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# SEARCH FOR EXCITED FERMIONS IN $ep$ COLLISIONS AT HERA*

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Heavy excited electrons and neutrinos have been sought by the H1 and ZEUS experiments at HERA. For the $e^*$ ($\nu^*$) searches, 120 pb$^{-1}$ (16 pb$^{-1}$) of $ep$ collision data have been analysed. No evidence for any excited lepton has been found, and limits on the characteristic couplings have been derived.

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## 1. Introduction

The observation of heavy excited states of fermions would indicate that these particles are composite rather than elementary. In high-energy $ep$ collisions, such excited states could be produced directly, with masses up to the centre-of-mass energy of the collider.

The recent excited-fermion searches performed by the H1 and ZEUS experiments have focused on $e^*$ and $\nu^*$ [1–4]. Excited states of electrons were sought using the following data sets, where the centre-of-mass energies and the approximate integrated luminosities per experiment are given in brackets: 1994–1997 $e^+p$ (300 GeV, 40 pb$^{-1}$), 1998–1999 $e^-p$ (318 GeV, 16 pb$^{-1}$), 1999–2000 (318 GeV, 66 pb$^{-1}$). The decay channels considered are $e^* \to e\gamma$, $e^* \to \nu W \to \nu q\bar{q}'$ and $e^* \to eZ \to eq\bar{q}$.

Excited states of neutrinos were sought in the $e^-p$ data sets only, since the $\nu^*$ production cross section for masses beyond 200 GeV in $e^-p$ collisions is two orders of magnitude higher than that in $e^+p$. The decay channels analysed are $\nu^* \to \nu\gamma$, $\nu^* \to eW \to eq\bar{q}'$ and $\nu^* \to \nu Z \to \nu q\bar{q}$.

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The simulation of $e^*$ and $\nu^*$ signal events was based on the phenomenological compositeness model by Hagiwara *et al.*, [5]. For estimating the backgrounds from Standard Model processes, Monte Carlo samples of NC and CC DIS as well as of photoproduction (PHP) and QED-Compton events were employed.

## 2. Searches for excited electrons

### *2.1.* $e^* \to e\gamma$

Among the $e^*$ channels considered, the photonic decay mode, $e^* \to e\gamma$, provides the most striking experimental signature, featuring two isolated electromagnetic clusters with large transverse energies. Typically, no further activity is observed in the detector, except for possible energy deposits by the proton remnant around the forward beam-pipe. As for the backgrounds, NC DIS and QED-Compton events contribute with similar magnitudes.

### *2.2.* $e^* \to \nu W \to \nu q\bar{q}'$

This final state is characterised by a large amount of missing transverse momentum, $\not{P}_{\mathrm{T}}$, due to the neutrino escaping undetected as well as by two hadronic jets from the $W$ decay. The relevant background processes are predominantly multi-jet CC DIS and, less pronounced, PHP. The H1 search required the identification of two jets, whereas ZEUS employed cuts on global event variables like transverse hadronic energy and hadronic mass. Both experiments applied an electron veto.

### *2.3.* $e^* \to eZ \to eq\bar{q}$

Due to the hadronic $Z$ decay, this final state features two jets with high transverse energy. In addition, there is a forward-going high-energy electron. The only relevant source of background is constituted by NC DIS. Again, the two experiments used different approaches in treating the hadronic final state, namely on the basis of jets (H1) and global event variables (ZEUS), respectively.

## 3. Searches for excited neutrinos

### *3.1.* $\nu^* \to \nu\gamma$

The photonic $\nu^*$ decay gives rise to a particularly rare experimental signature: one isolated, high-energy electromagnetic cluster in the forward direction plus a large amount of $\not{P}_{\mathrm{T}}$. Background arises predominantly from CC DIS.

### *3.2.* $\nu^* \to eW \to eq\bar{q}'$ *and* $\nu^* \to \nu Z \to \nu q\bar{q}$

The topologies of the $eq\bar{q}'$ and $\nu q\bar{q}'$ final states originating from $\nu^*$ decays are similar to the ones of the corresponding $e^*$ final states. Thus, similar selection criteria as in the corresponding $e^*$ channels were employed by the two experiments.

## 4. Results

The numbers of candidate and background events obtained by the searches are summarised in Table I. No excess of data events over the expected background has been observed in either of the decay channels analysed. Thus, upper limits at 95 % confidence level have been set on the cross section times the branching ratio, $\sigma \times$ BR, and on the coupling over the compositeness scale, $f/\Lambda$. The latter limits require as input branching ratios and cross sections from the specific model used.

TABLE I

Numbers of observed events and expected backgrounds in the six decay channels, given separately for the different data samples analysed by the two experiments. The errors stated are statistical and systematic for H1, and statistical for ZEUS.

| decay channel | data sample | H1 events | H1 background | ZEUS events | ZEUS background |
|---|---|---|---|---|---|
| $e^* \to e\gamma$ | 94–97 | 8 | $7.2 \pm 1.0 \pm 0.1$ | 18 | $20.1 \pm 1.2$ |
| | 98–99 | 4 | $4.0 \pm 0.7 \pm 0.2$ | 10 | 8.7 |
| | 99–00 | 12 | $15.6 \pm 1.7 \pm 0.4$ | 22 | 30.8 |
| $e^* \to \nu q\bar{q}'$ | 94–97 | 2 | $2.4 \pm 0.2 \pm 0.7$ | 13 | $13.9 \pm 1.1$ |
| | 98–99 | 5 | $3.9 \pm 0.2 \pm 0.7$ | | |
| | 99–00 | 8 | $6.1 \pm 0.4 \pm 1.5$ | | |
| $e^* \to eq\bar{q}$ | 94–97 | 6 | $7.1 \pm 2.1 \pm 2.8$ | 32 | $32.9 \pm 1.1$ |
| | 98–99 | 4 | $5.6 \pm 0.4 \pm 1.2$ | | |
| | 99–00 | 31 | $25.3 \pm 1.9 \pm 5.5$ | | |
| $\nu^* \to \nu\gamma$ | 98–99 | 2 | $3.0 \pm 0.2 \pm 1.2$ | 2 | $1.5 \pm 0.2$ |
| $\nu^* \to eq\bar{q}'$ | 98–99 | 6 | $7.0 \pm 0.6 \pm 1.4$ | 20 | $15.0 \pm 1.3$ |
| $\nu^* \to \nu q\bar{q}$ | 98–99 | 1 | $3.7 \pm 0.2 \pm 0.9$ | 16 | $13.5 \pm 0.6$ |

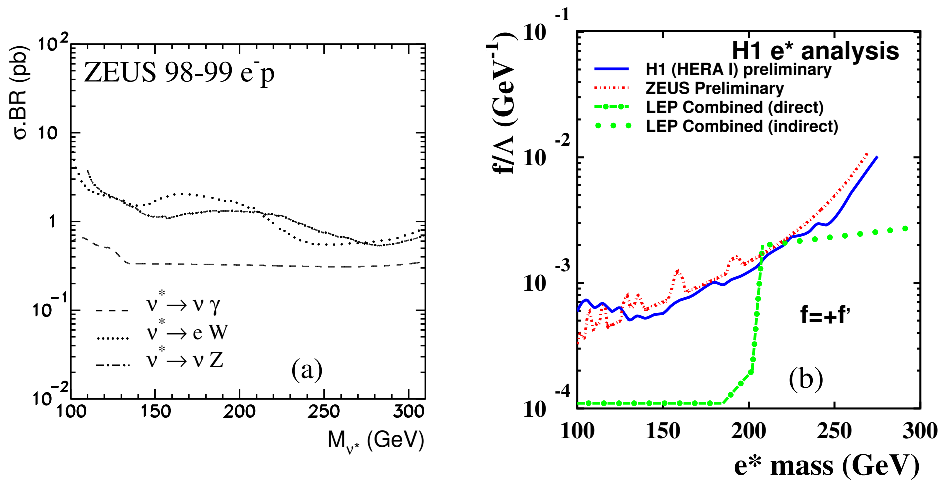


Fig. 1. (a) Upper limits at 95 % confidence level on $\sigma \times \mathrm{BR}$ as a function of the $\nu^*$ mass [3]. (b) Upper limits on $f/\Lambda$ for $e^*$. The H1 (ZEUS) limits are based on $120\,\mathrm{pb}^{-1}$ ($82\,\mathrm{pb}^{-1}$) of $ep$ data. For comparison, the corresponding limits by the LEP experiments are shown [7].

In Fig. 1 (a), the ZEUS upper limits on $\sigma \times \mathrm{BR}$ for excited neutrinos are displayed. In Fig. 1 (b), $f/\Lambda$ limits for excited electrons are shown. In all limit plots, the areas above the curves are excluded. The H1 curve in Fig. 1 (b) has been derived from combining the three decay channels considered, using the conventional assumption $f = f'$ for the coupling constants in the Hagiwara model; the ZEUS curve is from $e^* \to e\gamma$ only. In the $\nu^*$ case, $f/\Lambda$ limits are usually derived for both assumptions $f = f'$ and $f = -f'$. The H1 limits for the latter assumption, allowing for photonic $\nu^*$ decays, are shown in Fig. 2 (a).

In addition, H1 has derived less model-dependent $f/\Lambda$ limits for $\nu^*$. At each mass point, the ratio of the coupling constants was varied in the range $-5 < f'/f < 5$, the corresponding $f/\Lambda$ limit was calculated, and the worst of these limit values was chosen. The resulting curve is displayed in Fig. 2 (b).

In comparison with existing limits by H1 and ZEUS, the new $\sigma \times \mathrm{BR}$ and $f/\Lambda$ limits for $e^*$ and $\nu^*$ are more stringent and extend towards higher masses. For $\nu^*$, with no indirect limits available from the LEP experiments, H1 and ZEUS set the most stringent limits in the high-mass region.

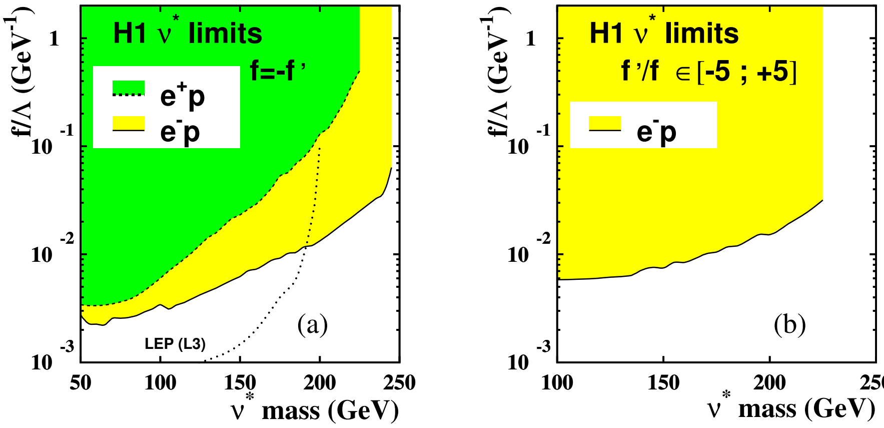


Fig. 2. (a) Upper limits on $f/\Lambda$ for $\nu^*$ assuming $f = -f'$. The $e^+p$ [6] and $e^-p$ [1] limits are based on integrated luminosities of 37 pb$^{-1}$ and 16 pb$^{-1}$, respectively. The $e^-p$ limits are more stringent, though, due to the higher $\nu^*$ production cross-section compared to $e^+p$ collisions. (b) Upper limits on $f/\Lambda$ for $\nu^*$, not depending on the ratio $f/f'$ [1].

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