Prospects for Diffraction at HERA-II *

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New opportunities for the Study of Diffraction in the second phase of HERA operation are discussed.

1. Introduction

The progress made in the understanding of hard diffraction has been one of the major success stories of the first phase of HERA operation. As can be seen from the many new results presented at the DIS02 workshop [1], there is still much to be learned from the HERA-I data. In mid-2000, work commenced on a major upgrade of HERA with the principal aim of improving the instantaneous luminosity. By the end of 2006, an integrated luminosity of 1 fb^{-1} is expected. In this report, the new possibilities for diffractive measurements offered by the improved statistics, new and upgraded detector components and polarised and reduced-energy beams are discussed.

2. Improved Statistics

Once the full HERA-I dataset has been fully analysed, systematically limited measurements of inclusive diffraction at moderate Q^2 and of vector meson cross sections at low Q^2 and $|t|$ are expected to be available. The most precise measurements of processes in which the proton is scattered elastically are currently obtained using large rapidity gap requirements. The limiting systematic uncertainty in this method arises from the unknown contributions from proton dissociation, typically at the level of 5-10% [2]. To obtain higher precision, large datasets with tagged leading protons, eliminating this dominant systematic, will be necessary.

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On the other hand, there are many diffractive final state and exclusive measurements where the limitations after analysis of the full HERA-I dataset will remain statistical. One example is diffractive D^* production. The ZEUS collaboration has now analysed the full HERA-I dataset [3], but the resulting sample of approximately 250 events in the $D^* \to K\pi\pi$ channel remains insufficient to clearly distinguish between models or to measure double differential cross sections. Diffractive dijet production [4] does not suffer from quite the same statistical limitations as diffractive charm, though very few events have so far been collected in the crucial regions of phase space where the diffractive final state consists exclusively of jets. The 'hard' exclusive production of two or three high p_T jets is particularly well suited to perturbative QCD (pQCD) calculations [5] and is sensitive to the nature of the diffractive production mechanism.

Exclusive vector meson production is strongly suppressed with increasing Q^2 due to the higher twist nature of the processes. Only very limited data exist so far for any vector meson process with $Q^2 \gtrsim 20$ GeV^2. In two-gluon exchange models, the appropriate factorisation scale at which the gluon density is probed may be significantly lower[1] than Q^2, which illustrates the need for precision measurements at higher Q^2, where pQCD can unambiguously be applied. The large $|t|$ region of vector meson production, which remains the most promising channel at HERA to clearly identify BFKL effects [7], is similarly suppressed by the steeply falling t distribution. For the Υ meson, the statistics are very poor so far [8]. - Large statsitcs from HERA-II are needed in order to test the predictions that the energy dependence of Υ photoproduction is even steeper than that of the J/ψ [9] and to investigate the large expected effects from skewing of the parton densities.

The first measurements of DVCS at HERA [10, 11] have generated great excitiement due to their relation to generalised parton densities (GPDs) [12]. Although the full HERA-I dataset as analysed by ZEUS [11] contains several thousand events, there is a clear need for much larger samples to measure the asymmetries which will lead to the first meaningful constraints on GPDs (see section 4).

3. Tagged Protons

As discussed above, substantial improvements in the precision on quantities such as F_2^D will require efficient proton tagging. Direct leading proton measurements also allow measurements of t depenendences and their vari-

[1] e.g. in [6], the scale for ρ production is taken to be $\bar{Q}^2 \sim z(1-z)Q^2 \leq Q^2/4$, where z is the fraction of the photon longitudinal momentum transferred to the quark in the $\gamma^* \to q\bar{q}$ splitting.

ations with other kinematic variables. Although variations in the energy dependence with t have now been measured for vector meson processes, leading to extractions of the effective pomeron trajectory, the results for inclusive diffraction remain inconclusive [13, 14]. The degree of 'shrinkage' with increasing energy has important consequences for the interpretation of inclusive diffraction in terms of hard (little shrinkage) and soft (more shrinkage) contributions. A further interesting possibility offered by tagged leading protons is the investigation of possible asymmetries in the distribution in azimuthal angle between the proton and lepton scarttering planes, where the first data are again inconclusive [13]. This asymmetry is sensitive to the longitudinal structure function F_L^D [15].

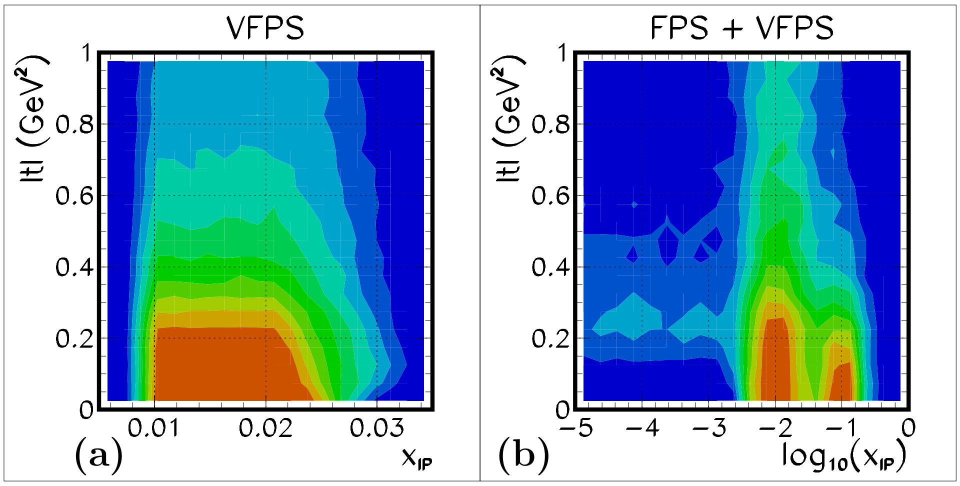

Fig. 1. Illustration of the acceptance regions of (a) the H1 VFPS and (b) the H1 VFPS and FPS combined. Acceptances of above 90% are coded red, with each subsequent colour coding covering a range of 10%.

At the end of 2002, the H1 collaboration will install a new 'Very Forward Proton Spectrometer' (VFPS) [16], approximately 200 m downstream of the interaction point. For a spectrometer in this region, the beam optics generate a dispersion in $x_{I\!P}$ and high acceptance can thus be maintained down to zero angle scattering ($t = t_{\mathrm{min}}$). The acceptance of the device in the $(x_{I\!P}, t)$ kinematic plane is illustrated in figure 3a. Although the acceptance in $x_{I\!P}$ is limited, the VFPS offers the opportunity to collect a very large sample of data ($\sim$ 350 pb^{-1} by 2006) in a well defined $x_{I\!P}$ and t region. Such a sample will be well suited to the extraction of diffractive parton densities at fixed $x_{I\!P}$ [17] and tests of diffractive hard scattering factorisation through dijet and charm measurements with leading protons also tagged in the VFPS. Performing this programme of work at fixed $x_{I\!P}$ removes the need for Regge assumptions on the $x_{I\!P}$ dependence. Together with the existing FPS stations nearer to the interaction region, there is at least some leading proton acceptance over a wide kinematic region (fig 3b).

4. Polarised Leptons

As a part of the HERA upgrade, new spin rotators and polarimeters have been installed, such that the lepton beam will be polarised as it passes H1 and ZEUS and the degree of polarisation measured with high accuracy. This opens up possibilities for improved studies of the helicity structure of vector meson production and offers the possibility of much improved constraints on GPDs. A variety of DVCS observables are sensitive to GPDs, which are comprehensively reviewed in [12]. Asymmetries in the cross section with the azimuthal angle ϕ between the lepton and proton scattering planes and with the polarisation and charge of the lepton beam are predicted to be relatively large and can all be measured at HERA-II. Measurements at lower energies have already been obtained by the HERMES collaboration [18].

5. Reduced Proton Beam Energy

The possibility of running HERA for a period with reduced proton beam energy, for example to collect a sample of approximately 50 pb^{-1} at $E_p = 400$ GeV has been discussed. The principle motivation is the measurement of the inclusive F_L and of F_2 at relatively large x and low Q^2. Such a run would raise several opportunities for diffractive studies.

Reducing E_p modifies the acceptance regions of the detectors as a function of kinematic variables, opening up new kinematic regions for study. An example is shown in figure 5a, which shows the acceptances for $\rho \rightarrow \pi^+\pi^-$ ($Q^2 > 4$ GeV^2) with the requirement that both decay pions lie within the approximate acceptance range of the main H1 and ZEUS tracking detectors ($20^\circ < \theta_\pi < 160^\circ$) for the current proton beam energy and for $E_p = 400$ GeV. The acceptance is extended to lower W than is previously the case, which would yield improved measurements of the energy dependence, enhanced sensitivity to the effective α' describing any possible shrinkage and, in the framework of two-gluon exchange models, sensitivity to the gluon density at larger values of x. Similar extensions to lower W would be available for all diffractive channels.

The available phase space for measurements of F_2^D would also be extended, either to higher $x_{I\!P}$ at fixed β or to higher β at fixed $x_{I\!P}$. This is illustrated in figure 5b, which shows the available phase space for F_2^D measurements in the (Q^2, β) plane with typical cuts, at fixed $x_{I\!P} = 0.05$ and

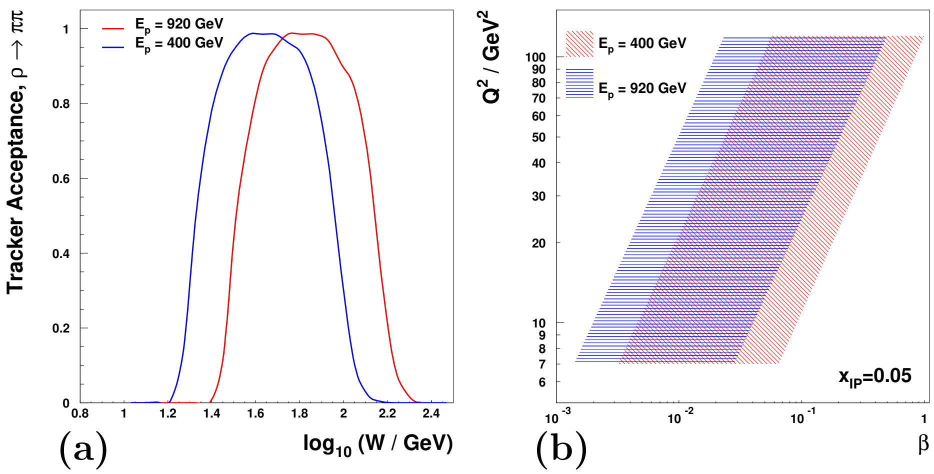

Fig. 2. (a) Acceptance functions at different E_p values for the detection of both pions from the decay $\rho^0 \to \pi^+\pi^-$ in the H1 and ZEUS central tracking detectors for exclusive ρ production with $Q^2 > 4$ GeV^2. (b) Accessible regions for measurements of F_2^D in the (β, Q^2) kinematic plane at $x_{\mathbb{P}} = 0.05$ for two different E_p values.

two different values of E_p. At these large $x_{\mathbb{P}}$ values, the extended phase space would improve the sensitivity to sub-leading exchanges. Throughout the phase space, more precise extractions of diffractive parton densities [17] at fixed $x_{\mathbb{P}}$ would be possible.

Most importantly, modifying the proton beam energy would lead to a direct F_L^D extraction, through comparison of F_2^D data at fixed x, Q^2 and $x_{\mathbb{P}}$, but different y values. Earlier studies [19] have shown that a 40% differential measurement of $F_L^{D(3)}$ with comparable statistical and systematic errors would be possible with 50 pb^{-1} at $E_p = 500$ GeV and 250 pb^{-1} at $E_p = 820$ GeV.

6. Outlook

At HERA-I, we have started to understand diffraction in QCD, but many important questions still do not have definitive answers. With the further factor of 10 increase in statistics expected at HERA-II, new detectors, lepton beam polarisation and the possibility of reduced proton beam energy running, many experimental and theoretical challenges still lie ahead. It is clear that the story of diffraction at HERA is far from over!

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