SEARCHES FOR NEW PHYSICS AT HERA

A. SCHÖNING
(on behalf of the H1 and ZEUS collaborations)
Institute of Particle Physics, ETH Zürich, ETH Hönggerberg, CH-8093 Zürich
E-mail: schoning@mail.desy.de

Results of a general search for new phenomena at high transverse momentum and of a dedicated search for events with isolated leptons and missing transverse momentum are reported. These searches were performed on a data sample collected at HERA in $e^{\pm}p$ collisions with the H1 detector in the period 1994–2004. The results obtained in the isolated lepton search are compared with those obtained by the ZEUS collaboration in the period 1994–2000 and limits on the anomalous FCNC production of single top events are presented.

1 Introduction

The high-energy frontiers of accelerators serve as ideal hunting grounds to look for new phenomena and physics beyond the Standard Model (SM). A general search for new phenomena at high transverse momentum was recently performed in a model independent framework by the H1 Collaboration [1]. The analysis used $e^{\pm}p$ data taken at center of mass energies $s^{1/2}$= 300, 320 GeV in the period 1994-2000 corresponding to an integrated luminosity of $\mathcal{L} = 118$ pb^{-1} and was repeated with recent data [2] taken after the HERA luminosity upgrade in 2003/2004 corresponding to $\mathcal{L} = 45$ pb^{-1} ($s^{1/2}$= 320 GeV). Results are presented in section 2.

The excess of events with isolated electrons or muons and missing transverse momentum (p_T) observed in the period 1994-2000 by the H1 collaboration [3,4] has motivated a repeat of the same analysis on the newest data taken in 2003/2004. In section 3 the event yields are compared with results obtained by the ZEUS collaboration [5,6] performed on data taken from 1994-2000 ($\mathcal{L} =$ 130 pb^{-1}) where a slight excess of tau events compared to the SM expectation was seen.

In section 4 searches for events from anomalously produced top quarks are discussed, which in case of the semileptonic decay contribute to the isolated lepton with missing p_T signature and might explain the observed excesses. Limits on the involved anomalous couplings are presented and compared with similar limits obtained at other colliders.

2 General search

The H1 collaboration has performed a general search for new phenomena by looking for deviation from the SM prediction at high transverse momentum [1]. For the first time all event topologies involving objects like electrons (e), photons (γ), muons (μ), neutrinos (ν = missing particles) and jets (j) are investigated in a single analysis. Event classes are defined consisting of at least two clearly identified and isolated objects i with a minimum transverse momentum of $p_T^i > 20$ GeV. Events were found in 22 classes. The event yields span several orders of magnitude, see fig 1. Overall good agreement with the SM prediction was found.

In order to enhance sensitivity to new physics processes differential distributions as function of the total invariant mass of all objects M_{All} and of the summed transverse momentum $\sum_i p_T^i$ were investigated. Possible deviations (excess or deficit) were searched for with a new algorithm and statistically quantified. After studying all event classes the most significant deviation was found in the $\mu j \nu$ channel, where the main SM background comes from single W-production.

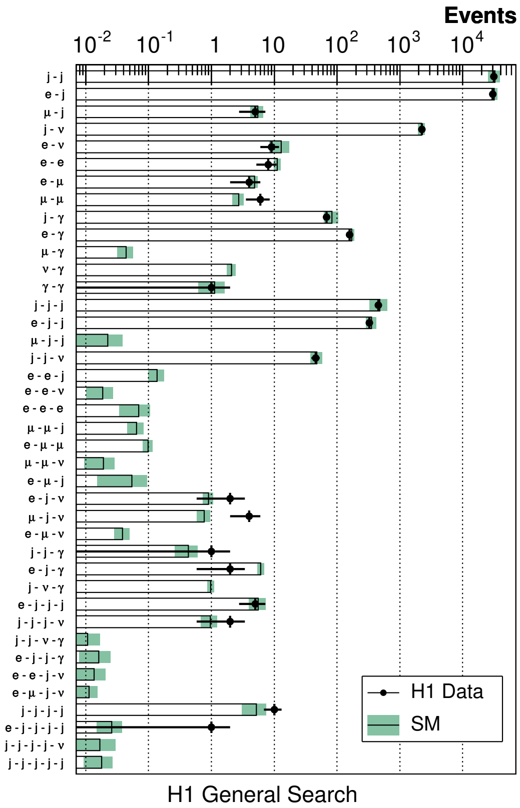

Figure 1. HERA I event yields in the general search for new phenomena at high p_T. Data (points) are compared to the SM expectation (histogram bars). The uncertainty of the SM prediction is indicated by the shaded band.

The probability of finding in the H1 data an excess in any of the event classes more significant than the observed excess in the $\mu j \nu$ class, was found to be 3% for the $\sum_i p_T^i$ distribution and 28% in the M_{All} distribution.

The same analysis was repeated with the recent data taken by the H1 experiment in 2003/2004 based on an integrated luminosity of 45 pb^{-1}. Again good overall agreement between data and the SM expectation was found. In this dataset the most significant deviation was found in the $ej\nu$ channel, to which also single W-production mainly contributes in the SM. The excesses observed in the $ej\nu$ and $\mu j \nu$ classes are further detailed in the next section.

3 Isolated leptons with missing transverse momentum

Events with isolated leptons and missing transverse momentum were selected by requiring an isolated high p_T lepton (electron, muon or tau) and missing transverse momentum. For the remaining hadronic final state (jet) the transverse momentum (p_T^X) is measured. In the radial plane the reconstructed missing transverse momentum vector is required not to point into the direction of the lepton or jet, which reduces genuine background from deep inelastic scattering, and ensures that the missing transverse momentum is due to an invisible particle (ν). The genuine SM "background" process is single W-production with the leptonic decay. Searches have been performed by both experiments H1 and ZEUS in the decay channels into electrons and muons [3,5], and taus [4,6].

In the HERA I analyses good agreement between data and the SM expectation were found at both experiments, see Table 1. However, after applying a cut $p_T^X > 25$ GeV 11 electron and muon events were observed by the H1 experiment compared to an expectation of 3.44±0.59, and 2 events were observed in the tau channel by the ZEUS collaboration compared to an expectation of 0.20 ± 0.05. Interestingly, neither of these excesses were confirmed by the partner experiment.

To enhance the limited statistics isolated lepton events were investigated in the recent HERA II dataset by the H1 collaboration [2]. The analyses were repeated in the electron and muon channel. In total 8 new events were found compared to an expectation of 5.28 ± 0.68 events, see Table 2. For $p_T^X > 25$ GeV 3 events, all found in the electron channel, survived compared to an expectation of 0.74 ± 0.16 in the electron and 0.76 ± 0.11 in the muon channel.

The distribution of the transverse momentum of the hadronic final state of all H1 data combined corresponding to an in-

Table 1. HERA I event yields in the search for isolated leptons with missing transverse momentum. The numbers are given for the electron, muon and tau channel for different cuts p_T^X.

HERA I 1994-2000	observed/expected		
H1 $\mathcal{L}(e^{\pm}p) = 118$ pb^{-1}	Electron	Muon	Tau
Full sample	11 / 11.5 $\pm$1.5	8 / 2.94 $\pm$ 0.51	5 / 5.81 $\pm$ 1.36
$P_T^X > 25$ GeV	**5** / 1.76 $\pm$ 0.29	**6** / 1.68 $\pm$ 0.30	0 / 0.53 $\pm$ 0.10
$P_T^X > 40$ GeV	3 / 0.66 $\pm$ 0.13	3 / 0.64 $\pm$ 0.14	0 / 0.22 $\pm$ 0.05
ZEUS $\mathcal{L}(e^{\pm}p) = 130$ pb^{-1}	Electron	Muon	Tau
Full sample	24 / 20.6 $\pm$3.2	12 / 11.9 $\pm$0.6	3 / 0.4 $\pm$0.12
$P_T^X > 25$ GeV	2 / 2.9 $\pm$0.46	5 / 2.75 $\pm$0.21	**2** / 0.2 $\pm$0.05
$P_T^X > 40$ GeV	0 / 0.94 $\pm$0.11	0 / 0.95 $\pm$0.12	1 / 0.07 $\pm$0.02

Table 2. HERA II event yields in the search for isolated leptons with missing transverse momentum. The numbers are given for the electron and muon channel, and after combination for different cuts p_T^X.

HERA II 2003-2004	observed/expected		
H1 $\mathcal{L}(e^{+}p) = 45$ pb^{-1}	Electron	Muon	Combined
Full sample	7 / 4.08 $\pm$ 0.58	1 / 1.2 $\pm$ 0.16	8 / 5.28 $\pm$ 0.68
$P_T^X > 25$ GeV	**3** / 0.74 $\pm$ 0.16	0 / 0.76 $\pm$ 0.11	3 / 1.5 $\pm$ 0.24

tegrated luminosity of 163 pb^{-1} is shown in Figure 2. For $p_T^X > 25$ GeV a clear excess of 14 events compared to 5.1 ± 1.0 expected is visible. However, more data and more detailed studies are required to resolve unambiguously the differences of event yields observed so far by the two collaborations H1 and ZEUS.

4 Single top production

The isolated lepton event class was discussed as possible signal for anomalous production of singe top quarks at HERA [7] with the subsequent semileptonic decay $t \to b\ \ell^+\nu$. As the SM expectation for the production of top quarks at HERA is negligible this process provides an ideal testing ground for the search for flavour changing neutral currents (FCNC).

Isolated lepton events consistent with a top quark decay signature were selected. The main criteria is the transverse momentum of the hadronic final state (p_T^X), which can be associated to the b-jet and is expected to be large. In order to gain sensitivity both experiments [8,5] have also studied the hadronic top decay, which is visible as three-jet events in both experiments. The event yields measured by both experiments were found to be consistent with the SM expectation and limits at the 95% confidence level were set on the top production cross section.

The cross section limits after combining the semileptonic and hadronic channels were found to be $\sigma(ep \to etX) < 0.43$ pb (H1) and $\sigma(ep \to etX) < 0.225$ pb (ZEUS). Both limits can be directly converted into a limit on the FCNC anomalous magnetic coupling of the top quark to a u-quark and a photon: $\kappa_{tu\gamma} < 0.27$ (H1) and $\kappa_{tu\gamma} < 0.175$ (ZEUS). $\kappa_{tu\gamma}$ can even be more constrained when allowing for a non vanishing top coupling to the Z-boson (v_{tuZ}), see ZEUS limit in Figure 3. Also shown are limits obtained at LEP from a search for single top production and obtained at Tevatron from the study of radiative top decays. The figure shows that HERA has an unique discovery potential for anomalous magnetic couplings of the top quark in

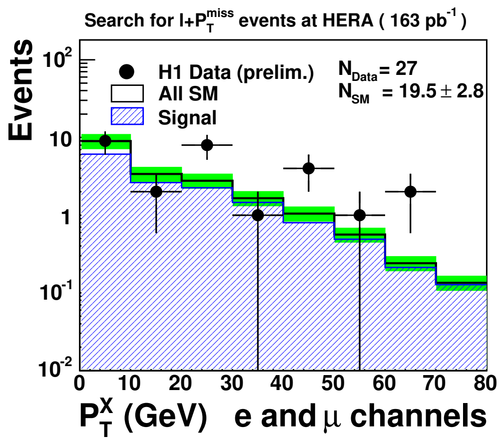

Figure 2. The hadronic transverse momentum distribution in the electron and muon channels combined ($\mathcal{L}$ = 163 pb^{-1}) compared to the SM expectation (open histogram). The SM expectation is dominated by real W production (hatched histogram). The total error on the SM expectation is given by the shaded band.

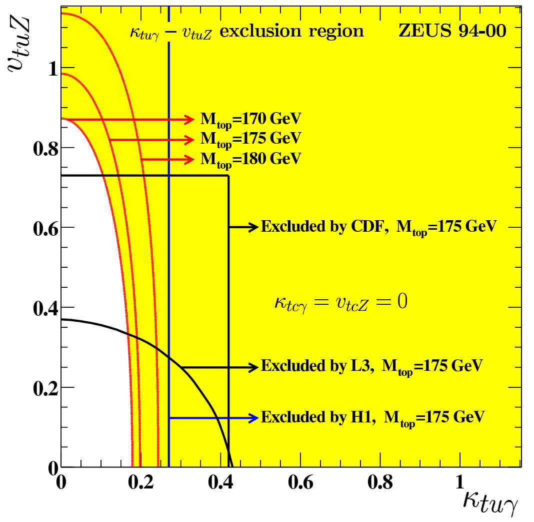

Figure 3. Summary of exclusion limits at 95% CL on the anomalous couplings $\kappa_{tu\gamma} - v_{tuZ}$ of the top quark. For details see text.

a parameter space not excluded by other experiments.

5 Conclusion

The *ep* accelerator HERA has seen a major upgrade program to provide higher luminosities and longitudinally polarised $e^{\pm}$ beams and first data have been taken in e^+p collisions. Recent results on a general model independent search, on a search for isolated lepton events with missing transverse momentum, and on the search for the anomalous production of single top quarks were presented. The trend of H1 at HERA I detecting more isolated lepton events than predicted seems also to continue at HERA II in the electron channel. At present, given the available statistics of isolated lepton events collected at the H1 and ZEUS experiments, the results are inconclusive and clearly more data, which are going to be collected in the upcoming years, will help to solve the puzzle.

References

1. A. Aktas *et al.*, accepted by *Phys.Lett.* B [arXiv:hep-ex/0408044].
2. H1 Collaboration, contributed paper, abstract 12-0765, ICHEP04, Beijing.
3. V. Andreev *et al.*, *Phys. Lett.* B **561** 241 (2003).
4. H1 Collaboration, contributed paper, abstract 12-0188, ICHEP04, Beijing.
5. S. Chekanov *et al.*, *Phys. Rev.* D **68** 052004 (2003);
   S. Chekanov *et al.*, Addendum: "Search for single-top production in ep collisions at HERA" DESY-03-188 (2003).
6. S. Chekanov *et al.*, *Phys. Lett.* B **583** 41-58 (2004).
7. D. Atwood, L. Reina and A. Soni, *Phys. Rev.* D **53** 1199 (1996);
   G.M. Divitiis, R. Petronzio and L. Silvestrini, *Nucl. Phys.* B **504** 45 (1997);
   R.D. Peccei and X. Zhang, *Nucl. Phys.* B **337** 269 (1990);
   H. Fritzsch and D. Holtmannspötter, *Phys. Lett.* B **457** 1199 (1999).
8. A. Aktas *et al.*, *Eur. Phys. J.* C **33**, 9 (2004) .