SEARCHES FOR NEW PHYSICS AT HERA

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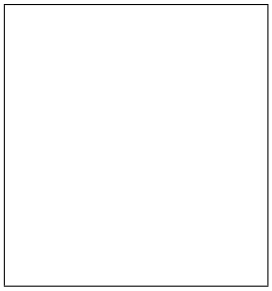

The high energy program of the HERA ep collider ended in March 2007, where a combined total integrated luminosity of 1 fb^{-1} was collected by the H1 and ZEUS experiment together. In this context, a summary of the most recent results of both experiments converning searches for new physics is presented. The topics covered are searches for leptoquarks, excited leptons, single top quark, as well as studies of the isolated lepton and multi-lepton topologies, and a general signature based search.

1 Introduction

At HERA electrons or positrons of 27.6 GeV and protons of 920 GeV are collided, resulting in a center-of-mass energy $\sqrt{s}$ of 319 GeV (301 GeV). After two running periods, the high energy data taking ended in March 2007. The integrated luminosity collected by each experiment have recorded 500 pb^{-1} of data, shared between e^+p and e^-p collision modes. These high energy ep interactions provide a testing ground for the Standard Model (SM) complementary to e^+e^- and $p\bar{p}$ scattering, giving access to rare processes with cross sections below 1 pb. They are therefore used to pursue a rich variety of searches for new phenomena.

2 Leptoquarks

An intriguing characteristic of the Standard Model is the observed symmetry between the lepton and quark sectors. This could be a possible indication of a new summetry between the lepton and quark, leading to "lepto-quark" interactions. Leptoquarks (LQs) are color triplet bosons of spin 0 or 1, carrying lepton (L) and baryon (B) number and fractional electric charge. They couple to lepton-quark pairs and appear naturally in many extentions of SM. Several types of

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LQs might exist, differing in their quantum numbers. A classification of LQs has been proposed by Buchmüller, Rückl and Wyler (BRW) [1] under the assumptions that LQs have pure chiral couplings to SM fermions of a given family. The interaction of the LQ with a lepton-quark pair is of Yukawa or vector nature and is parametrised by a coupling λ. At HERA, LQs can be resonantly produced in the s-channel or exchanged in the u-channel between the incoming lepton and a quark coming from the proton. The resonant production shows up as a peak in the mass spectrum or an enhancement in x distribution at the value corresponding to the mass M of leptoquark: $x = M^2/s$. As a consequence of quark densities in the proton, e^-p and e^+p collisions offer respectively best sensitivities to $F = 2$ and $F = 0$ leptoquarks.

H1 searched for leptoquarks [2] studying the inclusive Neutral Current (NC) and Charged Current (CC) Deep Inelastic Scattering high Q^2 $e^\pm p$ samples from HERA I and HERA II and using an integrated luminosity of 449 pb^{-1}. No signal is observed, in agreement with previous investigations at HERA I. The limits are derived within the phenomenological model proposed by BRW. The constraints on the $S_{0,L}$ LQs are presented in figure 1 and compared to the results obtained at LEP [3] and Tevatron [4] colliders.

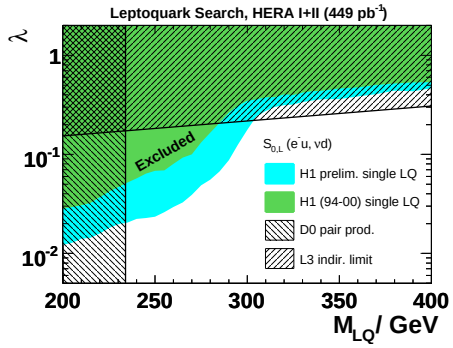

Figure 1: Exclusion limits at 95% CL on the coupling λ as a function of the leptoquark mass for $S_{0,L}$ in the BRW model. The indirect limit from LEP (OPAL and L3) [3] and the direct limts from Tevatron (D0) [4] are shown. The published H1 limit from HERA I data [5] is also shown for comparision.

3 Excited fermions

The direct observation of excited states of fermions ($f^\star$) as a natural consequence of the compositeness models [6,7,8] via their decay into a fermion and a gauge boson would be an evidence for new level of substructure. The interaction of an $f^\star$ with a gauge boson is described by a magnetic coupling proportional to $1/\Lambda$ where Λ is the compositeness scale. Proportionality constants f, f' and f_s result in different couplings to $U(1)$, $SU(2)$ and $SU(3)$ gauge bosons.

Excited leptons and quarks may be produced in electron(positron)-proton collisions at HERA via t-channel $\gamma(Z)$ or $W^\pm$ gauge boson exchange. Excited quark may also be exchanged in the u-channel with a non negligible cross section for high $q^\star$ masses and low values of Λ. H1 searched for excited electrons [9] and quarks [10] using all $e^\pm p$ data, corresponding to a total integrated luminosity of 475 pb^{-1}. In the case of excited neutrinos, the cross section is much larger in e^-p collisons than in e^+p collisions due to the favourable valence u-quark and the helicity enhancement, specific to CC-like processes. Therefore the search for excited neutrinos [11] used only e^-p sample data with an integrated luminosity of 184 pb^{-1}. No evidence for the production of excited fermions are observed. The new bound on the $\nu^\star$, $e^\star$ and $q^\star$ masses obtained as a function of f/Λ are presented in figure 2, under the assumptions $f = -f'$, $f = +f'$ and $f = +f'$ and $f_s = 0$, respectively. Assuming $f/\Lambda = 1/M_{\nu^\star}$ and $f = -f'$, masses below 213 GeV are ruled out for $\nu^\star$. Excited electrons of mass below 272 GeV are excluded if we assume $f/\Lambda = 1/M_{e^\star}$ and $f = +f$. Excited quarks with masses upto 259 GeV are excluded at 95% CL considering the assumption $f/\Lambda = 1/M_{q^\star}$ and $f_s = 0, f = f'$. As observed in figure 2, the H1 analysis has probed new parameter space regions and limits set extend at high masses previous bounds reached at LEP and Tevatron colliders.

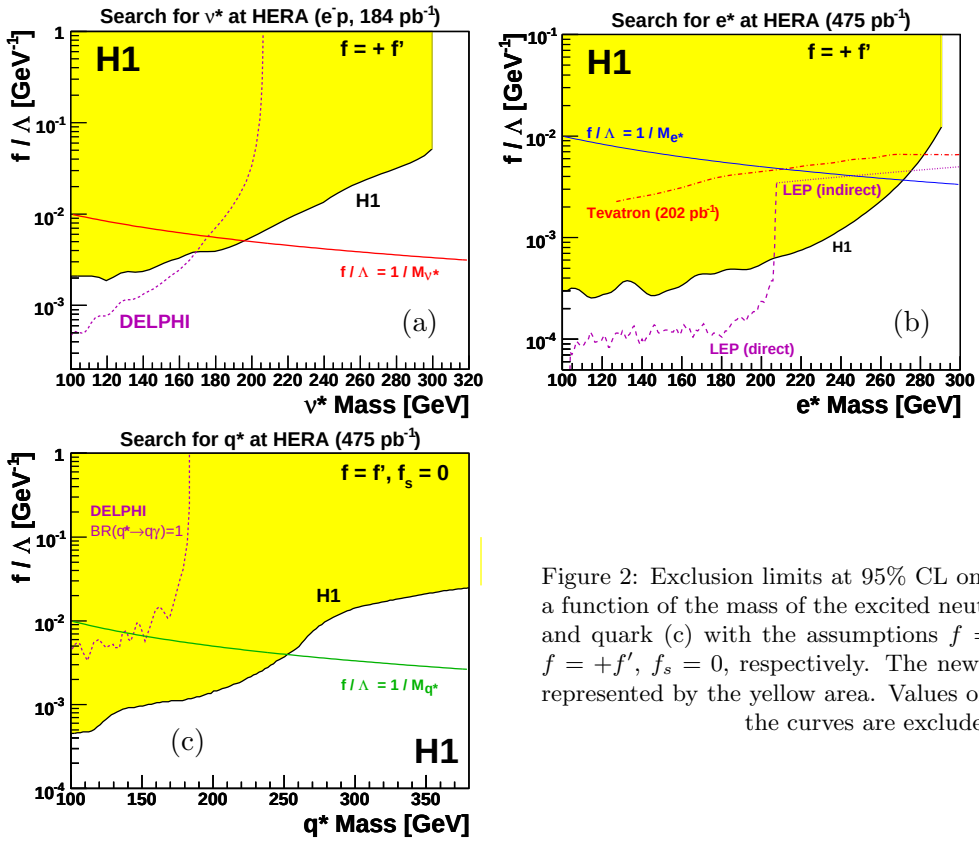

Figure 2: Exclusion limits at 95% CL on the coupling f/Λ as a function of the mass of the excited neutrino (a), electron (b) and quark (c) with the assumptions $f = -f'$, $f = +f'$ and $f = +f'$, $f_s = 0$, respectively. The new limits set by H1 are represented by the yellow area. Values of the couplings above the curves are excluded.

4 Anomalous single top production

At HERA top quarks can only be singly produced. SM single-top production proceeds via the CC interaction $ep \to \nu t \bar{b} X$. 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 Flavor Changing Neutral Current (FCNC). H1 searched for single top events in a sample of isolated leptons with high transverse momentum P_T using all $e^{\pm}p$ data corresponding to an integrated luminosity of 482 pb^{-1}. The analysis [12] searched for anomalous production of t decaying into $\bar{b}$ and W with subsequent decay of W into an electron or muon. An upper limit on the cross section set by H1 is $\sigma_{ep \to etX} < 0.16$ pb, leading to the most stringent limit on $k_{tu\gamma} < 0.14$ at 95% CL. Figure 3 represents the constraints on the couplings $k_{tu\gamma}$ and v_{tuZ}. The top mass is assumed to be $m_t = 175$ GeV in order to compare with previous results. The figure shows that HERA has an unique discovery potential for anomalous magmetic couplings of the top quark in a parameter space not excluded by other colliders.

5 Isolated leptons and missing transverse momentum events

Events with isolated leptons and missing transverse ($P_T^{\rm miss}$) momentum are selected by requiring an isolated high transverse momentum lepton (electron, muon or tau) and large $P_T^{\rm miss}$. For the remaining hadronic final state (jet) the transverse momentum (P_T^X) is measured. The main SM "background" contribution to such a signature comes from the production of a W boson with subsequent leptonic decay. Of particular interest are events with a hadronic system of large P_T^X. An abnormally large rate of high P_T^X events is observed by the H1 experiment [16] in the electron and muon channels. Searches have been performed, using now the full HERA data corresponding to an integrated luminosity of 474 pb^{-1} by the H1 experiment in the decay

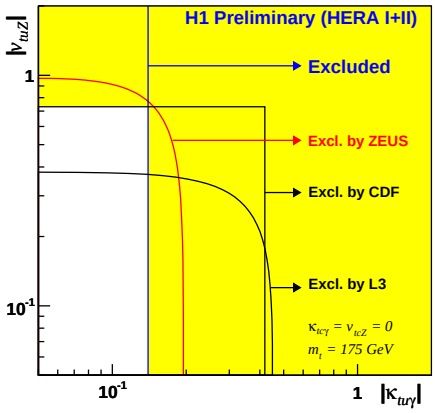

Figure 3: Exclusion limits at 95% CL on the anomalous $k_{tu\gamma}$ and v_{tuZ} couplings from H1 and ZEUS [13] compared to limits from LEP [14] and Tevatron [15]. Anomalous couplings of the cherm quark are neglected $k_{tu\gamma} = v_{tuZ} = 0$. Limits are shown assuming a top mass $m_t = 175$ GeV.

channels into electrons and muons and taus [17]. For $P_T^X > 25$ GeV, 53 data events are observed compared to a SM prediction of 54.1±7.4, where 40.4±6.3 are expected from signal processes, dominated by single W production. In this region, an excess of e^+p data events is observed, equivalent to a fluctuation of order 2.4σ. The observation in the e^-p data is consistent with the SM expectation. In the tau channel, at $P_T^X > 25$ GeV one event is observed in the data, compared to a SM expectation of 1.5±0.2.

The ZEUS experiment has carried out a similar analysis using 504 pb^{-1} of 1996-2007 data [18]. Figure 4 shows the observed P_T^X distributions of the isolated electron(a) and muon(b) events compared to the SM expectation for the $e^\pm p$ collision data. At high P_T^X in the combined electron and muon channels the number of data events observed by ZEUS is in agreement with the SM expectation in both e^+p and e^-p collisions (5/5.5±0.8 and 6/7.4±1.0, respectively).

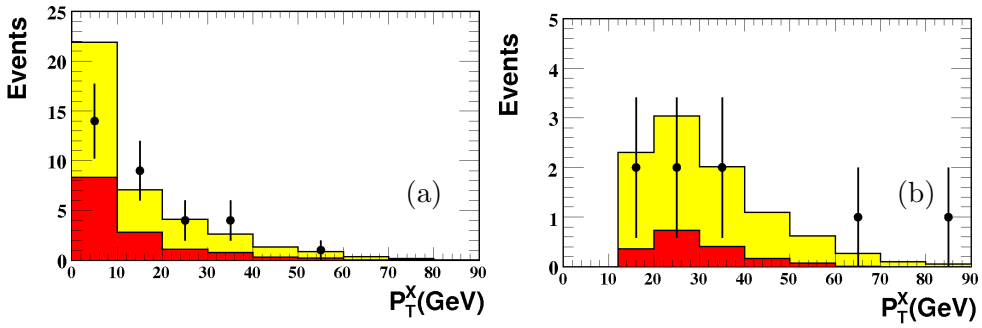

Figure 4: The hadronic transverse momentum P_T^X distributions in the electron(a) and muon(b) channels for all $e^\pm p$ collision data. The total SM expectation is represented by the color shaded histograms and the contribution from W by the dark-shaded histogram.

6 Multi-lepton events

Multi-lepton production has also been studied at HERA. The main production mechanism is photon-photon collisions. All event topologies with high P_T electrons and muons have been investigated by the H1 experiment [19] using all HERA data with an integrated luminosity of 463 pb^{-1}. The measured yields of di-lepton and tri-lepton events are in good agreement with the SM prediction, except in the tail of the distribution of the scalar sum of transverse momenta of the leptons ($\sum P_T$).In e^+p collisions, five data events have a $\sum P_T > 100$ GeV, whereas the corresponding SM expectation is 0.96±0.12. No such events are observed in e^-p collisions for a similar SM expectation of 0.64±0.09.

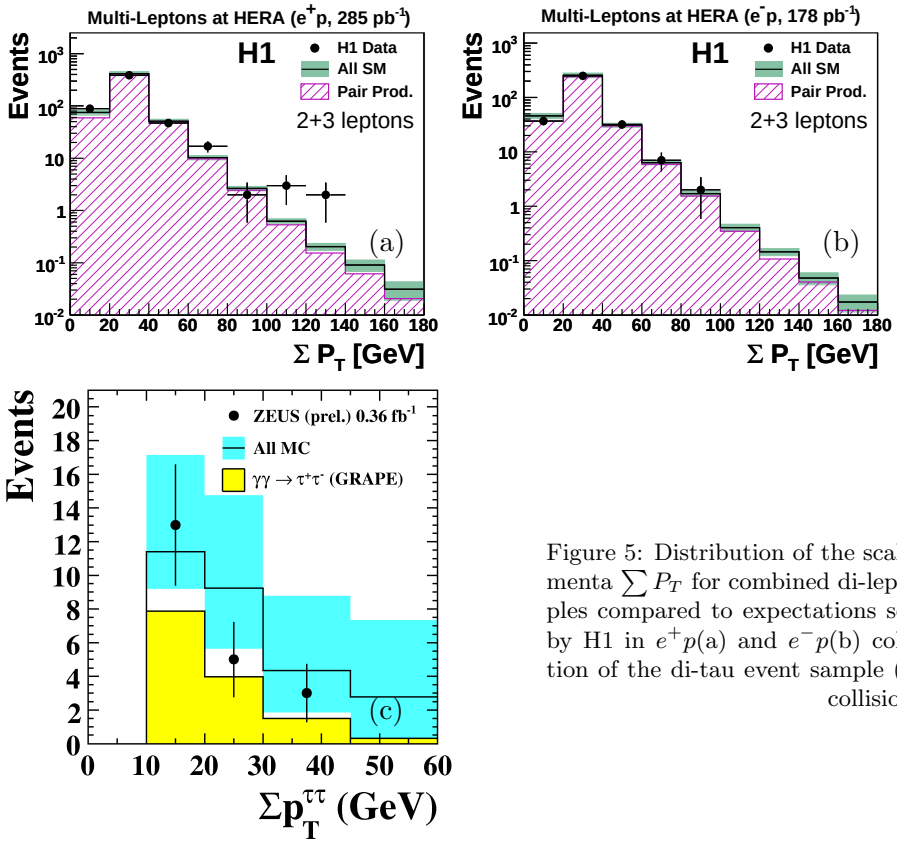

Figure 5: Distribution of the scalar sum of the transverse momenta $\sum P_T$ for combined di-lepton and tri-lepton event samples compared to expectations separately for events recorded by H1 in e^+p(a) and e^-p(b) collisions. The $\sum P_T$ distribution of the di-tau event sample (c) recorded by ZEUS in $e^{\pm}p$ collisions.

The analysis of di-lepton and tri-lepton topologies in the electron and muon channels is also carried out by ZEUS using 480 pb^{-1} of data [20]. Two data events are observed with $\sum P_T >$ 100 GeV compared to a SM prediction of 0.99±0.11 in e^+p collisions. No such events are observed in e^-p collisions for a similar SM expectation of 0.57±0.07. In the tau channel, a search for events containing two high P_T taus is performed by ZEUS using the full HERA II data [21], corresponding to 360 pb^{-1} of data.21 data events are observed compared to a SM prediction of 27.2±7.1, where 13.2±1.0 are expected from di-tau MC expectations.

7 A general search for new phenomena

A model independent general search for deviations from the SM has been performed by H1 using now all HERA I and HERA II data [22]. Following [23], all final states containing at least two objects (e, μ, j, γ, ν) with $P_T > 20$ GeV in the central region of the detector are investigated. The observed and predicted yields in each channel are presented in figure 6(a) and (b) for e^+p and e^-p collisions, respectively. The good agreement observed between data and SM prediction demonstrates the good understanding of the detector and of the contributions of the SM backgrounds. A statistical analysis is then used to quantify the significance of observed deviations. The largest deivation is found in the e-e event class, in e^+p collisions.

8 Conclusion

The complete statistics of 15 years of data taking is being exploited by H1 and ZEUS to improve the sensitivity of the searches for new physics in the unique HERA environment. The recent results of searches for new physics performed at the HERA collider have been presented. Most of the analyses fully exploit the complete data sample available which amounts to 500 pb^{-1} per

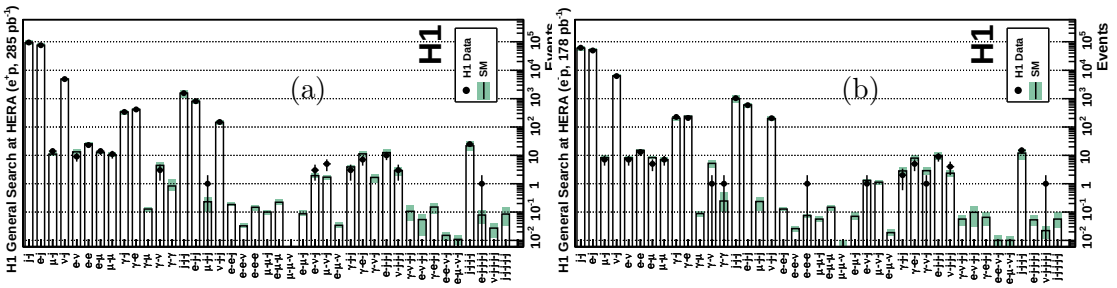

Figure 6: The data and the SM expectation in event classes investigated by the H1 general search. All channels with observed data events or a SM expectation greater than 0.01 event are displayed. The results are presented separately for e^+p(a) and e^-p(b) collisions modes.

experiment. HERA appears to be very well suited to search for new phenomena in specific cases, complementary to stringent bounds set at LEP and Tevatron. Nevertheless, no convincing evidence for the existence of new phenomena has been observed so far. Among all event topologies investigated, the largest deviation to the SM expectation is observed by the H1 experiment for isolated lepton events in e^+p collisions only. After having analysed all data recorded by H1, this deviation corresponds to a 2.4σ significance.

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