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SIGNALS FOR VIRTUAL LEPTOQUARK EXCHANGE AT COLLIDERS *

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Abstract

We study the effects of virtual leptoquark exchange on charged current and neutral current processes at HERA, on di-lepton production at the Tevatron, and on quark pair production at LEP II. We present the areas of parameter space that can be excluded at these colliders by searching for deviations from Standard Model expectations.

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DISCLAIMER

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ABSTRACT

We study the effects of virtual leptoquark exchange on charged current and neutral current processes at HERA, on di-lepton production at the Tevatron, and on quark pair production at LEP II. We present the areas of parameter space that can be excluded at these colliders by searching for deviations from Standard Model expectations.

Many theories which go beyond the Standard Model (SM) are inspired by the symmetry between the quark and lepton generations and try to relate them at a more fundamental level. As a result, many of these models contain new particles, called leptoquarks, which naturally couple to a lepton-quark pair. These particles need not be heavy; in fact, leptoquarks can have a mass $\sim 100\,\text{GeV}$ and still avoid[1] conflicts with rapid proton decay and dangerously large flavor changing neutral currents. This is particularly true in models where each generation of fermions has its own leptoquark(s) which couples only within that generation. Here, results are presented for the leptoquark present in superstring-inspired E_6 models[2]. These leptoquarks, denoted by S, are scalar, charge $-1/3$, baryon number $= +1/3$, lepton number $= +1$, weak iso-singlets. Their interactions are governed by the E_6 superpotential terms

$$\lambda_L L S^c Q + \lambda_R S u^c e^c + \lambda' \nu^c S d^c \,, \tag{1}$$

where L and Q represent the left-handed lepton and quark doublets, respectively, and the superscript c denotes the charge conjugate states. The Yukawa couplings, *i.e.*, the λ's, are *a priori* unknown. For calculational purposes, the Yukawa couplings are parameterized by (with $F_L = F_R \leq 1$)

$$\frac{\lambda^2_{L,R}}{4\pi} = F_{L,R} \;\; \alpha \,. \tag{2}$$

At e^+e^- colliders, direct leptoquark pair production can proceed through s-channel Z and γ exchange. The search region is essentially set by the kinematic reach of the collider, *i.e.*, $M_S \lesssim \sqrt{s}/2$. However, if a leptoquark is too heavy to be produced directly, perhaps it can be detected through its indirect effects via virtual exchange. This is similar in nature to the detection of the SM Z boson at PEP/PETRA. In e^+e^- collisions, leptoquarks can contribute to the process $e^+e^- \to q\bar{q}$ through t-channel exchange via their Yukawa couplings. The 95% C.L. bounds which can be obtained[3] at LEP II from such reactions is presented in Fig. 1 in the leptoquark coupling strength - mass plane for various values of integrated luminosity. Here, the search region corresponds to the area above the curves.

Direct leptoquark production at hadron colliders proceeds through gg fusion and $q\bar{q}$ annihilation and is also independent of the unknown Yukawa couplings. Present searches at the Tevatron have placed[4] the bound $M_S > 113\,\text{GeV}$. Leptoquarks can also contribute to the reverse of the process discussed above, *i.e.*,

$q\bar{q} \to e^+e^-$. However, preliminary investigation shows[5] that it is difficult to distinguish the leptoquark signal from the background in this case.

By its nature, the high-energy ep collider HERA is especially well-suited to study leptoquarks. Direct production can occur through an s-channel resonance via the Yukawa couplings at enormous rates with distinctive peaks in the x-distribution. HERA experimental searches are expected[6] to reach a discovery limit of $\sim 250\,\text{GeV}$ when the leptoquark coupling strength is of order $0.01\alpha_{em}$, and up to the kinematic limit if the coupling is equal to α_{em}. If leptoquarks are too massive to be produced directly at HERA, they again can be detected through their indirect effects via virtual exchange by searching for deviations from SM expectations for certain processes. Several authors[7] have examined such effects on the neutral current asymmetries that can be formed with polarized electron beams, and have found that departures from the SM are small, even for leptoquarks of low mass (*e.g.*, $\sim 400\,\text{GeV}$) and large couplings. The possible indirect effects on charged current as well as neutral current processes have also been systematically investigated[8]. The best results are obtained by examining the ratio $R = \sigma_{NC}/\sigma_{CC}$, where discovery limits can reach leptoquark masses of order $800\,\text{GeV}$ for electromagnetic coupling strengths (with 200pb^{-1} of integrated luminosity per e^+, e^- beam). Taking the ratio of neutral to charged current cross sections is also advantageous because several systematic uncertainties, as well as those from a lack of detailed knowledge of the parton distributions, will cancel. Neutral current events, *i.e.*, the reactions $e^\pm q \to e^\pm q$ and $e^\pm \bar{q} \to e^\pm \bar{q}$, occur through t-channel γ and Z exchange in the SM. Leptoquarks can also contribute via s- and u-channel exchanges. In the charged current case, *i.e.*, $e^\pm q \to \nu q$ and $e^\pm \bar{q} \to \nu \bar{q}$, leptoquarks can also contribute in these same channels. In order to ensure that the NC and CC events are cleanly separated and identified, cuts are imposed on the scaling variables x and y, as well as on the transverse momentum of the out-going lepton, $p_T(e) > 5\,\text{GeV}$ and $\not{p}_T(\nu) > 20\,\text{GeV}$. The 90% and 95% C.L. discovery region in the leptoquark coupling-mass plane, based on measurements of this observable is displayed in Fig. 2. Figure 2 shows the results for unpolarized $e^\pm$ beams with integrated luminosities of 20, 200, and 500pb^{-1} per beam. The region that can be explored with 200pb^{-1} per unpolarized beam is $m_S \lesssim 800\,\text{GeV}$ for large leptoquark-electron-quark couplings ($F \sim 1$), and $F \gtrsim 0.13$ for $m_S \sim 314\,\text{GeV}$.

In summary, we find that virtual leptoquark exchange can have significant contributions to processes in e^+e^- and ep colliders. We urge our experimental colleagues to search for these effects!

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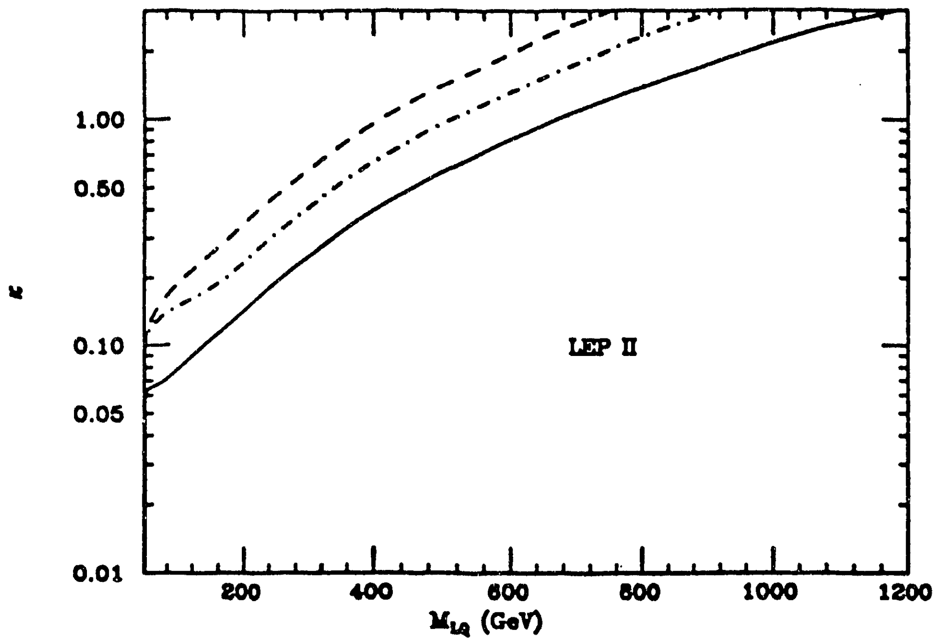

Fig. 1. 95% C.L. discovery region at LEP II (with $\sqrt{s} = 200\,\mathrm{GeV}$) in the leptoquark coupling - mass plane for various values of integrated luminosity. Here, $\kappa = 2F$ in the notation presented in the text.

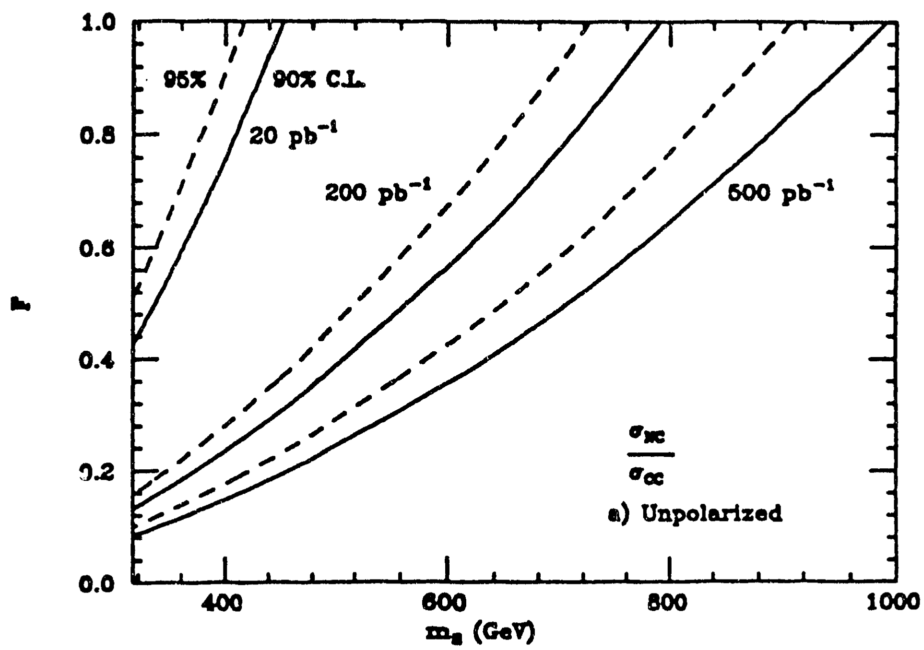

Fig. 2. Discovery region in the $m_S - F$ plane at HERA from the ratio, R, for different integrated luminosities as shown. The area to the upper left of the solid (dashed) curves can be excluded at the 90% (95%) C.L.

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