Search for New Physics at HERA

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Abstract. The HERA $e^\pm p$ collider operated between 1992 and 2007. The two colliding beam, general purpose experiments, H1 and ZEUS, collected together and integrated luminosity of $\sim 1 \text{ fb}^{-1}$. In the present paper it is presented a summary of the the most recent results on the search for new physics the above mentioned experiments. Most of the results have been obtained by making use of the full available statistics.

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INTRODUCTION

The HERA $e^\pm p$ collider was operated between 1992 and 2007. Electron or positron beams with an energy of 27.6 GeV were collided with proton beams with an energy up to 920 GeV, resulting in a center-of-mass energy $\sqrt{s}$ up to 319 GeV. The two colliding-beam general purpose experiments, H1 [1, 2] and ZEUS [3], collected an integrated luminosity of about 0.5 fb^{-1} each.

SEARCH FOR NEW PHYSICS AT HERA

At HERA the Deep Inelastic $e^\pm p$ Scattering (DIS) processes proceed via the exchange of an electro-weak boson, that can be either neutral (γ, Z^0) or charged ($W^\pm$). We will talk about Neutral Current (NC) processes in the first case, of Charged Current (CC) processes in the latter. The virtuality of the boson, Q^2 , sets the scale at which the proton is probed. New Physics, if exists, is expected to appear at high energies (small distances). At HERA we reached Q^2 values bigger 10^4 GeV^2 , which corresponds to a resolving power of the boson of $\sim 10^{-18} \text{ m}$.

The first effect we can look for at HERA are deviations in the Neutral Current DIS cross section. If the quark radius is not zero, we would expect deviation from the Standard Model (SM) at high- Q^2 , described by the additional quark form factor. Both H1 and ZEUS have compared their cross section measurements to the SM predictions [4, 5] and found no deviations. Therefore upper limits for the quark radius have been derived at 95% Confidence Level (CL): $R_q < 0.74 \times 10^{-18} \text{ m}$ (H1), $R_q < 0.62 \times 10^{-18} \text{ m}$ (ZEUS).

Any new interaction appearing at a much higher energy than the center-of-mass can be described in terms of a contact interaction, expected to be visible as deviations from the SM cross section. Since no deviations were observed by ZEUS [4] and H1 [6],

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limits were set at 95% CL on the effective scale of the new interaction. Depending on the chiral structure assumed, limits were set between 2.0 and 8.0 TeV in the ZEUS analysis, and between 1.6 and 5.5 TeV in the H1 analysis.

Another effect of fermion compositeness would be the existence of excited states of fermions. Such particles would decay to an ordinary fermion by emitting a gauge boson. The H1 collaboration investigated all the possible decay channels [7, 8, 9] and found no deviation from the SM prediction. Therefore upper limits were set on the coupling constants of excited to ordinary fermions, at 95% CL; from these limits lower limits on the excited fermion mass were derived. The mass limits ranged from ~ 200 GeV to ~ 270 GeV.

Many extensions to the SM predict the existence of leptoquarks (LQs), particles carrying both baryon and lepton numbers; they would have fractional electric charge and SU(3) color. The LQs are explored in the Buchmüller, Rückl and Wyler model [10]. At HERA they can be produced resonantly (s -channel exchange), or they can be exchanged between the incoming lepton and a quark coming from the proton (t -channel exchange). They are expected therefore to decay in electron-jet or neutrino-jet. H1 searched for LQs in NC and CC DIS data [11], and observed no excess over the SM prediction. Therefore upper limits were set on the coupling of LQs to ordinary leptons and quarks. These limits resulted to be competitive with the ones from LEP and TEVATRON experiments.

Events containing high energy leptons (electrons or muons) and missing transverse momentum (P_T) produced in high energy particle collisions are interesting as they may be a signature of physics beyond the SM. In the SM, the production of single W bosons with subsequent leptonic decay gives rise to this topology. The process has been studied by both the H1 [12] and ZEUS [13] collaborations. The H1 collaborations observed some excess in the e^+p collisions, in the region of high hadronic transverse momentum, $P_T^X > 25$ GeV. 17 events were observed in data, whereas 8.0 ± 1.3 are expected from the SM; the excess corresponds to 2.4 standard deviations. No excess was observed by H1 in the e^-p collisions, neither by ZEUS.

Isolated leptons (electrons or muons) with missing P_T are also the signature for single top production. In the SM single top can be produced in CC interactions, but the cross section is very small, $O(1$ fb). Flavor Changing NC processes, if existing, would contribute to the cross section. Both the collaborations have compared the data to the SM predictions [14, 15] and found no significant deviations. Therefore limits were set on the anomalous coupling $\kappa_{tu\gamma}$ at 95% CL; the more stringent result is from ZEUS: $\kappa_{tu\gamma} < 0.13$, that is competitive to the limits from the TEVATRON.

At HERA also the production of two or more high- P_T leptons (electrons or muons) have been investigated. The two collaborations have combined their data [16], and compared them to the prediction from the SM. The bigger contribution in the SM comes from the so called Bethe-Heitler process, where lepton pairs are produced via $\gamma\gamma$ interactions. The distribution of the scalar sum of all lepton's momenta ($\sum P_T$) is plotted in Fig. 1, separately for e^+p and e^-p collisions. In e^+p collisions, 7 events with $\sum P_T > 100$ GeV are observed, whereas 1.94 ± 0.17 events are predicted by the SM Monte Carlo; this excess corresponds to 2.6 standard deviations. No events with $\sum P_T > 100$ GeV are observed in e^-p collisions, whereas 1.19 ± 0.12 are expected.

The H1 collaboration performed a general search for new physics [17]. Events with at least one high- P_T electron, photon, muon, neutrino or jet are selected, and divided

FIGURE 1. The distribution of the scalar sum of the transverse momenta ΣP_T for the multi-lepton events.

in mutually exclusive classes, depending on the type and number of high- P_T objects found. In general a good agreement with the SM is found in the number of events for the selected topologies, Fig 2. Deviations from the SM are also searched for in the ΣP_T and invariant mass M_{all} distributions. All the observed deviations are compatible with the expected statistical fluctuations.

CONCLUSION

The H1 and ZEUS collaboration have analyzed the data collected between 1992 and 2007 at the HERA $e^\pm p$ collider, in the search for physics beyond the Standard Model. Many different final states have been studied. In general a good agreement between data and the Standard Model simulations is observed. In some few cases deviations are observed, but still compatible with statistical fluctuations.

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FIGURE 2. The data and SM expectation for all event classes with high- P_T objects, where at least 0.01 events are observed or expected.

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