Events with high energy isolated leptons and missing transverse momentum and excited fermion searches at HERA

Cristinel DIACONU

Centre de Physique des Particules de Marseille, 13288 Marseille cedex 09, France
E-mail: diaconu@cppm.in2p3.fr

The observation of events containing isolated leptons and missing transverse momentum in e^+p collisions at HERA is reported. H1 observed one event containing an electron e^- and five events containing muons $\mu^\pm$. ZEUS observed three events containing positrons e^+. All events have significant missing transverse momentum. The main Standard Model explanation is the production of $W^\pm$ bosons.
Excited fermion searches with H1 and ZEUS detectors are also presented. Several decay channels giving different experimental signatures are analysed. No experimental evidence for excited fermions is found. Limits on production and decay parameters versus the excited fermion mass are extracted for mass domains up to 250 GeV.

1 Introduction

At HERA 27.5 GeV positrons collide with 820 GeV protons resulting in a center of mass energy of 300 GeV. This configuration open an unexplored domain for new physics searches. This note presents two analysis performed by H1 and ZEUS collaborations on data samples corresponding to an integrated luminosity of 40 pb^{-1}/experiment.

In the first part the observation of events with high energy isolated leptons and missing transverse momentum is reported. The search for excited fermion production and decay is described in the second part.

2 Observation of events containing high energy isolated leptons and missing transverse momentum

In the frame of the Standard Model, events containing a high energy lepton together with significant missing energy are issued at HERA from the W production and decay in e-p collisions. The same final state topology can also provide a signature for the processes beyond the Standard Model like production of excited fermions or supersymmetric particles.

Both HERA collaborations have searched for events with high energy isolated leptons and missing transverse momentum [1,2]. The charged leptons are directly identified in compact detectors like H1 and ZEUS. The presence of non-detected particles can only be deduced from a transverse momentum imbalance.

2.1 H1 analysis

The H1 analysis [1] is based on the inclusive search for events with the calorimetric transverse momentum (P_T^{calo}) above 25 GeV. This condition ensures a good

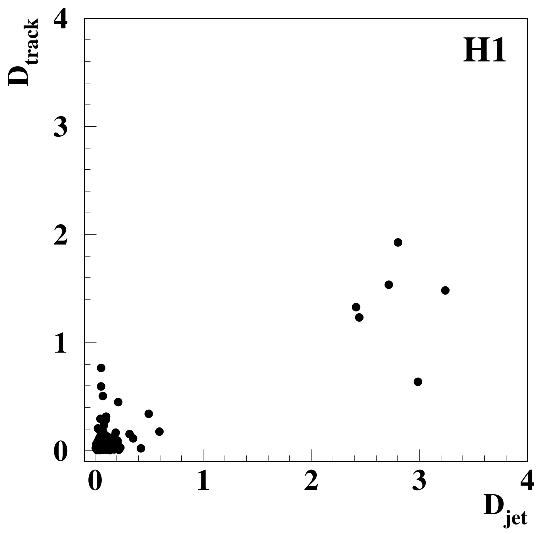

Figure 1: High energy track isolation with respect to the tracks (D_{track}) versus the isolation with respect the hadronic jets (D_{jet}) in the events with $P_T^{calo} > 25$ GeV.

understanding of experimental efficiencies and drastically reduces the contributions of neutral current deep inelastic scattering (NC-DIS) and photoproduction processes. Among the selected sample, 124 events contain also a high energy track with a transverse momentum $P_T > 10$ GeV. The isolation of those tracks with respect to the calorimetric deposits and to other tracks is quantified using the Cartesian distance in the $\eta-\phi$ plane, where η stand for pseudorapidity and ϕ is the azimuth in a right reference frame having its positive z direction along the incoming proton and the origin in the event interaction vertex. The isolation of high P_T tracks with respect to the closest track (D_{track}) and to the closest hadronic jet

(D_{jet}) is presented in the figure 1. A majority of high energy tracks present small isolation values corresponding to tracks inside hadronic jets. Six events have isolated high energy tracks ($D_{jet} > 1.0$ and $D_{track} > 0.5$). A loose lepton identification using calorimetric deposit shape for $e^{\pm}$ and the calorimeter and the muon detector information for $\mu^{\pm}$ reveals the leptonic nature of the isolated tracks: one event contain an e^{-} and five events contain muons: $2\mu^{+}$ $2\mu^{-}$ and one very energetic μ associated to a stiff track whose sign cannot be determined.

In all events a hadronic shower has been detected in the calorimeters. The leptonic signature has been investigated in details and found to be consistent with the assigned hypothesis. In particular, the path of calorimetric deposits for muon candidates sampled over at least seven interaction lengths has been found compatible with a minimum ionizing particle.

All events present significant imbalance in total transverse momentum, reconstructed using calorimetric information for the electron event and using in addition the muon track information for the muon events. The missing transverse momentum points to the presence of an undetected particle. Additional evidence supporting this hypothesis is provided by the acoplanarity ($\Delta\phi$) observed in most events between the hight P_T lepton and the hadronic system.

The processes within the Standard Model which may yield events with an isolated high P_T lepton and missing transverse momentum have been investigated by applying the selection procedure explained above. Events with more than one isolated lepton of the same generation have not been taken into account as they do not correspond to the topology of the observed events.

The main Standard Model contribution in both electron and muon channels is provided by the W boson production in e-p collisions. The subsequent W leptonic decay $W \rightarrow \ell\nu$ provide both an isolated high energy charged lepton and missing transverse momentum associated to the undetected neutrino. This process is studied using EPVEC generator [3]. The selection efficiencies are 33% in the electron channel and 10% in the muon channel. The expected number of events corresponding to an integrated luminosity of 37 pb^{-1} are 1.7 ± 0.5 in the electron channel and 0.5 ± 0.1 in the muon channel.

The lower acceptance in the muon channel is mainly due to the cut on the calorimetric transverse momentum at 25 GeV which selects events with a high P_T hadronic jet associated to the recoiling quark. This topology is disfavoured in the W production process, where the P_T distribution of the recoil hadronic jet peak at zero with and exponential tail towards higher values described by a perturbative computation in EPVEC.

Other standard Model contributions can yield events with isolated leptons and missing transverse momentum.

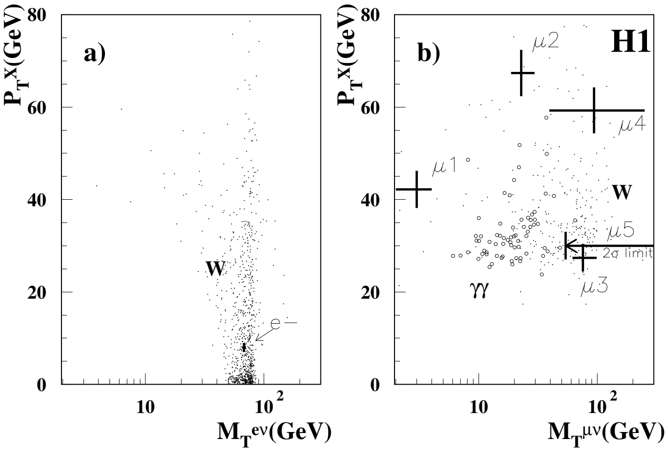

Figure 2: Comparison of the observed event (crosses) to the Standard Model contributions – W production(points) and photon-photon process (small circles) – in the plane defined by the hadronic transverse momentum P_T^X and the lepton-neutrino transverse mass $M_{\ell\nu}$. The Monte Carlo sample correspond to a luminosity a factor 500 higher than the data.

For instance, the NC-DIS process can produce events containing an isolated positron e^{+} and missing transverse momentum due to energy measurement fluctuations. The muon events topology may also be produced in photon-photon muon pair production, with one of the muons escaping down the beam pipe. All the other contributions have been estimated to bee small or negligible.

The analysis of the Standard Model processes concluded to an expected number of events of 2.4 ± 0.5 events in the electron channel ($1e^{-}$ event observed) and 0.8 ± 0.2 $\mu^{\pm}$ events in the muon channel (5 events observed).

The expectation being dominated by the W production process, in the figure 2 a comparison of the observed events and the W simulation is done in terms 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 are consistent with the Jacobian peak around the W mass. Three of the muon events only marginally agree with the W interpretation. None of the muon events is consistent with the muon pair production in photon-photon collisions also represented in the figure 2.

2.2 ZEUS analysis

The search for events with isolated leptons and missing transverse momentum has been done by the ZEUS collaboration in the frame of the W production analysis [2]. The selection in the electron channels is based on the requirement of a missing transverse momentum above 20 GeV for events with an identified $e^{\pm}$ having

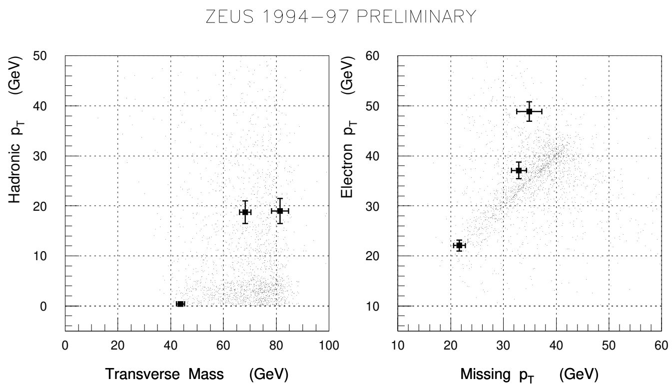

Figure 3: Comparison of the 3 e^+ observed events (crosses) to the W production in the planes defined by the hadronic transverse momentum P_T^X and the lepton-neutrino transverse mass $M_{\ell\nu}$(left) and electron transverse momentum versus missing transverse momentum (right). The Monte Carlo sample correspond to a luminosity a factor 1000 higher than the data.

a transverse momentum higher than 10 GeV. The NC-DIS events are rejected by removing from the sample the events with backward electrons ($\theta_e < 2$ rad.) or with electrons aligned to the hadronic system in the transverse plane ($\Delta\phi_{e-hadrons} > 0.3$ rad.). The efficiency to select W events was estimated to be 38% using EPVEC[3]. With those cuts three events have been selected in a data sample corresponding to an integrated luminosity of 46.6 pb^{-1}. The Standard Model expectation has been calculated to be 3 events, the W production accounting for 2 events. All observed data events contain a positron (e^+) and the kinematics is consistent with the W production and decay, as can be seen in the figure 3. Using those events, ZEUS collaboration computed the W production cross section $\sigma(e^+p \to e^+WX) = 1.0^{+1.0}_{-0.7} \pm 0.3(syst.)$

The selection of W events in the muon channel is based on the requirement of both calorimetric and missing transverse momentum above 15 GeV. The muon is then identified as a track reconstructed in the tracking system with a momentum higher than 5 GeV and corresponding to a minimum ionizing pattern in the calorimeters. The selection efficiency for W events is 11%. No events are selected in the ZEUS data for an expectation of 1.2 events (0.6 from W production). A limit on the W production cross section has been calculated in this analysis: $\sigma(e^+p \to e^+WX) < 4.4$ pb at 95% C.L. .

In order to compare to the H1 analysis, ZEUS searched for events having an identified muon and high calorimetric transverse momentum. For $P_T^{calo} > 20$ GeV 1 event is observed in the data for 2.3 events expected and no event is observed with $P_T^{calo} > 30$ GeV while 0.8 events are expected.

In conclusion, ZEUS collaboration observe three W-like events in the $e^\pm$ channel and no event with high

Table 1: H1 and ZEUS results in the isolated lepton and missing P_T event searches.

Analysis	$e^\pm$ channel		$\mu^\pm$ channel	
	DATA	MC	DATA	MC
Strategy	$P_T^{calo} > 25 P_T^{e} > 10$		$P_T^{calo} > 25 P_T^{\mu} > 10$	
H1	$1\ e^-$	2.4 ± 0.5	$5\ \mu^\pm$	0.8 ± 0.2
36.5 pb^{-1}				
Strategy	$P_T^{calo} > 20 P_T^{e} > 10$		$P_T^{calo} > 30 P_T^{\mu} > 5$	
ZEUS	$3\ e^+$	3.0 ± 0.7	$0\ \mu^\pm$	0.8 ± 0.3
46.6 pb^{-1}				

energy isolated muon and missing transverse momentum.

2.3 Comparison H1/ZEUS

Table 1 summarize the results obtained by H1 and ZEUS in searching for events containing high energy isolated leptons and missing transverse momentum. The observed and expected numbers of events are in agreement in the electron channel. In the muon channel, H1 analysis reveals an excess of events compared to the expectation. This excess is not present in the ZEUS data. Three of the H1 events are kinematically atypical for any Standard Model interpretation and can only be explained with the present data sample by a statistical fluctuation. Beyond the Standard Model possible explanations of such topology includes production and decay of excited quarks or supersymmetric particles [4].

3 Excited fermion searches at HERA

The excited fermions are one of the possible manifestations for the substructure of the nowadays fundamental particles. The production and decay of excited fermions F^* are described in terms of a phenomenological Lagrangian [5]:

$$L_{FF^*} = \frac{e}{\Lambda} \sum_{V}^{\gamma,Z,W} \bar{F}^* \sigma^{\mu\nu}(c_V - d_V\gamma^5) F \partial_\mu V_\nu + h.c.$$

where c_V and d_V are coupling constants at the $F \leftrightarrow F^*$ vertex labelled for each vector boson V, and Λ is the compositeness scale. The precise measurement of muon $g-2$ and the absence of electron and muon electric dipole moment implies that $c_V = d_V$ for compositeness scales less than 10–100 TeV. This fact lead to an interaction Lagrangian where the coupling constants of excited

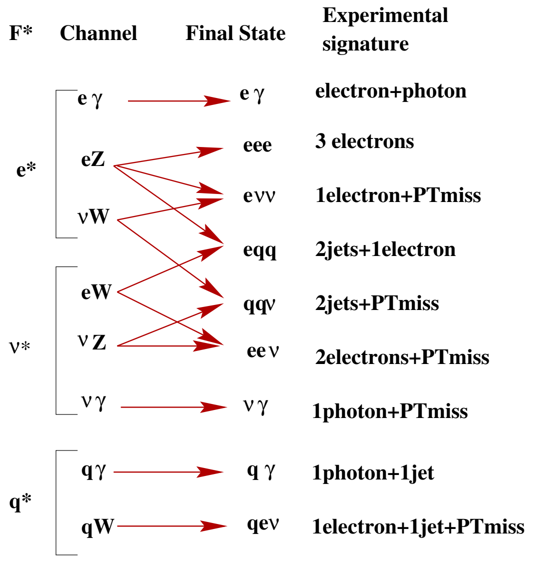

Figure 4: Analyzed decay modes and their experimental signatures for the excited fermion searches.

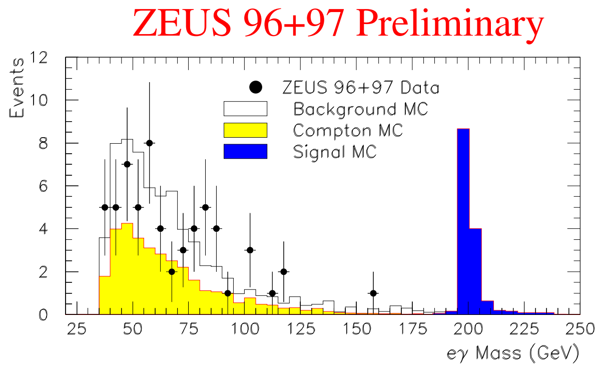

Figure 5: Distribution of the $e\gamma$ invariant mass for selected $e^* \to e\gamma$ candidates for the data (solid points) and for the total background from NC-DIS and QED Compton (open histogram). The contribution from the QED Compton is shown separately by the shaded histogram. An example of e^* signal with the mass of 200 GeV is also shown as a dark histogram in arbitrary normalization.

fermions to Standard Model gauge bosons are described in terms of three constants corresponding to the three gauge groups: f for $SU(2)_L$, f' for $SU(1)_Y$ and f_s for $SU(3)_C$. For specific assumptions relating f, f' and f_s the branching ratios can be predicted and the cross sections are described by a single parameter (e.g. f/Λ).

At HERA, excited fermions can be produced via t-channel exchange of a gauge boson: γ or Z for e^* and q^* production and $W^\pm$ for ν^* production. The excited states decay to known fermions and gauge bosons. The search for excited fermions is therefore a search for a fermion-boson resonance.

H1 and ZEUS collaboration have published excited fermion analysis [6] based on integrated luminosities of 2.75 pb^{-1} and 9.4 pb^{-1}, respectively. The results presented here summarize the new multi-channel H1 analysis [7] of a data sample corresponding to 37 pb^{-1} and ZEUS update [8] of the excited electron channel $e^* \to e\gamma$ with similar luminosity.

The decay channels analyzed and their experimental signatures are illustrated in the figure 4. The same final state may correspond to different excited fermion flavours and decay.

As an example, we will shortly describe the excited electron search in the channel $e^* \to e\gamma$. The branching ratio is relatively high (predicted to be 30% for e^* masses above 150 GeV) and the experimental signature particularly clear: two high energy electromagnetic clusters. The Standard Model contributions are NC-DIS and Compton $e\gamma$ scattering (QED Compton).

ZEUS $e^* \to e\gamma$ analysis require two electromagnetic clusters of transverse momentum above 10 GeV (30 GeV if the polar angle of the cluster is below 0.3 rad) consistent with a electron-photon final state and low activity in the tracking system (except the track associated to the electron). The last condition mainly selects the elastic and quasi-elastic production of excited electrons. The acceptance for the signal ranges from 60% for e^*masses of 100 GeV to 75% at higher masses.

H1 $e^* \to e\gamma$ analysis is splitted in the exclusive and inclusive strategies. The inclusive analysis demand the sum of the energies of the two clusters to be above 20 GeV and the residual energy deposited in the calorimeters to be below 5 GeV. The inclusive strategy, designed to improve the efficiency for masses above 50 GeV, ask for the transverse momentum of the two e.m. clusters to be above 10 and 20 GeV, respectively, relaxing in the same time the empty detector condition. This strategy selects also inelastic production of e^*. The efficiency ranges in the H1 analysis from 65% for e^* masses of 50 GeV and increases to about 80-85% at higher masses.

The invariant mass of the two electromagnetic clusters obtained in ZEUS analysis $e^* \to e\gamma$ is showed in the figure 5. No significant excess of events characteristic of a peak for e^* production is observed.

For all channels analyzed (see figure 4), good agreement between data and Standard Model expectation is observed. Limits at 95% confidence level (C.L.) are obtained for the parameters related to the excited fermions production and decay. This is done first in a model independent manner by extracting limits on the product between the production cross-section σ^* and the branching ratio Br^* corresponding to a particular final state. In the case of the excited electrons (figure 6), the best limits are obtained in the channel $e^* \to e\gamma$ thanks to

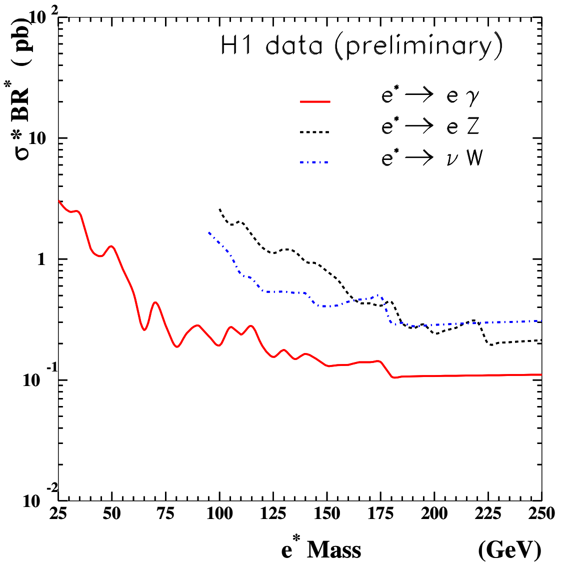

Figure 6: Limits on $\sigma^* Br^*$ for excited electron analysis in three decay modes. Upper regions are excluded at 95% C.L..

the high selection efficiency. Mass domains from 25 to 250 GeV are explored. For the highest mass region a limit $\sigma^* Br^* < 0.11$ pb at 95% C.L. is obtained in the H1 analysis. A similar result is obtained in the ZEUS update of that channel, improving by a factor of 4 the previous result.

For excited neutrino, H1 analysis set upper limits on $\sigma^* Br^*$ ranging from 0.2 pb for ν^* masses of 50 GeV to 0.3 pb at masses around 250 GeV. In the same mass range, the upper limits on $\sigma^* Br^*$ for the excited quarks are 0.3 to 0.2 pb.

Using the model described above and making assumptions for the coupling constants f, f' and f_s, limits on the ratio of couplings and the compositeness scale can be obtained. In the case of the excited electron, assuming equal strengths for the electromagnetic and weak couplings $f = f'$, upper limits for the ratio f/Λ from 0.6×10^{-3} to 1.0×10^{-2} are obtained for a e^* mass range between 60 GeV and 250 GeV. Assuming $f/\Lambda = 1/M_{e*}$, excited electron states with masses below 222 GeV are excluded at 95% C.L..

In the case of the excited neutrino, the assumption $f = -f'$ allows the radiative decay $\nu^* \to \nu\gamma$. The exclusion region of f/Λ , obtained in H1 analysis, is above values varying between 0.3×10^{-2} to 9×10^{-2} for a ν^* mass interval of 60 to 185 GeV.

The model dependent excited quark analysis suppose no strong coupling $f_s = 0$. This assumption is motivated by the results obtained in $p\bar{p}$ collisions at TEVATRON [9]. The excited quarks are produced in that case in a quark-gluon fusion mechanism which requires strong q^* coupling ($f_s \neq 0$). Excited quarks with masses in the range from 80 to 300 GeV are excluded for $f = f' = f_s$ values greater than 0.2 for the ansatz $\Lambda = M(q^*)$. Assuming, as explained above, only electroweak mechanisms for q^* production and equal strength for the electromagnetic and weak couplings $f = f'$, the exclusion region, obtained in the H1 analysis for masses between 60 to 230 GeV, correspond to values of f/Λ above 0.8×10^{-3} to 1.9×10^{-2}.

Excited fermions could be produced in e^+e^- collisions at LEP [10] or in $p\bar{p}$ interactions at TEVATRON [9]. LEP limits are more stringent up to masses corresponding to the center of mass energy, but HERA set limits beyond LEP kinematical reach for e^* and ν^*. In the case of excited quarks, HERA complements the TEVATRON results for the case of electroweak production mechanism.

Acknowledgements

The help in preparing this talk and the provision of information and plots by several H1 and ZEUS members are greatly appreciated.

References

1. C.Adloff et al., H1 Collaboration, preprint DESY 98-063, submitted to *Eur. Phys. Jour.* C.
2. ZEUS Collaboration, ICHEP98, contributed paper 756.
   T.Matsushita, these proceedings.
3. U.Baur, J.A.M. Vermaseren, D.Zeppenfeld, *Nucl. Phys.* B **375**, 3 (1992).
4. Z.Zhang, these proceedings.
   T.Kon et al., *Mod. Phys. Lett.* A **12**, 3143 (1997).
   E.Perez, talk at SUSY98, Oxford, 11-17, July 1998.
5. K.Hagiwara, S. Komamiya, D. Zeppenfeld, *Z. Phys.* C **29**, 115 (1985).
6. H1 Collaboration, S.Aid et al., *Nucl. Phys.* B **483**, 44 (1997),
   ZEUS Collaboration, J.Breitweg et al., *Z. Phys.* C **76**, 631 (1997). .
7. H1 Collaboration, ICHEP98, contributed paper 581.
8. ZEUS Collaboration, ICHEP98, contributed paper 758.
9. CDF Collaboration, F.Abe et al., *Phys. Rev.* D **55**, 5263 (1997).
   D0 Collaboration, I Bertram, FERMILAB-CONF-96/389-E.
10. R.Teuscher, these proceedings.