Update of Discovery Limits for Extra Neutral Gauge Bosons at Hadron Colliders

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We study and compare the discovery potential for heavy neutral gauge bosons (Z') at the various hadron colliders under discussion at Snowmass 2001 which range in $\sqrt{s}$ from 14 TeV for the LHC to 200 TeV for a variant of the VLHC. Typical search limits for pp colliders are $\sim 0.25 - 0.30 \times \sqrt{s}$ assuming 100 fb^{-1} to 1 ab^{-1} of integrated luminosity with some variation due to differences of fermion couplings in the different models. Discovery limits at the Tevatron are $\sim$ 1 TeV for 15 fb^{-1}, approximately 30–50% higher than this rough guideline, due to the higher $q\bar{q}$ luminosities in the $p\bar{p}$ beams.

Extended gauge symmetries and the associated heavy neutral gauge bosons, Z', are a feature of many extensions of the standard model such as grand unified theories, Left-Right symmetric models, and superstring theories. If a Z' were discovered it would have important implications for what lies beyond the standard model. It is therefore important to study and compare the discovery reach for extra gauge bosons at the various facilities that are under consideration for the future [1, 2, 3, 4, 5, 6]. Included in the list of proposed facilities considered at the Snowmass'01 workshop are high energy hadron colliders. In this report we update previous studies [1, 2, 3, 6] to include the high energy hadron colliders discussed at this meeting which range in $\sqrt{s}$ from 14 TeV to 200 TeV.

Many models that predict extra gauge bosons exist in the literature. We present search limits for several of these models that have received recent attention. Although far from exhaustive, the list forms a representative set for the purposes of comparison. The Effective Rank 5 E6 Model starts with the GUT group E_6 and breaks via the chain $E_6 \to SO(10)\times U(1)_\psi \to SU(5)\times U(1)_\chi \times U(1)_\psi$ with the Z' charges given by linear combinations of the $U(1)_\chi$ and $U(1)_\psi$ charges. Specific models are Z_χ corresponding to the extra Z' of $SO(10)$, Z_ψ corresponding to the extra Z' of E_6, and Z_η corresponding to the extra Z' arising in some superstring theories. The Left-Right symmetric model (LRM) is based on the gauge group $SU(2)_L\times SU(2)_R\times U(1)_{B-L}$, which has right-handed charged currents and restores parity at high energy. The Alternative Left-Right Symmetric model (ALRM) is based on the same gauge group as the LRM but now arising from E_6 where the fermion assignments are different from those of the LRM due to an ambiguity in how they are embedded in the **27** representation.. The Un-Unified model (UUM) is 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) 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 Z' with SM couplings (SSM). Details of these models and references are given in Ref. [1].

The signal for a Z' at a hadron collider consists of Drell-Yan production of lepton pairs [2, 3, 7, 8, 9] with high invariant mass via $pp \to Z' \to l^+l^-$. The cross section for the production of on-shell Z's is given by [3]:

$$\frac{d\sigma(pp\to f\bar{f})}{dy} = \frac{x_A x_B \pi^2 \alpha_{em}^2 (g_{Z'}/g_{Z^0})^4}{9 M_{Z'}\Gamma_{Z'}} \left({C_L^f}^2 + {C_R^f}^2\right) \sum_q \left({C_L^q}^2 + {C_R^q}^2\right) G_q^+(x_A, x_B, Q^2) \quad (1)$$

where

$$G_q^+(x_A, x_B, Q^2) = \sum_q \left[f_{q/A}(x_A) f_{\bar{q}/B}(x_B) + f_{\bar{q}/A}(x_A) f_{q/B}(x_B)\right] \quad (2)$$

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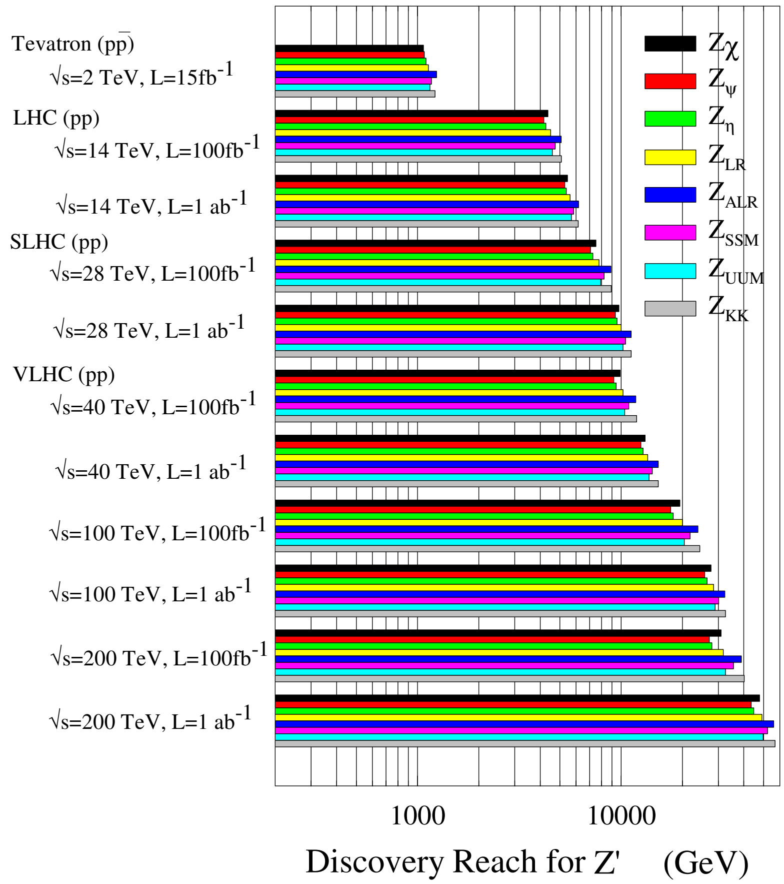

Figure 1: Discovery limits for extra neutral gauge bosons (Z') for the models described in the text based on 10 events in the $e^+e^- + \mu^+\mu^-$ channels.

The cross section for Z' production at hadron colliders is inversely proportional to the Z' width. If exotic decay modes are kinematically allowed, the Z' width will become larger and more significantly, the branching ratios to conventional fermions smaller. We will only consider the case that no new decay modes are allowed. The partial widths are given (at tree level) by

$$\Gamma_{Z' \to f\bar{f}} = M_{Z'} g_{Z'}^2 (C'^2_{f_L} + C'^2_{f_R})/24\pi \tag{3}$$

We obtain the discovery limits for this process based on 10 events in the $e^+e^- + \mu^+\mu^-$ channels using the EHLQ quark distribution functions [9] set 1, taking $\alpha = 1/128.5$, $\sin^2\theta_w = 0.23$, and including a 1-loop K-factor in the Z' production [10]. We include 2-loop QCD radiative corrections and 1-loop QED radiative corrections in calculating the Z' width. Using different quark distribution functions results in a roughly 10% variation in the Z' cross sections [6] with the subsequent change in discovery limits. Detailed detector simulations for the Tevatron and LHC validated our approximations as a good estimator of the true search reach. Furthermore, the results of our previous studies following this approach are totally consistent with subsequent experimental limits obtained at the Tevatron.

Lowering the number of events in the $e^+e^- + \mu^+\mu^-$ channels to 6 raises the discovery reach about 10% while lowering the luminosity by a factor of ten reduces the reach by about a factor of 3 [3].

In our calculations we assumed that the Z' only decays into the three conventional fermion families. If other decay channels were possible, such as to exotic fermions filling out larger fermion representations or supersymmetric partners, the Z' width would be larger, lowering the discovery limits. On the other hand, if decays to exotic fermions were kinematically allowed, the discovery of exotic fermions would be an important discovery in itself; the study of the corresponding decay modes would provide additional information on the nature of the extended gauge structure.

The discovery limits for various models at hadron colliders are shown in Fig. 1. These bounds are relatively insensitive to specific models. In addition, since they are based on a distinct signal with little background they are relatively robust limits. Typical search limits for pp colliders are $\sim 0.25 - 0.30 \times \sqrt{s}$ assuming 100 fb^{-1} to 1 ab^{-1} of integrated luminosity with some variation due to differences of fermion couplings in the different models. The Tevatron, a $p\bar{p}$ collider, has a 50% higher discovery reach than this rough guideline, indicating that valence quark contributions to the Drell-Yan production process are still important at these energies.

Acknowledgments

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