SEARCH FOR EXCITED FERMIONS AT HERA

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(On behalf of the H1 and ZEUS collaborations)

A search for excited fermions at HERA is described. No evidence for new particle production is found and exclusion limits on cross section and coupling constants in a specific model are derived.

1 Introduction

The interest of composite models of quarks and leptons is their potential of explaining the quark-lepton generation structure and the observed pattern of fermion masses . The most convincing evidence for a substructure of quarks and leptons would be the discovery of excited quarks and leptons which are a prediction of these models. Electron proton interactions at very high energies provide an excellent environment to look for the first generation of excited fermions. At HERA magnetic-transition couplings of the electron to a heavy fermion would allow single production of e^* through t-channel γ and Z boson exchange and of ν^* through t-channel W boson exchange. In the same way excited quarks could be produced through t-channel gauge boson exchange between the incoming electron and a quark of the proton.

The analysis described here has been made using the H1 94 data and the ZEUS 94 and 95 data which correspond respectively to an integrated luminosity of $2.75pb^{-1}$ and $9pb^{-1}$. The event selections of the different decay channels are extensively described in reference [1] .

2 Search for excited leptons

H1 and ZEUS have investigated decays of excited electrons into most of the possible electroweak gauge bosons as well as radiative decay of excited neutrinos because of the clear signature of this particular decay channel . In the following the description of the analysis is organised according to the signals left in the detectors .

2.1 Events with electromagnetic clusters : the $e^* \rightarrow e\gamma$ and $e^* \rightarrow eZ_{\hookrightarrow ee}$ channels

The $e^* \rightarrow e\gamma$ decay mode is the most interesting channel to search for the e^* because of its important branching ratio ($\simeq 30\%$ for e^* masses above [2] $150GeV$) and its very clear signature. It has been shown [3] that about half of the e^* production cross section is expected in the elastic channel. So H1 has made two analyses : the first one addresses mainly the elastic and quasi-elastic part of the e^* production and consists in requesting 2 electromagnetic clusters in the calorimeters ($E_t \geq 2GeV$) in an otherwise empty detector (analysis referred as exclusive analysis). The main background here is the Wide-Angle Bremsstrahlung (WAB) process with a well separated $e-\gamma$ pair in the final state. 250 candidates are selected for an expected background of 267 ± 14 events.

The second method, called inclusive analysis, looks for events with at least 2 high E_t electromagnetic clusters ($E_t \geq 20$ and $10GeV$). This selection gives 19 candidates and the foreseen background is equal to 15 ± 2.5 events. The average efficiency for these 2 methods is about 80%.

ZEUS has performed an analysis requesting 2 electromagnetic clusters ($E_t \geq 15GeV$) and momentum conservation. They found 29 candidates and have estimated their background to be equal to 44 ± 4 events. The efficiency for this channel is 75%.

The invariant $e-\gamma$ pair masses of the candidates are shown on figure 1 (H1) and figure 2 (ZEUS) together with the expected background. The shapes of the data distributions and the predictions of the standard model are in agreement.

Using the events selected in the inclusive analysis H1 studied the $e^* \rightarrow eZ_{\hookrightarrow ee}$ channel. Additional cuts like requesting one of the (ee) invariant masses to be near to the Z mass are applied. The whole selection has an efficiency of 74%. No event survives these cuts.

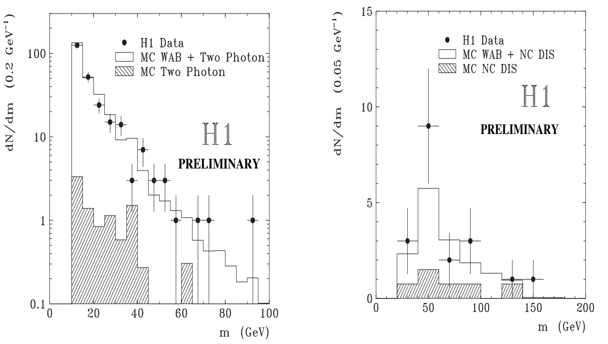

Figure 1: Mass spectrum of the selected electromagnetic cluster pairs : (left) exclusive analysis - (right) inclusive analysis

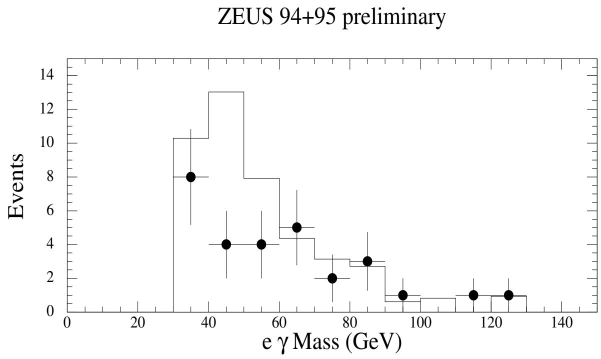

Figure 2: Mass spectrum of the selected high E_t electromagnetic cluster pairs. The solid points show the data and the histogram represents the expected background

2.2 *Inclusive muon analysis : the $e^* \to eZ_{\hookrightarrow \mu\mu}$ and $e^* \to \nu W_{\hookrightarrow \mu\nu}$ channels*

For this search, done by H1, events with at least one high tranverse momentum muon ($P_t \geq 10GeV$) in the final state are selected. Candidates for the $e^* \to eZ_{\hookrightarrow \mu\mu}$ channel should contain 2 muons with a high invariant mass ($M_{\mu\mu} \geq 60GeV$). The events with only one muon and little activity in the trackers are candidates for the $e^* \to \nu W_{\hookrightarrow \mu\nu}$ channel. The efficiencies for these 2 channels are respectively equal to 42% and 19%. No event survives the cuts.

2.3 *Channels with missing E_t and one electromagnetic cluster: $e^* \to eZ_{\hookrightarrow \nu\nu}$, $e^* \to \nu W_{\hookrightarrow e\nu}$ and $\nu^* \to \nu\gamma$*

H1 selects events with at least one isolated high E_t ($E_t \geq 20GeV$) electromagnetic cluster plus a large missing transverse energy ($E_t^{miss} \geq 20GeV$). The main backgrounds to these channels are the Charged Current DIS and the Neutral Current DIS processes with large fluctuations of missing transverse energy. 3 events are candidates for the e^* decay channels and the background is equal to (0.8 ± 0.5) events. The mean efficiencies are of the order of 80%.
No candidate is left for the $\nu^* \to \nu\gamma$ channel if it is requested that the electromagnetic cluster has no track pointing to it. Here the mean efficiency of selection is equal to 48%.

ZEUS made also a search for $\nu^* \to \nu\gamma$ candidates selecting events with one isolated electromagnetic cluster with $E_t \geq 15GeV$, no track pointing to it and missing E_t greater than $15GeV$. An additional cut on the total hadronic transverse energy ($E_t^{hadr} \geq 10GeV$) is made to take into account the recoil jet coming from the W propagator associated to the ν^* production. The expected background is (0.9 ± 0.3) event , the efficiency equals to 45% and no event is found.

2.4 *Channels with high E_t jets : $e^* \to eZ_{\hookrightarrow q\bar{q}}$, $\nu^* \to eW_{\hookrightarrow q\bar{q}}$, $e^* \to \nu W_{\hookrightarrow q\bar{q}}$, $\nu^* \to \nu Z_{\hookrightarrow q\bar{q}}$*

These channels are characterised by two high E_t jets with an electromagnetic cluster in the 2 first cases or with missing E_t for the 2 last channels. Background events are expected from the photoproduction, Neutral Current DIS or Charged Current DIS processes.

ZEUS has selected events with a high transverse hadronic energy deposited in the calorimeter ($E_t^{had} \geq 60GeV$ for the eZ and eW, $E_t^{had} \geq 40GeV$ for the νZ and νW) and a large reconstructed hadronic invariant mass (The definition of these variables is given in reference [4]). An additional cut requesting an electromagnetic cluster with $E_t \geq 15GeV$ selects the eZ and eW decay modes. The average efficiency is equal to 40% , 20 events are found with an expected background equal to 14 ± 2 events. 9 events are candidates for the νW and νZ decay channels if this last cut is replaced by a condition on the missing E_t

($E_t^{miss} \geq 15 GeV$). In this case the mean efficiency is also 40% and the background equal to 15 ± 1 events.

H1 has also done a search for the $e^* \to eZ_{\hookrightarrow q\bar{q}}$ and $e^* \to \nu W_{\hookrightarrow q\bar{q}}$ channels using a cone algorithm to define the jets. At least 2 jets should have a transverse energy greater than $15 GeV$ and a (jet-jet) invariant mass larger than $60 GeV$. The candidates for the first decay channel are then selected if they have in addition an isolated electromagnetic cluster with $E_t \geq 10 GeV$. 15 events are found when the background foreseen is equal to (14.6 ± 2.3) events, and the efficiency is equal to 59%. The second channel analysis rejects events with an electron found and requests the missing transverse energy to be greater than $20 GeV$. Here 3 events survive the cuts , the background is equal to (1.6 ± 1.2) events and the efficiency to 43%. The invariant masses M_{ejj} are shown on figure 3 .

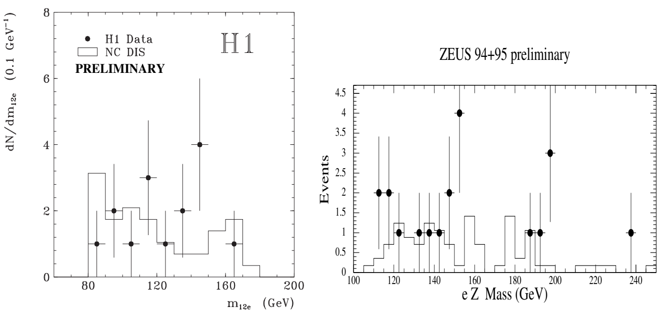

Figure 3: Distribution of the (e + 2jets) invariant masses : (left) H1 - (right) ZEUS

3 Search for excited quarks in the $q^* \to q\gamma$ channel

This search looks for a resonance in a (photon-jet) system and here the main backgrounds are coming from the photoproduction process with direct γ production or with high energetic π^0, Neutral Current DIS events when the track associated to the scattered electron is badly measured, and the WAB process when the electron is misidentified.

ZEUS selects events with a high E_t isolated electromagnetic cluster ($E_t \geq 15 GeV$), no track pointing to the cluster and the total transverse E_t deposited in the calorimeter larger than $30 GeV$. Furthermore the hadron system must approximatively balance the E_t of the photon. 24 candidates are found , the background is estimated to be 24 ± 3 events and the analysis efficiency is equal to 60%

In its analysis H1 asks for one high E_t isolated electromagnetic cluster ($E_t \geq 20 GeV$) with no track pointing to it and at least one jet which balances the transverse momentum of the γ . 8 events are selected corresponding to a background of (7.6 ± 1.7). The average efficiency is equal to 46%. On figure 4 the distributions of the invariant $\gamma - jet$ masses for the data and the expected background are shown. The shapes are in good agreement.

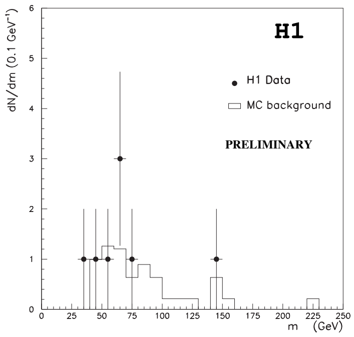

Figure 4: Invariant mass spectrum of the (photon-jet) system

4 Results

There is no evidence for excited leptons or excited quarks in the channels described above. Therefore upper limits on the product of the production cross section and the decay channel branching ratio have been derived at the 95% confidence level. These limits, given in function of the excited fermion mass, are shown on figure 5 for the H1 analysis and on figure 6 for the ZEUS analysis.

ZEUS has also set upper limits on the coupling strength in the compositeness model of Hagiwara, Komamiya, and Zeppenfeld [3]. On figure 7 the product of the coupling strength and the branching ratio : $\frac{\sqrt{|c_{VFf}|^2 + |d_{VFf}|^2}}{\Lambda} * \sqrt{BR(F \to f + V)}$ is shown in function of the excited fermion mass. These limits must be divided by $\sqrt{2}$ when comparing with published limits on $\frac{|c_{VFf}|}{\Lambda}$ (which assume $| c_{VFf} |=| d_{VFf} |$).

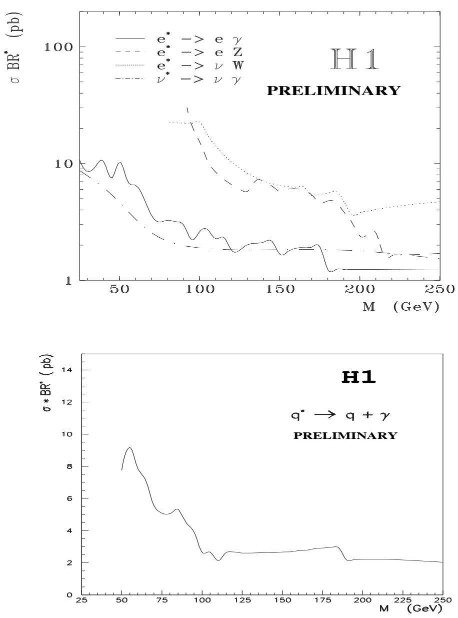

Figure 5: Upper limits at the 95% confidence level on the product of the cross section and the decay channel branching ratio: (top) e^* and ν^* production - (bottom) q^* production

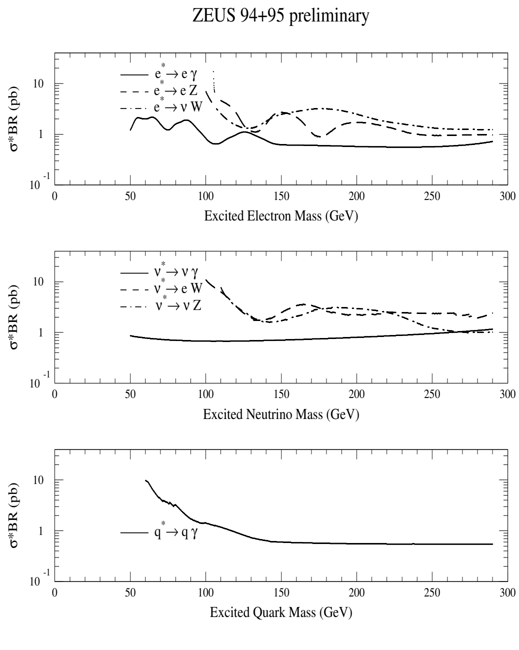

Figure 6: Upper limits at the 95% confidence level on the product of the cross section and the decay channel branching ratio

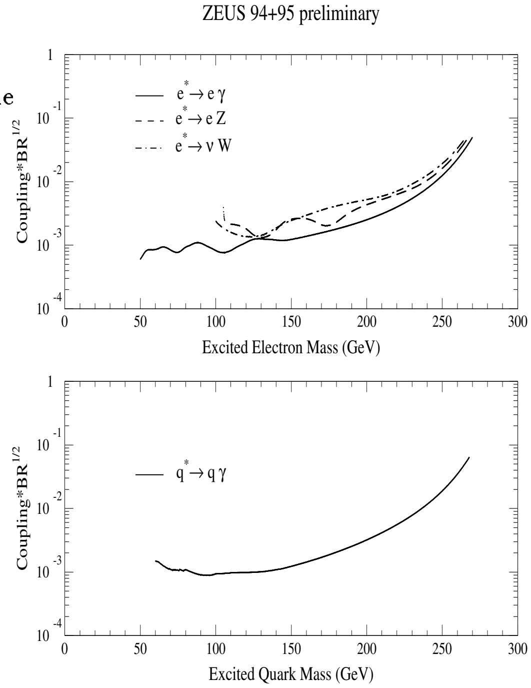

Figure 7: Upper limits at the 95% confidence level on the product of the coupling strength and the square root of the decay channel branching ratio

References

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2. U. Baur, M. Spira and P. Zerwas, *Phys. Rev.* D **42**, 815 (1990).
3. K. Hagiwara, S. Komamiya and D. Zeppenfeld, *Z. Phys.* C **29**, 115 (1985).
4. M. Derrick et al, *Z. Phys.* C **65**, 627 (1995).