Observation of Events with Isolated Charged Leptons and Large Missing Transverse Momentum and of Events with Multi-Electrons at HERA

Tancredi Carli[a]
DESY and University of Hamburg, Notkestr. 85, 22607 Hamburg
now at: CERN, EP Division, CH-1211 Geneva 23, Switzerland

Striking events with isolated charged leptons, large missing transverse momentum and large transverse momentum of the hadronic final state (P_T^X) have been observed at the electron proton collider HERA. In the full HERA-I data sample corresponding to an integrated luminosity of about 130 pb^{-1}, the H1 experiment observes 10 events with isolated electrons or muons and with $P_T^X > 25$ GeV. Only 2.9 ± 0.4 events are expected from Standard Model (SM) processes. Six of these events have $P_T^X > 40$ GeV, while 1.1 ± 0.2 events are expected. The ZEUS experiment observes good agreement with the SM. However, in a preliminary search ZEUS has found two events with a similar event topology, but tau-leptons instead of electrons or muons in the final state. Only 0.12 ± 0.02 events are expected from SM processes. Moreover, six events with two or more electrons forming an invariant mass bigger than 100 GeV have been observed by the H1 experiment. Three events have two electrons and three events have three electrons, while only 0.25 events are expected in each case. The ZEUS measurement is in agreement with the SM expectation.

1 Introduction

Despite the impressive success of the standard $SU(3) \otimes SU(2) \otimes U(1)$ Model (SM) of particle physics describing the electroweak and strong interaction between elementary particles in both the low- and the high-energy regime, it is still unsatisfactory in the sense that many fundamental facts such as the quark-lepton symmetry, the existence of three generations and their mass spectrum remain unexplained. Furthermore, the inclusion of the gravitation as an additional fundamental force in nature remains an open question. Recently, hints for the need of an extension of the SM have been obtained by the observation of neutrino oscillations suggesting a flavour mixing in the leptonic sector and non-zero neutrino rest masses [1]. Only future experiments will be able to fully clarify the nature of this phenomenon. An experimental observation of new heavy particles beyond the presently known particle spectrum would provide an important guidance toward a deeper understanding of the fundamental particles and their interactions.

The high centre-of-mass energy of HERA colliding positrons[b] with an energy of 27.5 GeV with proton with an energy[c] of 920 GeV, offers the possibility to directly produce new heavy particles with a mass up to the centre-of-mass energy of $\sqrt{s} \approx 320$ GeV. In addition, the interference of new heavy particles exchanged in the t-channel with SM processes could be experimentally

[a] Talk at: 38th Recontres de Moriond Electroweak Interactions and Unified Theories, Les Arc (France) 2003.

[b] In the data taking period 1998/1999 HERA collided electrons on protons. This period corresponds to an integrated luminosity of 14 pb^{-1}.

[c] In the data taking period 1994-1997 HERA collided protons with an energy of 820 GeV. This period corresponds to an integrated luminosity of about 30 pb^{-1}.

observed as enhancement or deficit in measured cross-sections over the SM expectation. In this case HERA is also sensitive to particles with masses higher than the centre-of-mass energy.

Searches for new particles and new BSM interactions at HERA have been recently reviewed[2]. Most results obtained in the first HERA data taking period (1994-2000) corresponding to an integrated luminosity of about 130 pb^{-1} are covered and furthermore constrains on various theories beyond the SM obtained from the HERA-I data are discussed. Here, the final HERA-I results[3,4] on the search for isolated electrons or muon with large missing transverse momentum (P_T^{miss}) and with large transverse momentum of the hadronic final state (P_T^X) are summarised. Furthermore a preliminary result on the search for isolated tau leptons with large P_T^{miss} is reported[5]. In addition, preliminary results on the search for final states with two or three electrons are presented[6,7]. Searches for other signatures predicted by BSM models are summarised in another contribution to this conference[8].

2 Observation of Events with Isolated Leptons and Missing Transverse Momentum

Large missing transverse momentum, isolated charged leptons and a hadronic final state at high transverse energy ($ep \to l\nu X$) is a typical possible signature of a singly produced heavy particle decaying into a charged lepton and a neutrino. Possible new heavy particles postulated by BSM models which could be produced at HERA and would cause such event signatures have recently been extensively discussed[9,10,11].

Within the SM the dominant process leading to isolated charged leptons and large P_T^{miss} is the direct production of $W^\pm$-bosons ($ep \to (e)W^\pm X$). This process has, however, a relatively small cross-section. The inclusive $W^\pm$-boson production cross-section is $\sigma(ep \to eW^\pm X) \approx 1$ pb. In this process the transverse momentum of the hadronic final state P_T^X is expected to be relatively small. If $P_T^X > 25$ GeV is required, the cross-section drops to approximately 0.2 pb. About two times more W^+- than W^--bosons are produced.

2.1 Calculation of SM Processes for $ep \to (e)W^\pm X$

Typical leading order Feynman diagrams of this process are shown in Fig. 1. The first two diagrams represent collisions of real photons with protons (photoproduction). In the second diagram the photon interacts directly as point-like particle (direct photoproduction), in the first diagram it splits into a quark anti-quark pair before interacting with the hard subprocess (resolved photoproduction). The third diagrams shows the deep-inelastic scattering (DIS) process, where the photon is virtual. If the photon virtuality is high, the scattered electron can be measured in the main detector.

The direct photoproduction process gives the dominant contribution to the total cross-section. The DIS contribution is about a factor of two smaller. The resolved photoproduction process is a factor of five smaller at low transverse $W^\pm$-boson momenta and is completely negligible at high transverse momenta. The process $ep \to \nu W^\pm X$ only contributes $\approx 5\%$ and can be neglected.

In each of the diagrams the $W^\pm$-boson is radiated from a quark in the proton. This is the dominant single contribution of in total six contributing diagrams (not shown). Of particular interest is the diagram where the interaction proceeds via the triple gauge boson coupling ($\gamma W^\pm W^\pm$). This process allows the anomalous trilinear coupling of gauge bosons to be tested at HERA.

The leading order ($\mathcal{O}(\alpha^2)$) calculation of the $ep \to eW^\pm X$ process has been available as an event generator since the start-up of HERA[12]. Recently, the QCD corrections $\mathcal{O}(\alpha^2\alpha_s)$ have been calculated for the dominant direct photoproduction contribution[13]. They include the virtual corrections due to one-loop diagrams generated by virtual gluon exchange and the real

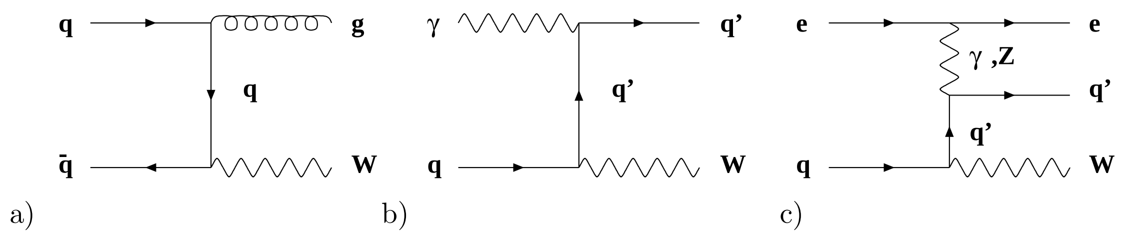

Figure 1: Examples of leading order Feynman diagrams for the direct production of $W^{\pm}$-bosons at HERA.

correction due to gluon radiation from the quark lines. In the calculation, the renormalisation and factorisation scale has been set to $\mu^2 = M_W^2$, where M_W is the mass of the $W^{\pm}$-boson. The QCD corrections modify the LO result by $\pm(10-15\%)$ and reduce the dependence of the calculated cross-section on μ from about 20% to about 5%. Including the uncertainty on the proton parton density function the total remaining uncertainty on the cross-section prediction is about $\pm 5\%$.

2.2 Observation of Events with Isolated Electrons and Muons

H1	ZEUS
$5^o < \theta_l < 140^o$	$17^o \lesssim \theta_l < 115^o$
$P_T^{\rm l} > 10$ GeV	$P_T^{\rm l} > 5$ GeV
$P_T^{\rm miss} > 12$ GeV	$P_T^{\rm miss} > 20$ GeV
$D_{\rm jet} > 1.0$	$D_{\rm jet} > 1.0$
$D_{\rm trk} > 0.5$	$D_{\rm trk} > 0.5$
$\Delta\phi_{lX} < 160^o$(e)$, 170^o(\mu)$	$\Delta\phi_{lX} < 172^o$ (e)
$\delta_{\rm miss} > 5$ GeV	$\delta_{\rm miss} > 8$ GeV (e)
$V_{ap}/V_p < 0.5$ (e)	
$\xi_e^2 > 5000$ GeV^2 (e)	

Table 1: Main H1 and ZEUS event selection cuts for events with isolated electrons or muon and missing transverse momentum. Some of the cuts are only applied in the electron (e) or in the muon (μ) channel.

Events are selected by requiring large $P_T^{\rm miss}$ and an electron (e) or muon (μ) in the acceptance of the calorimeter and/or the tracking system with high transverse momentum ($P_T^{\rm l}$). The lepton (l) has to be isolated, i.e. the distance in the $\eta-\phi$ plane[d] from the axis of the closest jet[e] $D_{\rm jet} = \sqrt{\Delta\eta_{l{\rm jet}}^2 + \Delta\phi_{l{\rm jet}}^2}$ and the distance from the nearest track $D_{\rm trk} = \sqrt{\Delta\eta_{l{\rm trk}}^2 + \Delta\phi_{l{\rm trk}}^2}$ has to be large. In the electron channel H1 applies the cut on $D_{\rm trk}$ only for electron polar angles bigger than 45^o. To efficiently remove neutral current (NC) DIS events with back-to-back topologies in the x-y-plane are rejected by a cut on the difference between the lepton and the hadronic final state momentum $\Delta\Phi_{lX}$. Different cut values are applied for the electron and muon channel. To further reject NC DIS events a cut on the longitudinal momentum balance $\delta_{\rm miss}$ is applied. The variable $\delta_{\rm miss}$ is defined as $\delta_{\rm miss} = 2E_e - \sum_i E_i(1-\cos\theta_i)$, where E_i and θ_i denotes the energy and the polar angle of each energy deposit and E_e is the electron beam energy. For an event where only momentum in the proton direction is undetected, e.g. NC DIS events, $\delta_{\rm miss} = 0$.

To gain sensitivity at low $P_T^{\rm miss}$ and to exploit the forward region of the detector, H1 uses the ratio of the anti-parallel (V_{ap}) to parallel (V_p) components of the transverse momentum measured in the calorimeter. This variable measures the azimuthal balance of the event. In addition, in the electron channel the reconstructed squared momentum transfer[f] $\xi_e^2 = 4E'_e E_e \cos\theta_e/2 > 5000$ GeV^2, where E'_e is the energy and θ_e the polar angle of the isolated electron, is used for $P_T^X < 25$ GeV. The main event selection criteria for H1 and ZEUS are summarised in Tab. 1. The main differences are the requirements on $P_T^{\rm miss}$ and the lepton acceptance.

[d] The variable η denotes the pseudo-rapidity defined by $\eta = -\ln\tan(\theta/2)$ and ϕ the azimuthal angle.

[e] Jets are defined by the inclusive longitudinally invariant k_T algorithm[19] requiring a transverse energy $E_T > 5$ GeV. ZEUS requires in addition $-1 < \eta < 2.5$.

[f] This observable corresponds to the photon virtuality Q^2, if the scattered electron in a NC DIS process is measured. Since the NC DIS cross-section steeply falls with Q^2, ξ_e^2 is generally lower in NC DIS than in the direct $W^{\pm}$ process.

	$P_T^X > 25$ GeV			$P_T^X > 40$ GeV		
H1	Data	SM	W-contr.	Data	SM	W-contr.
electron	4	1.5 ± 0.3	0.8	3	0.5 ± 0.1	0.45
muon	6	1.4 ± 0.3	1.3	3	0.6 ± 0.1	0.5
combined	10	2.9 ± 0.5	2.6	6	1.1 ± 0.2	1.0
ZEUS	Data	SM	W-contr.	Data	SM	W-contr.
electron	2	2.9 ± 0.4	1.3	0	0.9 ± 0.1	0.5
muon	5	2.8 ± 1.4	1.4	0	1.0 ± 0.1	0.6
combined	7	5.7 ± 0.6	2.7	0	1.9 ± 0.2	1.1

Table 2: Number of measured and expected events in the H1 and ZEUS analysis of events with isolated electrons or muons and large missing transverse momentum. The H1 numbers only include the e^+p data sample ($\int \mathcal{L}dt \approx 105$ pb^{-1}). The ZEUS numbers correspond to the full data set ($\int \mathcal{L}dt \approx 130$ pb^{-1}). The number of events expected by the SM and the one expected only from the $ep \rightarrow (e)W^\pm X$ process are given separately.

These selection criteria are designed to reject the main background processes with high cross-sections, i.e. mismeasured NC, $ep \rightarrow eX$, and charged current (CC), $ep \rightarrow \nu X$, DIS events, two jet photoproduction events, $ep \rightarrow \text{jet jet}\, X$, and events where two leptons are produced in inelastic photon-photon collisions[g], $ep \rightarrow e l^+ l^- X$. The H1 event selection has been optimised for direct $W^\pm$-boson production. H1 achieves a selection efficiency of 40% for $ep \rightarrow (e)W^\pm X$ events with $P_T^X > 25$ GeV. The ZEUS event selection is more oriented toward the search for a singly produced heavy particle and is less efficient for $W^\pm$-boson production.

In the e^+p data sample corresponding to an integrated luminosity of 105 pb^{-1} H1 observes 10 events in the electron channel and 8 events in the muon channel. An additional prominent event where a scattered muon balances exactly the transverse momentum of the hadronic system is rejected by the cut on $\Delta\phi_{lX}$. This spectacular event was found in the 1994 H1 data sample and is discussed elsewhere [14,15,16]. In the e^-p data period no event has been found[h].

In the electron (muon) channel 7.2 ± 1.2 (2.23 ± 0.43) events are expected from $ep \rightarrow W^\pm X$ and 2.68 ± 0.49 (0.33 ± 0.08) events from background processes. One event in the electron channel has a clearly identified electron (e^-), four events have a positron e^+. In the muon channel four events have a μ^+ and three a μ^-. For the remaining events the charge could not be determined.

The striking feature of these events is their large P_T^X. This is shown in Fig. 2d. While for low P_T^X the number of measured events roughly corresponds to the number of expected events, an excess of events is seen toward large P_T^X. The number of measured and expected events with electrons or muons and with $P_T^X > 25$ GeV or $P_T^X > 40$ GeV are summarised in Tab. 2. In the combined electron and muon channel H1 observes 6 events with $P_T^X > 40$ GeV, while only 1.1 ± 0.2 events are expected from direct $W^\pm$-boson production. Other SM processes make only a negligible contribution. The Poisson probability that the SM expectation fluctuates to this observed number of events or more is $\mathcal{O}(10^{-3})$.

Some distributions of other variables describing the topology of the H1 events are shown in Fig. 2. Most of the events have low charged lepton polar angles and are consistent with a uniform $\Delta\phi_{lX}$ distribution. Besides P_T^X, most interesting is the charged lepton-neutrino transverse mass distribution defined as $M_T = \sqrt{\left(P_T^{\text{miss}} + P_T^l\right)^2 - \left(\vec{P}_T^{\text{miss}} + \vec{P}_T^l\right)^2}$, where $\vec{P}_T^{\text{miss}}$ and $\vec{P}_T^l$ is the 3-vector of the missing transverse momentum and of the isolated lepton. For low M_T values the measured events are distributed according to the Jacobian peak expected from decaying $W^\pm$-boson and good agreement between the data and the SM expectation is found. For large M_T values more data events are observed than expected. Three events have $M_T > 100$ GeV. For the three events where the scattered electron is detected, the $W^\pm$ mass can be directly

[g] In these processes one of the photons has high virtuality such that the proton breaks-up. See also section 3.
[h] H1 has decided to quote the numbers for the e^+p and the e^-p region separately.

reconstructed. Values consistent with the $W^{\pm}$-boson are found.

The ZEUS data are in all kinematic regions consistent with the expected SM background. For $P_T^X > 25$ GeV , 7 events have been found and 5.7 ± 0.6 are expected from SM processes. No event with $P_T^X > 40$ GeV has been found, but 1.9 events are expected. Fig. 3 shows various event topology variables for the electron (a,c) and the muon (b,d) channel for a control sample with relaxed cuts. Only one event in the electron channel and one event in the muon channel reaches P_T^X values around 40 GeV. This event is later rejected, since it does not fulfil the requirement on $\delta_{\rm miss}$. The data are well described by the SM processes shown as open histogram. The SM expectation for the electron channel is dominated by mismeasured NC DIS processes and that for the muon channel by two photon processes. The shaded histogram indicates the expectations from a hypothetical process where a single top quark $ep \rightarrow (e)tX$ is produced via an anomalous flavour changing neutral current [10,17]. None of the measured events has such a topology.

2.3 Observation of Events with Isolated Tau-Leptons

In view of the excess reported by the H1 collaboration in the electron and muon channel and not confirmed by the ZEUS collaboration, it is interesting to search for events with isolated tau-leptons and large $P_T^{\rm miss}$ and large P_T^X. ZEUS has recently presented a preliminary analysis [5], where the tau-leptons are identified in their hadronic decay mode. In contrast to jets initiated by quarks or gluons, jets produced by tau-leptons are pencil-like, collimated and have a low charged particle multiplicity.

The main background process is CC DIS where a jet from the hadronic final state is misidentified as tau-lepton. The CC DIS cross-section is about three orders of magnitude higher than the signal from direct production of $W^{\pm}$-bosons followed by a $W \rightarrow \tau\nu_\tau$ decay. To strongly suppress this large background while keeping the tau-leptons with a sufficiently large efficiency, a multivariate discrimination technique, called PDE-RS[i] was used[18]. In this method the classification of a given event as signal or background is based on the signal (ρ_s) and the background (ρ_b) probability density in the n-dimensional vicinity of the event to be classified: $D = \rho_s/(\rho_s + \rho_b)$. The probability densities are sampled with MC simulations and are calculated using a very fast range search algorithm.

An inclusive CC DIS Monte Carlo simulation[j] was used as background and a simulation of direct $W^{\pm}$-boson production as signal process. Six observables are exploited to characterise the internal jet structure[k] : the first and second moment of the radial and longitudinal extension of the jet energy depositions with respect to the jet axis[l], the subjet multiplicity[m] and the observed invariant mass of the particles associated to the jet.

Fig. 4a shows the shape of the resulting discriminant D for data, background and signal simulation. The background (signal) is mostly located at low (large) D-values. The shape of the measured discriminant distribution is well described by the simulation. Only based on the discriminant D, for a signal efficiency of $\epsilon_{\rm sig} = 32\%$, a background rejection $1/\epsilon_{\rm bgd} = 154$ is obtained. If in addition jets with only one track are required, the signal efficiency is still $\epsilon_{\rm sig} = 24\%$ and the background rejection improves to $1/\epsilon_{\rm bgd} = 561$. The obtained results do

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[i] Probability Density Estimation based on Range Searching.

[j] Inclusive means here that the event selection is mainly based on the requirement of large missing transverse energy. See Ref. [22] for details.

[k] In general, the internal jet structure is well modeled by the MC simulations [20].

[l] Jets are defined using the inclusive longitudinally invariant K_T algorithm [19] and $E_T > 5$ GeV and $-1 < \eta < 2.5$ is required.

[m] The subjet multiplicity describes the number of localised energy depositions within a jet that can be resolved using a certain resolution criterion. An exact definition can be found in Refs. [20,21].

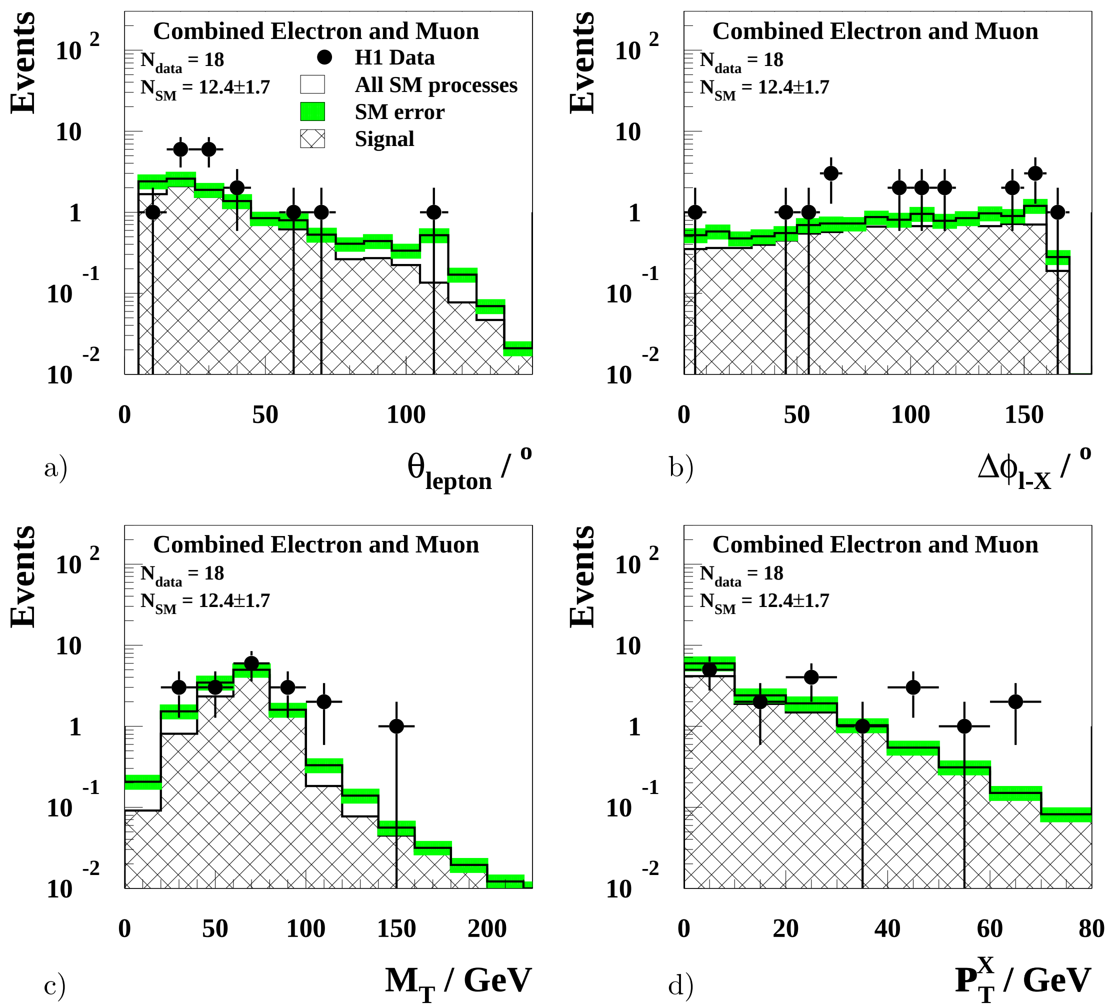

Figure 2: Distribution of kinematic variables measured by H1 for events with isolated electrons or muons and missing transverse momentum: a) the polar angle of the lepton, b) the azimuthal angle between the lepton and the hadronic final state, c) the transverse mass and d) transverse momentum of the hadronic final state. The open histogram indicates the expectation for SM processes, the shaded band the total uncertainty. The hatched histogram indicates the contribution from direct production of $W^{\pm}$-bosons. Also given is the total number of observed data events (N_{data}) and the total number of expected SM events (N_{SM}).

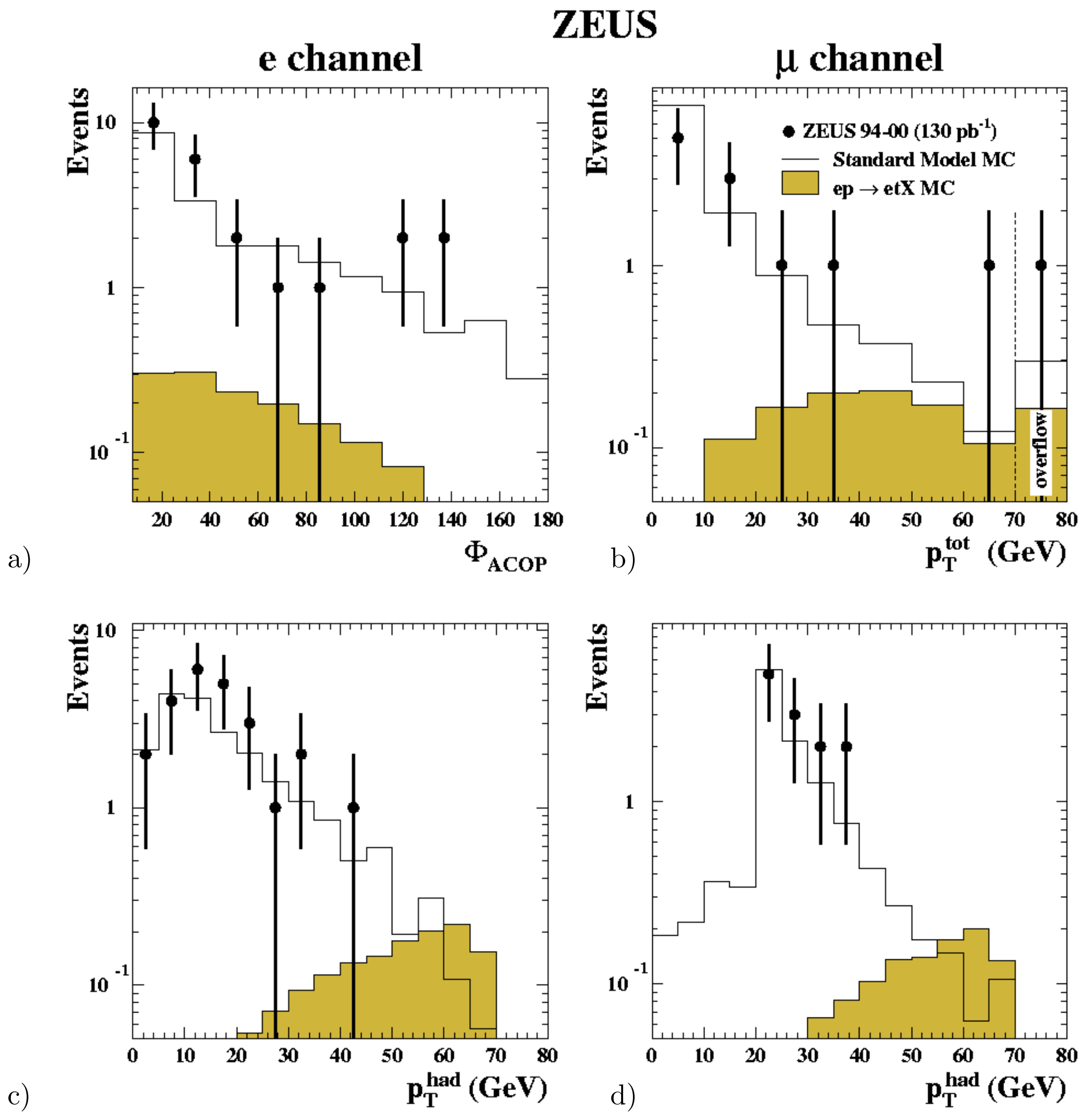

Figure 3: Distribution of kinematic variables measured by ZEUS for events with isolated electrons (a, c) or muons (b, d) and missing transverse momentum (with relaxed cuts): a) the azimuthal angle difference between the electron and the hadronic final state, b) the total transverse momentum of all particles including the muon, c) and d) the transverse momentum of the hadronic final state. The observable P_T^{had} is identical to P_T^X in the text. The open histogram shows the SM expectation. The shaded histogram illustrates a possible contribution of a single top quark produced via an anomalous FCNC coupling. This histogram is normalised to the upper cross-section limits obtained by the ZEUS analysis.

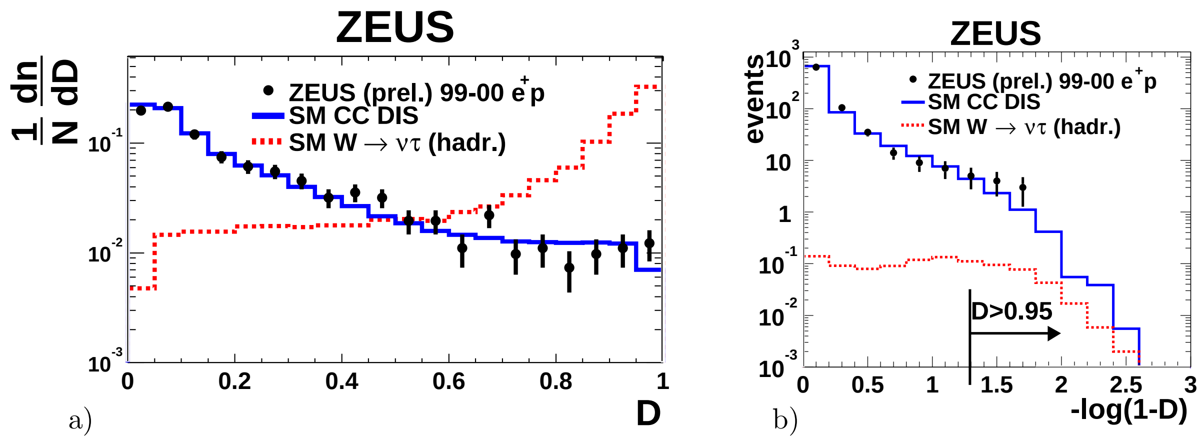

Figure 4: The discriminant D separating hadronic 1-prong tau-lepton decays from jets induced by quarks or gluons. a) shows the shape of the D distribution, b) shows the absolute number of measured and expected events. The data measured by ZEUS correspond to an inclusive selection on missing transverse momentum. The solid line indicates the background expectation from CC DIS processes, the shaded line the signal of tau-leptons from $W^{\pm}$-boson decays. In b) the x-axis is stretched to make the large D values where the tau-lepton signal is expected more visible.

not depend on the chosen modeling of higher order parton radiation (MEPS[n] or CDM[o]). Using a NC DIS data sample the probability to misidentify an electron or a jet with one track as tau-lepton is determined to be on the permille level[23]. The MC simulations predict the same misidentification probabilities.

In Fig. 4b the absolute number of measured and expected events is shown. To make the region of large D values more visible the x-axis is stretched according to $-\log(1-D)$. For this inclusive CC event control selection good agreement between data and simulation is found. However, at the largest D values slightly more events are found than expected by the SM processes.

When applying similar cuts as in the electron and muon analyses, but dropping the cut on P_T^X and the requirement that the isolated track has to associated with an identified electron or muon and in addition tightening the jet isolation to $D_{jet} > 1.8$, four events remain in the data sample, while only 1.5 ± 0.2 are expected from SM processes. Out of these four events three are consistent with the tau hypothesis as can be deduced from the distribution of the tau discriminant (see Fig. 5a). Out of the three events passing the cut $D > 0.95$, two events have a high transverse momentum, i.e. $P_T^X = 48$ GeV and $P_T^X = 37$ GeV, similar to the events found in the H1 analysis of the electron and the muon channel.

For $P_T^X > 25$ GeV ($P_T^X > 40$ GeV) two (one) events are (is) found in the data and only 0.12 (0.06) events are expected from SM processes. The SM expectation is largely dominated by direct $W^{\pm}$-boson production. The Poisson probability to observe two or more events when 0.12 are expected is $6 \cdot 10^{-3}$.

2.4 Conclusions

The H1 and ZEUS results are summarised in Tab. 3. The H1 experiment observes 10 events in the electron and muon channel while only 2.9 events are expected from SM processes. The excess of measured over expected events has a significance of approximately three standard deviations. The ZEUS results are in good agreement with the SM. The effect is therefore smaller when the two experiments are combined. However, ZEUS observes 2 events in the tau-channel where only 0.12 events are expected. So far, H1 has not released results in the tau-channel.

[n] Matrix Element and Parton Shower.
[o] Colour Dipole Model.

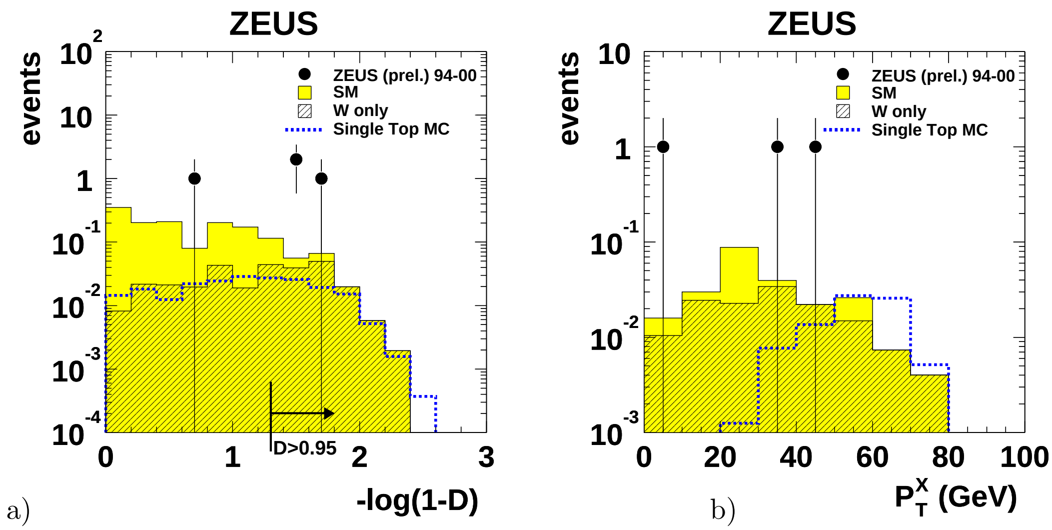

Figure 5: a) The discriminant D for the four events having an isolated track with high transverse momentum and large missing transverse energy, b) the P_T^X distribution of the events where a least one jet is consistent with the tau hypothesis, i.e. $D > 0.95$.

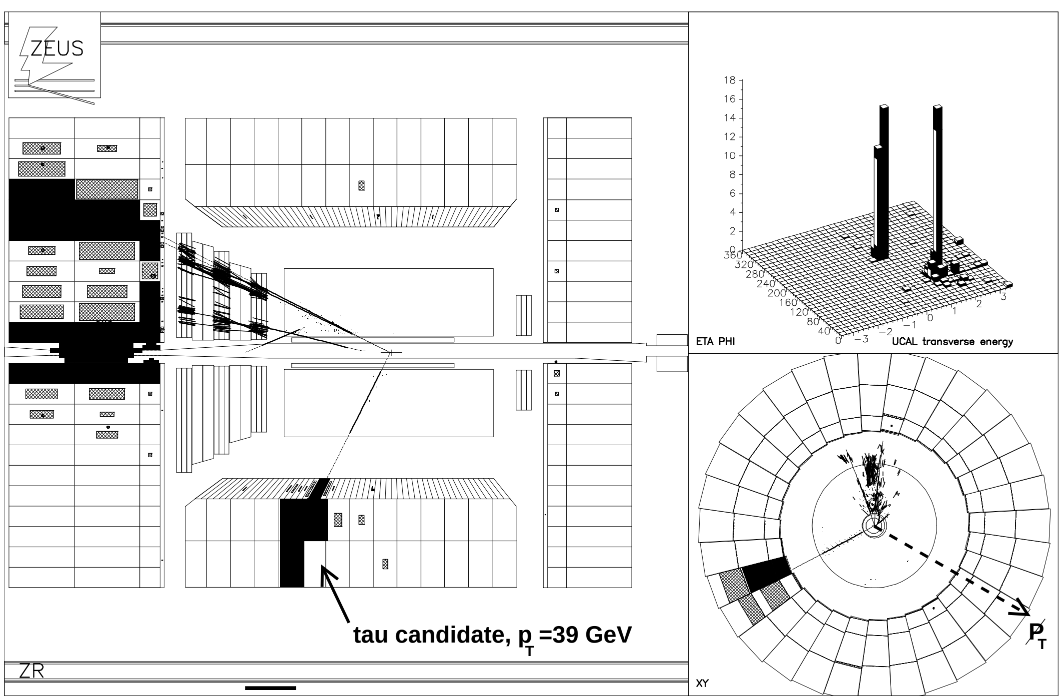

Figure 6: ZEUS event display of one of the two events with an isolated tau-lepton and large missing transverse momentum.

	electron/muon channel combined				tau channel	
	H1		ZEUS		ZEUS	
	Data	SM	Data	SM	Data	SM
$P_T^X > 25$ GeV	10	2.9 ± 0.5	7	5.7 ± 0.6	2	0.12 ± 0.02
$P_T^X > 40$ GeV	6	1.1 ± 0.2	0	1.9 ± 0.2	1	0.06 ± 0.01

Table 3: Overview of the results in the combined electron and muon channel and in the tau-channel.

Searches for events where the $W^{\pm}$-boson decays hadronically have also been performed[3,4]. However, in this channel the backgrounds are so high that no firm conclusions can be drawn. In the H1 as well as in the ZEUS analysis the measured events are in agreement with the SM expectation. Since the expected number of events from $W^{\pm}$-boson production is very small, an anomalous high production cross-section of events with isolated leptons and missing transverse momentum can not be excluded.

In a random experiment the ZEUS measurement in the electron, muon and tau-lepton channel and the H1 measurement would be simulanously produced only in about 0.01% of the cases[24]. If one allows for an anomalous $W^{\pm}$ production process, the ZEUS tau-lepton results would require the largest cross-section due to the small selection efficiency. Even in this case only about in 1% of the cases the H1 and ZEUS measurements would in a random experiment be simulanously realised. However, the ZEUS tau-lepton results and the H1 results in the electron and muon channel are compatible within one standard deviation. If one allows for an anomalous tau-lepton production process the H1 and ZEUS results would be realised in a few percent of the cases in a random experiment, i.e. all the measured results would be consistent. In this case only tau-leptons are produced and the electrons and muons signals are generated via the tau-decay. This assumption also models a coupling which is much stronger for the tau-lepton than for the leptons of the first two families. Such an interaction can be incorporated in supersymmetric models where the R-parity is broken. Also the production of two heavy Majorana neutrinos N exchanged in the t-channel, i.e. $ep \rightarrow WNW \rightarrow \nu l^+ l^+ X$, predicts an enhancement of tau-leptons over electrons or muons[p] [11].

The high luminosity expected for the HERA-II data taking period will be needed to clarify whether the excess of measured events in the electron, muon and tau-lepton channel over the SM process are due to a statistical fluctuation or to a new BSM interaction. Another possible explanation is that the hard spectrum of the hadronic final state is generated by higher order QCD effects which are presently only included to the first order of the strong coupling constant.

Assuming that the ZEUS result in the muon and the electron channel is a downwards fluctuations and H1 measures the real rate, an additional data set of 200 pb^{-1} will be required to get an excess of two standard deviations in the ZEUS analysis. In this case the H1 excess will be on the five sigma level. If one assumes that the H1 and ZEUS experiments measured the average rate in $1994 - 2000$, an additional data set of 500 pb^{-1} will be required to observe a deviation of five standard deviation in the combined H1 and ZEUS analysis. The signficance will be increased, if the tau-lepton channel is also considered.

[p] One of the leptons is in most case outside the detector acceptance.

3 Observation of Events with Multi-Electrons at High Transverse Energy

$M_{1,2} > 100$ GeV :

	Data	SM	$\gamma\gamma$	fake
			H1	
$= 2e^{\pm}$	3	0.25 ± 0.05	0.21 ± 0.04	0.04 ± 0.03
$= 3e^{\pm}$	3	0.23 ± 0.04	0.23 ± 0.04	0.00 ± 0.00
			ZEUS	
	Data	SM	$\gamma\gamma$	fake
$= 2e^{\pm}$	2	0.77 ± 0.08	0.47 ± 0.05	0.3 ± 0.09
$= 3e^{\pm}$	0	0.37 ± 0.04	0.37 ± 0.04	0.0 ± 0.00
$\geq 2e^{\pm}$	2	1.14 ± 0.09	0.84 ± 0.06	0.3 ± 0.09

Table 4: Number of events with two, three or two or more electrons measured by H1 and ZEUS and expected from SM processes.

The high centre-of-mass energy of HERA offers the possibility of producing events with two or more leptons at high transverse energy. The production rates of such events can be accurately predicted by the SM. These processes are therefore sensitive to possible small signals beyond the SM.

Events with two electrons are produced in photon-photon ($\gamma - \gamma$) collisions. The photons are radiated off from the incoming proton and the electron, i.e. $ep \rightarrow \gamma\gamma \rightarrow e^+e^-(e^{\pm})X$. Since the cross-section is anti-proportional to the virtualities t_1^2 and t_2^2 of the two photons, i.e. $d\sigma/dQ^2 \propto \frac{1}{t_1^2}\frac{1}{t_2^2}$, the photons are real in most cases. However, in some cases one of the photon virtualities can be larger. Then also the scattered electron can be measured in the detector. The process $\gamma\gamma \rightarrow e^+e^-$ can be simulated using GRAPE[25]. It is based on the exact electroweak matrix element at tree level for γ (Z)-γ (Z) collisions and internal photon conversions. Depending on the photon virtuality on the proton side either elastic, quasi-elastic or inelastic processes are simulated.

Events are selected by requiring an isolated collimated electromagnetic cluster with high energy and a track associated to it. H1 requires two electrons in the acceptance of the central drift chambers ($20^o < \theta < 150^o$) with a transverse energy $E_T > 5$ GeV. The electron with the highest E_T has to fulfil $E_T > 10$ GeV. Additional electrons can have any E_T and do not need to be associated to a track. ZEUS required two electrons within the acceptance of the central drift chamber, i.e. $17.2^o < \theta < 164^o$, and a transverse energy $E_T > 10$ GeV. A track with a momentum well matched to the measured energy has to be associated with the cluster. Electrons in the forward and backward regions were measured without a track requirement. Under certain kinematic conditions they could be used in the determination of the invariant two electron mass.

One of the difficulties in this analysis is to control the background from photons and jets which are misidentified as electrons. This is particularly difficult in the forward region. Photons produced in the reaction $ep \rightarrow \gamma e \rightarrow \gamma e$ (QED Compton) can convert near the beam pipe. If the photon conversion is asymmetric, e.g. the created electron has high momentum and the created positrons has a low one, the photon can not be distinguished from a genuine electron. Another background is due to NC DIS events where the scattered quark produces a jet with only one track and a high electromagnetic fraction.

Fig. 7 shows the invariant mass distribution ($M_{1,2}$) measured by H1 for two (a) and three (b) electron events in a data sample collected from 1994-2000 corresponding to an integrated luminosity of 115 pb^{-1}. In the three electron case $M_{1,2}$ is calculated from the electrons with the highest E_T. Shown as histogram is the expectation of SM processes, i.e. the genuine multi-electron events and the background from misidentified electrons. The good agreement between data and SM expectation demonstrates the good understanding of the $\gamma\gamma \rightarrow e^+e^-$ reaction and of detector effects. At high masses more events are measured than expected by the SM processes. H1 measures three events with two electrons and three events with three electrons, while only 0.25 events are expected in each case.

Also events with two muons instead of two electrons haved analysed. No excess of the data over the SM expectation is found in the H1 and ZEUS analyses. However, due to the smaller

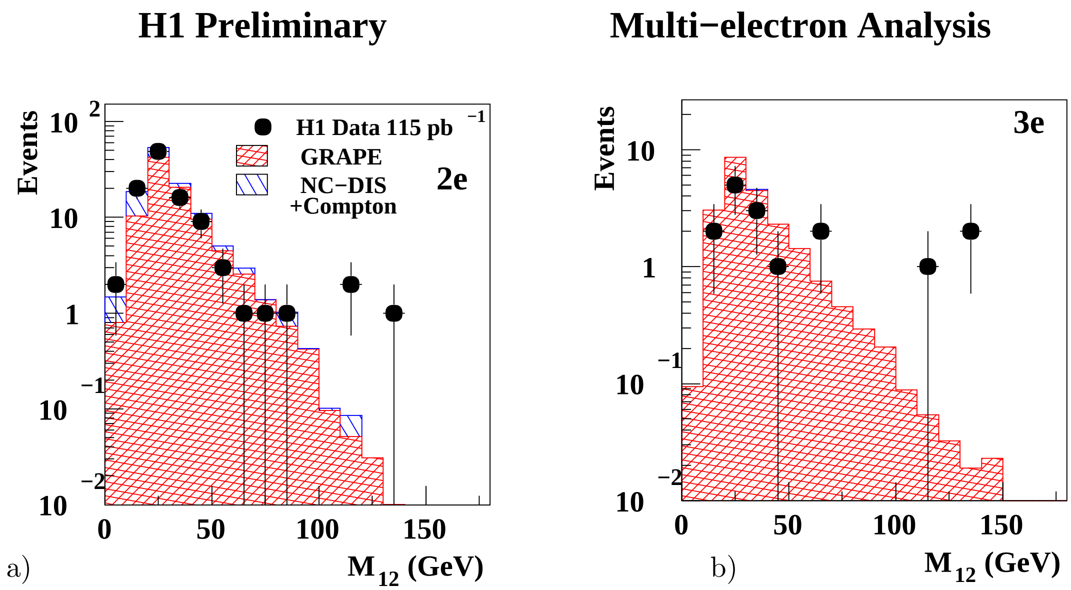

Figure 7: Invariant mass of events with 2 (a) and 3 (b) electrons measured by H1 and expected by SM processes.

available data sample and the lower detection efficiency this does not contradict a possible signal in the electron channel.

The invariant mass distribution of events with two or more electrons measured by ZEUS is shown in Fig. 8a. Also shown is the transverse energy distribution of the electron with the highest E_T. A good agreement between data and simulated SM processes is found over the full kinematic region. ZEUS measures two events with $M_{1,2} > 100$ GeV, while 1.14 events are expected. The analysed data sample was collected in 1994-2000 and corresponds to an integrated luminosity of 130.5 pb^{-1}.

The results from H1 and ZEUS are summarised in Tab. 4. Due to the larger angular acceptance in the backward direction, ZEUS expects more $\gamma\gamma$ events, as well more background events.

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References

1. Super-Kamiokande Coll., Y. Fukuda et al., Phys. Rev. Lett. 81 (1998) 1562; SNO Coll., Q.R. Ahmad et al., Phys. Rev. Lett. 87 (2001) 071201; KamLAND Coll., Phys. Rev. Lett. 90 (2003) 021802; Y. Koshido, hep-ex/0306002, these proceedings; J. Kameda, these proceedings; K. Heeger, these proceedings; K. Inoue, hep-ex/0307030, these proceedings.
2. M. Kuze and Y. Sirois, Prog. Part. Nucl. Phys. 50 (2003) 1.
3. H1 Coll., V. Andreev et al., Phys. Lett. B 561 (2003) 241.
4. ZEUS Coll., S. Chekanov et al. Phys. Lett. B 559 (2003) 153;
   see also: ZEUS Coll., J. Breitweg et al., Phys. Lett. B 471 (2000) 411.
5. ZEUS Coll., S. Chekanov et al., Abstract: 909, Session: 10, XXXI Int. Conf. on HEP, Amsterdam (The Netherlands) 2002.
6. C. Vallée, High-P_T Multi-Electron Production at HERA, in: 10th International Workshop on Deep Inelastic Scattering, Cracow (Poland) 2002.

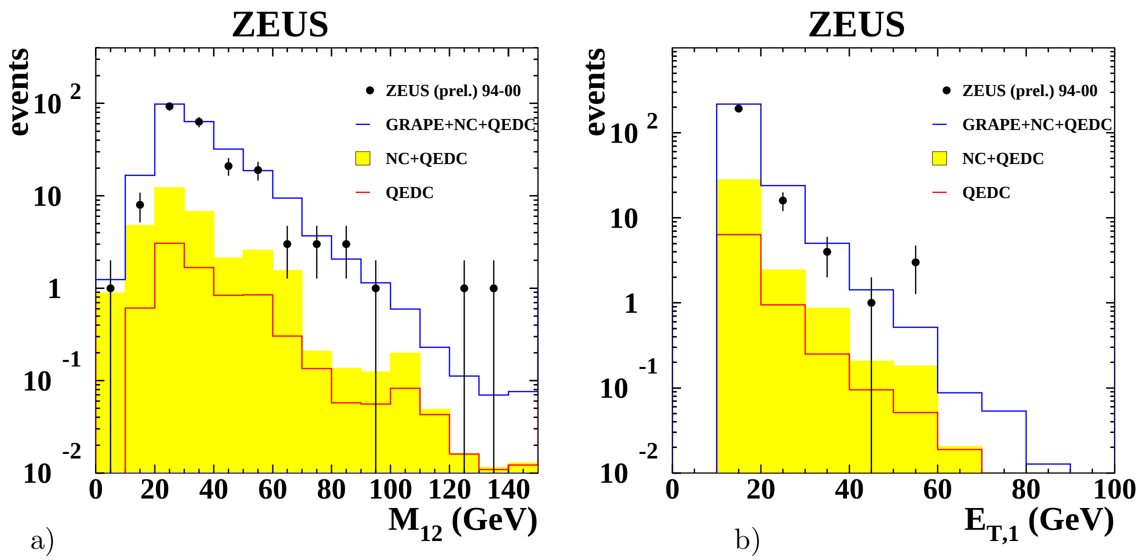

Figure 8: Invariant mass (a) and transverse energy (E_T) distribution of the electron with the highest E_T for events with two or three electrons measured by ZEUS.

7. ZEUS Collab., Study of multi-lepton production in $e^{\pm}$ interactions at HERA, contribution 910, XXXI Int. Conf. on HEP, Amsterdam (The Netherlands) 2002.
8. J. Haller, hep-ex/0305021, these proceedings.
9. T. Kon, T. Kobayashi and S. Kitamura, Phys. Lett. B 376 (1996) 227; T. Kon, T. Kobayashi, S. Kitamura and T. Iimura, Phys. Lett. B 494 (2000) 280.
10. H. Fritzsch and D. Holtmannspötter, Phys. Lett. B 457 (1999) 186.
11. W. Rodejohann and K. Zuber, PR D 62 (2000) 094017.
12. U. Baur, J.A.M Vermaseren and D. Zeppenfeld, Nucl. Phys. B 375 (1992) 3.
13. K. P. O. Diener, C. Schwanenberger and M. Spira, Eur. Phys. J. C 25 (2002) 405; see also: P. Nason, R. Rückl and M. Spira, J. Phys. G 25 (1999) 1434.
14. H1 Coll., T. Ahmed et al., DESY report 94-248 (1994).
15. H1 Coll., C. Adloff et al., Eur. Phys. J. C 5 (1998) 575.
16. H1 Coll., S. Aid et al., Z. Phys. C 71 (1996) 211.
17. A. Belyaev and N. Kidonakis, Phys. Rev. D 65 (2002) 037501; T. Han and J. L. Hewett, Phys. Rev. D 60 (1998) 074015.
18. T. Carli and B. Koblitz, Nucl. Inst. Meth. A501 (2003) 576.
19. S. D. Ellis and D. E. Soper, Phys. Rev. D 48 (1993) 3160. S. Catani et al., Nucl. Phys. B 406 (1993) 187.
20. H1 Coll., C. Adloff et al., Nucl. Phys. B 545 (1999) 3; ZEUS Coll., S. Chekanov et al., Phys. Lett. B 558 (2003) 41;
21. J.R. Forshaw and M.H. Seymour, JHEP 09 (1999) 009; M.H. Seymour, Nucl. Phys. B 421 (1994) 545.
22. ZEUS Coll., S. Chekanov et al., Phys. Lett. B 539 (2002) 197.
23. D. Lelas, Phd-thesis, Univ. Hamburg, in preparation.
24. D. Dannheim, Phd-thesis, Univ. Hamburg, in preparation. available at: http://www-library.desy.de/diss03.html
25. T. Abe et al., Comp. Phys. Comm. 71 (1992) 15.