HIGH Q^2 DEEP INELASTIC SCATTERING RESULTS AND SEARCH FOR LEPTOQUARKS AT HERA

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The analysis of high Q^2 deep inelastic scattering at HERA using 37 pb^{-1} of e^+p data taken by the H1 experiment between 1994 and 1997 is reported. This includes the measurement of the double differential neutral current cross-section at high Q^2 and the update of our previous publication in that kinematic domain with the increase of statistics due to the 23 pb^{-1} of 1997 data. The results obtained are used to derive new rejection limits for first generation scalar leptoquarks.

1 Introduction

The HERA machine, which delivers collisions between 27.5 GeV positrons and 820 GeV protons, allows to probe the proton at very small distances via t channel exchange of a highly virtual gauge boson in Deep Inelastic Scattering (DIS) processes. The bosons involved are γ or Z^0 in Neutral Current (NC) and W in Charged Current (CC) DIS. The kinematics of inclusive DIS is described by two independent variables which are usually taken as the transfered momentum Q^2 and the fraction x of the proton momentum carried by the quark participating to the hard process. These two variables are related with the inelasticity y via $Q^2 = xys$ where $\sqrt{s} = 300$ GeV. Though the Z^0 contribution is neglected at low transfered momenta Q^2, the γ/Z^0 interference, which is negative in the e^+p mode, plays an important role at $Q^2 \gtrsim 10000$ GeV^2.

Possessing both leptonic and baryonic numbers in the initial state, HERA is a unique facility to search for new bosons coupling to lepton-quark pairs up to the kinematic limit $\sqrt{s} = 300$ GeV. These new bosons (e.g. leptoquarks, or squarks in R-parity violating supersymmetry) could be produced via s channel e^+q fusion. In that case, the best suited variables are the mass $M = \sqrt{sx}$ of the lepton-quark pair and y, since it is directly related to the angle of the final lepton in the lepton-quark centre of mass frame by $y = (1 + \cos\theta^*)/2$ and thus sensitive to the spin of the new particle.

Previous analysis at high Q^2 have been reported by the HERA experiments [1,2] using data taken between 1994 and 1996. The H1 analysis reported here includes the 1997 data and corresponds to an integrated luminosity of 37 pb^{-1}.

2 Kinematics reconstruction and experimental improvements

Due to the over-constraint of NC DIS events, various methods allow to reconstruct the kinematics. Looking for the best resolution at high Q^2 and limited migration due to QED radiation in the initial state, we choose the electron method which uses the energy and the polar angle of the scattered positron measured in the liquid argon (LAr) calorimeter of H1.

The increase of statistics has allowed to perform an *in situ* calibration of the electromagnetic section of the LAr, especially in its forward part where we depended on the results of beam tests at CERN. This calibration has been made using the double-angle method, which by energy conservation predicts the positron energy, with NC DIS and elastic QED compton events. The systematic uncertainty on the electromagnetic energy scale is reduced to $\pm 1\%$ for $80 < \theta < 150°$ ($\Rightarrow Q^2 \lesssim 1000$ GeV^2) and is $\pm 3\%$ in the forward part ($\Rightarrow Q^2 \gtrsim 2500$ GeV^2).

Concerning the hadronic measurement, which is the only information for CC DIS events, the uncertainty on the hadronic energy scale is $\pm 4\%$. Progress has been made on the measurement of the hadronic flow in the forward part, allowing to use the Σ method to reach a better precision on x at very low y where the resolution of the electron method deteriorates.

3 Neutral current double differential cross-section

The selection of this analysis which covers the kinematic domain $200 \leq Q^2 \leq 30000$ GeV^2 and $0.005 \leq x \leq 0.65$ is based on the identification of the scattered positron and requires that $E_{e^+} > 11$ GeV. The kinematics is reconstructed with the so-called $e\Sigma$ method which uses x_Σ and Q^2_e. The results are expressed via the reduced cross-section which is defined by:

$$\sigma(x, Q^2) = \frac{xQ^4}{2\pi\alpha^2(1 + (1-y)^2)} \frac{\mathrm{d}^2\sigma}{\mathrm{d}x\mathrm{d}Q^2} \qquad (= F_2(x, Q^2) \text{ for pure } \gamma \text{ exchange}).$$

Figure 1(left) shows $\sigma(x, Q^2)$ as function of Q^2 for various values of x as measured at HERA and by fixed target experiments. The extension to larger values of Q^2 allows to test the DGLAP equations predicted by QCD over 4 orders of magnitude. The data is well described by standard model expectation of DIS using the MRS(H) parton density parametrization, except at very high Q^2 and $x \simeq 0.45$ where the data overshoots the expectation. This excess of events will be investigated in the

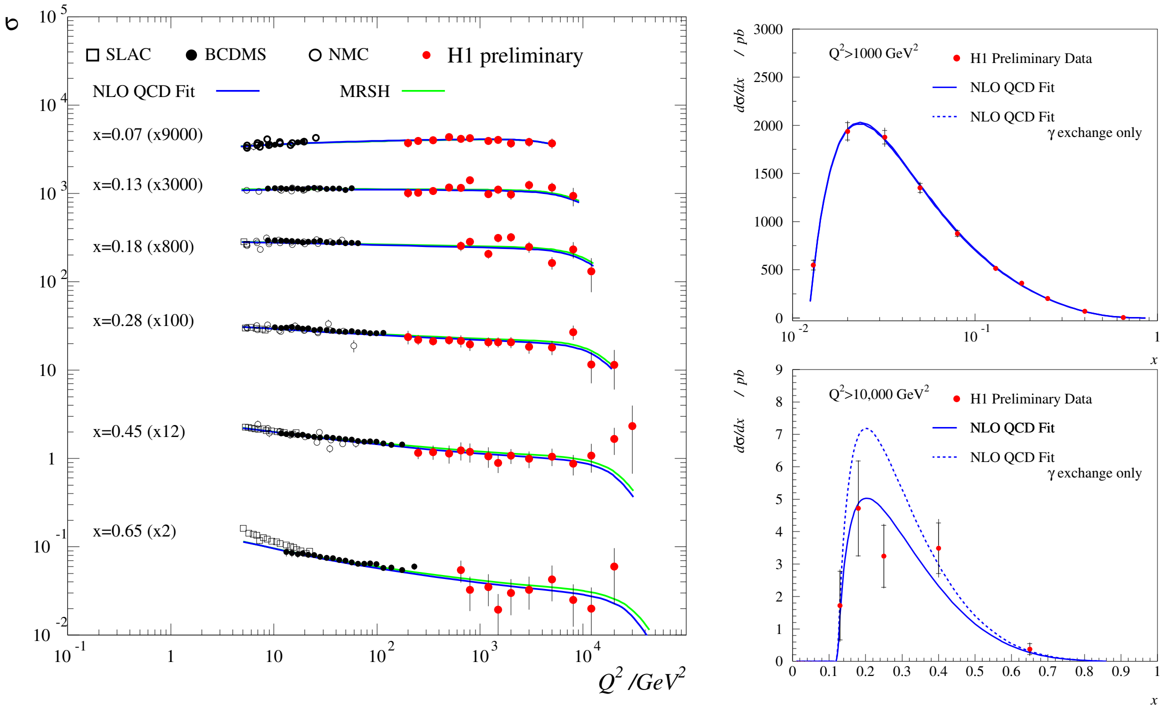

Figure 1: Left: double differential reduced cross-section as measured at HERA and at fixed target experiments. The lines indicate the prediction of the standard model of DIS with MRS(H) parton densities parametrization and the result of a NLO QCD fit including the new measurement at HERA. Right: integrated cross-section $\mathrm{d}\sigma/\mathrm{d}x$ for $Q^2 > 1000$ GeV^2 and $Q^2 > 10000$ GeV^2 compared to the expectation taking into account the Z^0 contribution or not.

next section. A NLO QCD analysis using this new measurement and fixed target data shows that for the first time HERA measurement plays a role at high x. The obtained fit tends to be below the MRS(H) prediction at high Q^2. Figure 1(right) shows integrated cross-sections $\mathrm{d}\sigma/\mathrm{d}x$ as function of x. At $Q^2 > 1000$ GeV^2, we are still in a region where sea quarks dominate. At $Q^2 > 10000$ GeV^2, the figure shows that valence quarks contribute and that the data significantly supports the negative γ/Z^0 interference.

4 Neutral current inclusive analysis at high $\mathbf{Q^2}$

This analysis relies on an inclusive selection close to that of reference [1], with minor changes allowing to enlarge the statistics, and performs a general comparison of the Q^2, M and y spectra. The kinematic requirements are $Q^2 > 2500$ GeV^2 and $0.1 < y < 0.9$ where the kinematic variables are computed with the electron method. There are 1297 accepted events, in good agreement with 1276$\pm$98 events expected from standard model of DIS. The selected events in the (M, y) plane are displayed in figure 2(left).

The Q^2 spectrum is shown in figure 2(right). Though there is a good agreement at medium Q^2 values, there is a slight deficit of events at $Q^2 \simeq 15000$ GeV^2 and an excess of events for larger Q^2 values, which is mainly due to the excess of events in the 1994-1996 data reported in reference [1]. Table 1(left) quantifies this excess by giving the number of observed (N_{obs}) and expected (N_{DIS}) events above various Q^2 cuts as well as the probability $\mathcal{P}(N \geq N_{obs})$ that the number of NC DIS events fluctuates to values equal or larger than N_{obs} in a random set of experiments. Performing migration and resolution deconvolution using standard parton densities, these results have been translated into integrated Born cross-sections $\sigma_{Born}(Q^2 > Q^2_{min}, y < 0.9)$, given in table 1(right).

Figure 3 shows the mass spectrum for $y > 0.4$. The excess of events at high Q^2 is visible in the mass window $|M - 200| < 12.5$ GeV where 8 events are observed and 3.01 ± 0.54 are expected. Of the observed events, 5 originate from the 1994-1996 data (38% of $\mathcal{L}$) and 3 from the 1997 data (62% of $\mathcal{L}$). Hence, no significant excess is seen in the mass spectrum for the 1997 data alone and the "clustering" around $M \sim 200$ GeV is, overall, less significant than that observed with 1994-1996 data only.

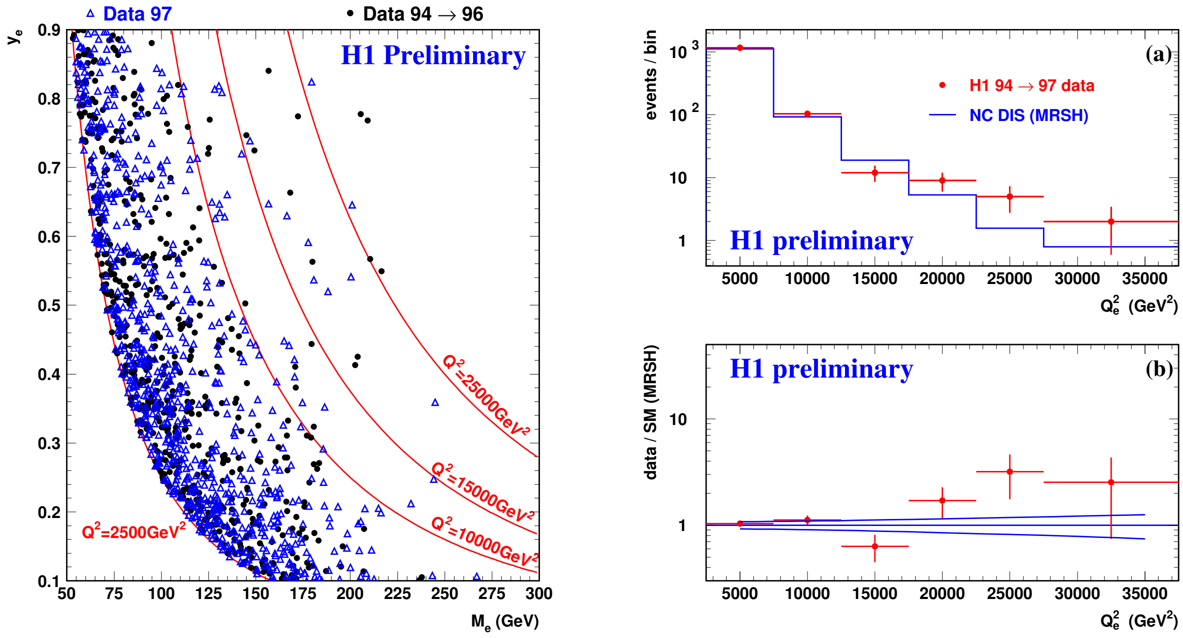

Figure 2: Left: Selected NC events in the (M, y) plane. Right: the Q^2 spectrum (upper plot) for the data (symbols) and the expectation (histogram) and the ratio of the observed and expected numbers of events as function of Q^2 (lower plot). The lines above and below unity specify the $\pm 1\sigma$ levels of uncertainty for the expectation.

Table 1: Left: Number of observed (N_{obs}) and expected (N_{DIS}) events above various Q^2 cuts. Right: Born cross-section $\sigma_{Born}(Q^2 > Q^2_{min}, y < 0.9)$ predicted by the standard model of DIS using MRS(H) (SM) and measured at HERA (H1).

Q^2_{min} (GeV^2)	2500	5000	10000	15000	20000	25000
N_{obs}	1297	322	51	22	10	6
N_{DIS}	1276 $\pm$98	336 $\pm$29.6	55.0 $\pm$6.42	14.8 $\pm$2.13	4.39 $\pm$0.73	1.58 $\pm$0.29
$\mathcal{P}(N \geq N_{obs})$	42%	56%	60%	5.9%	1.8%	0.64%

$\sigma_{Born}(Q^2 > Q^2_{min}, y < 0.9)$ (pb)		
Q^2_{min}	SM	H1
5000	9.03	$8.69^{+0.77}_{-0.77}$
15000	0.38	$0.59^{+0.15}_{-0.13}$
25000	0.040	$0.168^{+0.083}_{-0.060}$

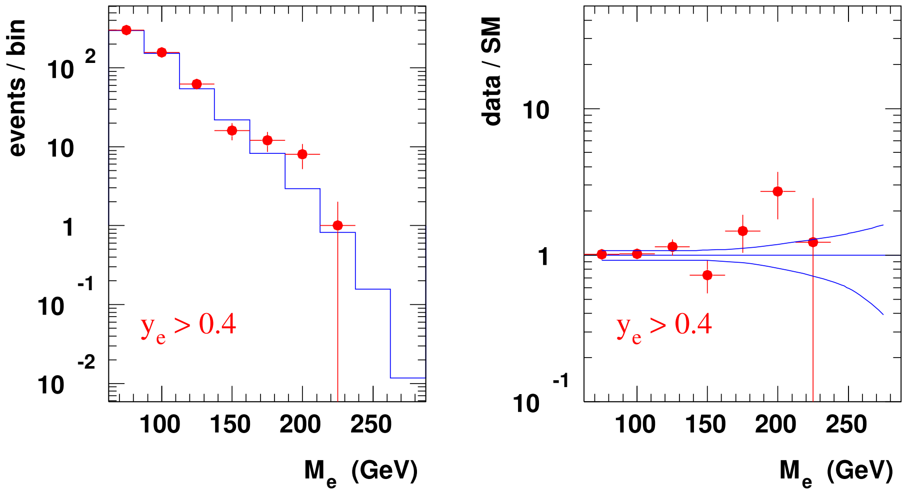

Figure 3: Left: the mass spectrum for the data (symbols) and for the expectation (histogram). Right: the ratio of the observed and expected numbers of events as function of M. The lines above and below unity specify the $\pm 1\sigma$ levels of uncertainty for the expectation.

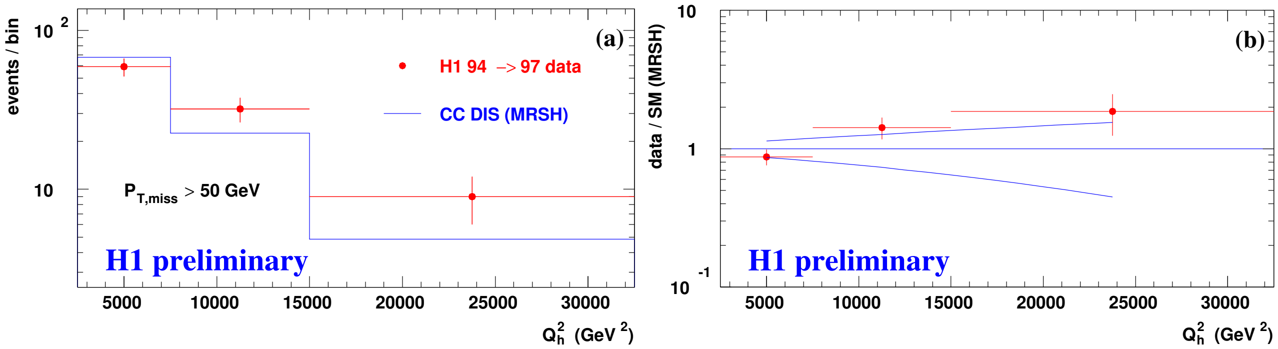

Figure 4: Left: the Q^2 spectrum for the data (symbols) and for the expectation (histogram). Right: the ratio of the observed and expected numbers of events as function of Q^2. The lines above and below unity specify the $\pm 1\sigma$ levels of uncertainty for the expectation.

5 Charged current inclusive analysis at high Q^2

The selection for the charged current analysis is close to that of reference[1]. The kinematic requirements are $Q^2 > 2500$ GeV^2 and $y < 0.9$. We require that the undetected $\bar{\nu}_e$ carries a large transverse energy by asking that $P_{\perp,miss} > 50$ GeV. There are 100 accepted events, in good agreement with 95.3 ± 16.7 events expected from standard model of DIS.

The Figure 4 shows the Q^2 spectrum of the selected events. At $Q^2 > 15000$ GeV^2, 9 events are observed where 5.07 ± 2.8 are expected. This slight excess is compatible with the large uncertainty on the expectation which is due to the uncertainty on the hadronic energy scale. Efforts are being made to reduce this uncertainty. This reduction is all the more important since CC DIS in e^+p mode is the only way at HERA to probe directly the d quark content of the proton.

6 Constraints on first generation scalar leptoquarks

The NC analysis summarized in section 4 is used to constrain the direct s channel production of first generation scalar leptoquarks (LQ), assuming that the observation contains at most two components, an unknown LQ signal and a known expectation from NC DIS. Here leptoquark generically means particle coupling to lepton-quark pairs via a Yukawa coupling λ. So it includes leptoquarks from the Buchmüller-Rückl-Wyler effective model[3] as well as squarks in supersymmetry with R_p violation.

These scalar resonances are expected to have a very narrow intrinsic width $\Gamma = \lambda^2 M_{LQ}/16\pi$ (e.g. $\Gamma \simeq 1$ GeV for $\lambda = e$ et $M_{LQ} = 200$ GeV). In the case these particles decay into a lepton and a quark, the final state is pratically indistinguishable event-by-event from NC or CC DIS events. In order to identify statistically the new signal from the DIS background, the variables M and y are well suited. First of all the mass spectrum should show a peak at the mass M_{LQ} of the produced particle. Then one should exploit the fact that a scalar particle decays isotropically in its centre of mass frame leading to a flat $d\sigma/dy$, in contrast to the $d\sigma/dy \sim y^{-2}$ distribution at fixed x of DIS. In the narrow width approximation and considering only the NC DIS-like decays, the cross-section of scalar LQ at HERA is:

$$\sigma(e^+p \to LQ \to e^+X) = \frac{\pi}{4s}\lambda^2 \mathcal{B}_e \times q(x = M_{LQ}^2/s)$$

where $\mathcal{B}_e$ is the branching ratio of the LQ in the NC decay and $q(x = M_{LQ}^2/s)$ is the parton density of the quark involved in the production evaluated at x corresponding to the mass of the LQ.

The method used here is the one presented in previous H1 publications[4]. For each M_{LQ}, only events that are in a mass window surrounding M_{LQ} whose width contains 68.3% of the signal are taken into account. On top of that a $y_{min}(M_{LQ})$ cut, optimized to maximise the sensitivity to the signal, is applied. An upper limit at 95% Confidence Level (CL) is then derived for $\sigma(e^+p \to LQ \to e^+X)$ as a function of M_{LQ}.

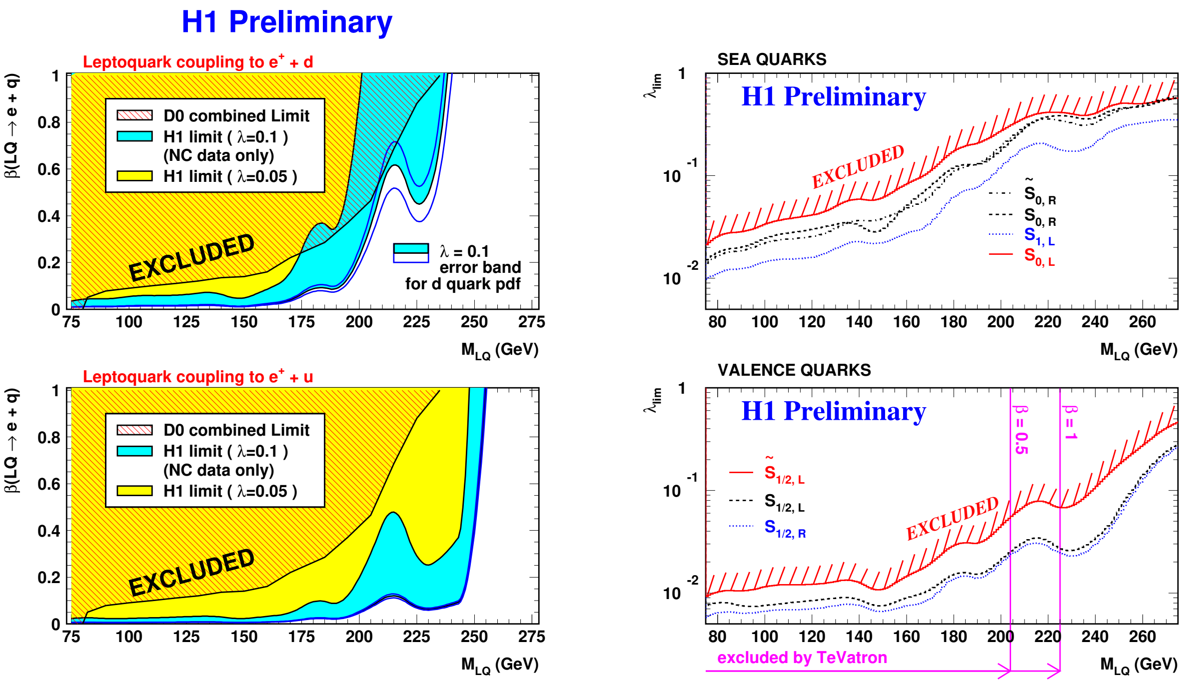

Figure 5: Left: rejection limits $\mathcal{B}_e$ vs. M_{LQ} for first generation scalar LQ. Right: rejection limits λ vs. M_{LQ} for LQ of the Buchmüller-Rückl-Wyler model. In both cases, rejection limits derived at the TeVatron are drawn.

Assuming a given value for the Yukawa coupling λ, mass dependent limits on the branching ratio $\mathcal{B}_e$ can be derived. The results are shown in figure 5(left) in the $(M_{LQ}, \mathcal{B}_e)$ plane for LQ produced via e^+d or e^+u fusion. For already small values of λ, domains excluded by this analysis extend beyond the region excluded by TeVatron [5], even in the less favorable case of LQ coupling to e^+d. For small values of $\mathcal{B}_e$, the current sensitivity of TeVatron does not reach the high mass domain. Hence the high mass region constitutes an open window for a discovery at HERA, provided that $\mathcal{B}_e$ is not too high.

When assuming a specific model in which $\mathcal{B}_e$ is known, the upper limit on $\sigma(e^+p \to LQ \to e^+X)$ can be translated to mass dependent limits on the Yukawa coupling λ. Rejection limits at 95% CL have been derived in the framework of the Buchmüller-Rückl-Wyler model. They are shown in figure 5(right) for LQ having fermionic number $F = -2$ (coupling to sea quarks) or $F = 0$ (coupling to valence quarks). In the latter case, the limits represent an improvement of a factor ~ 3 compared to H1 previous publications [4].

7 Summary

For the first time, using 37 pb^{-1} of e^+p data taken by the H1 detector, the NC DIS double differential cross-section has been measured at HERA, in a kinematic domain far beyond the one covered by fixed target experiments. This extension concerns especially the very high Q^2 region, where the γ/Z^0 can no longer be neglected, and the high x region, where the valence quarks dominate. An excess of events at very high Q^2 is still present, though its magnitude is reduced when adding the 1997 data. In particular no significant clustering in the mass spectrum is observed with the 1997 data alone. Using the NC results, rejection limits for first generation scalar leptoquarks have been derived. H1 extends the domain of leptoquark parameters excluded so far by other experiments.

References

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