NEW GAUGE BOSON SEARCHES AT THE TEVATRON

JoAnne L. Hewett* and Thomas G. Rizzo†

*Department of Physics, University of Wisconsin, Madison, WI 53706
†Ames Laboratory and Department of Physics, Iowa State University, Ames, IA 50011

ABSTRACT

The discovery reach of the Tevatron in the 1990's for new gauge bosons which originate in a wide range of extensions to the Standard Model is obtained. Most searches make use of the conventional leptonic decay mode of the $Z'$, whereas others require the observation of a dijet mass peak above the QCD background from hadronic decays.

New gauge bosons are common features of many extensions of the Standard Model (SM) and their discovery would be a clear and inescapable signal for new physics. Hadron colliders, such as the Tevatron and the SSC, provide an excellent means to search for such new particles but the discovery "reach" of these colliders generally depends on the physics from which the new gauge bosons originate. Thus, we must consider a rather broad spectrum of new gauge boson scenarios in our discussion of potential search limits. We will compute the existing limits on these particles from the recent Tevatron run and compare them with what can be obtained at the Tevatron in the 1990's.

The following models with extra gauge bosons are considered: (i) the $E_6$ string-inspired Effective Rank-5 Model (ERSM)[1] where the additional $Z$ arises from the breaking of $E_6$ and its coupling to fermions is parameterized by an angle $\theta$ (with the range $-90^\circ \leq \theta \leq 90^\circ$). (ii) The Left-Right Model (LRM)[2], which is based on the group SU(2)$_L \times$SU(2)$_R \times$U(1) and contains both a $W'$ and a $Z'$. (iii) The Alternative Left-Right Model (ALRM)[3] is also based on the SU(2)$_L \times$SU(2)$_R \times$U(1) group but interchanges the particle quantum number assignments of the more conventional LRM. (iv) a "Sequential Standard Model" (SSM), with the $Z'$ being just a heavy version of the SM Z. (v) The "Un-unified Model" (HARVM)[4], where the left-handed quarks and leptons are in doublets under two different SU(2) groups. This model contains an essentially degenerate $W'$, $Z'$ pair and a free parameter $s_\varphi$ which has the allowed range 0.22 $\leq s_\varphi$ $\leq$ 0.99. (vi) The "Extended Color" Model (FH)[5], where the additional $Z'$ arises from the breaking of SU(4)$_c$ or SU(5)$_c$ down to SU(3)$_c$ and couples only to quarks. Models (i)-(v) can be probed by looking for the conventional leptonic decay modes of the new $Z$, while the FH model requires a search for a dijet mass bump since this $Z'$ has no leptonic couplings. The rather strong $q\bar{q}Z'$ and $q\bar{q}W'$ couplings in the HARV model (together with the $W'$ and $Z'$ degeneracy) makes the dijet search viable in this case as well.

In performing these calculations we have included the appropriate electroweak radiative corrections[6] to the various couplings, taking a top quark mass ($m_t$) and a Higgs boson mass ($m_H$) of 100 GeV (and with $M_Z = 91.177$ GeV as measured at LEP). We have also allowed for phase space suppression due to a finite $m_t$. QCD corrections to the $Z'$ decay modes through lowest order have been included as well as a $K$-factor in new gauge boson production[7]; both are evaluated with $\alpha_s(M_Z^2) = 0.12$, which is allowed to run with the scale set by the new gauge boson mass assuming $\alpha_{QCD} = 0.2$ GeV. In order to examine the sensitivity to the structure function parameterizations, we have used both DO1 and EHLQ[8] in our calculations. We assume the same detection efficiencies as for the present[9] CDF $W'$ and $Z'$ searches, e.g., $\sigma(p\bar{p} \rightarrow Z') \cdot B(Z' \rightarrow \ell \ell \nu \nu) \leq 1.0$ pb with an integrated luminosity of 4.7 pb$^{-1}$. This corresponds roughly to a discovery limit of 5 events per detector.

Figures 1(a)–(b) and 2(a)–(b) show the existing and future limits on the new gauge bosons in the ERSM and HARV models, respectively, arising from the leptonic decays of these particles. The corresponding limits for the LRM, ALRM, and SSM are shown in Table I. Note that while the limit in the ERSM is relatively independent of $\theta$, the limits on the $Z'$ from the HARV model are very sensitive to the choice of $s_\varphi$. The ER5M shows a modest sensitivity to the choice of parton distributions, particularly in the region near $\theta \approx -5^\circ$ where the $u\bar{u}Z'$ coupling vanishes. In the HARV model case, larger values of $s_\varphi$ produce the strongest limits from the dilepton search since small $s_\varphi$ leads to drastically reduced leptonic branching fractions. By comparing the results displayed in Figs. 1, 2, and Table I, we see that the $Z'$ search limits obtainable at a fixed integrated luminosity vary widely over
the spectrum of possible models.

Fig. 1: Present (a) and future (b) search limits on the $Z'$ mass ($M_2$) in the ER5M as a function of the angle $\theta$ for DO1 and EHLQ1 structure functions with integrated luminosities of 4.7, 25, 75, 100, and 325 pb$^{-1}$ assumed.

In models with both a $W'$ and $Z'$, their masses and, hence, their search limits are correlated. In the ALRM, e.g., $M_{W_R} \approx 0.834M_{Z_R}$, so that a limit of 450 (600, 705, 755, 840) GeV on the $Z_R$ mass implies $M_{W_R} > 375$ (500, 586, 612, 697) GeV. This is quite important since $W_R$ cannot be singly produced in this model as it carries lepton number and negative R-parity[3]. In the LRM case, a bound on the $Z_R$ mass of 360 (730) GeV implies $M_{W_R} > 212$ (430) GeV or $M_{W_R} > 300$ (600) GeV depending on whether the SU(2)$_R$ breaking is done by triplets or doublets, respectively. Since $W_R$ production can be suppressed in this case by various alternative forms of the right-handed KM matrix[10] these indirect search limits can provide important constraints.

Fig. 2: Cross-sections times leptonic branching fractions for $W'$ and $Z'$ production at the Tevatron as a function of $s_4$ for the HARV model with various masses assumed for those particles. DO1 distribution functions are assumed. The top curve in both cases corresponds to $M_{Z'} = 100$ GeV with each successive curve being an increase in this quantity by 100 GeV.

Table I

<table>
<thead>
<tr>
<th>Model</th>
<th>4.7 pb$^{-1}$</th>
<th>25 pb$^{-1}$</th>
<th>75 pb$^{-1}$</th>
<th>100 pb$^{-1}$</th>
<th>325 pb$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>LRM</td>
<td>383 (355)</td>
<td>503 (493)</td>
<td>603 (592)</td>
<td>630 (618)</td>
<td>737 (723)</td>
</tr>
<tr>
<td>ALRM</td>
<td>452 (448)</td>
<td>602 (599)</td>
<td>707 (699)</td>
<td>734 (725)</td>
<td>840 (828)</td>
</tr>
<tr>
<td>SSM</td>
<td>394 (388)</td>
<td>651 (541)</td>
<td>655 (843)</td>
<td>680 (668)</td>
<td>786 (772)</td>
</tr>
</tbody>
</table>
Figures 3(a) and (b) show the dijet mass spectrum from new gauge boson production and subsequent decay to $q\bar{q}$ in the HARV and FH models. In the HARV case, the $W_T^\pm$ and $Z_H$ contributions are summed as these fields are degenerate. Clearly, the $Z'$ in the FH model with a mass of 600 GeV does not lead to a statistically significant increase in the number of events, even for a luminosity of 325 pb$^{-1}$. In the HARV case, if both $W_H$ and $Z_H$ have a mass of 500 GeV with $s_\phi = 0.25$ (0.50, 0.75), a 5$\sigma$ excess over the QCD background (in a bin 100 GeV wide centered on the $Z'$ mass) is attained for an integrated luminosity of 2.2 (20, 653) pb$^{-1}$. Thus a 500 GeV $Z'$ with a small $s_\phi$ value can already be excluded. If the $Z'$ mass were 750 GeV and $s_\phi = 0.25$ (0.50, 0.75), a 5$\sigma$ excess would develop for an integrated luminosity of 7.6 (134, 3.3 x 10$^8$) pb$^{-1}$. We find that in the region $s_\phi \lesssim 0.5$, which is most suited for the dijet bump search, $Z'$ mass scales as large as 900 GeV could be probed with a luminosity of 325 pb$^{-1}$. This would complement the dilepton search for new gauge bosons in this model.

Fig. 3: Dijet mass distribution for (a) the HARV model with degenerate $W_T^\pm$ and $Z_H$ for $s_\phi = 0.25$ (0.50, 0.75) corresponding to dotted (dashed, dash-dotted) curves and the (solid) QCD background assuming $M_{Z'} = 500$ GeV, and (b) for the $Z'$ of mass 600 GeV in the FH model using DO1 structure functions.

Our results show that within the next decade, the Tevatron will be able to probe for new gauge bosons in the mass region $M_{Z'} \lesssim 700-900$ GeV for a wide class of extensions to the SM. This gives the Tevatron a large discovery potential in the pre-SSC era.

ACKNOWLEDGEMENTS

This research was supported in part by the University of Wisconsin Research Committee with funds granted by the Wisconsin Alumni Research Foundation, and in part by the U. S. Department of Energy under contracts DE-AC02-76ER00881 and W-7405-Eng-82.

REFERENCES


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