Diffraction Dissociation in Photoproduction

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Abstract. Differential cross sections for the process $\gamma p \to XY$ are measured as a function of the invariant mass M_X of the system produced at the photon vertex. Results are presented in two fixed ranges of the mass M_Y of the system Y, the lower of which, $M_Y < 1.6$ GeV, is heavily dominated by the single photon dissociation process $\gamma p \to Xp$. Both the centre of mass energy W and the M_X^2 dependence of H1 single dissociation data and those from a fixed target experiment may simultaneously be described in a triple-Regge model. Diffraction is found to dominate at low M_X, though a sizable subleading contribution is present at larger masses. The pomeron intercept is found to be $\alpha_{\mathbb{P}}(0) = 1.068 \pm 0.016$ (stat.) $\pm\, 0.022$ (syst.) $\pm\, 0.041$ (model), in good agreement with values obtained from total and elastic hadronic and photoproduction cross sections. The diffractive contribution to the process $\gamma p \to Xp$ with $M_X^2/W^2 < 0.05$ is measured to be 22.2 ± 0.6 (stat.) $\pm\, 2.6$ (syst.) $\pm\, 1.7$ (model) % of the total γp cross section at $\langle W \rangle = 187$ GeV.

The dependence on centre of mass energy of elastic and, via the optical theorem, total hadron-hadron cross sections has been remarkably well described in a large kinematic domain by Regge phenomenology [1]. In this framework, interactions take place via the t-channel exchange of reggeons related to mesons and of the leading vacuum singularity, the pomeron ($\mathbb{P}$).[1] Following the successful application of these ideas to the description of the total photoproduction cross section [2] and of elastic light vector meson photoproduction [3], the dissociation of the photon to higher mass systems is investigated in this contribution in the Regge framework . Cross sections for the quasi two-body photoproduction process $\gamma p \to XY$ (figure 1a) are presented. The γp centre of mass energy and the square of the four-momentum transferred are denoted W and t respectively. Emphasis is placed here on the cross section definitions,[2]

1) Here, the word 'diffraction' is used synonymously with t-channel pomeron exchange.
2) These definitions are also highly relevant to other contributions to this workshop [4,5].

experimental selection of events at low M_X and M_Y and the Regge analysis of the single photon dissociation process, $\gamma p \to Xp$. A more complete discussion, including details of the experimental procedure and results for larger M_Y may be found in [6].

By definition, the two systems X and Y are separated by the largest gap in the rapidity distribution of final state hadrons, Y being the system closest to the proton beam direction. This scheme of event decomposition provides a means of defining hadron level cross sections without assumptions regarding the interaction mechanism. A Regge description is appropriate to the kinematic region in which M_X and M_Y are small by comparison with W, which is also the region in which a large rapidity gap is expected from kinematic considerations alone.

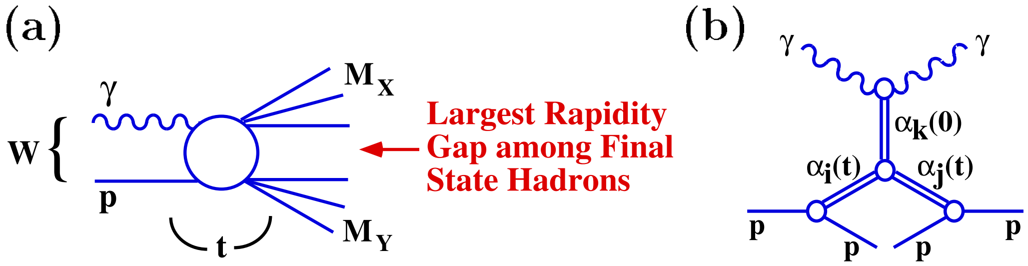

FIGURE 1. (a) Illustration of the generic process, $\gamma p \to XY$, in which the low mass states X and Y are separated by the largest gap in the final state rapidity distribution. (b) A triple Regge amplitude contributing to the cross section for the process shown in (a) where the system Y is a proton in the limit $W^2 \gg M_X^2 \gg m_p^2, t$.

Viewing the process shown in figure 1a in terms of a t-channel exchange between the proton and the photon, the exchanged object carries a fraction $x_{\mathbb{P}} = q.(P - p_Y)/q.P$ of the longitudinal momentum of the incoming proton, where q, P and p_Y are respectively the 4-vectors of the incoming photon, the incoming proton and the final state system Y. For the single photon dissociation process, this fraction can be determined directly by measurement of the final state protons. In all cases where the systems X and Y are unambiguously separated in rapidity, it can be determined by measuring the mass of the system X according to $x_{\mathbb{P}} \simeq M_X^2/W^2$ for $Q^2 = 0$. The latter method is used here, since the final state proton is not tagged and in the kinematic region of the measurement, the system X can be reconstructed with good resolution in the central trackers and calorimeters of the detector. This still leaves unresolved the question of whether the unobserved system Y consists of an intact proton or of a low mass dissociated system. It is possible to measure M_Y when its value is large [6]. When M_Y is small, it is constrained by the extent of the rapidity gap separating X and Y in the proton direction.

Components of the H1 detector [7] that are nearest to the outgoing proton direction tag hadronic activity at high pseudorapidity. At all but the smallest values of M_Y, rescattering of primary particles with the beam-pipe and the surrounding material yields showers of secondary particles which are observable in these detectors, such that they are sensitive to hadronic energy flow up to pseudorapidities $\eta \simeq 7.5$. By demanding an absence of activity in these detectors, the system Y is constrained to have mass $M_Y \lesssim 1.6$ GeV independently of W or Q^2 and the 4-momentum transfer satisfies $|t| \lesssim 1$ GeV^2.[3] With the additional requirement of no activity in the region $\eta > 3.2$ of the main calorimeter, the systems X and Y are separated by a pseudorapidity gap $\Delta\eta \gtrsim 4.3$ units.

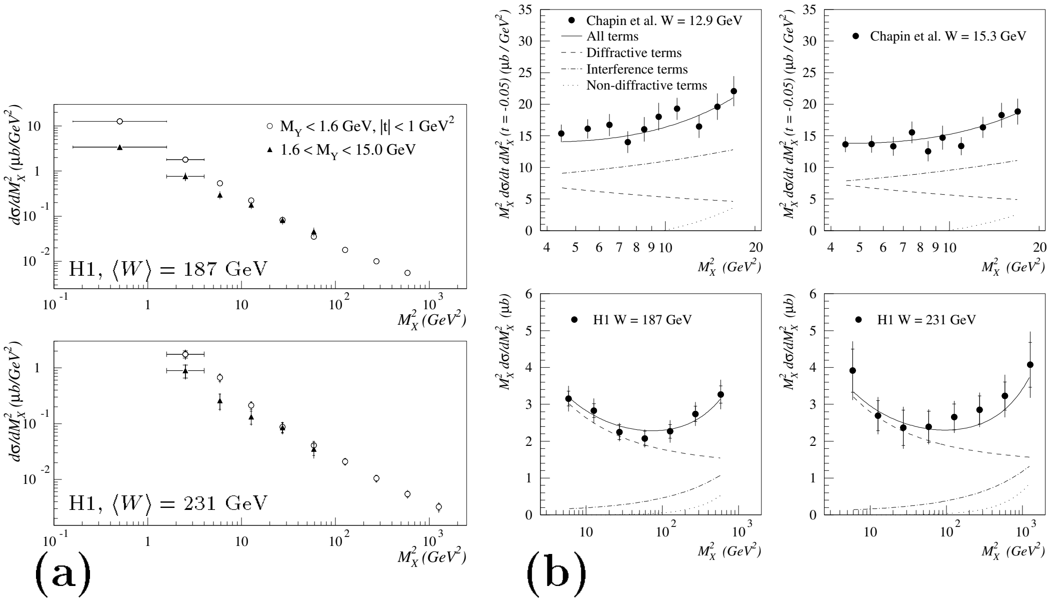

FIGURE 2. (a) Measurements of $\mathrm{d}\sigma_{\gamma p \to XY}/\mathrm{d}M_X^2$ with $M_Y < 1.6$ GeV, $|t| < 1.0$ GeV^2 and with $1.6 < M_Y < 15.0$ GeV, all t. (b) $M_X^2\,\mathrm{d}\sigma_{\gamma p \to Xp}/\mathrm{d}M_X^2\,\mathrm{d}t$ at $t = -0.05$ GeV^2 from [8] and $M_X^2\,\mathrm{d}\sigma_{\gamma p \to XY}/\mathrm{d}M_X^2 (M_Y < 1.6\text{ GeV}, |t| < 1.0\text{ GeV}^2)$ as measured by H1. The triple-Regge fit (2) with maximal constructive interference and the resulting decomposition of the cross section is superimposed.

Figure 2a shows H1 measurements of $\mathrm{d}\sigma_{\gamma p \to XY}/\mathrm{d}M_X^2$ at two average values of W for M_X values satisfying $x_{I\!P} < 0.025$. Results are presented integrated over $M_Y < 1.6$ GeV, $|t| < 1.0$ GeV^2 and over $1.6 < M_Y < 15.0$ GeV, all t.[4] Both sets of data approximately follow the $\mathrm{d}\sigma/\mathrm{d}M_X^2 \sim 1/M_X^2$ behaviour that is characteristic of diffraction dissociation cross sections at fixed centre of mass energy, small $x_{I\!P}$ and comparatively large M_X. There is a considerable enhancement relative to this behaviour at the lowest values of M_X, where quasi-elastic vector meson production is the dominant process [3]. In the larger

[3] More precisely, the correction necessary for imperfect acceptance and resolution is minimised when the cross section is corrected to this region.
[4] The resolution in transverse momentum is insufficient for a differential measurement of the t dependence.

M_Y region, corresponding to the case where the proton dissociates, there is no substantial enhancement in the vector meson region compared to a $1/M_X^2$ behaviour. The cross section at large M_Y falls less quickly with increasing M_X than that for small M_Y. The form of the cross section with $M_Y < 1.6$ GeV and $|t| < 1.0$ GeV^2 is shown in more detail in terms of $M_X^2 \mathrm{d}\sigma_{\gamma p \to XY}/\mathrm{d}M_X^2$ in the bottom two plots of figure 2b. The rise in this quantity at large M_X cannot be explained without the introduction of non-diffractive contributions.

A Regge model, the full details of which can be found in [6], is devised to further investigate the single dissociation cross section. Both the centre of mass energy and the dissociation mass dependence of the dissociation cross section can be treated via Mueller's generalisation of the optical theorem [9] in terms of 'triple Regge' amplitudes (fig 1b). The dissociation cross section decomposes according to [1]

$$\frac{\mathrm{d}\sigma}{\mathrm{d}t\,\mathrm{d}M_X^2} = \frac{s_0}{W^4} \sum_{i,j,k} G_{ijk}(t) \left(\frac{W^2}{M_X^2}\right)^{\alpha_i(t)+\alpha_j(t)} \left(\frac{M_X^2}{s_0}\right)^{\alpha_k(0)} \cos\left[\phi_i(t) - \phi_j(t)\right] \ ,$$

where i, j and k refer to the three reggeons as shown in figure 1b, s_0 is a hadronic mass scale customarily taken to be 1 GeV^2, $\phi_i(t)$ is the phase of reggeon i, completely specified by the signature factor, and $G_{ijk}(t)$ contains all of the couplings in the triple Regge amplitude ijk.

To give a large variation in W, fixed target data [8] for $M_X^2 \mathrm{d}\sigma_{\gamma p \to X p}/\mathrm{d}M_X^2 \mathrm{d}t$ at $|t| = 0.05$ GeV^2 are also included in the fits (see figure 2b). To satisfy the triple Regge limit, only data points with $M_X^2 > 4$ GeV^2 are used. The pomeron and a subleading trajectory $\alpha_{\mathrm{I\!R}}(t) \sim 0.55 \pm 0.9t$ (denoted $\mathrm{I\!R}$), consistent with any of the approximately degenerate trajectories with the quantum numbers of the ρ, ω f_2 and a_2 mesons, are considered.[5] A total of 6 distinct amplitudes result, two of which are diffractive ($ijk = \mathrm{I\!P I\!P I\!P}$, $\mathrm{I\!P I\!P I\!R}$), two of which are non-diffractive ($ijk = \mathrm{I\!R I\!R I\!P}$, $\mathrm{I\!R I\!R I\!R}$) and two of which correspond to possible interference contributions ($ijk = \mathrm{I\!P I\!R I\!P}$, $\mathrm{I\!P I\!R I\!R}$). The t dependences and the non-diffractive trajectory are taken from previous data. The cross sections in the model are multiplied by a factor 1.10 ± 0.06 for the H1 data to account for the contribution with $M_Y < 1.6$ GeV where Y is not a single proton. This does not account for the possibility of states Y with isospin or its third component different from that of the proton (e.g. $Y = n$, Δ), which arise only where the exchange has non-zero isospin. Three fits representing slightly different scenarios all give acceptable fits to the data:

1. The two trajectories do not interfere and the secondary trajectory is pure isoscalar, as would be expected if the ω dominates.
2. The two trajectories interfere fully coherently and the secondary trajectory is pure isoscalar, as would be expected for f dominance.

[5] The quality of the fits deteriorates if the π trajectory is used to model the subleading exchange instead.

3. The two trajectories do not interfere and the secondary trajectory has an isovector (ρ, a) component, giving additional states Y such as n, Δ in the H1 data.

The results of the fits are summarised in table 1. Fit 2 and the corresponding decomposition of the cross section are superimposed on figure 2b. The values obtained for the pomeron intercept $\alpha_{I\!P}(0)$ are broadly consistent with those found from hadronic processes that are governed by soft pomeron exchange and significantly different from the value obtained in Regge analyses at large Q^2 [4]. The dominant uncertainty in $\alpha_{I\!P}(0)$ arises from the assumptions regarding the subleading exchange. The total diffractive contribution to the cross section for $\gamma p \to Xp$ with $M_Y < 1.6$ GeV, $|t| < 1.0$ GeV^2 and $x_{I\!P} < 0.05$ is found in the fit to be at the level of 20 % of the total photoproduction cross section.

Fit	χ^2/n.d.f.	$\alpha_{I\!P}(0)$	$\sigma^{\rm D}/\sigma^{\rm tot}$ ($W = 187$ GeV)
1	28.8/30	$1.03 \pm 0.01 \pm 0.01 \pm 0.01$	$23.1 \pm 0.5 \pm 2.6 \pm 1.5$ %
2	19.9/30	$1.10 \pm 0.01 \pm 0.02 \pm 0.02$	$21.4 \pm 0.6 \pm 2.1 \pm 1.4$ %
3	18.4/29	$1.07 \pm 0.02 \pm 0.02 \pm 0.02$	$22.2 \pm 0.7 \pm 2.2 \pm 1.5$ %
Average		$1.07 \pm 0.02 \pm 0.02 \pm 0.04$	$22.2 \pm 0.6 \pm 2.6 \pm 1.7$ %

TABLE 1. The values of the χ^2/n.d.f made from statistical errors, the pomeron intercept $\alpha_{I\!P}(0)$ and the ratio of the diffractive contribution $\sigma^{\rm D}$ to the process $\gamma p \to Xp$ with $x_{I\!P} < 0.05$ to the total γp cross section at $W = 187$ GeV in the three fit scenarios. The errors quoted are respectively statistical, systematic and related to uncertainties in the model.

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