Multi-lepton production and a search for doubly-charged Higgs at HERA

Jolanta Sztuk-Dambietz
on behalf the H1 and ZEUS Collaborations
Hamburg University, Institute of Exp. Physics,
Luruper Chaussee 149, 22761 Hamburg, Germany
E-mail: jsztuk@mail.desy.de

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 samples collected in the period 1994-2007. Yields of di-lepton and tri-lepton events are investigated and a general good agreement is found with the Standard Model (SM) prediction. Multi-lepton events at high transverse momenta, where the SM prediction is low, are of special interest as these signature might reveal new physics beyond the Standard Model. An example is the single production of a doubly-charged Higgs boson (H⁺⁻) decaying into a high mass pair of same charge leptons. This possibility has been investigated and H⁺⁻ decays involving electrons, muons and taus are considered. No evidence for doubly-charged Higgs production is observed and mass-dependent upper limits are derived on the Yukawa couplings $h_{ij}$ of the Higgs boson to leptons of flavour $i$ and $j$.

Keywords: Multi-leptons, Doubly Charged Higgs

1. Introduction

The large center-of-mass energy of the electron-Proton collisions at HERA allows the production of events with two or more leptons with high transverse momentum ($P_T$) in the final state. The Standard Model (SM) cross section for the production of a lepton pair is dominated by the two photon process, $\gamma\gamma \to l^+l^-$, and can be accurately predicted [1]. In the region of large invariant masses, multi-lepton production may also be sensitive to new physics and so the measurement of the multi-lepton event yields is particularly interesting. The H1 Collaboration has reported an excess of events in both di-electron and tri-electron samples at large di-electron masses [2].

Doubly-charged Higgs bosons (H⁺⁻) appear naturally in various extents of the SM in which the usual Higgs sector is extended by one or more triplet(s) with non-zero hypercharge [3]. The Higgs triplet(s) may couple to matter fields via the Yukawa coupling. Examples are provided by some Left-Right Symmetric (LRS) models [4, 5, 6] with a spontaneously broken $SU(2)_L \times SU(2)_R \times U(1)_{B-L}$ symmetry. These models are

† In the following the term “electron” is used to refer to both electrons and positrons.
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 decaying into electrons, muons and taus are presented using data taken in the period 1994-2000 by H1 collaboration.

2. Events with Multi-leptons

Events with clearly identified isolated, high $P_T$ electrons and muons are selected and classified into the following final state topologies: $ee$, $eee$ (investigated by H1 and ZEUS), $e\mu$, $\mu\mu$ and $e\mu\mu$ (H1 only). The multi-lepton selection requires that there be at least two central ($20^\circ < \theta_l < 150^\circ$) lepton candidates of which one must have $P_L^T > 10$ GeV and the other $P_L^T > 5$ GeV. The selected events are classified in a two lepton sample if only two central leptons are identified, and in a three lepton sample if exactly one additional lepton (electron with $E > 5$ GeV or muon with $p_T > 2$ GeV) is found in a detector ($5^\circ < \theta_l < 175^\circ$). The measured scalar sum of transverse momentum of the combination of 2 and 3 lepton events (dots) compared to the SM expectations from H1 and ZEUS are shown in Fig.1 and Fig.2, respectively. Yields of di-lepton and tri-lepton events are measured and a general good agreement is found with the SM predictions. Combining all channels, seven events are observed with a scalar sum of lepton transverse momenta ($\Sigma P_T$) greater than 100 GeV, compared to a SM expectation of 3.5. Six events with $\Sigma P_T > 100$ GeV are observed in $e^+p$ collisions, only where the SM expectation is 2.1.

3. Search for Doubly-Charged Higgs Production

The search for single doubly-charged Higgs production is based on studies of di-lepton production $ee$, $\mu\mu$, and new multi-lepton searches for the $e\mu$ and $\tau\tau$ final states at high $P_T$. The analyses of $ee$, $\mu\mu$ and $e\mu$ channels are based on published analyses [2, 7] and make use of the data collected by H1 experiment from 1994-2000 which amounts to a luminosity of 118 pb$^{-1}$. The analysis of final states involving a $\tau$ lepton is based on 88 pb$^{-1}$ of $e^+p$ data recorded during the same period. Tau pairs are searched for taking into account leptonic and hadronic $\tau$-decays in the events classes: $\tau \rightarrow e\mu, e\mu, \mu\mu$ plus missing energy from the unobserved tau neutrinos. 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.

After the final Higgs selection criteria no significant excess over the SM expectation is observed in the data (only one candidate event $(H^{++} \rightarrow e^+e^+)$ is found for $M_H > 100$ GeV. Assuming that only one Yukawa coupling $h_{el}$ is non-vanishingly small, these constraints are translated into mass dependent upper limits on the coupling $h_{el}$ as shown in Fig.3. If the doubly-charged Higgs boson couples only to an electron pair (Fig.3(left)) the $ee$ analysis rules out $H^{\pm\pm}$ masses below 138 GeV for a coupling of electromagnetic strength, $h_{ee} = 0.3$. The result is compared to the bounds obtained
Figure 1. Comparison of the measured scalar sum of transverse momentum of the combination of 2 and 3 lepton events (dots) with the SM expectations for H1 data taken in $e^+p$ (upper left) and $e^-p$ (upper right) collisions, respectively. Combination of all H1 HERA data is shown in the bottom plot.

Figure 2. Comparison of the measured scalar sum of transverse momentum of the combination of 2 and 3 electron events (dots) with the SM expectations for ZEUS data taken in $e^+p$ (left) and $e^-p$ (middle) collisions, respectively. Combination of all ZEUS HERA data is shown in the right plot.

from searches for $H^{\pm\pm}$ pair production at LEP [8] and by CDF [9], and to both the indirect and direct limits obtained by the OPAL experiment [10], the later being the most stringent. Assuming that the $H^{\pm\pm}$ boson couples only to an electron-muon (electron-tau) pair, the $e\mu$ ($e\tau$) analysis allows masses below 141 GeV (112 GeV) to be ruled out for $h_{e\mu(e\tau)} = 0.3$ as is shown in Fig.3(middle) (Fig.3(right)). The H1 limits extend the excluded region in the $e\mu$ and $e\tau$ channels to masses that are beyond those reached in previous searches.
4. Conclusion

The production of multi-leptons (electrons and muons) at high transverse momenta in $e^\pm p$ scattering has been studied using all HERA data collected by the H1 and ZEUS experiments. This data sample corresponds to an integrated luminosity of 0.94 fb$^{-1}$. Yields of multi-lepton events are measured and in general a good agreement is found with the SM prediction. Combining all channels 7 events are observed with a scalar sum of lepton transverse momenta, $\Sigma P_T > 100$ GeV, compared to the SM expectation of 3.5. Six of those events are observed in $e^+p$ collisions where the SM expectation is of 2.1, whereas one event is observed in $e^-p$ data for the SM prediction of 1.4. A search for the single production of doubly-charged Higgs bosons is also presented which includes the analysis of the $ee$, $\mu\mu$, $e\mu$, $\tau\tau$ and $e\tau$ final states. No evidence for H$^{\pm\pm}$ bosons production is found. The limits on the H$^{\pm\pm}$ mass and its Yukawa coupling to electrons, muons and taus are obtained.

References

[1] J. A. M. Vermaseren, (1983) *Nucl. Phys.* B 229 347
[2] A. Aktas et al. [H1 Collaboration], (2003) *Eur. Phys. J.* C 31 17 [hep-ex/0307015]
[3] R. N. Mohapatra and G. Senjanovic, (1980) *Phys. Rev. Lett.* 44 912
[4] G. Senjanovic and R. N. Mohapatra, (1975) *Phys. Rev.* D 12, 1502
[5] C. S. Aulakh, A. Melfo and G. Senjanovic, (1998) *Phys. Rev.* D 57 4174 [hep-ph/9707256]
[6] B. Dutta and R. N. Mohapatra, (1999) *Phys. Rev.* D 59 015018 [hep-ph/9804277]
[7] A. Aktas et al. [H1 Collaboration], (2004) *Phys. Lett.* B 583 28 [hep-ex/0311015]
[8] J. Abdallah et al. [DELPHI Collaboration], (2003) *Phys. Lett.* B 552 127 [hep-ex/0303026]
[9] P. Achard et al. [L3 Collaboration], (2003) *Phys. Lett.* B 576 18 [hep-ex/0309076]
[10] G. Abbiendi et al. [OPAL Collaboration], (2002) *Phys. Lett.* B 526 221 [hep-ex/0111059]
[11] D. Acosta et al. [CDF Collaboration], (2004) *Phys. Rev. Lett.* 93 221802 [hep-ex/0406073]
[12] G. Abbiendi et al. [OPAL Collaboration], (2003) *Phys. Lett.* B 577 93 [hep-ex/0308052]