High-t Diffraction *

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The study of those rapidity gap processes where a large momentum is transferred across the rapidity gap provides an ideal opportunity to understand the gap producing mechanism wholly within the framework of QCD perturbation theory. The current theoretical and experimental status of this 'high-t diffraction' is reviewed.

1. INTRODUCTION

High-t diffraction is the scattering of two particles A and B into a final state which is made up wholly of two systems X and Y which are far apart in rapidity and between which there is a large relative transverse momentum, P_t. The square of the exchanged four-momentum is $t \approx -P_t^2$. High t means that $-t \gg \Lambda^2_{\rm QCD}$. By studying this class of events we can hope to gain valuable insight into the Regge limit of strong interactions using the methods of perturbative QCD. It has been shown that large t is a very effective way of squeezing the rapidity gap producing mechanism to short distances regardless of the sizes of the external particles [1].

Perturbative QCD in the Regge limit leads to the production of rapidity gaps via the exchange of a pair of interacting reggeised gluons in an overall colour singlet configuration (a reggeised gluon can be thought of as a colour octet compound state of any number of ordinary gluons). To leading logarithmic accuracy this colour singlet exchange is described by the BFKL equation [2] and predicts a strong rise in the cross-section as the rapidity gap increases. It should be remembered that a characteristic of all leading logarithmic BFKL calculations is a large uncertainty in the overall normalisation of cross-sections. Next-to-leading logarithmic corrections to the BFKL equation have not yet been computed for $t \neq 0$.

2. GAPS BETWEEN JETS

One way of selecting high-t events is to look for events which contain one or more jets in system X and one or more in system Y [3,4]. The leading contribution to this process comes from the elastic scattering of partons via colour singlet exchange; the outgoing partons hadronise to produce the jets which are seen. Experiments at FNAL and HERA have reported their first results on the fraction of all dijet events which contain a gap in rapidity [5–8]. For rapidities greater than about 3 units between the jet centres, all see a clear excess of rapidity gap events over the number expected in the absence of a strongly interacting colour singlet exchange. It is worth recalling that a large excess of gap events at high-t cannot be explained by traditional soft pomeron exchange since such a contribution will have died away long before due to shrinkage.

Unfortunately, spectator interactions can spoil the gap. This physics is poorly understood and is often modeled by an overall 'gap survival' factor. Assuming the gap survival factor depends only upon the centre-of-mass energy of the colliding beams, the gap fraction data are mostly in agreement with the leading order BFKL predictions with $\alpha_s \approx 0.2$ (it doesn't make sense to run the coupling in the leading order BFKL formalism). But the data still have rather large errors and it is too early to draw definitive conclusions. Notwithstanding this, there appears to be a problem for BFKL: the E_T dependence of the D0 gap fraction shows a rise with increasing E_T whereas the BFKL prediction is flat or falling, see Fig.1. A few comments are in order. Firstly, the solid

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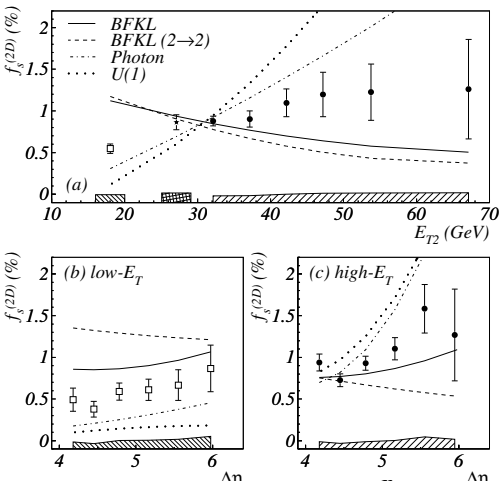

Figure 1. D0 data compared to different Monte Carlo models. The solid line is the BFKL prediction produced by HERWIG. Plot from [7].

line on Fig.1 falls as E_{T2} increases as a consequence of the running of the QCD coupling (the gap fraction goes like $\sim \alpha_s^4/\alpha_s^2$). Fixing the coupling, as is strictly proper in the leading logarithmic BFKL approach, leads to an essentially flat E_{T2} distribution. As an aside, it might be of interest to note that a fixed coupling was needed in order to explain the high-t data on high energy $p\bar{p}$ elastic scattering [9]. Secondly, it is to be noted that all jets appearing in Fig.1 are corrected for an underlying event using minimum bias data. Typically, this means subtracting around 1 GeV from the jets. This is true even for the jets which make up the numerator of the gap fraction which, by definition, are produced in an environment free of any underlying event. This correction is not made in generating the theoretical prediction (solid line) which, roughly speaking, means that the theory curve ought to be multiplied by $[E_{T2}/(E_{T2}+1\mathrm{GeV})]^4$ (since both the numerator and denominator fall as $1/t^2$). For the lowest bin at $E_{T2} = 18$ GeV this correction factor is 0.8. The upshot is that theory is probably consistent with a flat E_{T2} spectrum at large E_{T2} falling to 80% of this value in the lowest E_{T2} bin, and this is not inconsistent with the D0 data [10].

The gaps between jets process has a number of drawbacks: the rapidity reach is seriously compromised by the need to see the two jets; there is the usual theoretical uncertainty in going from partons to jets; there is the cloudy issue of gap survival to deal with. One way of improving the situation is to look at the more inclusive double dissociation sample [11].

3. GLUON REGGEISATION

As mentioned above, gluons reggeise in QCD. The effect of their reggeisation can be studied directly in present day experiments by measuring a process first suggested in [4]. The process is $h_1 + h_2 \to j_1 + j_2 + X$ where h_1 and h_2 are the incoming hadrons, j_1 and j_2 are the outgoing jets which are far apart in rapidity and X is the rest of the final state subject to the constraint that, in the region between the two jets, there be no jets with transverse momentum larger than some value, μ. The μ dependence of the ratio of these events to all dijet events is interesting since it provides a direct test of gluon reggeisation. The ratio goes (for $\mu \ll P_t$) like $\mathrm{e}^{2\Delta\eta(\alpha_g(P_t)-1)}$ where $\alpha_g(P_t) = 1 - (N_c/\pi)\alpha_s \ln(P_t/\mu)$. Another interesting consequence of gluon reggeisation is that, at large t, it indicates that fixed order perturbation theory can lead one to infer the wrong physics. To see this, one needs to realise that the first correction to two-gluon exchange contains a piece like $\Delta = \alpha_s \ln\left(\frac{\mathbf{k}^2(\mathbf{k}-\mathbf{q})^2}{t^2}\right) \ln s$, where $\mathbf{k}$ and $\mathbf{k}-\mathbf{q}$ are the transverse momenta of the two internal gluons (to get to a cross-section requires an integration over these momenta with a weighting function dependent upon the system to which they couple). Such a contribution invites one to conclude that the most important configuration arises when one gluon carries all the momentum transfer ($\mathbf{q}^2 = -t$) and the other carries none. However this is not the case, to order α_s^2 the contribution goes like $\Delta^2/2$ and more generally the series exponentiates to e^{Δ} which strongly suppresses the asymmetric configurations. Consequently, the dominant configurations are the symmetric ones where the exchanged gluons share the momentum transfer equally [12].

4. EXCLUSIVE VECTOR MESON AND PHOTON PRODUCTION

At HERA, focusing on the more exclusive subsample of high-t diffractive events in which the photon dissociates to either a photon or a vector meson and nothing else allows one to neatly sidestep the issue of gap survival. The detection of vector mesons and photons is also clean enough to allow the t distribution (here t is essentially determined by the transverse momentum of the vector particle) to be measured down to small values. H1 has measured the t distribution for J/Ψ production all the way from $-t \approx 0$ out to $-t \approx 10$ GeV^2. The data agree with the leading order BFKL calculation with $\alpha_s = 0.2$ [13]. In addition, ZEUS has investigated ρ mesons produced at high t [14]. The ability of the experiments to determine the kinematics without needing to observe the proton dissociation system is the crucial factor which allows the HERA experiments to study events with rapidity gaps as large as 6 units. Gaps of this size are certainly well into the region of theoretical interest. Leading logarithmic level calculations now exist for both vector meson production [12,15] and photon production [16]. As well as teaching us about colour singlet exchange, high-t vector meson production can also help us understand the vector meson production mechanism. In this respect, ratios of vector meson production will be particularly useful.

Over the coming years HERA promises to produce high quality data on light and heavy vector meson production, and on photon production (where there is no uncertainty due to wavefunction effects). These data, in combination with the data on the more inclusive processes discussed above, will set the benchmark against which we can test our ever evolving understanding of QCD in the high energy domain.

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REFERENCES

1. J.R. Forshaw and P.J. Sutton, Euro. Phys. J. **C14** (1998) 285.
2. I. Balitsky and L.N. Lipatov, Sov. J. Nucl. Phys. **28** (1978) 822.
3. J.D. Bjorken, Phys. Rev. **D47** (1992) 101.
4. A. H. Mueller and W.-K. Tang, Phys. Lett. **B284** (1992) 123.
5. M. Derrick et al (ZEUS collaboration), Phys. Lett. **B369** (1996) 55.
6. H1 Collaboration, "Rapidity Gaps between Jets in Photoproduction at HERA", contribution to the International Europhysics Conference on High Energy Physics, August 1997, Jerusalem, Israel.
7. S. Abachi et al (D0 collaboration), Phys. Rev. Lett. **72** (1994) 2332; Phys. Rev. Lett. **76** (1996) 734; B. Abbott et al (D0 collaboration), Phys. Lett. **B440** (1998) 189.
8. F. Abe et al (CDF collaboration), Phys. Rev. Lett. **74** (1995) 855; Phys. Rev. Lett. **80** (1998) 1156; Phys. Rev. Lett. **81** (1998) 5278.
9. A. Donnachie and P. V. Landshoff, Z. Phys. **C2** (1979) 55, erratum-ibid **C2** (1979) 372; Phys. Lett. **B387** (1996) 637.
10. B. E. Cox, J. R. Forshaw and L. Lönnblad, in preparation.
11. B. E. Cox: "Double Diffraction Dissociation at large $|t|$ from H1", contribution to the DIS99 Workshop, Zeuthen, Germany, 1999; B. E. Cox and J. R. Forshaw, Phys. Lett. **B434** (1998) 133.
12. J. R. Forshaw and M. G. Ryskin, Z. Phys. **C68** (1995) 137.
13. H1 Collaboration: "Production of J/ψ Mesons with large $|t|$ at HERA", contribution to the International Europhysics Conference on High Energy Physics, Jerusalem, Israel, 1997.
14. J. Crittenden: "Recent Results from Decay-Angle Analyses of ρ^0 Photoproduction at High Momentum Transfer from ZEUS", contribution to the DIS99 Workshop, Zeuthen, Germany, 1999.
15. J. Bartels, J. R. Forshaw, H. Lotter and M. Wüsthoff, Phys. Lett. **B375** (1996) 301; D.Yu. Ivanov, Phys. Rev. **D53** (1996) 3564;

I.F. Ginzburg and D.Yu. Ivanov, Phys. Rev. **D54** (1996) 5523; D.Yu. Ivanov and R. Kirschner, Phys. Rev. **D58** (1998) 114026.
16. D. Yu. Ivanov and M. Wüsthoff (1999), Eur. Phys. J. **C8** (1999) 107; N. G. Evanson and J. R. Forshaw, hep-ph/9902481, to appear in Phys. Rev. **D**.