Searches for (non-SUSY) Exotics at HERA

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Abstract.
We review latest published and preliminary results of searches for non-SUSY exotics at HERA. Results of searches for isolated leptons and missing transverse momentum, rare multi-lepton final states, doubly-charged Higgs bosons and excited neutrinos are presented.

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SEARCH FOR ISOLATED LEPTONS AND MISSING P_T

The HERA collaborations H1 and ZEUS have previously reported [1, 2, 3, 4] the observation of events with an isolated high energy lepton and missing transverse momentum in $e^\pm p$ collisions recorded during the period 1994-2000. The dominant Standard Model (SM) contribution to this topology is real W boson production with subsequent leptonic decay. Such events can also be a signature of new phenomena beyond the SM [5].

Searches for events with a high energy isolated electron or muon and missing transverse momentum have been performed at the electron-proton collider HERA. The H1 analysis of the data collected in the period 1994-2000 (HERA I) and corresponding to an integrated luminosity of $118.3\,\mathrm{pb}^{-1}$ revealed an excess of events with transverse momentum of the hadronic system (P_T^X) greater than 25 GeV [2]. The latest preliminary results are presented, obtained using recent data collected in the period 2003-2006 (HERA II) in $e^- p$ and $e^+ p$ collisions. Tab. 1 shows the search results of both the H1 and the ZEUS experiment. The H1 experiment observes an excess in the $e^+ p$ data of 9 data events in

TABLE 1. Summary of the results of searches for events with isolated leptons, missing transverse momentum and large P_T^X at HERA.

HERA 1994-2006 $e^\pm p$		Electron obs. / exp.	Muon obs. / exp.	Tau obs. / exp.*
H1 (prelim.)	Full Sample	$30 / 27.2 \pm 3.8$	$10 / 7.2 \pm 1.1$	$25 / 24.2^{+4.2}_{-5.8}$
$e^- p$ $121\,\mathrm{pb}^{-1}$	$P_T^X > 25\mathrm{GeV}$	$2 / 2.4 \pm 0.5$	$0 / 2.0 \pm 0.3$	$3 / 0.35^{+0.10}_{-0.08}$
$e^+ p$ $158\,\mathrm{pb}^{-1}$		$9 / 2.3 \pm 0.4$	$6 / 2.3 \pm 0.4$	$0 / 0.40^{+0.10}_{-0.10}$
ZEUS (prelim.)	Full Sample	$9 / 7.9 \pm 0.6$	$6 / 5.9 \pm 0.4$	$3 / 0.40^{+0.12}_{-0.13}$
$e^- p$ $143\,\mathrm{pb}^{-1}$	$P_T^X > 25\mathrm{GeV}$	$3 / 2.9 \pm 0.76$	$2 / 1.6 \pm 0.2$	$2 / 0.20^{+0.05}_{-0.05}$
$e^+ p$ $106\,\mathrm{pb}^{-1}$		$1 / 1.5 \pm 0.15$	$1 / 1.5 \pm 0.2$	

* H1 [6]: $e^- p$ $125\,\mathrm{pb}^{-1}$, $e^+ p$ $153\,\mathrm{pb}^{-1}$; ZEUS [7]: $e^\pm p$ $130\,\mathrm{pb}^{-1}$.
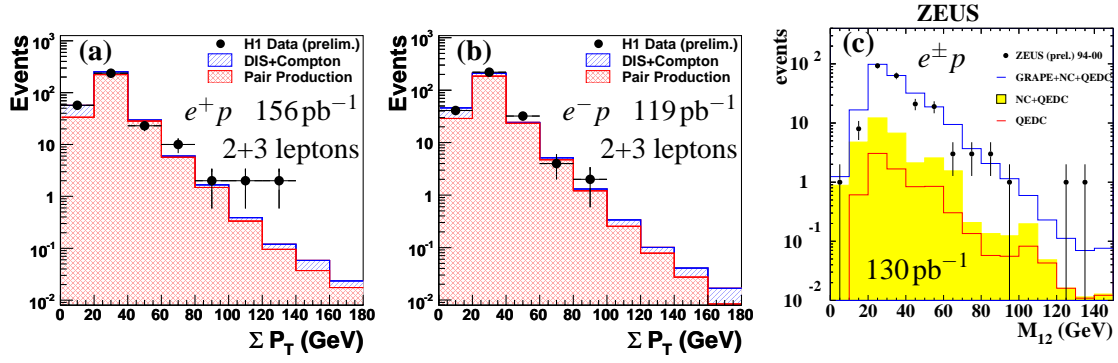
FIGURE 1. Results of searches for multi-lepton final states at HERA. Scalar sum of lepton momenta in $e^- p$ (a) and $e^+ p$ (b) data analysed by the H1 experiment. (c) Invariant mass of two electrons with highest invariant mass searched for in $e^\pm p$ data by the ZEUS experiment.

the electron channel above a SM background of 2.3 ± 0.4 events, whereas the search by the ZEUS experiment yields data compatible with the SM expectation. The ZEUS experiment published in [7] a slight excess in the tau channel of 2 events with $P_T^X > 25\,\text{GeV}$ where $0.2^{+0.05}_{-0.02}$ events are expected from SM.

SEARCH FOR MULTI-LEPTON FINAL STATES

A search for multi-lepton (electron or muon) events at high transverse momenta is performed on a data sample collected in $e^\pm p$ collisions with the H1 detector at HERA during the period 1994-2005. This data sample corresponds to an integrated luminosity of $275\,\text{pb}^{-1}$, which includes $52\,\text{pb}^{-1}$ of $e^+ p$ data taken in 2003-2004 and $105\,\text{pb}^{-1}$ of $e^- p$ data taken in 2005. With respect to the published HERA I multi-electron and multi-muon analyses [8, 9], additional topologies with high P_T electrons and muons are investigated. Yields of di-lepton and tri-lepton events are measured and in general a good agreement is found with the SM predictions (see Fig. 1(a,b)). 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 1.1 ± 0.2 events. The four events with $\sum P_T > 100$ GeV are observed in $e^+ p$ collisions only where the SM expectation is 0.6 ± 0.1 events. The search performed by the ZEUS experiment makes use of $130\,\text{pb}^{-1}$ of $e^\pm p$ data and covers only the di- and tri-electron topologies. The invariant mass distribution of multi-electron events observed by the ZEUS experiment is depicted in Fig. 1(c).

SEARCH FOR DOUBLY-CHARGED HIGGS BOSONS

Doubly charged Higgs bosons ($H^{\pm\pm}$) appear in several extensions to the SM and can in principle be light enough to be detectable at HERA. Examples are provided by some Left-Right Symmetry (LRS) models [10], where the extended symmetry $SU(2)_L \times SU(2)_R \times U(1)_{B-L}$ is spontaneously broken to the SM symmetry $SU(2)_L \times U(1)_Y$ by a $SU(2)_R$ triplet of scalar fields, whose neutral component acquires
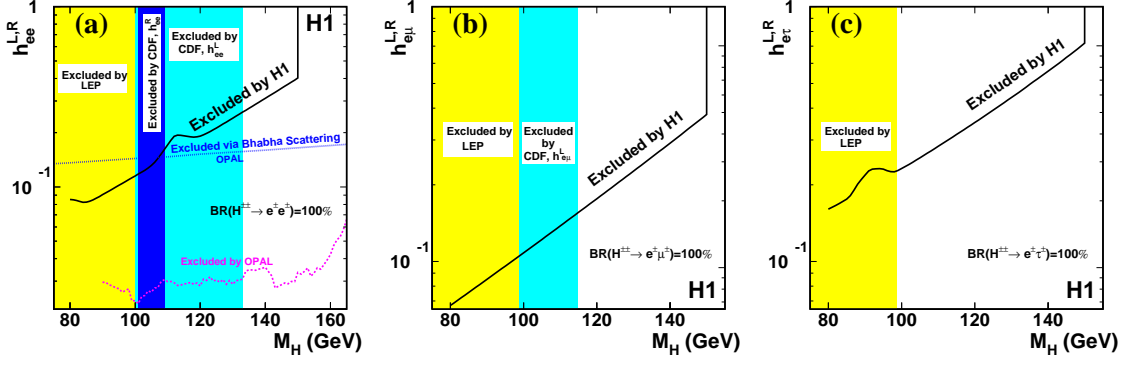
FIGURE 2. Limits at 95% confidence level (CL) on the coupling $h_{ee}^{L,R}$ (a), $h_{e\mu}^{L,R}$ (b) and $h_{e\tau}^{L,R}$ (c) of a doubly-charged Higgs boson as a function of its mass.

a non-vanishing vacuum expectation value (vev). At the tree level, doubly charged Higgs bosons couple to charged leptons and to other Higgs and gauge bosons. Couplings to quarks are not allowed by charge conservation. Their coupling to charged leptons can be generally described by the Lagrangian

$$\mathscr{L} = h_{ij}^{L,R} H^{--} \bar{l}_i^c P_{L,R} l_j \; + \; h.c. \, ,$$

where $i, j = e, \mu, \tau$ are lepton generation indices, $P_{L,R} = (1 \mp \gamma^5)/2$, l are the charged lepton fields and the superscript c denotes the charge conjugate spinors. The Yukawa couplings $h_{ij}^{L,R}$ are free parameters of the model. Since the production processes at HERA I are insensitive to the chirality of the lepton fields, the generic case of an either right-handed or left-handed coupling, h_{ij}, is considered here.

A recently published search [11] for the single production of doubly-charged Higgs bosons $H^{\pm\pm}$ in ep collisions is reviewed. The signal is searched for via the Higgs decay to a high mass pair of same charge leptons, one of them being an electron. The analysis uses up to $118\,\mathrm{pb}^{-1}$ of ep data collected by the H1 experiment at HERA. No evidence for doubly-charged Higgs production is observed and mass dependent upper limits are derived on the Yukawa couplings h_{el} of the Higgs boson to an electron-lepton pair (see Fig. 2). Assuming that the doubly-charged Higgs only decays into an electron and a muon via a coupling of electromagnetic strength $h_{e\mu} = 0.3$, a lower limit of $141\,\mathrm{GeV}$ on the $H^{\pm\pm}$ mass is obtained at 95% confidence level (CL). For a doubly-charged Higgs decaying only into an electron and a tau with a coupling $h_{e\tau} = 0.3$, masses below $112\,\mathrm{GeV}$ are ruled out at 95% CL. Whereas the limits on h_{ee} can not compete with existing constraints, the limits on $h_{e\mu}$ and $h_{e\tau}$ extend the excluded region significantly.

SEARCH FOR EXCITED NEUTRINOS

Composite lepton models may introduce excited neutrinos and an effective Lagrangian of the form

$$\mathscr{L}_{\mathrm{int}} = \frac{1}{2\Lambda} \bar{F}_R^* \sigma^{\mu\nu} \left[gf \frac{\tau^a}{2} W_{\mu\nu}^a + g'f' \frac{Y}{2} B_{\mu\nu} + g_s f_s \frac{\lambda^a}{2} G_{\mu\nu}^a \right] F_L,$$
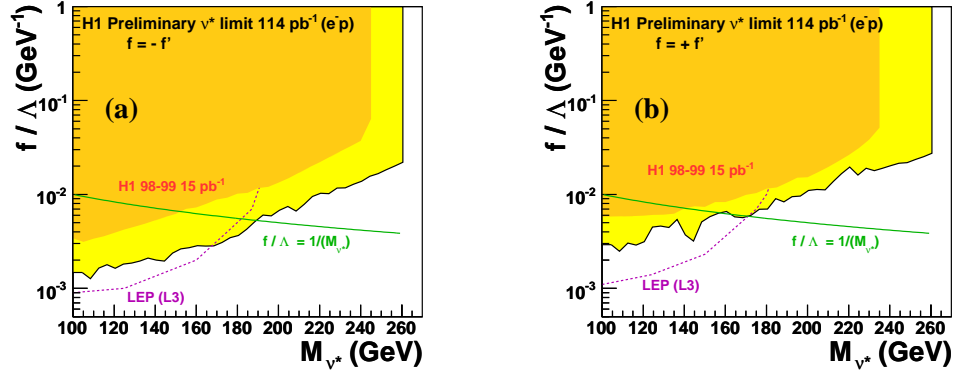
FIGURE 3. H1 preliminary limits at 95% CL on the ratio of the coupling of excited neutrinos to the compositeness scale, f/Λ, as a function of the excited neutrino mass for the assumption $f = -f'$ (a) and $f = +f'$ (b). The assumption $f/\Lambda = 1/M_{\nu^*}$ and the limit from the L3 experiment [13] are also shown.

including the compositeness scale Λ, the excited fermion doublet $F^* = F_L^* + F_R^*$, the weak hypercharge Y, the usual weak coupling constants g and g', the strong coupling constant g_s, the Pauli and Gell-Mann matrices τ^a and λ^a, the weak boson and gluon fields W^a, B and G^a, and parameters of the coupling scales f, f' and f_s [12].

The latest search for excited neutrinos by the H1 experiment includes $e^- p$ data collected in 2005 corresponding to an integrated luminosity of $114 \, \text{pb}^{-1}$. The electroweak decays of excited neutrinos, $\nu^* \to \nu \gamma$, $\nu^* \to \nu Z$ and $\nu^* \to eW$ are considered and possible final states resulting from the Z or W hadronic decays are taken into account. No evidence for excited neutrino production is found. Mass dependent exclusion limits are determined for the ratio of the coupling to the compositeness scale, f/Λ, as can be seen from Fig. 3. These limits extend the excluded region to higher masses than has been possible in previous searches, e.g. [13]. Assuming $f/\Lambda = 1/M_{\nu^*}$ and $f = -f'$, excited neutrinos with masses below 188 GeV are ruled out at 95% CL.

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