Diffraction in deep inelastic scattering at HERA

J. J. Whitmore (on behalf of the ZEUS and H1 Collaborations) [a*]

[a]Department of Physics, Penn State University,
University Park, PA 16802, USA

Recent results on diffraction from the ZEUS and H1 collaborations at HERA are reviewed. Inclusive diffraction, exclusive vector meson production and diffractive jet and charm production are discussed.

1. INTRODUCTION

Inclusive diffraction at HERA corresponds to the excitation of the virtual γ into a system with mass M_X which has the same quantum numbers as the photon. This means that the final baryonic system also has the same quantum numbers as the initial proton. This is viewed in Regge phenomenology as Pomeron ($\mathbb{P}$) exchange in the t-channel. Typically $\sim 10\%$ of the DIS events at HERA have a rapidity gap near the proton (forward) direction which is one of the experimental signatures of diffraction. The other techniques involve the measurement of M_X directly and the detection of a track in a leading proton spectrometer.

For a general discussion of deep inelastic scattering (DIS), the standard variables are: $Q^2 = -q^2 = -(k-k')^2 = 2E_eE_e'(1-\cos\theta)$, the negative of the four-momentum transfer squared ($-$mass^2 of the virtual photon); $x = \frac{Q^2}{2P\cdot q} = \frac{Q^2}{sy}$, the momentum fraction of the struck parton in the proton; and $W^2 = (P+q)^2$, the square of the photon-proton center-of-mass energy. For diffractive studies, in addition to the above, one needs $t = (p-p')^2$; $x_{\mathbb{P}} = \frac{q\cdot(p-p')}{q\cdot p} \approx \frac{M_X^2+Q^2-t}{W^2+Q^2+M_p^2}$, the fraction of the proton beam momentum carried by the $\mathbb{P}$; $\beta = \frac{x}{x_{\mathbb{P}}} = \frac{Q^2}{2q\cdot(p-p')} \approx \frac{Q^2}{M_X^2+Q^2-t}$, the fraction of the $\mathbb{P}$ momentum carried by the struck quark. For vector meson (VM) production, an additional variable is M_{VM}^2.

2. INCLUSIVE DIFFRACTION

The structure function is defined by $\frac{d^4\sigma}{d\beta dQ^2 dx_{\mathbb{P}} dt} = \frac{4\pi\alpha_{em}^2}{\beta Q^4}[1-y+\frac{y^2}{2}]F_2^{D(4)}(\beta, Q^2, x_{\mathbb{P}}, t)$. Integration over t yields $F_2^{D(3)}(\beta, Q^2, x_{\mathbb{P}})$. The original H1 NLO diffractive fits [1] were based on the 1994 measurements of $F_2^{D(3)}$, and included fits with both diffractive ($\mathbb{P}$) and sub-leading (Reggeon) trajectories. These fits yielded a dominant gluon component at high β.

*Work supported in part by the U.S. National Science Foundation and by the U.S.-Israel Binational Science Foundation.

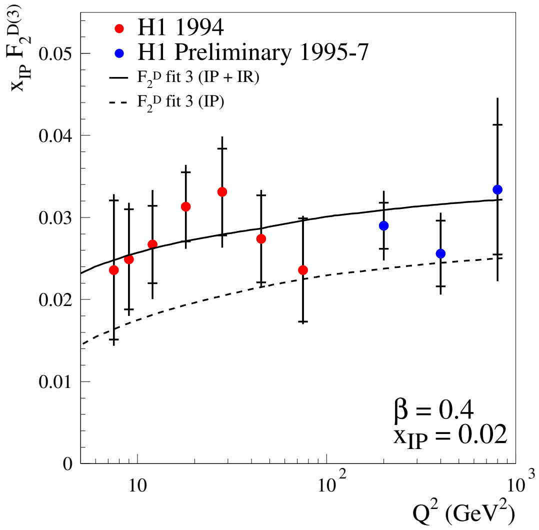

Figure 1. Preliminary measurements of $x_{\mathbb{P}} F_2^{D(3)}$ as a function of Q^2 at fixed values of $x_{\mathbb{P}} = 0.02$ and $\beta = 0.4$.

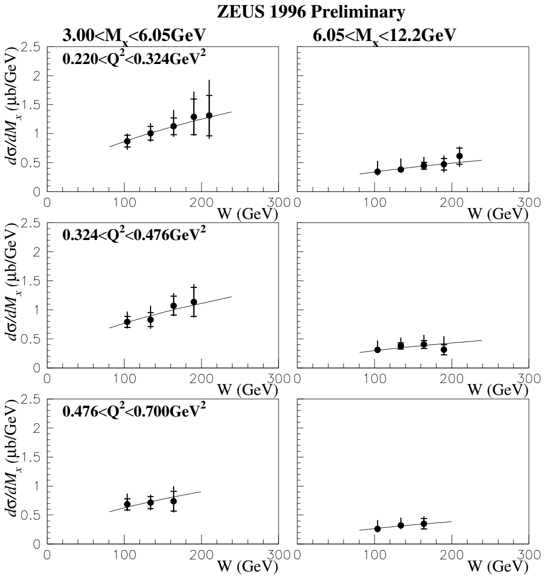

Figure 2. Diffractive cross sections for varying Q^2 and M_X as a function of W.

These fits are compared to the new H1 data [2] in Fig. 1 which shows that in a study of $x_{\mathbb{P}} F_2^{D(3)}$, at high Q^2 (200-800 GeV^2), their QCD fit at low Q^2 gives a good description when extrapolated to high Q^2. This figure also demonstrates that scaling violations in diffractive F_2 occur at high $\beta \sim 0.4$ (different from that observed in the inclusive F_2). DGLAP evolution requires gluons at large β, consistent with the gluon density found in the original H1 fits [1].

In a study of diffraction at low Q^2, ZEUS [3] has measured the inclusive diffractive cross section with the M_X method. Fig. 2 shows the data and fits to $\frac{d\sigma^{\gamma * p}}{dM_X} \sim (W^2)^{2\tilde{\alpha}_{\mathbb{P}}-2}$ yielding $\tilde{\alpha}_{\mathbb{P}} = 1.133 \pm 0.026(stat.)^{+0.013}_{-0.062}(syst.)$. Since $\tilde{\alpha}_{\mathbb{P}} = \alpha_{\mathbb{P}}(0) - \frac{\alpha'}{b}$, with $\alpha'_{\mathbb{P}} = 0.25$ GeV^{-2} and $b = 7 \pm 1 \pm 1$ GeV^{-2} (independent of Q^2), these data are consistent with the soft Pomeron ($\alpha_{\mathbb{P}}(0) = 1.08$) at low Q^2.

3. VECTOR MESON PRODUCTION

Vector meson (VM) production has proven to be an interesting testing ground for comparisons between data and pQCD models. In addition to the features discussed elsewhere [4], two additional topics are of interest. The dependence of the cross section on Q^2 has been studied in new ZEUS data for ω production yielding [5] $\sigma \sim (M_\omega^2 + Q^2)^{-2}$. This is consistent with earlier results for ρ^0 and ϕ production. New data for J/ψ production show $\sigma \sim (M_{J/\psi}^2 + Q^2)^{-n}$ with $n = 2.38 \pm 0.11$. An expectation from pQCD [6] is $\sim \frac{\alpha_s^2(Q^2)}{Q^{4.8}}$.

By studying the shrinkage of the diffractive t distribution for VM production, one may determine the Regge parameters of the exchanged object. Recent H1 data for J/ψ production [7] show that fitting $d\sigma/dt \sim exp(bt)$ yields $b = 4.3 \pm 0.2$ GeV^{-2} (averaged over W). If measured as a function of W, fig. 3 shows that in fact little or no W dependence is observed (E401 is a low energy fixed target experiment).

Figure 4 shows the results, for $\alpha(t)$, of fitting the cross section at fixed t as a function

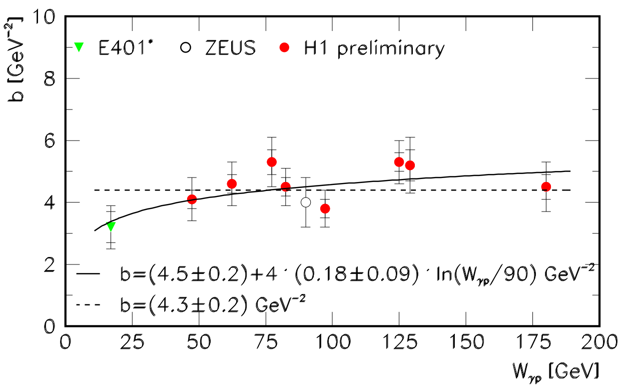

Figure 3. The slope parameter, b, for the t-dependence of exclusive J/ψ production as a function of W.

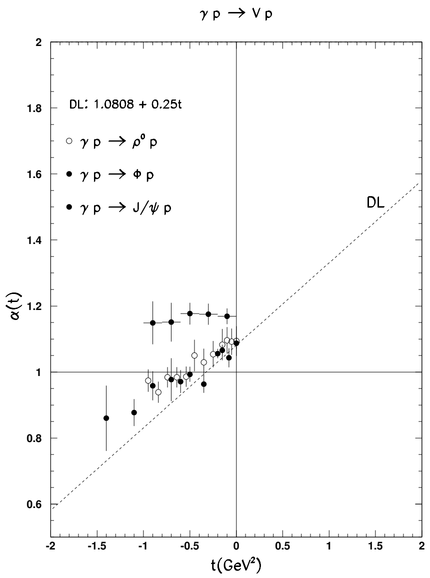

Figure 4. Measurements of the Pomeron trajectory, as determined from exclusive ρ^0, ϕ and J/ψ production.

of W to the form $\sigma \sim W^{4(\alpha(t)-1)}$ for different t values. The figure shows data [8] for ρ^0, ϕ and J/ψ production. The data for ρ^0 and ϕ are consistent with the Donnachie-Landshoff (DL) parametrization, $\alpha(t) = 1.08 + 0.25t$. The J/ψ values are inconsistent with DL and display almost no t dependence, ie no shrinkage. The H1 data yield $\alpha(t) = (1.26 \pm 0.05) + (0.05 \pm 0.15)t$, consistent with the value found by Levy [9] based on earlier ZEUS data: $\alpha(t) = (1.153 \pm 0.027) + (-0.001 \pm 0.072)t$.

3.1. Diffractive jet production

A test of the diffractive parton distribution functions obtained from the fits to $F_2^{D(3)}$ can be obtained from properties of the diffractive final state. Since dijet production is dominated by the boson-gluon fusion (BGF) process, Fig. 5, jet production will be driven by diffractive gluons. The H1 collaboration has measured diffractive DIS dijet production [10]. Figure 6 shows for $4 < Q^2 < 80$ GeV^2, $x_{\mathbb{P}} < 0.05$ and $p_{T,jet} > 4$ GeV the dijet cross section as a function of Q^2 and the jet transverse momentum, $p_{T,jet}$. The curves show the predictions from the H1 fits [1] for two different factorization scales. The rates are in reasonable agreement with the predictions, giving confirmation of a universal diffractive gluon distribution.

3.2. Diffractive charm production

Another test of the diffractive gluon density comes from diffractive DIS charm production. Clear diffractive $D^{*\pm}$ signals have been observed in both experiments: H1 observe [11] $38 \pm 10 \pm 4$ events while ZEUS measure [12] 121 ± 24 events. It is found (not shown) that the diffractive/total charm is $\sim 7\%$, independent of Q^2 or W. The ZEUS cross section for their kinematic region is $398 \pm 83(stat)^{+154}_{-180}(syst)$ pb. A recent calculation (ACTW) based on the HVQDIS program with diffractive parton distributions yields [13] 360 pb, in excellent agreement with the ZEUS data.

The H1 experiment, in a slightly different kinematic region, finds $154 \pm 40(stat) \pm$

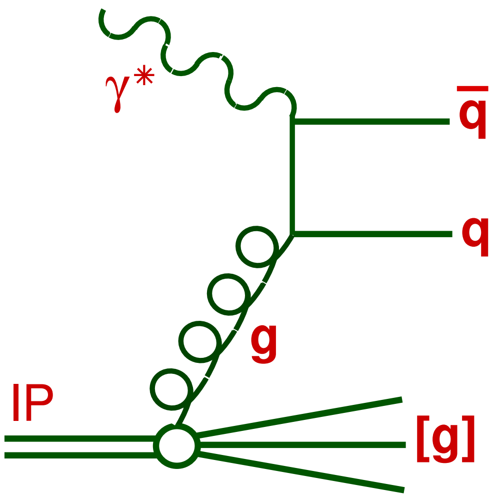

Figure 5. Schematic diagram of the boson-gluon fusion (BGF) process.

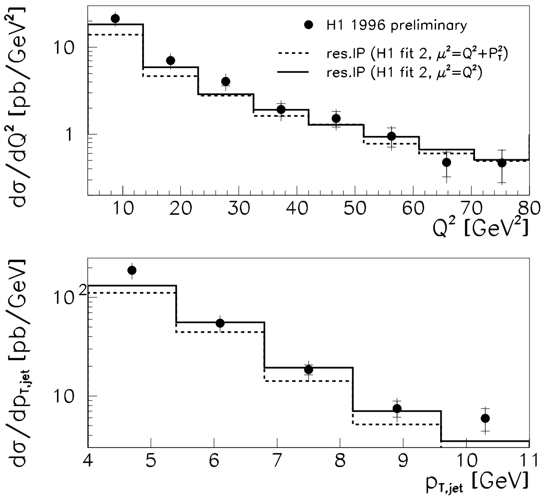

Figure 6. Differential cross sections for diffractive dijet production as a function of Q^2 and p_T, the transverse momentum of the jet.

35($syst$) pb, to be compared with the ACTW prediction of 650 pb. The H1 collaboration also finds disagreement with their cross section and various Monte Carlo predictions based on the H1 fits, eg. their cross section is $\sim 1/3$ of the RAPGAP prediction. At the present time, this is an unresolved experimental disagreement between the H1 and ZEUS results.

4. SUMMARY

Diffraction in Deep Inelastic Scattering at HERA has shown that a hard gluon component exists and that DGLAP works well in the diffractive regime. Exclusive vector meson production shows that the J/ψ production displays little shrinkage of the t-distribution. Both dijet and open charm production in diffractive DIS are dominated by boson-gluon fusion and yield a consistent diffractive gluon density.

REFERENCES

1. H1 Collab., C. Adloff et al., Zeit. f. Phys. C76, 613 (1998).
2. H1 Collab., Paper #571, ICHEP98, Vancouver (1998).
3. ZEUS Collab., Paper #500, EPS99, Tampere (1999).
4. J. J. Whitmore, these proceedings.
5. ZEUS Collab., Paper #499, EPS99, Tampere (1999).
6. L. Frankfurt, W. Koepf and M. Strikman, Phys. Rev. D57, 512 (1998).
7. H1 Collab., Paper #157aj, EPS99, Tampere (1999).
8. ZEUS Collab., J. Breitweg et al., DESY 99-160 (1999).
9. A. Levy, Phys. Lett. B424, 191 (1998).
10. H1 Collab., Paper #157ae, EPS99, Tampere (1999).
11. H1 Collab., Paper #157ag, EPS99, Tampere (1999).
12. ZEUS Collab., Paper #527, EPS99, Tampere (1999).
13. L. Alvero et al., hep-ph/9806340.