PROCEEDINGS OF SCIENCE

Multi-lepton production at HERA

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Events with at least two high transverse momentum leptons (electrons or muons) are studied using the H1 and ZEUS detectors at HERA with an integrated luminosity of 0.94 fb^{-1}. The observed numbers of events are in general agreement with the Standard Model predictions. Seven di- and tri-lepton events are observed in e^+p collision data with a scalar sum of the lepton transverse momenta above 100 GeV, while 1.94 ± 0.17 events are expected. Such events are not observed in e^-p collisions for which 1.19 ± 0.12 are predicted. Total visible and differential di-electron and di-muon photoproduction cross sections are extracted in a restricted phase space dominated by photon-photon collisions.

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1. Introduction

Within the Standard Model (SM) the production of multi-lepton events in ep collisions mainly proceeds via photon-photon interactions [1]. The clean experimental signature of leptons with high transverse momenta, P_T, together with the precisely calculable small SM cross section provides high sensitivity to possible contributions of physics beyond the SM.

Lepton-pair production ($ep \to e\ell^+\ell^- X$) is simulated with the GRAPE [2] Monte Carlo program, which includes all electroweak matrix elements at tree level. Backgrounds to the ee final state arise from neutral current (NC) deep inelastic scattering (DIS) events ($ep \to eX$) in which, in addition to the scattered electron, hadrons or radiated photons are wrongly identified as electrons, and from QED Compton (QEDC) events ($ep \to e\gamma X$) if the photon is misidentified as an electron. Background to the $e\mu$ final state arises from NC DIS events if hadrons are misidentified as muons.

The analysed data were collected between 1994 and 2007 at the HERA electron[1]-proton collider using the H1 and ZEUS detectors. The centre-of-mass energy was 301 GeV or 319 GeV, depending on the data taking period.

2. H1 multi-lepton analysis

The H1 analysis [3] is based on all the available integrated luminosity, L=463 pb^{-1}. The events are selected by requiring the presence of at least two lepton (electron or muon) candidates in the central angular region, $20^\circ < \theta < 150^\circ$, one of which must have $P_T > 10$ GeV and the other $P_T > 5$ GeV. Additional electrons are searched for in the $5^\circ < \theta < 175^\circ$ region, having an energy greater than 5 GeV (if $20^\circ < \theta < 175^\circ$) or 10 GeV (if $5^\circ < \theta < 20^\circ$); additional muons are searched for in the $20^\circ < \theta < 160^\circ$ region, having $P_T > 2$ GeV. The events are classified according to the flavour and number of the identified leptons; events are observed in the ee, $\mu\mu$, $e\mu$, eee, $e\mu\mu$, $ee\mu$ and $eeee$ classes.

The total yields, as well as the distributions of the invariant mass M_{12} of the two highest P_T leptons and of the scalar sum of the lepton transverse momenta $\sum P_T$, are found to be in good overall agreement with the SM expectation. In the region $\sum P_T > 100$ GeV, 5 events are found, compared to a SM expectation of 1.60 ± 0.20 (see Table 1). All the 5 events are observed in the e^+p collisions, for 0.96 ± 0.12 expected; no events are observed in e^-p data.

Data sample	Data	SM	Pair Production (GRAPE)	NC-DIS + QEDC
e^+p (285 pb^{-1})	5	0.96 ± 0.12	0.78 ± 0.09	0.18 ± 0.05
e^-p (178 pb^{-1})	0	0.64 ± 0.09	0.51 ± 0.07	0.13 ± 0.04
All (463 pb^{-1})	5	1.60 ± 0.20	1.29 ± 0.15	0.31 ± 0.09

Table 1: Observed and predicted multi-lepton event yields for $\sum P_T > 100$ GeV in the H1 analysis. All the event classes are combined. The errors on the predictions include model uncertainties and experimental systematic errors added in quadrature.

[1]Here and in the following, the term "electron" denotes generically both the electron and the positron.

3. ZEUS multi-lepton analysis

The ZEUS analysis [4] is also based on all the available integrated luminosity, L=480 pb^{-1}. The events are selected by requiring the presence of at least two lepton (electron or muon) candidates in the central region, $20^\circ < \theta < 150^\circ$, having $P_T^{\ell_1} > 10$ GeV and $P_T^{\ell_2} > 5$ GeV. Additional electrons are searched for in the $5^\circ < \theta < 175^\circ$ region, having an energy greater than 5 GeV (if $150^\circ < \theta < 175^\circ$) or 10 GeV (if $5^\circ < \theta < 150^\circ$); additional muons are searched for in the $20^\circ < \theta < 160^\circ$ region, having $P_T > 2$ GeV. Events are observed in the ee, $\mu\mu$, $e\mu$, eee, $e\mu\mu$, $eeee$ and $ee\mu\mu$ classes.

The total yields, as well as the distributions of M_{12} and $\sum P_T$, are in agreement with the SM expectations. In the region $\sum P_T > 100$ GeV, 2 events are found, compared to a SM expectation of 1.56 ± 0.15 (see Table 2).

Data sample	Data	SM	Pair Production (GRAPE)	NC-DIS	QEDC
All (480 pb^{-1})	2	1.56 ± 0.15	1.16 ± 0.13	0.05 ± 0.02	0.35 ± 0.06

Table 2: Observed and predicted multi-lepton event yields for $\sum P_T > 100$ GeV in the ZEUS analysis. All the event classes are combined. The quoted uncertainties consist of model uncertainties, Monte Carlo statistical uncertainties and systematic experimental uncertainties added in quadrature.

4. H1 and ZEUS combined analysis

Given the fact that no deviation from the SM has been observed, the H1 and ZEUS results presented in the previous sections have been combined [5] in order to achieve a better sensitivity to small effects. The combined data set corresponds to an integrated luminosity of 0.94 fb^{-1}. In order to coherently combine the results of both experiments, a common phase space has been established. The final multi-lepton selection requires the presence in the event of at least two central ($20^\circ < \theta < 150^\circ$) lepton (electron or muon) candidates, one of which must have $P_T > 10$ GeV and the other $P_T > 5$ GeV. Additional electrons are searched for in the $5^\circ < \theta < 175^\circ$ angular region, having an energy greater than 5 GeV (if $150^\circ < \theta < 175^\circ$) or 10 GeV (if $5^\circ < \theta < 150^\circ$); additional muons are searched for in the $20^\circ < \theta < 160^\circ$ angular range, having $P_T > 2$ GeV. With respect to the H1 analysis the energy cut for the electron candidates has been raised from 5 GeV to 10 GeV in the central region, $20^\circ < \theta < 150^\circ$.

The observed event yields are in general agreement with the SM expectations. The distribution of the invariant mass of the two highest P_T leptons is shown in Fig. 1 for all the di- and tri-lepton classes where at least one event is observed. When requiring $\sum P_T > 100$ GeV, 7 events are left, compared to a SM expectation of 3.13 ± 0.26 (see Table 3). All the 7 events are observed in the e^+p collisions, for 1.94 ± 0.17 expected; no events are observed in e^-p data.

Subsamples of ee and $\mu\mu$ events, dominated by photon-photon collisions, are selected by requiring the difference $E - P_z$ between the energy and the longitudinal momentum of all visible particles to be lower than 45 GeV. Those subsamples are used to measure the total visible and differential cross sections for di-electron and di-muon photoproduction. The kinematic domain of the measurement is defined by $20^\circ < \theta^{\ell_{1,2}} < 150^\circ$, $P_T^{\ell_1} > 10$ GeV, $P_T^{\ell_2} > 5$ GeV, $Q^2 < 1$ GeV^2, $y < 0.82$ and $D_{\eta-\phi}^{\ell_1,\ell_2} > 0.5$, where $D_{\eta-\phi}^{\ell_1,\ell_2}$ is the distance in the $\eta - \phi$ plane between the two leptons.

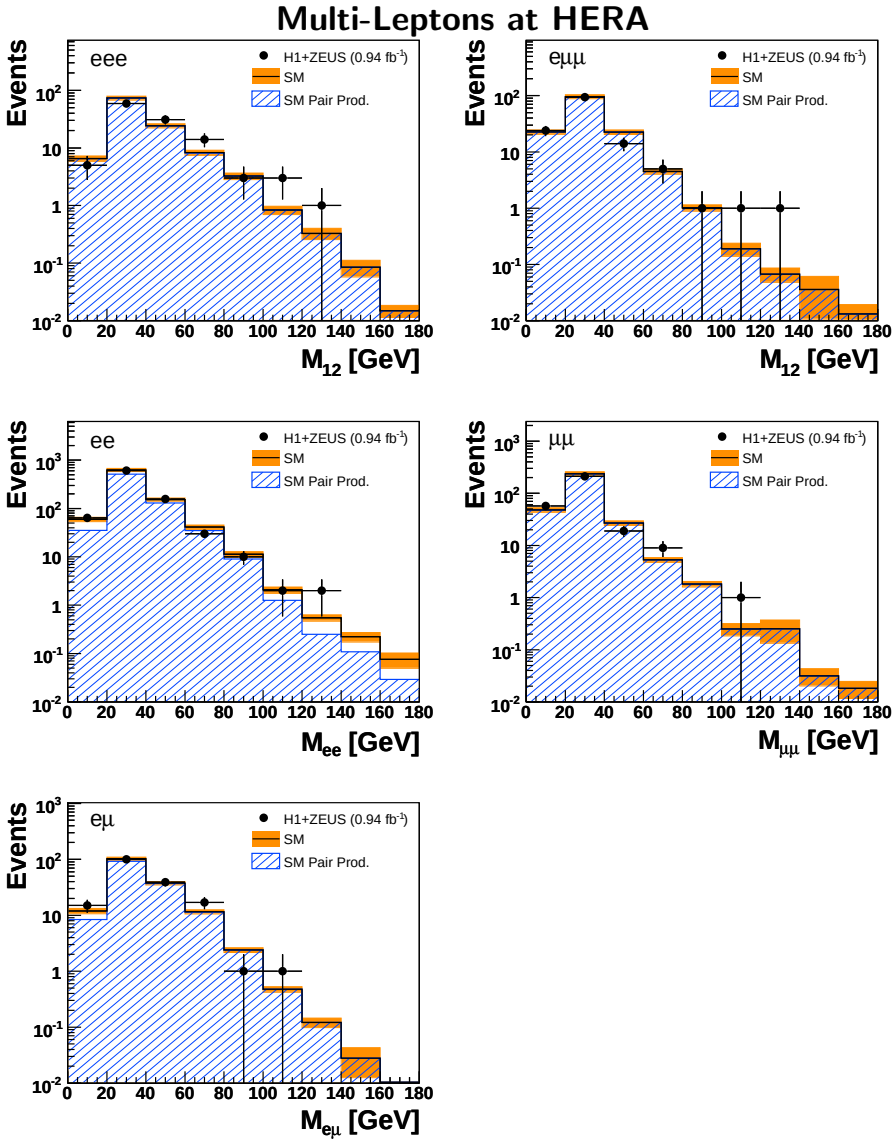

Figure 1: The distribution of the invariant mass of the two highest P_T leptons for all the di- and tri-lepton classes where at least one event is observed. The points correspond to the observed data events and the histogram to the SM expectation. The total uncertainty on the SM expectation is given by the shaded band. The component of the SM expectation arising from lepton pair production is given by the hatched histogram.

Data sample	Data	SM	Pair Production	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

Table 3: Yield of multi-lepton events with $\sum P_T > 100$ GeV for H1 and ZEUS data combined. The errors on the prediction include model uncertainties and experimental systematic errors added in quadrature.

The effect of the $D^{\ell_1,\ell_2}_{\eta-\phi}$ requirement is small ($< 1\%$). The measured total cross section for the di-lepton photoproduction is $\sigma = 0.66 \pm 0.03 \pm 0.03$ pb, in agreement with the GRAPE prediction, 0.69 ± 0.02 pb. The differential cross sections are shown in Fig. 2.

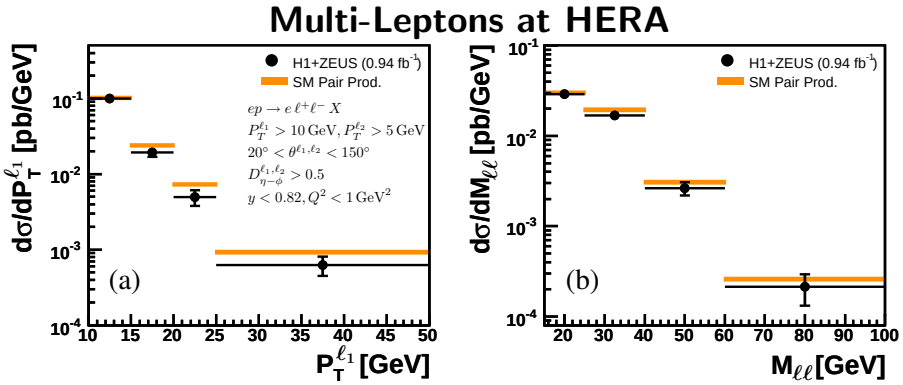

Figure 2: The cross section for lepton pair photoproduction in a restricted phase space as a function of the leading lepton transverse momentum $P_T^{\ell 1}$ (a) and the invariant mass of the lepton pair $M_{\ell\ell}$ (b). The total error bar is shown, representing the statistical and systematic uncertainties added in quadrature, which is dominated by the statistical. The bands represent the one standard deviation uncertainty in the SM prediction, dominated by the photon-photon process.

5. Summary

A search for multi-lepton event production has been performed with the H1 and ZEUS detectors using all the HERA data, corresponding to an integrated luminosity of 0.94 fb^{-1}; all the final states with two or more electrons or muons (or a combination of the two leptons) have been investigated. The event yields are in agreement with the SM predictions. A few events are observed in the e^+p collisions having $\sum P_T > 100$ GeV, a region where the SM expectation is low.

The total and differential cross sections for lepton pair photoproduction have been measured in a restricted phase space dominated by photon-photon interactions. The measured cross sections are in agreement with the SM predictions.

References

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