Events with an Isolated Lepton and Missing Transverse Momentum at ZEUS

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A search for events with isolated high transverse energy leptons and large missing transverse momentum has been performed with the ZEUS detector at HERA using data samples with a total integrated luminosity of 432 pb^{-1} taken during the 1996-2006 running period. The results are compared to the Standard Model predictions.

1 Introduction

These proceedings report on the results of an investigation of the production of isolated leptons in events with a topology matching the electron[a] or muon decay channel of singly produced W bosons in electron-proton collisions at centre of mass energies of 300 and 318 GeV. Single W production is a rare Standard Model (SM) process and an important source of background to searches for physics beyond the Standard Model. Investigations of the process $ep \to eWX, W \to l\nu$, where $l = \mu, e, \tau$, have been performed at HERA by both the H1 [3] and ZEUS [2] collaborations. The H1 collaboration observed an excess of events with isolated muons or electrons, high missing transverse momentum and large values of hadronic transverse momentum over the SM prediction. The search presented here uses ZEUS data collected over a ten year period from 1996 to 2006 for both electron and muon channels and does not confirm this excess.

The study was performed by selecting events containing isolated electrons or muons with high transverse momentum, in events with large missing transverse momentum. The data set comprises the 1996-97, 1999-2000, 2003-04, 2006 e^+p and the 1998-99, 2004-06 e^-p running periods, with total integrated luminosities of 228 and 204 pb^{-1}, respectively. The centre of mass energy ($\sqrt{s}$) was 318 GeV in all running periods apart from 1996-1997 when it was 300 GeV.

2 Monte Carlo simulation of the signal $e^{\pm}p \to e^{\pm}WX$ and of the background

The leading order (LO) cross section for $e^{\pm}p \to e^{\pm}WX$ has been calculated using the Epvec generator[4]. Epvec calculates the cross section in two regions, corresponding to photoproduction and deep inelastic scattering. The photon and proton structure functions used in the calculation are GRV-G(LO) and CTEQ5D, respectively. The final state simulation does not include hard gluon radiation. Such calculations yield a total cross section of 0.9 pb for $\sqrt{s} = 300$ GeV and 1.1 pb for $\sqrt{s} = 318$ GeV. The uncertainties on these values are approximately 5% for the choice of boundary between the two regions (set at 25 GeV ^{2}), 5% for the choice of proton structure function, 10% for the choice of photon structure function and 10% from the choice of Q^2 scale used in Epvec. Next-to-leading order corrections have been calculated to be of the order of 10%, but they were not used in this analysis.

[a] In this paper "electron" refers both to electrons and positrons unless specified.

The most important background to W production in the electron decay-channel arises from high Q^2 charged and neutral current deep inelastic scattering (DIS) events. These DIS events have been simulated using the DJANGO6 interface to the Monte Carlo (MC) programs HERACLES 4.5 and LEPTO 6.5. Leading order electroweak radiative corrections were included and higher order QCD effects were simulated using the colour-dipole model (CDM) of ARIADNE or parton showers based on a leading-logarithm approximation (MEPS). The hadronisation of the partonic final state was performed by JETSET. The process $\gamma\gamma \rightarrow l^+l^-$, which is a minor contribution to the background in the electron decay channel of W boson, is the most important background in the muon channel was simulated using the GRAPE dilepton generator. Direct and resolved photoproduction processes were simulated using the HERWIG 6.1 event generator but they are found not to contribute after the event pre-selection.

The generated events were passed through the GEANT-based ZEUS detector and trigger simulation programs. They were reconstructed and analysed by the same program chain as the data.

3 Event Reconstruction and Data Preselection

The missing transverse momentum is defined as: $P_T = \sqrt{\left(\sum_i p_{X,i}\right)^2 + \left(\sum_i p_{Y,i}\right)^2}$, where $p_{X,i} = E_i \sin\theta_i \cos\phi_i$ and $p_{Y,i} = E_i \sin\theta_i \sin\phi_i$ are calculated from individual energy deposits in clusters of calorimeter cells corrected for energy loss in inactive material. The angles θ_i and ϕ_i are estimated from the geometric cell centres and the event vertex. In $W \rightarrow e\nu$ events, P_T as defined above is an estimate of the missing transverse momentum carried by the neutrino. In $W \rightarrow \mu\nu$ events the muon as a minimum ionising particle deposits very little energy in the calorimeter and therefore a better estimate of the transverse momentum carried by the neutrino can be obtained if the momentum of the muon is calculated from the muon track measured in the central tracking detector. Events that passed the trigger requirements were further required to have P_T greater than 12 GeV. The transverse momentum calculated excluding the inner ring of calorimeter cells around the forward beam pipe hole, also had to be greater than 9 GeV. Hadron transverse momentum P_T^X is defined as the sum over those calorimeter cells that are not assigned to lepton candidate clusters and for the muon-channel it was required that $P_T^X > 9$ GeV. The transverse momentum of the leptons had to be $P_T^e > 5$ GeV and $P_T^\mu > 10$ GeV, respectively. Longitudinal momentum conservation ensures that $E - p_Z$ (δ), defined as: $\delta \equiv \sum_i E_i(1 - \cos\theta_i)$ with the sum over all energy deposits, peaks at twice the electron beam energy $E_\mathrm{e} = 27.5$ GeV for fully contained events. Only events with $5 < \delta < 60$ GeV for the electron channel and with $\delta < 70$ GeV for the muon channel were chosen in the preselection. The transverse mass is defined as: $M_T = \sqrt{2P_T^l P_T^\nu(1 - \cos\phi^{l\nu})}$, where P_T^l is the lepton transverse momentum, P_T^ν is the magnitude of P_T and $\phi^{l\nu}$ is the azimuthal separation of the lepton and the missing P_T vectors. For electrons the preselection required $M_T > 10$ GeV, whereas, for muons the cut was at $M_T > 5$ GeV. The polar angle of the lepton track had to be less than 2 rad to reduce the contribution from neutral current processes which rise significantly beyond that point. In addition, since most fake leptons are misidentified hadrons close to jets, the background was further reduced by requiring that the lepton track be separated by at least 0.5 units in $\{\eta, \phi\}$ space from other tracks associated with the event vertex with momentum larger than

0.2 GeV, where ϕ is the azimuthal angle and $\eta = -\log(\tan(\theta/2))$ is the pseudo-rapidity, a measure of the polar angle. This track isolation cut was augmented by a similar cut on isolation of the lepton's energy deposit in the calorimeter which required that the energy not associated with the lepton had to be less than 4 GeV in a cone with radius 0.8 units in $\{\eta, \phi\}$ space around the lepton cluster. Other pre-selection cuts were applied to ensure that the track associated with the lepton was well reconstructed and to avoid contamination from non ep interaction backgrounds.

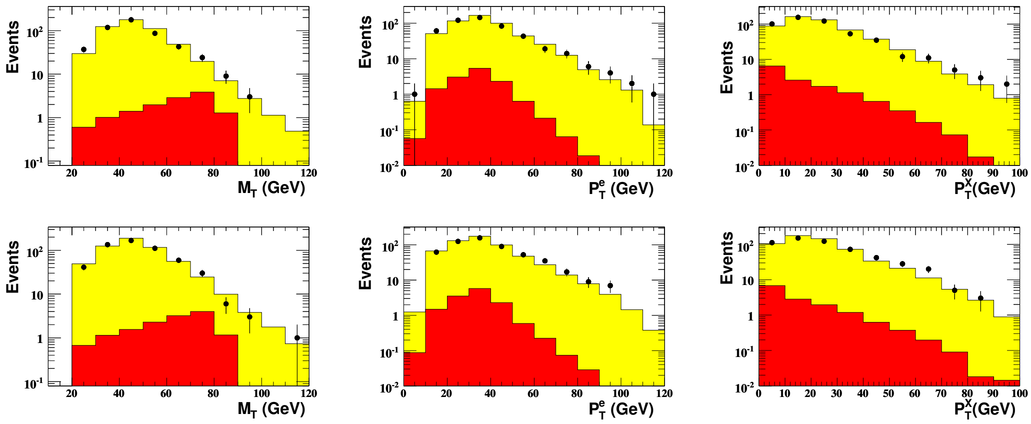

Figure 1: Electron-channel preselection 96-06 e^+p (top row) and 98-06 e^-p (bottom row). The SM expectation is show in yellow (light grey), the contribution of the signal in red (dark grey).

Figures 1 and 2, show the level of agreement, for the electron and muon channels respectively, between the measured quantities and the SM expectation, after the above preselection is applied. The plots demonstrate that the backgrounds are well understood. Further cuts are now applied to select events matching the topology of single W production. In the electron-channel the selection is refined by increasing the cut on the electron's transverse momentum to $P_T^e > 10$ GeV, reducing δ to below 50 GeV and requiring a lower cut on the acoplanarity angle $\phi_{\rm ACOP} > 0.3$ which is applied for events with $P_T^X > 4$ GeV. The acoplanarity angle is the azimuthal separation of the outgoing lepton and the vector in the $\{X, Y\}$ plane that balances the P_T^X vector. For well measured neutral current events, the acoplanarity angle is close to zero, while large acoplanarity angles indicate large missing energies. The missing transverse momentum is increased to $P_T > 25$ GeV unless $\xi_e^2 > 5000$ GeV^2, where the quantity ξ_e^2 is defined as $\xi_e^2 = 2E_eE'_e(1 + \cos\theta_e)$, where E_e is the electron beam energy and E'_e, θ_e are the energy and the angle of th eisolated elecron as measured in the calorimeter. For neutral current events with the scattered beam electron identified as the isolated lepton ξ_e^2 is Q^2. Neutral current events will generally have low values of ξ_e^2 whilst electrons from W decay will generally have high values of ξ_e^2. The muon-channel was required to satisfy three cuts after the preselection: $\phi_{\rm ACOP} > 0.2$, $P_T^X > 12$ GeV and $P_T > 12$ GeV.

The numbers of data events and the Standard Model expectations after these final sets of cuts are summarised in Tab. 1 for the e^-p and e^+p data separately. The first two columns show the electron and muon-channel separately and the third column is the sum of these

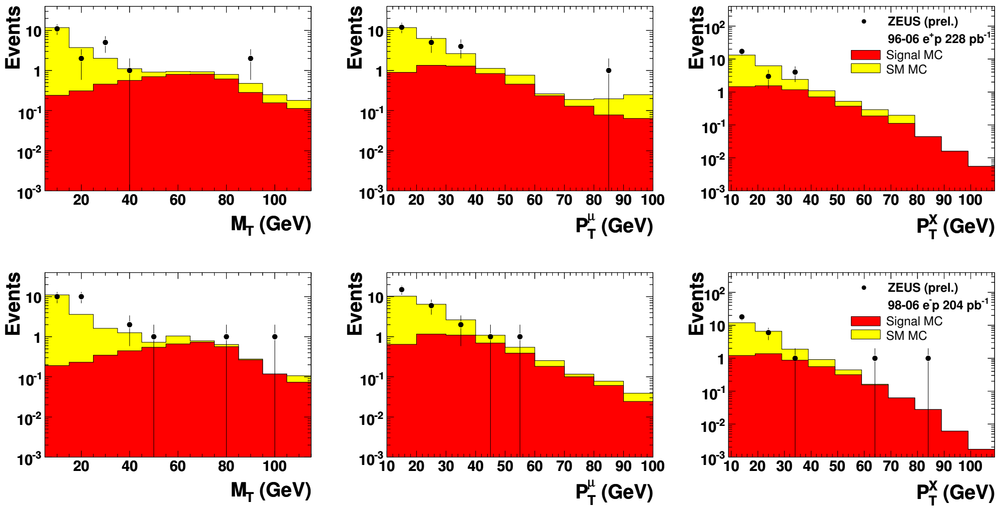

Figure 2: Muon-channel preselection 96-06 e^+p (top row) and 98-06 e^-p (bottom row). The SM expectation is show in yellow (light grey), the contribution of the signal in red (dark grey).

ZEUS $P_T^X > 25$ GeV	e channel obs./exp. (signal)	μ channel obs./exp. (signal)	e and μ obs./exp. (signal)
e^-p 204 pb^{-1}	$5/3.8 \pm 0.6$ (55%)	$2/2.2 \pm 0.3$ (68%)	$7/6.0 \pm 0.7$ (60%)
e^+p 228 pb^{-1}	$1/3.2 \pm 0.4$ (75%)	$3/3.1 \pm 0.5$ (80%)	$4/6.3 \pm 0.6$ (77%)

Table 1: Final numbers of electron and muon events against the SM expectations with the number in brackets giving the fraction of the W signal contribution to the latter.

two. In every case, the agreement between the obseved data events and the Standard Model expectation is good and the excess observed by H1 cannot be confirmed.

The errors take into account statistical and systematic uncertainties. However, theoretical uncertainities on the W production cross section were not included in the errors on the SM prediction.

References

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