Analysis of Rapidity Gap Cuts in Diffractive DIS

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The requirement of a large pseudo-rapidity gap to select diffractive DIS events at HERA restricts the kinematically accessible region of phase space for a significant range of Q^2, β and $x_{I\!P}$. Consequences of this include a breakdown of $x_{I\!P}$-factorization in large rapidity gap diffractive samples and an enhancement in the relative contribution of quark-antiquark-gluon processes over dijet processes in the diffractive DIS sample.

1. Introduction

Large Rapidity Gap (LRG) cuts, used in some analyses of diffractive DIS at HERA to select diffractive events, restrict the kinematically accessible phase space for a significant range of the kinematic parameters, Q^2, β and $x_{I\!P}$ [1]. One consequence of this is a systematic reduction in the diffractive structure function. Further, since LRG cuts provide a stronger constraint on diffractive dijet production than on higher-multiplicity diffractive final states, these cuts are expected to lead to a relative enhancement in the contribution from $q\bar{q}g$ and higher-order diffractive final states. The sensitivity of the phase space constraints to $x_{I\!P}$ also means that one cannot extract a well-defined pomeron structure function from LRG data for which phase space effects are expected.

In the next section we briefly discuss the relevant kinematics and hadronization effects. In section 3 we explain the relationship between pseudo-rapidity cuts and phase space constraints in diffractive DIS, and describe the region of HERA parameter space in which such effects might be observed. Following this, we explore the consequences of LRG cuts on the extraction of diffractive and pomeron structure functions, and constraints on $q\bar{q}g$ and higher-order diffractive final states.

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2. Kinematics

We use the usual variables of DIS and diffractive DIS, where pseudo-rapidity, η, is defined by

$$\eta = -\ln\tan\frac{\theta_{\mathrm{lab}}}{2}, \tag{1}$$

where θ_{lab} is the HERA LAB angle between the forward proton direction and any significant hadronic activity from the diffractive final state.

Another interesting kinematic variable is the transverse momentum, $p_\perp^2$, of final-state partons in the virtual photon-pomeron centre-of-momentum (CMS) system. For dijet final states, this is given by

$$p_\perp^2 = \frac{M_X^2}{4}\sin^2\theta_{\mathrm{cms}}, \tag{2}$$

where θ_{cms} is the CMS scattering angle between the final state parton in the diffractive system which couples to the same vertex as the pomeron, and the $\gamma^* - I\!P$ axis. A similar relation can easily be constructed for higher-order diffractive final states.

In order to relate pseudo-rapidity cuts, which are made at hadron level in the HERA LAB frame, to $p_\perp^2$, defined above at parton level in the $\gamma^* - I\!P$ CMS system, one must first make some assumption about hadronization effects, and also calculate the boost between the LAB and CMS systems. We assume that the final-state partons hadronize into a jet with a radius of half a unit of pseudo-rapidity. Thus, for example, a pseudo-rapidity cut, η_{max}, of 3.2 made at hadron level corresponds to a pseudo-rapidity interval of about 2.7 at parton level.

3. Consequences of LRG Cuts

3.1. Constraints on Diffractive Final-State Phase Space for Dijet Production

One can express the final-state phase space for diffractive DIS in terms of the transverse momentum variable, $p_\perp^2$, defined in the previous section. To calculate the diffractive structure function, one integrates over the full range of $p_\perp^2$. However, the large pseudo-rapidity gap cuts imposed in some analyses of diffractive DIS at HERA restrict the kinematically accessible range of $p_\perp^2$.

To see this, one calculates the boost that relates angles in the HERA LAB and $\gamma^* - I\!P$ CMS systems in terms of the parameters Q^2, β and $x_{I\!P}$ and the proton and electron initial energies (see [2] for details). Since pseudo-rapidity is related to the LAB scattering angle, and $p_\perp^2$ to the CMS scattering angle, we have the result for a pseudo-rapidity cut $\eta_{\rm max}$:

$$\eta_{\rm max} \Rightarrow \theta_{\rm min}^{\rm lab} \Rightarrow \theta_{\rm min}^{\rm cms} \Rightarrow p_{\perp\,\rm min}^2. \qquad (3)$$

In Figs. 1 and 2, we show the dependence of $p_{\perp\,\rm min}^2$ on Q^2, β and $x_{I\!P}$ for dijet production for a very strong pseudo-rapidity cut of $\eta_{\rm max} = 1.8$, corresponding to early H1 analyses [3], and for the much weaker cut of $\eta_{\rm max} = 3.2$ which has been used in recent analyses [4,5]. It is important to note that for a large range of Q^2, β and $x_{I\!P}$, one finds that $p_{\perp\,\rm min}^2 \lesssim 1\,{\rm GeV}^2$, that is, there is no strong constraint. However, even for the weaker cut, we see that $p_{\perp\,\rm min}^2$ can be significant at large $x_{I\!P}$, and at small β.

3.2. Diffractive Structure Function

The diffractive structure function can be expressed as an integral over the diffractive scattering cross section via

$$F_2^{D(3)}(Q^2,\beta,x_{I\!P}) \sim \int_{p_{\perp\,\rm min}^2}^{\frac{M_X^2}{4}} {\rm d}p_\perp^2 \, \frac{{\rm d}^4\sigma^{eP\to ePX}}{{\rm d}Q^2{\rm d}\beta{\rm d}x_{I\!P}{\rm d}p_\perp^2}. \qquad (4)$$

From Eq. 4, it is clear that for cuts which constrain $p_{\perp\,\rm min}^2$ to be greater than a few GeV^2, we are not extracting the full diffractive structure

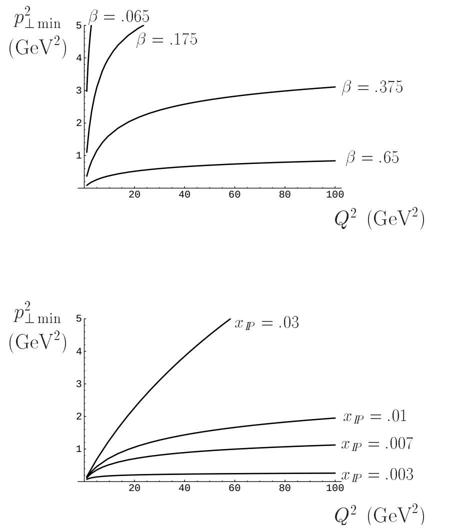

Figure 1. *Dependence of $p_{\perp\,\rm min}^2$ on Q^2, β, and $x_{I\!P}$. Both graphs correspond to a pseudo-rapidity cut of $\eta_{\rm max} = 1.8$, and for the top graph $x_{I\!P} = 0.007$, while for the lower graph $\beta = 0.6$.*

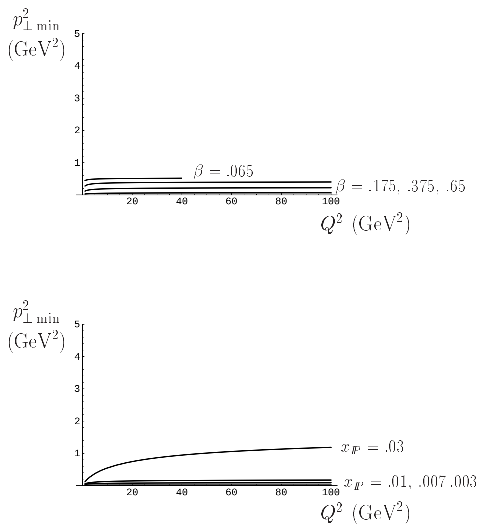

Figure 2. *Dependence of $p_{\perp\,\rm min}^2$ on Q^2, β, and $x_{I\!P}$, for a pseudo-rapidity cut of $\eta_{\rm max} = 3.2$. For the top graph $x_{I\!P} = 0.007$, while for the lower graph $\beta = 0.6$.*

function from the data. In particular, since $p^2_{\perp\,\mathrm{min}}$ varies with Q^2, β and $x_{I\!P}$, there is a systematic decrease in the extracted $F_2^{D(3)}$ compared to that which would be extracted using techniques which do not impose such constraints.

3.3. Multi-Jet Final States

We have also calculated the constraints for production of $q\bar{q}g$ and higher-order diffractive final states, and find a weaker constraint applies:

$$p^2_{\perp\,\mathrm{min,multi-jet}} \approx \frac{1}{3} p^2_{\perp\,\mathrm{min,dijet}}\,. \qquad (5)$$

Hence, in regions where $p^2_{\perp\,\mathrm{min,dijet}}$ is significant, one would expect to find a relative enhancement in the contribution to the diffractive structure function from the rapidity gap data from multi-jet final states over that in the full diffractive structure function, since

$$F^{D(3)}_{2,\mathrm{multi-jet}}(Q^2,\beta,x_{I\!P}) \sim \int_{\frac{1}{3}p^2_{\perp\,\mathrm{min,dijet}}}^{\frac{M_X^2}{4}} \mathrm{d}p^2_\perp \, \frac{\mathrm{d}^4\sigma}{\mathrm{d}Q^2\mathrm{d}\beta\mathrm{d}x_{I\!P}\mathrm{d}p^2_\perp}\,. \qquad (6)$$

3.4. Factorization and pomeron structure function

In the Ingelman-Schlein model of diffractive DIS [6], one assumes the pomeron to behave somewhat like an hadronic state, and expects the diffractive structure function to factorize into the product of an $x_{I\!P}$-dependent pomeron flux factor, $f_{I\!P/P}(x_{I\!P})$, and an $x_{I\!P}$-independent "pomeron structure function", $F_2^{I\!P}(Q^2,\beta)$, via

$$F_2^{D(3)}(Q^2,\beta,x_{I\!P}) = f_{I\!P/P}(x_{I\!P})F_2^{I\!P}(Q^2,\beta)\,. \qquad (7)$$

However, from Eq. 4, we see that the LRG diffractive structure function depends on $p^2_{\perp\,\mathrm{min}}$. Hence, since $p^2_{\perp\,\mathrm{min}}$ is a rather sensitive function of $x_{I\!P}$, even though the full diffractive structure function might factorize, $F_2^{D(3)}$ extracted from LRG data for which $p^2_{\perp\,\mathrm{min}}$ is significant is not expected to factorize due to the additional $x_{I\!P}$ dependence introduced through the lower limit of the phase space integral. This breakdown of $x_{I\!P}$-factorization through data selection cuts means that one cannot extract a well-defined $x_{I\!P}$-independent pomeron structure function in the region of parameter space in which there are phase space restrictions due to LRG cuts.

4. Summary

We have discussed the result [1] that pseudo-rapidity cuts restrict the phase space available for diffractive deep-inelastic scattering for some range of Q^2, β and $x_{I\!P}$, by expressing the phase space constraints in terms of a restriction on the transverse momentum structure of the diffractive final state. For the weaker pseudo-rapidity cuts employed in recent H1 analyses [4,5], we still expect a reduction in the diffractive structure function extracted at large $x_{I\!P}$, and at low β over that observed with other techniques such as leading proton detection.

Since the phase space constraints depend on $x_{I\!P}$, this effect will also lead to a breakdown of $x_{I\!P}$-factorization in the extracted diffractive structure function. Further, we find that the constraints on diffractive final states with three or more partons are rather weaker than on dijet production [2], and hence also predict that LRG cuts lead to a comparative enhancement of $q\bar{q}g$ and higher-order events over dijet events.

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REFERENCES

1. J. Ellis and G.G. Ross, Phys. Lett. B384 (1996) 293.
2. J. Ellis, G.G. Ross and J. Williams, hep-ph/9812385.
3. H1, T. Ahmed et al., Nucl. Phys. B429 (1994) 477.
4. H1, T. Ahmed et al., Phys. Lett. B348 (1995) 681.
5. H1, C. Adloff et al., Eur. Phys. J. C1 (1998) 495.
6. G. Ingelman and P.E. Schlein, Phys. Lett. 152B (1985) 256.