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Leptoquark Pair Production at HERA

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Abstract

The scalar and vector leptoquark pair production cross sections for deep inelastic *ep* scattering are calculated. Estimates are presented for the search potential at HERA.

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1 Introduction

In many extensions of the Standard Model bosonic states carrying both lepton and quark quantum numbers, so–called leptoquarks, are contained. Leptoquarks may exist in the mass range reached by high energy colliders if their couplings are B and L conserving. A general classification of these states was given in ref. [1] demanding also non–derivative and family diagonal couplings. In most of the scenarios the fermionic leptoquark couplings are not predicted. Moreover, a detailed analysis of low energy data [2] showed that the these leptoquark couplings are small in the mass range up to $O(1\ \mathrm{TeV})$. Thus processes depending on the fermionic couplings can not be used to obtain rigorous mass bounds for these states.

On the other hand, the couplings of the leptoquarks to the electroweak gauge bosons and gluons are determined by the respective gauge symmetries. In the case of scalar leptoquarks the couplings are thus completely predicted. For vector leptoquarks additionally anomalous couplings may contribute. Due to the small fermionic couplings the pair production cross sections depend only on the bosonic couplings and mass limits may be derived directly.

In the present paper a brief account is given on results obtained in refs. [3, 4] and estimates are presented for the search potential in the HERA energy range.

2 The Pair Production Cross Sections

The integral leptoquark pair production cross sections in deep inelastic ep collisions are described by

$$\sigma_{S,V}^{ep,tot} = \sigma_{S,V}^{ep,dir} + \sigma_{S,V}^{ep,res}, \tag{1}$$

containing a direct and a resolved photon contribution which are given by

$$\sigma_{S,V}^{ep,dir} = \int_{y_{min}}^{y_{max}} dy \int_{x_{min}}^{x_{max}} dx \phi_{\gamma/e}(y) G_p(x,\mu^2) \hat{\sigma}_{S,V}^{dir}(\hat{s}, M_\Phi) \theta(\hat{s} - 4M_\Phi^2), \tag{2}$$

and

$$
\begin{aligned}
\sigma_{S,V}^{ep,res}(s, M_\Phi) &= \int_{y_{min}}^{y_{max}} dy \int_{4M_\Phi^2/Sy}^{1} dz \int_{4M_\Phi^2/Syz}^{1} dx \phi_{\gamma/e}(y)\theta(\hat{s} - 4M_\Phi^2) \\
&\times \left\{ \sum_{f=1}^{N_f} \left[q_f^\gamma(z,\mu_1)\overline{q}_f^p(x,\mu_2) + \overline{q}_f^\gamma(z,\mu_1) q_f^p(x,\mu_2) \right] \hat{\sigma}_{S,V}^q(\hat{s}, M_\Phi) \right. \\
&+ \left. G^\gamma(z,\mu_1) G^p(x,\mu_2) \hat{\sigma}_{S,V}^g(\hat{s}, M_\Phi) \right\}, \qquad (3)
\end{aligned}
$$

respectively. Here $\phi_{\gamma/e}$ denotes the Weizsäcker–Williams distribution and M_Φ is the leptoquark mass. q_f^γ and $G^{p(\gamma)}$ are the quark and gluon distributions in the photon and proton, respectively, $\hat{s} = Sxy$, and μ_1 and μ_2 denote the factorization scales.

The subsystem scattering cross sections $\hat{\sigma}_{S,V}^{q,g}(\hat{s}, M_\Phi)$ were calculated in [3] for the direct process and in [4] for the resolved processes, both for scalar and vector leptoquarks. There also the differential scattering cross were derived. In the case of vector leptoquarks the scattering cross sections were calculated accounting both for anomalous photon κ_A, λ_A, and gluon couplings, κ_G, λ_G. These contributions are understood in an effective description being valid in the threshold range, i.e. for $S \sim 4M_\Phi^2$. Due to the anomalous couplings the pair production cross sections for vector leptoquarks obtain as well unitarity violating pieces which however are assumed to never become large. It is hardly possible in general, to provide a correct high energy description in a model–independent way, as intended in the present paper focussing on the threshold range only. This, instead, requests to consider a specific scenario accounting also for the details of the respective pattern of symmetry breaking.

For all details of the calculation we refer to refs. [3] and [4].

3 Numerical Results

In figures 1 and 2 the integrated scattering cross sections for a series of scalar and vector leptoquarks are shown in dependence of the leptoquark mass and charges. For the vector leptoquarks different choices of anomalous couplings are also considered. For simplicity we identified $\kappa_A = \kappa_G$ and $\lambda_A = \lambda_G$. It is interesting to note that not the Yang–Mills type couplings, $\kappa = \lambda = 0$, but the so–called minimal couplings, $\kappa = 1, \lambda = 0$, result in the smallest cross section. In further experimental studies it might be interesting to vary even all the four anomalous couplings independently. As seen in figures 1 and 2 the integral cross sections behave about like

$$
\sigma_{tot}^{S,V}(M_\Phi) \sim A \exp(-BM_\phi). \qquad (4)
$$

This relation can be used to obtain an estimate of the respective search limits which can be reached at a given integrated luminosity, $\mathcal{L}$.

For $\mathcal{L} = 100$ pb^{-1} and $\sqrt{s} = 314\,\mathrm{GeV}$ the search limits for charge $|Q_\Phi| = 5/3$ scalar leptoquarks ranges up to 60 (45) GeV and for vector leptoquarks up to 70 (55) GeV, given a signal sample of 10 (100) events, respectively.

For most of the channels the experiments at LEP 1 have excluded leptoquarks with masses below $M_Z/2$. At present the most stringent mass bound for both scalar [5] and vector leptoquarks[1]

[1]Studies considering also anomalous leptoquark couplings were not performed yet.

decaying into the fermions of the first and second family come from TEVATRON and exclude the range $M_\Phi \lesssim 90$ GeV. For some leptoquark types the range $M_\Phi \lesssim 130$ GeV is excluded [5]. No bounds were yet derived for 3rd generation leptoquarks, e.g. those decaying as $\Phi_{S,V} \rightarrow b\ \tau$, etc., in the TEVATRON analyses. Due to the lower background rates, an investigation of particularly this channel may be more suited to ep or e^+e^- collisions than for proton collisions.

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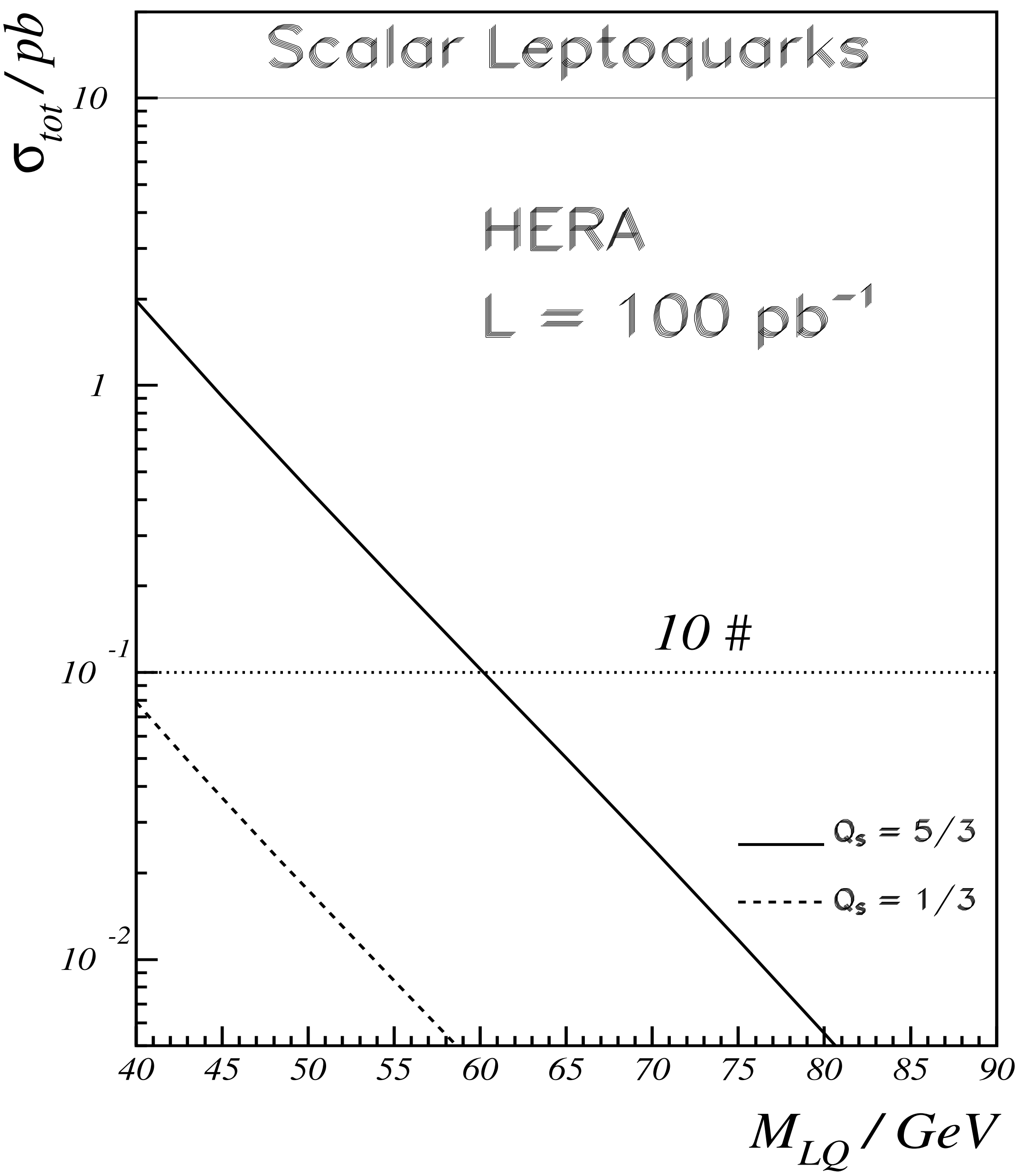

Figure 1: Integrated cross sections for scalar leptoquark pair production at HERA, $\sqrt{S} = 314$ GeV. Full line: σ_{tot} for $|Q_\Phi| = 5/3$; dotted line: σ_{dir} for $|Q_\Phi| = 5/3$; dashed line: σ_{tot} for $|Q_\Phi| = 1/3$; dash–dotted line: σ_{dir} for $|Q_\Phi| = 1/3$.

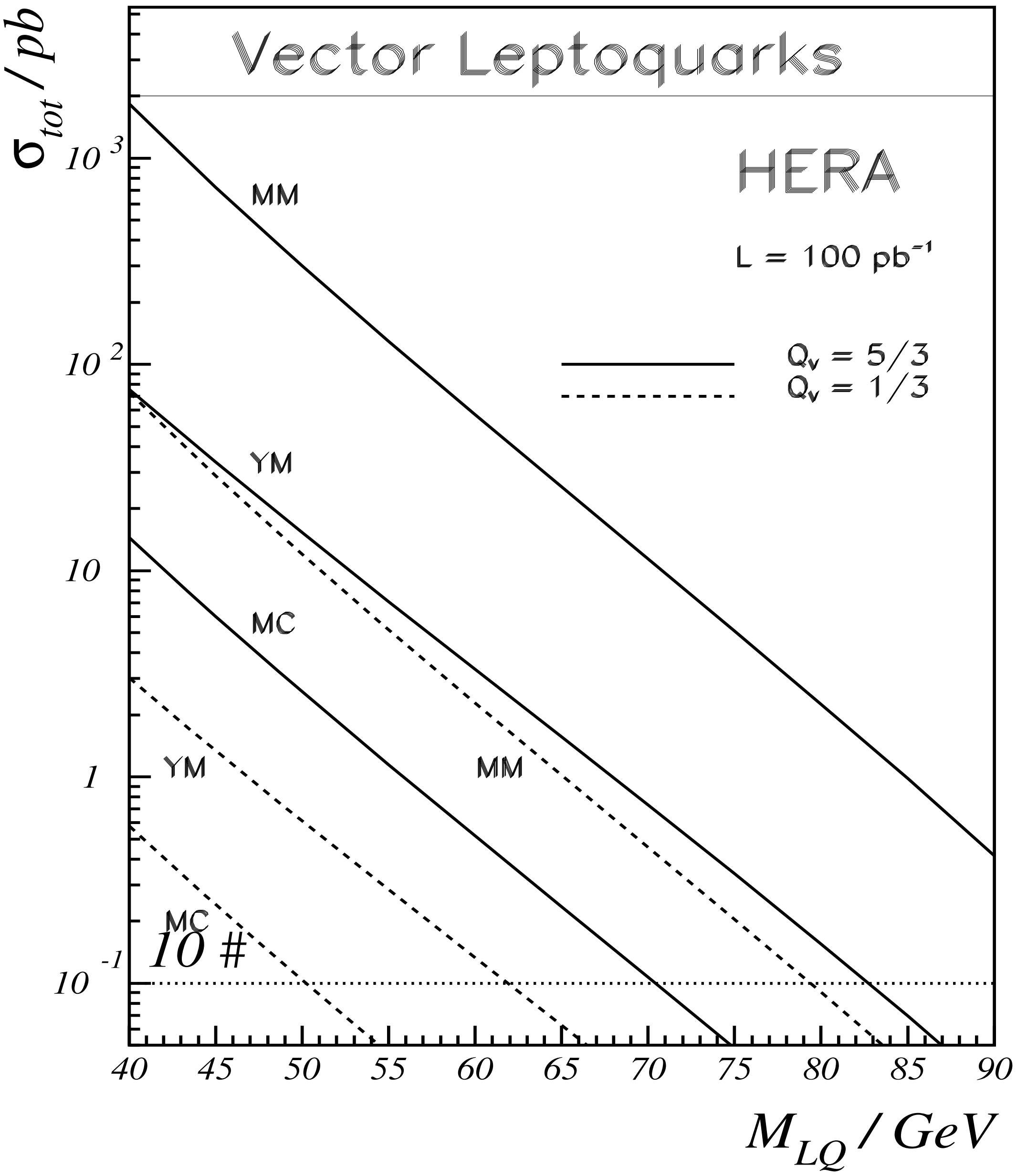

Figure 2: Integrated cross sections $\sigma_{tot} = \sigma_{dir} + \sigma_{res}$ for vector leptoquark pair production at HERA, $\sqrt{S} = 314$ GeV. Upper full line: $|Q_\Phi| = 5/3, \kappa_{A,G} = \lambda_{A,G} = -1$ (MM5); Upper dashed line: $|Q_\Phi| = 5/3, \kappa_{A,G} = \lambda_{A,G} = 0$ (YM5); Upper dotted line: $|Q_\Phi| = 5/3, \kappa_{A,G} = 1, \lambda_{A,G} = 0$ (MC5). The corresponding lower lines are those for $|Q_\Phi = 1/3$.