Multi-Lepton Production in ep Collisions at H1

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A search for multi-lepton (electron or muon) events at high transverse momenta in the data sample of $e^{\pm}p$ collisions collected with the H1 detector at HERA in the years 1994-2007 is presented [1]. The data sample corresponds to an integrated luminosity of 459 pb^{-1}. Yields of di-lepton and tri-lepton events are measured and a general good agreement is found with Standard Model (SM) predictions. Combining all channels, four events are observed with a scalar sum of lepton transverse momenta ($\sum P_T$) greater than 100 GeV, compared to a SM expectation of 1.9 ± 0.4.

1 Introduction

Multi-lepton events at high transverse momenta are of special interest as these signatures might reveal new physics beyond the SM. Events with two or more leptons with high transverse momentum P_T are measured in electron-proton collisions at HERA using the full HERA I+II high-energy data sample at centre-of-mass energies up to $\sqrt{s} = 320$ GeV. The data were collected in the years 1994-2007 and correspond to an integrated luminosity of 459 pb^{-1}. This comprises of 286 pb^{-1} of e^+p collisions and 173 pb^{-1} of e^-p collisions.

Within the SM the production of multi-lepton events in ep collisions mainly proceeds via photon-photon interactions [2]. Precise cross-section measurements of both electron (e) and muon (μ) pair production at high P_T have already been performed by the H1 collaboration using HERA I data [3, 4].

2 Selection

Electron candidates are identified as compact clusters in the calorimeters with energies above 5 GeV and in the polar angular range $5^\circ < \theta < 175^\circ$. They are required to be isolated from other leptons or jets. In the central region $20^\circ < \theta < 150^\circ$ the electron identification is complemented by tracking conditions, requiring a tight geometrical and P_T match between track and cluster.

Muon candidates are identified with $P_T > 2$ GeV in the range $20^\circ < \theta < 160^\circ$ by associating a track in the inner tracking systems with a track segment or an energy deposit in the outer muon chambers. Calorimetric energy depositions in the vicinity of the track are required to be typical for minimally ionising particles, such as muons. In di-muon events, cosmic background radiation is reduced by the requirement that the opening angle between the two muons is smaller than 160°.

The final multi-lepton selection requires that there be at least two lepton candidates (electron or muon) identified in the central region, of which one must have $P_T > 10$ GeV and the other $P_T > 5$ GeV. Additional identified lepton candidates are accepted without extra requirements. Leptons are counted and the events are classified into di-lepton ee, $\mu\mu$ and $e\mu$ samples, and tri-lepton eee and $e\mu\mu$ samples.

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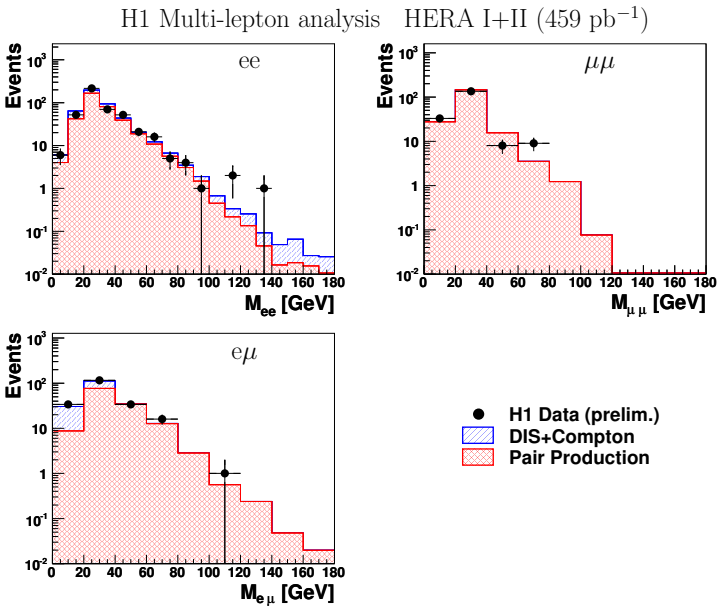

Figure 1: Invariant masses $M_{\ell\ell'}$ of the leptons for events selected in the di-lepton (ee, $\mu\mu$ and $e\mu$) classes compared to the SM expectation.

3 Results

The invariant mass $M_{\ell\ell'}$ distributions for the two leptons in the di-lepton classes are shown in Fig. 1. The invariant mass distributions of the two highest P_T leptons in the eee class M_{12}, and for the $ee\mu$ class the highest P_T muon with the electron $M_{e\mu}$ and the second muon $M_{\mu\mu}$ are shown in Fig. 2. The observed event yields are in good agreement with the SM expectation which is dominated by pair production.

The event yields for all classes in the region $M_{\ell\ell'} > 100$ GeV are shown in Tab. 1, also for collisions with a positron or electron beam separately. The interesting events seen at high invariant masses in the ee and eee classes were observed in HERA I e^+p data and previously reported [3]. Two e$\mu\mu$ events are observed in the new HERA II data, one of which has a high $\mu - \mu$ and the other a high $e - \mu$ invariant mass.

The event yields for events with $\sum P_T > 100$ GeV are shown in Tab. 2. Four events are observed in all channels combined while 1.9 ± 0.4 are expected in the SM. These four data events correspond to the three ee events observed in HERA I data [3] and one new e$\mu\mu$ event observed in HERA II data. The four events with $\sum P_T > 100$ GeV are all observed in e^+p collisions only, where the SM expectation is 1.2 ± 0.2 events.

4 Conclusions

Multi-lepton events with electrons and muons were studied using the full HERA I+II data set. The measurement extends previous analyses by including HERA II data. The event yields in the di-lepton (ee, $\mu\mu$ and $e\mu$) and tri-lepton (eee and $e\mu\mu$) sub-samples are in

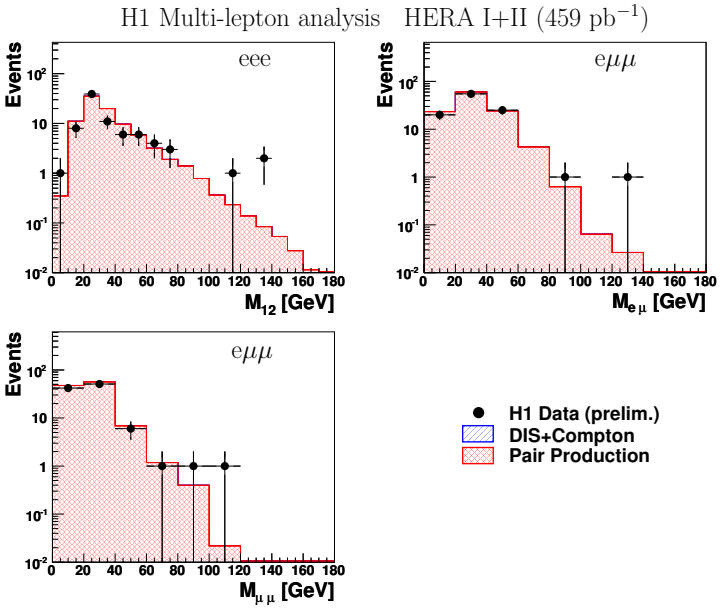

Figure 2: Distribution of the invariant mass M_{12} of the two highest P_T electrons for the *eee* sample (top left). For the e$\mu\mu$ sample, invariant mass combinations of the electron with the higest P_T muon ($M_{e\mu}$, top right) and of both muons ($M_{\mu\mu}$, bottom left) are presented.

H1 Multi-lepton analysis HERA I+II (preliminary)

Selection	Data	SM	Pair Production	NC-DIS + Compton
e^+p collisions (286 pb^{-1})				
ee M_{12} >100 GeV	3	1.0 ± 0.2	0.6 ± 0.2	0.4 ± 0.1
$\mu\mu$ $M_{\mu\mu}$ >100 GeV	0	0.06 ± 0.03	0.06 ± 0.03	—
eμ $M_{e\mu}$ >100 GeV	1	0.53 ± 0.05	0.53 ± 0.05	—
eee M_{12} >100 GeV	3	0.6 ± 0.1	0.6 ± 0.1	—
e$\mu\mu$ $M_{e\mu}$ >100 GeV	1	0.04 ± 0.02	0.04 ± 0.02	—
e$\mu\mu$ $M_{\mu\mu}$ >100 GeV	1	0.007 ± 0.005	0.007 ± 0.005	—
e^-p collisions (173 pb^{-1})				
ee M_{12} >100 GeV	0	0.55 ± 0.1	0.3 ± 0.1	0.25 ± 0.07
$\mu\mu$ $M_{\mu\mu}$ >100 GeV	0	0.03 ± 0.02	0.03 ± 0.02	—
eμ $M_{e\mu}$ >100 GeV	0	0.3 ± 0.05	0.3 ± 0.05	—
eee M_{12} >100 GeV	0	0.32 ± 0.06	0.32 ± 0.06	—
e$\mu\mu$ $M_{e\mu}$ >100 GeV	0	0.04 ± 0.01	0.04 ± 0.01	—
e$\mu\mu$ $M_{\mu\mu}$ >100 GeV	0	0.006 ± 0.004	0.006 ± 0.004	—
All data (459 pb^{-1})				
ee M_{12} >100 GeV	3	1.5 ± 0.3	0.9 ± 0.2	0.6 ± 0.2
$\mu\mu$ $M_{\mu\mu}$ >100 GeV	0	0.09 ± 0.05	0.09 ± 0.05	—
eμ $M_{e\mu}$ >100 GeV	1	0.9 ± 0.1	0.9 ± 0.1	—
eee M_{12} >100 GeV	3	0.9 ± 0.2	0.9 ± 0.2	—
e$\mu\mu$ $M_{e\mu}$ >100 GeV	1	0.1 ± 0.04	0.1 ± 0.04	—
e$\mu\mu$ $M_{\mu\mu}$ >100 GeV	1	0.03 ± 0.02	0.03 ± 0.02	—

Table 1: Yields for high di-lepton masses, $M > 100$ GeV in all analysed samples. For the *eee* sample, the mass of the two highest P_T electrons is shown. The errors on the prediction include model uncertainties and experimental systematic errors added in quadrature.

H1 Multi-lepton analysis HERA I+II (459 pb^{-1}, preliminary)

ΣE_T >100 GeV				
Data sample	Data	SM	Pair Production	NC-DIS + Compton
e^+p (286 pb^{-1})	4	1.2 ± 0.2	1.0 ± 0.2	0.2 ± 0.1
e^-p (173 pb^{-1})	0	0.8 ± 0.2	0.6 ± 0.2	0.2 ± 0.1
All (459 pb^{-1})	4	1.9 ± 0.4	1.5 ± 0.3	0.4 ± 0.1

Table 2: Yields of events with $\sum P_T > 100$ GeV for the combination of di- and tri-leptons. The errors on the prediction include model uncertainties and experimental systematic errors added in quadrature.

good agreement with the SM prediction. The distribution of the scalar sum of transverse momenta of the leptons is studied for the combination of all di- and tri-lepton sub-samples. The overall agreement with the SM is good, but four interesting events with a large scalar sum of transverse momenta are observed in e^+p collisions only, in a region where the SM expectation is 1.2 ± 0.2.

References

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