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DIFFRACTIVE HARD SCATTERING AT *ep* AND $p\bar{p}$ COLLIDERS*

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ABSTRACT

Models for diffractive scattering based on the exchange of a pomeron with a parton structure are analysed in terms of hard scattering processes and the resulting characteristics of the final state. Diffractive deep inelastic *ep* scattering is considered in connection with the recently observed rapidity gap events at HERA. Heavy flavour and W, Z production in $p\bar{p}$ interactions are interesting measures of the gluon and quark component, respectively, in the pomeron.

Following the idea [1] of Diffractive Hard Scattering (DHS) we have studied [2-4] models for the structure of the pomeron (IP), exchanged in diffractive interactions. The possible quark and/or gluon structure of the pomeron can here be probed through electroweak or strong hard scattering processes and expressed through a pomeron structure function. Models with different assumptions on this structure have been used in calculations applicable to both $p\bar{p}$ and *ep* scattering (see e.g. [5] and references therein). Based on a simple model that can represent different ideas of DHS, we have developed a Monte Carlo (MC) program [6] in order to perform more detailed calculations and study the event characteristics.

The cross section for the diffractive hard $p\bar{p}$ or *ep* scattering process (cf. Fig. 1) can be written

$$\frac{d\sigma(Yp \to p+X)}{dx_{I\!P}dt\,dx_1dx_2} = f_{I\!P/p}(x_{I\!P},t)\frac{d\sigma(YI\!P \to X)}{dx_1dx_2} \qquad (1)$$

The first factor gives the 'emission' of a pomeron with a fraction $x_{I\!P} < 0.1$ of the proton at the lower vertex with a small momentum transfer t. The second factor is the cross section for the hard pomeron-particle ($Y = e$ or p) scattering resulting in the final state X with mass given by $M_X^2 = x_{I\!P}s$. The pomeron 'flux' factor can be taken as the ratio [1,5]

$$f_{I\!P/p}(x_{I\!P},t) = \frac{d\sigma/dx_{I\!P}dt}{\sigma_{I\!Pp\to X}} = \frac{6.38e^{8t}+0.424e^{3t}}{2.3\,x_{I\!P}} \qquad (2)$$

where the diffractive cross section and the pomeron-proton total cross section are obtained from data. Another functional form of the flux factor is given in [7], but is numerically about the same in the region of small t which dominates the inclusive cross sections below.

The hard scattering cross-section is given by

$$\frac{d\sigma(YI\!P \to X)}{dx_1dx_2d\hat{t}} = f_{p_1/I\!P}(x_1,Q^2)f_{p_2/Y}(x_2,Q^2)\frac{d\hat{\sigma}}{d\hat{t}} \qquad (3)$$

in terms of the pomeron and the particle Y densities of partons (p_i having momentum fractions x_i) and the appropriate hard scattering subprocess cross section $d\hat{\sigma}$ (momentum transfer $\hat{t}$). For $Y = e$ both direct and resolved exchanged photon interactions can be incorporated. For the unknown pomeron structure function one may try the alternatives:

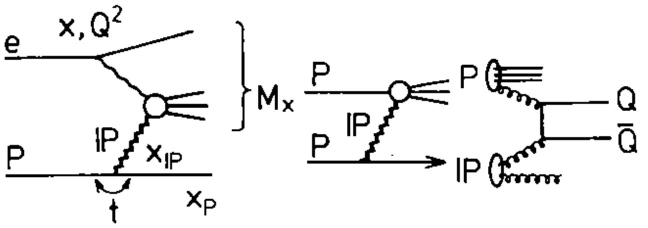

Figure 1: Diffractive hard scattering in (a) deep inelastic *ep* scattering and (b) in $p\bar{p}$ with (c) a $I\!Pp$ hard scattering subprocess producing heavy flavours.

(i) IP=soft gluons (SG): $xf_{g/I\!P}(x) = 6(1-x)^5$
(ii) IP=hard gluons (HG): $xf_{g/I\!P}(x) = 6x(1-x)$
(iii) IP=hard quarks ($q\bar{q}$): $xf_{q/I\!P}(x) = \frac{6}{4}x(1-x)$
The momentum sum rule $\int_0^1 xf(x)dx = 1$ is here assumed for the normalisation. Although this is a natural expectation that can be given some motivation, it does not obviously apply to the virtual exchanged pomeron. The quark-dominated pomeron model in [7] can be obtained from *(iii)* by a factor 7.5 reduced normalization.

The quark content of the pomeron can be most directly and cleanly measured in deep inelastic *ep* scattering (DIS), whereas the gluon content here requires the suppressed order α_s process $\gamma g \to q\bar{q}$ [2]. The rapidity gap events observed by ZEUS [8] and H1 at HERA can be interpreted as such diffractive scattering. The observed distribution in η_{max}, the pseudo-rapidity of the particle closest to the proton direction ($\eta > 0$), shows an excess for $\eta_{max} < 1.5$ which cannot be understood by normal DIS Monte Carlo simulations. Applying the experimental conditions ($Q^2 > 10\,GeV$, $E_e > 5\,GeV$ etc) to the Monte Carlo models for diffractive scattering give the results in Fig. 2a in general accordance with the data. In a sizeable fraction of the DHS MC

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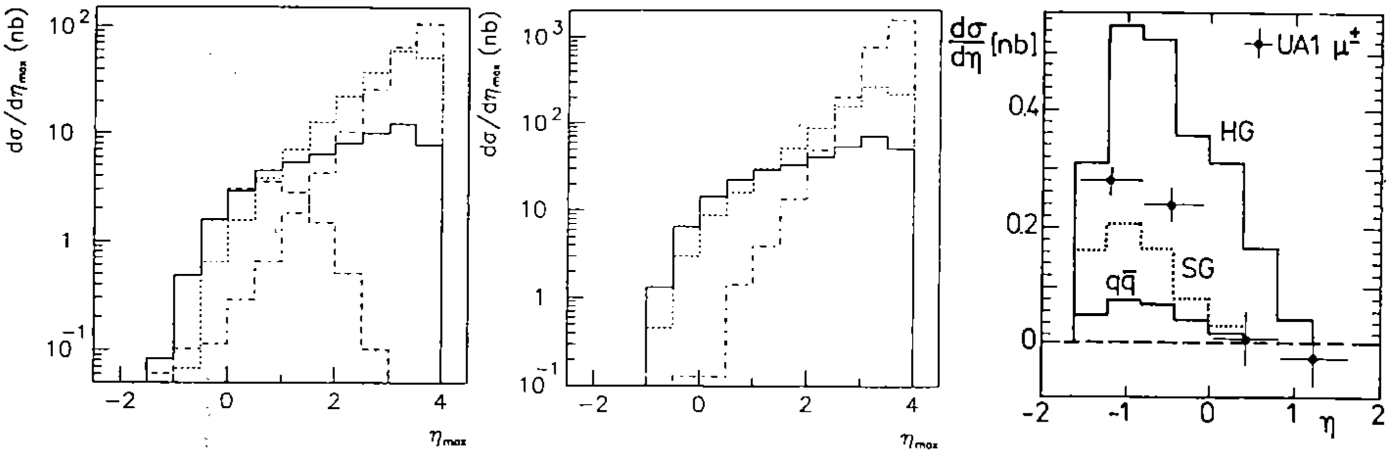

Figure 2: **(a)** Distribution in η_{max} in ep DIS at HERA with ZEUS conditions ($2.2° < \theta < 176.4°$) obtained from DHS models $xf_{q/\mathbb{P}}(x) = 1.5(1-x)^5$ (dotted) and $1.5x(1-x)$ (full), with restriction $\sqrt{s_{e\mathbb{P}}} \leq 20\,GeV$ (dashed), compared to non-diffractive DIS (dash-dotted).
(b) As in (a) but for photoproduction through $\gamma g \to q\bar{q}$ with $\hat{p}_\perp > 1.5\,GeV$ in ep at HERA.
(c) Pseudo-rapidity distribution of muons, with $p_\perp > 6\,GeV$, in diffractive $p\bar{p}$ events having a jet, with $p_\perp > 8\,GeV$. UA1 data [10] compared to the hard gluon, soft gluon and $q\bar{q}$ pomeron models.

events the system X is totally in the hemisphere opposite to the proton, corresponding to an empty forward detector (i.e. a large rapidity gap). The Table compares the experimental and model cross sections giving some preference for a hard quark distribution in the pomeron with a normalization that should not be too much lower than given by the sum rule. These conclusions are, however, very preliminary since a detailed comparison would need the data to be acceptance corrected or the MC events to be detector simulated.

$xf_{q/\mathbb{P}}(x) =$	$\frac{6}{4}(1-x)^5$	$\frac{6}{4}x(1-x)$	ZEUS [8]
σ $[nb]$	2.4	3.9	3.2 ± 0.2 †
$\frac{\sigma(x<0.0008)}{\sigma(0.0008<x<0.003)}$	4	1.4	1

† lower limit

Similar diffractive phenomena are also expected in photoproduction, i.e. ep at $Q^2 \simeq 0$. For both direct photon and resolved photon interactions our MC predicts rapidity gap events (Fig. 2b). The cross sections for $\eta_{max} < 1.5$ are observably large and substantially higher than the tail of non-diffractive events.

The different pomeron models may also be distinguished in ep through the resulting differences in heavy flavour production and event topologies, e.g. energy flows and jets [2].

The first observation of DHS was by UA8 [9] in terms of diffractive jet production in $p\bar{p}$. In addition, UA1 [10] has given evidence for diffractive bottom production. Since heavy flavour production at $p\bar{p}$ colliders is dominated by the gluon fusion subprocess (Fig. 1c) this may probe the gluon content of the pomeron. In Fig. 2c we compare the data [10] with the results from the above models [4] (including the experimental cuts). The $q\bar{q}$ dominated pomeron requires the process $q\bar{q} \to b\bar{b}$, which is suppressed compared to gluon fusion $gg \to b\bar{b}$, resulting in a cross section below the data even without a possible momentum sum rule suppression factor. A gluon-dominated pomeron can account for the data, but no firm conclusion can be made given the normalisation uncertainty in the models and the experimental errors.

The pomeron's quark content can similarly be probed by a process which is dominantly quark induced. We have therefore investigated [3] diffractive W and Z production in $p\bar{p}$, where the leading order hard subprocess $q\bar{q} \to W/Z$ gives a larger cross section than the next-to-leading order process $gq \to q + W/Z$. This results in observably large differences between a quark- and gluon-dominated pomeron [3]. Furthermore, the simple kinematics of the process $q\bar{q} \to Z^0 \to \mu^+\mu^-$ allows a reconstruction of the x-shape of the $\mathbb{P} = q\bar{q}$ structure from the muon momenta as demonstrated in [3].

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