Search for Excited Leptons at HERA

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Searches for excited electrons and neutrinos have been performed using the complete HERA I and II data samples collected by the H1 detector at $\sqrt{s} = 320$ GeV corresponding to an integrated luminosity of up to 435 pb^{-1}. In absence of a signal, the limits on the ratio of the coupling to the compositeness scale derived extend the excluded region to higher masses than has been possible in previous searches.

1 Introduction

Compositeness models [2] attempt to explain the hierarchy of masses in the Standard Model (SM) by the existence of a substructure within the fermions. Several of these models predict excited states of the known leptons. Excited leptons (F^*) are assumed to have the same electroweak SU(2) and U(1) gauge couplings, g and g', to the vector bosons, but are expected to be grouped into both left- and right-handed weak isodoublets with vector couplings. The existence of the right-handed doublets is required to protect the ordinary light leptons from radiatively acquiring a large anomalous magnetic moment via the F^*FV interaction (where V is a γ, Z, or W). Considering only the electroweak interaction, the phenomenological model describes this interaction by the Lagrangian density:

$$L_{F^*F} = \frac{1}{2\Lambda}\bar{F}^*_R \sigma^{\mu\nu}[gf\frac{\vec{\tau}}{2}\partial_\mu \vec{W}_\nu + g'f'\frac{Y}{2}\partial_\mu B_\nu]F_L + h.c.$$

where the new weights f and f' multiply the standard coupling constants g and g' corresponding to the weak SU(2) and the electromagnetic U(1) sectors respectively. The matrix $\sigma^{\mu\nu}$ is the covariant bilinear tensor, τ are the Pauli matrices, $W_{\mu\nu}$ and $B_{\mu\nu}$ represent the fully gauge invariant field tensors, and Y is the weak hypercharge. The parameter Λ has units of energy and can be regarded as the compositeness scale. The relative values of f and f' affect the size of the single-production cross section, their detection efficiencies and also the branching ratios of excited leptons.

Excited electrons and neutrinos may be produced in electron(positron)-proton collisions at HERA via t-channel $\gamma(Z)$ or $W^\pm$ gauge boson exchange. In the case of excited neutrinos, the cross section is much larger in e^-p collsions than in e^+p collsions due to the favourable valence u-quark and the helicity enhancement, specific to CC-like processes. Therefore the search for excited neutrinos uses only e^-p sample data with an integrated luminosity of 184 pb^{-1}. In the case of excited electrons, both e^-p and e^+p collision modes are used, corresponding to total integrated luminosity of 435 pb^{-1}.

2 Data analysis and results

Excited leptons ($l = e, \nu$) are searched for in the following decay channels: $l^* \to l\gamma$, $l^* \to lZ$, $l^* \to lW$. The final states resulting from the Z or W hadronic decays are taken into account

Search for e*, ν^* HERA I+II ($\sqrt{s} = 320$ GeV, preliminary)

Selection	Data	SM	Efficiency × BR
$e^*\to\nu W_{\hookrightarrow qq}$	172	175 ± 39	∼ 40 %
$e^*\to eZ_{\hookrightarrow qq}$	351	318 ± 64	∼ 45 %
$e^*\to e\gamma$	112	125 ± 19	60–70 %
$\nu^*\to\nu\gamma$	9	15 ± 4	50 %
$\nu^*\to eW_{\hookrightarrow qq}$	198	189 ± 33	30–40 %
$\nu^*\to\nu Z_{\hookrightarrow qq}$	111	102 ± 24	40 %
$\nu^*\to eW_{\hookrightarrow \nu\mu}$	0	0.54 ± 0.04	3–4.5 %
$\nu^*\to eW_{\hookrightarrow \nu e}$	0	0.6 ± 0.3	4–6 %
$\nu^*\to\nu Z_{\hookrightarrow ee}$	0	0.12 ± 0.04	2 %

Table 1: Observed and predicted event yields for the event classes of e^* and ν^* searches. The selection efficiency for the signal multiplied by the branching ratio (BR) in each decay channel is also presented.

for both excited electrons and neutrinos and the Z or W leptonic decays are taken into account only for excited neutrinos. In the following, the selection criteria are described for the decay channels.

The $\nu^* \to \nu\gamma$ channel

Candidate events are selected by requiring missing transverse momentum $P_T^{miss} > 15$ GeV, where the photon is identified as an isolated electromagnetic (e.m.) cluster in the LAr calorimeter within a polar angle of 5° to 120°. The photon candidates measured within the acceptance of the central tracker ($\theta^\gamma > 20°$) are required to have no associated tracks. The neutral current (NC) and charged current (CC) backgrounds are reduced by imposing the longitudinal momentum balance $E - P_Z > 45$ GeV for events with photon candidates at lower transverse momentum $P_T^\gamma < 40$ GeV and by requiring the virtuality (Q^2_γ) to satisfy log(Q^2_γ)> 3.5 GeV^2. The background is further suppressed by rejecting events with a transverse momentum of the final hadronic in the calorimeter $P_T^h < 5$ GeV.

The $e^* \to e\gamma$ channel

Candidate events are selected with two isolated e.m. clusters in the LAr calorimeter of transverse energy greater than 20 GeV and 15 GeV, respectively, and with a polar angle between 5° and 130°. The sum of the energies of the two clusters has to be greater than 100 GeV. The background from NC is further suppressed by rejecting events with a total transverse energy of the two isolated e.m. clusters lower than 75 GeV.

The $e^* \to eZ, \nu W$ and $\nu^* \to eW, \nu Z$ channels with $Z, W \to qq'$

These channels use subsample of events with at least two jets with high transverse momentum $P_T^{j1(j2)} > 20(15)$ GeV reconstructed within $5° < \theta^{j1(j2)} < 130°$. The dijet invariant mass must be compatible with the relevant boson mass and should be closest to them.

Events with two high P_T jets and one electron: The channels $e^* \to eZ_{\to qq}$ and $\nu^* \to eW_{\to qq}$ are characterised by at least two high P_T jets and an energetic isolated e.m. cluster P_T^e >10 GeV (P_T^e >20 GeV for $e^* \to eZ_{\to qq}$) in the polar angle $5° < \theta^e < 130°$. The polar angle of the highest P_T jet resulting from W boson should be lower than 80°. The dijet invariant mass has to be greater than 60 GeV. If P_T^e <65 GeV, the dijet invariant mass must be greater than 75 GeV. In the case of the $\nu^* \to eW_{\to qq}$ channel, to reduce the NC background, the polar angle of e.m. cluster must be lower than 90°. Furthermore, the background is reduced by requiring the virtuality computed from the e.m. cluster kinematics Q^2 >2500 GeV^2 if P_T^e <25 GeV and by requiring a third jet with P_T >5 GeV to be present in the event if P_T^e >50 GeV.

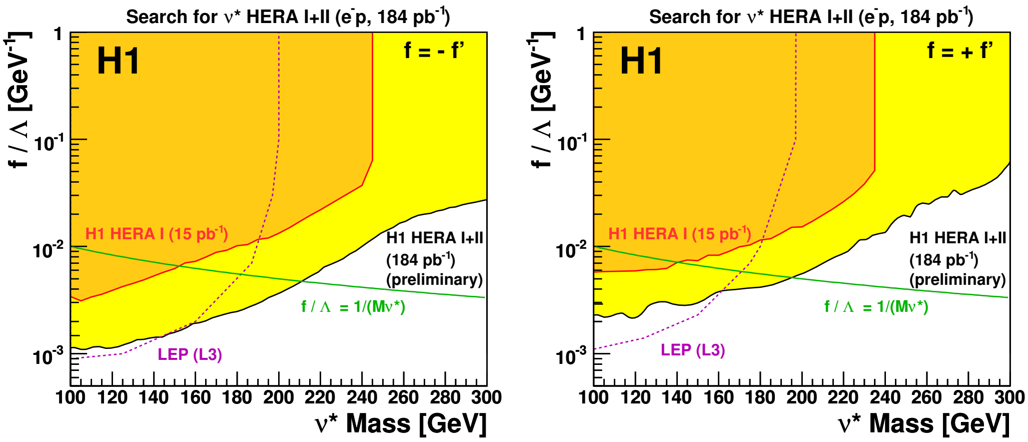

Figure 1: The 95% C.L. limits obtained for coupling constants (f/Λ) as a function of the excited neutrino mass within two assumptions: $f = -f'$ (left) and $f = +f'$ (right). The observed limits from this analysis using all H1 e^-p data is presented by the yellow area. Values of the couplings above the curves are excluded. The orange-dark area corresponds to the exclusion domain published by the H1 experiment using 98/99 data and the dashed line to the exclusion limit from the L3 experiment at LEP [4].

Events with two high P_T jets and P_T^{miss}: The channels $e^* \to \nu W_{\to qq}$ and $\nu^* \to \nu Z_{\to qq}$ are characterised by at least two high jets and P_T^{miss} >12 GeV. In the case of $e^* \to \nu W_{\to qq}$ channel, the ratio V_{ap}/V_p of transverse energy flow anti-parallel and parallel to the hadronic final state [3] is required to be lower than 0.3 to reject the photoproduction (γp) background. The dijet invariant mass is required to be greater than 50 GeV. Furthermore, if P_T^{miss} <65 GeV the dijet is required to have an invariant mass above 65 GeV. In the case of the $\nu^* \to \nu Z_{\to qq}$ channel, a dijet invariant mass greater than 60 GeV is required. In order to reduce CC background, the total hadronic system is required to have a polar angle above 20° and a third jet with P_T >5 GeV has to be present in the event if P_T^{miss} <65 GeV. The longitudinal balance $E - P_Z$ >25 GeV is imposed if P_T^{miss} <50 GeV. In addition, events with P_T^{miss} <30 GeV are only accepted if the topological variable V_{ap}/V_p >0.1.

The $\nu^* \to eW, \nu Z$ channels with $Z \to ee$, $W \to \nu e(\mu)$

Events with two electron and P_T^{miss}: These channels use a subsample of events with two high P_T isolated e.m. clusters $P_T^{e1(e2)} > 20(15)$ GeV and a polar angle $5° < \theta^{e1(e1)} < 100°(120°)$ and P_T^{miss} >12 GeV. The clusters are required to have associated tracks if they are measured within the acceptance of the central tracker.

Events with one muon and an electron: Candidate events containing an islolated muon plus an isolated electron, both having a high transverse momentum $P_T^{e(\mu)} > 20(10)$ GeV and a polar angle $5° < \theta^{e(\mu)} < 100°(160°)$ are selected. A cut P_T^{miss} >12 GeV is applied. The backgrounds are reduced by requiring the virtuality (Q_e^2) to satisfy log(Q_e^2)>3 GeV^2.

The observed number of events are compared to the expected SM background in table 1 for each search channel. A good overall agreement is found for all channels. No significant deviation is observed in the data. The selection efficiency for each decay channel for the both e^* and ν^* search is presented also in the table 1.

3 Interpretation and Conclusions

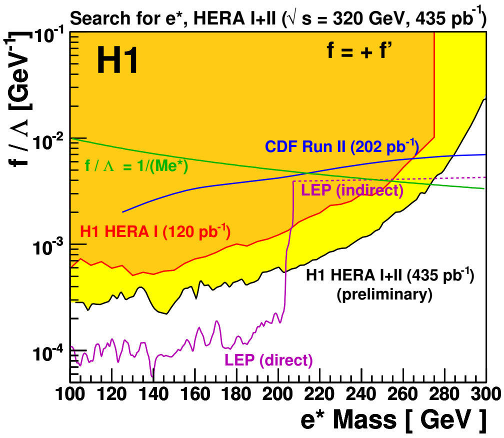

Figure 2: The 95% C.L. limits obtained for coupling constants (f/Λ) as a function of the excited electron mass within assumption: $f = +f'$. The observed limit from this analysis using 435 pb^{-1} of H1 data is presented by the yellow area. The orange-dark area corresponds to the exclusion domain published by the H1 experiment using HERA I data. The combined exclusion limit from LEP experiments is presented by the violet line. The result of the CDF [5] experiment at the Tevatron is also shown.

In absence of a signal for both excited electron and neutrino production, upper limits on the coupling f/Λ have been derived at 95% Confidence Level (C.L.) as a function of excited electron and neutrino masses. In case of excited neutrinos production, the obtained limits are displayed for the two assumptions $f = -f'$ and $f = +f'$ (figure 1). For $f = -f'$ (maximal $\gamma\nu{*}\nu$ coupling) and assuming $f/\Lambda = 1/M_{\nu*}$, excited neutrinos with masses below 211 GeV are excluded at 95% C.L. The limits on the ratio f/Λ also are given for the excited electron for the hypothesis $f = +f'$ (figure 2). We do not consider the case $f = -f'$, because the $\gamma e^* e$ coupling constant would be equal to zero and the production cross section of the excited electron is very small. For this hypothesis and assuming $f/\Lambda = 1/M_{e^*}$, excited electrons with masses below 273 GeV are excluded at 95% C.L.

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