ABSTRACT

The search reaches for both scalar ($S$) and vector ($V$) leptoquarks at future hadron colliders are summarized. In particular we evaluate the production cross sections of both leptoquark types at TeV33 and LHC as well as the proposed 60 and 200 TeV colliders through both quark-antiquark annihilation and gluon-gluon fusion: $q\bar{q}, gg \rightarrow SS, VV$. Experiments at these machines should easily discover such particles if their masses are not in excess of the few TeV range.

I. INTRODUCTION

Many extensions of the standard model (SM) which place quarks and leptons on a symmetric footing predict the existence of leptoquarks, which are spin-0 or 1, color-triplet objects that couple to $q\ell$ or $\bar{q}\ell$ pair [1]. While these particles may be sought indirectly through their influence on low energy processes[2], the most promising approach is via direct production at colliders. In particular, searches for leptoquarks at LEP[3], HERA[4], and the Tevatron[5] have already been performed, in most cases concentrating on the specific scenario of scalar leptoquarks. Based on both the direct and indirect searches we might expect that if leptoquarks exist their masses must be above a few hundred GeV, and possibly up in the TeV range. In this paper we will examine the search reach for both scalar and vector leptoquarks at future hadron colliders. The production rates for leptoquarks at such colliders will be shown to be sufficiently large so that particles of this type in the TeV mass range and above become accessible. In addition, we will see that the size of the production cross section alone is sufficient to distinguish scalar from vector leptoquark types.

II. LEPTOQUARK PAIR PRODUCTION

Leptoquarks can be produced either singly or in pairs in hadronic collisions. The cross section for single production, however, relies on the size of the a priori unknown Yukawa couplings of the leptoquark and is therefore model dependent. Pair production, on the other hand, proceeds through QCD interactions and thus depends only on the leptoquark spin and the fact that it is a color triplet field. It has been shown in Ref.[6] that this mechanism will be dominant unless the Yukawa couplings, which are governed by the electroweak interactions, are rather large, i.e., of order electromagnetic strength or greater. This is an important result in that the production of both scalar and vector leptoquarks at hadron colliders is not dependent upon the electroweak properties of these particles. Of course, the converse is also true, i.e., the production properties cannot be used to probe the detailed nature of the leptoquark type.

The production cross section for pairs of scalar leptoquarks ($S$) in either $gg$ or $q\bar{q}$ collisions is easily calculated and has been available for some time; we use the results of Hewett et al. in Ref.[6] in what follows. Given the mass of $S$ there are no real ambiguities in this calculation except for the possible inclusion of a $K$-factor (which we omit) to account for higher order QCD corrections and leads to a slight enhancement in the rate.

The vector leptoquark ($V$) case is not as straightforward. In order to calculate the $gg \rightarrow VV$ cross section we need to determine both the trilinear $gVV$ and quartic $ggVV$ couplings, which may naively at first glance appear to be unknown. For the $q\bar{q}$ subprocess, only the $gVV$ coupling is required. However, in any realistic model wherein vector leptoquarks appear and are fundamental objects, they will be the gauge bosons of an extended gauge group like $SU(5)$. In this case the $gVV$ and $ggVV$ couplings are completely fixed by extended gauge invariance. These particular couplings will also insure that the subprocess cross sections obey tree-level unitarity, as is the hallmark of all gauge theories. Of course, it might be that the appearance of vector leptoquarks is simply some low energy

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Figure 1: Production cross section for a pair of 1 TeV vector leptquarks at the LHC as a function of $\kappa$. The dotted(dashed) curve corresponds to the $gg(q\bar{q})$ production subprocess whereas the solid curve is their sum.
manifestation of a more fundamental theory at a higher scale and that these particles may even be composite. In this case so-called `anomalous' couplings in both the $gVV$ and $ggVV$ vertices can appear. One possible coupling of this type is an `anomalous chromomagnetic moment', usually described in the literature by the parameter $\kappa$, which takes the value of unity in the more realistic gauge theory case. Among these `anomalous couplings', the term which induces $\kappa$ is quite special in that it is the only one that conserves $CP$ and is of dimension 4.

Figure 2: Scalar leptoquark pair production cross section as a function of mass at a 60 TeV $pp$ (left) or $p\bar{p}$ (right) LSGNA collider. The dotted (dashed) curve corresponds to the $gg(q\bar{q})$ production subprocess whereas the solid curve is their sum. MRSA' parton densities whereas the solid curve is their sum.

Figure 3: Same as the previous figure but now for a spin-1 vector leptoquark with $\kappa = 1$.

III. RESULTS

We now turn to some numerical results. We will consider the production of only a single type of leptoquark at a time and ignore the possibility of a degenerate multiplet of leptoquarks being produced simultaneously. Here we concentrate on cross sections for $S$ and $V$ pair production at the $\sqrt{s}=60$ (LSGNA) and 200 (PIPETRON) TeV machines, which are displayed in Figures 2, 3, 4 and 5, since the corresponding results for the Tevatron and LHC can be found in, e.g., Ref.[8]. In these figures, the contributions of the two distinct subprocesses $gg \rightarrow SS,VV$ and $q\bar{q} \rightarrow SS,VV$ are separately displayed together with their sum. From Figures 2 and 3 several conclusions are immediately obvious for leptoquark production at the $\sqrt{s} = 60$ TeV collider: (i) The vector leptoquark cross section is substantially larger than that for scalars in both $pp$ and $p\bar{p}$ collisions since the rates for both $gg \rightarrow VV$ and $q\bar{q} \rightarrow VV$ are larger than their scalar counterparts. (ii) Due to the contribution of the $q\bar{q}$ production mode, $p\bar{p}$ colliders have larger leptoquark cross sections than do $pp$ colliders. For example, the ratio of $p\bar{p}$ to $pp$ cross sections for a 4(6) TeV scalar(vector) leptoquark is approximately 2(6) at $\sqrt{s} = 60$ TeV. At $pp$ machines, for both vector and scalar leptoquarks, the cross sections are dominated by the $gg$ process out to the machine's anticipated mass reach. In the $\sqrt{s} = 60$ TeV $p\bar{p}$ case, the $q\bar{q}$ process dominates over $gg$ for masses greater than about 3.0(1.8) TeV for scalar(vector) leptoquarks. The mass reaches for the 60 TeV machine can be found in Table I.

Figure 4: Same as Fig. 2 but now at the 200 TeV PIPETRON collider.
At $\sqrt{s}=200$ TeV, the patterns observed at 60 TeV are repeated. For example, the ratio of $p\bar{p}$ to $pp$ cross sections for a 10(15) TeV scalar(vector) leptoquark is approximately 1.5(3.5). In the $p\bar{p}$ collider mode, the $q\bar{q}$ process dominates over $gg$ for masses greater than about 10(6) TeV for scalar(vector) leptoquarks.

Table I: Search reaches in TeV for scalar($S$) and vector($V$) leptoquarks at future hadron colliders assuming a branching fraction into a charged lepton plus a jet of unity($1/2$). For vector leptoquarks, $\kappa=1$ has been assumed and in both cases the MRSA' parton densities have been employed. These results are based on the assumption of 10 signal events.

<table>
<thead>
<tr>
<th>Machine</th>
<th>$\mathcal{L}(fb^{-1})$</th>
<th>$S$</th>
<th>$V$</th>
</tr>
</thead>
<tbody>
<tr>
<td>LHC</td>
<td>100</td>
<td>1.34(1.27)</td>
<td>2.1(2.0)</td>
</tr>
<tr>
<td>60 TeV($pp$)</td>
<td>100</td>
<td>4.9(4.4)</td>
<td>7.6(7.0)</td>
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<tr>
<td>60 TeV($p\bar{p}$)</td>
<td>100</td>
<td>5.7(5.2)</td>
<td>9.6(9.0)</td>
</tr>
<tr>
<td>200 TeV($pp$)</td>
<td>1000</td>
<td>15.4(14.1)</td>
<td>24.2(23.3)</td>
</tr>
<tr>
<td>200 TeV($p\bar{p}$)</td>
<td>1000</td>
<td>18.1(16.2)</td>
<td>31.1(29.0)</td>
</tr>
<tr>
<td>TeV33</td>
<td>30</td>
<td>$\simeq$ 0.35</td>
<td>$\simeq$ 0.58</td>
</tr>
</tbody>
</table>

Figure 5: Same as Fig. 3 but now for the 200 TeV PIPETRON collider.

IV. ACKNOWLEDGEMENTS

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V. REFERENCES


