

Multi-Lepton Events at H1 and Search for Doubly-Charged Higgs Bosons

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Abstract.

Events with two or more leptons (electrons or muons) with high transverse momentum are measured in electron-proton collisions at HERA using the data sample collected in the period 1994-2005. Multi-lepton events at high transverse momenta are of special interest as these signature might reveal new physics beyond the Standard Model. An example is the single production of doubly-charged Higgs bosons $H_{L,R}^{\pm\pm}$, which couple to leptons of the i 'th and j 'th generation via Yukawa couplings $h_{ij}^{L,R}$. Results from a search for doubly-charged Higgs bosons in the decays into electrons, muons and taus are presented using data taken in the period 1994-2000. No evidence for doubly-charged Higgs production is found and we derive limits on the $h_{ee}^{L,R}$ and $h_{e\mu}^{L,R}$ Yukawa couplings as a function of the $H_{L,R}^{\pm\pm}$ mass.

Keywords: Higgs, Doubly-Charged Higgs, Leptons, H1, HERA

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INTRODUCTION

The H1 experiment has reported an excess of di-electron and tri-electron events with invariant masses above 100 GeV observed in ep collisions at HERA I in the period 1994-2000 [1]. In this talk results from a recent multi-lepton search at high transverse momentum are presented using the HERA I+II data samples collected in 1994-2005.

Multi-lepton events at high transverse momenta are of special interest as this signature might reveal new physics beyond the Standard Model. An example is the single production of doubly-charged Higgs bosons $H_{L,R}^{\pm\pm}$, which couples to leptons of the i 'th and j 'th generation via Yukawa couplings $h_{ij}^{L,R}$.

Doubly-charged Higgs bosons ($H^{\pm\pm}$) appear naturally in various extensions of the Standard Model (SM) in which the usual Higgs sector is extended by one or more triplet(s) [2, 3]. Examples are provided by some Left-Right Symmetric (LRS) models [4, 5] with a spontaneously broken $SU(2)_L \times SU(2)_R \times U(1)_{B-L}$ symmetry. These models are of particular interest as Higgs triplets can give Majorana masses to neutrinos, which are known to be massive from recent experimental data. Results from a search for doubly-charged Higgs bosons in the decays into electrons, muons and taus are presented using data taken in the period 1994-2000.

TABLE 1. H1 preliminary event yields for 1994-2004 $e^\pm p$ data ($L=163 \text{ pb}^{-1}$) of the different multi-lepton channels for $M_{\ell\ell'} > 100 \text{ GeV}$. The numbers are compared with the expectations from the Standard Model and from pair production only.

channel	data events	Standard Model	Pair Production
ee	3	0.4 ± 0.1	0.32
$\mu\mu$	0	0.04 ± 0.02	0.04
$e\mu$	0	0.31 ± 0.03	0.31
eee	3	0.31 ± 0.08	0.31
$e\mu\mu$ ($M_{e\mu}$)	1	0.04 ± 0.01	0.04
$e\mu\mu$ ($M_{\mu\mu}$)	1	0.02 ± 0.01	0.02

EVENTS WITH MULTI-LEPTONS

Events with clearly identified isolated electrons and muons at high transverse momentum (p_T) are selected and classified into the following final state topologies: ee , eee , $e\mu$, $\mu\mu$, $e\mu\mu$, etc.). Within the Standard Model such events are mainly produced via photon-photon collisions. The invariant mass distribution of the two highest p_T electrons are shown for the ee and eee classes in Fig. 1 using 163 pb^{-1} of HERA I+II data. The event yields for all classes after the cut $M_{\ell\ell'} > 100 \text{ GeV}$ are shown in Tab. 1. An excess of data events over the SM expectation is seen in the ee and eee classes.

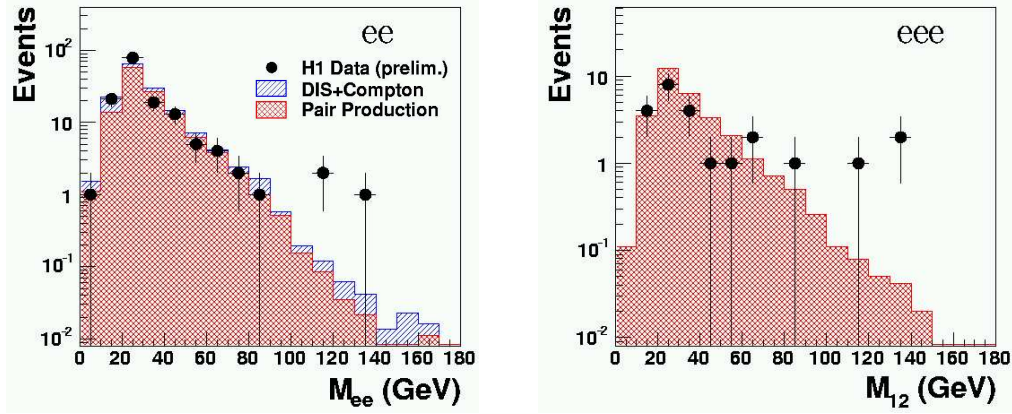
For some event classes the same analysis was repeated using the most recent $e^- p$ dataset from 2004/05 (21 pb^{-1}), see Fig. 1. No new event was found for $M_{\ell\ell'} > 100 \text{ GeV}$ in the analysed $ee, e\mu, eee, e\mu\mu$ event classes in agreement with the SM expectation.

DOUBLY-CHARGED HIGGS PRODUCTION

The search for single doubly-charged Higgs production is based on studies of dilepton production $ee, \mu\mu$ [1, 6], and new multi-lepton searches for the $e\mu$ and $\tau\tau$ final states at high p_T . The analyses use data collected at HERA I from 1994-2000 ($ee, \mu\mu$ and $e\mu$) and 1999/2000 ($\tau\tau$). The selections involving electrons and muons are identical to those described in the previous section. Tau pairs are searched for taking into account leptonic and hadronic τ -decays in the event classes $\tau\tau \rightarrow e\mu, ej, \mu j, jj$ plus missing energy from the unobserved tau neutrinos. The invariant mass of the $H^{\pm\pm}$ is fitted by exploiting energy and momentum conservation resulting in a resolution of $2.5 - 4.0 \text{ GeV}$.

Further $H^{\pm\pm}$ selection criteria are applied to all multi-lepton final states. Events where the charges of the highest p_T leptons are measured to be inconsistent with the $H^{\pm\pm}$ hypothesis are rejected. For the $H^{\pm\pm} \rightarrow e^\pm e^\pm$ decay both electrons are required to have large transverse energies in the calorimeter. After the final selections only one candidate event ($H^{\pm\pm} \rightarrow e^\pm e^\pm$) is found for $M_H > 100 \text{ GeV}$. Various limits are derived as function of M_H at 95% CL on the product $\sigma \times \text{BR}$ for each decay topology, see Fig 2 left, and on the coupling $h_{ee}^{L,R}$ assuming a model with democratic couplings $\text{BR}(H^{\pm\pm} \rightarrow l^\pm l^\pm) = 1/3$ (right). In Fig. 3 exclusion limits on $h_{ee}^{L,R}$ (left) and $h_{ee}^{L,R}$ (right) are shown as function of M_H assuming a decay branching ratio of 100% for each case. For comparison direct and indirect limits from other experiments are shown [7, 8, 9].

H1 Preliminary HERA I+II $e^\pm p$ (163 pb^{-1})



H1 Preliminary HERA II $e^- p$ (21 pb^{-1})

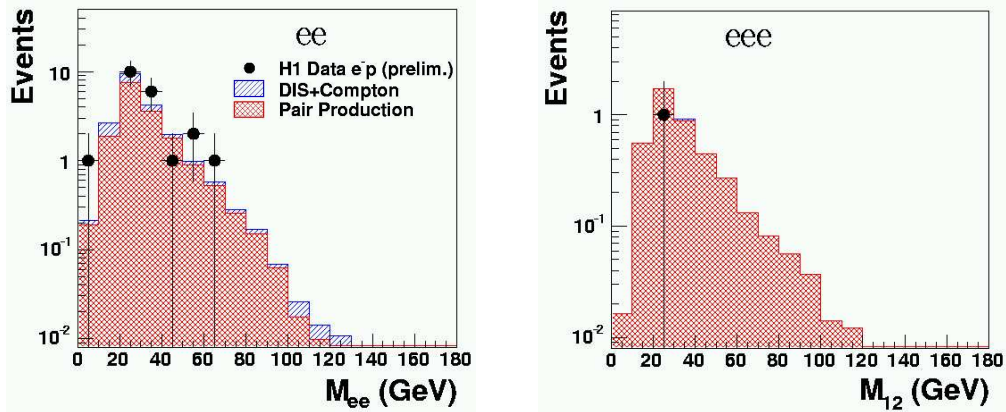


FIGURE 1. Invariant masses M of the two highest p_T leptons compared to expectations for ee and eee classified event. The data samples correspond to an integrated luminosity of 163 pb^{-1} (1994+2004, top figures) and to 21 pb^{-1} of the recent $e^- p$ data taken in 2004/05 (bottom).

CONCLUSION

Multi-lepton events with electrons and muons are studied using HERA I+II data. No new di-electron and tri-electron events are observed with invariant masses above 100 GeV in the most recent $e^- p$ dataset. More integrated luminosity is required to enhance the sensitivity at high masses. No evidence for doubly-charged Higgs production is found and various limits on $H_{L,R}^{\pm\pm}$ Yukawa couplings $h_{\ell\ell'}^{L,R}$ were derived.

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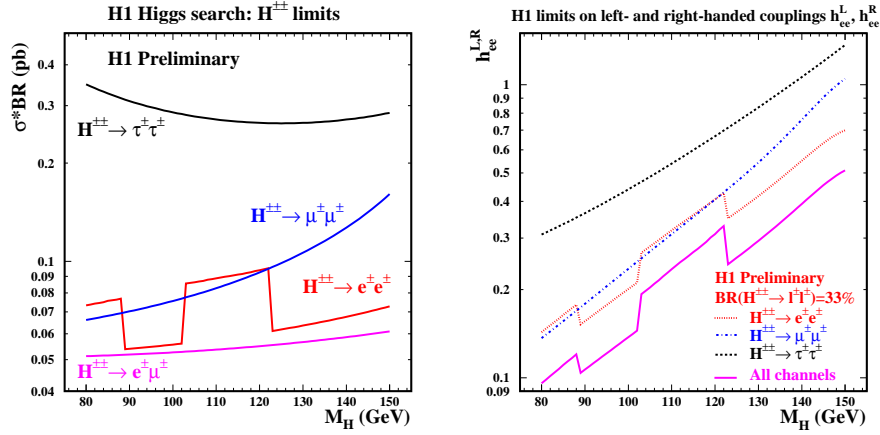


FIGURE 2. Left: upper limits at 95% CL on $\sigma(e^\pm p \rightarrow e^\mp H^{\pm\pm} X) \times \text{BR}(H^{\pm\pm} \rightarrow \ell^\pm \ell^\pm)$ as a function of the doubly-charged Higgs mass. Right: exclusion limits on the coupling $h_{ee}^{L,R}$ at 95% CL as function of M_H for the decay channels $H^{\pm\pm} \rightarrow e^\pm e^\pm, \mu^\pm \mu^\pm, \tau^\pm \tau^\pm$ and their combination (full curve) assuming democratic couplings, i.e. $\text{BR}(H^{\pm\pm} \rightarrow \ell^\pm \ell^\pm) = 1/3$.

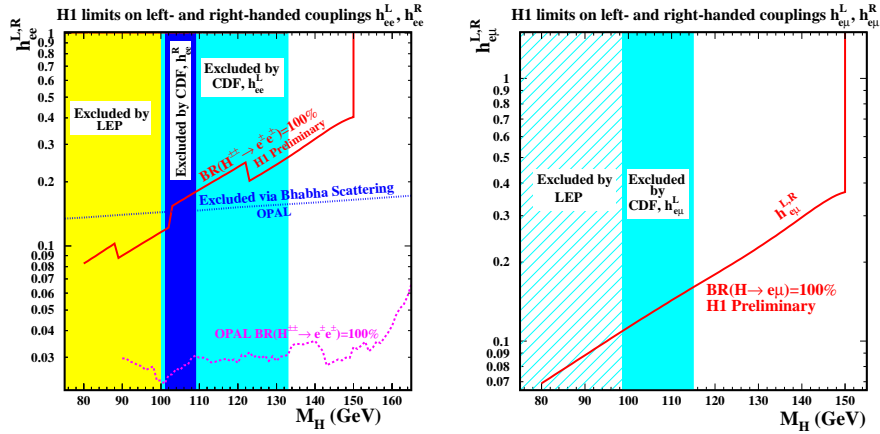


FIGURE 3. Left: exclusion limits on the coupling $h_{ee}^{L,R}$ at 95% CL as a function of the doubly-charged Higgs mass for the decay $H^{\pm\pm} \rightarrow e^\pm e^\pm$ assuming $\text{BR}(H^{\pm\pm} \rightarrow e^\pm e^\pm) = 1$. Right: exclusion limits on the coupling $h_{e\mu}^{L,R}$ at 95% CL as a function of M_H for the decay $H^{\pm\pm} \rightarrow e^\pm \mu^\pm$ assuming $\text{BR}(H^{\pm\pm} \rightarrow e^\pm \mu^\pm) = 1$. The results are compared to direct and indirect limits (Bhabha scattering) obtained by OPAL (single production), and LEP and CDF (pair production).

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