into the description of DIS in the CDM does not really contain any new physics, as far as the actual rapidity gaps are concerned, since these are governed completely by the functions f_P^p and $f_P^{\bar{p}}$, which are not directly predicted by the dipole model but put in by hand. The treatment of subsequent QCD radiation from the dipole between the struck quark and the pomeron remnant is, however, governed by the same simple coherence conditions, used when a proton remnant is involved. Therefore it is predicted that the structure of the hadronic system of mass M_x in a large rapidity gap event should be the same as in a normal DIS event without rapidity gaps, with $W = M_x$, except for effects due to different sizes of the proton and pomeron.

Compared with the situation in e^+e^- annihilation, where event generators are able to reproduce detailed features of the hadronic final state to a high precision, the understanding of the final states in DIS is very poor. Hopefully, as more data will be analysed at HERA, the event generators will improve, to help increasing our knowledge of the underlying physics.

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