Observation of Very High Q^2 Events at HERA

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Abstract. Deep-inelastic scattering events produced in positron-proton collisions with momentum transfers up to $\approx$ 30000 GeV^2 have been observed at HERA using the data sample from the years 1994-1996 recorded by the H1 detector. The number of observed neutral and charged current events is compared to the extrapolated standard DIS cross-section expectation.

I INTRODUCTION

Due to the high center of mass energy of $\sqrt{s} = 300$ GeV the positron-proton accelerator HERA can produce deep-inelastic scattering (DIS) events with momentum transfers Q^2 up to the kinematic limit of 90000 GeV^2. This offers the unique possibility to probe the proton at very small distances ($\approx 10^{-16}$ cm) via t-channel exchange of highly virtual gauge bosons.

A simple diagram of a positron-proton scattering is shown in Fig.1. Besides Q^2, the center of mass energy M available in the positron parton system characterizes this scattering process. M is closely related to Bjorken-x by $x = M^2/s$. The scaling variable y can be expressed as $y = Q^2/M^2$. In the parton model the proton is assumed to be composed of point-like constituents through which it couples to the positron by an electroweak interaction. The total cross-section is given by the product of the hard sub-process calculable in the framework of perturbative QCD and of the proton structure function F_2, which has to be extracted from data. The parton density distributions in the proton can be determined from the measured F_2 by a global fit analysis [1]. Once they are known for a given value Q_0^2, they can be extrapolated using known evolution equations to any point in the kinematic plane.

The DIS prediction of $\sigma^\pm \approx F_2 \mp (Y_-/Y_+) x F_3$ with $Y_\pm = 1 \pm (1-y)^2$ is shown in Fig.1. The variation due to different F_2 parametisations [1] is smaller than about 10%. At very high Q^2 the Z^0 couplings introduce a helicity dependence entering via F_3 in $\sigma^\pm$. Colliding electrons instead of positrons would therefore increase the expected DIS cross-section. An artificial increase of the parton density function at high x which - given the difficulties of non-perturbative and higher twist effects at low Q^2 and high x - seems possible [2], but would have a considerable impact on the charged current cross-section either in e^+p or e^-p collisions and is therefore unlikely to explain an increase of the total cross-section [3].

The knowledge on the parton density functions at high x mainly stems from lepton-nucleon scattering fixed target experiments [4]. These experiments cover a wide range in x, but only reach $Q^2 \lesssim 200$ GeV^2. Using the 1994 data H1 and ZEUS have extended these measurements [5] towards larger Q^2.

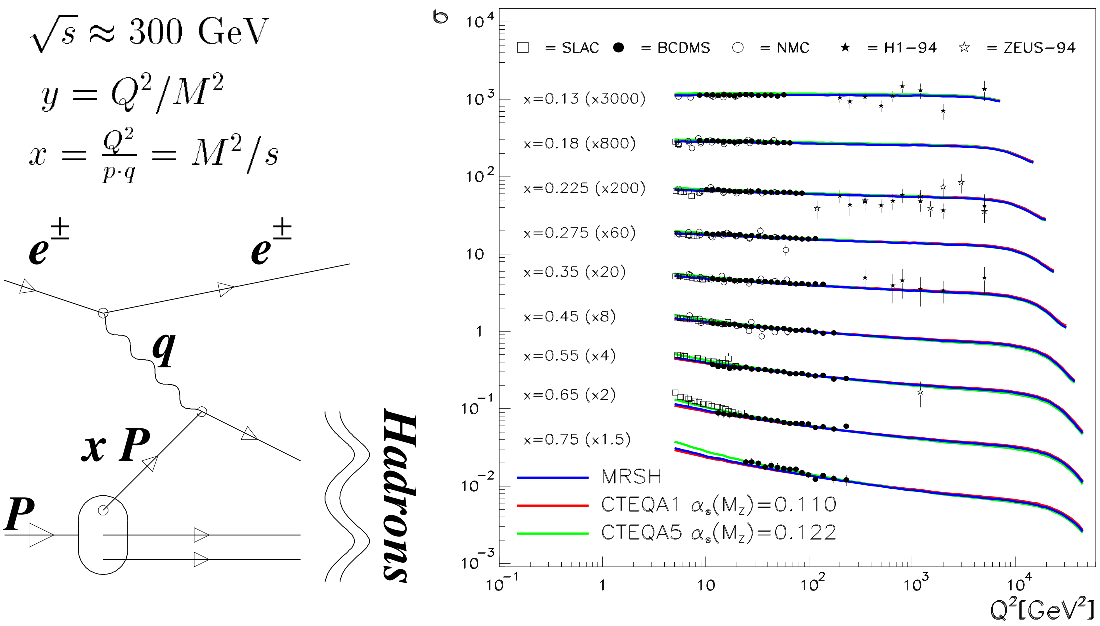

FIGURE 1. Left: Diagram of a simple lepton-proton scattering. Right: $\sigma^{\pm}$ as function of Q^2, $\sigma^{\pm}$ is defined in the text. Symbols represent data points from fixed target experiments, H1 and ZEUS (1994). Overlayed is the standard DIS prediction from two global analysis and two different values of the strong coupling constant $\alpha_s(M_Z)$.

The large data sample accumulated from 1994 to 1996 corresponding to an integrated luminosity of 14.2 pb^{-1} allows the standard DIS model to be further tested in a previously unexplored kinematic domain extending to Q^2 values up to ≈ 30000 GeV^2 [6].

II RECONSTRUCTION OF THE KINEMATICS

The kinematics of DIS events can be determined using the information of either the scattered positron or the hadronic final state alone or by a combination of both [7]. The 'electron method' leads, at not too small y, to a good estimation of the event kinematics and is insensitiv to migration from low to high masses. The 'double angle method' only relying on the directions of the scattered positron and the hadronic final state provides an important cross-check of the understanding of the energy scale. This method is however rather sensitive to initial state radiation and difficult to control on an event-by-event basis. Moreover it leads to large migrations torwards high masses. The 'Σ method' [8] using the angle and energy of the scattered positron and the longitudinal momentum balance of the hadronic final state is insensitive to QED radiation and provides good resolution also at low y.

When using the 'electron method' a key issue is the understanding of the linearity of the calorimeter for transverse momenta (E_T) up to $\approx$ 100 GeV. The excellent linearity of the H1 calorimeter has been demonstrated in test beam measurements. A deviation from linearity of less than 1% has been achieved for electron energies (E_e) ranging from 5 GeV to 166 GeV [10]. These test beam data could be reproduced within 0.5% for $E_e > 50$ GeV by a detailed and fast Monte Carlo simulation [11]. Studying the transverse momentum balance in DIS events an understanding within 3% of the hadronic jet in the forward calorimeter has been demonstrated for E_T up to 100 GeV. The linearity of the electronic chain can be tested by the pulser system injecting a charge directly into the calorimeter cells. For maximum signals the non-linear terms for all channels are found to be smaller than 1%.

III RESULTS

The neutral current (NC) event selection essentially relies on the identification of the scattered electron fully exploiting the characteristic energy deposition of an electromagnetic shower in the finely segmented H1 liquid argon sampling calorimeter [9]. The charged current (CC) events are selected by requiring that $E_{T\text{miss}} > 50$ GeV and $(E_T - E_{T\text{miss}})/E_T < 0.5$.

For $0.1 < y < 0.9$ and $Q^2 > 2500$ GeV^2, 443 NC events are selected. This is in good agreement with 427 ± 38 events expected from standard DIS events after full simulation of the H1 detector. The contamination from other processes like photoproduction of single $W^{\pm}$, jets or prompt photons at high transverse momenta is estimated to be less than 0.1% at 95% confidence level. For $Q^2 > 2500$ GeV^2 and $y < 0.9$ 31 CC events have been found. Standard DIS predicts 34.2 ± 5.8 events. At $Q^2 > 15000$ GeV^2, 1.77 ± 0.87 events are expected and 4 have been found in the data.

For Q^2 up to 15000 GeV^2, the distributions of M (Fig. 2a) and y (Fig. 2b) are well reproduced by the expectation of standard NC DIS. This demonstrates that the present understanding of DIS extends into a previously unexplored Q^2 domain. It also indicates that background due to processes at low Q^2 faking a higher Q^2 DIS signal are well under control. At $Q^2 > 15000$ GeV^2 an excess of events in the highest accessible mass region is apparent (Fig. 2c). This excess is most pronounced at high y (Fig. 2d). While for $M < 180$ GeV, the y distribution is well described (Fig. 2e), an excess of large y events is seen for very high masses (Fig. 2f). For $M > 180$ GeV and $y > 0.4$, 7 events have been observed. Only 1.83 ± 0.33 events are expected for DIS. This corresponds to a Possion probability that the NC DIS signal fluctuates to values equal or larger than the number of observed events in a random set of experiment of 0.38%. Table 1 summarizes the detailed kinematics of these 7 events. All three considered reconstruction methods lead to comparable results proving the quality of the measurement and the understanding of systematic effects showing that these events are well measured and that the systematics are under control. In event 5, where the 'electron' and 'double angle method' differ, a photon has been detected in the backward photon calorimeter near the beampipe. The 'Σ method' less sensitiv to QED effects agrees with the electron measurement.

event	M_e (GeV)	M_Σ (GeV)	$M_{2\alpha}$ (GeV)	y_e	y_Σ	$y_{2\alpha}$	Q^2_e (GeV^2)	Q^2_Σ (GeV^2)	$Q^2_{2\alpha}$ (GeV^2)
1	196	196	198	0.439	0.443	0.434	16950	17100	17100
2	208	209	200	0.563	0.592	0.582	24350	25930	23320
3	188	188	185	0.566	0.561	0.573	19950	19760	19640
4	198	196	199	0.790	0.786	0.787	30870	30230	31320
5	211	210	227	0.562	0.525	0.526	25030	23120	27100
6	192	190	190	0.440	0.501	0.443	16130	18140	16050
7	200	202	213	0.783	0.786	0.762	31420	31940	34450

TABLE 1. Comparison of M, y and Q^2 as obtained with the electron, Σ and double angle methods for the 7 events observed by H1 in the kinematic range $M > 180$ GeV and $y > 0.4$.

IV CONCLUSION

Given the existing experimental data and their interpretation in terms of parton distributions in the proton at high x and lower Q^2, and given the agreement of the resulting predictions for NC DIS found for Q^2 below 15000 GeV^2, it is unlikely that the excess of events at higher Q^2 can be understood within the DIS model. Within this model, the only explanation is therefore a statistical fluctuation. Whether the excess can be interpreted in terms of new physics requires, however, the acquisition of more data.

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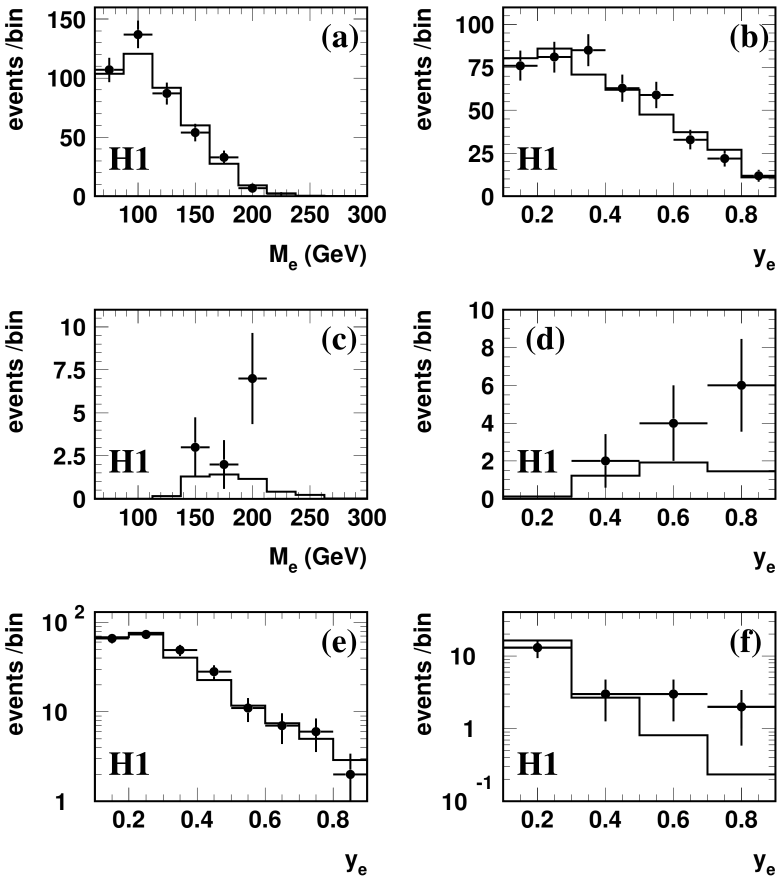

FIGURE 2. M and y distribution for NC-DIS events, (a) and (b) for $2500\,\mathrm{GeV}^2 < Q^2 < 15000\,\mathrm{GeV}^2$, (c) and (d) for $Q^2 > 15000\,\mathrm{GeV}^2$, (e) for $100 < M < 180$ GeV and (f) for $M > 180$ GeV. Data are shown as closed symbols. Superimposed is the expectation for standard DIS.