SEARCHES FOR NEW PHYSICS AT HERA

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Recent results on searches for new physics from the ep collider HERA are presented which are mainly based on e^+p data samples of 47 pb^{-1} and 37 pb^{-1} collected in the years 1994-1997 by the ZEUS and H1 Collaborations, respectively. Some preliminary results from the recent e^-p running in 1998-1999 are also included.

1 Introduction

In the years 1994-1997 positrons, e^+, with an energy of 27.5 GeV were brought into collision with protons of an energy of 820 GeV at the ep collider HERA, resulting in data samples of 47 pb^{-1} and 37 pb^{-1} collected by the ZEUS and H1 experiments, respectively. This leads to sensitivity to new physics beyond the Standard Model (SM) competitive and in several areas beyond what has been reached so far at LEP or at the TeVatron. The appearance of new physics may be dependent on the lepton charge or it may just show up above a certain energy threshold which makes it very interesting to analyse the 1998-1999 data which have been taken with electrons, e^-, on protons of 920 GeV yielding an increase of the center of mass energy from 300 GeV to 318 GeV. In this report some preliminary results based on the first 5 pb^{-1} of these data are discussed.

2 Contact Interactions

In many scenarios for new physics anomalous eq interactions are indistinguishable from SM Neutral Current Deep Inelastic Scattering (NC DIS) on an event by event basis, however they can manifest themselves in distortions of the differential NC DIS cross section through their interference with the Standard Model. The currently available high statistics of the e^+p data allow detailed comparisons of the measured NC DIS cross section [1] with it's SM expectation over a wide range of more than six orders of magnitude for Q^2 up to values of the order of

Table 1: Summary of 95 % CL lower imits on the couplings Λ for contact interaction models tested by H1 and ZEUS. The two limits given for each model correspond to the two choices of the overall sign of the couplings.

	Up Quark Coupling				Down Quark Coupling				ZEUS (TeV)		H1 (prelim.) (TeV)	
Model	LL	LR	RL	RR	LL	LR	RL	RR	$\varepsilon = -1$	$\varepsilon = +1$	$\varepsilon = -1$	$\varepsilon = +1$
LL	$+\varepsilon$				$+\varepsilon$						1.2	2.3
LR		$+\varepsilon$				$+\varepsilon$					1.5	3.0
RL			$+\varepsilon$				$+\varepsilon$				1.5	3.0
RR				$+\varepsilon$				$+\varepsilon$			1.2	2.3
VV	$+\varepsilon$	$+\varepsilon$	$+\varepsilon$	$+\varepsilon$	$+\varepsilon$	$+\varepsilon$	$+\varepsilon$	$+\varepsilon$	5.0	4.7	1.9	5.0
AA	$+\varepsilon$	$-\varepsilon$	$-\varepsilon$	$+\varepsilon$	$+\varepsilon$	$-\varepsilon$	$-\varepsilon$	$+\varepsilon$	3.7	2.6	3.4	2.0
VA	$+\varepsilon$	$-\varepsilon$	$+\varepsilon$	$-\varepsilon$	$+\varepsilon$	$-\varepsilon$	$+\varepsilon$	$-\varepsilon$	2.6	2.5	2.6	2.6
X1	$+\varepsilon$	$-\varepsilon$			$+\varepsilon$	$-\varepsilon$			2.8	1.8		
X2	$+\varepsilon$		$+\varepsilon$		$+\varepsilon$		$+\varepsilon$		3.1	3.4		
X3	$+\varepsilon$			$+\varepsilon$	$+\varepsilon$			$+\varepsilon$	2.8	2.9	1.3	3.1
X4		$+\varepsilon$	$+\varepsilon$			$+\varepsilon$	$+\varepsilon$		4.3	4.0	1.8	4.1
X5		$+\varepsilon$		$+\varepsilon$		$+\varepsilon$		$+\varepsilon$	3.3	3.5		
X6			$+\varepsilon$	$-\varepsilon$			$+\varepsilon$	$-\varepsilon$	1.7	2.8		
U1	$+\varepsilon$	$-\varepsilon$							2.6	2.0		
U2	$+\varepsilon$		$+\varepsilon$						3.9	4.0		
U3	$+\varepsilon$			$+\varepsilon$					3.5	3.7		
U4		$+\varepsilon$	$+\varepsilon$						4.8	4.4		
U5		$+\varepsilon$		$+\varepsilon$					4.2	4.0		
U6			$+\varepsilon$	$-\varepsilon$					1.8	2.4		

30000 GeV^2. Possible deviations can be analysed in terms of four-fermion pointlike $eq \rightarrow eq$ contact interactions representing the low energy limit of a new interaction. The general chiral invariant contact (vectorlike) interaction Lagrange density can be written as :

$$\mathcal{L}_{CI} = \frac{g^2}{\Lambda^2} \sum_{\substack{a,b=L,R \\ q=u,d}} \varepsilon^q_{ab} (\bar{e}_a \gamma^\mu e_a)(\bar{q}_b \gamma_\mu q_b) \qquad (1)$$

where Λ is the effective mass scale, g the coupling strength and ε^q_{ab} determines the relative sign of the individual terms. When quoting limits on Λ we follow the usual convention of $g^2 = 4\pi$ and $|\varepsilon^q_{ab}| = 0$ or $= 1$. A number of different models have been tested by ZEUS [2] and H1 [3]. Within these models no significant deviation of the measurement from the expectation has been observed, which can be translated into 95% CL lower limits for the mass scale Λ. The experimental findings are summarised in table 1. With the exception of the first four models all scenarios are not yet constrained by the otherwise strong limits from Atomic Parity Violation measurements. The limits reach values up to 5 TeV which are compatible with equivalent results obtained at LEP and the TeVatron. For some of the models limits exist only from HERA.

3 Leptoquarks

Leptoquarks are scalar or vector bosons which couple to quark-lepton pairs and naturally appear in many extensions of the SM, like for instance GUT theories, Superstring inspired E_6 models or composite models. Again no spectacular event topologies are expected since the events would look like normal NC (neutral current) or CC (charged current) DIS events. However at HERA leptoquarks can be resonantly produced in the s-channel which might lead to a narrow resonance in $\mathrm{d}\sigma/\mathrm{d}x$ since the mass of the hypothetical particle and Bjorken-x are related by $M_{LQ} = \sqrt{xs}$. In the search one makes use of the characteristic angular distribution which distinguishes standard DIS ($\mathrm{d}\sigma/\mathrm{d}y \propto y^{-2}$) from scalar ($\mathrm{d}\sigma/\mathrm{d}y$=const) and vector ($\mathrm{d}\sigma/\mathrm{d}y \propto (1-y)^{-2}$) leptoquarks, where $y = (1 - \cos\Theta^*_e)/2$. After applying a cut $y > y_{cut}(M_{LQ})$, which is designed to give optimal signal to background ratio, the number of observed events is compared with the number of expected events. As an example the left part of fig. 1 shows the mass spectrum for the NC DIS data sample before and after the cut in the case of H1 [4]. While there is overall agreement in the total number of events (312 events seen versus 306 ± 23 expected), a small excess remains around 200 GeV. In the narrow width approximation (NWA) the cross section is given by

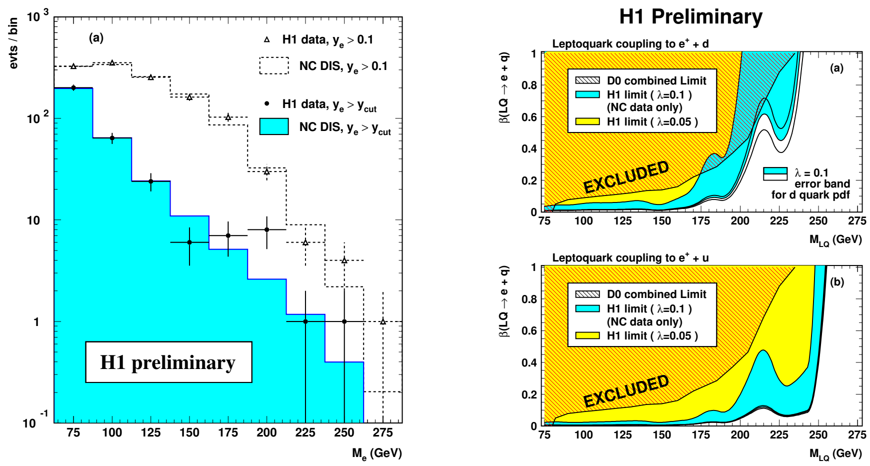

Figure 1: Mass spectra for NC DIS like final states (left) data and MC expectation before and after a cut on y. The right plots show mass dependent exlusion limits on the branching ratio $\beta_e = BR(LQ \to eq)$ for scalar leptoquarks produced by (a) e^+d and (b) e^+u fusion. Two exclusion regions corresponding to $\lambda = 0.1$ and $\lambda = 0.05$ are represented as grey areas. The D0 limit is also shown as hatched region.

$\sigma(eq \to LQ \to eq) \propto \lambda^2 \beta q(x)$, where λ is the Yukawa coupling, β is the branching ratio for the decay of the leptoquark back into a eq pair and $q(x)$ is the parton density of the quark involved in the production evaluated at the x-value corresponding to the mass of the leptoquark. There are different ways to present limits on the production of leptoquarks. The choice made in the right part of fig. 1 is to show exclusion regions in the plane β versus M_{LQ} for some fixed values of λ. The H1 result is overlayed with limits obtained from D0 indicating the remaining high discovery potential at HERA in particular for the case when β is small and the leptoquark couples to u quarks. The reduction in sensitivity around 200 GeV reflects the small excess of events observed in this region. Preliminary results on leptoquark limits exist also from ZEUS [5].

4 Supersymmetry

Another class of new particles that could be produced at HERA via the fusion of the initial positron and a quark coming from the incident proton are squarks, the supersymmetric (SUSY) partners of the quarks. This is the case in SUSY models where R-parity (R_p, which distinguishes particles from s-particles) is violated via Yukawa couplings λ. The generalised superpotential of the Minimal Supersymmetric Model (MSSM) which allows for violation of R_p is given by:

$$W_{SUSY} = W_{MSSM} + \lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k \tag{2}$$

where i, j, k are generation indices and L_i, Q_j and $\bar{D}_k$ contain respectively the left-handed lepton doublet, quark doublet and the right-handed quark singlet. Of special interest at HERA are those Yukawa vertices which couple a squark to a lepton-quark pair of the first generation. These are described by the term $\lambda'_{1j1} L_1 Q_j \bar{D}_1$. The decay of the squarks can proceed either via their Yukawa couplings into SM fermions, in which case the event signature is that of NC or CC DIS, or via their gauge couplings into a quark and a neutralino, χ^0, or a chargino, χ^+. For gauge coupling decays various event topologies can be expected which involve charged leptons and/or jets in the final state, and possibly missing energy. Both experiments have performed searches [6,7] for R_p-violating squark production by applying event selection cuts tailored for each event topology and comparing the number of data events with predictions of the SM background. From these comparisons limits on the couplings λ'_{1j1} as a function of the mass of the hypothetical squark are derived. The resulting exclusion regions depend on the assumptions on the mass and

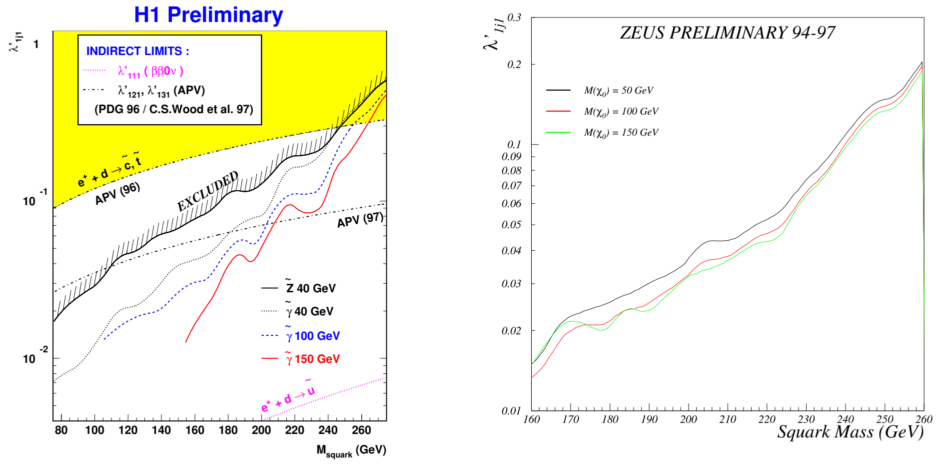

Figure 2: Exclusion regions on R_P-violating SUSY in the plane of squark-lepton-quark coupling λ'_{1j1} versus squark mass in the case of H1 (left) and ZEUS (right).

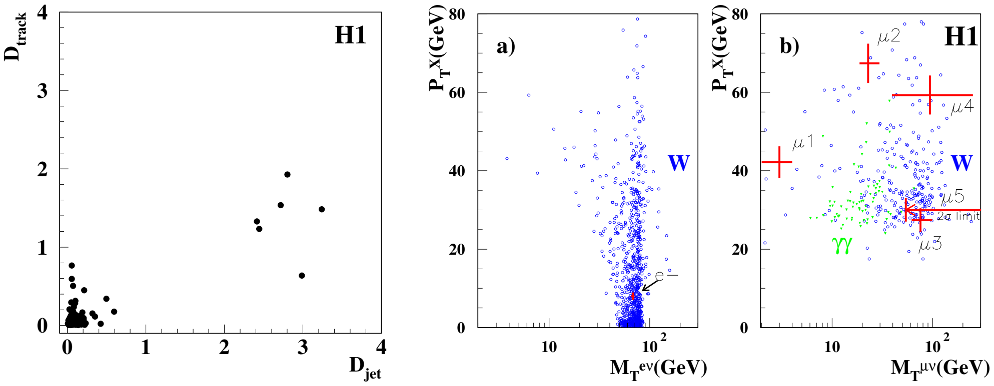

Figure 3: Kinematical distributions of events with an isolated high p_t lepton and large P_T observed by H1 in 36.5 pb^{-1} of e^+p data. The left plot illustrates the striking isolation properties of the track in the event. In the middle (right) plot the distribution of P_T^X versus $M_T^{l\nu}$ for electron (muon) events is compared to the dominant SM contributions (W production and $\gamma\gamma$ processes in the muon channel) which correspond to a luminosity a factor 500 higher than in the data. The size of the crosses indicate one sigma uncertainties of the data points.

mixture of the χ^0 and are shown in fig. 2. In the H1 case they are also compared to the best indirect limits which come from the non-observation of neutrinoless double beta decay (λ'_{111}) and from constraints from Atomic Parity Violation (λ'_{121}, λ'_{131}).

5 Isolated Leptons

The first event having a high transverse momentum, p_t, muon in combination with large missing transverse momentum in the calorimeter, P_T, was observed in the 1994 data of H1. Both collaborations have searched for further events of this type in their full 1994-1997 data samples. After applying the cut $P_T > 25$ GeV and requiring at least one track with $p_t > 10$ GeV H1 observes in total 6 events [8] with a high momentum track exhibiting outstanding features in terms of large distances in the η-ϕ plane to the closest track, $D_{track} \geq 0.5$, and to the closest jet, $D_{jet} \geq 1.0$ as displayed in fig. 3. All 6 tracks satisfy the criteria for lepton identification: there is 1 e^-, 2μ^+, 2μ^- and 1 μ whose sign is not known. The dominant SM process yielding events with isolated lepton and missing P_T is W production followed by a leptonic decay of the W.

Table 2: The number of events with an isolated lepton and large P_T^X observed by H1 and ZEUS compared to the expectations in the SM.

	e^+p ($\sqrt{s}$ = 300 GeV)		e^-p ($\sqrt{s}$ = 318 GeV, prelim.)	
H1 Lumi:	36.5 pb^{-1}		5.1 pb^{-1}	
	Data	Expectation (from W only)	Data	Expectation (from W only)
H1 e	1	2.4 $\pm$ 0.5 (1.7 $\pm$ 0.5)	0	0.37 $\pm$ 0.07 (0.23 $\pm$ 0.07)
H1 μ	5	0.8 $\pm$ 0.2 (0.5 $\pm$ 0.1)	0	0.14 $\pm$ 0.04 (0.09 $\pm$ 0.02)
ZEUS Lumi:	47.7 pb^{-1}		5.1 pb^{-1}	
	Data	Expectation	Data	Expectation
ZEUS e	3	3.5 $\pm$ 0.7	1	0.24 $\pm$ 0.14
ZEUS μ	0	2.0 $\pm$ 0.4	0	0.24 $\pm$ 0.03

This interpretation is tested, separately for e and μ, in fig. 3 where the distribution of the events in the plane of hadronic transverse momentum, P_T^X, and transverse mass of the lepton-neutrino system, $M_T^{l\nu}$, is compared with expectations from W production (and $\gamma\gamma \to \mu^+\mu^-$) Monte Carlo samples corresponding to a luminosity 500 times larger than that of the data sample. The events $\mu1$, $\mu2$ and $\mu4$ have kinematic properties that render an interpretation in terms of W production rather unlikely, which suggests a production mechanism outside the SM processes considered. ZEUS has performed an equivalent analysis[9] with the result that no excess of events were observed. Table 2 summarizes the results including the preliminary numbers for a search in the first 5.1 pb^{-1} of the 1998-1999 e^-p data, where no excess events of this topology were found so far. Clearly much more luminosity is needed in order to understand the production mechanism of these events.

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