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SEARCH FOR Z' AND W' AT CDF

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ABSTRACT

We have searched for heavy neutral and charged gauge bosons via the decays $Z' \to ee$ and $W' \to e\nu$ in $\bar{p}p$ collisions at $\sqrt{s} = 1.8$ TeV. The data were obtained using the CDF detector during 1992-1993 run corresponding to an integrated luminosity of 19.7 ± 0.7 pb^{-1}. We present a 95% confidence level upper limit on the production cross section times branching ratio of Z' and W' as a function of Z' and W' mass. Assuming Standard Model coupling strengths, we exclude a Z' with mass less than 505 GeV/c^2 and a W' with mass less than 652 GeV/c^2. We also present lower mass limits for Z' bosons from E_6 models and the Alternative Left-Right Model.

1. Introduction

Z' bosons are expected in most extensions of the Standard Model. W' bosons are expected in extended gauge models where left-right symmetry of the weak force are restored.[1] In $\bar{p}p$ collisions, these bosons may be observed directly via their decay to high P_T leptons. The current experimental mass limits, $M_{Z'} > 412$ GeV/c^2 and $M_{W'} > 512$ GeV/c^2 (95% C.L.) were established by the CDF collaboration assuming Standard Model (SM) coupling strengths. This result used data from the 1988-89 run corresponding 4 pb^{-1}. Reported here[2,3] is an extension of this search for the processes $Z' \to ee$ and $W' \to e\nu$ using 19.7 pb^{-1} of integrated luminosity from the 1992-93 run. We also report a status of the Z' search from the current 1994 run.

The CDF detector has been described in detail elsewhere. We give a brief description of the components relevant to this analysis. Momenta of charged particles are measured in the Central Tracking Chamber (CTC), which is immersed in a 1.4 T axial magnetic field. Outside the CTC, electromagnetic and hadronic calorimeters are arranged in a projective tower geometry. The central electromagnetic calorimeter (CEM) covers $|\eta| < 1.1$ and the plug electromagnetic calorimeter (PEM) covers $1.1 < |\eta| < 2.4$, where $\eta = -\ln(\tan\frac{\theta}{2})$ and θ is the polar angle with respect to the direction of the proton beam.

2. Z' Search

To select Z' candidate events, we require at least one electron in CEM and a second electron in the CEM or PEM. The electrons are required to have $E_T > 25$

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GeV and to be isolated. Central electrons are required to have a track with $P_T >$ 13 GeV/c matched to the CEM cluster in both position and transverse momentum, and also to have the ratio of hadronic to electromagnetic energy (HAD/EM) less than 12.5%. For PEM electrons we require that the lateral shower shape be consistent with that measured for test beam electrons. Finally, the $\overline{p}p$ interaction point (Z_{int}) which is distributed by an approximate gaussian with sigma of 26 cm along the beam direction is required to satisfy $|Z_{int}| < 60$ cm.

The dielectron invariant mass (M_{ee}) distribution for events passing these selection criteria is shown in Fig. 1 a). The sample contains 1371 events, of which 640 have both electrons in the central calorimeter (CC) and 731 have one electron in the central and one in the plug calorimeter (CP). The largest mass observed is 320 GeV/c^2.

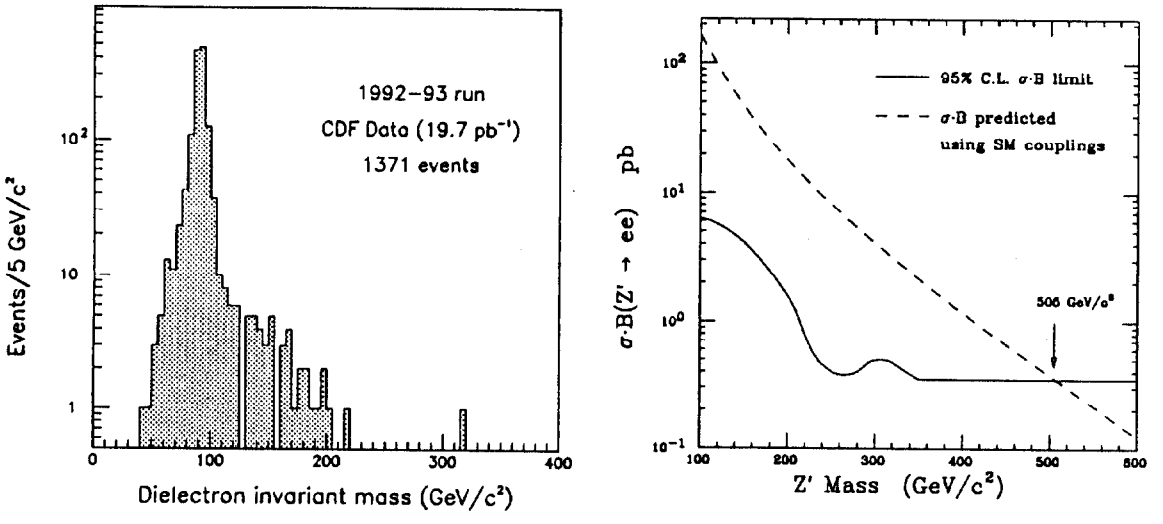

Figure 1: a) The dielectron invariant mass distribution of the events in the Z' search sample. b) The 95% C.L. upper limit on $\sigma \cdot \mathrm{B}(\overline{p}p \rightarrow Z' \rightarrow ee)$ (solid line) and the prediction of $\sigma \cdot \mathrm{B}$ (dashed line) and using the MRS D$'_-$ p.d.f. and SM couplings. The intercept of the curves determines the lower mass limit, $M_{Z'} > 505$ GeV/c^2.

We find the event selection efficiency is independent of the electron E_T in the range $25 < E_T < 350$ GeV and 86% for CC and 82% for CP events. The total Z' detection efficiency, including the acceptance, is estimated to be 28% at the Z^0 mass and rises to 44% for $M_{ee} > 250$ GeV/c^2. The Monte Carlo uses MRS D$'_-$ parton distribution functions (p.d.f.) for estimating the acceptance. The overall systematic uncertainty is 6%, including uncertainties due to detector acceptance (2.2%), efficiency of the event selection cuts (2.7%) and luminosity normalization (3.6%).

At large M_{ee} the dominant background is from the Drell-Yan process. We estimate $\sim$1 event with $M_{ee} > 250$ GeV/c^2 and $\sim$0.5 event with $M_{ee} > 300$ GeV/c^2 from this process. We observe one event in this region with a mass of 320 GeV/c^2, in agreement with the Drell-Yan expectations. The estimated background from sources other than

Z^0 and Drell-Yan is small. In extracting limits on Z' production, we take a conservative approach by assuming the background only from the Z^0 and Drell-Yan production.

We fit the observed M_{ee} distribution using a binned maximum-likelihood method to a superposition of the predicted distributions from Z' production together with Standard Model Drell-Yan and Z^0 production. The fit is repeated for a variety of Z' masses in the range 100 to 350 GeV/c^2. SM couplings are assumed in generating the Z' events and the Z' width is set equal to the Z^0 width scaled by a factor $M_{Z'}/M_{Z^0}$. To calculate B($Z' \rightarrow ee$) we have assumed a top mass of 174 GeV/c^2. For each Z' mass considered, the systematic uncertainties discussed above are numerically folded into the likelihood function. Above 350 GeV/c^2, where there are no observed events, we calculate the cross section limit from the limit on the expected number of events at the 95% C.L. from Poisson statistics. The 95% C.L. upper limit on $\sigma \cdot \mathrm{B}(\bar{p}p \rightarrow Z' \rightarrow ee)$ is shown as the solid line in Fig. 1 b). The dashed line in Fig. 1 b) is the predicted $\sigma \cdot$B using MRS D'_ p.d.f. and SM couplings. The intercept of the two curves at 505 GeV/c^2 determines the 95% C.L. lower limit on the Z' mass.

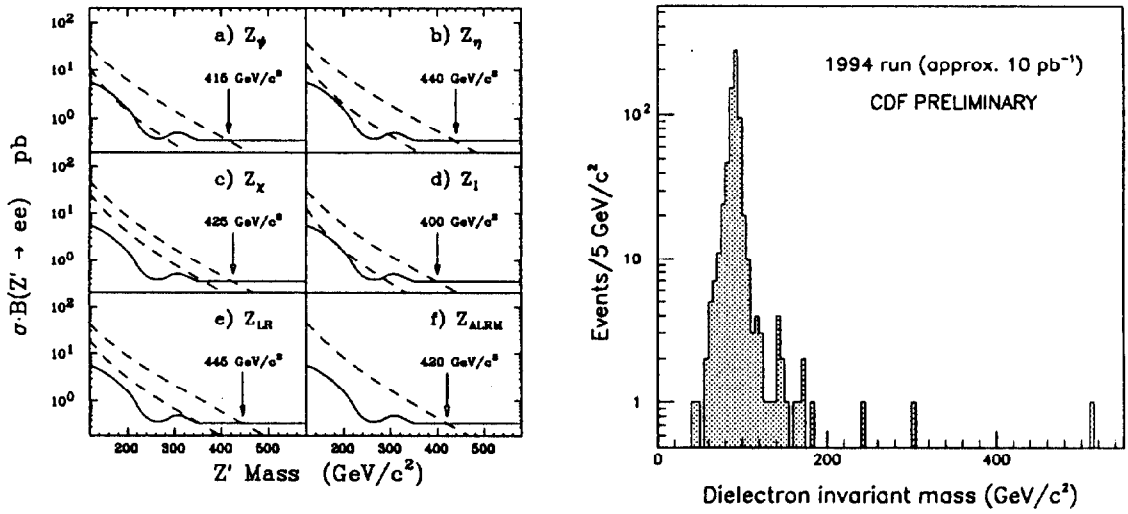

Figure 2: a) The 95% C.L. lower mass limit for five Z' models from the E_6 symmetry group and one from the Alternative Left-Right Model b) The dielectron invariant mass distribution from the current 1994 run.

Figure 2 a) shows our 95% C.L. limit curve (solid line) together with predictions from several E_6 models (dashed lines) and with the prediction of a right-handed Z' in an Alternative Left-Right Model (ALRM). In each plot the upper dashed curve corresponds to the model's prediction for Z' decaying only to known (SM) fermions. The lower dashed curve is the expectation for Z' decaying to all fermions (SM, supersymmetric, and exotic) that occur in the representations of the model. For these calculations we assume the masses of the supersymmetric and exotic fermions to be 200 and 45.5 GeV/c^2 respectively. For the ALRM case we only consider the new vector boson decaying to known fermions and to W pairs. From the intersections of the solid

and upper dashed curves in each plot we set the lower mass limits for Z_ψ, Z_η, Z_χ, Z_I, Z_{LR} and $Z_{\rm ALRM}$ to be 415, 440, 425, 400, 445, and 420 GeV/c^2, respectively.

Figure 2 b) shows the preliminary result, dielectron invariant mass distribution from the current 1994 CDF run, corresponding $\sim$ 10 pb^{-1}. We have observed one very high mass event, with $M_{ee} \sim 510$ GeV/c^2.

3. W' Search

To select W' candidate events, we require an electron in CEM with $E_T > 30$ GeV and an isolated track with $P_T > 13$ GeV/c measured in CTC. We also require HAD/EM of the electron candidate to be less than $0.055 + 0.045 * (E/100)$ where E is expressed in GeV. A transverse momentum imbalance is required to signal the presence of the noninteracting neutrino. We require $\not\!\!E_T > 30$ GeV, where the missing transverse momentum ($\not\!\!E_T$) is defined as the vector sum of the E_T in all calorimeter towers with $|\eta| < 3.6$. We also require $|Z_{int}| < 60$ cm and E_T(out-of-time) < 100 GeV, where E_T(out-of-time) is the total accidental calorimetry energy not in time with the $\overline{p}p$ collision measured by the timing in the hadron calorimeters. There are 10845 events passing above cuts. Of these, 82 events are removed as Z^0 candidates which have additional isolated tracks with $P_T > 10$ GeV/c pointing to electromagnetic clusters. Also, 229 events are removed as mismeasured QCD jet events. These events have clusters of CTC tracks pointing to calorimeter cracks and $\Delta\phi < 18°$, where $\Delta\phi$ is the angle between the total P_T of the cluster and the $\not\!\!E_T$ vector.

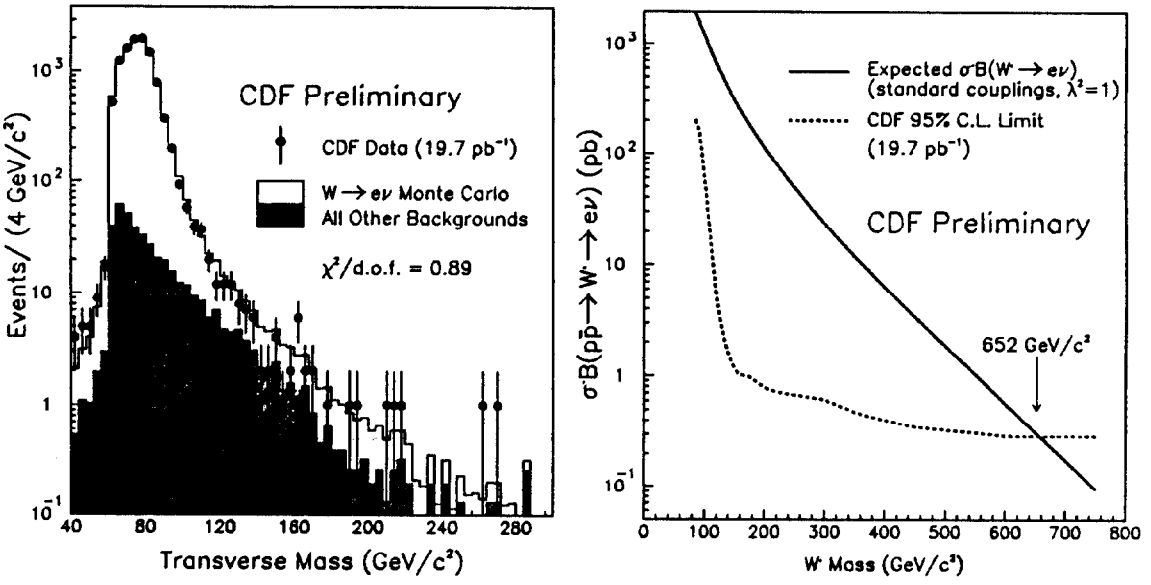

Figure 3: **a)** Transverse mass spectrum of the events in the W' search sample, along with the expected contributions from non-W backgrounds and from $W \to e\nu$ events. **b)** The 95% C.L. upper limit on $\sigma \cdot$ B($\overline{p}p \to W' \to e\nu$) (dashed line) and the prediction of $\sigma \cdot$ B (solid line) and using the MRS D$'_-$ p.d.f. and SM couplings. The intercept of the curves determines the lower mass limit, $M_{W'} > 652$ GeV/c^2.

Figure 3 a) shows the transverse mass distribution of the remaining 10534 events.

The transverse mass (M_T) is defined as $M_T = \sqrt{2E_T^e \not\!\!E_T(1 - cos(\Delta\phi))}$ where $\Delta\phi$ is the azimuthal angle between the electron and $\not\!\!E_T$. The primary background to the W' signal is $W \rightarrow e\nu$ decay. Several other processes can also mimic the W' signal. They are from Z^0, $W \rightarrow \tau\nu$, and QCD jet processes. The transverse mass distributions of the expected background events are also shown in Fig. 3 a). We observe 5 events with $M_T > 200$ GeV/c^2, while 7 events are expected from background processes. Event selection efficiency with all the cuts described above is found to be ~93% for $M_{W'} = 80$ to 600 GeV/c^2. The total efficiency of detecting $M_{W'}$, including the acceptance, is 20% at $M_{W'} = 80$ GeV/c^2 and ~ 52% (essentially constant) for $M_{W'} > 400$ GeV/c^2. The overall systematic uncertainty is 5%, including uncertainties due to detector acceptance (3%), efficiency of the event selection cuts (2%) and luminosity normalization (3.6%).

Limits on $\sigma \cdot \mathrm{B}(\bar{p}p \rightarrow W' \rightarrow e\nu)$ are placed using a binned likelihood fit as for the Z' analysis. The transverse mass spectrum is fit to the sum of three components: $W' \rightarrow e\nu$ decays, $W \rightarrow e\nu$ decays, and other backgrounds. The 95% C.L. upper limit on $\sigma \cdot \mathrm{B}(\bar{p}p \rightarrow W' \rightarrow e\nu)$ as a function of $M_{W'}$ is shown in Fig. 3 b). Also shown is the expected $\sigma \cdot \mathrm{B}$ assuming SM couplings and left-right symmetry, as calculated by the same Monte Carlo as used in the acceptance study. The Monte Carlo uses MRS D$'_-$ parton distribution functions. The intersection of the two curves set the mass limit, $M_{W'} > 652$ GeV/c^2 (95% C.L.).

4. Summary

We have presented a search for heavy neutral and charged gauge bosons via the decays $Z' \rightarrow ee$ and $W' \rightarrow e\nu$ in $\bar{p}p$ collisions at $\sqrt{s} = 1.8$ TeV. The data correspond to an integrated luminosity of 19.7±0.7 pb^{-1}. The observed dielectron invariant mass spectrum and transverse mass spectrum of electron E_T and $\not\!\!E_T$ are consistent with the Standard Model expectations. We obtain a 95% C.L. limit on $\sigma \cdot \mathrm{B}(\bar{p}p \rightarrow Z' \rightarrow ee)$ and $\sigma \cdot \mathrm{B}(\bar{p}p \rightarrow W' \rightarrow e\nu)$ as a function of $M_{Z'}$ and $M_{W'}$. Assuming Standard Model coupling strengths, we exclude a Z' with mass less than 505 GeV/c^2 (95% C.L.). In addition, we set Z' mass limits for several models based on the E_6 symmetry group and the Alternative Left-Right Model. We also exclude a W' with mass less than 652 GeV/c^2 (95% C.L.) with the assumption that the W' has SM couplings to fermions, the right-handed neutrino is noninteracting and stable, and has a mass much smaller than $M_{W'}$. The Z' search continues in the current 1994 run and a preliminary M_{ee} distribution for ~ 10 pb^{-1} is shown.

References

1. For large values of $M_{W'}$, left-right symmetry models supress the decay $W' \rightarrow WZ^0$. This search ignores the decay mode and also assumes the ν_R is noninteracting and stable, and has a mass much smaller than $M_{W'}$.
2. Z' search; CDF Collaboration, (K. Maeshima (Contact Person)), submitted as a contribution paper to ICHEP94 Glasgow (GLS0434); FERMILAB-Pub-94/198-E, submitted to Phy. Rev. Lett. (references therein).
3. W' search; CDF Collaboration, (S.E. Kopp (Contact Person)), submitted as a contribution paper to ICHEP94 Glasgow (GLS0411); to be submitted to Phys. Rev. Lett. (references therein).