Excited fermions and other searches at HERA

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This paper reports a search in ep collisions for events with isolated τ leptons and large missing transverse momentum and for heavy excited fermions. The analysis of events with isolated τ followed the same strategy used for the search of isolated electrons and muons. Two candidates events were found, while 0.12 ± 0.02 were expected from the Standard Model. The search for excited electrons and neutrinos leads to direct constraints on the couplings and masses of these new states, which are the best ever reported for masses beyond 200 GeV.

1. Introduction

Events with isolated leptons and large missing transverse momentum in ep collisions are an interesting signature for processes beyond the Standard Model (SM). The background due to the SM processes is expected to be small and due almost completely to W boson production. Both HERA collaborations have previously reported results for the electron and the muon channels which lead to constraints on the single-top production mediated by an anomalous FCNC coupling [1–4]. A search in the τ channel, performed by the ZEUS collaboration, is reported.
HERA is also an ideal place to look for excited fermion states that would be a clear signal of the fermion compositness. Such new states could be produced directly via t-channel exchange of a gauge boson followed by decay to a known fermion and a gauge boson. The results of a search for excited electrons and neutrinos are presented and compared to results obtained at LEP.

2. Search for isolated τ

ZEUS data, corresponding to $\sim 130\,\mathrm{pb}^{-1}$, were used in this analysis [5]. The search for τ leptons is based on the hadronic decays with one charged particle detected in the central tracking detector. The narrow jets with low charged-particle multiplicity that characterized τ decay, were used to distinguish them from quark- and gluon-induced jets [6]. The internal jet structure was parametrized by six variables related to the jet shapes. The separation between signal and background was studied using Monte Carlo (MC) events, $W \to \tau\nu_\tau$ for the signal and charged current (CC) DIS for the background. In order to separate signal from background the six variables were combined in a discriminant D. Fig. 1 shows the tau discriminant distribution for the MC signal and background events and for CC DIS data. The event selection was the same used in

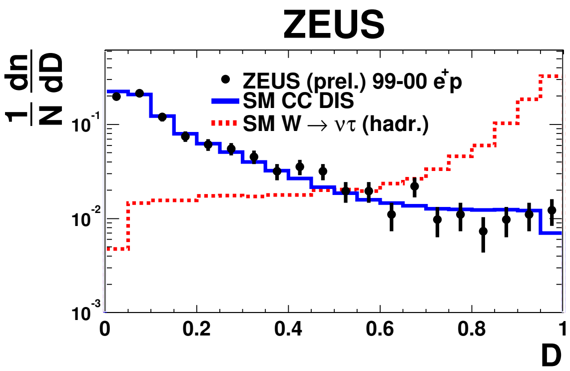

Figure 1. Distribution of the tau discriminant D for an inclusive selection of CC DIS events. The histograms are normalized to the total number of events N.

the previous ZEUS searches for events with isolated leptons and large missing P_t [3,4] and was based on the requirement of an isolated track with

transverse momentum, $p_T > 5$ GeV and calorimeter transverse momentum, $P_T^{CAL} > 20$ GeV. At least one jet with transverse energy, $E_T > 5$ GeV within the range $-1.0 < \eta < 2.5$ was also required. Events with identified electrons and a topology characteristic of neutral current (NC) DIS events were rejected.
In order to selects τ candidates, $D > 0.95$ was required for the selected events whose isolated tracks were not identified as muons or electrons and, to further reject CC DIS, the isolation requirement between the track and the closest jet was tightened. At this stage three events remain while 0.23 ± 0.06 are expected from the SM. Figure 2 shows the hadronic transverse momentum (P_T^X) distributions of the data and MC events that survive the τ selections. The final cuts have

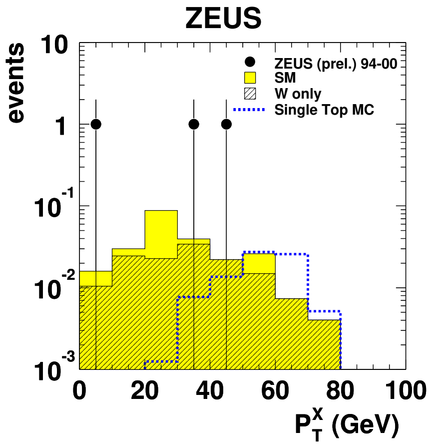

Figure 2. Distribution of the hadronic transverse momentum, P_T^X. The data (points) are compared to the SM expectations (shaded histogram). The dashed histogram represents the contribution from W production. The dashed line represents the single-top signal MC normalized to the cross section limit obtained by the previous ZEUS search [4].

been designed using the single-top MC as a template. A cut at $P_T^X > 25$ GeV gave the best expected upper limit assuming no signal. Two events remained in the data, while 0.12 ± 0.02 are expected from the SM, mainly from direct W production. The observed excess cannot be explained by single-top production, since this process is already strongly constrained by the electron and the muon channel results which have a much higher sensitivity.

3. Excited fermions

In this section a search for excited electrons and neutrinos are presented [7–9]. At HERA excited electrons (neutrinos) could be singly produced through t-channel γ and Z (W) boson exchange. Their production cross-section and partial decay width have been calculated using an effective Lagrangian [10,11] which depends on a compositness scale Λ and on form factors f and f', reduced here to constants, describing the relative coupling strengths of the excited leptons to the $SU(2)_L$ and $U(1)_Y$ gauge bosons, respectively. Usually these coupling parameters are assumed to be of comparable strength and the relationships $f = +f'$ and $f = -f'$ are imposed. In this case the production cross sections and partial decay widths depend only on the excited lepton mass and the ratio f/Λ. All the decay channels $e^*(\nu^*) \to e(\nu)\gamma$, $e^*(\nu^*) \to \nu(e)W$ and $e^*(\nu^*) \to e(\nu)Z$ have been searched for, considering the subsequent W and Z hadron decay (the ZEUS collaboration also considered in the e^* case the $Z \to \nu\bar{\nu}$ decay). The signature of such processes is very clear: a highly energetic electron and/or large missing transverse momentum in addition to a peak in the invariant mass of the lepton and the gauge boson. Such clear signatures allowed a signal selection with high efficiency. For the e^* decay in $e\gamma$ channel, the efficiency was in the range $70-80\%$, while in the other cases it was typically $30-60\%$ for masses in the range $130-250$ GeV. The most important sources of backgrounds are the NC and CC DIS and the W production processes. Since no excess over the SM expectations was found, limits at 95% confidence level were set on the e^* and ν^* masses as a function of f/Λ. Figure 3 shows the HERA and LEP e^* results for $f = +f'$ while figure 4 shows H1 and L3 [12] ν^* results (the ZEUS collaboration has similar results [7]) for $f = -f'$.

The HERA limits extends the excluded region to higher masses than reached in previous direct searches.

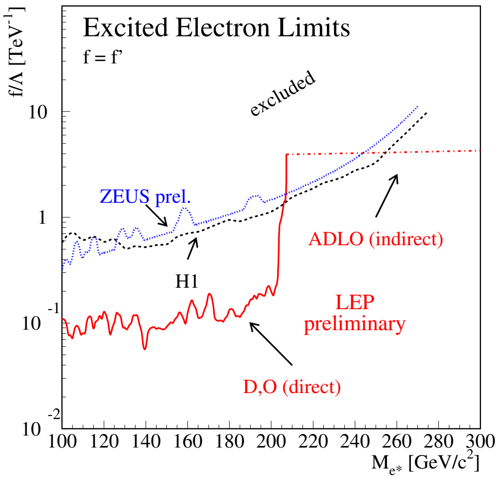

Figure 3. Exclusion limit on f/Λ at 95% confidence level as a function of the e^* mass for $f = +f'$. Exclusion limit are reported for H1 (~ 120 pb^{-1} of 1994-2000 $e^{\pm}p$ data), ZEUS (~ 47 pb^{-1} of 1994-1997 e^+p) and LEP experiments.

4. Conclusions

A search was presented for isolated τs and excited fermions at HERA. The isolated τ search extends the previous searches performed by the H1 and the ZEUS collaborations for high-pt isolated electrons and muons in events with large missing transverse momentum. Two events have been selected while the SM expectation is 0.12 ± 0.02. The observed excess is unlikely to be explained by the single-top production, since this process is already strongly constrained by the electron and the muon channels data.
Limits on f/Λ as a function of the mass were presented for excited electrons and neutrinos. The HERA limits extends the excluded region

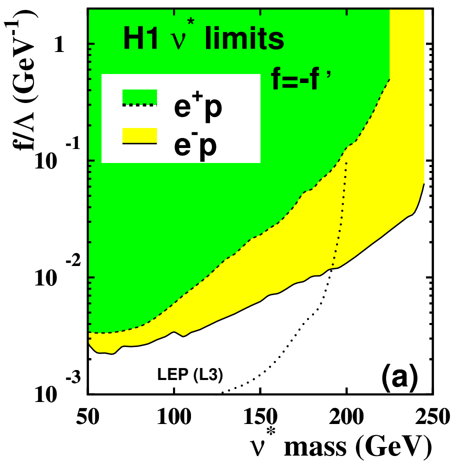

Figure 4. Exclusion limit on f/Λ at 95% confidence level as a function of the ν^* mass for $f = -f'$. Exclusion limit reported by H1 refers to e^-p data collected in 1998-1999 (~ 15 pb^{-1}) and to e^+p data collected in 1994-1997 (~ 37 pb^{-1}).

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