Search for New Heavy Particles in the $WZ^0$ Final State in $pp\bar{p}$ Collisions at $\sqrt{s} = 1.8$ TeV

T. Affolder

*Ernest Orlando Lawrence Berkeley National Laboratory, Berkeley, California*

Kenneth A. Bloom

*University of Nebraska-Lincoln, kbloom2@unl.edu*

Collider Detector at Fermilab Collaboration

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Search for New Heavy Particles in the WZ Final State in p ¯ p Collisions at \( \sqrt{s} = 1.8 \) TeV

The standard model (SM) of particle physics is widely believed to be incomplete. Because alternative models are numerous and varied, it is advantageous to search for new physics using methods that are not specific to a single model, but which retain the most compelling aspects of currently favored scenarios [1].

A number of theories, including extended gauge models, nonlinear realizations of electroweak symmetry, a strongly interacting Higgs, and Technicolor, all predict new high mass particles which decay via $WZ^0 \rightarrow ev + jj$ as a function of $M_X$ and $\Gamma(X)$ in $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV. No evidence is found for production of $X$ in 110 pb$^{-1}$ of data collected by the Collider Detector at Fermilab. General cross section limits are set at the 95% C.L. as a function of mass and width of the new particle. The results are further interpreted as mass limits on the production of new heavy charged vector bosons which decay via $W' \rightarrow WZ^0$ in an extended gauge model as a function of the width, $\Gamma(W')$, and mixing factor between the $W'$ and the standard model $W$ bosons.

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We present the first general search for new heavy particles, $X$, which decay via $X \rightarrow WZ^0 \rightarrow ev + jj$ as a function of $M_X$ and $\Gamma(X)$ in $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV. No evidence is found for production of $X$ in 110 pb$^{-1}$ of data collected by the Collider Detector at Fermilab. General cross section limits are set at the 95% C.L. as a function of mass and width of the new particle. The results are further interpreted as mass limits on the production of new heavy charged vector bosons which decay via $W' \rightarrow WZ^0$ in an extended gauge model as a function of the width, $\Gamma(W')$, and mixing factor between the $W'$ and the standard model $W$ bosons.
vs the $W + \text{jets}$ background in the fit is fixed such that the sum of the signal and all backgrounds equals the number of events observed in the data. The relative magnitude of the signal and the $W + \text{jets}$ background is the only free parameter in the fit [17]. The $W + \text{jets}$ mass spectrum for the data and background is shown in Fig. 1 for events with the dijet mass around $M_{\text{jet}}$ and in the regions outside a 25 GeV/c\(^2\) mass window, with the expected distributions plotted assuming no signal contribution. The results of the fit require no significant signal contribution and there is no evidence of resonant $WZ^0$ production for any mass or width for the acceptance model.

To set general limits on the process $p\bar{p} \rightarrow X \rightarrow WZ^0$, we take $X$ to be a $W'$ in an extended gauge model as it spans both the $M_X$ and $\Gamma(X)$ parameter space. Following the prescription of Ref. [5] (no additional fermions and the $W$ and $W'$ vertex couplings, $Wq\bar{q}'$, $W(\nu$, and $WWZ^0$ are identical), the production cross sections are uniquely determined as a function of mass, and the partial width of the $W'$, $\Gamma(W' \rightarrow WZ^0)$, is determined by a mixing factor, labeled $\xi$, which describes the amount of mixing between the $W$ and the $W'$. While this makes $\Gamma$ a free parameter in the theory, we quote results in two specific cases. The full mixing case, or reference model [5], is where the new particle $X$ couples in the same way as the SM $W$ ($\xi = 1$).
and gives $\Gamma(W' \to WZ^0) \propto M_W^{5/2}$, yielding a large branching fraction into $WZ^0$, and widths comparable to the mass for $M_W = 425$ GeV/c$^2$. A second special case is $\xi = (M_W/M_{W'})^2$ as in extended gauge models which restore left-right symmetry to the weak force and predict an effective $W'WZ^0$ vertex term [2]. In this case, $\Gamma(W') \ll M_W$ for all masses.

We set limits on $\sigma(p\bar{p} \to X) \cdot B$, where $B = B(X \to WZ^0) \cdot B(W \to e\nu)$, using the fit technique described above and convoluting in systematic uncertainties, which depend on both mass and width, using the same methods as in Ref. [18]. The dominant source of uncertainty is the jet energy scale which would bias the measurement of the dijet and W + dijet masses from the new particle X. The effect of such a bias is largest at lower mass, where increased background in the signal region can cause a large variation in the cross section limit. For example, the effect is between 50% and 100% for the reference model and between 30% and 60% for $\xi = (M_W/M_{W'})^2$. Other notable sources of uncertainty are uncertainty in the jet resolution (between 15% and 30%), effect of the $Q^2$ scale on the W + jets background shape (between 5% and 25%), choice of parton distribution functions (between 10% and 30%), uncertainty in $W'$ acceptance (between 5% and 30%), and MC modeling of initial and final state radiation (between 5% and 15%). The total systematic uncertainty is found by adding the above sources in quadrature, and varies between 50%–100% for the reference model and 40%–75% for $\xi = (M_W/M_{W'})^2$.

The 95% C.L. upper limits on $\sigma \cdot B$ for $M_X = 200$, 300, 400, and 500 GeV/c$^2$ are shown in Fig. 2 as a function of the width. While these limits are not sensitive enough to set mass limits on $\rho_T \to WZ^0$ production [4], they exclude a large region of $W'$ parameter space. Table I gives a summary of results for the $\Gamma(W') \ll M_W$ approximation using $\xi = (M_W/M_{W'})^2$. The results in Fig. 2 can be interpreted as the first cross section limits as a function of $W'$ width, and Fig. 3 shows the first $W'$ exclusion region for $\xi vs M_W$, where the theoretical cross section exceeds the calculated 95% C.L. upper limit. Other direct searches for $W'$ at the Tevatron in the $W' \to \ell\nu$ and $W' \to jj$ channels have established a limit of $M_{W'} > 786$ GeV/c$^2$ [16,18,19], but only in the region of $\xi = 0$, which is

![FIG. 2. The 95% C.L. upper limits on $\sigma \cdot B$ as a function of the width. We use $\Gamma(W')$ because it uniquely determines the $W' \to WZ^0$ branching ratio. Our results include the $W' \to WZ^0$ and $W \to e\nu$ branching ratios.](image1)

<table>
<thead>
<tr>
<th>$M_X$ (GeV/c$^2$)</th>
<th>$A_X$</th>
<th>95% C.L. $\sigma \cdot B$ limit (pb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>0.07</td>
<td>9.5</td>
</tr>
<tr>
<td>300</td>
<td>0.17</td>
<td>4.5</td>
</tr>
<tr>
<td>400</td>
<td>0.24</td>
<td>1.3</td>
</tr>
<tr>
<td>500</td>
<td>0.29</td>
<td>0.7</td>
</tr>
<tr>
<td>600</td>
<td>0.31</td>
<td>0.5</td>
</tr>
</tbody>
</table>

![FIG. 3. The 95% C.L. excluded region in the $\xi vs M_W$ plane, where $\xi$ is the mixing factor between the $W'$ and the SM W boson. While the branching fraction goes up with increasing values of $\xi$ and mass, the acceptance goes down as $\xi$ and the width increase. This causes the “nose” effect in the exclusion region. The largest mass exclusion occurs for $\xi = 0.3$, where we exclude $M_{W'} < 560$ GeV/c$^2$.](image2)
complementary to the region excluded in Fig. 3, and is only valid for $\Gamma(W') \ll M_{W'}$. A previous search for $W' \to WZ^0$ [20] sets cross section limits for $M_{W'} = 200, 350,$ and $500 \text{ GeV}/c^2$, but only for $\Gamma(W') \ll M_{W'}$.

For a $W'$ in the reference model ($\xi = 1$), we exclude the region $200 \leq M_{W'} \leq 480 \text{ GeV}/c^2$. For masses below $200 \text{ GeV}/c^2$, the widths are small and the reference model is excluded in the 95% C.L. by the $W$ model is now excluded. These results are generally applicable to other new particles $X$ with wide widths [3].

In conclusion, we have conducted a general search for new particles which decay via $X \to WZ^0$ in the $e\nu jj$ channel. We observe no evidence of resonant production and estimate production cross section limits as a function of mass and width. The results are further interpreted as mass limits on the production of new heavy charged vector bosons which decay via $W' \to WZ^0$ in extended gauge models as a function of the width, $\Gamma(W')$, and mixing factor between the $W'$ and the $W$ bosons. These are the first limits on $X \to WZ^0$ as a function of both mass and width, and are the only direct mass limits on $W' \to WZ^0$ to date.

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*Present address: Northwestern University, Evanston, Illinois 60208.

†Present address: Carnegie Mellon University, Pittsburgh, Pennsylvania 15213.


[7] We use cylindrical coordinates where positive $z$ points along the proton beam and is zero at the center of the detector. The pseudorapidity, $\eta$, is defined as $\eta = -\ln[\tan(\theta/2)]$, where $\theta$ is the polar angle with respect to the proton beam direction and $\phi$ is the azimuthal angle. The transverse energy is defined as $E_T = E \sin\theta$, where $E$ is measured in the calorimeter.

[8] We require that the electron candidate pass identification and isolation requirements. The scalar sum of the $p_T$ of all tracks in the tracking chamber within a cone of $\Delta R = 0.25$ surrounding, but not including, the electron must be less than 5 GeV/c, and that the $E_T$ in a cone of $\Delta R = 0.4$ around, but not including, the electron candidate must be less than 10% of the electron $E_T$.

[9] The fiducial region is $0.05 \leq |\eta| < 1.05$ and away from the edges of the calorimeter; for a more complete discussion of the fiducial region, see F. Abe et al., Phys. Rev. D 52, 2624 (1995), Sec. 2.C.


[17] We note that the assumption of fixing the normalization of the non-$W$ backgrounds has between a 1%–5% effect on the limit. This variation has been incorporated into the overall systematic uncertainty.


