High Q^2 Events in ep Collisions

A.F.Żarnecki
for the ZEUS Collaboration

DESY – F1, Notkestraße 85, 22607 Hamburg, Germany

Abstract. Using the ZEUS detector at HERA, we have studied the reaction $e^+p \to e^+X$ for $Q^2 > 5000\,\mathrm{GeV}^2$ with a $20.1\,\mathrm{pb}^{-1}$ data sample collected during the years 1994 to 1996. For Q^2 below $15000\,\mathrm{GeV}^2$, the data are in good agreement with Standard Model expectations. For $Q^2 > 35000\,\mathrm{GeV}^2$, two events are observed while 0.145 ± 0.013 events are expected. For $x > 0.55$ and $y > 0.25$, four events are observed where 0.91 ± 0.08 events are expected. The observed excess above Standard Model expectations is particularly interesting because it occurs in a previously unexplored kinematic region.

INTRODUCTION

This paper presents results from e^+p running with the ZEUS detector during the years 1994 to 1996, at proton and positron beam energies of $E_p = 820\,\mathrm{GeV}$ and $E_e = 27.5\,\mathrm{GeV}$. With the integrated luminosity of $20.1\,\mathrm{pb}^{-1}$ collected in this period, we search for deviations from Standard Model predictions in the region $Q^2 > 5000\,\mathrm{GeV}^2$.

For details on the analysis presented here, the interested reader is referred to [1]. A description of the ZEUS detector can be found in references [2,3].

NC DIS EVENT SELECTION

A key signature of high Q^2 $e^+p \to e^+X$ events is an isolated high transverse momentum positron. In order to identify and reconstruct this positron, while rejecting events in which other final state particles mimic a positron, a dedicated algorithm was used which combines calorimeter (CAL) and central tracking detector (CTD) information. Other important characteristics that were required to distinguish high-Q^2 NC DIS from background processes are: p_t balance and conservation of $E - p_Z$. For reconstruction of kinematic variables we choose the double–angle method [4] because it is least sensitive to uncertainties in the energy measurement. The variables are corrected for systematic shifts based on MC simulation. For $y > 0.25$ and $x > 0.45$, the resolution in $x_{\rm DA}$ is 9%; it improves to 6% for $y > 0.5$. The resolution in $Q^2_{\rm DA}$ is typically 5% at large x and y. For the final event selection we require that the reconstructed $Q^2_{\rm DA}$ is above 5000 GeV^2.

NC DIS events were simulated using the MRSA parton distribution set [5]. The event simulation included electroweak radiative corrections, leading order QCD effects and parton showers. All MC events were passed through a simulation of the ZEUS detector and trigger, and analyzed with the same reconstruction and offline selection procedures as the data.

The overall selection efficiency, estimated using Monte Carlo NC events generated with $Q^2 > 5000\,{\rm GeV}^2$, is 81%. After all selection cuts 196.5 events are expected, 191 events were selected from data.

DATA AND EXPECTATIONS AT LARGE x AND Q^2

In Table 1, the numbers of observed events are compared with the Standard Model expectations in bins of $x_{\rm DA}$ and $y_{\rm DA}$. In general, the agreement between the data and the Standard Model expectations is good. However, five events, in four $(x_{\rm DA}, y_{\rm DA})$ bins occur at high $x_{\rm DA}$ and $Q^2_{\rm DA}$ where the expected numbers of events are small. Four lie in the region $x_{\rm DA} > 0.55$ and $y_{\rm DA} > 0.25$, while

TABLE 1. The observed numbers of events in bins of $x_{\rm DA}$ and $y_{\rm DA}$ (bottom number in each box), compared to the expected number of e^+p NC events (top number in each box).

$x_{\rm DA}^{\rm min}$ $x_{\rm DA}^{\rm max}$	0.05 0.15	0.15 0.25	0.25 0.35	0.35 0.45	0.45 0.55	0.55 0.65	0.65 0.75	0.75 0.85	0.85 0.95
$0.95 < y_{\rm DA} < 1.00$	0.15	0.015	0.033	0.013	0.0055	0.0015	0.0012		
$0.85 < y_{\rm DA} < 0.95$	8.8 **9**	1.2 **3**	0.32	0.10	0.028 **1**	0.01	0.0034		
$0.75 < y_{\rm DA} < 0.85$	12 **16**	2.5 **4**	0.50 **1**	0.15	0.050	0.011	0.0039		
$0.65 < y_{\rm DA} < 0.75$	13 **10**	3.7 **3**	0.86	0.26	0.082	0.022	0.0054 **1**	0.0020	
$0.55 < y_{\rm DA} < 0.65$	15 **12**	6.1 **3**	1.65 **3**	0.46 **1**	0.15	0.046	0.0090	0.0024	
$0.45 < y_{\rm DA} < 0.55$	12 **6**	11 **13**	2.5 **1**	0.85	0.28	0.084 **1**	0.0208	0.0032	
$0.35 < y_{\rm DA} < 0.45$	4.6 **3**	18 **17**	5.5 **6**	1.75	0.52	0.16	0.0403	0.0093	
$0.25 < y_{\rm DA} < 0.35$		18 **23**	11 **6**	3.74 **7**	1.19 **1**	0.34 **2**	0.1104	0.0175	0.0066
$0.15 < y_{\rm DA} < 0.25$		2.2 **1**	14 **15**	9.6 **10**	3.32 **3**	1.2	0.2784 **1**	0.0717	0.0077
$0.05 < y_{\rm DA} < 0.15$				1.3 **1**	2.14 **3**	1.6 **2**	0.9052 **1**	0.3022 **1**	0.1216

the fifth has $x_{\mathrm{DA}} = 0.48$ and a very high Q^2_{DA} of $37\,500\,\mathrm{GeV}^2$.

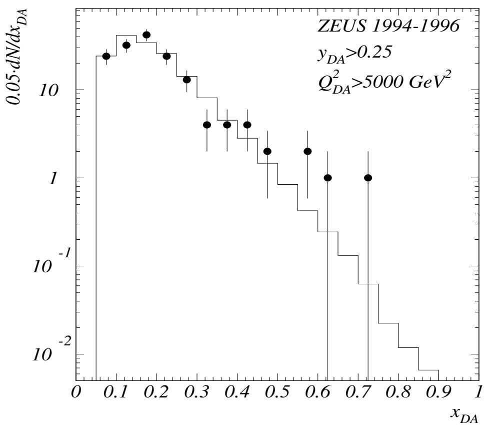
Figure 1 shows the x_{DA} (for $y_{\mathrm{DA}} > 0.25$) and Q^2_{DA} distributions of the final event sample. The e^+p NC predictions for the same integrated luminosity are superimposed as a solid histogram. Again, the agreement with the Standard Model is good at lower values of x_{DA} and Q^2_{DA}, but an excess is observed at high x_{DA} and at high Q^2_{DA}.

The five high-x, high-Q^2 events have clean, well-identified and isolated positrons and jets in the final state. None lie close to any of the selection cuts described in the previous section. For these events, the scattering angles and energies of the final state positrons and jets are measured with good precision, making it unlikely that resolution smearing has moved any of these events from low Q^2 to the measured Q^2_{DA}.

BACKGROUND AND UNCERTAINTIES

Potential background processes to e^+p DIS events at large x and y are those processes which yield an isolated positron or electron of high transverse energy, or a photon or π^0 which could be misidentified as a scattered positron. The estimated cross sections from the possible background sources are listed in Table 2 along with the e^+p NC cross section. The backgrounds are much smaller than the DIS signal in the region of interest, and are neglected.

The predicted numbers of e^+p NC DIS events depend on (i) the measured luminosity, (ii) the electroweak parameters, (iii) electroweak radiative corrections, mainly due to initial state radiation (ISR), (iv) the quark densities in the relevant region of x and Q^2 and (v) the Monte Carlo simulation of the



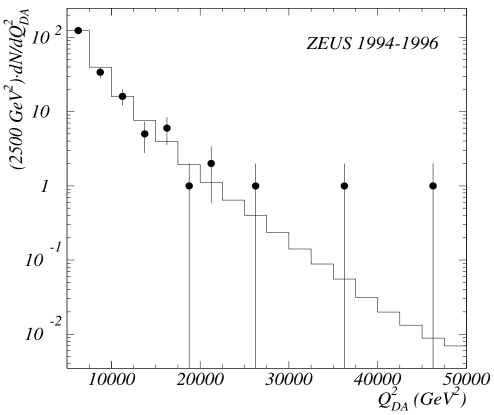


FIGURE 1. The x_{DA} distribution (left ; with the cuts shown) and the Q^2_{DA} distribution (right) of the observed events (full dots), compared to the Standard Model e^+p NC expectation (histogram).

TABLE 2. Expected cross sections for different background processes.

Background Process	cross section [fb][a] $x_{\mathrm{DA}} > 0.45$ $y_{\mathrm{DA}} > 0.25$	$x_{\mathrm{DA}} > 0.55$ $y_{\mathrm{DA}} > 0.25$
$\gamma p \to \gamma X$	0.28	0.28
$\gamma p \to$ dijets	<1.8	<1.8
$ep \to e\gamma X$	<0.2	<0.2
$\gamma\gamma \to \ell\ell$	<0.1	<0.1
$W \to e\nu$	<0.5	<0.5
Expected NC DIS	165	46

[a] The expected numbers of background events are obtained by multiplying these cross sections with the integrated luminosity of $0.02\,\mathrm{fb}^{-1}$. The quoted limits are at 90% CL.

detector. Table 3 presents the estimated contributions of these uncertainties to the systematic error on the Standard Model predictions for $x_{\mathrm{DA}} > 0.55$ and $y_{\mathrm{DA}} > 0.25$. At the large x and Q^2 values discussed here the overall uncertainty of the number of events predicted is 8.4%.

SIGNIFICANCE OF EXCESS

As presented in table 1 there is very good agreement between data and $e^+p \to e^+X$ expectations over the entire $x - y$ plane, except in the region of high x_{DA} and y_{DA}. The numbers of observed and expected events was studied above various Q^2_{DA} thresholds. The data agree well with the Standard Model predictions up to Q^2_{DA} of 1.5×10^4 GeV^2. For bigger Q^2_{DA} the Poisson probability that the number of events observed above a given Q^2_{DA} is compatible with Standard Model predictions decreases. The minimum probability of 0.39% (corresponding to 2.7 Gaussian standard deviations) occurs for $Q^2_{\mathrm{DA}} > 3.75 \times 10^4$ GeV^2 where two events are observed while 0.091 ± 0.010 are expected.

TABLE 3. Systematic errors on the expected number of events for $x_{\mathrm{DA}} > 0.55, y_{\mathrm{DA}} > 0.25$.

Source of uncertainty	Relative error on SM predictions
Luminosity measurement	±2.3 %
Electroweak parameters	±0.3 %
Radiative corrections	±2.0 %
Experimental uncertainties of low-Q^2 high-x structure function data	±6.2 %
Evolution error due to α_s uncertainty $0.113 < \alpha_s < 0.123$	±1.9 %
Detector simulation including ±3% energy scale uncertainty	±4.4 %
Total uncertainty	±8.4 %

We have performed a similar analysis of the $x_{\rm DA}$ spectrum in the region $y_{\rm DA} > 0.25$. Here the minimum probability of 0.60% (corresponding to 2.5 Gaussian standard deviations) occurs for $x_{\rm DA} > 0.57$ where four events are observed and 0.71 ± 0.06 are expected.

To gauge the significance of these probabilities, one must consider that it is possible to observe a statistical fluctuation above *any* $Q^2_{\rm DA}$ or $x_{\rm DA}$ within the region studied. We generated a large ensemble of simulated experiments according to Standard Model assumptions, each with a luminosity of 20.1 $\rm pb^{-1}$ and asked how often an experiment would find a probability below 0.39% for *any* $Q^2_{\rm DA}$. The resulting probability to find such a fluctuation was 6.0%. Similarly, we determined that the probability for an experiment to have a probability below 0.60% in the region $y_{\rm DA} > 0.25$ for *any* $x_{\rm DA}$ was 7.2%.

CONCLUSIONS

Using the ZEUS detector at HERA, we have studied the reaction $e^+p \to e^+X$ for $Q^2 > 5000\,\rm GeV^2$ with a $20.1\,\rm pb^{-1}$ data sample collected during the years 1994 to 1996.

For Q^2 below $15000\,\rm GeV^2$, the data are in good agreement with Standard Model expectations. For $Q^2 > 35000\,\rm GeV^2$, two events are observed while 0.145 ± 0.013 events are expected. For $x > 0.55$ and $y > 0.25$, four events are observed where 0.91 ± 0.08 events are expected. The observed excess above Standard Model expectations is particularly interesting because it occurs in a previously unexplored kinematic region.

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