

# Multi-Lepton Production at HERA

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A search for events with two or more isolated leptons in the final state is performed on a data sample collected in  $e^+p$  collisions with the H1 and ZEUS detectors at the HERA collider. The data sample corresponds to an integrated luminosity of  $\sim 1 \text{ fb}^{-1}$ , representing the full HERA high-energy data set. The yields of di- and tri-lepton events are measured and compared to the Standard Model predictions, looking for possible deviations. No significant discrepancy with respect to the Standard Model expectations is observed.

## 1 Introduction

At the electron-proton collider, HERA, which operated at a center-of-mass energy of  $\sim 318 \text{ GeV}$ , possible signatures of physics beyond the Standard Model (SM) were investigated by looking for events in which two or more high transverse momentum ( $p_T$ ) leptons were found in the final state. The production of multi-lepton final states in electron-proton collisions is predicted with high precision within the framework of the Standard Model (SM). The leptons provide a clean event signature, and the investigation of the high mass, high  $p_T$  regions, where the SM expectation is low, could reveal some signal of new physics.

The two experiments ZEUS and H1 at HERA have published [1, 2] their final results on the search for multi-lepton events, using the full available statistics of  $\sim 0.5 \text{ fb}^{-1}$  per experiment. A combination of the data of the two Collaborations has also been performed and the preliminary results are also presented in this report [3].

## 2 Multi-lepton events

In the SM, the production of multi-lepton events in  $ep$  collisions proceeds mainly via photon-photon interactions [4]. Since this is a quantum electrodynamic (QED) process, the cross section is precisely calculable in the SM.

Multi-lepton events were simulated using the GRAPE [5] Monte Carlo (MC) program, which includes all electroweak matrix elements at tree level. Many possible sources of background to multi-lepton events were investigated. The background contamination in the data depends on the number and flavour of the identified leptons. Neutral current deep inelastic scattering (NC DIS,  $ep \rightarrow eX$ ) and QED Compton scattering (QEDC,  $ep \rightarrow e\gamma X$ ) constitute a significant background only for event topologies in which two leptons, one of which is an electron, are found in the final state. The background contributions are negligible in events in which two muons or more than two leptons are observed.

The analysis strategy followed a similar logic in both the H1 and ZEUS Collaboration and the selection criteria are also similar. First, electron or muon candidates were identified in a wide angular region using looser selection criteria. Then, at least two central ( $20^\circ < \theta < 150^\circ$ ) lepton candidates were required in the event.

Electrons were identified in the region  $5^\circ < \theta < 175^\circ$  and required to have energy greater than 5 GeV. The energy threshold was raised to 10 GeV in the region  $5^\circ < \theta < 20^\circ$  (forward region) in the H1 analysis and in the region  $5^\circ < \theta < 150^\circ$  in the ZEUS analysis. Muons were identified in the region  $20^\circ < \theta < 160^\circ$  and required to have transverse momentum  $p_T > 2$  GeV.

The final event selection required at least two central lepton candidates, one with  $p_T > 10$  GeV and the other with  $p_T > 5$  GeV. Additional leptons identified according to the above criteria could be present in the event. The leptons had to be isolated from each other by a minimum distance of 0.5 units in the  $\eta - \phi$  plane, where  $\eta = -\log(\tan(\theta/2))$  and  $\phi$  is the azimuthal angle. According to the number and the flavours of the identified leptons the events were classified into mutually exclusive topologies.

Cross sections were also measured by both Collaborations in the photoproduction regime, in which the virtuality  $Q^2$  of the photon emitted by the beam lepton is low. Photoproduction events were selected by requiring the difference  $E - p_z$  between the energy and the longitudinal momentum of all the visible particles to be lower than 45 GeV: this requirement selects events in which the scattered lepton is lost in the beam pipe and corresponds to cuts on  $Q^2 < 1$  GeV<sup>2</sup> and on the event inelasticity  $y < 0.82$ .

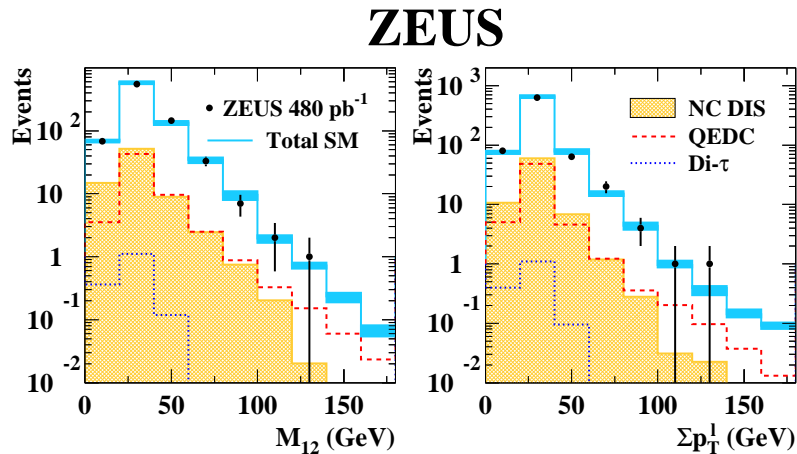


Figure 1: Distributions of the invariant mass of the two highest- $p_T$  leptons (left) and the sum of the transverse momenta of all the leptons (right) for all the individual lepton topologies combined.

## 2.1 Multi-leptons at ZEUS

The ZEUS Collaboration published [1] the final results on the search for multi-lepton events, based on the full available data sample ( $\mathcal{L} = 480$  pb<sup>-1</sup>, of which 278 pb<sup>-1</sup> from  $e^+p$  and 202 pb<sup>-1</sup> from  $e^-p$  collisions). All the possible lepton topologies were investigated. The number of selected events in the various observed topologies ( $ee$ ,  $\mu\mu$ ,  $e\mu$ ,  $eee$ ,  $e\mu\mu$ ) were compared to SM predictions and found in good agreement. The invariant mass of the two highest- $p_T$  leptons,  $M_{12}$ , and the sum of the momenta of all the identified leptons,  $\sum P_T$ , were evaluated and compared to the SM predictions. The results are shown in Fig. 1. Good agreement was found between the data and the predictions of the SM. Some interesting

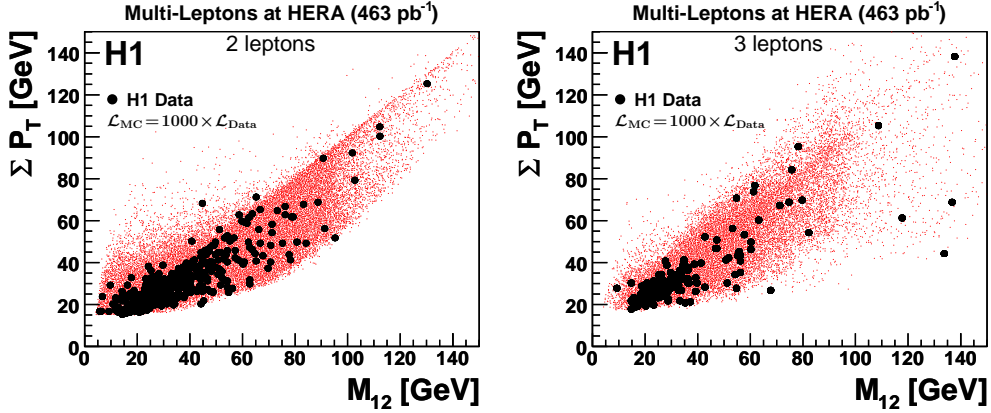


Figure 2: Correlation between the invariant mass,  $M_{12}$ , and the scalar sum of the transverse momenta,  $\sum P_T$ , for di-lepton and tri-lepton events.

events were observed in the high- $M_{12}$  and high- $\sum P_T$  regions: in particular, 2 events were observed having  $\sum P_T > 100$  GeV.

## 2.2 Multi-leptons at H1

The H1 Collaboration published [2] the final results on the search for multi-lepton events, based on the full available data sample ( $\mathcal{L} = 463 \text{ pb}^{-1}$ , of which  $285 \text{ pb}^{-1}$  from  $e^+p$  and  $178 \text{ pb}^{-1}$  from  $e^-p$  collisions). Also in this case, a general good agreement was observed between the data and the SM predictions. A total of five events were observed in the region  $\sum P_T > 100$  GeV, all in  $e^+p$  collisions. The corresponding SM expectations were  $1.60 \pm 0.20$  for the full data sample, of which  $0.96 \pm 0.12$  were from  $e^+p$  collisions.

Some high- $M_{12}$  events were also observed, however, not all of them showed also high  $\sum P_T$ . The correlation between these two variables for the events observed by H1 is shown in Fig. 2, separately for events in which two or three leptons were identified. From the Figure it can be seen that for di-lepton events high mass implies high  $\sum P_T$ , while for tri-lepton events intermediate  $\sum P_T$  events can show high  $M_{12}$ . This usually happens when one forward and one backward leptons are identified in the event.

## 2.3 Combined H1+ZEUS multi-lepton analysis

Preliminary results were presented [3] on the combination of the H1 and ZEUS multi-lepton analyses. The luminosity of the combined data sample is  $\mathcal{L} = 0.94 \text{ fb}^{-1}$ . A common phase space was defined, corresponding to the respective tighter selection cuts of the two experiments. For example, in the H1 analysis the electron energy threshold in the central region was raised from 5 to 10 GeV. Both the number of the observed events and the cross sections for multi-lepton production measured by the two experiments were combined. This allows a better sensitivity to rare processes in the high- $M_{12}$  and high- $\sum P_T$  regions and an improved precision of the measured cross sections.

| H1+ZEUS Multi-Lepton analysis HERA I+II (0.94 fb <sup>-1</sup> , preliminary) |      |             |                         |               |
|---|------|-------------|-------------------------|---------------|
| $\sum P_T > 100$ GeV  |      |             |                         |               |
| Data sample   | Data | SM          | Pair Production (GRAPE) | NC DIS + QEDC |
| e <sup>+</sup> p (0.56 fb <sup>-1</sup> )                                     | 7    | 1.94 ± 0.17 | 1.52 ± 0.14             | 0.42 ± 0.07   |
| e <sup>-</sup> p (0.38 fb <sup>-1</sup> )                                     | 0    | 1.19 ± 0.12 | 0.90 ± 0.10             | 0.29 ± 0.05   |
| All (0.94 fb <sup>-1</sup> )  | 7    | 3.13 ± 0.26 | 2.42 ± 0.21             | 0.71 ± 0.10   |

Table 1: Observed and predicted multi-lepton event yields for  $\sum P_T > 100$  GeV.

The results of the combination of the  $\sum P_T$  distributions for the full data sample and divided into  $e^+p$  and  $e^-p$  samples are shown in Table 1 and Fig. 3. In general good agreement was found between the data and the SM predictions. For  $\sum P_T > 100$  GeV, seven events were observed in total, compared to  $3.13 \pm 0.26$  expected from the SM. These seven events were all recorded in  $e^+p$  data, for which the SM expectation is  $1.94 \pm 0.17$ . Moreover events were observed in  $ee$ ,  $\mu\mu$ ,  $e\mu$ ,  $eee$  and  $e\mu\mu$  topologies with  $M_{12} > 100$  GeV. Both experiments recorded these interesting events in  $e^+p$  collisions only [3].

The differential cross sections for lepton-pair photoproduction as a function of the transverse momentum of the leading lepton,  $P_T^{\ell_1}$ , and of the invariant mass of the lepton pair,  $M_{\ell\ell}$ , are shown in Fig. 4. The measurements are in good agreement with the SM predictions.

### 3 Conclusions

The H1 and ZEUS Collaborations have published their final results on the search for events in which two or more high transverse momentum isolated leptons were identified. General good agreement with the SM predictions was found. In both the analyses some events were observed with high invariant mass of the two highest transverse momentum leptons,  $M_{12} > 100$  GeV, and high scalar sum of the lepton transverse momenta,  $\sum P_T > 100$  GeV. All the interesting events were observed in  $e^+p$  collisions only, while, for comparable SM expectations, none were observed in  $e^-p$  collisions. Preliminary results from the combination of the data from the two experiments showed that seven events have  $\sum P_T > 100$  GeV, to be compared with a SM expectation for  $e^+p$  collisions

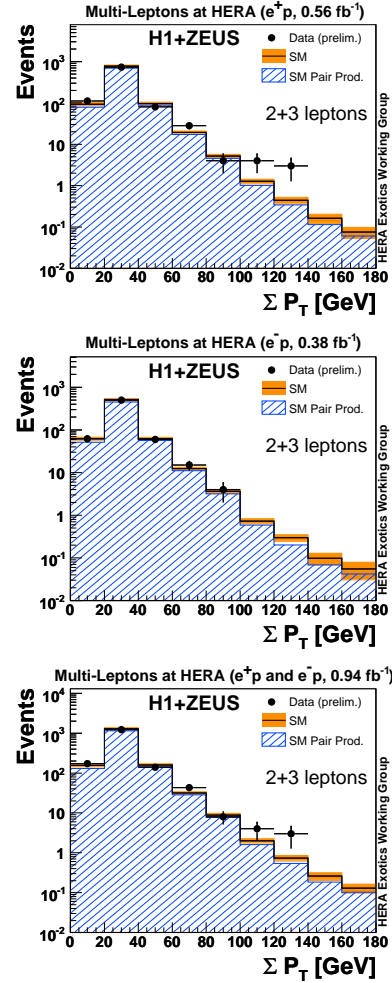


Figure 3: The  $\sum P_T$  distribution for combined di- and tri-lepton topologies shown for all data as well as for  $e^+p$  and  $e^-p$ .

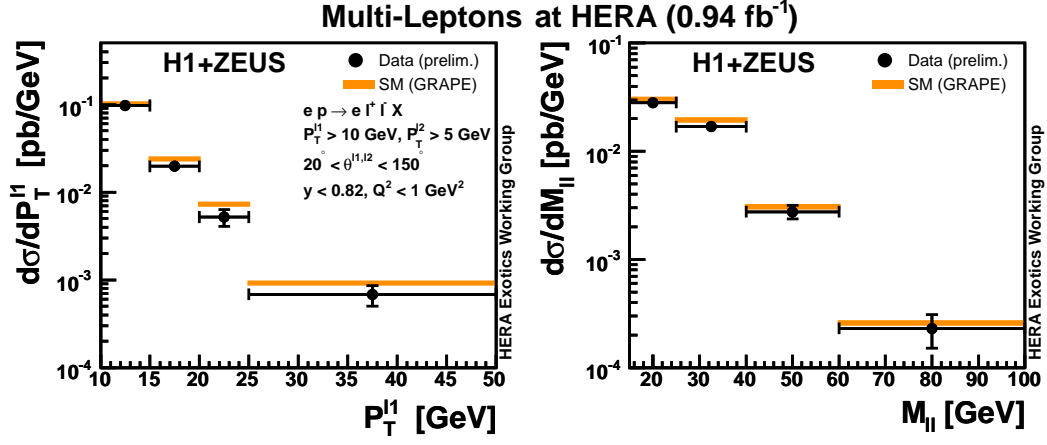


Figure 4: The cross section for lepton-pair photoproduction as a function of the transverse momentum of the leading lepton,  $P_T^{l1}$ , and of the invariant mass of the lepton pair,  $M_{\ell\ell}$ .

of  $1.94 \pm 0.17$ .

The differential cross sections for lepton-pair production were measured in the photoproduction regime. The measured cross sections are in agreement with the SM expectations.

## References

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