Search for Scalar Leptoquarks with Polarized Protons (and Neutrons) at HERA and Future $ep(n)$ Machines

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The effects of Scalar Leptoquarks in various channels have been analysed for the HERA collider and also for an eventual new ep machine running at higher energies. We emphasize the relevance of polarized beams.

1. INTRODUCTION

We present the effects of Scalar LQ in the Neutral Current (NC) and Charged Current (CC) channels at HERA, with high integrated luminosities and also at an eventual new ep collider running at higher energies, like the TESLAxHERA or LEPxLHC projects [1]. We estimate the constraints that can be reached using those facilities for several Leptoquark scenarios. We emphasize the relevance of having polarized lepton and proton beams as well as also having neutron beams (through polarized He^3 nuclei), in order to disentangle the chiral structure of these various models.

We adopt the "model independent" approach of Buchmüller-Rückl-Wyler [2] (BRW) where the LQ are classified according to their quantum numbers and have to fulfill several assumptions like B and L conservation, $SU(3)\mathrm{x}SU(2)\mathrm{x}U(1)$ invariance ... (see [2] for more details). The interaction lagrangian is given by :

$$\begin{aligned}\mathcal{L} &= (g_{1L}\bar{q}_L^c i\tau_2 \ell_L + g_{1R}\bar{u}_R^c e_R)\,.\mathbf{S_1} + \tilde{g}_{1R}\bar{d}_R^c e_R.\tilde{\mathbf{S}}_\mathbf{1} \\ &+ g_{3L}\bar{q}_L^c i\tau_2 \tau \ell_L.\mathbf{S_3} + \tilde{h}_2 L \bar{d}_R \ell_L.\tilde{\mathbf{R}}_\mathbf{2} \\ &+ (h_{2L}\bar{u}_R \ell_L + h_{2R}\bar{q}_L i\tau_2 e_R)\,.\mathbf{R_2}, \qquad (1)\end{aligned}$$

where the LQ S_1, $\tilde{S}_1$ are singlets, R_2, $\tilde{R}_2$ are doublets and S_3 is a triplet. ℓ_L, q_L (e_R, d_R, u_R) are the usual lepton and quark doublets (singlets). In what follows we denote generically by λ the LQ coupling and by M the associated mass.

These LQ are severely constrained by several different experiments, and we refer to [3] for some detailled discussions.

Now, in order to simplify the analysis, we make the following assumptions : *i*) the LQ couple to the first generation only, *ii*) one LQ multiplet is present at a time, *iii*) the different LQ components within one LQ multiplet are degenerate in mass, *iv*) there is no mixing among LQ's. From these assumptions and from eq.1, it is possible to deduce some of the coupling properties of the LQ, which are summarized in the table 1 of [4]. We stress from this table that the LQ couplings are flavour dependent and chiral.

2. FUTURE CONSTRAINTS

We consider the HERA collider but with some high integrated luminosities, namely $L_{e^-} = L_{e^+} = 500\,pb^{-1}$. The other parameters for the analysis being : $e^{\pm}p$ collisions, $\sqrt{s} = 300\,GeV$, $0.01 < y < 0.9$, $(\Delta\sigma/\sigma)_{syst} \sim 3\,\%$ and GRV pdf set [5]. We have considered also the impact on the constraints of higher energies by considering, in the one hand, an energy $\sqrt{s} = 380\,GeV$ which is closed to the maximal reach of HERA, and in the other hand, an energy $\sqrt{s} = 1\,TeV$ which could be obtained at the distant projects TESLAxHERA and/or LEPxLHC [1]. Limits at 95% CL for the various LQ models have been obtained from a χ^2 analysis performed on the unpolarized

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NC cross sections (best observables). In figure 1 we compare the sensitivities of various present and future experiments for R_{2L} as an example.

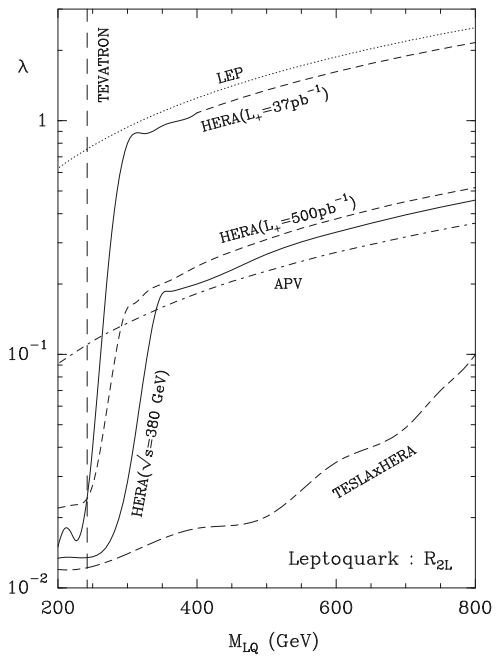

Figure 1. Constraints at 95% CL from various present and future experiments for R_{2L}.

We can remark the followings : 1) LEP limits are already covered by present HERA data [6]. 2) For virtual exchange, the LENC constraints (in particular APV experiments) are stronger than what could be obtained at HERA even with higher integrated luminosities and energies. 3) For real exchange, Tevatron data cover an important part of the parameter space. However, the bounds obtained from LQ pair production at Tevatron are strongly sensitive to $BR(LQ \to eq)$ [3]. It means that there is still an important window for discovery at HERA in the real domain, especially for more exotic models like R-parity violating squarks in SUSY models [4]. 4) To increase this window of sensitivity (for real exchange), it is more important to increase the energy than the integrated luminosity. 5) A 1 TeV ep collider will give access to a domain (both real and virtual) which is unconstrained presently.

3. CHIRAL STRUCTURE ANALYSIS

3.1. Unpolarized case

An effect in NC allows the separation of two classes of models. A deviation for $\sigma^{NC}_{e^-p}$ indicates the class (S_{1L},S_{1R}, $\tilde{S}_1$,S_3), whereas for $\sigma^{NC}_{e^+p}$ it corresponds to (R_{2L},R_{2R},$\tilde{R}_2$). For CC events, only S_{1L} and S_3 can induce a deviation from SM expectations (if we do not assume LQ mixing). This means that the analysis of $\sigma^{CC}_{e^-p}$ can separate the former class into (S_{1L},S_3) and (S_{1R},$\tilde{S}_1$). If we want to go further into the identification of the LQ we need to separate "eu" from "ed" interactions, which seems to be impossible with ep collisions except if the number of anomalous events is huge. So, if we want a "complete" separation of the LQ species we need to consider ep and en collisions as well, where some observables like the ratios of cross sections $R = \sigma^{NC}_{ep}/\sigma^{NC}_{en}$ for instance, will allow it. However, as soon as we relax one of our working assumptions (*i-iv*) some ambiguities will remain. The situation will be better with polarized collisions.

3.2. Polarized case

According to our previous experience [7] we know that in general the Parity Violating (PV) two spin asymmetries exhibit stronger sensitivities to new chiral effects than the single spin asymmetries. Then we consider the case where the e and p (or neutrons) beams are both polarized. The PV asymmetries are defined by $A^{PV}_{LL} = (\sigma^{--}_{NC} - \sigma^{++}_{NC})/(\sigma^{--}_{NC} + \sigma^{++}_{NC})$, where $\sigma^{\lambda_e\lambda_p}_{NC} \equiv (d\sigma_{NC}/dQ^2)^{\lambda_e\lambda_p}$, and λ_e, λ_p are the helicities of the lepton and the proton, respectively. A LQ will induce some effects in these asymmetries, and the directions of the deviations from SM expectations allow the distinction between several classes of models. For instance, a positive deviation for $A^{PV}_{LL}(e^-p)$ pins down the class (S_{1L},S_3) and, a negative one, the class (S_{1R},$\tilde{S}_1$). Similarly, an effect for $A^{PV}_{LL}(e^+p)$ makes a distinction between the model R_{2R} and the class (R_{2L},$\tilde{R}_2$). This last fact can be seen in figure 2 which represents A^{PV}_{LL} for e^+p collisions at TESLAxHERA energies with a LQ of mass 500 GeV and coupling $\lambda = 0.2$, the large (small) bars corresponding to

$L = 100(500)\,pb^{-1}$ (a global systematic error of $(\Delta A/A)_{syst} = 10\,\%$ has been added in quadrature).

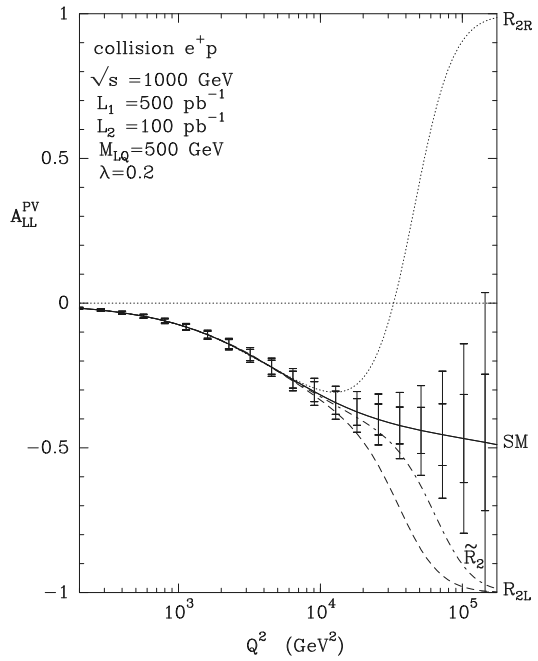

Figure 2. $A_{LL}^{PV}(e^+p)$ vs Q^2 for the BRW models.

Some other observables, defined in [7], could be used to go further into the separation of the models. However the sensitivities of these asymmetries are rather weak, and they can be useful only for some particularly favorable values of the parameters (M,λ). Consequently, polarized $\vec{e}\vec{n}$ collisions are mandatory to perform the distinction between the LQ models. This can be seen through the ratio of asymmetries $R = A_{LL}^{PV}(ep)/A_{LL}^{PV}(en)$, which for an e^+ beam distinguishes the models R_{2L} (positive deviation) and $\tilde{R}_2$ (negative one). This ratio is presented in figure 3 and the separation is obvious. Similarly, for an e^- beam, a positive (negative) deviation in $R(e^-)$ indicates the class (S_{1R},S_3) ((S_{1L},$\tilde{S}_1$)). Since these classes are complementary to the ones obtained from $A_{LL}^{PV}(e^-p)$, it indicates a non-ambiguous separation of the LQ models.

Finally, if we relax the working assumptions *i-iv*, the LQ can have some more complex structures. Then some ambiguities can remain. Nevertheless, the use of additional asymmetries, like the huge number of charge and PC spin asymmetries that one can define with lepton plus nucleon polarizations [7], should be very useful for the determination of the chiral structure of the new interaction.

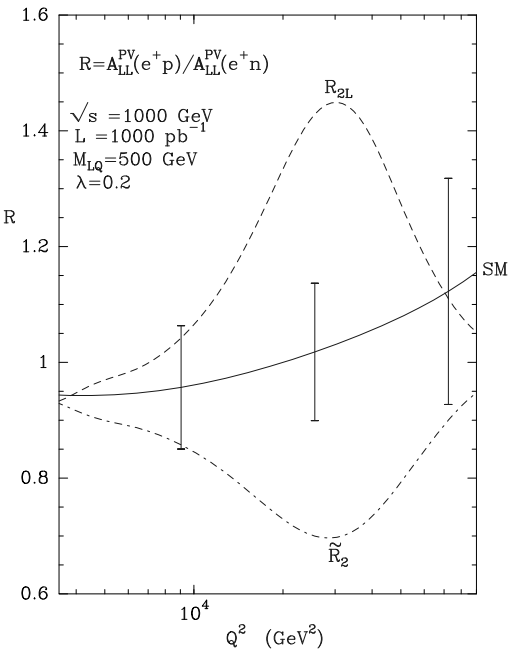

Figure 3. R vs Q^2 to distinguish R_{2L} and $\tilde{R}_2$ models.

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