SEARCH FOR NEW PHYSICS AT HERA USING COMBINED H1 AND ZEUS DATA

S.V. LEVONIAN
on behalf of the H1 and ZEUS Collaborations
Deutsches Elektronen-Synchrotron DESY, Notkestraße 85, 22607 Hamburg, Germany

Two event classes having high sensitivity to New Physics are studied using combined $e^{\pm}p$ data sample collected by H1 and ZEUS experiments at HERA collider in the period 1994 – 2007. The data correspond to an integrated luminosity of about 1 fb^{-1}. Although interesting events are observed at high P_T tails of distributions both for events with at least two high transverse momentum leptons and events containing an isolated lepton and missing transverse momentum, no significant deviations from Standard Model are found. The total single W boson production cross section at $\sqrt{(s)} = 317$ GeV is measured as 1.06 ± 0.16 (stat.) $\pm$ 0.07 (sys.) pb, in agreement with the SM expectation of 1.26 ± 0.19 pb.

1 Introduction

HERA, so far the only *ep* collider in the world, provides a unique opportunity to search for new physics beyond the Standard Model. Promising experimental topologies for this purpose are events with one or more high P_T isolated leptons in the final state, as well as in combination with missing transverse momentum. Such events have clean signature, low Standard Model expectation and hence high sensitivity to novel phenomena. After 15 years of successful data taking two collider experiments, H1 and ZEUS, have collected 0.5 fb^{-1} of data each. In order to fully exploit HERA potential and to benefit from increasing statistical significance combined analyzes of such rare final states were performed in a common phase space, resulting in a total integrated luminosity of about 1 fb^{-1}. Cross sections measured by H1 and ZEUS are combined bin by bin using weighted average.

2 Multi-Lepton Events with High Transverse Momentum

Within the Standard Model (SM) the production of high P_T multi-lepton final states in ep collisions proceeds predominantly via $\gamma\gamma$ interactions. The clean experimental signature together with small and precisely calculable SM cross section provides high sensitivity to possible contributions of physics beyond the SM. Measurements of multi-lepton production at HERA have been performed by the H1 [1] and ZEUS [2] collaborations. A combined analysis of H1 and ZEUS data is performed in a common phase space in which both detectors have high and well understood acceptance, and using full statistics available to both experiments [3].

Electrons are identified in the polar-angle range $5^o < \theta_e < 175^o$, with $E_e > 10$ GeV for $\theta_e < 150^o$ and $E_e > 5$ GeV for $\theta_e > 150^o$. Muons are identified in the range $20^o < \theta_\mu < 160^o$ with $P_T^\mu > 2$ GeV. All lepton candidates are required to be isolated with respect to each other by at least 0.5 units in $\eta - \phi$ plane (where pseudorapidity η is defined as $\eta = -\ln\tan(\theta/2)$). At least two leptons are required in the central region ($20^o < \theta_e < 150^o$): one with $P_T^l > 10$ GeV and the other having $P_T^l > 5$ GeV. Additional leptons identified according to the criteria given above may be present in the event. Selected events are then classified into mutually exclusive samples with different number and flavour of lepton candidates: $ee, \mu\mu, e\mu, eee, e\mu\mu$.

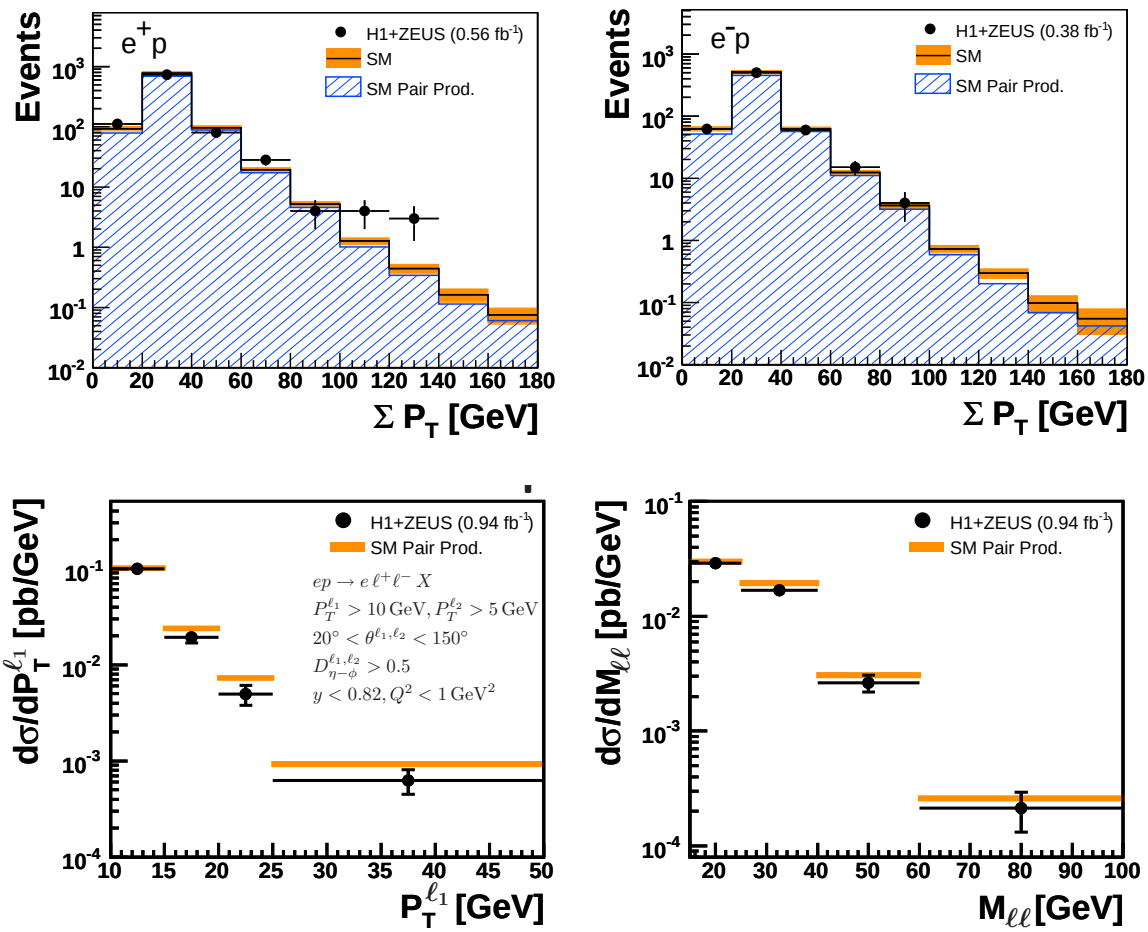

Figure 1: Multi-Lepton events at HERA. Top: the distribution of the scalar sum $\sum P_T$ for combined multi-lepton event topologies in e^+p and e^-p data. Bottom: The cross section for lepton pair photoproduction in a restricted phase space as a function of the leading lepton transverse momentum P_T^{l1} and the invariant mass of the lepton pair M_{ll}. The total error bars represent the statistical and systematic uncertainties added in quadrature. The bands represent the uncertainty in the SM prediction, dominated by the $\gamma\gamma$ process.

Table 1: Observed and predicted multi-lepton event yields for $\sum P_T > 100$ GeV. Di-lepton and tri-lepton events are combined. The uncertainties on the predictions include model uncertainties and experimental systematic uncertainties added in quadrature.

Data sample	Data	SM	Pair Production (GRAPE)	NC DIS + QEDC
e^+p (0.56 fb^{-1})	7	1.94 ± 0.17	1.52 ± 0.14	0.42 ± 0.07
e^-p (0.38 fb^{-1})	0	1.19 ± 0.12	0.90 ± 0.10	0.29 ± 0.05
All (0.94 fb^{-1})	7	3.13 ± 0.26	2.42 ± 0.21	0.71 ± 0.10

A good overall agreement is observed with the SM in all event topologies [3]. Some excess over SM expectation with significance of $\sim 2.6\sigma$ is observed for events with high $\sum P_T^l > 100$ GeV, but only in e^+p data, as can be seen in Table 1 and Figure 1 (top). The lepton pair production cross section of $0.66 \pm 0.03(stat.) \pm 0.03(sys.)$ pb is measured in the phase space dominated by $\gamma\gamma$ interactions, in agreement with the SM prediction of 0.69 ± 0.02 pb. The differential cross sections are also measured as a function of leading lepton $P_T^{l_1}$ and the invariant mass of the lepton pair M_{ll}, as shown in Figure 1 (bottom).

3 Events with Isolated Lepton and Missing Transverse Momentum

Events containing isolated high P_T lepton and large missing transverse momentum, $P_T^{\rm miss}$, is a typical signature in many BSM extensions. In the SM main source of such events in ep collisions is a single W boson production with subsequent decay via leptonic channels. Events of such topology have been observed at HERA by both H1 [4] and ZEUS [5]. In order to increase sensitivity to new physics a combined analysis of the full available data set has been performed in the common phase space [6].

The event selection requires an isolated lepton (e or μ) with $P_T^l > 10$ GeV to be in the central region of the detector $15^o < \theta_e < 120^o$ together with the presence of the hadronic jet reconstructed using k_T algorithm. In addition the event must exhibit significant missing transverse momentum, $P_T^{\rm miss} > 12$ GeV. Further cuts are then applied to minimize SM background [6].

The result of the analysis is summarized in the Table 2. In general, a good agreement is observed between the data and the SM prediction, in which the signal component is dominated by single W production. The lepton-neutrino transverse mass distribution as shown in Figure 2 (left) exhibits a characteristic Jacobean peak around W mass value. A small excess of the data in the region of high transverse momentum of the hadronic final state, $P_T^X > 25$ GeV, which was observed in the H1 analysis [4] almost completely vanishes in the combined HERA data sample. The single W production cross section is measured as 1.06 ± 0.16 (stat.) ± 0.07 (sys.) pb, in

Table 2: Summary of the combined H1 and ZEUS search for events with an isolated electron or muon and missing transverse momentum for the full HERA data set as compared to the SM expectation. The quoted uncertainties contain statistical and systematic errors added in quadrature.

H1+ZEUS 1994–2007 $e^\pm p$ 0.98 fb^{-1}		Data	SM Expectation	SM Signal	Other SM Processes
Electron	Total	61	69.2 ± 8.2	48.3 ± 7.4	20.9 ± 3.2
	$P_T^X > 25$ GeV	16	13.0 ± 1.7	10.0 ± 1.6	3.1 ± 0.7
Muon	Total	20	18.6 ± 2.7	16.4 ± 2.6	2.2 ± 0.5
	$P_T^X > 25$ GeV	13	11.0 ± 1.6	9.8 ± 1.6	1.2 ± 0.3
Combined	Total	81	87.8 ± 11.0	64.7 ± 9.9	23.1 ± 3.3
	$P_T^X > 25$ GeV	29	24.0 ± 3.2	19.7 ± 3.1	4.3 ± 0.8

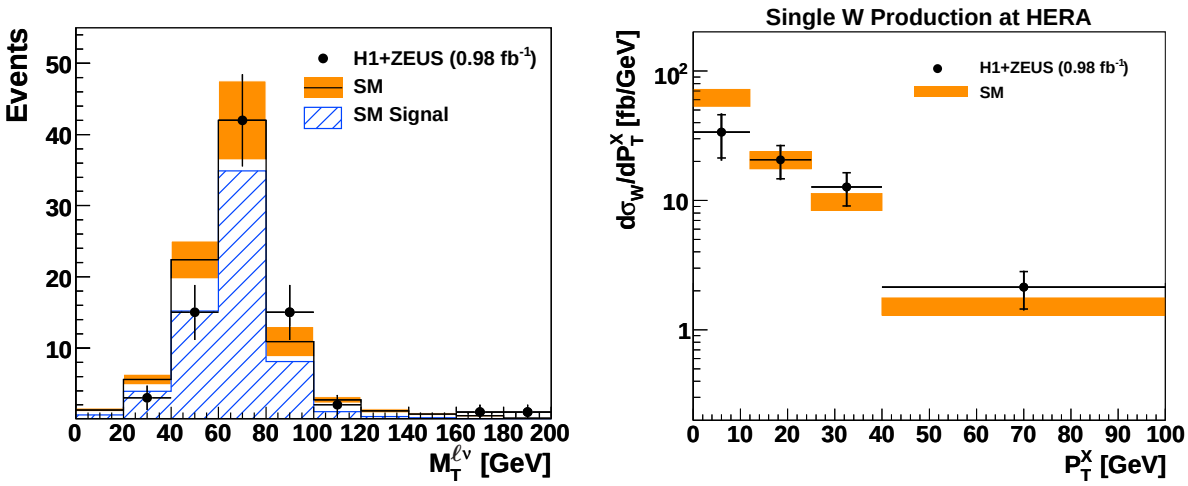

Figure 2: Left: The lepton-neutrino transverse mass $M_T^{l\nu}$ of events with an isolated electron or muon and missing transverse momentum. The data (points) are compared to the SM expectation (open histogram). The signal component of the SM expectation, dominated by single W production, is shown as the hatched histogram. The total uncertainty on the SM expectation is shown as the shaded band. Right: The single W production cross section as a function of the hadronic transverse momentum, P_T^X, measured using the combined H1 and ZEUS data at a centre–of–mass energy of $\sqrt{s} = 317$ GeV. The inner error bar represents the statistical error and the outer error bar indicates the statistical and systematic uncertainties added in quadrature. The shaded band represents the uncertainty on the SM prediction.

agreement with SM prediction of 1.26 ± 0.19 pb. The cross section is also measured as a function of P_T^X, as shown in Fig. 2 (right).

4 Summary

Production of multi-lepton events with high transverse momenta and events containing isolated lepton with $P_T^{\rm miss}$ in ep collisions has been studied. Combined H1 and ZEUS analyzes were performed in a common phase space, to take advantage of complete available HERA high energy data. Good overall agreement is observed with the SM predictions. The cross sections for multi-lepton and single W production in ep collisions at average $\sqrt{s} = 317$ GeV are measured with a greater precision as compared to previously published individual H1 and ZEUS results. A few interesting events are observed by both H1 and ZEUS in e^+p data at high P_T and high mass region where the SM expectation is low.

We thus conclude, that the Standard Model survived full combined HERA data and is now waiting for next challenges expected at the LHC.

References

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