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Search for excited fermions

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Abstract. Recent results on searches for excited fermions at the LEP, HERA and Tevatron colliders are reported. These results improve the limits on the masses and couplings of excited fermions.

PACS. 12.60.Rc Composite models – 12.60.Cn Extensions of electroweak gauge sector – 13.66.Hk Production of non-standard model particles in e^-e^+ interactions – 13.60.Hb Total and inclusive cross sections (including deep-inelastic processes) – 13.85.Rm Limits on production of particles

1 Introduction

If leptons and quarks are not elementary particles, but composite, excited states of these particles can exist, called excited fermions.

The interactions between two excited fermions (f^*) and a gauge boson (f^*f^*V) is assumed to be vector-like. The single production and decays of excited fermions are determined by the coupling (f^*fV) which is described by the SU(3)×SU(2)×U(1) invariant lagrangian [1]:

$$\mathcal{L}_{f^*f} = \frac{1}{2\Lambda}\bar{f}^*_R\sigma^{\mu\nu}[g_s f_s \frac{\lambda_a}{2}G^a_{\mu\nu} + gf\frac{\tau}{2}W_{\mu\nu} + g'f'\frac{Y}{2}B_{\mu\nu}]f_L + h.c. \quad (1)$$

where Λ is the compositeness energy scale, the subscripts L, R stand for left-handed and right-handed respectively, g_s, g, g' are the Standard Model (SM) gauge coupling constants, $G^a_{\mu\nu}, W_{\mu\nu}, B_{\mu\nu}$ are the field strength tensors of the SU(3), SU(2) and U(1) fields, $\sigma_{\mu\nu}$ is the covariant bilinear tensor and f_s, f', f are parameters that govern the intensity of the couplings.

At HERA, excited electrons or quarks could be produced by the t-channel exchange of a γ or a Z, and excited neutrinos by the t-channel exchange of a W. Excited leptons ($e^*, \mu^*, \tau^*, \nu^*_e, \nu^*_\mu, \nu^*_\tau$) are accesible at LEP through pair production (exchanging a Z or a γ in s-channel) or single production (both in s-channel and t-channel). At the Tevatron, the production mechanism are similar to those at LEP, with an additional contribution arising from the exchange of gluons. Tevatron is sensitive mainly to the existence of excited quarks. Limits are commonly calculated assuming the relations between constants given in Table 1.

Table 1. Usual assumption for parameters in the search for excited fermions

Accelerator	assumption
HERA	$f = f', f_s = 0$ or $f = -f', f_s = 0$
LEP	$f = f', f_s = 0$ or $f = -f', f_s = 0$
Tevatron	$f = f' = f_s$

2 Experimental searches

Searches presented by the experiments operating at the HERA collider are performed using data collected at center of mass energies of 300 and 315 GeV, with a total luminosity per experiment of around 100 pb^{-1}. At LEP, center of mass energies go up to 209 GeV, and the total luminosity per experiment is about 500 pb^{-1}. At the Tevatron, a luminosity of 109 pb^{-1} at a center of mass energy of 1.8 TeV is used.

The experimental signatures of excited fermions depend on the collider, but the number of possible final states in , in any case, large. Nevertheless, there are several capabilities that must be present at any detector doing a sensitive search, because the possible final states involve isolated leptons, isolated photons, jets, missing energy and missing momentum. As an example, the main topologies of the possible final states at LEP are listed in Table 2.

Selection of the signal needs a good identification of photons, electrons, muons and jets, and a good determination of the missing energy and momentum. At HERA and LEP, many topologies are analysed, as was commented before. At Tevatron, the results presented here come from the analysis of events with two jets of high transverse momentum in the final state. A good reconstruction of the invariant masses in the final state is required to identify the possible presence of peaks.

Table 2. Final state topologies corresponding to the different production and decay modes of excited leptons at LEP (ℓ stands for charged lepton, j for hadronic jet)

channel	single production	pair production
$\ell^* \to \ell\gamma$	$\ell\ell\gamma, \ell\gamma$	$\ell\ell\gamma\gamma$
$\ell^* \to \nu W$	$jj\ell, jj$	$jj\ell, jjj$
$\ell^* \to \ell Z$	$jj\ell\ell, jj\ell$	-
$\nu^* \to \nu\gamma$	γ	$\gamma\gamma$
$\nu^* \to \ell W$	$jj\ell, jj$	$jj\ell\ell\ell, jj\ell\ell, jjjj\ell\ell$
$\nu^* \to \nu Z$	jj	-

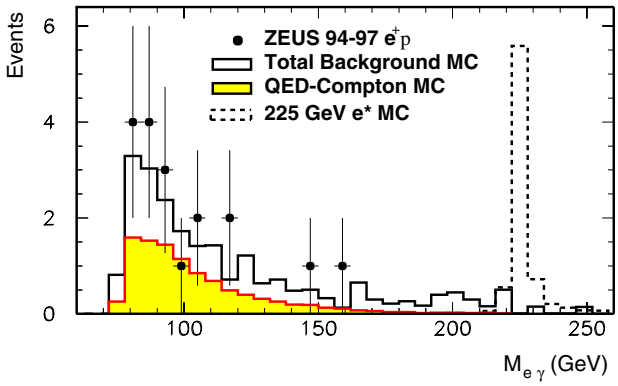

Fig. 1. Distribution of invariant mass of electron-photon pair from the ZEUS experiment at HERA collider (H1 has similar results). Dots are data, open histogram shows the SM expectations, shaded histogram the contribution of QED and dashed histogram the expected signal from an excited electron with mass of 225 GeV

Figure 1 shows a typical invariant mass distribution obtained in the experiments of the HERA collider [2]. Data are in good agreement with the Standard Model prediction in all the channels investigated.

At the LEP collider, data are also in very good agreement with the SM predictions in all the channels analysed [3]. Some distribuions are shown in Fig. 2.

The invariant mass distribution of the two high p_T jets measured by the D0 experiment at the Tevatron [4] and the expectations of the SM and of excited quarks of several masses can be seen in Fig. 3. Once more, data and SM are in agreement.

3 Results

Being data in good agreement with the SM predictions, no evidence is found for the existence of excited fermions. Then, some regions in the parameter space of the theory describing excited fermions can be excluded. Ususally, the exclusion regions are presented in the plane defined by the mass of the excited fermions and the coupling constant.

Typical exclusion regions are presented in Figs. 4, 5 and 6 for HERA [2], LEP [3] and Tevatron [4] colliders respectively for one of the common assumptions for the

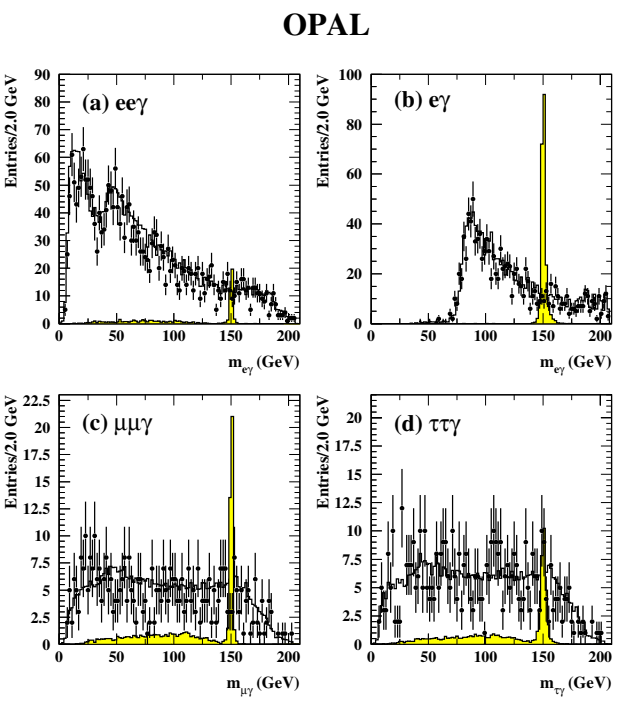

Fig. 2. Distribution of invariant masses in several channels obtained in the OPAL experiment at LEP (DELPHI and L3 have similar results). Data (dots) are in good agreement with the SM (open histograms) and not with the expectation if excited leptons were present (shaded histograms)

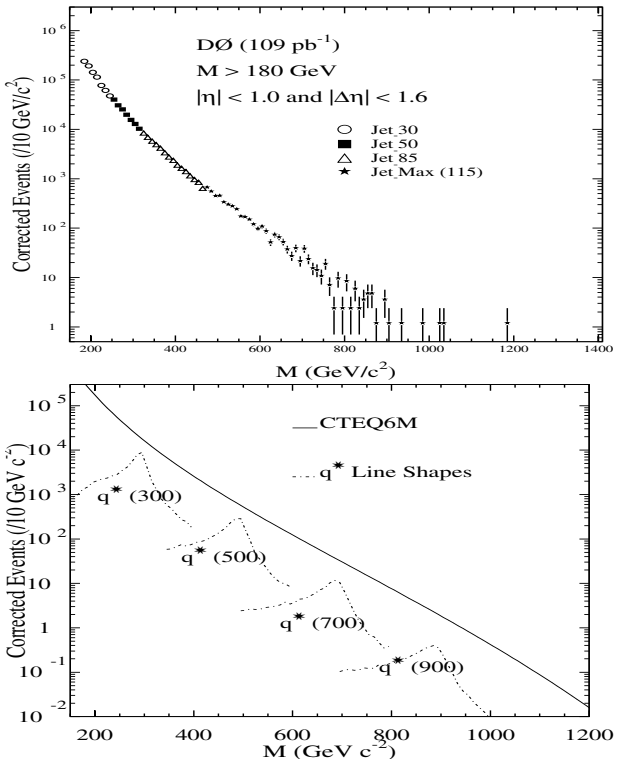

Fig. 3. Invariant mass distribution of the two jets with high p_T in the D0 experiment at Tevatron (top part). Data are in good agreement with the SM prediction that can be seen at the bottom together with the expectations coming from the existence of excited quarks of different masses (peaks)

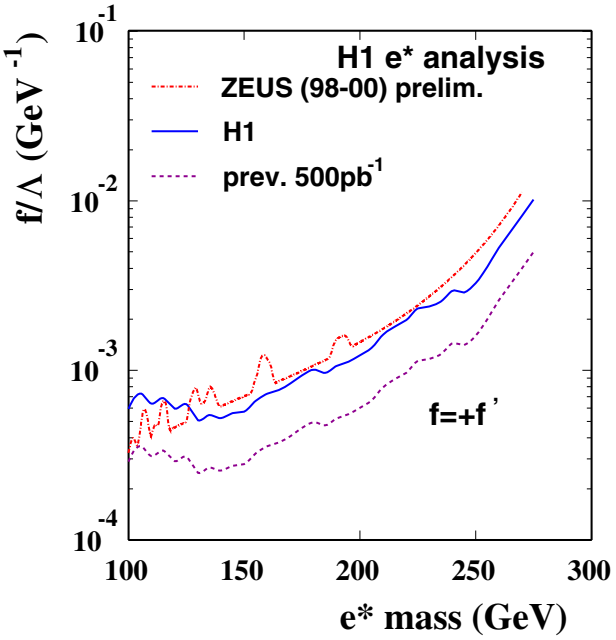

Fig. 4. Exclusion regions obtained by the HERA experiments. The region from the curves to the top of the plot is excluded. The expectation for the next phase of the HERA collider is also plotted

couplings ($f = f'$). For the other one the results are similar [2,3,4].

At LEP, an indirect search for excited electrons is also performed, using multiphoton final states [5]. It is complementary to the direct search, excluding regions of high mass (as no signal is found).

4 Conclusions

No evidence of excited fermions is found. Masses for excited leptons up to around 100 GeV are excluded by LEP for any coupling. D0 excludes masses of excited quarks up to 770 GeV for $f_s = f = f'$.

These searches will be performed with better sensitivity in the run-II of Tevatron, the next phase of HERA collider and LHC.

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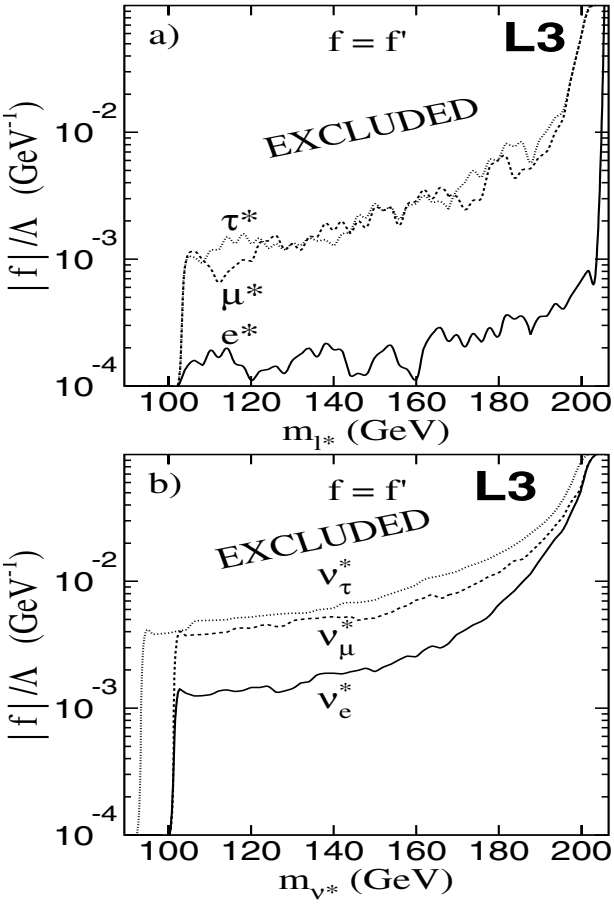

Fig. 5. Exclusion regions in the search for excited charged leptons (**a**) and excited neutrinos (**b**) obtained in the L3 experiment at LEP (DELPHI and OPAL have similar results)

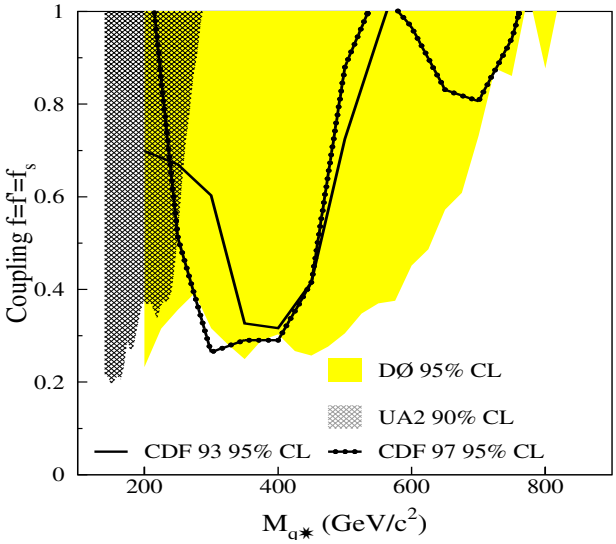

Fig. 6. Exclusion regions obtained in hadron colliders. Dark shaded region is excluded by UA2 experiment, light shaded region by D0 experiment. Regions excluded by the CDF experiment are also presented