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Searches for excited fermions in ep collisions

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Abstract. Searches for excited electrons and neutrinos are presented using the complete data sample collected by the H1 experiment at HERA at a center-of-mass energy of 320 GeV and corresponding to an integrated luminosity of up to 435 pb⁻¹. In absence of excited neutrino and electron signal, limits on the ratio f/Λ of the coupling to the compositeness scale are derived and greatly extend the excluded region to higher masses than previous searches.

1 Introduction

Excited fermions states (f^*) should be a signal for substructure at a characteristic new scale $\mathcal{O}(\Lambda)$. If known quarks and leptons are composite, they should be considered as the ground state to a rich spectrum of excited states. Composite models have the potentiality of explaining the threefold replica of fermion generation and should be possible alternatives to the conventional Standard Model description of the electroweak symmetry breaking. Excited fermions can carry different spin and isospin values [1]; in the present study they are assumed to have spin 1/2 and isospin 1/2 and be organised in left/right weak iso-doublets. Effective models describing the interactions between standard and excited fermions have been proposed [2, 3, 4]. In [3], transitions between f^* and f described by a contact interaction Lagrangian are also introduced. This model is not considered in this paper. In [2, 4], an f^* is coupled to a standard fermion via a gauge boson and the interactions are described by a magnetic coupling proportional to f/Λ , f'/Λ and f_s/Λ for couplings to $U(1)$, $SU(2)$ and $SU(3)$ gauge bosons respectively. In this gauge mediated model, excited fermions may be produced in electron(positron)-proton collisions at HERA via t -channel γ , Z or W^\pm gauge boson exchange. This paper is devoted to search for both excited neutrinos and electrons using HERA collider data collected in the H1 detector at a center-of-mass energy of 320 GeV and corresponding to an integrated luminosity of up to 435 pb⁻¹. Excited neutrinos and electrons are searched for through their de-excitation in a standard fermion by the emission of a γ , Z or W^\pm gauge boson.

2 Search for excited neutrinos

Since the ν^* production cross section is predicted to be much larger for e^-p collisions than for e^+p (for a ν^* mass of 200 GeV the ratio of the production cross section is of order 100), only the

e^-p data are used to search excited neutrinos. The corresponding integrated luminosity is 184 pb^{-1} [5]. In the ν^* search, the final states resulting from the W and Z hadronic and leptonic decays are investigated. Table 1 summarizes the different decay channels of this analysis which cover a total fraction of ν^* decays of 90%. The selection criteria of the three main channels are described in the following.

$\nu^* \rightarrow \nu\gamma$: the main signature of this channel consists of one photon candidate and a missing transverse momentum (P_T^{miss}) arising from the presence of a neutrino. A photon is tagged by identifying an isolated electromagnetic cluster with no well measured track pointing to it. Events with $P_T^{miss} > 20 \text{ GeV}$ are selected. The main background, which arises from charged current (CC) events with an isolated π^0 or a radiated photon, is reduced by requiring $P_T^\gamma > 20 \text{ GeV}$. For signal events, in most cases the final states contains a recoil jet. Hence the presence of at least one jet with $P_T^{jet} > 5 \text{ GeV}$ is also required.

$\nu^* \rightarrow eW_{\rightarrow q\bar{q}}$: in this channel, events with one electron in the LAr calorimeter in the polar angle range $5^\circ < \theta^e < 90^\circ$ and with $P_T^e > 25 \text{ GeV}$ are selected. At least two high P_T jets are also required with $P_T^{jet1} > 20 \text{ GeV}$ and $P_T^{jet2} > 15 \text{ GeV}$. Multi-jet neutral current (NC) DIS events constitute the main background contribution from SM processes. The restriction on the electron polar angle to the forward region of the LAr removes a large part of this background. In each event, a W candidate is then reconstructed from the combination of the two jets with an invariant mass closest to the nominal W boson mass. The two-jets reconstructed mass is required to be above 40 GeV .

$\nu^* \rightarrow \nu Z_{\rightarrow q\bar{q}}$: the signature of this decay channel consists of two jets with high transverse momentum in events with large P_T^{miss} . The SM background is dominated by multi-jet CC DIS events. Events with $P_T^{miss} > 20 \text{ GeV}$ and containing at least two jets with $P_T^{jet1} > 20 \text{ GeV}$ and $P_T^{jet2} > 15 \text{ GeV}$ are selected. For events with low $P_T^{miss} (< 30 \text{ GeV})$, a cut on the ratio V_{ap}/V_p of transverse energy flow anti-parallel and parallel to the hadronic final state [6] is applied to reduce the contribution of CC DIS processes. In the same way as in the $\nu^* \rightarrow eW_{\rightarrow q\bar{q}}$ channel, in each event, a Z candidate is reconstructed from the combination of two jets and the reconstructed Z candidate is required to have an invariant mass above 60 GeV .

The results of the selection in each decay channel are summarised in table 1. The numbers of observed events are compatible with the SM expectations and no deviation is observed in invariant mass distributions of excited neutrino candidates reconstructed in each decay channel.

selection	Data	SM	Efficiency \times BR
$\nu^* \rightarrow \nu\gamma$	7	12.3 ± 3.0	50-55 %
$\nu^* \rightarrow eW_{\rightarrow q\bar{q}}$	220	223 ± 47	40-65 %
$\nu^* \rightarrow \nu Z_{\rightarrow q\bar{q}}$	89	95 ± 21	25-55 %
$\nu^* \rightarrow \nu Z_{\rightarrow ee}$	0	0.19 ± 0.05	45 %
$\nu^* \rightarrow eW_{\rightarrow e\nu}$	0	0.70 ± 0.10	45 %
$\nu^* \rightarrow eW_{\rightarrow \mu\nu}$	0	0.40 ± 0.05	35 %

Table 1: Observed and predicted events yields in the studied ν^* decay channels. Errors on the prediction include model uncertainties and experimental systematic errors added in quadrature.

In absence of a signal, upper limits on the coupling f/Λ have been derived at 95% of confidence level (C.L.) as a function of the excited neutrino mass and under the conventional assumptions

$f = -f'$ (figure 1 left) and $f = +f'$ (figure 1 right). For $f = -f'$ (corresponding to the maximal $\gamma\nu^*\nu$ coupling) and assuming $f/\Lambda = 1/M_{\nu^*}$, excited neutrinos with masses below 213 GeV are excluded at 95% C.L. For masses beyond the LEP reach, these results demonstrate the unique sensitivity of HERA.

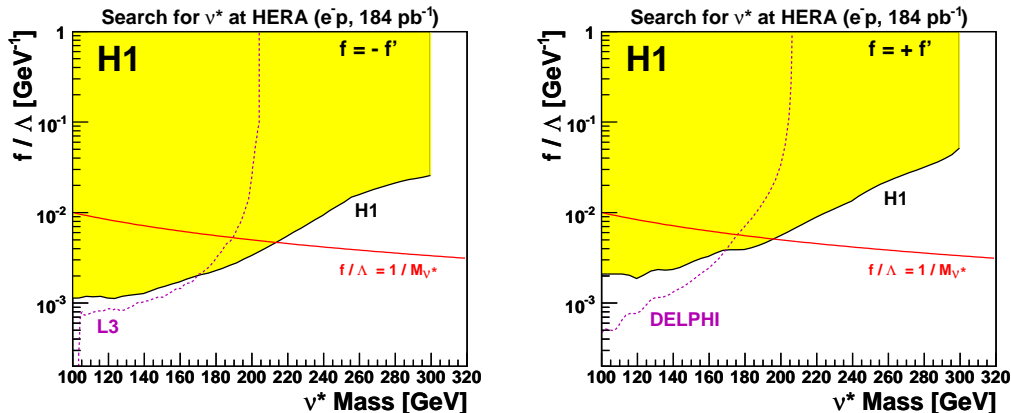


Figure 1: Exclusion limits on the coupling f/Λ at 95% C.L. as a function of the mass of the excited neutrino with the assumptions $f = -f'$ (left) and $f = +f'$ (right).

3 Search for excited electrons

Both electron-proton and positron-proton collisions are used to search for excited electron, corresponding to an integrated luminosity of 435 pb^{-1} . In the e^* search, only the hadronic decay channels of the W and Z bosons are considered. The total fraction of e^* decays accessed is around 80%.

$e^* \rightarrow e\gamma$: events with two electromagnetic clusters with a transverse momentum larger than 20 and 15 GeV are selected. To reduce the main SM background which arises in this channel from elastic and inelastic Compton events, the sum of the energies and of the transverse momenta of the two electromagnetic clusters has to be larger than 100 and 75 GeV respectively.

$e^* \rightarrow \nu W_{\rightarrow q\bar{q}}$ and $e^* \rightarrow eZ_{\rightarrow q\bar{q}}$: for these two channels, since the two final states $\nu q\bar{q}$ and $e q\bar{q}$ are similar to those of the $\nu^* \rightarrow \nu Z_{\rightarrow q\bar{q}}$ and $\nu^* \rightarrow eW_{\rightarrow q\bar{q}}$ channels of the excited neutrino search, similar selection criteria are used.

The observed events yields and the SM expectations in each channel are summarized in table 2. They are in good agreement and, in each channel, no deviation is observed in the invariant mass distributions of excited electron candidate .

Upper limit on the coupling f/Λ as a function of the e^* mass is derived using the assumption $f = +f'$ (figure 2). The case $f = -f'$ is not considered since the $\gamma e^* e$ coupling constant is zero and the production cross section of the excited electron is very small. Assuming $f/\Lambda = 1/M_{e^*}$, e^* masses below 273 GeV are excluded at 95% C.L. if $f = +f'$.

selection	Data	SM	Efficiency \times BR
$e^* \rightarrow e\gamma$	112	125 ± 19	60-70 %
$e^* \rightarrow \nu W_{\rightarrow q\bar{q}}$	172	175 ± 39	40 %
$e^* \rightarrow \nu Z_{\rightarrow q\bar{q}}$	351	318 ± 64	45 %

Table 2: Number of observed and predicted events in the studied e^* decay channels. Errors on the prediction include model uncertainties and experimental systematic errors added in quadrature.

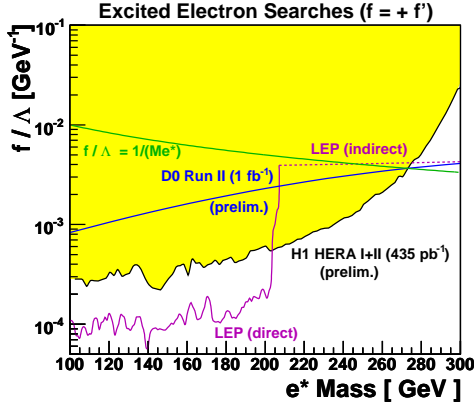


Figure 2: Exclusion limits on the coupling f/Λ at 95% C.L. as a function of the mass of the excited electron with the assumptions $f = +f'$.

4 Conclusion

The full e^-p data sample collected by the H1 experiment (184 pb^{-1}) is used to search for excited neutrinos and almost the full $e^\pm p$ data (435 pb^{-1}) to search for excited electrons. No signal is found and new upper limits have been derived on the ratio of the coupling constant f over the compositeness scale Λ for the specific relations between the couplings $f = +f'$ and $f = -f'$. Assuming $f/\Lambda = 1/M_{\nu^*}$ and $f = -f'$ excited neutrinos lighter than 213 GeV are excluded. Assuming $f/\Lambda = 1/M_{e^*}$ and $f = f'$ excited electrons lighter than 273 GeV are excluded. The results presented in this letter demonstrate the unique sensitivity of HERA for first generation excited leptons with a mass between 200 and 300 GeV.

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