SEARCH FOR PHYSICS BEYOND THE STANDARD MODEL AT HERA

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Results from searches for physics beyond the Standard Model based on HERA 1994-2000 data are reviewed.

1 Introduction

In the years 1994-2000 HERA collided protons and electrons (or positrons) at a center of mass energy $\sqrt{s}$ of 300 and 318 GeV. Each of the two detectors, H1 and ZEUS, collected about 110pb^{-1} of e^+p collisions and about 15pb^{-1} of e^-p collision, giving a good opportunity to probe physics beyond the Standard Model (SM). Most of the results presented here are preliminary results based on the whole collected statistics. For more details see the papers presented at the EPS2001 conference [1,2]. In ep collisions new physics could show up in different ways: as a deviation from the SM in the ep scattering cross section at high Q^2 (section 2), as the direct production of new particles (section 3) or as an excess of events with a topology which is rare in the SM (section 4). Searches for excited fermions and for lepton flavor violation are not covered here.

2 Analysis of the ep Cross Section at High Q^2

New physics at energy scales above $\sqrt{s}$ could be detected as a deviation from the SM in the ep cross section at the highest transferred momenta Q. The SM gives an accurate prediction for the $e^{\pm}p \to e^{\pm}X$ cross section at high Q^2, with a theoretical uncertainty of $\sim 5\%$ at $Q^2 = 10000$ GeV^2. H1 and ZEUS measured the $e^{\pm}p \to e^{\pm}X$ cross section up to $Q^2 = 40000$ GeV^2 and found it in agreement with the SM, as explained in another contribution to these proceedings [3]. A comparison of the measured cross section with the predictions from models of new physics can therefore be used to derive limits. A possible model of new physics is quark compositness: if quarks were not pointlike the ep cross section would decrease at high Q^2 as the exchanged boson starts to resolve the quark structure. Quarks larger than 1/1000 of the proton size are excluded by HERA data, as shown in figure 1.

The exchange of particles with mass $\gg \sqrt{s}$ can be parametrized as a $eeqq$

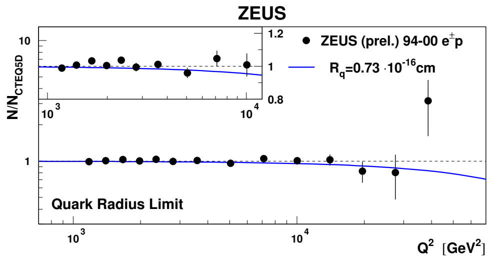

Figure 1. Ratio of the number of $e^{\pm}p \to e^{\pm}X$ events measured by ZEUS over the Standard Model prediction as a function of Q^2. The curve shows the effect of the finite quark radius excluded by the measurement.

Table 1. Limits on $eeqq$ Contact Interactions from H1 and ZEUS compared to typical limits from Tevatron and LEP experiments. The table shows the limit on the effective mass scale Λ for vector-vector (VV) and axial-axial (AA) interaction with positive and negative coupling (+/−).

95 % lower limit on Λ_{eeqq} [TeV]				
CI Scenario	ZEUS (prel.) $eq \to eq$	H1 (prel.) $eq \to eq$	CDF $q\bar{q} \to e^+e^-$	OPAL $e^+e^- \to q\bar{q}$
VV+/−	6.5/7.0	9.2/3.0	3.5/5.2	4.7/7.2
AA+/−	4.6/5.3	3.5/5.8	3.8/4.8	4.2/8.1

contact interaction (CI) contributing to the $eq \to eq$ scattering amplitude. H1 and ZEUS extracted limits on many CI scenarios, characterized by different chiral structures. Table 1 shows selected limits on the effective mass scale Λ (the 4-fermion coupling being $g = \pm\sqrt{4\pi}/\Lambda$) for vector-vector and axial-axial CI scenarios compared to results from LEP and Tevatron.

In models with large extra dimensions, gravitational effects can become large at a relatively low energy, of the order of an effective Plank scale M_s . In the case of ep scattering graviton exchange can give a measurable contribution at high-Q^2. Due to the absence of a visible graviton contribution ZEUS and H1 excluded $M_s < 0.8$ TeV.

3 Direct production of new particles

HERA is the ideal place to search for particles directly produced by eq fusion such as leptoquarks (LQs), new bosons carrying lepton and baryon number predicted by Grand Unification Theories. A LQ can be directly produced from eq fusion if its mass $M_{\rm LQ}$ is below $\sqrt{s}$. Its following decay into eq or

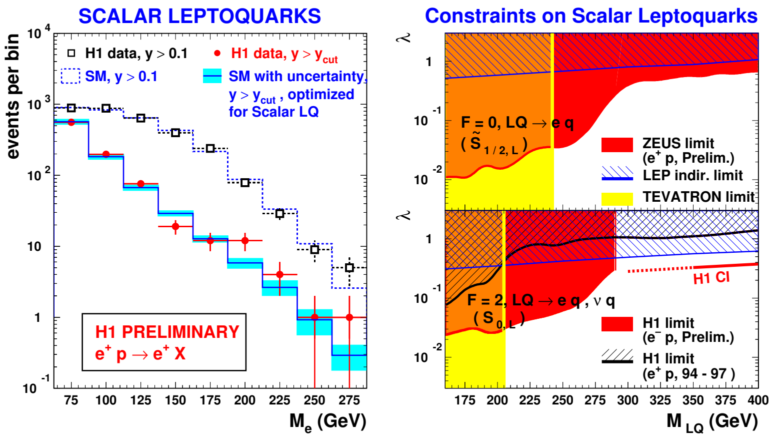

Figure 2. Left: eq mass spectrum measured by H1 in the full $e^+p \to e^+X$ sample (squares) and after cuts optimized for the search of scalar leptoquarks (full points) compared to SM prediction. Right: upper limits on the LQ coupling λ as a function of $M_{\rm LQ}$ for scalar leptoquarks with fermion number F=0 decaying to eq and for F=2 decaying to eq and νq with the same probability. Regions excluded by LEP and Tevatron are also shown.

νq would produce a characteristic peak in the lepton-quark invariant mass distribution. H1 and ZEUS searched for a signal both in the eq and in the νq channel, analyzing separately e^+p and e^-p collisions that are sensitive to LQs with different fermion number F. LQs with F=0 are indeed produced by e^+q fusion and those with F=2 by e^-q. Figure 2 (left) shows the mass spectrum reconstructed by H1 from e^+p data. No significant excess is observed. The excess observed in the '94-'96 data was not confirmed by the rest of the data although it can be still recognized in the figure as a bump around $M_{eq} \sim 200$ GeV. Limits were set on the LQ coupling λ as a function of $M_{\rm LQ}$. Figure 2 (right) shows examples of limits on scalar leptoquarks. For $M_{\rm LQ}$ above $\sqrt{s}$ the limits are derived from virtual effects, in a way similar to the CI analysis. The combination of the νq and eq channels allows to set limits independently of the relative fraction of the two decay modes. For a coupling of electromagnetic strength $\lambda = 0.3$, scalar LQs below $M_{LQ} = 280$ GeV are excluded.

In supersymmetric models with R-parity violation ($\not{R}_{\rm p}$), squarks ($\tilde{q}$) could be produced from eq fusion through the $\not{R}_{\rm p}$coupling λ'. The squark would then decay into eq or νq, giving a signature similar to "normal" LQs, or into a quark and a gaugino χ, starting a cascade decay in which at least one lepton and two

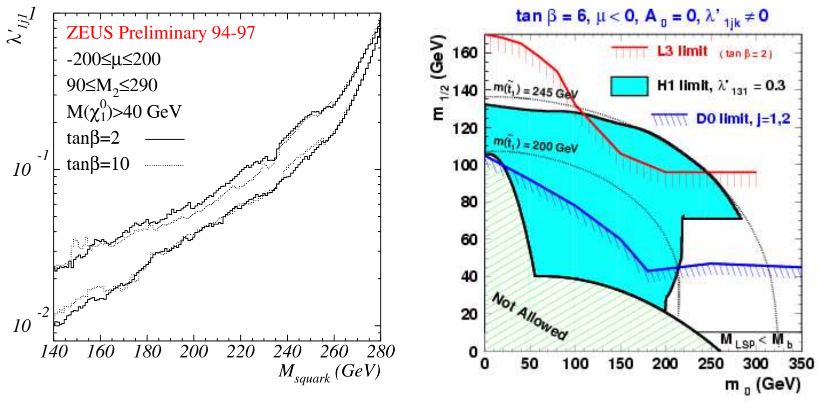

Figure 3. Limits on R-parity violating squarks. Left: ZEUS limits on the coupling λ' as a function of the squark mass in the MSSM. The curves correspond to the best and worst limit obtained by varying the MSSM parameters in the shown range. Right: excluded region for a $\not{R}_p$stop in the mSUGRA parameter space. The region excluded by H1 for $\lambda' = 0.3$ and $\tan\beta = 6$ is compared to limits from L3 and D0.

Table 2. Observed / expected number of events with isolated leptons and missing momentum for two different cuts on the transverse momentum of the hadronic system P_T^X .

	ZEUS prel. $e^{\pm}p$		H1 prel. e^+p	
	Electrons	Muons	Electrons	Muons
$P_t^X > 25$ GeV	1/1.14±0.06	1/1.29±0.16	4/1.29± 0.33	6/1.54±0.41
$P_t^X > 40$ GeV	0/0.46±0.03	0/0.50±0.08	2/0.41± 0.12	4/0.58±0.16

more quarks are produced (e.g. $e^+q \to \tilde{q}' \to q'\chi^0 \to q'q''\bar{q'''}l$). H1 and ZEUS searched for squarks decaying in different topologies, including many-jets plus electron, many-jets plus missing momentum and “wrong sign electron” (i.e. events with an e^- in e^+p interactions). The ’94-’97 data, analyzed so far, are in good agreement with the SM, allowing to set limits. Figure 3 (left) shows the ZEUS limits on λ' as a function of the squark mass in the context of the unconstrained minimal supersymmetric model (MSSM). For $M_{\tilde{q}} = 200$ GeV, $\lambda' > 0.05$ is excluded for a large set of MSSM parameters. The minimal Super Gravity model (mSUGRA) tends to favor a lighter stop than the other squarks. The plot on the right of fig. 3 shows the region excluded by H1 in the mSUGRA parameter space assuming a stop with $\lambda' = 0.3$. A stop mass below 245 GeV are excluded in a large area of the plane.

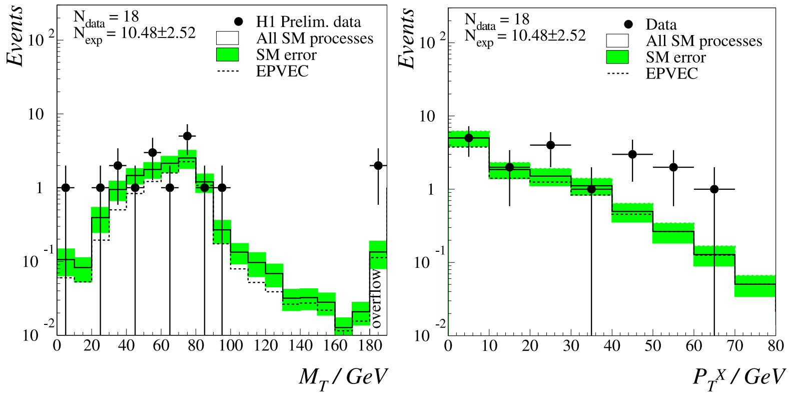

Figure 4. Transverse mass (left) and transverse momentum of the hadronic system (right) for events with a lepton and missing P_t measured by H1 .

4 Events with a lepton and missing momentum and FCNC

Events with an isolated high-p_t lepton $l = e, \mu$ and large missing transverse momentum are quite rare in the SM and are therefore a good place to look for new phenomena. In the SM the main source of this kind of events is W production followed by the leptonic decay $W \to l\nu$ for which the SM cross section is $\sim$ 0.1pb for each lepton. H1 observed an excess of such events. Figure 4 shows the distributions of the transverse mass M_T of the $l\not{P}_{\rm t}$ system (left) and of the transverse momentum P_T^X of the hadronic system for these events. While M_T is compatible with W production, the excess is concentrated at large P_T^X, where the SM expectation is small. Table 2 gives the number of lepton and $\not{P}_{\rm t}$ events observed by H1 and ZEUS at large P_T^X, in the muon and in the electron channel. While H1 has an excess, the ZEUS data are in good agreement with the SM. Only further luminosity will sort out if this is a statistical fluctuation or something else.

Events with leptons, $\not{P}_{\rm t}$and large P_t^X could be explained as top quark decays $t \to b(W \to l\nu)$. The SM top cross section is negligible at HERA but flavor changing neutral currents (FCNC) may induce a sizable single top production ($eu \to et$) rate through the anomalous coupling κ_γ. ZEUS and H1 searched for events compatible with top decays both in the leptonic ($W \to l\nu$) and in the hadronic ($W \to q\bar{q}$) channels. In the leptonic channel ZEUS didn't find any candidate and H1 selects 5 top-like candidates, to be compared with the 1.8 expected from the SM background. No excess was found in the

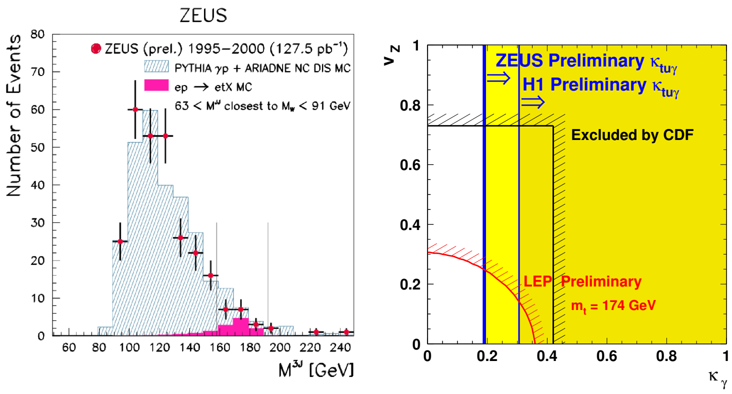

Figure 5. Search for single top production. Left: 3-jet mass measured by ZEUS for events in which the mass of a pair of jets is close to M_W, compared to the expectation from the background (γp+NC DIS) and from FCNC single top production. Right: excluded regions in the κ_γ-v_Z plane.

hadronic channel. Figure 5 (left) shows the 3-jet mass distribution measured by ZEUS in the hadronic channel and (right) the region excluded in the plane defined by the two FCNC anomalous top couplings κ_γ and V_Z.

5 Conclusion

Stringent limits on different models of physics beyond the SM have been obtained from the first running period of HERA. After a major luminosity upgrade the second running period is starting and is expected to provide a factor 10 increase in the integrated luminosity. It will give the opportunity to extend substantially the searches for new physics, especially in those sectors in which the sensitivity is now limited by statistics such as CI, LQs at small λ and $l + \not{P}_t$ events.

References

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3. J.Martin, these proceedings.