Submitted to

Europhysics Conference on High Energy Physics, EPS2007, July 19-25, 2007, Manchester

Abstract:	**196**
Parallel Session	**Physics Beyond the Standard Model**
Electronic Access:	*www-h1.desy.de/h1/www/publications/conf/conf_list.html*
	www-zeus.desy.de/physics/phch/conf/eps07/index.html

H1prelim-07-162
ZEUS-prel-07-029
July 2007

Search for Events with Isolated Leptons and Missing Transverse Momentum at HERA

H1 and ZEUS Collaborations

Abstract

The search for events containing isolated leptons (electrons or muons) and missing transverse momentum produced in $e^{\pm}p$ collisions is performed with the H1 and ZEUS detectors at HERA in the period 1994–2007. The analysed data sample corresponds to an integrated luminosity of 0.97 fb^{-1}. A total of 87 events are observed in the data, compared to a Standard Model (SM) prediction of 92.7 $\pm$ 11.2. At large hadronic transverse momentum $P_T^X > 25$ GeV, a total of 29 events are observed compared to a SM prediction of 25.3 $\pm$ 3.2. In this kinematic region, 23 events are observed in the e^+p data compared to a SM prediction of 14.6 $\pm$ 1.9.

1 Introduction

Events containing a high P_T isolated electron or muon associated with missing transverse momentum have been observed at HERA [1–4]. An excess of HERA I (1994–2000) data events compared to the Standard Model (SM) prediction at large hadronic transverse momentum P_T^X was reported by the H1 Collaboration [2], where the analysed data set corresponds to an integrated luminosity of 118 pb^{-1}, most of which was taken in e^+p collisions. This result was not confirmed by the ZEUS Collaboration [4], although the analysis was performed in a more restricted phase space. Both collaborations have recently performed the analysis on their respective complete HERA I+II data sets, which correspond to approximately 0.5 fb^{-1} per experiment [5, 6]. Presented here is the result of the combination of the H1 and ZEUS analyses.

The main SM contribution to the signal topology is the production of real W bosons via photoproduction with subsequent leptonic decay: $ep \rightarrow eW^{\pm}(\rightarrow l\nu)X$. The equivalent charged current process $ep \rightarrow \nu W^{\pm}(\rightarrow l\nu)X$ also contributes to the total signal rate, although only at a level of around 7%. The production of Z^0 bosons with subsequent decay to neutrinos $ep \rightarrow eZ^0(\rightarrow \nu\bar{\nu})X$ results in a further minor contribution[1] to the total signal rate in the electron channel at a level of 3%. SM background enters the electron channel due to mismeasured neutral current (NC) events and enters the muon channel due to lepton pair (LP) events in which one muon escapes detection, both cases resulting in apparent missing transverse momentum. Charged current (CC) background, which contains intrinsic missing transverse momentum, enters the final sample of both lepton channels, where a final state particle is interpreted as the isolated electron or muon.

2 A Combined H1-ZEUS Analysis

The main difference in the H1 [2] and ZEUS [3] event selections is the cut on lepton polar angle, which is $5\,^{\circ} < \theta_l < 140\,^{\circ}$ for H1 and $17\,^{\circ} < \theta_e < 86\,^{\circ}$, $17\,^{\circ} < \theta_\mu < 115\,^{\circ}$ in the ZEUS analysis. Previous analyses by ZEUS have additionally focussed on the more exclusive higher hadronic momentum region. A study of the selection efficiency for signal process using Monte Carlo (MC) generator EPVEC [7] found the H1 and ZEUS analyses to be compatible in the kinematic region where they are directly comparable [8, 9]. It was also found that the majority of the data events observed by H1 at $P_T^X > 25$ GeV fall into the region of overlap of the two analyses. Nevertheless, in order to coherently combine the results a common phase space has been established by the two experiments.

The common H1-ZEUS event selection is detailed in table 1 and is based on the H1 event selection [2,5], albeit with a more restricted lepton polar angle range of $15\,^{\circ} < \theta_l < 120\,^{\circ}$. This reduction in phase space has only a small effect on the signal efficiency in the backward region, but is more severe in the forward direction, where signal events are observed to peak [8, 9]. An additional change with respect to the H1 event selection is that the cut on longitudinal momentum imbalance in the electron channel is simplified in that it is always applied. This is found to make only a negligible difference to the SM expectation. It is worth noting that this event selection is now also used in the nominal ZEUS analysis, presented in [6].

[1] This process is not included in the present ZEUS analysis.

Variable	Electron	Muon
θ_l	$15° < \theta_l < 120°$	
P_T^l	> 10 GeV	
$P_T^{\rm calo}$	> 12 GeV	
$P_T^{\rm miss}$	> 12 GeV	
P_T^X	–	> 12 GeV
$D_{\rm jet}$	> 1.0	
$D_{\rm track}$	> 0.5 for $\theta_e \geq 45°$	> 0.5
ζ_l^2	> 5000 GeV^2 for $P_T^{\rm calo} < 25$ GeV	–
$\frac{V_{ap}}{V_p}$	< 0.5 (< 0.15 for $P_T^e < 25$ GeV)	< 0.5 (< 0.15 for $P_T^{\rm calo} < 25$ GeV)
$\Delta\phi_{l-X}$	$< 160°$	$< 170°$
$\delta_{\rm miss}$	> 5 GeV	–
# isolated μ	0	1

Table 1: Selection requirements for the electron and muon channels in the common H1-ZEUS search for events with isolated leptons and missing transverse momentum.

The main selection requirements are as follows: The lepton should have high transverse momentum P_T^l, be observed in the central region of the detector, defined by the polar angle θ_l and be isolated with respect to jets and other tracks in the event. The isolation of the lepton is quantified using the distances in $\eta - \phi$ space to the nearest jet $D_{\rm jet}$ and nearest track $D_{\rm track}$. The isolation of the electron with respect to jets in the event is implicit in the ZEUS analysis. The event should contain a large transverse momentum imbalance, both measured in the calorimeter, $P_T^{\rm calo}$ and over the complete event, $P_T^{\rm miss}$. In order to reduce background contributions, further cuts are then applied using variables sensitive to the presence of high energy undetected particles in the event: The azimuthal balance of the event $\frac{V_{ap}}{V_p}$, the difference in azimuthal angle between the lepton and the hadronic system, $\Delta\phi_{l-X}$ and the longitudinal momentum imbalance $\delta_{\rm miss}$. Additionally, muon events are required to have a minimum P_T^X and electron events with low values of $P_T^{\rm calo}$ are required to have large ζ_l^2, which is equivalent to the four momentum transfer squared Q^2 in NC events. To ensure that the two lepton channels are exclusive, electron events must contain no isolated muons.

The signal expectation rates of the H1 and ZEUS analyses using the common event selection are found to be comparable, taking into account the respective luminosities of the data sets and the signal processes included. The respective H1 and ZEUS signal contributions are thus combined and assigned a correlated theory error of 15%, based on the next to leading order (NLO) Quantum Chromodynamics (QCD) calculation [10] applied to EPVEC. The background expectation rates, although slightly higher in the ZEUS analysis, are also found to be compatible. Each background process from each experiment is assigned an uncorrelated systematic error dependent on the level agreement between data and MC. The systematic error on the total SM expectation is therefore formed by summing in quadrature the systematic error of each background contribution from each experiment with the systematic error of the combined signal contribution. Total errors are formed by adding systematic and statistical errors in quadrature.

3 Results

The results of the combined H1-ZEUS search for events containing isolated leptons and missing transverse momentum are summarised in table 2. Results are shown for the electron and muon channels separately as well as combined in the e^+p data (0.58 fb^{-1}), e^-p data (0.39 fb^{-1}) and the full HERA I+II $e^{\pm}p$ data set (0.97 fb^{-1}). The results are shown for the full selected sample and for a subsample at large $P_T^X > 25$ GeV. The signal contribution, dominated by real W production, is also shown and dominates the SM expectation in all data samples.

In the e^+p data, 39 electron events and 18 muon events are observed compared to SM predictions of 41.3 $\pm$ 5.0 and 11.8 $\pm$ 1.6 respectively. In the e^-p data, 25 electron events and 5 muon events are observed compared to SM predictions of 31.6 $\pm$ 4.1 and 8.0 $\pm$ 1.1 respectively. In the $e^{\pm}p$ data, 64 electron events and 23 muon events are observed compared to SM predictions of 72.9 $\pm$ 8.9 and 19.9 $\pm$ 2.6 respectively.

Figure 1 shows the transverse mass $M_T^{l\nu}$ and P_T^X distributions of the e^+p data for the combined electron and muon channels. Figure 2 shows $M_T^{l\nu}$ and P_T^X distributions of the e^-p data for the combined electron and muon channels. Figure 3 shows the $M_T^{l\nu}$ and P_T^X distributions of the $e^{\pm}p$ data for the combined electron and muon channels. The distribution of events in $M_T^{l\nu}$ in all data sets is compatible with the Jacobian peak expected from W production. Similarly for P_T^X, the observed distribution is combatible with that expected from W production, peaking at low values of hadronic transverse momentum.

At large hadronic transverse momentum $P_T^X > 25$ GeV a total of 29 events are observed in the data compared to a SM prediction of 25.3 $\pm$ 3.2. In the e^+p data alone, where an excess of data over SM of order 3σ is reported in the H1 nominal analysis [5], 23 events are observed with $P_T^X > 25$ GeV compared to a SM prediction of 14.6 $\pm$ 1.9. Seventeen of the 23 data events are observed in the H1 data, compared to a SM expectation of 7.1 $\pm$ 0.9.

4 Summary

The search for events containing isolated electrons or muons and large missing transverse momentum produced in $e^{\pm}p$ collisions is performed with the H1 and ZEUS detectors at HERA in the period 1994–2007. The full HERA I+II $e^{\pm}p$ high energy data sample from each experiment is analysed, corresponding to an integrated luminosity of 0.97 fb^{-1}. A total of 87 events are observed in the data, compared to a SM prediction of 92.7 $\pm$ 11.2.

At large hadronic transverse momentum $P_T^X > 25$ GeV a total of 23 data events are observed in the e^+p data compared to a SM prediction of 14.6 $\pm$ 1.9. The probability for the SM expectation to fluctuate to the observed number of e^+p data events or more in this kinematic region is 0.0385, corresponding to an excess of data over SM of order 1.8σ.

References

[1] C. Adloff *et al.* [H1 Collaboration], Eur. Phys. J. C **5** (1998) 575 [hep-ex/9806009].

[2] V. Andreev *et al.* [H1 Collaboration], Phys. Lett. B **561** (2003) 241 [hep-ex/0301030].

[3] J. Breitweg *et al.* [ZEUS Collaboration], Phys. Lett. B **471** (2000) 411 [hep-ex/9907023].

[4] S. Chekanov *et al.* [ZEUS Collaboration], Phys. Lett. B **559** (2003) 153 [hep-ex/0302010].

[5] H1 Collaboration, *"Search for Events with Isolated Leptons and Missing Transverse Momentum with H1 at HERA"*, contributed paper to *The International Europhysics Conference on High Energy Physics, EPS07*, Manchester 2007, **Abstract 228**.

[6] ZEUS Collaboration, *"Search for High-P_T Isolated Leptons with ZEUS at HERA"*, contributed paper to *The International Europhysics Conference on High Energy Physics, EPS07*, Manchester 2007, **Abstract 79**.

[7] U. Baur, J. A. Vermaseren and D. Zeppenfeld, Nucl. Phys. B **375** (1992) 3.

[8] H1 Collaboration, *"Search for Events with Isolated Leptons and Missing Transverse Momentum at HERA"*, contributed paper to *The XXXIII International Conference on High Energy Physics, ICHEP06*, Moscow 2006.

[9] ZEUS Collaboration, *"Search for High-P_T Isolated Leptons with ZEUS at HERA"*, contributed paper to *The XXXIII International Conference on High Energy Physics, ICHEP06*, Moscow 2006.

[10] K. P. Diener, C. Schwanenberger and M. Spira, Eur. Phys. J. C **25** (2002) 405 [hep-ph/0203269];
P. Nason, R. Rückl and M. Spira, J. Phys. G **25**, (1999) 1434 [hep-ph/9902296];
M. Spira, [hep-ph/9905469].

H1+ZEUS Preliminary l+$P_T^{\rm miss}$ events at HERA I+II		Electron obs./exp. (Signal contribution)	Muon obs./exp. (Signal contribution)	Combined obs./exp. (Signal contribution)
1994-2007 e^+p 0.58 fb^{-1}	Full Sample	39 / 41.3 $\pm$ 5.0 (70%)	18 / 11.8 $\pm$ 1.6 (85%)	57 / 53.1 $\pm$ 6.4 (73%)
	P_T^X $>$ 25 GeV	12 / 7.4 $\pm$ 1.0 (78%)	11 / 7.2 $\pm$ 1.0 (85%)	23 / 14.6 $\pm$ 1.9 (81%)
1998-2006 e^-p 0.39 fb^{-1}	Full Sample	25 / 31.6 $\pm$ 4.1 (63%)	5 / 8.0 $\pm$ 1.1 (86%)	30 / 39.6 $\pm$ 5.0 (68%)
	P_T^X $>$ 25 GeV	4 / 6.0 $\pm$ 0.8 (67%)	2 / 4.8 $\pm$ 0.7 (87%)	6 / 10.6 $\pm$ 1.4 (76%)
1994-2007 $e^{\pm}p$ 0.97 fb^{-1}	Full Sample	64 / 72.9 $\pm$ 8.9 (67%)	23 / 19.9 $\pm$ 2.6 (85%)	87 / 92.7 $\pm$ 11.2 (71%)
	P_T^X $>$ 25 GeV	16 / 13.3 $\pm$ 1.7 (73%)	13 / 12.0 $\pm$ 1.6 (86%)	29 / 25.3 $\pm$ 3.2 (79%)

Table 2: Summary of the combined H1 and ZEUS results in the serch for events with isolated electrons or muons and missing transverse momentum for the e^+p data (0.58 fb^{-1}), e^-p data (0.39 fb^{-1}) and the full HERA I+II $e^{\pm}p$ data (0.97 fb^{-1}). The results are shown for the full selected sample and for a subsample at large $P_T^X > 25$ GeV. The number of observed data events is compared to the SM prediction. The signal component of the SM expectation, dominated by real W production, is given as a percentage in parentheses. The quoted errors contain statistical and systematic uncertainties added in quadrature.

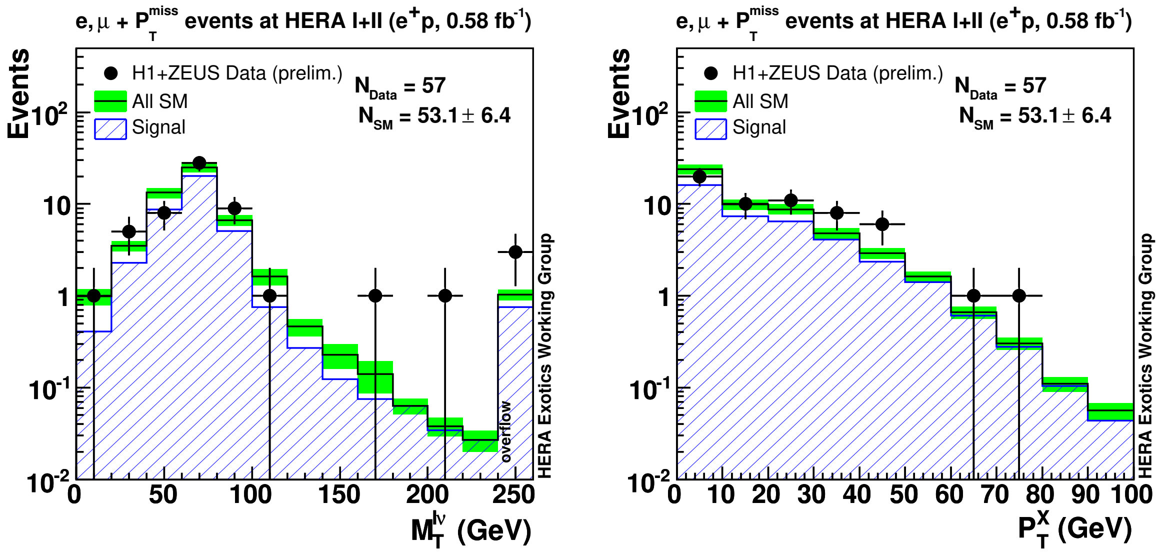

Figure 1: The transverse mass (left) and hadronic transverse momentum (right) distributions of the combined H1 and ZEUS e^+p data (HERA I+II, 0.58 fb^{-1}). The data (points) are compared to the SM expectation (open histogram). The signal component of the SM expectation, dominated by real W production, is given by the hatched histogram. $\mathrm{N_{Data}}$ is the total number of data events observed, $\mathrm{N_{SM}}$ is the total SM expectation. The total error on the SM expectation is given by the shaded band.

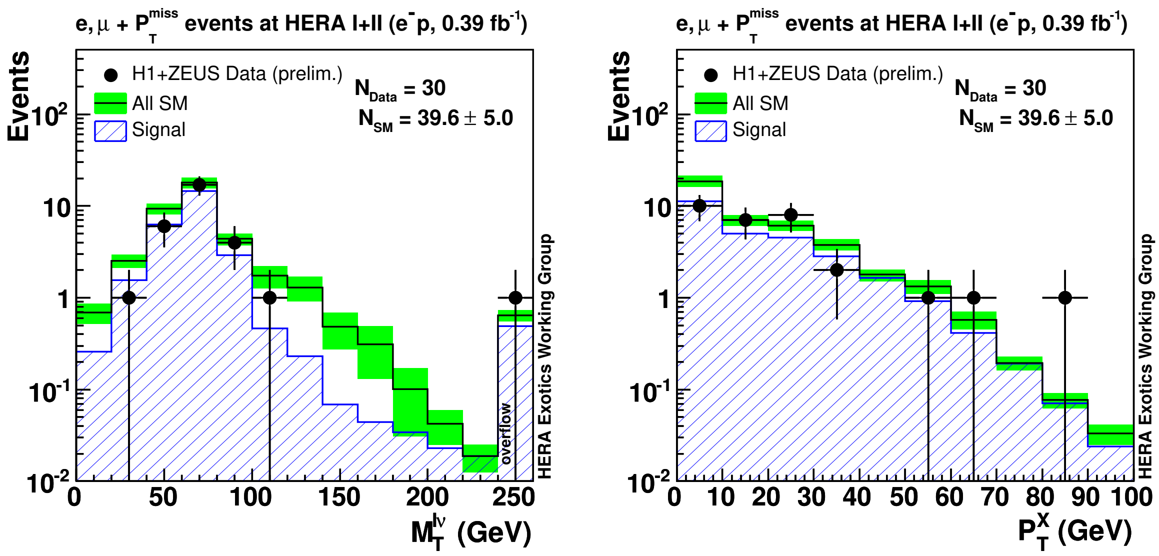

Figure 2: The transverse mass (left) and hadronic transverse momentum (right) distributions of the combined H1 and ZEUS e^-p data (HERA I+II, 0.39 fb^{-1}). The data (points) are compared to the SM expectation (open histogram). The signal component of the SM expectation, dominated by real W production, is given by the hatched histogram. $\mathrm{N_{Data}}$ is the total number of data events observed, $\mathrm{N_{SM}}$ is the total SM expectation. The total error on the SM expectation is given by the shaded band.

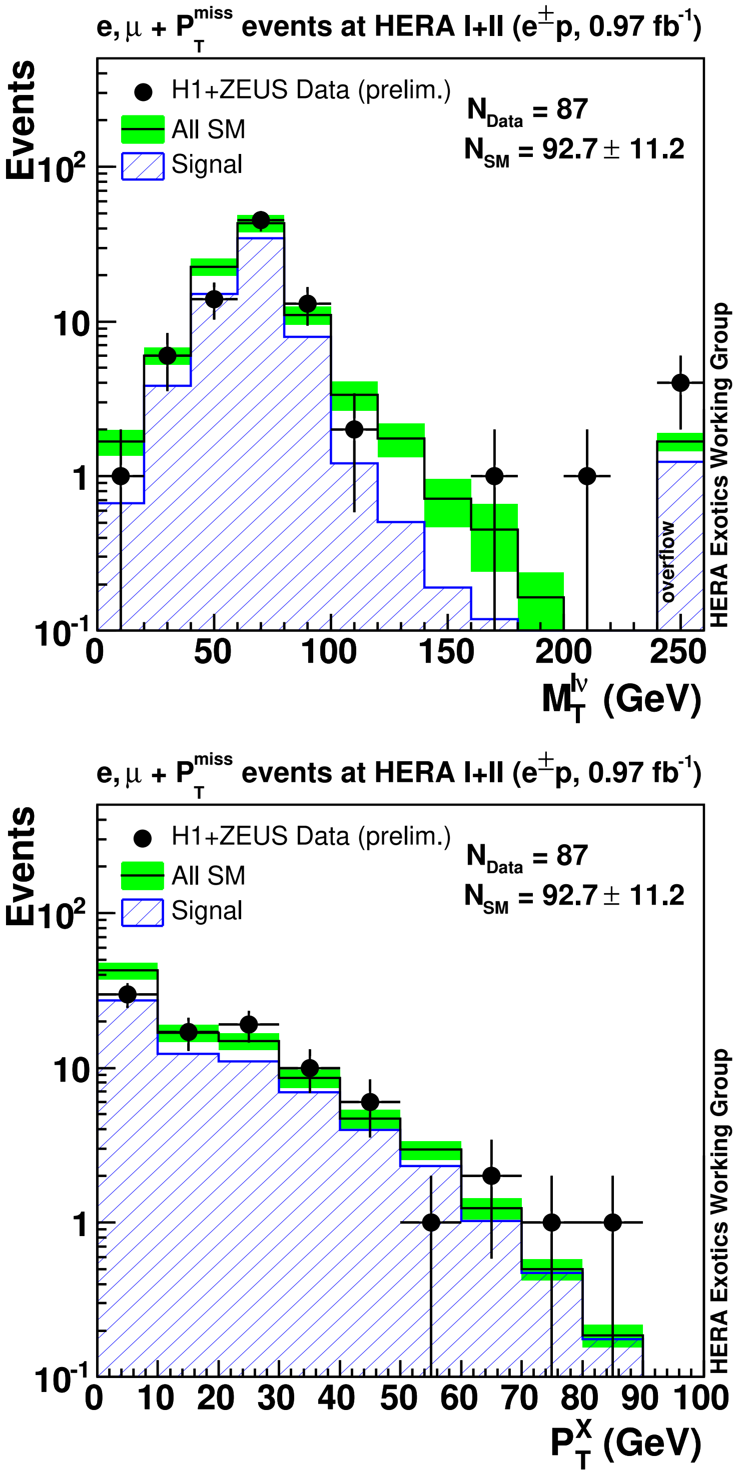

Figure 3: The transverse mass (top) and hadronic transverse momentum (bottom) distributions of the combined H1 and ZEUS $e^{\pm}p$ data (HERA I+II, 0.97 fb^{-1}). The data (points) are compared to the SM expectation (open histogram). The signal component of the SM expectation, dominated by real W production, is given by the hatched histogram. $\mathrm{N_{Data}}$ is the total number of data events observed, $\mathrm{N_{SM}}$ is the total SM expectation. The total error on the SM expectation is given by the shaded band.