Search for Physics beyond Standard Model at HERA

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Abstract. Recent results on searches for signals of physics beyond Standard Model (SM) at the *ep* collider HERA are reviewed. Limits obtained for contact interaction models, large extra dimensions and finite quark radius are presented. Searches for excited-fermion resonances yield unique limits on excited electrons and neutrinos. Finally, measurement of *W* production cross section in *ep* collision is presented.

Keywords: HERA, H1, ZEUS, DIS, neutral current, charged current, contact interaction, large extra dimension, quark radius, excited fermion, excited electron, excited neutrino, compositeness, W production, isolated lepton, FCNC, standard model
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INTRODUCTION

HERA was the only *ep* collider in the world. It collided 27 GeV electrons or positrons with 920 GeV protons, yielding a center-of-mass energy of 320 GeV. Its operation terminated in June last year and each collider experiment, H1 and ZEUS, collected approximately 0.5 fb^{-1} of data for physics analysis.[1]

At HERA, the lepton and hadron undergo deep inelastic scattering (DIS) by an exchange of t-channel boson (γ, Z or $W^{\pm}$), and at large values of Q^2, the momentum transfer squared, it can be regarded as *eq* interaction at a very short distance (see Fig. 1). Hence, by measuring the parton distribution functions using DIS events at low Q^2 and extrapolating them to high Q^2 with QCD, and comparing the SM prediction with the observed events, one can search for signatures of physics beyond the SM.

In this paper, recent results on searches for contact interactions and for excited fermions are presented, as well as the most recent result on W production cross section measurement. The results on searches for signatures related to supersymmetry are reported elsewhere in the same conference [1].

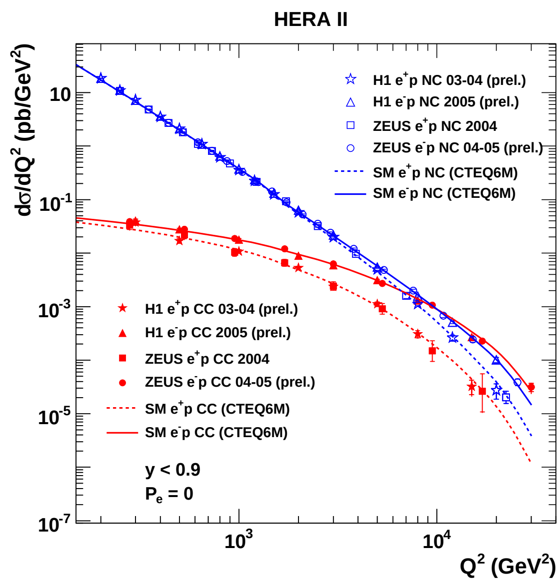

FIGURE 1. High-Q^2 neutral current (NC) and charged current (CC) cross sections measured at HERA. It is seen that at large values of Q^2 the electromagnetic and weak interactions are unified and become of the same order of magnitude.

CONTACT INTERACTIONS AND RELATED SIGNATURES

Physics at very high mass scales can appear at much lower energies as rare processes via virtual effects. The phenomena can be generally described as contact interactions (CI), reducing the unknown details of the interaction to a coupling constant having a dimension of inverse mass. A classical example is the early days of weak interaction, when the interaction was considered as a four-fermion CI having a 'small' coupling constant G_F having a dimension of inverse mass squared. Later it was clarified that this smallness comes from the large mass of the propagator boson, the W. At HERA, *eeqq*-CI can affect the neutral current DIS cross sections at large Q^2. The same CI can also be tested at LEP e^+e^- collider and TeVatron $p\bar{p}$ collider. It is conventional to define the mass scale Λ assuming the value of fundamental coupling constant at $\sqrt{4\pi}$.

[1] The data before the luminosity upgrade in 2000 are referred to as HERA-I and those afterwards, with longitudinal lepton polarization, are referred to as HERA-II data.

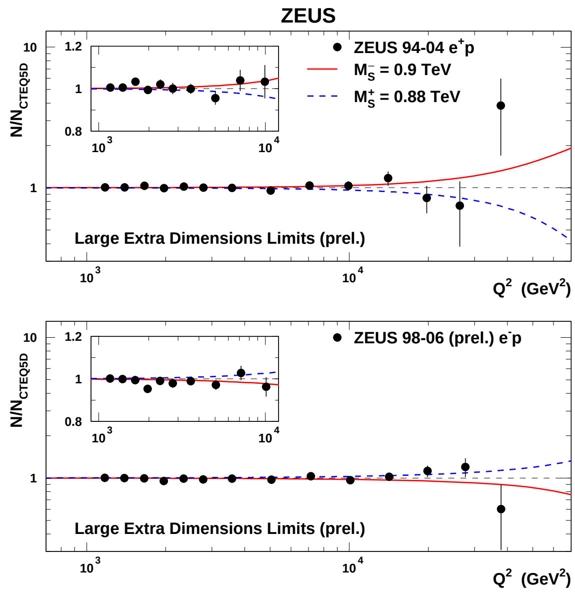

FIGURE 2. The points show the ratios of high-Q^2 NC DIS events to SM prediction from ZEUS e^+p (upper) and e^-p (lower) data. The lines are fits to models with large extra dimensions.

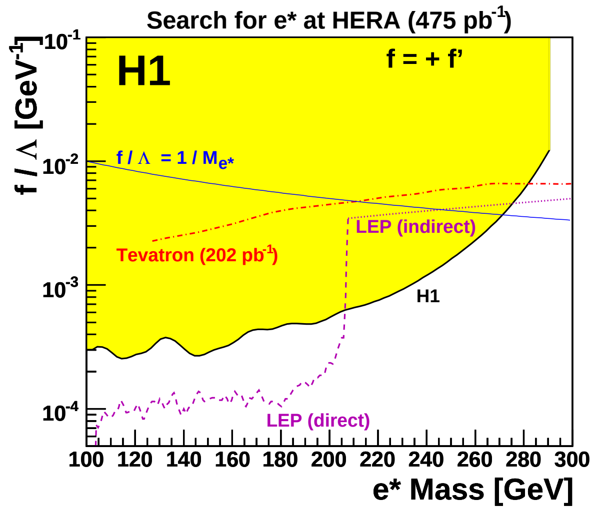

FIGURE 3. Limits on f/Λ as a function of excited electron mass obtained from H1 HERA-II data.

Various models of the new interaction can be considered, depending on the chiral structure of the coupling to left- and right-handed leptons and quarks. Each model causes different interference with SM interaction, showing different behavior of NC DIS events at high Q^2 for e^+p and e^-p scattering.

A fit has been made for HERA-II ZEUS data for 19 CI models, yielding lower limits for the mass scale Λ between 2.0 and 8.0 TeV at 95% CL. These results are complementary to those from other colliders and some are unique limits. H1 collaboration also derived limits between 1.6 and 5.5 TeV using HERA-I data.

If there are in space-time n extra dimensions which are compactified to a relatively large scale R, and only the gravitational interaction can propagate in these extra dimensions, the real GUT scale M_S can be as low as TeV, much lower than the Planck scale ($R^n M_s^{n+2} \approx M_{\rm Planck}^2$) [2]. This is an attractive hypothesis to solve the hierarchy problem, and its collider consequence is that exchange of Kaluza-Klein excitations of gravitons modifies the SM-particle scattering at high energy. Phenomenologically, it can be reduced to a CI-like formalism with λ/M_s^4 as a parameter. Fits to HERA-II ZEUS data (HERA-I H1 data), shown in Fig. 2, yield lower limits on M_s of 0.88 (0.82) TeV for λ=+1 and 0.90 (0.78) TeV for λ=−1, respectively.

Finally, from the same data set, a classical approach on measuring the form factor of a quark can be performed, repeating the Hofstadter measurement on the proton but at a scale of $Q^2 \approx 40{,}000$ GeV^2 instead of 1 GeV^2. At this scale, the spatial resolution reaches the order of 10^{-16} cm, one thousandth of the proton radius. If the quark is not elementary but has a finite radius, the scattering cross section would decrease as the virtual-boson probe 'penetrates' into it, since it begins to see less electroweak charge. The upper limit from ZEUS (H1) NC data on the quark size, assuming the electron is point-like, is 0.62×10^{-16} (0.74×10^{-16}) cm.

EXCITED FERMIONS

It can be seen at each scale of Nature that whenever there is compositeness (structure) of matter, there are excited states and emission (radiation) phenomena between the ground and excited states. For example, excited molecule does light emission (eV scale), excited atoms emit X-ray (keV), excited nuclei and gamma ray (MeV), and excited nucleons (resonances) decay with pion (0.1 GeV) emission. Therefore, if the leptons/quarks are not elementary but composite, their excited states could radiate gauge bosons (0.1 TeV) when decaying to the ordinary state.

Both H1 and ZEUS collaborations search for mass resonances in fermion+boson pairs. Figure 3 shows the latest results from H1 [3] for an excited electron (e^*) search. The resonance was searched for in $e\gamma$, νW and eZ decay modes, followed by hadronic and leptonic decays of W/Z. The limits are expressed in coupling over composite scale, f/Λ, as a function of the e^* mass (M_{e^*}). Assuming the relation $f/\Lambda = 1/M_{e^*}$, lower limit of $M_{e^*} >$ 272 GeV can be obtained, which is more stringent than

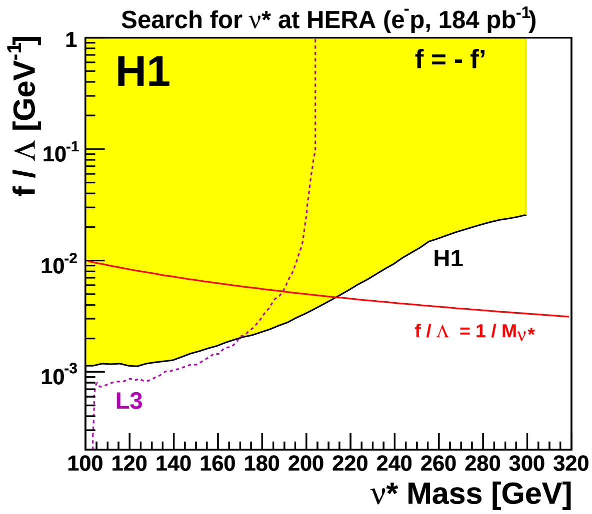

FIGURE 4. Limits on f/Λ as a function of excited neutrino mass obtained from H1 HERA-II data.

LEP and TeVatron limits. The indirect limits from LEP above 200 GeV come from $e^+e^- \to \gamma\gamma$ process.

Figure 4 shows the H1 results [4] for an excited neutrino (ν^*) search. Since the production ($ep \to \nu^* X$) proceeds through W exchange (charged current), e^-p collision gives much higher sensitivity than e^+p. The search was done for $\nu\gamma$, eW and νZ decay modes. It can be seen that HERA has unique sensitivity for excited neutrinos in the mass range above 200 GeV. In the result shown in the figure, the lower limit on ν^* mass for the same assumption as above is obtained to be 216 GeV.

W PRODUCTION

Finally, the most recent results from ZEUS are presented concerning events with a topology with a lepton with high transverse momentum (P_T) and missing P_T [5]. Largest SM contribution to this topology comes from on-shell W production, and excess of such events with additional large hadronic P_T (P_T^X) could be a signature of e.g. FCNC single-top production with subsequent decay $t \to bW$.

From the whole HERA data set (504 pb^{-1}), ZEUS observed 11 isolated electron or muon events with P_T^X>25 GeV, compared with SM expectation of 12.9±1.7 events (of which 77% comes from W production). Also in the lower-P_T^X region the observation was in agreement with SM prediction. Figure 5 shows the transverse-mass distribution for electron events, which shows a clear Jacobian peak expected for W production.

From these events, the total cross section for W production in ep collisions was obtained to be

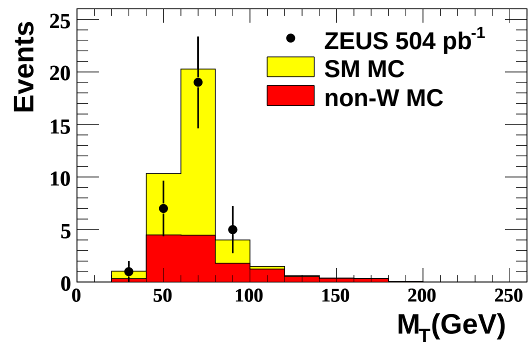

FIGURE 5. Distribution of transverse mass for the ZEUS events with high-P_T isolated electron and missing P_T.

$0.89^{+0.25}_{-0.22}$(stat.)±0.10(syst.) pb. This is the smallest total cross section measured at HERA, and in agreement with theoretical prediction at NLO calculation.

SUMMARY

HERA has ceased data-taking after about 15 years, with $\approx 0.5\text{fb}^{-1}$ per experiment of high-energy ep collision data. The data give solid confidence of perturbative QCD and indispensable inputs to LHC physics. The short distance eq interaction has an unique opportunity to search for particles and forces beyond SM. Limits on contact interactions, large extra dimensions and quark radius, and on excited electrons and neutrinos are presented, for example. Many results are competitive/complementary with other colliders. The search list is not yet exhaustive, and many results from whole HERA data are expected to come. Also a combined-results working group from H1 and ZEUS has been formed.

ACKNOWLEDGMENTS

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