Searches for signatures of physics beyond the Standard Model with high-P_T leptons at HERA

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The latest HERA results on searches for events with high-P_T leptons in ep collisions are presented. The full HERA I data set, corresponding to 115 pb^{-1} (H1) and 130 pb^{-1} (ZEUS), is used. Searches for W production and for signatures of new physics including single top production via flavor changing neutral currents have been performed in events with high-P_T leptons and missing transverse momentum. The production of multi-lepton events at high transverse momenta has been studied. Some 2- and 3-electron events are observed at high di-electron masses, for which the Standard Model expectation is low. A possible interpretation in terms of doubly charged Higgs boson production is ruled out.

1. ISOLATED LEPTONS AND W PRODUCTION

The H1 and ZEUS collaborations at HERA have investigated events with leptons which have the topology of a W produced in ep collisions at $\sqrt{s} \approx 320$ GeV ($ep \to eWX$). The latest measurements use a data sample corresponding to three times the luminosity of the previously published results [1,2]. The events are required to contain an isolated lepton with high transverse momentum, P_T^{ℓ}, substantial missing transverse momentum, P_T^{miss}, and may also have a hadronic final state X with transverse momentum P_T^X. The H1 selection is optimized for W-like topologies [3], while ZEUS carries out an inclusive selection, with a higher expectation from non-W background processes, as well as a selection designed to identify W bosons at high P_T^X [4].

At low values of P_T^X the observed event yields are in agreement with the Standard Model (SM) prediction. At high P_T^X, ZEUS also sees good agreement with the SM in the electron and muon channels, while H1 observes an excess of events. The hadronic transverse momentum distribution of the H1 events is shown in Fig. 1. The observed H1 and ZEUS event rates at high P_T^X are summarized in tables 1 and 2. ZEUS has recently carried out a search in the tau channel [5], looking for hadronic decays of the tau. At $P_T^X > 25$ GeV two events are observed for 0.12 ± 0.02 expected. They have similar characteristics as the outstanding H1 electron and muon events.

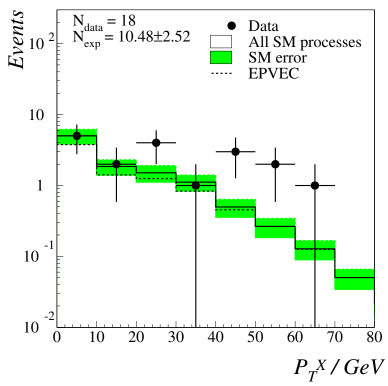

Figure 1. Hadronic transverse momentum distribution of the H1 isolated lepton events (electrons and muons combined).

2. SINGLE TOP PRODUCTION

A possible interpretation of the excess of isolated lepton events at high P_T^X could be the production of top quarks in flavor changing neutral current (FCNC) processes with a coupling $\kappa_{tu\gamma}$ of the top quark to a u-quark and a photon.

*On behalf of the H1 and ZEUS collaborations.

Table 1
Observed and expected lepton event yields at high P_T^X for the H1 analysis.

H1 preliminary e^+p (101.6 pb^{-1})	Electrons obs./exp. (W)	Muons obs./exp. (W)
$P_T^X > 25$ GeV	4 / 1.29 ± 0.33 (1.05)	6 / 1.54 ± 0.41 (1.29)
$P_T^X > 40$ GeV	2 / 0.41 ± 0.12 (0.40)	4 / 0.58 ± 0.16 (0.53)

Table 2
Observed and expected lepton event yields at high P_T^X for the ZEUS analysis.

ZEUS preliminary $e^\pm$p (130.5 pb^{-1})	Electrons obs./exp. (W)	Muons obs./exp. (W)	Taus obs./exp. (W)
$P_T^X > 25$ GeV	1 / 1.14 ± 0.06 (1.10)	1 / 1.29 ± 0.16 (0.95)	2 / 0.12 ± 0.02 (0.10)
$P_T^X > 40$ GeV	0 / 0.46 ± 0.03 (0.46)	0 / 0.50 ± 0.08 (0.41)	1 / 0.06 ± 0.01 (0.05)

In top quark decays ($t \to bW$) a high hadronic transverse momentum is expected. The search for top quarks has been carried out in both the leptonic and hadronic decay modes of the W boson ($W \to \ell\nu$, $W \to q\bar{q}'$).

2.1. Leptonic channel

To search for top candidates, the lepton events that pass the W selection are required to have P_T^X >25 (40) GeV for H1 (ZEUS) [4,6]. ZEUS observes no event for an expectation of 1.0. To enhance a possible top signal, H1 applies an additional cut on the transverse mass of the lepton-neutrino system ($M_T > 10$ GeV) and requires a positive lepton charge (since $\bar{t}$ production is strongly suppressed). After this selection, H1 sees 5 events for 1.8 ± 0.5 expected. The mass of the lepton-neutrino-X system can be computed after reconstructing the neutrino kinematics, applying a W mass constraint. For each event two solutions are possible. Several of these masses are compatible with the top mass distribution.

2.2. Hadronic channel

In the hadronic decay channel of the top quark, events with at least three high-P_T jets are selected. In addition, mass windows are set around the di-jet mass closest to the W mass and the 3-jet mass [4,6]. Both experiments see agreement with the Standard Model. ZEUS observes 19 events for 20.0 expected, H1 observes 14 events and expects 19.6 ± 7.8. The 3-jet mass distribution of the ZEUS events is shown in Fig. 2. Although no sign of top quark production is seen in the hadronic channel, these results do not rule out a possible top interpretation of the H1 isolated lepton excess. Given the H1 result in the hadronic channel, one would expect less than 5.4 events in the leptonic channel at 95% CL.

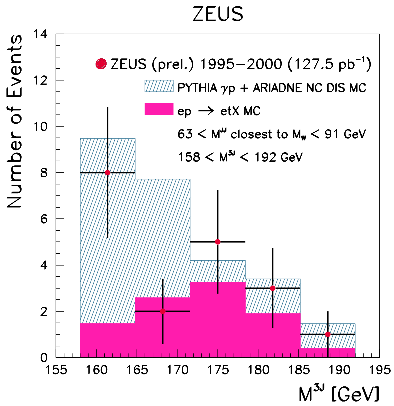

Figure 2. 3-jet mass distribution of the top candidates in the ZEUS hadronic channel compared to the SM prediction and the top simulation (arbitrary normalization).

2.3. Limit on the anomalous coupling $\kappa_{tu\gamma}$

Combining the results of the top searches in the leptonic and hadronic channels, limits on the FCNC coupling of the top quark to a u-quark and a photon are obtained by ZEUS ($\kappa_{tu\gamma} < 0.19$) and H1 ($\kappa_{tu\gamma} < 0.22$). The HERA limits extend into a region of parameter space not excluded by the LEP and TeVatron collider experiments (Fig. 3).

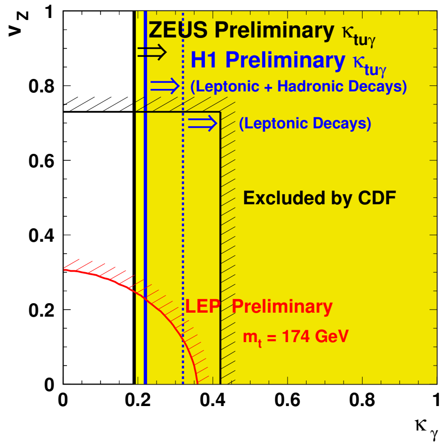

Figure 3. Present exclusion limits on the anomalous $tu\gamma$ and tuZ couplings obtained by HERA, LEP and TeVatron experiments.

3. MULTI-LEPTON EVENTS

Studies of events containing two or more leptons in the final state have been carried out at HERA. The dominant SM contribution to multi-lepton production comes from photon-photon interactions, where one photon is radiated from the incoming electron, the other from the proton. The transverse momentum spectrum of the produced leptons (P_T^ℓ) falls off steeply, making multi-lepton events with high P_T^ℓ a possible place to search for new physics. Additional experimental backgrounds are neutral current and QED Compton interactions in which a photon or a hadron is misidentified as an electron.

The selection of multi-electron events mainly requires two central electron candidates in the polar angle range $20° < \theta_e < 150°$ ($17° < \theta_e < 164°$) for H1 (ZEUS). The transverse momentum of at least one electron must be above 10 GeV. Events with two central electrons are classified as di-electrons, while events containing an additional third electron candidate within $5° < \theta_e < 175°$ are assigned to a 3-electron sample. More details are given in [7,8]. The selections for the di-muon analyses can be found in [8,9].

In both the electron and muon analyses, overall agreement is observed by H1 and ZEUS between the observed multi-lepton event yields and the expectation from SM processes. In the multi-electron analyses, however, some outstanding events are observed with high electron transverse momenta and invariant masses, M_{12}, of the highest-P_T electron pair. H1 sees three 2-electron and three 3-electron events with masses $M_{12} > 100$ GeV for a SM expectation of 0.25 ± 0.05 and 0.23 ± 0.04 events, respectively. ZEUS sees two di-electron events with $M_{12} > 100$ GeV for 0.77 ± 0.08 expected and no 3-electron event for 0.37 ± 0.04 expected (see table 3 and Fig. 4). The higher ZEUS rate for the $\gamma\gamma$ contribution to the SM expectation is due to the extended polar angle range of the electrons compared to H1.

In the muon channel no excess above the SM prediction is seen by H1 or ZEUS in a smaller data sample of 105 pb^{-1} (ZEUS) and 71 pb^{-1} (H1). In particular, no event is seen with a di-muon mass above 100 GeV. Taking into account the difference in integrated luminosities and selection efficiencies for the electrons and muons, the two channels are compatible for high masses.

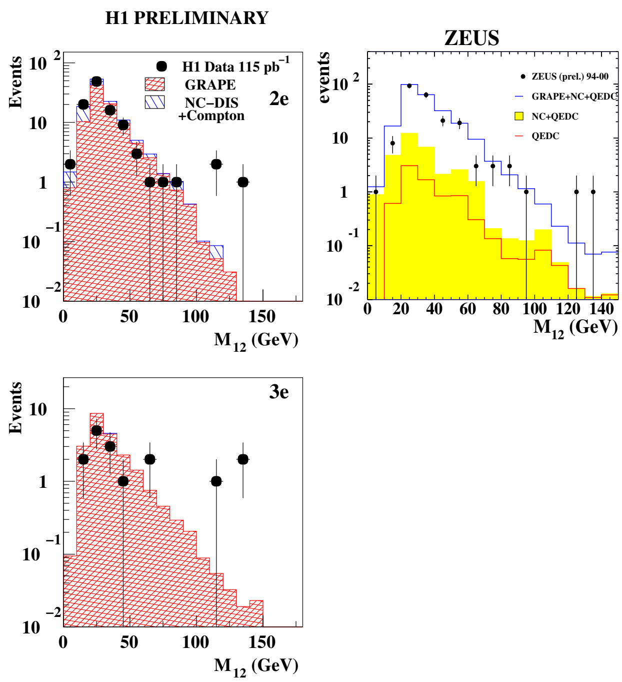

Figure 4. Invariant mass of the highest-P_T electron pair in the H1 and ZEUS multi-electron selection. (Left: H1 2e and 3e events, right: ZEUS 2e and 3e events combined).

Table 3
Multi-electron event yields for di-electron masses M_{12} above 100 GeV.

Selection	H1 DATA	SM expectation	ZEUS DATA	SM expectation
2e $M_{12} > 100$ GeV	3	0.25 ± 0.05	2	0.77 ± 0.08
3e $M_{12} > 100$ GeV	3	0.23 ± 0.04	0	0.37 ± 0.04

4. SEARCH FOR DOUBLY CHARGED HIGGS BOSONS

The search for doubly charged Higgs bosons carried out by H1 is motivated by the high mass multi-electron events discussed above. The search is performed in the framework of models with a Higgs triplet coupling to leptons of the i^{th} generation via Yukawa couplings h_{ii}. The Higgs signal is searched for in the electronic and muonic decay modes ($H^{\pm\pm} \rightarrow e^{\pm}e^{\pm}$ or $\mu^{\pm}\mu^{\pm}$). Details of the selection can be found in [10]. Only one of the six high mass events in the electron channel is a doubly charged Higgs candidate. No candidate is found in the muon channel. Thus a limit is set on the coupling h_{ee} as a function of the $H^{\pm\pm}$ mass. It is shown in Fig. 5 together with the preliminary bounds recently obtained by the OPAL collaboration [11] at LEP. The results of the H1 Higgs search and the new strong bounds from OPAL rule out an interpretation of the multi-electron excess as doubly charged Higgs decays.

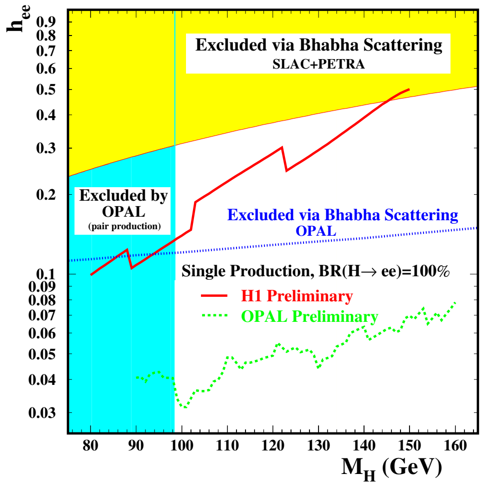

Figure 5. Exclusion limits on the coupling h_{ee} as a function of the doubly charged Higgs mass.

5. OUTLOOK

HERA is currently starting a phase of operation at higher luminosity. The goal is to achieve luminosities a factor of ~ five greater than possible to date at HERA. The new data will shed more light on the H1 and ZEUS results for the production of high-P_T leptons with missing P_T, and the multi-electron events observed at high masses.

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