SEARCHES FOR EVENTS WITH ISOLATED LEPTONS AND LARGE MISSING TRANSVERSE MOMENTUM AND FOR EXCITED FERMIONS AT HERA *

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(On behalf of the H1 and ZEUS Collaborations)

Searches for events with isolated leptons and large missing transverse momentum, and for excited fermions in e^+p collisions at 300 GeV centre of mass energy have been performed at the HERA collider by both the ZEUS and H1 Collaborations. Results based on data taken by both experiments from 1994 to 1997 are presented.

1 Introduction

At the HERA ep collider the luminosity accumulated from 1994 to 1997 has allowed several searches for exotic particles to be performed. With up to $\simeq 40$ pb^{-1} of e^+p data per experiment, one becomes sensitive to physics processes with cross sections of the order of 1 pb. Both H1 and ZEUS collaborations have searched for signs of physics beyond the Standard Model, looking in particular for SUSY particles, leptoquarks, and excited fermions. In 1994, the H1 Collaboration has observed an outstanding event[1] featuring a high P_T muon together with large missing P_T. This triggered in both experiments a dedicated search for such events, with either an isolated electron or a muon. These searches are presented in the first section of this paper. The observation by H1 of a number of events with a muon exceeding the expectation from Standard Model processes is discussed. This excess is not in contradiction, at the present statistical level, with the non observation of such events by ZEUS, where this result is consistent with W production. In the second part, the searches for excited fermions are presented. Since no signal has been observed, constraints on the production of excited fermions are given.

2 Events with Isolated Leptons and missing P_T

2.1 H1 analysis

The H1 analysis[2] is based on a data sample of 36.5 ± 1.1 pb^{-1}. Requiring an imbalance in calorimetric transverse momentum greater than 25 GeV and high energy tracks ($P_T > 10$ GeV) the event sample is reduced to 124. Most of these events are of the charged current type, with a high P_T track within or close to hadronic jets. Defining in the η-ϕ plane, for each energetic track, D_{track} and D_{jet} as its distance to the closest track and to the closest jet respectively, only 6 events[2] survive the isolation cuts $D_{track} > 0.5$ and $D_{jet} > 1.0$.

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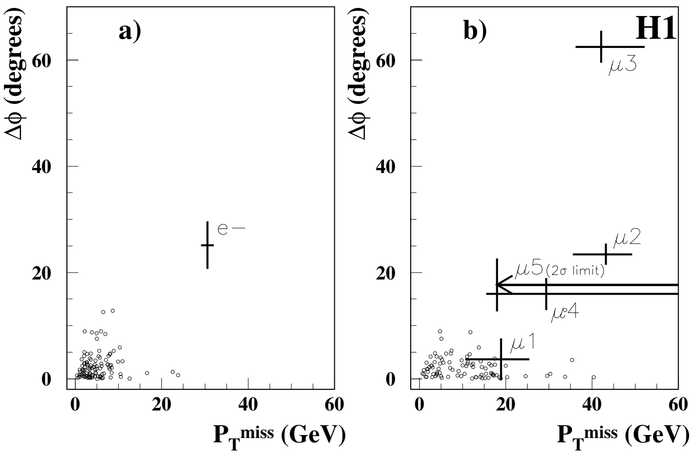

Figure 1. Distribution of events in P_T^{miss} and $\Delta\phi$: a) electron channel ; b) muon channel. The six events are displayed with their individual measurement errors. The open circles show the distributions for a neutral current control sample, described in the text.

Lepton identification criteria are applied to these tracks with the result that one of them contains an electron (e^-) and the other five are well identified as a muon (2 μ^+, 2 μ^- and one whose sign could not be determined because of its track stiffness). The events with a muon are labelled $\mu 1$ to $\mu 5$. All these events have a hadronic jet detected in the calorimeters and a significant missing total transverse momentum $\vec{P}_T^{miss} = -(\vec{P}_T^{lepton(s)} + \vec{P}_T^X)$, defined from the vector sum of the transverse momenta of all observed final states particles, P_T^X being the transverse momentum of the hadronic system. To make sure that the imbalance in P_T is not faked as a result of measurement uncertainties or high energy proton remnants lost in the beam pipe, the correlation between the final state acoplanarity $\Delta\phi$ (angle in the transverse plane between the hadronic system and the direction opposite to that of the isolated lepton) and the missing transverse momentum P_T^{miss} for each of the six observed events is compared in Fig.1 to that measured with a control sample of neutral current deep inelastic (NC-DIS) events selected from the same 37 pb^{-1} of data. For the muon channel, the electron track of the NC event is used to determine the relevant variables of the control sample in Fig. 1b. The probability for a NC-DIS event to have both $\Delta\phi$ and P_T^{miss} values higher than those measured for a given candidate is estimated from a high statistics simulation to be 1% for event $\mu 1$ and less than 0.1% for the other events.

The rates of Standard Model processes yielding events with isolated leptons and missing P_T are dominated by W production, the W decaying leptonically. The total number of events predicted by the Standard Model is 2.4±0.5 for the e-channel and 0.8±0.2 for the muon channel.

In Fig. 2 the 6 observed events are compared to W production Monte Carlo

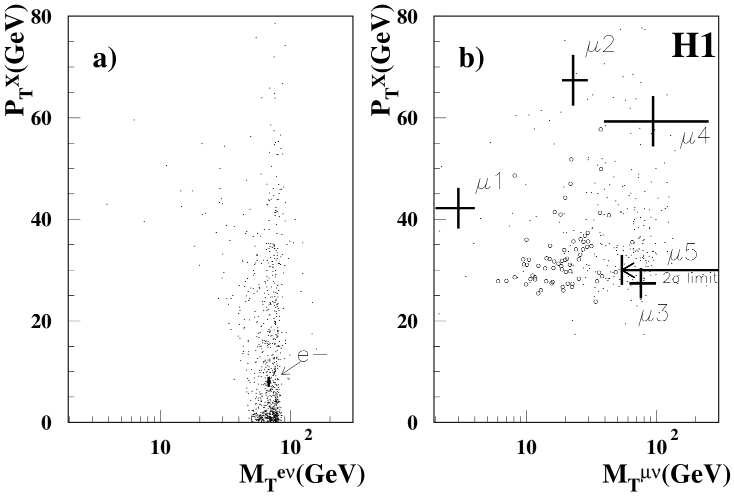

Figure 2. Comparison of the observed events with Standard Model distributions in the plane defined by the hadronic transverse momentum, P_T^X, and the lepton-neutrino transverse mass, $M_T^{\ell\nu}$. The W production and $\gamma\gamma \rightarrow \mu^+\mu^-$ Monte Carlo samples, indicated by points and open circles respectively, correspond to an integrated luminosity a factor 500 greater than the data.

events in the plane of the transverse momentum of the hadronic system, P_T^X, versus the transverse mass of the lepton-neutrino system, $M_T^{\ell\nu}$. The electron event and two of the muon events, ($\mu 3$ and $\mu 5$) are kinematically consistent with the Jacobian peak located around the W mass, and the low P_T^X expected for W production. The three other muon events can only marginally be accomodated within this interpretation. The number and the distribution of observed events in the P_T^X and $M_T^{\ell\nu}$ phase space make it unlikely that they are caused by two-photon physics ($\gamma\gamma \rightarrow \mu^+\mu^-$), also shown in Fig. 2.

The event $\mu 3$ [2] shown in Fig. 3 has in addition a low momentum e^+. Assuming that this is the scattered positron, the computed $\mu\nu$ invariant mass is found to be equal to 82^{+19}_{-12} GeV, compatible with the W mass.

2.2 ZEUS analysis

The search for events with isolated leptons and missing transverse momentum was done by the ZEUS collaboration in the frame of a W search[3], using the electron or the muon channels. The data sample corresponds to 46.6 pb^{-1}. For the electron channel, a missing P_T of 20 GeV is required for events with an identified e^+ or e^- with $P_T > 10$ GeV. The additional cuts $\theta_e < 1.5$ rad. and $\Delta\phi_{e-hadrons} > 0.3$ rad. remove NC-DIS events with backward electrons or with electrons back to back to the hadronic system in the transverse plane. Three events were found, the Standard Model expectation being of 3.0 events, 2.0 of which from W production. All observed events contain an e^+ and have kinematics consistent with W production and decay, as shown in Fig. 4. Using these events and the efficiency of 38 % to

$$e^+p \rightarrow e^+\mu^-X$$

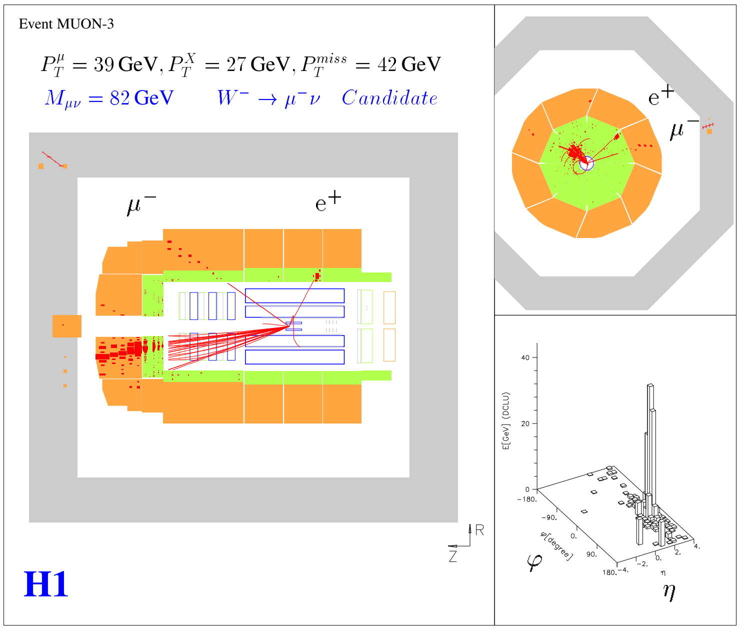

Figure 3. Event $\mu3$ which is compatible with $W^- \rightarrow \mu^-\nu$

select W$\rightarrow$eν events (estimated using the EPVEC[4] Monte Carlo) the W production cross section is : $\sigma(e^+p \rightarrow e^+WX) = 1.0^{+1.0}_{-0.7} \pm 0.3\ (syst)$ pb, which is consistent with the Standard Model prediction.

W events in the muon channel are required to have both calorimetric and total missing transverse momentum above 15 GeV. The muon is identified as a track with a momentum higher than 5 GeV and having a minimum ionizing pattern in the calorimeters. The selection efficiency in this case is 11 %. No events were found while 1.2 were expected, 0.6 from W production, allowing to set a limit on the W production cross section: $\sigma(e^+p \rightarrow \mu^+WX)\ < 4.4$ pb (95 % C.L.). A second analysis[5] (ZEUS-2 in table 1) has been performed, in which the same strategy as used by H1 was applied. Four events with a well isolated high P_T track were found, all identified as e$^+$. No event with a muon was found, for a Monte Carlo expectation of 1.5$\pm$0.4 events.

2.3 Comparison of H1 and ZEUS results

The results of the searches for events with isolated leptons and large missing transverse momentum are summarised in Table 1. H1 sees an excess of events with a muon whereas ZEUS does not. A comparison of $P_T > 10$ GeV track finding efficiencies for both experiments[6] shows that the isolated muons of the H1 events are at polar angles where the ZEUS track finding efficiency is already high. At present

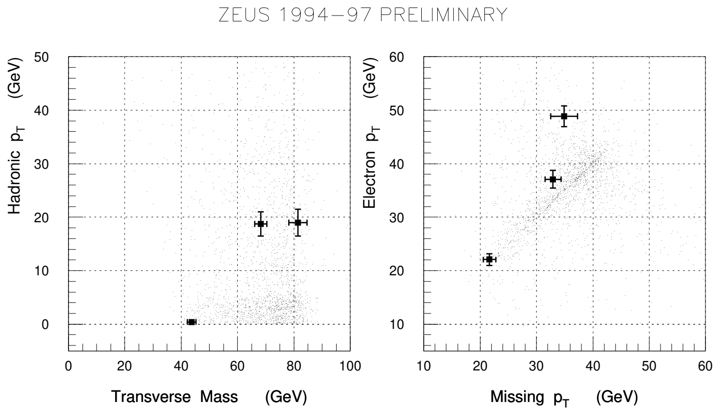

Figure 4. Comparison of the 3 observed e^+ events (crosses) to the W production from a Monte Carlo sample corresponding to a luminosity a factor 1000 higher than the data. The left plot shows the hadronic transverse momentum P_T^X versus the electron-neutrino transverse mass $M_T^{e\nu}$ and the right one shows the electron transverse momentum versus the missing transverse momentum.

Table 1. Summary on HERA searches for isolated leptons with missing transverse momentum. ZEUS-2 is the ZEUS analysis done using H1 selection criteria.

	Electrons		Muons	
	DATA	MC	DATA	MC
H1 $36.5\ pb^{-1}$	1 e^-	2.4 ± 0.5	5 $2\mu^+, 2\mu^-, 1\mu$	0.8 ± 0.2
ZEUS-1 $46.6\ pb^{-1}$	3 e^+	3.0 ± 0.6	0	0.8 ± 0.3
ZEUS-2 $46.6\ pb^{-1}$	4 e^+	4.2 ± 0.6	0	1.5 ± 0.4

there is no contradiction between the two experiments and a statistical fluctuation cannot be ruled out. Possible interpretations for the H1 events marginally fitting the Standard Model W production topology, include production and decay of supersymmetric particles[7].

3 Searches for Excited Fermions

In composite models of quarks and leptons the production of new heavy particles, interpreted as excitations of the ground state, may be expected. Therefore the direct observation of either excited leptons or excited quarks would provide strong evidence for a new layer in the substructure of matter. At HERA, production of excited fermions could occur via t-channel exchange of a gauge boson, γ or Z in the e^* and q^* cases and $W^\pm$ for ν^*. Such excited states decay to known

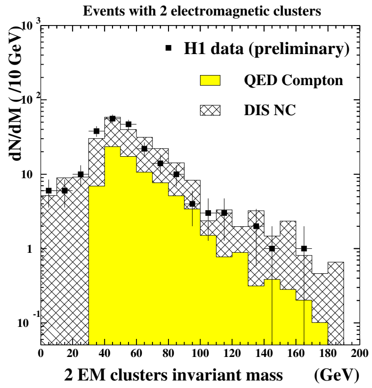

Figure 5. Invariant mass of the 2 electromagnetic clusters of the H1 analysis. The squares correspond to the data selected in the inclusive analysis. The different expected Standard Model contributions, normalized to the luminosity of the experiment are also shown.

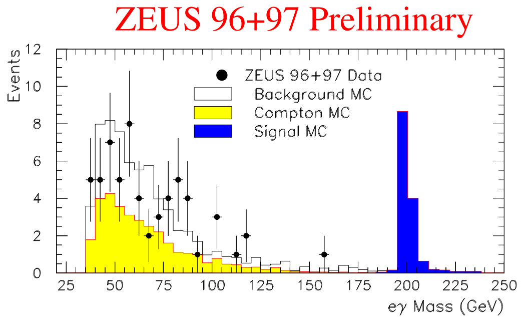

Figure 6. eγ invariant mass of the selected e* candidates of the ZEUS analysis (points) and of the total background from NC-DIS and QED Compton (open histogram). The QED Compton contribution alone is shown separately (shaded histogram). An example of e* signal with a mass of 200 GeV is also shown (dark histogram, arbitrary normalization).

fermions and gauge bosons, therefore the strategy for excited fermion searches is to look for a fermion-boson resonance. The H1 and ZEUS collaborations have previously published excited fermion analyses[8,9] based on respectively 2.75 pb^{-1} and 9.4 pb-1 of e$^+$p data. The results presented here are the same as those presented at ICHEP98[10,11], based on 37 pb^{-1}. Among the many possible channels we shall concentrate here on searches of e* decaying into eγ. The relatively high branching ratio (expected to be 30 % for M$_{e^*} > 150$ GeV) and the clear experimental signature of two electromagnetic clusters make the search quite straightforward. The main background sources are the QED Compton process with a well separated e - γ pair in the final state and the neutral current DIS with photon radiation or an isolated π^0. The contribution of electron pair production in two-photon processes is found to be small.

3.1 H1 analysis

Both exclusive and inclusive analyses have been performed. In the first case, 2 isolated electromagnetic clusters are required, with a total energy above 20 GeV together with an "empty detector" condition where less than 5 GeV should be deposited elsewhere in the calorimeters. The average efficiency for e* masses above 50 GeV is 47 %. The inclusive analysis is meant to improve the acceptance for e* masses above 50 Ge : the empty detector condition is relaxed and 2 high E$_T$ isolated electromagnetic clusters (above 10 and 20 GeV respectively) are required. The efficiency for e* masses of 50 GeV is then 65 %, increasing to 80-85 % at higher masses. In this inclusive analysis, 223 candidate events were found, for an expected Standard Model background of 239$\pm$6 events (76 QED Compton, 161 NC DIS and 2 $\gamma\gamma$). The invariant mass spectrum of the 2 electromagnetic clusters is shown in

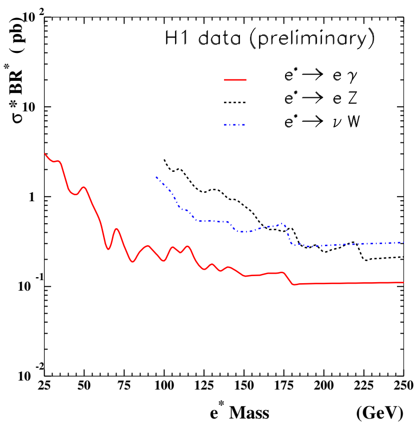

Figure 7. Limits on $\sigma^* \times Br^*$ for the H1 excited electron search in three decay modes. The regions above the curves are excluded at 95% C.L..

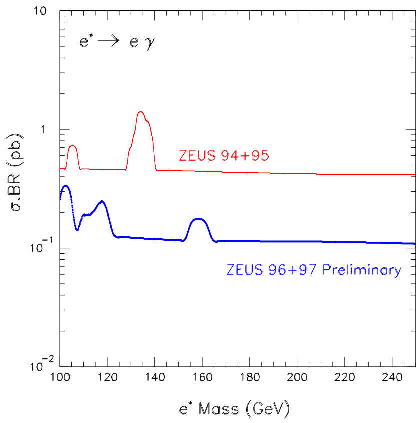

Figure 8. Limits on $\sigma^* \times Br^*$ for the ZEUS excited electron search in the e* $\rightarrow$ eγ channel. The regions above the curves are excluded at 95% C.L..

Fig. 5, together with the expected background. The shapes of the observed and expected distributions are in good agreement and no excess of events is observed.

3.2 ZEUS analysis

Here, two electromagnetic clusters of transverse momentum above 10 GeV (30 GeV if the polar angle of the cluster is below 0.3 rad) are required. Low activity in the tracking system, except for the track associated to the electron is also required, to select elastic and quasi-elastic production of e*. The acceptance for e* ranges from 60% for mases of 100 GeV to 75% at higher masses. 60 candidate events are found, for an expected Standard Model background of 68±2 events. The invariant mass spectrum of the 2 electromagnetic clusters is shown in Fig. 6. Here again, no peak in the mass distribution, characteristic of e* production, is observed.

3.3 e cross section exclusion limits*

With the present data, good agreement with the Standard Model expectation for production of e* is observed by both experiments. Limits can thus be obtained, independently of any model, on the product $\sigma^* \times \mathrm{Br}^*$ of the production cross section and the branching ratio to a given final state. These limits are shown in Figs. 7 and 8. The best limits are obtained with the channel e* $\rightarrow$ eγ (Fig.7) due to the higher selection efficiency. Both experiments obtain similar results in the mass domain 25 to 250 GeV. For the highest mass region a limit of $\sigma^* \times \mathrm{Br}^* < 0.1$ pb can be set. Using a phenomenological model[12] and assuming relations between the coupling constants f, f' and f_s of an excited fermion to a $SU(2)_L$, $U(1)_L$ and $SU(3)_C$ gauge boson respectively, the cross sections depend on a single parameter (e.g. f/Λ, where Λ is the substructure scale), besides the excited fermion mass. The HERA results allow upper limits for the ratio f/Λ to be derived, from 0.6×10^{-3} to 1.0×10^{-2} GeV^{-1}, for an e* mass range from 60 to 250 GeV. Assuming $f/\Lambda = 1/M_{e^*}$, excited electron states with masses below 222 GeV are excluded at 95% C.L. This result improves the present limits on the e* mass given by the LEP experiments. The best limit is given by the L3 experiment[13] where e^* with masses below 91.1 GeV are excluded at 95 % C.L. assuming they are produced in pairs. For single e* production, also studied at LEP, the limits on f/Λ are more stringent than the HERA ones up to masses corresponding to the highest LEP centre of mass energy (about 180 GeV with LEP2). The HERA results extend these limits to higher masses.

For the ν^*, the H1 search[10] sets upper limits on f/Λ ranging between 0.3×10^{-2} and 9×10^{-2} GeV^{-1} for an ν^* mass interval of 60 to 185 GeV, slightly improving the limits set by the LEP experiments. In the case of the search for q*, the HERA results complement those obtained by the TeVatron experiments, using different assumptions on the f_S coupling constant. At HERA it is assumed that f_S=0 (electroweak couplings), whereas at the TeVatron, assuming that q* production takes place through a quark-gluon fusion mechanism, requiring a strong q* coupling (i.e. $f_S\neq0$), $f=f'=f_S=1$ is used. The HERA[10] exclusion region for q* masses between 60 and 230 GeV corresponds to values of f/Λ above 0.8×10^{-3} to 1.9×10^{-2} GeV^{-1}.

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References

1. T. Ahmed *et al.*, DESY 94-248.
2. C. Adloff *et al.*, DESY 98-063, 1998, Eur.Phys. J. C 5 (1998) 4,575-584.
3. ZEUS Coll., ICHEP98, contributed paper 756.
4. U. Baur, J.A.M. Vermaseren, D. Zeppenfeld, *Nucl. Phys.* B **375**, 3 (1992).
5. T. Matsushita, talk at the 3rd UK Phenomenology Workshop on HERA Physics, St John's College, Durham, UK, Sept. 1998.
6. C. Diaconu *et al.*, contribution to the 3rd UK Phenomenology Workshop on HERA Physics, St John's College, Durham, UK, Sept. 1998, hep-ph/9901335.
7. T. Kon *et al.*, *Mod. Phys. Lett.* A **12**, 3143 (1997).
   E. Perez, talk at SUSY98, Oxford, July 11-17 1998.
8. H1 Coll., S. Aid *et al.*, *Nucl. Phys.* B **483**, 44 (1997).
9. ZEUS Coll., J. Breitweg *et al.*, *Z. Phys.* C **76**, 631 (1997).
10. H1 Coll., ICHEP98, contributed paper 581.
11. ZEUS Coll., ICHEP98, contributed paper 758.
12. K. Hagiwara *et al.*, *Z. Phys.* C **29**, 115 (1985).
13. L3 Collaboration, ICHEP98, contributed paper 498.