Outstanding problems in the phenomenology of hard diffractive scattering

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Abstract. This paper is a summary of the discussion within the Diffractive and Low-x Physics Working Group at the 1999 Durham Collider Workshop of the interpretation of the Tevatron and HERA measurements of inclusive hard diffraction.

1. The problems

Although it has long been suspected that the factorisation of the hard component of diffractive scattering should not apply for hadron-hadron collisions, the magnitude of the breakdown at the Tevatron has come as a surprise. A model for diffractive hard scattering that contains all the essential features of the factorisation hypothesis is that of Ingelman and Schlein [1]. In diffractive DIS at HERA, for example, large rapidity gap events can be interpreted as the result of a highly virtual photon probing the structure of a pomeron 'emitted' from the proton. Collins has recently proved factorisation for lepton induced diffractive processes [2], but as expected the proof is not valid for hadron-hadron collisions. Alvero and collaborators [3] have quantified this breakdown by extracting diffractive parton densities (which in the Ingelman-Schlein picture would be interpreted as parton distributions of the pomeron) from the HERA diffractive DIS and diffractive jet photoproduction data and using them to predict diffractive jet, W, Z and charm production and double pomeron exchange rates in $p\bar{p}$ collisions at the Tevatron. The diffractive parton distributions themselves are found to need a large amount of glue at the starting scale in order to fit the HERA photoproduction data. Hard gluon distributions ($1-\beta$ at large β) are preferred, although the present data cannot rule out an even harder distribution, similar to the form presented by the H1 Collaboration in their analysis of the diffractive DIS data [4], that is strongly peaked towards $\beta = 1$. The predicted cross sections for the above processes at the Tevatron are consistently larger than those measured, the differences ranging from factors of a few for diffractive W and Z production to factors of up to 30 for the gluon dominated fits in dijet production, indicating a severe breakdown of factorisation. The breakdown in the double pomeron rate is even more severe, where the gluon dominated fits fail by factors of order 100. For all processes, the low-glue fits, that are unfavoured at HERA, yield much better results. With this background, several questions present themselves. Firstly, is the picture of diffraction a la Ingelman-Schlein valid ? Are the parton distributions extracted at HERA any use outside HERA ? Should a new approach be sought ? Whilst not providing any answers, we will review several suggestions that may provide a starting point for future work.

2. Possible Solutions

2.1. Rapidity Gap Survival Probability

Perhaps the most obvious solution to the apparent low yield of rapidity gap events at the Tevatron relative to HERA is to attribute the difference to a rapidity gap survival factor. Such factors are able to explain the qualitative differences in rapidity gaps between jets fractions in $\sim$ 200 GeV γp collisions at HERA ($\sim 10\%$) and in 630 GeV ($\sim 3\%$) and 1800 GeV ($\sim 1\%$) $p\bar{p}$ collisions at the Tevatron [5], although large uncertainties remain. The idea is simple, although the creation of viable models is an extremely difficult problem [5, 6]. A rapidity gap produced by the exchange of a colour-singlet object may be filled in by secondary interactions between spectator partons in the event. Since there are more spectator partons in $p\bar{p}$ collisions than in γp collisions, and the number density of partons increases with increasing centre of mass energy, one would expect the rate of gap destruction to be significantly larger at the Tevatron than at HERA, and to increase with centre of mass energy. Such an analysis has yet to be performed for the case of hard diffractive scattering [7]. It is worth noting that, certainly in the gaps between jets case, it may be possible to control the non-perturbative physics by a careful definition of a rapidity gap. For example, a gap event may be defined as an event in which the total energy in a given rapidity region is greater than some value Q, where $Q \gg \Lambda_{QCD}$ [8], or as an event in which there is no jet with $E_T^{jet} > E_{T(min)}$ in some rapidity region [5].

An interesting question to ask in the context of gap survival is whether or not the gap destruction mechanism depends on the gap production subprocess. Most models to date introduce gap survival as a multiplicative factor dependent only on centre of mass energy, although this is almost certainly an over-simplification. In which case, the shapes of the diffractive parton distributions measured at different colliders and centre of mass energies would necessarily be different. Such a difference is present in the β distributions measured by CDF and those extracted by H1 in diffractive DIS.

CDF measured the diffractive structure function of the antiproton using a method employing two samples of dijet events produced in $p\bar{p}$ collisions at $\sqrt{s}$ = 1800 GeV: a diffractive sample, collected by triggering on a leading antiproton detected in a forward Roman Pot Spectrometer (RPS), and an inclusive sample, collected with a minimum bias trigger. In leading order QCD, the ratio of the diffractive to inclusive cross sections as a function of the Bjorken x of the struck parton of the antiproton, obtained from the dijet kinematics, is equal to the ratio of the corresponding structure functions. Thus, the diffractive structure can be calculated by multiplying the measured ratio of cross sections by the known inclusive structure. This method, which bypasses the use of (model dependent) Monte Carlo generators, yields the colour-weighted structure function

$$F_{jj}^{D}(x) = x\left\{g^{D}(x) + \frac{4}{9}\sum_{i}\left[q_{i}^{D}(x) + \bar{q}_{i}^{D}(x)\right]\right\}$$

where $g^D(x)$ and $q^D(x)$ are the antiproton gluon and quark diffractive parton densities. Changing variables from x to $\beta = x/\xi$, where ξ is the $\bar{p}$ fractional momentum loss measured by the RPS, yields the structure function $F_{jj}^{D(3)}(\xi, \beta, Q^2)$. In Fig. 1, the

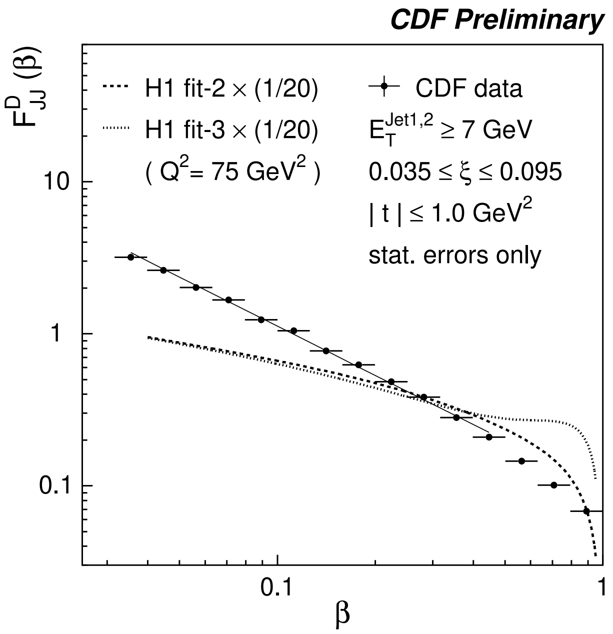

Figure 1. CDF β distribution (points) and fit (solid line) compared with expectations based on diffractive parton densities extracted from diffractive DIS measurements by the H1 Collaboration (dashed: fit2, dotted: fit 3).

$F_{jj}^{D(3)}(\xi, \beta, Q^2)$ measured by CDF at the Tevatron for $\langle Q^2 \rangle \approx 75$ GeV^2 in the region of $0.035 < \xi < 0.095$ and $|t| < 1$ GeV^2 is compared (see [9]) with that calculated using parton densities extracted by the H1 Collaboration from diffractive DIS measurements at HERA, scaled down by a factor of 20. The Tevatron and HERA β distributions disagree both in normalisation and shape. One should note, however, that the H1 data are in a different ξ region to the Tevatron data, namely $\xi < 0.04$. In the H1 analysis, in which the data are fitted with two components, pomeron and reggeon, there are significant reggeon contributions in the ξ region of the Tevatron data. For the reggeon, a pion structure function is assumed by H1. Allowing for a different reggeon structure, constrained by the data, could introduce some flexibility in the gluon component extracted from the diffractive DIS measurements. Furthermore, one should note that the Tevatron data are mostly sensitive to the diffractive gluon content which, in the diffractive parton densities published by the H1 collaboration[4], is derived from the observed scaling violations of the diffractive structure function. The question awaiting an answer must then be, is there a common set of diffractive pdf's which will fit in shape *both* the HERA and Tevatron measurements, leaving an overall normalisation factor which can be explained by a simple factorisable gap survival factor. Even if this is not so, can a sufficiently refined gap survival model account for the differences in the shape of the extracted diffractive pdf's? Or is a more fundamental revision of diffractive phenomenology called for?

2.2. Soft Colour Interactions

The soft colour interaction approach [10, 11] differs from the above phenomenology in that it moves the gap formation from the initial state to the hadronisation phase. The hard subprocess and the perturbative evolution of partons is treated exactly the same for gap and non-gap events. However, after the perturbative phase, the colour structure of an event can be rearranged by exchange of soft gluons, typically between the perturbatively produced partons and the *background colour field* of the hadrons. Such colour reconnections may result in regions devoid of colour, i.e. rapidity gaps. A review can be found in these proceedings [12], where it is shown that fixing some global parameter for the reconnection probability to describe DIS gap events at HERA, it is not only possible to describe diffractive jet production (single **and** double diffraction) and diffractive W production at the Tevatron, but also a good description of high-$p_\perp$ quarkonium production is obtained.

Some questionable features of the soft colour interaction models were pointed out during the workshop. The fact that the models do not modify in anyway the perturbative evolution of an event, means that e.g. the size of a rapidity gap in diffractive DIS events is completely determined by the most forward parton emitted in the perturbative phase. But so far the reproduction of DIS gap events has only been possible when implementing the soft colour interaction in the LEPTO generator [13] which is known not to be able to describe perturbative emissions in the forward region (see e.g. [14]). Also, it has been shown [15] that introducing a similar reconnection model in the ARIADNE [16] program – which *is* able to describe perturbative features of the forward region – neither the rate nor the distribution of rapidity gap events can be adequately described. The rate could, of course, be fixed by modifying the cut-off in the perturbative cascade or the reconnection probability, but this would not change the fact that e.g. the m_X distribution comes out completely wrong.

Although this casts serious doubts on the physical relevance of the soft colour interaction models, it does not prove that they are wrong. But to prove that they have anything to do with physics, it is highly desirable that they be implemented in an event generator which gives a reasonable description of the perturbative emissions in the forward region. After the workshop, work has started [17] to implement soft colour interactions in the RAPGAP [18] program, which is similar to LEPTO but implements a *resolved virtual photon* model to obtain a good description of e.g. forward jet rates. The model must also describe all diffractive HERA data. (i.e. charm, jets, photoproduction, etc).

2.3. A new approach

A totally new approach has been suggested by one of us which avoids the above complications regarding gap survival, and allows the structure of the pomeron to be derived from that of the parent hadron. Using a non-factorizing ansatz for $F_2^{D(3)}$, inspired by the observed scaling behavior of the soft single diffractive cross section[19]

$$\frac{d\sigma_{sd}}{dM^2} \propto \frac{1}{(M^2)^{1+\epsilon}} \tag{1}$$

a formula is obtained which can be interpreted as a renormalized pomeron flux folded with the structure function F_2 of the proton in the pomeron–proton scattering subsystem. Details can be found in these proceedings [20].

3. Outlook

Hard diffraction at HERA and the Tevatron is clearly not fully understood. The factorized pomerom picture does not explain all the data, and whether or not any of the alternative models suggested will be fully successful remains to be seen. This difficult border region between perturbative and non-perturbative QCD remains a challenge, which will probably require more experimental data before it can be met successfully.

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