Diffraction at HERA and Prospects with H1 *

P. Marage[a]

[a]Université Libre de Bruxelles - CP 230, Boulevard du Triomphe, B-1050 Bruxelles, Belgium
e-mail: pmarage@ulb.ac.be

After the tremendous progress achieved at HERA in the field of diffraction, a new level of statistical and systematic precision is needed. H1 will install a very forward proton spectrometer in the cold section of HERA, with $\simeq 100$ % acceptance down to $|t| = 0$ for $x_{I\!P} = 0.01$. Large statistics of data, in particular in the presence of a hard scale, will be collected with unambiguous proton tagging and a measurement of the t distribution.

1. TREMENDOUS PROGRESS

Over the last ten years, tremendous progress has been achieved at HERA in the field of diffraction [1].

• The observation at high energy of a diffractive contribution of 8 to 10 % of the total γp cross section in the DIS domain [2].

• The measurement of the energy dependence of inclusive diffraction in DIS [3,4], harder than for hadron–hadron interactions [5] and photoproduction [6], but softer than for inclusive ep interactions. In the dipole model approach, this is attributed to the interplay of a soft component, due to photon fluctuations into large dipoles (partons with very asymmetric longitudinal momentum shares), and a hard component due to fluctuations into small dipoles (large p_t, small distance partons).

• A measurement [7] of the t dependence of inclusive diffraction ($\mathrm{d}\sigma/\mathrm{d}t \propto e^{b \cdot t}$), with $b \simeq 7$ GeV^{-2}, smaller than for soft diffraction but larger than for hard diffraction (e.g. J/ψ production, see below).

• The measurement of the diffractive structure function $F_2^{D(3)}(x_{I\!P}, \beta, Q^2)$ [3,4] and the extraction of gluon dominated parton distributions from positive scaling violations up to large β. Of major importance is the factorisation theorem [8] justifying the use of these parton distributions into exclusive processes in DIS, whereas factorisation is broken for hadron–hadron and for resolved photoproduction interactions.

• Compatibility of the data with the presence of a large higher twist longitudinal component at high β [9].

• Possible indications of saturation effects at very low x [10,11], expected to be more important in diffraction than for the total cross section, because of the large gluon component.

• A study of diffractive dijet production in DIS [12,13], including a successful comparison of differential distributions with predictions based on the inclusive parton distributions, showing that dijet production is a powerful tool to access directly the gluonic content of the pomeron.

• A measurement of open charm production in DIS [14], another probe of the gluon content of the pomeron. In spite of very limited statistics, differential distributions indicate, as for dijet production, the dominance of $(q\bar{q}g)$ fluctuations in the proton or, equivalently, the presence of pomeron remnants not participating to the hard process.

*Talk given at the Workshop DIFFRACTION 2000, Cetraro, Italy, Septembre 2000.

• Studies of hadronic final states [12], presenting marked differences with non-diffractive interactions but similarities to e^+e^- annihilation; Monte-Carlo simulations using inclusive parton distributions provide a good description of the data.

• For J/ψ photoproduction [15,16], a short distance process governed by the large charm quark mass, the observation of a hard energy dependence reflecting the gluon distribution in the proton and a hard t distribution ($b \simeq 4.5$ GeV^{-2}). For ρ mesons, the energy dependence appears to become harder as Q^2 increases [17,18], and the b slope decreases at high Q^2 towards that for J/ψ [18].

• The dominance of σ_L over σ_T as Q^2 increases in vector meson production [18,19].

• The observation of a common production rate for vector mesons $(\rho, \omega, \phi, J/\psi)$ as a function of the variable $Q^2 + M_V^2$, when taking into account quark counting [20].

• The observation of deeply virtual Compton scattering $(e + p \to e + p + \gamma)$ [21], at a rate compatible with perturbative QCD calculations using skewed parton distributions.

2. MISSING MEASUREMENTS AND EXPERIMENTAL UNCERTAINTIES

In spite of this bright success, the accumulated statistics remain very limited in several important channels, especially in the presence of a hard scale (charm, high Q^2). Several pieces of information are completely missing, and several short-comings affect the experimental measurements.

2.1. t distributions

The measurement of the t distribution, which is directly related to the size of the interacting dipole, is of crucial importance [11]. Both the ZEUS and H1 detectors include forward proton spectrometers giving access to t distributions, but their acceptance is only of the order of 5 % and the accessible range $0.01 \lesssim x_{I\!P} \lesssim 0.03$ and $0.1 \lesssim |t| \lesssim 0.4$ GeV^2; in addition, the alignment of these detectors is difficult and leads to significant systematic uncertainties.

No fully differential measurement has thus been performed of the inclusive $F_2^{D(4)}(x_{I\!P}, \beta, Q^2, t)$ structure function, and no measurements exist of t distributions in the presence of a hard scale (jets, charm), except for vector mesons.

2.2. Longitudinal cross section and higher twist

The longitudinal cross section F_L^D and its predicted higher twist behaviour are sensitive tests of different models of diffraction [22]. The standard way of performing the measurement is by using different beam energies, which has not happened so far at HERA.

Access to F_L^D is also possible through the distribution of the angle ϕ between the electron and the proton scattering planes, which is modulated by the longitudinal–transverse interference [23].

2.3. Proton dissociation and other experimental uncertainties

Because of the small acceptance of the present spectrometers, most measurements of diffraction rely on the presence of a large rapidity domain devoid of hadronic energy in the region of the detector situated in the outgoing proton beam direction ("forward" direction), without a direct tagging of the scattered proton. This leads to large corrections, with large uncertainties, for the subtraction of the proton dissociation background and the extraction of the elastic cross section: 11 ± 5 % for H1 and up to 31 ± 15 % [4] for ZEUS. This is the dominant systematic error for many channels (see fig. 1).

The proton dissociation background is also usually assumed to lead to an overall normalisation effect, which is certainly not justified (see e.g. the strong Q^2 dependence for the ratio of proton dissociation to elastic ρ production [24]).

Discrepancies appear in some measurements between H1 and ZEUS, in particular for some (Q^2, β) bins of the $F_2^{D(3)}$ structure function. These discrepancies may disappear with new, more precise measurements. They may also be related to different ways of extracting the diffractive signal, since none of the two experiments uses the direct measurement of the scattered proton: H1 selects events with a rapidity gap [3] and ZEUS selects the non-exponentially suppressed part of the M_X distribution [4].

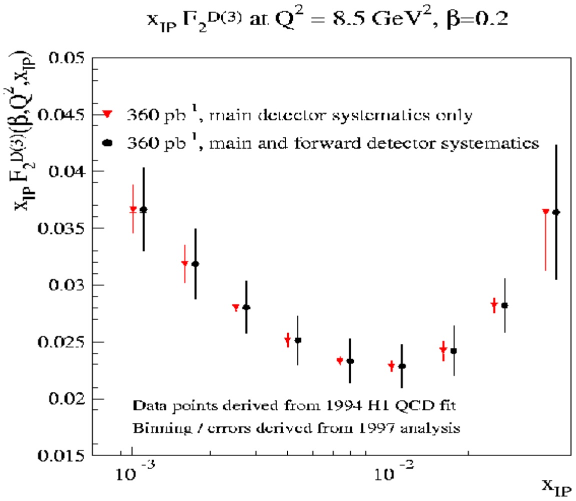

Figure 1. Estimated uncertainties for the measurement by H1 of $F_2^{D(3)}$ as a function of $x_{\mathbb{P}}$ in the bin (Q^2 = 8.5 GeV^2, β = 0.2), for 350 pb^{-1}, the luminosity expected in 2002-2005. The smaller error bars represent the errors due only to the main detector measurement, the larger errors include those due to the present use of the forward detectors to subtract the proton dissociation background.

3. A VERY FORWARD PROTON SPECTROMETER FOR H1

3.1. A very large acceptance detector

Higher precision measurements, both from a statistical and a systematic point of view, and the access to new physical quantities are necessary to discriminate between several theoretical models, which are broadly compatible with the present measurements. This implies collecting large statistics of high quality data, in various inclusive, semi-inclusive and exclusive channels.

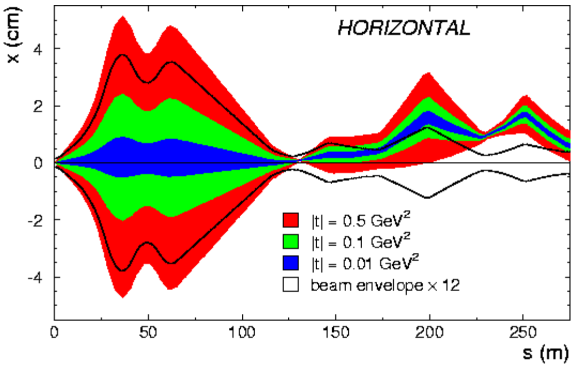

Figure 2. Horizontal projection of the distance of the scattered proton to the beam, shown for $x_{\mathbb{P}}$ = 0.01 and for three different values of t (shaded areas), and 12 sigma beam envelope, as a function of the distance to the interaction point.

The H1 collaboration has thus proposed [25] to install in 2002 a very forward proton spectrometer (VFPS), consisting of two roman pots equipped with scintillating fiber detectors, in the cold section of the HERA beam line, 220 m downstream of the interaction point. This is where the spectrometer effect of the horizontal HERA bend is strongest (see fig. 2).

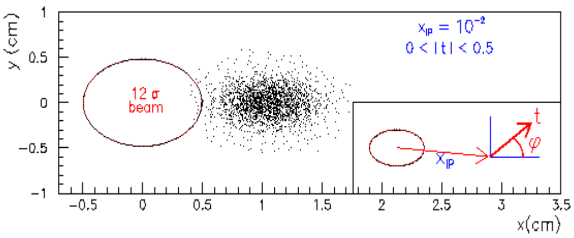

Figure 3. Spread of the impact point of diffractively scattered protons in the (x, y) plane for $x_{\mathbb{P}} = 0.01$ and $0 \leq |t| \leq 0.5$ GeV^2, with the 12 σ beam envelope. Insert: Illustration of the relation between the impact point of the scattered proton in the transverse (x, y) plane and the variables $x_{\mathbb{P}}$, $|t|$ and ϕ.

The acceptance will be $\simeq$ 100% for $x_{\mathbb{P}} = 0.01$ (see figs. 3 and 4), down to the lowest $|t|$ values. This is a large improvement compared to

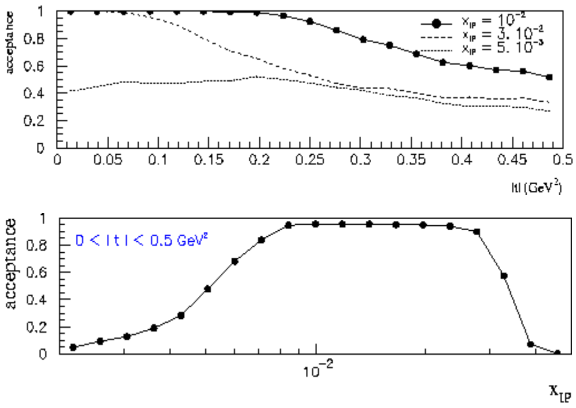

Figure 4. VFPS acceptances, as a function of t (top) and of $x_{I\!P}$ (bottom).

the present proton spectrometers (see fig. 5).

Full advantage will thus be taken of the 5-fold luminosity increase after the HERA upgrade, and uncertainties in the cross section measurements due to extrapolations in t are avoided. Also, the error due to the uncertainty on the precise positioning of the pots is avoided, in contrast with the present case where the acceptance varies strongly with t. The detector will be aligned using the position of the t peak and ρ photoproduction.

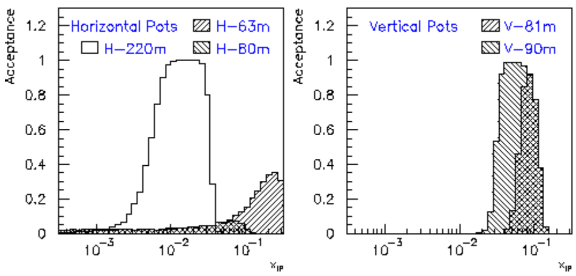

Figure 5. Acceptance as a function of $x_{I\!P}$ for the VFPS and the present H1 spectrometer (horizontal and vertical stations, respectively).

3.2. Physics issues

With the VFPS, the direct tagging of the scattered proton will eliminate the largest source of uncertainty in most channels, i.e. the proton dissociation background.

The emphasis will be put on precise measurements of diffractive processes in the presence of a hard scale: high Q^2 values, large transverse momenta (large E_T jets), large quark masses (charm production), and on the measurement of the t slope.

For the inclusive and the semi-inclusive processes (jets, charm production), the measurement of the t distribution with 3 to 4 bins for $0 \leq |t| \leq 0.6$ GeV^2 will permit discriminating between large ($b \gtrsim 7$ GeV^{-2}) and small ($b \simeq 4.5$ GeV^{-2}) dipoles.

• The fully differential structure function $F_2^{D(4)}$ will be measured in the purely diffractive domain $x_{I\!P} \lesssim 0.01$, where the contribution from meson exchange is negligible, in 3 or 4 bins in t. The $x_{I\!P}$ variable will be measured both with the VFPS and using the main detector, leading to improved precision.

• For 350 pb^{-1} data taken in 2002-2005, 10 000 dijet events with $p_T > 5$ GeV, $Q^2 > 7.5$ GeV^2 and $0.1 < y < 0.7$ are expected to be tagged by the VFPS. It will be possible to estimate higher order contributions, like resolved virtual photon. In photoproduction, 60 000 events are expected, and comparison between rates for direct ($x_\gamma > 0.8$) and resolved ($x_\gamma < 0.8$) photons will permit investigating the mechanisms which destroy the rapidity gap ("gap survival probability" [26]).

• Some 400 charm events are expected in the truly diffractive domain $5 \cdot 10^{-3} < x_{I\!P} < 3 \cdot 10^{-2}$, to be compared with a few tens of events presently accumulated on basis of the presence of a rapidity gap. Given the statistical precision (5 %), it is essential for a cross section measurement to tag the scattered proton and to eliminate the systematic error due to proton dissociation.

• Large samples of high Q^2 vector meson and DVCS events will be accumulated (7000 DVCS events with $Q^2 > 8$ GeV^2), with no proton dissociation background.

• Information will be obtained on the longitudinal structure function using the modulation of the diffractive cross section in ϕ, the angle between the electron and proton scattering planes. According to models, the effect can be of the order of $15 - 25$ % for $\beta \gtrsim 0.8$, depending on Q^2 and β. The angle ϕ (see fig. 3) will be measured in 4 or 5 bins, for $|t| > 0.1$ GeV^2.

• Proton dissociation samples of events will be selected as the difference between the events selected by the observation of a rapidity gap in the main detector, and those which are in addition tagged by the VFPS. This will open a completely new field in diffraction, related to factorisation breaking effects expected in QCD.

4. CONCLUSIONS

With the increase of luminosity after 2001 and the installation by H1 of the VFPS in 2002, very significant improvements will be achieved in HERA to the precision of the diffraction measurements. The dipole approach will be quantitatively tested, discrimination between several models will be possible, and a new field of research will be opened with the study of factorisation breaking.

ACKNOWLEDGEMENTS

It is a pleasure to thank the organisors of DIFFRACTION 2000, and in particular R. Fiore, for a very pleasant and fruitful workshop.

REFERENCES

1. H. Abramowicz, these proc.
2. ZEUS Coll., M. Derrick et al., *Phys. Lett.* **B315** (1993) 481;H1 Coll., T. Ahmed et al., *Nucl. Phys.* **B429** (1994) 477.
3. H1 Coll., C. Adloff et al., *Zeit. Phys.* **C76** (1997) 613.
4. ZEUS Coll., J. Breitweg et al., *Eur. Phys. J.* **C6** (1999) 43.
5. see e.g. A. Donnachie, P.V. Landshoff, *Phys. Lett.* **B296** (1992) 227.
6. H1 Coll., C. Adloff et al., *Zeit. Phys.* **C74** (1997) 221; ZEUS Coll., J. Breitweg et al., *Zeit. Phys.* **C75** (1997) 421.
7. ZEUS Coll., J. Breitweg et al., *Eur. Phys. J.* **C2** (1998) 237.
8. J.C. Collins, *Phys. Rev.* **D57** (1998) 3051; **D61** (2000) 019902.
9. J. Bartels et al., *Eur. Phys. J.* **C7** (1999) 443.
10. see e.g. K. Golec-Biernat and M. Wusthoff, *Phys. Rev.* **D60** (1999) 114023.
11. M. F. McDermott, hep-ph/0008260 (2000).
12. R. Wichmann, these proc.
13. H1 Coll., paper 960 subm. to the ICHEP2000 Conf., Osaka (2000).
14. P. Thompson, these proc.
15. L. Adamczyk, these proc.
16. H1 Coll., C. Adloff et al., *Phys. Lett.* **B483** (2000) 23; ZEUS Coll., paper 878 subm. to the ICHEP2000 Conf., Osaka (2000).
17. ZEUS Coll., J. Breitweg et al., *Eur. Phys. J.* **C6** (1999) 603.
18. H1 Coll., C. Adloff et al., *Eur. Phys. J.* **C13** (2000) 371.
19. ZEUS Coll., J. Breitweg et al., *Eur. Phys. J.* **C12** (2000) 393.
20. B. Clerbaux, hep-ph/9908519 (1999).
21. D. Reyna, these proc.
22. see e.g. M.F. McDermott and G. Briskin, proc. of the workshop "Future Physics at HERA", Hamburg (1996) 691.
23. N.N. Nikolaev and B.G. Zakharov, proc. of the DIS97 conf., AIP Conf. Proc. 407, 445.
24. A. Droutskoi, proc. of the DIS99 conf., Nucl. Phys. (Proc. Suppl.) **79** (1999) 330.
25. http://web.iihe.ac.be/h1pot
26. J. Bjorken, *Phys. Rev.* **D47** (1993) 101; E. Gotsman, E. Levin and U. Maor, *Phys. Lett.* **B309** (1993) 199.