THE H1 FORWARD PROTON TAGGERS: PHYSICS PROSPECTS*

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A Very Forward Proton Spectrometer (VFPS) has been installed in the proton beam line of the H1 experiment. This device, located at 220 m downstream of the interaction point, is based on the Roman Pot technique and consists of two stations in the cold section of the proton beam line. We discuss the major physics issues which can be addressed with these forward proton taggers.

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1. Introduction

With the considerable amount of experimental results on diffractive processes collected at the HERA I running, the understanding of diffraction has substantially progressed with the focus gradually moving from aspects related to inclusive properties towards processes which are marked by the presence of a "hard" scale.

The measurement of a diffractive structure function $F_2^{D(3)}(Q^2, x, x_{\mathbb{P}})$[1] has led to the important result that the energy dependence of diffractive photon dissociation in the deep inelastic domain is stronger than the one obtained from "soft" hadron–hadron processes. From this measurement, using QCD evolution, parton distributions in the pomeron were extracted which indicate that the pomeron is dominated by gluons.

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[1] Q^2 is the negative of the intermediate photon four-momentum squared, x is the Bjorken scaling variable and $x_{\mathbb{P}} = \frac{Q^2+M_X^2}{Q^2+W^2}$ is the fraction of the proton momentum carried by the colourless exchange; W being the total hadronic energy of the system and M_X the hadronic mass.

Several studies regarding semi-inclusive features of the hadronic final state in diffractive deep-inelastic scattering (DIS) have been performed: event shapes [1, 2], multiplicity distributions [3], energy flow and single particle spectra [2, 4]. Almost all of these final state characteristics are in qualitative agreement with model predictions based on the parton distributions in the pomeron extracted from the inclusive measurements, indicating that these parton distributions universally describe diffractive DIS observables.

Of particular importance, in connection with QCD predictions, are the measurements performed on those diffractive final states which exhibit the presence of a "hard" scale: diffractive dijet production (both in photo- and in electroproduction) [5, 6] and diffractive charm production (via the $D^* \to D\pi \to K\pi\pi$) [7].

These first generation experiments at HERA have thus led to important observations and conclusions concerning diffraction: transition from a "soft" to a "hard" behaviour with increasing hard scales, gluon dominance in the pomeron, consistency with the DGLAP evolution of parton distributions. The presence of a hard scale in the final state allowed more detailed QCD predictions to be verified. However, the quality of these measurements are subject to a number of limitations. Firstly, diffractive interactions have typically been selected from the presence of a rapidity gap in the diffractive final state, but not by direct tagging of the scattered proton. Consequently, a clean separation between elastic and proton dissociation events is not possible, and a recourse to model dependent techniques is necessary to evaluate the latter contribution. Secondly, statistics are still quite limited in several channels with a manifest hard scale. Thirdly, quantities of basic importance have still eluded measurement: a fully differential $F_2^{D(4)}$ measurement and the measurement of the longitudinal diffractive cross section. Therefore, a Very Forward Proton Spectrometer (VFPS), based on the Roman Pot technique, has been installed at 220 m downstream of the interaction point [8]. It provides a clean selection of diffractive events by directly tagging the scattered proton. In addition, it is possible to measure the proton momentum and thus extract the full set of kinematic variables $x_{I\!P}$, $|t|$ and ϕ which determine the diffractive process.

2. The H1 forward proton taggers

The H1 Collaboration already operated Roman Pot detectors during the HERA I running period. These stations were however positioned close to the interaction point and the acceptance was limited. Nevertheless this Forward Proton Spectrometer (FPS) has yielded interesting results, based on a limited number of events.

The search of an optimal location for the VFPS was guided by the need for a large acceptance for protons with an energy loss of 1%. Detailed beam studies showed that the diffractive protons leave the nominal beam horizontally at 220 m downstream of the interaction point. Roman Pots will therefore approach the beam horizontally and exploit the spectrometer effect of the HERA bend. This location is in the cold section of the HERA ring and therefore a horizontal bypass has been built for the cold lines.

The acceptance for the horizontal and vertical FPS stations and for the VFPS is given in Table II. The resolution on the kinematic variables is dominated by the beam characteristics and allows us to measure 4 bins in $|t|$ [2] and 15 bins in ϕ [3].

TABLE I

The acceptance range for the FPS (horizontal and vertical stations) and the VFPS.

	FPS-H	FPS-V	VFPS
t	0.2–0.4	0.–0.15	0.–0.25
$x_{I\!P}$	10^{-5}–10^{-2}	0.05–0.15	0.01–0.02
local acc.	30%	100%	100%

3. Physics prospects

In the following sections we discuss the physics potential of the proton taggers. All studies shown are based on an integrated luminosity of 350 pb^{-1} for which the device will be operational. This assumes three years of operation, with approximately 50 % of the full luminosity delivered available for analysis.

3.1. Inclusive measurements

Measurements on $F_2^{D(3)}(Q^2, x, x_{I\!P})$ have been performed by the H1 and ZEUS experiments during the HERA I running period. However, proton elastic events have not been tagged unambiguously, leading to uncertainties related to the presence of proton dissociation backgrounds. On the other hand, the measurements performed using the previous proton taggers, provide only limited statistics and an acceptance which does not extend below $|t| = 0.1$ GeV^2, whereas with the new VFPS, the fully differential $F_2^{D(4)}(Q^2, x, x_{I\!P}, t)$ diffractive structure function will be measured, down to the lowest values of $|t|$.

[2] t is the four-momentum transfer squared at the proton vertex.
[3] ϕ is the azimuthal angle of the diffractive scattered proton.

The $F_2^{D(4)}(Q^2, x, x_{I\!P}, t)$ measurements will be performed in the purely diffractive region with $x_{I\!P} < 0.01$, where the contribution of meson exchange is negligible.

The VFPS will provide an excellent test of hard scattering factorisation (*i.e.* the factorisation of the cross section into the parton density functions and partonic cross sections). It will be possible to make a precise measurement of the structure function $F_2^D(\beta, Q^2)$ [4] at fixed $x_{I\!P}$ in bins of, or integrated over $|t|$. At the same time, we will be able to test Regge factorisation (*i.e.* the factorisation of the cross section into a factor depending only on $x_{I\!P}$ and $|t|$ and another factor depending only on Q^2 and β) by looking for variations in the diffractive parton density functions with $x_{I\!P}$ or $|t|$.

Since the scattered proton is tagged directly, no systematic errors due to double dissociation background have to be taken into account. Moreover, the uncorrelated systematic errors are expected to approach the level obtained in the measurement of the inclusive structure function F_2 (a few %) [9]. The reason here is that the systematic errors associated to the VFPS are common to all data points and thus result in a global normalisation uncertainty. A preview of expected results on F_2^D is shown in Fig. 1.

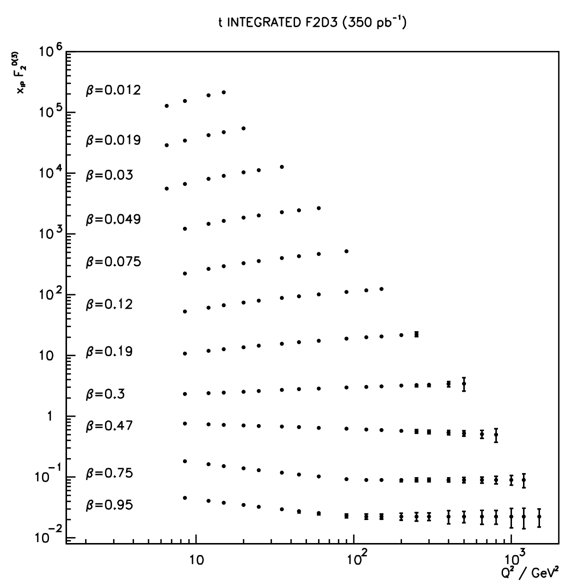

Fig. 1. Expected precision for 350 pb^{-1} on $F_2^{D(3)}(\beta, Q^2, x_{I\!P})$ at $x_{I\!P} = 0.017$, integrated over $|t| < 0.8$ GeV^2, measured in the region $0.011 < x_{I\!P} < 0.024$. The data points at different β are scaled by arbitrary factors for visibility.

[4] β is the longitudinal momentum fraction of the colourless exchange carried by the struck quark.

3.2. Hadronic final states

The study of hadronic final states provides an independent cross-check of the conclusions drawn from the inclusive studies using the same experimental data. Mainly diffractive charm and dijet production are powerful tools for the understanding of the underlying dynamics, since they are directly sensitive to the role of gluons in the colourless exchange. The VFPS offers the possibility of comparing measurements of these processes with predictions based on diffractive parton densities extracted from inclusive diffractive data using a common region of $x_{I\!P}$ and t with resulting cancellations of systematic effects.

3.2.1. Open charm production

Cross sections for diffractive open charm production in DIS have been measured by H1 using the channel $D^* \to D^0\pi_{\rm slow} \to K\pi\pi_{\rm slow}$ [10]. The previous measurement was however limited to 46 ± 10 events. The HERA II expectation with the VFPS is 380 events. About half of all diffractive D^* events which can be detected by H1 will have a proton tag from the VFPS. This allows us to perform more differential studies.

3.2.2. Diffractive dijet production

Diffractive dijet production does not suffer from quite the same statistical limitations as diffractive charm production, since there are no large factors due to branching ratios to observable channels. Despite the large global sample, statistics remain poor in regions of particular interest for 2-jet production and certainly for 3-jet production (only 2500 2-jet events have been analysed by H1) [11]. The HERA II expectation using the VFPS is 22900 dijet events.

Fig. 2 shows the $x_{I\!P}$ distribution of charm and dijet electroproduction events observable in H1.

Diffractive dijet photoproduction provides an important control experiment in attempting to understand the relationship between diffractive DIS at HERA and diffractive $p\bar{p}$ scattering, for instance at the Tevatron [12]. At present, hard diffractive scattering rates at the Tevatron fall short of predictions based on parton densities extracted from $F_2^{D(3)}$ at HERA by one order of magnitude. This failure of diffractive hard scattering factorisation is usually interpreted in terms of secondary scattering effects in processes where hadronic remnants exist, leading to "Rapidity gap survival probabilities" lower than unity [13]. Diffractive dijet photoproduction enables us to separate the direct contributions (no hadronic remnant of the photon) from the resolved contributions (hadronic remnant exists) and study the effect of breaking up the rapidity gap.

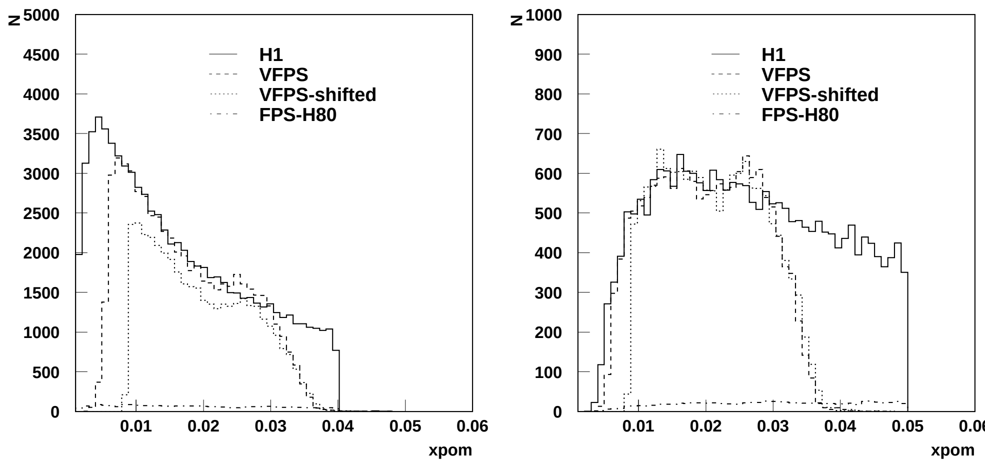

Fig. 2. $x_{I\!P}$ distribution of charm (left) and dijet (right) electroproduction events observable in H1. The full lines show the distribution for the full H1 central detector acceptance. The subset of events tagged by the VFPS is given by the dotted lines and the events tagged by the FPS are also shown. The overall normalisation is arbitrary.

3.3. Azimuthal asymmetries

By measuring the azimuthal scattering angle we gain information on the diffractive cross section for longitudinally polarised photons. The interference between the longitudinal and transverse contributions and between the two different transverse contributions give rise to azimuthal asymmetries:

$$\frac{d\sigma^D}{d\Delta\phi} = \sigma_\mathrm{T} + \sigma_\mathrm{L} - 2\sqrt{\epsilon(1-\epsilon)}\sigma_\mathrm{LT}\cos\Delta\phi - \epsilon\sigma_\mathrm{TT}\cos 2\Delta\phi\,, \tag{1}$$

where the polarisation parameter ϵ a function is of y only and very close to unity throughout most of the measurable kinematic range. $\Delta\phi$ is the angle between the proton and electron scattering planes.

The ZEUS Collaboration measured the asymmetry with their Leading Proton Spectrometer [14]: $A_\mathrm{LT} = -0.049 \pm 0.058(\mathrm{stat})^{+0.056}_{-0.009}(\mathrm{syst})$, with $\frac{d\sigma^D}{d\Delta\phi} = 1 + A_\mathrm{LT}\cos\Delta\phi$.

Since the precision on the electron ϕ obtained from the H1 central detector is extremely good, the resolution on $\Delta\phi$ is entirely determined by the VFPS. We expect to measure 15 bins in ϕ with 10000 events in each bin. This would allow us to measure the asymmetry as a function of β or Q^2. Strong variations as a function of these variables are expected, as the higher twist longitudinal photon induced cross section is predicted to dominate at large β and small Q^2 [15].

3.4. Exclusive channels

The study of the Deeply Virtual Compton Scattering (DVCS) process, *i.e.* the hard diffractive scattering of a virtual photon off the proton ($ep \to ep\gamma$) provides access to the skewed parton densities, which are generalisations of the familiar parton distributions of deep-inelastic scattering, but include parton momentum correlations. The process itself is fully calculable in perturbative QCD and thus provides a good testing ground for QCD. An analysis of DVCS based on data collected by H1 in 1997 yielded only 25 events with $Q^2 > 8$ GeV^2 (out of a total of 100 events with $Q^2 > 2$GeV^2) [16]. The expectation for the HERA II running period is to collect 3600 DVCS events in the same Q^2 range. The VFPS extends the accessible kinematic range towards low W and low Q^2, doubling the number of events that can be triggered by the central H1 detector alone.

4. Conclusions

It has been shown that the VFPS is mandatory to effectively trigger diffractive events during the HERA II running period. It allows us to tag the diffractive scattered proton directly. The VFPS has a high and well understood acceptance in a window around $x_{I\!P} = 0.01$, while the resolution on the reconstructed proton momentum is sufficient to allow exciting physics analyses.

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