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Search for Excited Fermions in H1

H1 Collaboration

Abstract

We present a search for excited electrons and quarks using H1 data with an integrated luminosity of 21 pb^{-1}. No evidence for new particle production is found and exclusion limits on cross sections are derived.

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1 Introduction

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 composite 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 . 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.

A full description of the H1 detector can be found in reference [1]. The analysis uses the e^+p data accumulated from 1994 to 1996 and a part of the 1997 data, over periods in which the main H1 components, the central jet chambers, the LAr calorimeter, and the luminosity system were fully operational. It corresponds to an integrated luminosity of 21 pb^{-1} .

Background not related to e^+p collisions is rejected demanding that the event time coincides with the time of the bunch crossing, using topological filters, and requesting a primary vertex within ± 35 cm of the nominal vertex value.

The search for excited electrons is made through the study of the channels $e^* \to e\gamma$, $e^* \to eZ \hookrightarrow ee$, $e^* \to eZ \hookrightarrow q\bar{q}$, $e^* \to \nu W \hookrightarrow q\bar{q}$ and the analysis on excited quark is done through the search for its radiative decay. Therefore the selection of events is based on the requirement of high E_t electromagnetic showers, high E_t jets or missing transverse energy.

2 Monte Carlo Description

The main Standard Model backgrounds which could mimic the above signatures are Deep Inelastic Scattering (DIS) Neutral Current, DIS Charged Current, Photoproduction processes and QED Compton scattering. Others processes, corresponding to much lower cross sections, such as prompt γ photoproduction or $\gamma - \gamma$ interactions have, also been simulated. The description of the Monte Carlo programs used are summarised in table 1 together with their integrated luminosities.

Reaction	Generator	Luminosity pb^{-1}
NC-DIS	DJANGO [5] HERACLES [6] + ARIADNE [7]	293.
CC-DIS	DJANGO HERACLES + ARIADNE	1421.
QED Compton	COMPTON [8]	416.
$\gamma p \to X$ (resolved) $\gamma p \to X$ (direct)	PYTHIA57 [9]	155. 185.
$\gamma p \to \gamma + X$ (resolved) $\gamma p \to \gamma + X$ (direct)	PYTHIA57	500. 500.
$\gamma\gamma \to e^+e^-$	LPAIR [10]	3100.

Table 1: Background Monte Carlo samples

To calculate the acceptance times efficiency of our selection criteria, a Monte Carlo simulation of excited fermion production and decay is necessary. This analysis uses the COMPOS [2] generator which is based on the cross section described in reference [3] for the e^* generation. The q^* simulation is performed following the expressions given in reference [4].

All Monte Carlo are interfaced to a full simulation of the H1 detector response.

3 Search for Excited Electrons

In the following the description of the analysis is organised according to the experimental signature.

3.1 Events with 2 electromagnetic clusters : the $e^* \to e\gamma$ and $e^* \to eZ_{\hookrightarrow ee}$ channels

The $e^* \to e\gamma$ decay mode is the most interesting channel to search for the e^* because of its large branching ratio ($\simeq 30\%$ for e^* masses above 150 GeV [11]) and its very clear signature. We look for events with 2 high E_t isolated electromagnetic clusters ($E_t \geq 20$ and 10 GeV). The main backgrounds are the Compton QED process with a well separated $e-\gamma$ pair in the final state and Neutral Current DIS with photon radiation or an isolated π^0. To reduce the latter NC DIS contribution, a cut on multiplicity of tracks pointing to the cluster is made for the events identified as 2 electrons. Additional cuts are applied to remove events with further detector activity at high E_t. The latter include a jet with E_t above 15 GeV, an electromagnetic cluster with E_t bigger than 5 GeV, or additional energy which amounts to 15% or more of the total transverse energy. This reduces Neutral Current DIS background. Another cut on longitudinal momentum conservation ($20 < \sum(E_i - P_{z_i}) < 80$ GeV) rejects photoproduction background, where E_i and P_{z_i} are the energy and the longitudinal momentum in the calorimeter cell i.

64 candidates are selected for an expected background of 68.6 events (50.7 ± 1.6 Compton and 17.9 ± 1.5 NC DIS). The efficiency of this selection is given in table 2. The invariant $e-\gamma$ pair masses of the candidates are shown on figure 1 together with the expected background. The shapes of the data distributions and the predictions of the Standard Model are in agreement.

Using the sub sample of events with 2 high E_t electromagnetic clusters, a third electromagnetic cluster with $E_t \geq 5$ GeV is requested. Then one event is left and (0.7 ± 0.4) background event is expected from NC DIS. The invariant mass of the 3 electromagnetic clusters is equal to 155 GeV. The acceptance of this selection is given in table 2.

M(f^*) GeV	50	75	100	150	200	250
$e^* \to e\gamma$	50	67	75	82	82	76
$q^* \to q\gamma$	27	42	48	51	54	51

M(e^*) GeV	95	120	150	200	250
$e^* \to eZ \hookrightarrow ee$	0.6	80	81	79	77
$e^* \to eZ \hookrightarrow q\bar{q}$	0.2	54	55	50	43
$e^* \to \nu W \hookrightarrow q\bar{q}$	0.5	33	48	47	38

Table 2: Efficiencies for different decay modes of the excited fermions f^*. They are given as percentages and are based on 1000 simulated events per mass and per channel.

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

These channels are characterised by two high E_t jets with an electromagnetic cluster in the first case or with missing E_t for the second one. Background events are expected from the Photoproduction, Neutral Current DIS or Charged Current DIS processes. A cone algorithm withe radius $R = 1$ in the $\eta - \phi$ plane is used to define the jets. At least 2 jets should have a transverse energy greater than 15 GeV, their polar angle greater than 10^o and a (jet-jet) invariant mass larger than 60 GeV . Candidates for the first decay channel are then selected if they have in addition an isolated electromagnetic cluster with $E_t \geq 10$ GeV and with a direction relatively forward ($10^o < \theta < 100^o$). A cut on longitudinal momentum conservation ($35 < \sum(E_i - P_{z_i}) < 65$ GeV) rejects Photoproduction background. 20 events are found for an estimated background of 32.6 events (32 ± 3 NC DIS and 0.6 ± 0.3 γp) events. The invariant mass M_{ejj} is shown on figure 2 .

The second channel analysis rejects events with an electron found and requests a minimum missing transverse energy of 25 GeV. An additional cut is made on E_t^{miss-p} which is calculated by projecting the missing transverse momentum vector $\vec{P}_t^{miss}$ on each of the 2 jets. E_t^{miss-p} is taken as the maximum absolute value of the 2 projections and is requested to be greater than 10 GeV. After these cuts one event is left to be compared to an expected background of 2.2 events (2.1 ± 0.2 CC DIS and 0.1 ± 0.1 γp events). The invariant $q\bar{q}$ and $\nu q\bar{q}$ masses of the candidate are respectively equal to 75 GeV and 182 GeV. The acceptance efficiencies of these 2 channels are given in table 2.

4 Search for Excited Quarks in the $q^* \rightarrow q\gamma$ channel

The production of q^* is dominated by γ exchange with small values of the squared momentum transfer and the scattered positron is often unseen in the detector. The final state is characterised by a photon and a jet and the main backgrounds are coming from the photoproduction processes with prompt γ production or with high energetic π^0, and Neutral Current DIS events when the track associated to the scattered electron is badly measured. In this analysis we ask for one high E_t isolated electromagnetic cluster $E_t(\gamma) \geq 20$ GeV, $10^o < \theta(\gamma) < 90^o$, and with no track pointing to it. We request also a high E_t jet with $E_t(jet) > 15$ GeV and $\theta(jet) > 5^o$ and no electron of E_t above 5 GeV. 23 events are selected corresponding to a background of 25.7 events (4.7 ± 1.1 NC DIS, 6.9 ± 1.2 γp, and 14.1 ± 0.8 prompt photon). On figure 3 the distributions of the invariant $\gamma - jet$ masses for the data and the expected background are shown. Two events have an invariant $\gamma - jet$ mass above 110 GeV when 1.4 are expected. But the Monte-Carlo used for the evaluation of the expected NC DIS number of events in this channel does not take into account the processes of photon emission by the quark. So this prediction should be considered as a lower limit.

5 Upper Limits on Excited Fermion production

In this analysis the number of events observed in the different channels and the predictions of the Standard Model are in good agreement, as well as the invariant masses distributions shapes. Therefore upper limits on the product of the f^* 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 electron mass and of the excited quark mass are shown on figure 4 and figure 5 respectively. The results improve significantly earlier published H1 results [12]. As an example the excluded cross section limit for the $e^* \rightarrow e\gamma$ cross section is about six times better. Similar analysis has been done by the ZEUS collaboration [13] which give limits on production cross sections and on coupling strengths in a compositeness model [3]. Our limits on cross sections are below those reported by ZEUS because the sample analysed by H1 corresponds to a larger integrated luminosity.

6 Conclusion

Using data taken from 1994 to 1996 and a part of those taken in 1997 a search for e^* and q^* production has been done. For excited electron the study uses the decay channels $e^* \rightarrow e\gamma$, $e^* \rightarrow eZ \hookrightarrow ee$, $e^* \rightarrow eZ \hookrightarrow q\bar{q}$ and $e^* \rightarrow \nu W \hookrightarrow q\bar{q}$. The analysis on excited quark is done through the search for its radiative decay. New limits for the production of excited electrons and quarks in high energy electron proton interactions have been obtained.

Acknowledgements

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Figures

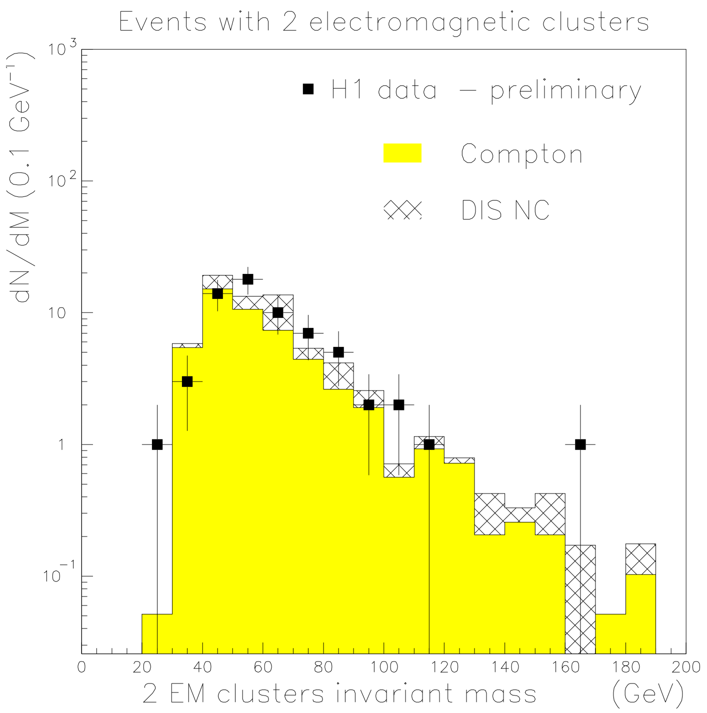

Figure 1: Invariant mass of the 2 electromagnetic clusters. Squares correspond to the data and the histograms to the different expected contributions of Standard Model processes

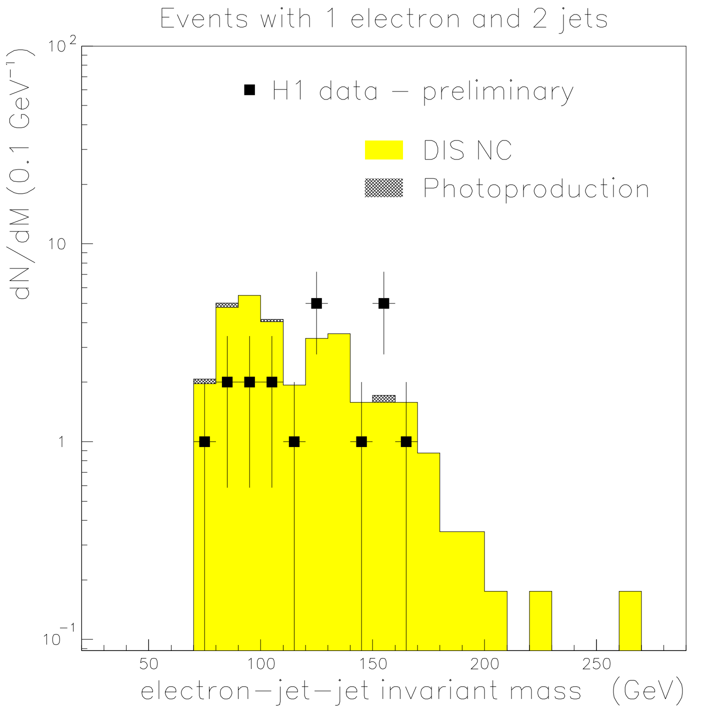

Figure 2: Invariant mass of the electromagnetic cluster and the 2 jets. Squares correspond to the data and the histograms to the different expected contributions of Standard Model processes

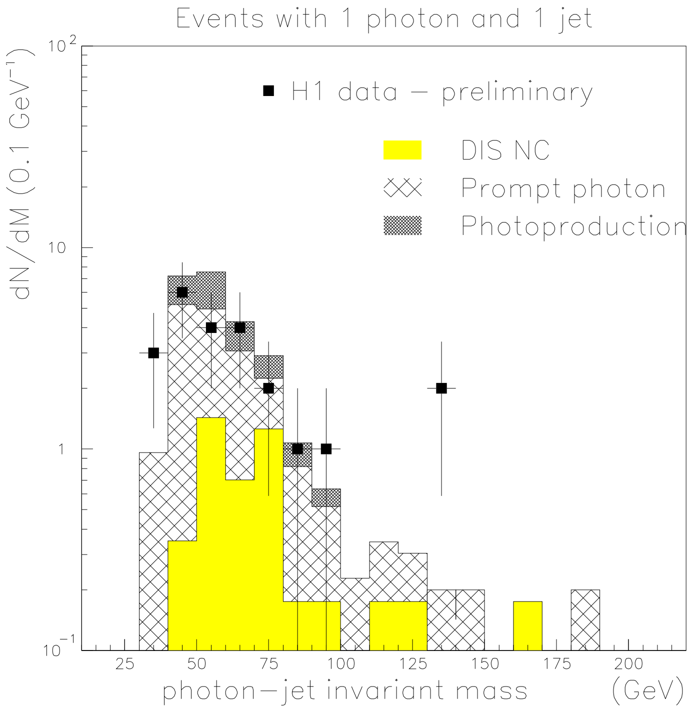

Figure 3: Invariant mass of the electromagnetic cluster and the jet . Squares correspond to the data and the histograms to the different expected contributions of Standard Model processes

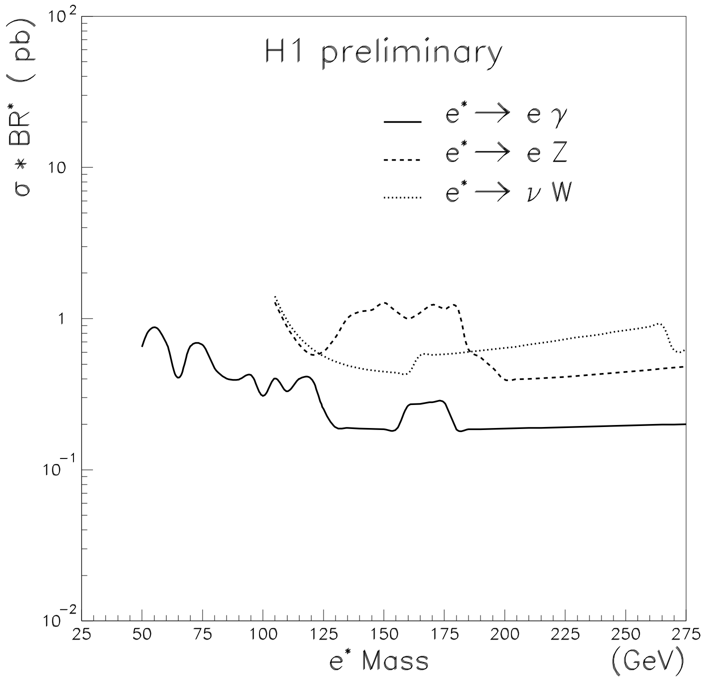

Figure 4: Upper limits at the 95% confidence level on the product of the cross section and the decay channel branching ratio for excited electron production

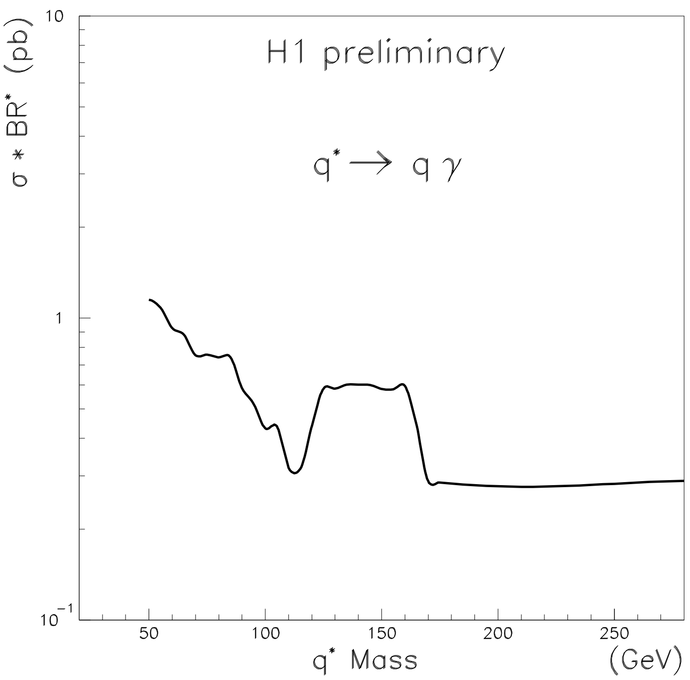

Figure 5: Upper limits at the 95% confidence level on the product of the cross section and the decay channel branching ratio for excited quark production