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SEARCH FOR NEW GAUGE BOSONS AT DØ

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ABSTRACT

We have searched for evidence of $W' \to e\nu$ and $Z' \to ee$ in data collected with the DØ detector at the Tevatron during the 1992–1993 $p\bar{p}$ collider run at $\sqrt{s} = 1.8$ TeV. We exclude the existence of a W' of mass less than 600 GeV/c^2 and a Z' of mass less than 480 GeV/c^2 at the 95% confidence level, assuming standard model couplings to quarks and leptons.

1. Introduction

Additional heavy gauge bosons, generically called W', Z', are predicted by numerous extensions to the standard model. One of the first of these extensions was the addition of a right-handed gauge group to the electro-weak sector giving: $SU(2)_R \times SU(2)_L \times U(1)$. This is referred to as the left-right symmetric model and, in effect, it restores parity at higher energy.[1] This group may be embedded in the larger gauge groups of some grand unification schemes including some versions of supersymmetry. Other unification schemes also predict W', Z' associated with different gauge groups.[2]

We have searched for W', Z' in the decay channels $W' \to e\nu$ and $Z' \to ee$ in data collected with the DØ detector at the Tevatron during the 1992–1993 $p\bar{p}$ collider run at $\sqrt{s} = 1.8$ TeV. We set mass limits for a hypothetical W', Z' with the same couplings to quarks and leptons as the standard model W, Z. We assume that the neutrino from the W' decay escapes the detector without depositing energy. The top quark mass is set at 160 GeV, and the decay to top is provided for sufficiently massive W', Z'. The widths of the W', Z' are taken as the W, Z widths scaled with the mass, allowing for decay to top.

2. The DØ Detector

The most relevant part of the DØ detector[3] for this analysis is the liquid argon calorimeter. The calorimeter is hermetic with coverage to $|\eta_{det.}| = 4.2$. The electromagnetic (EM) section consists of 4 layers radially with segmentation $.1 \times .1$ in $\eta \times \phi$ in layer 1, 2, and, 4 and $.05 \times .05$ at shower maximum, layer 3. It is 21 radiation lengths in depth. The calorimeter is in 3 sections, a central barrel, CC, and 2 end caps, EC. The fiducial region for electrons in the CC is $|\eta_{det.}| < 1.1$, and $1.5 < |\eta_{det.}| < 2.5$ in the EC. In the CC, the distance to module cracks spaced $.2\pi$ in ϕ must be $> .01$ in ϕ.

*Representing the DØ Collaboration.

3. Event Selection

The W trigger requires an isolated EM cluster, $E_t > 20$ GeV with shape and profile consistent with an electron, arising from a $.2 \times .2$ $(\eta \times \phi)$ EM trigger tower with $E_t > 10$ GeV. For the Z, the trigger requires 2 EM clusters with $E_t > 20$ GeV arising from 2 EM trigger towers with $E_t > 7$ GeV.

The following cuts are applied after event reconstruction in which the electron energy is scaled to give the LEP Z mass. Kinematic: for the W, electron $E_t > 25$ GeV and $\not{E}_t > 25$ GeV are required; for the Z, 2 electrons, $E_t > 30$ GeV. Electron quality: isolation < 0.15, EM fraction > 0.9, and H-matrix $\chi^2 < 100$, CC (< 200 for Z's), and < 200, EC. Isolation is defined: $(E_{t,R=.4} - E^{EM}_{t,R=.2})/E^{EM}_{t,R=.2}$. EM fraction is defined: $(E^e - E^{had})/(E^e + \textit{additional associated hadronic energy})$. H-matrix χ^2 is the χ^2 of the inverse of the correlation matrix for shower shape, trained on test beam data.

For the W, there must be a track pointing to the cluster with match significance < 10. Track match significance is defined $[(\frac{\Delta z}{\delta z})^2 + (\frac{\Delta \phi}{\delta \phi})^2]^{\frac{1}{2}}$, CC. For EC, substitute θ for z. The efficiency for finding a track of this significance is $.85 \pm .02$, CC, and $.76 \pm .03$, EC. To increase acceptance in the Z sample, one of the electron clusters is required to have a track match significance < 5 and the other has no track match requirement. Also for the Z sample, there must be at least one cluster in the CC.

There are 886 events in the Z sample from an integrated luminosity of $14.4 \pm 1.7 pb^{-1}$. For the W sample, 12798 events from $13.4 \pm 1.6 pb^{-1}$.

4. Background

The principal background in both the W and Z samples is QCD multi-jet events in which jets are reconstructed as electrons, and there is mis-measured $\not{E}_t$ in the case of the W. Fake electrons can arise from jets in which a π^0 carrying most of the jet energy is overlapped with a charged particle, from the charge exchange interaction of charged pions near the surface of the EM calorimeter, and from converted photons, principally from π^0 decay. The amount of this background is determined from the data.

To determine this background in the Z sample, events are selected with one "good" electron and one jet, each with $E_t > 30$ GeV. No effort is made to remove real W's and Z's from this sample and their contribution is estimated to be 2.5%. The fake cross section obtained from this sample is divided by the exclusive dijet cross section for jets with $E_t > 30$ GeV to get a fake rate. The $rate^2 \times \sigma_{inclusive\ dijet} \times$ *integrated luminosity* gives the predicted number of fake di-electrons in the Z sample, 38 ± 2. Appropriate allowances are made for the the fact that there are two types of "good" electrons (with and without matching track) and different fake probabilities in the CC and EC. Note that the large systematic errors in luminosity used in this calculation cancel since only DØ measured cross sections are used. To get the distribution of this background, the inclusive dijet invariant mass spectrum is normalized to 38 events. Varying the jet energy by $\pm 2\sigma$ of jet energy scale uncertainty does not noticeably affect this spectrum.

The number of QCD fakes in the W sample is determined by selecting an event sample similar to the W but with $\not{E}_t < 10$ GeV. The cross section for this process is than extrapolated to the region of $\not{E}_t > 25$ GeV by studying the $\not{E}_t$ distribution of

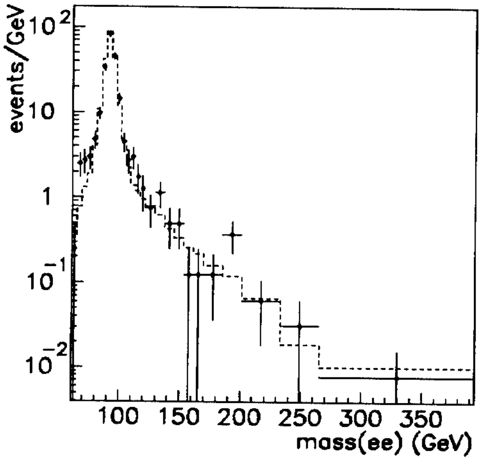

Figure 1. Data, shown with errors, and $Z-\gamma^*$ MC + QCD background, dashed.

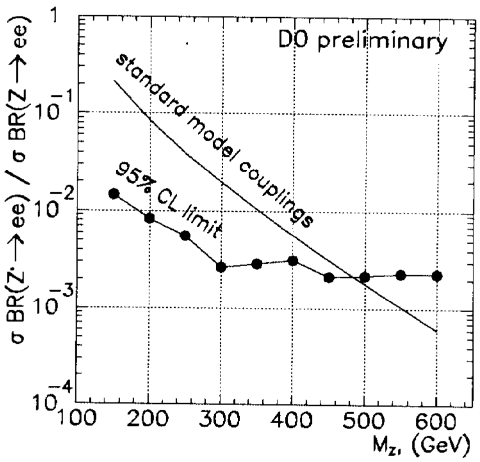

Figure 2. $M_{Z'} < 480$ GeV is excluded.

events similar to W events but with EM clusters of poor quality that are primarily not real electrons. The predicted QCD fake background is 770 ± 120 events.

5. The Z' Limit

The principal background to the Z' is Z–Drell-Yan production. Z–γ^* production is modeled using Pythia,[4] version 5.7, with CTEQ 2M parton distribution functions. The Monte Carlo (MC) output is smeared for detector energy and angular resolution. The di-electron invariant mass spectrum from data is compared to the sum of Z–γ^* MC plus QCD background spectra, in fig. 1. The MC plus QCD is normalized to the data.

Z'–Z–γ^* is also modeled by MC in the same manner. The difference between this and Z–γ^* is the Z' signal. The kinematic and fiducial acceptance is taken from the MC. The trigger and reconstruction efficiency is assumed to be the same for Z''s as for the Z. The expected number of Z' events for a given Z' mass is then scaled from the observed events in the vicinity of the Z peak after subtracting the QCD background:

$$N_{Z'} = \frac{(A \times \sigma \times BR)_{Z'}}{(A \times \sigma \times BR)_Z} \times N_Z, \tag{1}$$

where $N_{Z'} \equiv$ expected Z' signal, $A \equiv$ kinematic and geometric acceptance, and $N_Z \equiv$ observed events in $M_Z \pm 20$ GeV, less background. $N_{Z'}$ is accurate to $\pm 4\% stat. \pm 3\% sys.$

The 95% confidence level limit is calculated in a single invariant mass bin for each Z' mass using Poisson statistics.[5] The lower bound of the mass bin is chosen at $.8M_{Z'}$, below which there is no net Z' signal expected. The ratio $\sigma \times BR_{Z'}/\sigma \times BR_Z$ and the 95% confidence level limit are shown in fig. 2 for $M_{Z'}$ 150 – 600 GeV. From the intersection of these two curves, we may exclude with 95% confidence a Z' with mass 150–480 GeV and standard model couplings to quarks and leptons.

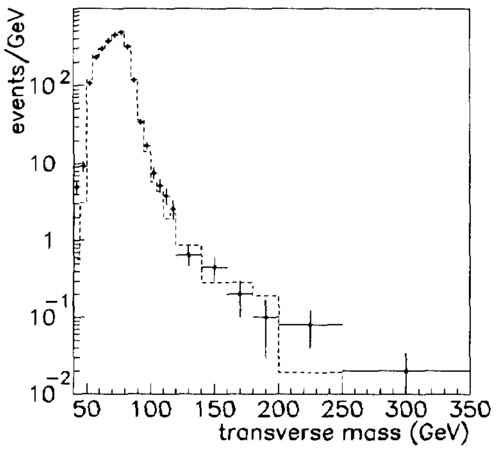

Figure 3. Data, shown with errors, and W MC, dashed.

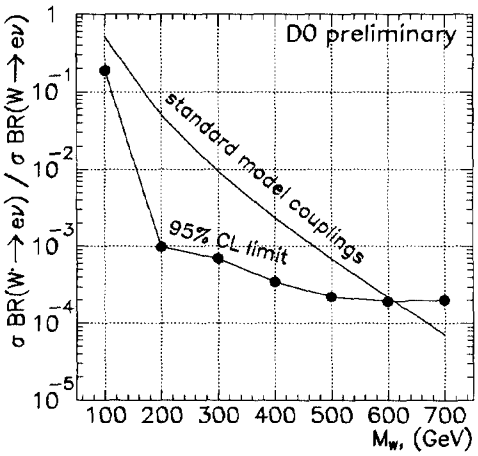

Figure 4. $M_{W'} < 600$ GeV is excluded.

6. The W' Limit

The W' and its principal background W are also generated using Pythia and CTEQ 2M PDF's. The MC events are then processed through a calorimeter simulator in which the energy is smeared cell by cell to simulate the $\not{E}_t$ response of the detector. The process $W'(W) \to \nu\tau \to \nu\nu\nu e$ is included in the MC generation and thus is treated as signal (background). The transverse mass spectrum of the W sample is compared to W MC in fig. 3. The MC is normalized to the observed W candidates without background subtraction. The QCD background is not modeled.

The expected number of W' events is calculated by (1) with the substitution of W for Z. The expected QCD background is subtracted from the observed W signal. $N_{W'}$ is accurate to $\pm 2\% stat. \pm 3\% sys$. The ratio $\sigma \times BR_{W'}/\sigma \times BR_W$ and the 95% confidence level limit are shown in fig. 4. The 95% confidence level limit and expected events are calculated in $M_t > 150$ GeV for $M_{W'}$ 100–300 GeV and $M_t > 350$ GeV for $M_{W'}$ 400–700 GeV. From the intersection of the two curves, a W' with mass 100–600 GeV and standard model couplings to quarks and leptons is excluded.

References

1. For a general survey, including original references, see R.N. Mohapatra, *Unification and Supersymmetry*, Springer-Verlag, New York, 1986.
2. For example: E. Ma, Mod. Phys. Lett. A **3**, 319 (1988); J.L. Hewett and T.G. Rizzo, Phys. Rep. **183**, 193 (1989) and references.
3. S. Abachi et al, Nucl. Instr. and Meth. A **338**, 185 (1994).
4. H.-U. Bengtsson, T. Sjöstrand, Comp. Phys. Comm., **46**, 43 (1987).
5. Particle Data Group, Phys. Rev. D, **45**, III.40 (1992).