DISCOVERY AND IDENTIFICATION OF $W'$ BOSONS AT $e^+e^-$ COLLIDERS*

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We report on studies of the sensitivity to extra gauge bosons of the reactions $e^+e^- \rightarrow \nu\bar{\nu}\gamma$ and $e\gamma \rightarrow \nu q+X$ to extract discovery limits for $W'$s. The discovery potential for a $W'$ is, for some models, comparable to that of the LHC. These processes may be also useful for determining $W'$ and $Z'$ couplings to fermions which would complement measurements made at the Large Hadron Collider.

Extra gauge bosons, both charged ($W'$) and/or neutral ($Z'$), arise in many models of physics beyond the Standard Model (SM). Examples that we consider are the Left-Right symmetric model (LRM) based on the gauge group $SU(2)_L \times SU(2)_R \times U(1)_{B-L}$, the Un-Unified model (UUM) based on the gauge group $SU(2)_q \times SU(2)_l \times U(1)_Y$ where the quarks and leptons each transform under their own $SU(2)$, and the KK model (KK) which contains the Kaluza-Klein excitations of the SM gauge bosons that are a possible consequence of theories with large extra dimensions. We also consider a $W'$ with SM couplings (SSM). In this contribution we give a brief summary of our work on indirect searches for $W'$ bosons in $e^+e^-$ collisions. We are interested in two issues; the sensitivity to $W'$ discovery and the measurement of its couplings to thereby determine its origins. We refer the interested reader to the more detailed presentations of the process $e^+e^- \rightarrow \nu\bar{\nu}\gamma$ in Ref. 2 and of the process $e\gamma \rightarrow \nu q+X$ in Ref. 3.

The first process we consider is $e^+e^- \rightarrow \nu\bar{\nu}\gamma$. The kinematic variables of interest are the photon’s energy, $E_\gamma$, and its angle relative to the incident electron, $\theta_\gamma$, both defined in the $e^+e^-$ centre-of-mass frame. To take into account finite detector acceptance we imposed the constraints on the kinematic variables: $E_\gamma \geq 10$ GeV and $10^\circ \leq \theta_\gamma \leq 170^\circ$. The most serious background is radiative

*This research was supported in part by the Natural Sciences and Engineering Research Council of Canada. The work of M.A.D. was supported, in part, by the Commonwealth College of The Pennsylvania State University under a Research Development Grant (RDG).
Discovery and Identification of $W'$ Bosons...

Table 1. $W'$ discovery limits in TeV.

| Model | $\sqrt{s} = 0.5$ TeV, $L_{\text{int}} = 500$ fb$^{-1}$ | $\sqrt{s} = 1$ TeV, $L_{\text{int}} = 500$ fb$^{-1}$ |
|-------|-------------------------------------------------|-------------------------------------------------|
|       | $e^+ e^- \to \nu\bar{\nu}\gamma$ | $e^- e^+ \to \nu\bar{\nu}\gamma$ | $e^+ e^- \to \nu\bar{\nu} + X$ | $e^- e^+ \to \nu\bar{\nu} + X$ |
|       | $e^+ e^- \to \nu\bar{\nu} + X$ | $e^- e^+ \to \nu\bar{\nu} + X$ |
| SSM   | no syst. | syst. | no syst. | syst. | no syst. | syst. | no syst. | syst. |
| W$'$  | 4.3      | 1.7   | 4.1      | 2.6    | 5.3      | 2.2    | 5.8      | 4.2   |
| LRM   | 1.2      | 0.6   | 0.8      | 0.6    | 1.6      | 1.1    | 1.2      | 1.1   |
| UUM   | 2.1      | 0.6   | 4.1      | 2.6    | 2.5      | 1.1    | 5.8      | 4.2   |
| KK    | 4.6      | 1.8   | 5.7      | 3.6    | 5.8      | 2.2    | 8.3      | 6.0   |

Bhabha scattering where the scattered $e^+$ and $e^-$ go undetected down the beam pipe. We suppress this background by restricting the photon’s transverse momentum to $p_T^\gamma > \sqrt{s} \sin \theta_e / (\sin \theta_e + \sin \theta_v)$ where $\theta_e = 25$ mrad and is the minimum angle to which the veto detectors may observe electrons or positrons. There are also higher order backgrounds which cannot be suppressed, such as $e^+ e^- \to \nu\bar{\nu}'\nu'\gamma$, and so must be included in an analysis of real data.

There is a large contribution to the cross-section from the radiative return of the $Z^0$ which is not sensitive to $W'$s and can be eliminated with a suitable cut on $E_\gamma$. The statistical significance can be increased by binning the $E_\gamma$ distribution and calculating the $\chi^2$. The limits obtained with and without a 2% systematic error added in quadrature with the statistical error are given in Table 1.

The second process we consider is $e\gamma \to \nu q + X$ using photon spectra from both the Weizsacker Williams process and from a backscattered laser. Starting with the process $e\gamma \to \nu q\bar{q}$ the $W'$ contributions can be enhanced by imposing the kinematic cut that either the $q$ or $\bar{q}$ is collinear to the beam axis. In this kinematic region the process $e\gamma \to \nu q\bar{q}$ is approximated quite well by the simpler process $eq \to \nu q'$ where the quark is described by the quark parton content of the photon, the so-called resolved photon approximation. We use the process $eq \to \nu q'$ to obtain limits as it is computationally much faster and the limits obtained in this approximation are in good agreement with those using the full process. The details of the calculation are given in Ref. 3.

To take into account detector acceptance we restrict the angle of the outgoing $q(\bar{q})$ to the range $10^\circ \leq \theta_{q(\bar{q})} \leq 170^\circ$. We have included $u$, $d$, $s$, and $c$-quark contributions and used the leading order GRV distributions. The search limits are fairly insensitive to the specific choice of distribution. The kinematic variable most sensitive to $W'$ is the $p_{Tq}$ distribution. The dominant backgrounds arise from two jet final states such as $\gamma\gamma \to q\bar{q}$, $\gamma g \to q\bar{q}$, $gg \to q\bar{q}$..., where one of the jets goes down the beam pipe and is not observed. These backgrounds can be effectively eliminated by imposing the constraint $p_{Tq} > 40(75)$ GeV for $\sqrt{s} = 0.5(1.0)$ TeV. Discovery limits were obtained by binning the $p_{Tq}$ distribution and calculating the $\chi^2$ for an assumed integrated luminosity. As before, a 2% systematic error was included in quadrature with the statistical error. The discovery limits using the backscattered laser spectrum are given in Table 1.

If a signal was already detected for a $W'$ with mass lower than its search limit we can use the processes $e^+ e^- \to \nu\bar{\nu}\gamma$ and $e^- e^+ \to \nu\bar{\nu} + X$ to put constraints on the
Discovery and Identification of W' Bosons

Fig. 1. 95% C.L. constraints on W' couplings for $\sqrt{s} = 0.5$ TeV and $L_{int} = 500$ fb$^{-1}$ with systematic errors and for different W' masses. (a) For the process $e^+ e^- \rightarrow \nu \bar{\nu} \gamma$ assuming a SSM W' (indicated by a star) using $\sigma$ and $A_{LR}$. We take 90% electron and 60% positron polarization and include a systematic error of 2% (1%) for $\sigma$ ($A_{LR}$). (b) For the process $e \gamma \rightarrow \nu q + X$ with a backscattered laser spectrum assuming the SM and using the $d\sigma/dp_T$ with a 2% systematic error. The SSM, LRM and the KK model are indicated by a full star, a dot and an open star, respectively. (Note the different coupling normalizations in (a) and (b)).

W' couplings. In Fig. 1 we show constraints on W' couplings for a collider with $\sqrt{s} = 500$ GeV and $L_{int} = 500$ fb$^{-1}$ for different W' masses. The constraints in Fig. 1a are for the process $e^+ e^- \rightarrow \nu \bar{\nu} \gamma$ found by combining the observables $\sigma$ and $A_{LR}$ for the process. The axes correspond to couplings normalized as $L_f(W) = C_W^f g/(2\sqrt{2})$ and similarly for $R_f(W)$. Fig. 1b shows the constraints on $C_L$ and $C_R$ found by binning the $p_T\gamma$ distribution using the process $e \gamma \rightarrow \nu q + X$. In Fig. 1b figure we have taken $C_L^\nu = C_L(\bar{\nu})$ which is satisfied in many models.

We have shown that measurements at high energy $e^+ e^-$ colliders are sensitive to W' bosons much higher in mass than their centre-of-mass energy. For some models the discovery reach is competitive with the LHC. If a W' were discovered, measurements of its couplings in the processes $e^+ e^- \rightarrow \nu \bar{\nu} \gamma$ and $e \gamma \rightarrow \nu q + X$ would provide a valuable complement to measurements at the LHC.

References

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