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Search for Charged Bosons Heavier than the W in $p\bar{p}$ Collisions at $\sqrt{s}$=1800 GeV

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Abstract

We have searched for new, heavy, charged bosons, W', through the decay $W' \to e\nu$ in $p\overline{p}$ collisions at $\sqrt{s}$ = 1.8 TeV. The data used in the search represent 19.7 pb^{-1} collected by CDF at the Fermilab Tevatron Collider. Limits are placed on $\sigma \cdot B(p\overline{p} \to W' \to e\nu)$ as a function of $M_{W'}$. Assuming standard couplings of the W' to fermions, we establish the limit $M_{W'} > 652$ GeV/c^2 (95% C.L.).

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This paper presents a search for new, heavy, charged bosons, W', through the process $p\overline{p} \to W' \to e\nu$. In its simplest form, the W' appears as a heavier version of the left-handed W, which has a mass $M_W \approx 80$ GeV/c^2. In this case, the primary decay of the W' for very large masses is $W' \to WZ$. However, in extended gauge models,[1] proposed to restore left-right symmetry to the weak force, the right-handed W' can decay with large probability to right-handed $\ell_R \overline{\nu}_R$ pairs, since it is expected[2] that the coupling at the $W'WZ^0$ vertex is multiplied by a left-right mixing angle $\xi \sim \left(\frac{M_W}{M_{W'}}\right)^2$, thereby suppressing the decay $W' \to WZ^0$. This search assumes that the decay $W' \to WZ^0$ is suppressed and that the ν_R is sufficiently light that the process $W' \to \ell_R \overline{\nu}_R$ can occur.

The coupling of the W' to fermions, which determines the production cross section of the W' in $p\overline{p}$ collisions, is not known. Lorentz-invariance and renormalizability restrict the W'-fermion coupling to be of the form $\frac{ig}{2\sqrt{2}} \overline{\psi}_i(a+b\gamma_5)\gamma_\mu W^\mu \psi_j U_{ij}$, where a and b are constants and U_{ij} is the CKM matrix element connecting fermions i and j. $SU(2)_L$ gauge-invariance in the Standard Model leads to the V-A character of the weak interaction with $a = 1$, $b = -1$. In the Standard Model, furthermore, the CKM matrix is approximately diagonal: $U_L \sim 1$. No such constraints exist for a and b or for the right-handed CKM matrix in the context of extended gauge models. With this coupling the partial width to fermions is

$$\Gamma(W' \rightarrow f_i f_j) = \left(\frac{a^2 + b^2}{2}\right)\left(\frac{N_c G_F M_W^2 M_{W'}}{6\sqrt{2}\pi}\right) |U_{ij}|^2, \qquad [1]$$

where N_c is the color factor of 3 for quarks and is 1 for leptons. The case of "standard strength couplings," where $\lambda^2 \equiv \frac{1}{2}(a^2+b^2) = 1$, holds true in the Standard Model. It also holds in models in which the left- and right-handed gauge sectors couple to matter with equal strengths, known as left-right symmetry. Manifest left-right symmetry further implies $U_R = U_L$. The cross section limits in this paper assume $U_R = U_L$, and the mass limit further assumes $\lambda^2 = 1$.

Many previous searches have been conducted for the W'. For very light neutrino masses, the most stringent limits are astrophysical or cosmological (all 90% C.L. unless otherwise noted): for $m_\nu < 1\ MeV$ constraints from big bang nucleosynthesis[3] imply $M_{W'} > 1\ TeV$, and the energetics of Supernova 1987A can in some models imply[4] $M_{W'} > 16\ TeV$. Assuming manifest left-right symmetry, a limit of $M_{W'} > 1.3\ TeV$ has also been derived[5] using experimental data from muon decay,[6] the measured difference between the K_L and K_S masses,[7] the semileptonic branching ratio $b \rightarrow X\ell\nu$,[8] B_d-$\overline{B}_d$ mixing,[9] and neutrinoless atomic double beta decay.[10] Finally, direct searches for the decay $W' \rightarrow \ell\nu$ at $p\overline{p}$ colliders have established the limit[11] $M_{W'} > 520\ GeV/c^2$ (95% C.L.) for the case of manifest left-right symmetry.

We search for the W' in $p\overline{p}$ collisions through the decay $W' \rightarrow e\nu$. This search is specific to neither right- nor left-handed bosons, but in the case of the W_R' it is assumed that the ν_R is noninteracting and stable. It is not assumed that the ν_R is massless, only that it is much lighter than the W' (for $M_{W'} = 600\ GeV/c^2$ and $m_\nu = 60\ GeV/c^2$, for example, our cross section limit below is affected by < 1%, and the effect on the mass limit is negligible). We search for the signature of a new Jacobian peak in the transverse mass (defined below) spectrum of electron + missing transverse momentum data and set a limit on $\sigma \cdot B(p\ \overline{p} \rightarrow W' \rightarrow e\nu)$.

This search was conducted using a dataset with an integrated luminosity of $19.7 \pm 0.7\ pb^{-1}$ collected with the Collider Detector at Fermilab (CDF) during the 1992-1993 Tevatron collider run. Detailed descriptions of the detector can be found elsewhere.[12] The portions of the detector relevant to this search are (i) electromagnetic and hadronic calorimeters covering the pseudorapidity[13] range $|\eta| < 4.2$ and arranged in a projective tower geometry; (ii) a drift chamber (CTC) immersed in a 1.4 T solenoidal magnetic field for tracking charged particles in the range $|\eta| < 1.4$; (iii) a time-projection chamber (VTX) for vertex finding; and (iv) two arrays of scintillator hodoscopes located on either side of the detector for triggering and luminosity monitoring.

To select candidate events, we require an electron in the central, barrel region of the detector ($|\eta| < 1.05$) with $E_T > 30\ GeV$[14] and $P_T > 13\ GeV/c$, as measured in the CTC. In addition we require the electron track to be isolated in the CTC, requiring $Iso(trk) < 5\ GeV/c$, where $Iso(trk)$ is defined as the scalar sum of the P_T of all tracks except the electron track within a cone centered on the electron of half-angle $\Delta R = 0.25$ in η–ϕ space, where $\Delta R \equiv \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2}$. The ratio of energy in the hadron (Had) and electromagnetic (EM) calorimeter towers of the electron cluster is required to satisfy Had/EM $< 0.055 + 0.045 \times \left(\frac{E\ (\mathrm{GeV})}{100}\right)$ 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 negative of the vector sum of the E_T in all calorimeter towers with $|\eta| < 3.6$. Finally, the $p\overline{p}$ interaction point, which is distributed by an approximate gaussian with width $\sigma_Z = 26\ cm$ about the center of the detector, is required to satisfy $|Z_{int}| < 60$ cm and the total accidental calorimeter energy not in time with the $p\overline{p}$ collision (measured by the timing in the hadron calorimeters) is required to be E_T(out-of-time) $< 100\ GeV$. There are 10845 events passing these cuts. Of these, 82 events with second isolated, tracks with $P_T > 10\ GeV/c$ pointing to electromagnetic clusters are removed from the sample as Z^0 candidates. Also, 229 events with clusters of tracks in the CTC in which $\Delta\phi < 18°$, where $\Delta\phi$ is the angle between the tracks and the E_T vector, and in which the tracks point to calorimeter cracks, are removed from the search sample as mismeasured *QCD* jet events ("dijets"), leaving 10534 events.

From a study of electrons from $Z^0 \rightarrow e^+e^-$ decays, the efficiency of the isolation, Had/EM, out of time energy, and vertex cuts is found to be (95±2) % for $M_{W'} = 80\ GeV/c^2$. The Had/EM efficiency, furthermore, agrees well with the efficiency found from an electron testbeam and is observed to be flat up to $E \approx 175$ GeV. A Monte Carlo simulation of the detector shows no degradation in the Had/EM efficiency up to $E \approx 500\ GeV$. A Monte Carlo calculation[15] including radiative effects indicates that the isolation efficiency will drop by ~1% between $M_{W'} = 80$ and $600\ GeV/c^2$ due to conversions of photons radiated by W' electrons in the tracking volume. We estimate the efficiency of the Z^0 removal cuts for W' events to be (99.9±0.1)%, and the dijet removal cuts are estimated to be (99.5±0.2)% efficient for W' events.

The primary background to the W' signal is $W \rightarrow e\nu$ decay. Several other processes can also mimic the W' signal. The process $W \rightarrow \tau\nu \rightarrow e\nu\nu\nu$ has a signature similar to that of the W', but at much lower transverse mass. The process $Z^0 \rightarrow e^+e^-$, where one electron is detected and the other is lost because it falls into an uninstrumented region of the detector, can produce the signal of an electron and $\not{E}_T$, as can *QCD* dijet events, where one jet passes our electron selection criteria and the other is mismeasured or falls into an uninstrumented region of the calorimeter. We estimate the number of $Z^0 \rightarrow e^+e^-$ and $W \rightarrow \tau\nu$ decays contaminating the search sample using the ISAJET Monte Carlo program[16] and a detector simulation. We normalize to the measured[17] cross sections $\sigma \cdot B(p\overline{p} \rightarrow Z^0 \rightarrow e^+e^-)$ and $\sigma \cdot B(p\overline{p} \rightarrow W \rightarrow e\nu)$. We find that the number of Z^0 events remaining in the sample is 57 ± 17 events and the background from $W \rightarrow \tau\nu$ is 150 ± 45 events. The *QCD* dijet background is estimated[18] by studying a data sample of events with an "electron" + $\not{E}_T$, where the "electron" has $Iso(trk) > 6$ GeV/c. These events are presumably mismeasured dijets. We study the efficiency of our dijet removal cuts on this sample and normalize to the number (229) of events in the sample removed using these cuts. We estimate that the number of dijets left in the sample is 241 ± 40 events. After background subtraction, there are N_{cand} = 10086 eligible W plus W' candidates. Figure 1 shows the transverse mass distribution of the 10534 events and the expected contribution of the backgrounds, where $M_T \equiv \sqrt{2E_T^{ele} \not{E}_T(1-\cos(\Delta\phi))}$ and $\Delta\phi$ is the azimuthal angle between the electron and $\not{E}_T$. We observe 5 events with $M_T > 200$ GeV/c^2, while 2.2 events are expected from *QCD* dijet events and 4.8 events are expected from $W \rightarrow e\nu$ decays.

The acceptance, $A_{W'}$, is defined as the efficiency for W' events to pass the kinematic cuts on the electron and neutrino and for the electron to be in the fiducial region of the calorimeter. The acceptance is determined using a Monte Carlo program which generates W' events using the leading order diagram $q\overline{q} \rightarrow W'$, and decays the W' into an electron and a neutrino. We use the MRSD-' structure functions.[19] The effects of higher order diagrams for W' production are mimicked by giving the bosons P_T according to a previous measurement[20] of the P_T^W

spectrum. The dependence of the P_T spectrum with $M_{W'}$ is small.[21] The lepton momenta are passed through a simulation of the detector response. Systematic uncertainties in the acceptance calculation come from the choice of parton distribution functions (1.7%), the modeling of the detector response (1.3%), the effect of higher-order diagrams (0.8%),[22] and the uncertainty in the P_T^W distribution (0.6%). The total relative uncertainty in $A_{W'}$ is found to be 3%. The W' decay width used in the acceptance calculation is calculated from Equation 1, and includes the decay $W' \rightarrow t\bar{b}$ when kinematically allowed.[23] The W' acceptance for $M_{W'} = 80\ GeV/c^2$ is found to be $A_{W'} = 22\%$ and to increase with $M_{W'}$ to a plateau of 57% for $M_{W'} > 400\ GeV/c^2$. The difference in acceptances for left- and right-handed W' is negligible.

To determine a limit on $\sigma \cdot B(p\bar{p} \rightarrow W' \rightarrow e\nu)$, a binned log-likelihood fit to the transverse mass spectrum in Figure 1 is performed. 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 fraction of the data that is from W' decays is determined from the fit. The observed number of events, x_i, in each bin of the transverse mass spectrum is compared to the expectation, μ_i, per bin, where $\mu_i \equiv (N_{cand} - \alpha) W_i + \alpha W_i' + Bck_i$ and $N_{cand} = 10086$ is the number of candidates after background subtraction. Here, the background normalization is known bin-by-bin, and the normalization of the known W shape and the W' shape for a given W' mass is determined from the fit. The parameter α is required to lie in the range $(0.0 \leq \alpha \leq N_{cand})$.[24] The case $\alpha = 0$ corresponds to no W' events.

The probability function $P(\alpha)$ is computed for each W' mass, where $P(\alpha)$ is the probability of obtaining the value α as determined from the likelihood. The systematic uncertainties in the normalization from the acceptance, backgrounds, efficiencies, and luminosity and the systematic uncertainty in the M_T shape from the W P_T are used to "smear" the probability distribution $P(\alpha)$.[25] The 95% C.L. upper limit on the W' content in the data is obtained from the point α where $\int_0^{\alpha} \tilde{P}(\alpha')d\alpha' = 0.95$, where $\tilde{P}(\alpha)$ is the smeared probability distribution. For very high W' masses, where there are no events in the data, the fit returns a maximum allowed W' contribution of 3 events, as expected from Poisson statistics.

The 95% upper limit on the W' cross section times branching ratio is obtained using the 95% C.L. for α :

$$\sigma \cdot B\,(95\%\ \text{C.L.}) = \frac{\alpha\ (95\%)}{A_{W'} \varepsilon_{W'} \int \mathcal{L}\, dt} \qquad [2]$$

where α (95%) is determined from the fit, $\int \mathcal{L}\, dt$ is the integrated luminosity, $A_{W'}$ is the W' acceptance and $\varepsilon_{W'}$ is the efficiency. The 95% C.L. limit on the cross section times branching ratio as a function of the W' mass is shown in Figure 2. Also shown is the expected $\sigma \cdot B$ assuming standard couplings and $U_R = U_L$, as calculated by the same Monte Carlo as used in the acceptances. For the case of standard couplings to fermions, we establish the limit $M_{W'} > 652\ GeV/c^2$ (95% C.L.), the mass at which our cross section upper limit intersects with the theoretical prediction.

In conclusion, we have conducted a search for new charged bosons W' through the decay $W' \rightarrow e\nu$ in 19.7 pb^{-1} of $p\bar{p}$ collisions at $\sqrt{s} = 1800\ GeV$. Assuming that the W' has standard couplings to fermions, and assuming the right-handed neutrino is noninteracting, is stable, and has a mass below $M_{W'}$, the 95% C.L. limit $M_{W'} > 652\ GeV/c^2$ is obtained.

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References

[1] J. Pati and A. Salam, Phys. Rev. **D 11**, 566 and 2558 (1975); R.N. Mohapatra and J.C. Pati, Phys. Rev. **D 11**, 566 (1975); Phys. Rev. **D 11**, 2558 (1975); G. Senjanovic and R.N. Mohapatra, Phys. Rev. **D 12**, 1520 (1975).

[2] P. Ramond, Ann. Rev. Nucl. Part. Sci. **33**, 31 (1983).

[3] G. Stiegman, K.A. Olive, and D. Schramm, Phys. Rev. Lett. **43**, 239 (1979); Nucl. Phys. **B 180**, 497 (1981).

[4] R. Barbieri and R.N. Mohapatra, Phys. Rev. **D 39**, 1229 (1989); G. Raffelt and D. Seckel, Phys. Rev. Lett. **60**, 1793 (1988).

[5] For an excellent review, see P. Langacker and S. Uma Sankar, Phys. Rev. **D 40**, 1569 (1989).

[6] A.E. Jodidio *et al.*, Phys. Rev. **D 34**, 1967 (1986); *Erratum* Phys. Rev. **D 37**, 237 (1988); J. Imazato *et al.*, Phys. Rev. Lett. **69**, 877 (1992).

[7] G. Beal, M. Bander, and A. Soni, Phys. Rev. Lett. **48**, 848 (1982); F.I. Olness and M.E. Ebel, Phys. Rev. **D 30**, 1034 (1984).

[8] F.J. Gilman and M.H. Reno, Phys. Rev. **D 29**, 937 (1984).

[9] G. Altarelli and P. Franzini, Z. Phys. **C 37**, 271 (1988).

[10] R.N. Mohapatra, Phys. Rev. **D 34**, 909 (1986).

[11] F. Abe *et al.*, Phys. Rev. Lett. **67**, 2609 (1991).

[12] F. Abe *et al.*, Nucl. Instr. and Meth. **A 271**, 387 (1988).

[13] At CDF, cylindrical coordinates r, ϕ, and z, are used, where ϕ is the azimuthal angle and z points in the proton beam direction and is zero at the center of the detector. The pseudorapidity, η, is defined as $\eta \equiv -\ln(\tan(\theta/2))$, where θ is the angle with respect to the proton beam direction.

[14] The transverse energy is defined as $E_T = E \times \sin\theta$, where E is measured in the calorimeter

[15] R. G. Wagner (unpublished), based on calculations by F. Berends *et al.*, Z. Phys. **C27**, 155 (1985) and F. Berends and R. Kleiss, Z. Phys. **C27**, 365 (1985).

[16] F. Paige and S. D. Protopopescu, ISAJET Monte Carlo program, BNL Report No. BNL38034, 1986 (*unpublished*).

[17] F. Abe *et. al*, Phys. Rev. D 44, 29 (1991). The results of these measurements are scaled up by a factor of 1.109 to account for a correction to the luminosity determination at CDF (see Ref. [23]).

[18] S. Kopp, Ph.D. Thesis, The University of Chicago, 1994 (unpublished).

[19] A.D. Martin, R.G. Roberts, and W.J. Stirling, Phys. Lett. **306 B**, 145 (1993); *Erratum* Phys. Lett. **309 B**, 492 (1993).

[20] F. Abe *et al.*, Phys. Rev. Lett. **66**, 2951 (1991).

[21] P. Arnold and R. Kauffman, Nucl. Phys. **B349**, 381 (1991), and P. Arnold, private communication.

[22] We have compared our Monte Carlo with a next-to-leading order Monte Carlo written by W. Giele, D. Glover, and D. Kosower, Fermilab Preprint 92/230-T.

[23] Evidence for the top quark with mass $m_{top} = 174 \pm 17$ GeV/c^2 has recently appeared in F. Abe, *et al.*, Phys. Rev. Lett **73**, 225, (1994). Including this decay mode leads to a more conservative W' limit.

[24] M. Aguilar *et al.*, Particle Data Group, Phys. Lett. **B 204**, 1 (1988).

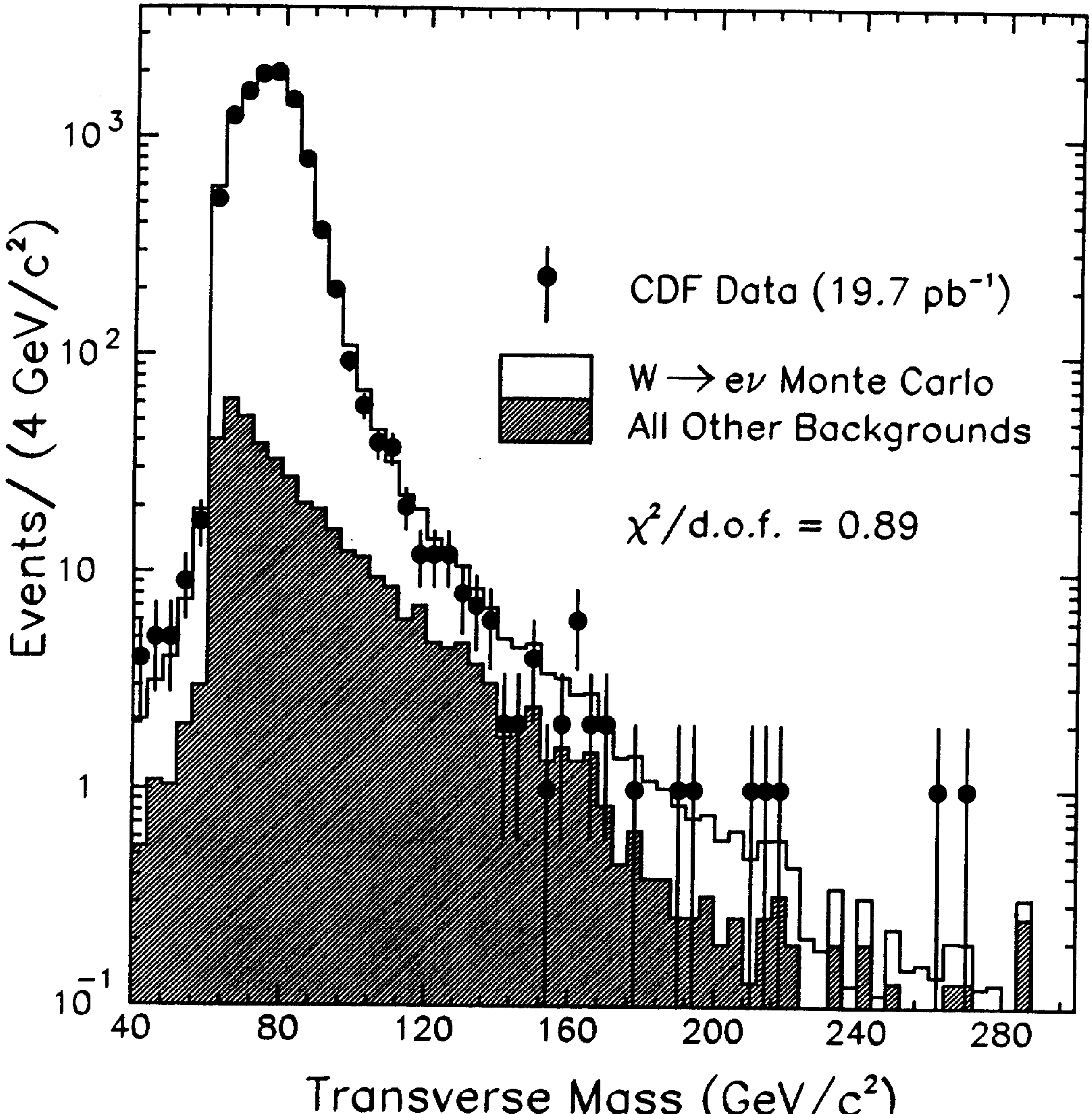
[25] This procedure is given in detail in F. Abe *et al.*, Phys. Rev. **D 43**, 664 (1991).

Figure Captions

Figure 1: Transverse mass spectrum of the events in the W' search sample, along with the expected contributions from backgrounds and from $W \rightarrow e\nu$ events. The $W \rightarrow e\nu$ curve is calculated with the Monte Carlo program used to calculate the W' acceptances.

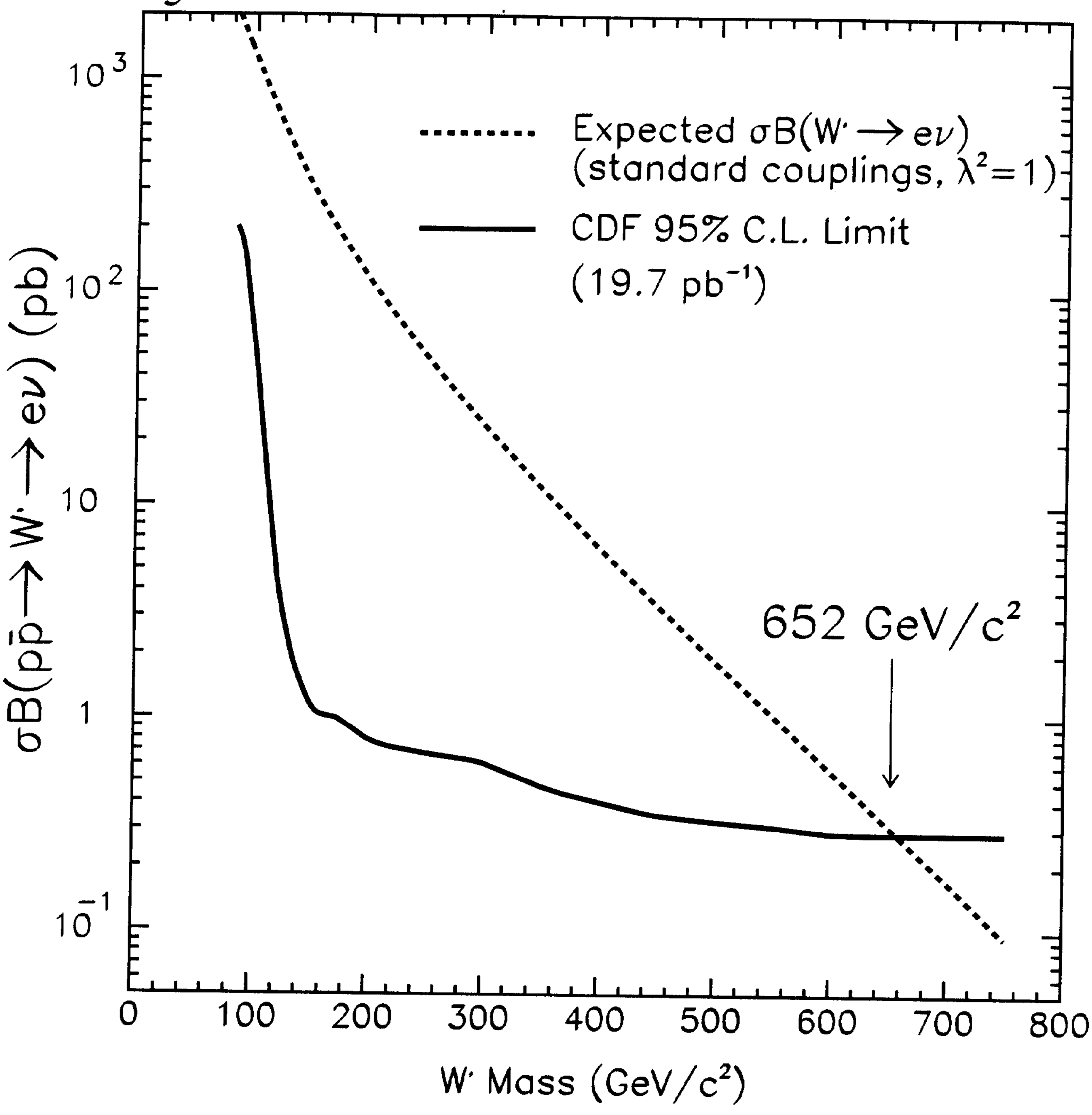
Figure 2: The 95% C.L. limit on $\sigma \cdot B(p\bar{p} \rightarrow W' \rightarrow e\nu)$ v.s. the W' mass. Also shown is the expected $\sigma \cdot B$, assuming standard couplings. The point $M_{W'}$ = 652 GeV/c^2 is our limit, assuming standard couplings.

Figure 1



CDF Data (19.7 pb⁻¹)
W → eν Monte Carlo
All Other Backgrounds
χ²/d.o.f. = 0.89
Events/ (4 GeV/c²)
Transverse Mass (GeV/c²)
10³
10²
10
1
10⁻¹
40
80
120
160
200
240
280

Figure 2



Expected σB(W' → eν)
(standard couplings, λ²=1)
CDF 95% C.L. Limit
(19.7 pb⁻¹)
652 GeV/c²
σB(pp̄ → W' → eν) (pb)
W' Mass (GeV/c²)
10³
10²
10
1
10⁻¹
0
100
200
300
400
500
600
700
800