Beyond the Standard Model Physics at HERA

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On behalf of the H1 and ZEUS collaborations

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New results from searches for physics beyond the Standard Model from HERA experiments H1 and ZEUS are presented. The topics includes excited fermions, MSSM and high Q2 neutral current analysis.

1. Introduction

In the storage ring HERA, 27.5 GeV electrons collide with 820 GeV protons at a center of mass energy of 300 GeV, opening an unexplored domain for new physics searches [1]. In this paper new results from excited fermions and Minimal Supersymmetric Standard Model (MSSM) analysis done by ZEUS collaboration are presented toghether with the analysis of neutral current (NC) deep inelastic scattering (DIS) in the high Q^2 regime done by H1 and ZEUS.

2. Excited fermions

Excited fermions represents the natural scenario for the compositness extensions of the Standard Model. The production and decay of excited fermions are described in terms of the phenomenological Lagrangian proposed in the Ref. [2].

$$L_{ff^*} = \frac{e}{\Lambda}\sum_{V}^{\gamma,Z,W} \bar{f}^* \sigma^{\mu\nu}(c_V - d_V\gamma^5) f \partial_\mu V_\nu + h.c. \quad (1)$$

where c_V and d_V are coupling constants at the $f \leftrightarrow f^*$ vertex labelled for each vector boson V, and Λ is the compositeness scale. The precise measurement of muon $g-2$ and the absence of electron and muon electric dipole moment implies that $c_V = d_V$ for compositness scales less than 10–100 TeV. This fact lead to an interaction Lagrangian where the coupling constants of excited fermions to Standard Model gauge bosons are described in terms of three constants corresponding to the three gauge groups: f for $SU(2)_L$, f' for $SU(1)_Y$ and f_s for $SU(3)_C$. For specific assumptions relating f, f' and f_s the branching ratios can be predicted and the cross sections are described by a single parameter (e.g. f/Λ).

Searches for excited fermions based on 2.75 pb^{-1} have been reported recently by the H1 collaborations [3]. We present here the results of the analysis performed by ZEUS based on 9.4 pb^{-1} [4]. This analysis search for excited fermions with masses above 30 GeV, decaying to a light fermion trough electroweak mechanism. The decay channels and the corresponding search strategies are the following:

- $e^* \rightarrow e\gamma$. Two electromagnetic clusters.
- $e^* \rightarrow eZ^0 \rightarrow eq\bar{q}$ and $\nu_e^* \rightarrow eW \rightarrow eq\bar{q}$. An electromagnetic cluster, large hadronic transverse energy and mass.
- $e^* \rightarrow \nu_e W \rightarrow \nu_e q\bar{q}$ and $\nu_e^* \rightarrow \nu_e Z^0 \rightarrow \nu_e q\bar{q}$. Missing transverse momentum, large hadronic transverse energy and mass.
- $\nu_e^* \rightarrow \nu_e\gamma$. Missing transverse momentum and an electromagnetic cluster without tracks in its vicinity.
- $e^* \rightarrow eZ^0 \rightarrow e\nu\bar{\nu}$ and $e^* \rightarrow \nu_e W \rightarrow e\nu\bar{\nu}$. Missing transverse momentum and a track matching an electromagnetic cluster.
- $\nu_e^* \rightarrow eW \rightarrow e\bar{e}\nu_e$. Missing transverse momentum and two electromagnetic clusters.
- $q^* \rightarrow q\gamma$. Electromagnetic cluster (no track) and large hadronic transverse energy.

- $q^* \rightarrow qW \rightarrow q\bar{e}\nu_e$. Missing transverse momentum, an electromagnetic cluster and large transverse hadronic energy.

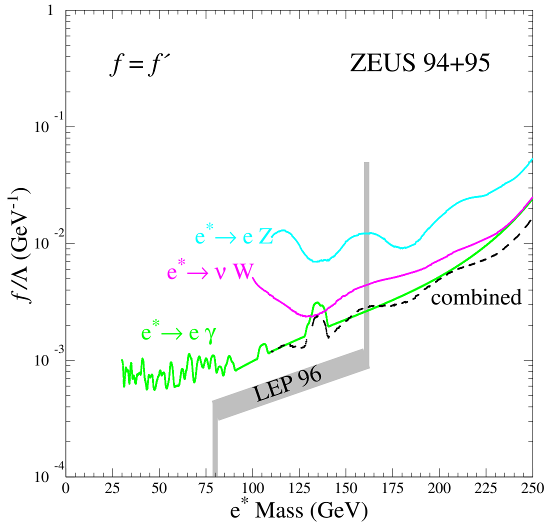

Figure 1. Excited electron channels: f/Λ versus mass upper limits at 95% confidence level.

No positive evidence for resonant final states is found in the channels described above. Limits are calculated for the product between the branching ratio and the production cross section. Those limits are tipically below 1 pb^{-1} at 95% confidence level. Using the model described above [2], limits for the ratio f/Λ are computed as a function of the excited fermion masses. The Fig. 1 presents upper limits at the 95% confidence level for the excited electron channels assuming $f = f'$.

With the choice $f/\Lambda = 1/M_f$, this analysis excludes excited electrons with mass between 30 and 200 GeV, excited electron neutrinos with mass between 40 and 96 GeV, and excited quarks coupled electroweakly with mass between 40 and 169 GeV.

2.1. MSSM

A promising candidate for a theory beyond the Standard Model is the supersymmety (SUSY). This theory relates fermions to bosons and predicts for each SM particle a partner with spin differing by half a unit. So the selectrons and sneutrinos are the supersymmetric scalar partners of electrons and neutrinos. The partners of the gauge bosons $W^{\pm}$, Z^0, γ and the two Higgs doublets necessary to give masses to quarks and leptons, are called gauginos and higgsinos. They can mix and form four neutral mass eigenstates (neutralinos $\chi_{0,1,2,3}$) and two charged mass eigenstates (charginos $\chi^{\pm}_{1,2}$). The supersymetry beaking introduces two new mass parameters M_2 and M_1 for the $SU(2)$ and $U(1)$ gauginos. The masses of charginos and neutralinos depend on M_1, M_2, $\tan\beta = v_2/v_1$ and the higgsino mass parameter μ. In the MSSM is assumed that the multiplicative quantum number R-parity is conserved ($R = +1$ for the SM particles and $R = -1$ for the SUSY partners).

At HERA, the dominant MSSM process is the production of a selectron and a squark via neutralino exchange $ep \rightarrow \tilde{e}\tilde{q}X$ with subsequent decays $\tilde{e} \rightarrow e\chi^0_1$ and $\tilde{q} \rightarrow q\chi^0_1$. The signature of such a process is an electron accompanied by a jet and missing energy due to undetected neutralinos. The search for this process has been reported by the H1 collaboration [5]. We present here the results of ZEUS analysis based on 1994-1996 data (19.95 pb^{-1}).

The selection is based on the presence of an electron with transverse momentum above 4 GeV not aligned to the hadronic system in the plane transverse to the beam direction ($|\Delta\phi| - \pi < 0.25$ rad.). The hadron system transverse momentum has to be higher than 4 GeV. The missing transverse momentum has to be above 12 GeV with significant momentum imbalance in the logitudinal direction also ($E - P_z < 50$).

No excess is observed with respect to the Standard Model predictions and limits on the selectron and squark masses are calculated under certains assumption on M_1, M_2, $\tan\beta = v_2/v_1$ parameters: equal messes for left- and right-handed SUSY partners of the leptons and quarks and the GUT-inspired relation $M_1 = 5/3\tan^2\theta_W M2$.

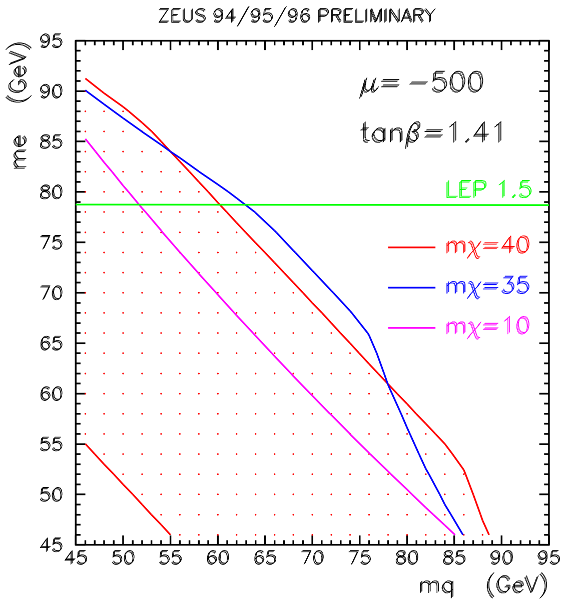

Figure 2. Lower limits for selectron and squark masses at 95% confidence level for different neutralino mass values.

The Fig. 2 shows the 95% confidence lower limit in the $M_{\tilde{e}}$–$M_{\tilde{q}}$ for different neutralino masses. The highest limit for the selectron mass, $M_{\tilde{e}} > 92$ GeV at 95% confidence level, is obtained for $M_{\chi} = 40$ GeV and $M_{\tilde{q}} = 46 GeV$.

3. High Q2 neutral current events

Physics beyond the Standard Model could manifest itself in a deviation of the observed from the predicted cross section at high Q^2. Both ZEUS and H1 collaboration have published [6,7] the analysis of NC DIS process in the high Q^2 region based on 1994-1996 data (14.3 pb^{-1} for H1 and 20.1 pb^{-1} for ZEUS) and those results will be shortly summarized hereafter.

The selection is based on the presence of a high transverse momentum positron: $P_T > 25$ GeV in H1 analysis and $P_T > 20$ GeV for positron polar angle $\theta_e > 17.2°$ and $P_T > 30$ GeV for $\theta_e < 17.2°$ in ZEUS analysis. The combined acceptance and efficiency is $\sim 80\%$ for both experiments.

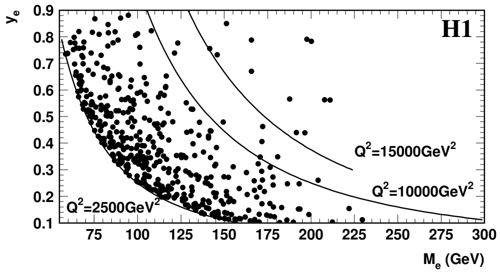

Figure 3. H1 selected NC DIS candidate events in the $M_e - y_e$ plane.

In the neutral current events, four quantities are measured: electron and hadrons energies and electrons and hadrons angles. Thus the kinematics of the event is determined by any two of the four measured quantities, which can be used to reconstruct the x, y, and Q^2. H1 uses the electron energy and angle. This method ("e"-method) take advantage of the good electromagnetic shower resolution. ZEUS uses the angles of the electron and of the hadronic system, this method beeing independent of the calorimeter energy scale (double angle "DA"-method).

The H1 data is shown in Fig. 3 as a function of y_e and M_e, the invariant mass for the eq final state ($M_e = 300\sqrt{x_e}$ GeV). Above $Q^2 = 15000$ GeV 12 events are observed, while the number of expected events is 4.71 ± 0.76. The Poisson probability to observe at least as many events as were observed is 0.6%. In a 25 GeV mass window centered on 200 GeV, 7 events are observed while 0.95 ± 0.18 are expected. The probability to observe a statistical fluctuation from the Standard Model in that mass mass window is 2.6×10^{-4} and the probalility to observe this in any mass window is of the order of 1%.

The ZEUS data is presented in Fig. 4 in the y_{DA}–x_{DA} plane. The number of observed events in the region $x_{DA} > 0.55$ and $y_{DA} > 0.25$ is 4, while the number of expected events is 0.91 ± 0.08, the corresponding Poisson probability is 1.4%.

Table 1
Comparison between H1 and ZEUS results for NC DIS high Q2 analysis

	H1 14.2 pb^{-1}		ZEUS 20.1 pb^{-1}	
Q^2 cut	Observed	Expected	Observed	Expected
$Q^2 > 10000$ GeV^2	20	18.3 ± 2.4	33	32.2 ± 2.0
$Q^2 > 15000$ GeV^2	12	4.71 ± 0.76	12	8.66 ± 0.66
$Q^2 > 20000$ GeV^2	5	1.32 ± 0.27	5	2.76 ± 0.24
$Q^2 > 25000$ GeV^2	3	0.51 ± 0.16	3	1.01 ± 0.09
$Q^2 > 30000$ GeV^2	2	0.23 ± 0.05	2	0.37 ± 0.04
$Q^2 > 35000$ GeV^2	0	0.08 ± 0.04	2	0.15 ± 0.01

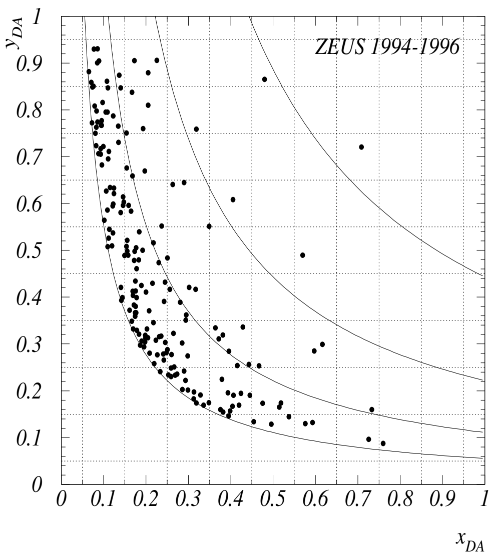

Figure 4. ZEUS selected NC DIS candidate events in the $x_{DA} - y_{DA}$ plane.

The mimimum probablity of 0.6% is obtained for a cut $x_{DA} > 0.57$. The probability to obtain such a statistical fluctuation from the Standard Model for any x_{DA} cut is 7.6%.

The H1 and ZEUS data and expectations as a function of a Q^2 lower limit are shown in table 1. The probability to observe such an excess at $Q^2 > 15000$ GeV^2 due to statistical fluctuations from the Standard Model is less than 1%. More statistics is needed in order to clarify the excess observed by H1 and ZEUS in the NC DIS high Q^2 regime. If the excess persists, then it could be interpreted in terms of leptoquark production, R-parity violating SUSY process or contact terms.

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