Search for New Particles Decaying into $b\bar{b}$ and Produced in Association with W Bosons Decaying into $e\nu$ or $\mu\nu$ at the Fermilab Tevatron

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Hylen,[7] H. Ikeda,[36] M. Incagli,[27] J. Incandela,[7] G. Introzzi,[27] J. Iwai,[36] Y. Iwata,[12] H. Jensen,[7] U. Joshi,[7] R. W. Kadel,[18] E. Kajfasz,[25] H. Kambara,[10] T. Kamon,[34] T. Kaneko,[36] K. Karr,[37] H. Kasha,[39] Y. Kato,[24] T. A. Keaffaber,[29] K. Kelley,[19] R. D. Kennedy,[7] R. Kephart,[7] P. Kesten,[18] D. Kestenbaum,[11] H. Keutelian,[7] F. Keyvan,[4] B. Kharadia,[13] B. J. Kim,[30] D. H. Kim,[7,*] H. S. Kim,[14] S. B. Kim,[20] S. H. Kim,[36] Y. K. Kim,[18] L. Kirsch,[3] P. Koehn,[23] K. Kondo,[36] J. Konigsberg,[8] S. Kopp,[5] K. Kordas,[14] A. Korytov,[8] W. Koska,[7] E. Kovacs,[7,*] W. Kowald,[6] M. Krasberg,[20] J. Kroll,[7] M. Kruse,[30] S. E. Kuhlmann,[1] E. Kuns,[32] T. Kuwabara,[36] A. T. Laasanen,[29] S. Lami,[27] S. Lammel,[7] J. I. Lamoureux,[3] M. Lancaster,[18] M. Lanzoni,[27] G. Latino,[27] T. LeCompte,[1] S. Leone,[27] J. D. Lewis,[7] P. Limon,[7] M. Lindgren,[4] T. M. Liss,[13] J. B. Liu,[30] Y. C. Liu,[33] N. Lockyer,[26] O. Long,[26] C. 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(Received 15 July 1997)

We search for new particles that decay into $b\overline{b}$ and are produced with W bosons in $p\overline{p}$ collisions at $\sqrt{s} = 1.8$ TeV. The search uses 109 ± 7 pb^{-1} accumulated by the CDF experiment at Fermilab. We select events with an $e\nu$ or $\mu\nu$, and two jets, one of them b tagged. The number of events and the two-jet mass distribution are consistent with expectations. Using W + Higgs production as a model for the acceptance, we set an upper limit on the production cross section times branching ratio for the new particle ranging from 14 to 19 pb (95% C.L.) as the particle mass varies from 70 to 120 GeV/c^2. [S0031-9007(97)04545-6]

PACS numbers: 13.85.Qk, 13.38.Be, 13.85.Rm, 14.80.–j

For several decades, the standard model has been remarkably successful in explaining and predicting experimental data. However, the mechanism of electroweak symmetry breaking is still not known. The two most popular mechanisms to induce spontaneous symmetry breaking of a gauge theory, resulting in the gauge bosons and fermions acquiring masses, are the Higgs mechanism [1] and the dynamics of a new interaction such as Technicolor [2]. Both mechanisms predict the existence of a new particle X with unknown mass which could be produced at the Tevatron through $p\overline{p} \to WX$ with a production cross section of the order of 0.1 to 10 pb. In this Letter, we present a search for new particles that decay into $b\overline{b}$ and are produced in association with a W boson in $p\overline{p}$ collisions at $\sqrt{s} = 1.8$ TeV. The search is based on 109 ± 7 pb^{-1} of data accumulated by the CDF experiment at Fermilab Tevatron from 1992 through 1995.

The experimental signature considered is WX with $W \to e\nu$ or $\mu\nu$, and $X \to b\overline{b}$, giving final states with one high-P_T lepton, large missing transverse energy ($\not\!\!E_T$) due to the undetected neutrino and two b jets [3]. The ability to tag b jets with high efficiency and a low mistag rate is vital for searching for the decay of $X \to b\overline{b}$. We use the secondary vertex (SECVTX) and soft-lepton (SLT) b-tagging algorithms developed for the top quark discovery [4].

The CDF detector consists of a magnetic spectrometer surrounded by calorimeters and muon chambers [5]. A four-layer silicon vertex detector [6], located immediately outside the beam pipe, provides precise track reconstruction in the plane transverse to the beam and is used to identify secondary vertices from b and c hadron decays. The momenta of charged particles are measured in the central tracking chamber (CTC), which is inside a 1.4-T superconducting solenoid. Outside the CTC, electromagnetic and hadronic calorimeters are segmented in projective towers in the pseudorapidity region $|\eta| < 4.2$ [3] and are used to identify electron candidates and jets. The calorimeters are also used to measure the missing transverse energy ($\not\!\!E_T$), which can indicate the presence of energetic neutrinos. Outside the calorimeters, drift chambers in the region $|\eta| < 1.0$ provide muon identification. A three-level trigger selects events that contain an electron or a muon for this analysis.

The event selection for the search starts with the requirement of a primary lepton, either an isolated electron with $E_T > 20$ GeV or an isolated muon with $P_T > 20$ GeV/c, in the central region ($|\eta| < 1.0$) [7]. A W boson sample is selected by requiring $\not\!\!E_T > 20$ GeV. Events which contain a second, same-flavor lepton with $P_T > 10$ GeV/c are removed as possible Z boson candidates if the reconstructed ee or $\mu\mu$ invariant mass is between 75 and 105 GeV/c^2. The events must also not be accepted by the CDF top dilepton analysis [4]. To further reduce the dilepton backgrounds, we reject events with an additional high-P_T isolated track ($P_T > 15$ GeV/c) with opposite charge to that of the primary lepton [8]. The remaining events are classified according to jet multiplicity. A jet is defined as a cluster of E_T-weighted calorimeter towers within a fixed radius $\Delta R = \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2} = 0.4$, and is required to have an observed $E_T > 15$ GeV and $|\eta| < 2.0$. The $W + 2$ jet bin is expected to contain most of the signal, while the other bins are used to check the background calculation.

In order to enhance the signal in the $W + 2$ jet bin, we require that one or both of the jets be identified ("tagged") as coming from a b hadron. We require at least one jet to be tagged by the SECVTX algorithm, which has a higher signal-to-noise ratio than the SLT algorithm. For the single-tag analysis, the other jet must not be tagged, while for the double-tag analysis the second jet must be tagged by either the SECVTX algorithm or the SLT algorithm.

The SECVTX tagging algorithm begins by searching for secondary vertices that contain three or more displaced tracks. If none is found, the algorithm searches for two-track vertices using more stringent track criteria. A jet is declared tagged if it contains a secondary vertex with a transverse displacement from the primary vertex (L_{xy}) divided by the measurement uncertainty (σ) satisfying $L_{xy}/\sigma > 3$.

The SLT tagging algorithm identifies electrons and muons from semileptonic b decays by matching CTC tracks with $P_T > 2$ GeV/c with clusters of electromagnetic energy in the calorimeters or tracks in the muon chambers. To gain additional background rejection, we require the SLT track to lie within $\Delta R < 0.4$ of the axis of a jet and to be displaced in the transverse plane from the primary vertex by at least two standard deviations in the jet direction ("positive signed impact parameter"). This latter requirement reduces lepton misidentifications by a factor of 5 while retaining 65% of the efficiency.

The acceptance for identifying WX events is calculated from data and a standard model simulation of Higgs production [9] via $W^* \to WH^0 \to Wb\overline{b}$, where the Higgs is forced to decay into $b\overline{b}$ with a 100% branching ratio. This is done as a function of the Higgs mass (M_{H^0}) using the selection cuts described above. The lepton identification efficiencies are measured from $Z \to \ell^+\ell^-$ events to be $92 \pm 1\%$ for muons and $82 \pm 1\%$ for electrons. The trigger efficiency is determined from a combination of data and simulation to be $81.5 \pm 8.0\%$ for muons and $99.8 \pm 0.2\%$ for electrons. The SECVTX and SLT b-tagging efficiencies are obtained from a combination of data and Monte Carlo calculations [4];

for a Higgs mass of 110 GeV/c^2, the probability of a single SECVTX tag is 25 ± 2%, of a double SECVTX tag is 8.2 ± 1.3%, and of a SECVTX-SLT double tag is 2.2 ± 0.2%. The total acceptance is calculated as a product of the kinematic and geometric acceptance, the lepton identification efficiency, the trigger efficiency, the b-tagging efficiency, and the W leptonic branching ratios. A 25% systematic uncertainty in the acceptance comes from uncertainties in the modeling of initial and final state radiation (20%), jet energy (10%), b-tag efficiency (8%), average electron and muon trigger efficiency (5%), and lepton identification (5%). The acceptance increases monotonically from 0.53 ± 0.13% (0.17 ± 0.04%) to 1.1 ± 0.3% (0.42 ± 0.11%) for single (double) tagging as M_{H^0} increases from 70 to 120 GeV/c^2.

Background events come predominantly from the direct production of W bosons in association with heavy quarks ($Wb\bar{b}, Wc\bar{c}, Wc$), mistags due to track mismeasurements, and $t\bar{t}$ and single top production ($W^* \rightarrow tb, gW \rightarrow tb$) [10]. Other small backgrounds include $b\bar{b}$, diboson (WW or WZ) and Drell-Yan lepton pair production, and $Z \rightarrow \tau^+\tau^-$ decays. To determine the number of mistags we first parametrize the mistag rate in an inclusive jet sample [4] as a function of jet E_T and track multiplicity. We apply this to the W + jets sample to estimate the expected number of mistagged events. To estimate the W plus heavy quark backgrounds, we use the HERWIG [11] Monte Carlo program to calculate, in each jet multiplicity bin, the fraction of W + jet events that contain heavy quarks and the corresponding tagging efficiencies. The number of background events in a given jet multiplicity bin is then obtained as the product of these quantities times the observed number of W + jet events corrected for contributions from top production and other small backgrounds. The top quark contributions ($t\bar{t}$ and single top) are estimated with HERWIG and PYTHIA [9] Monte Carlo calculations, using the CDF measured cross section ($\sigma_{t\bar{t}} = 7.5^{+1.9}_{-1.6}$ pb) [12] and a theoretical calculation of single top production ($\sigma_{W^*\rightarrow tb} = 0.74 \pm 0.05$ pb and $\sigma_{gW\rightarrow tb} = 1.8 \pm 0.5$ pb) [10], for a top quark mass of 175 GeV/c^2. The other small backgrounds are estimated from a combination of Monte Carlo simulations and data.

The numbers of observed single-tagged and double-tagged events and the corresponding background estimates are shown in Table I. By construction, data and expectations are in reasonably good agreement in the W + ≥3 jet bins, which, along with other $t\bar{t}$ decay channels, were used to measure the $t\bar{t}$ production cross section [12]. The number of b tags in the W + 1 and 2 jet bins can be compared to the background calculation. The W + 2 jet bin shows a small excess of single-tagged and double-tagged events. Using a Monte Carlo simulation that accounts for the correlations among tags, we compute a probability that the expected number of single-tagged events fluctuates to 36 or more and that of double-tagged events to 6 or more. This probability is found to correspond to one standard deviation.

To increase the sensitivity of the search, we look for a resonant mass peak in the reconstructed two-jet invariant mass distribution using the 4-momenta of jets as measured by the calorimeter, corrected for detector effects [13]. The distributions for single-tagged and double-tagged events are shown in Fig. 1, along with the background expectation. The two-jet mass distributions from the various QCD backgrounds ($Wb\bar{b}$, $Wc\bar{c}$, Wc, mistags, and other small backgrounds) are similar, while top production yields a distribution shifted towards higher masses. The single-tag data show a slight excess of events at higher two-jet mass but there is no mass peak as would be expected from the two-body decay of a new particle. The expected two-jet invariant mass distribution for standard model WH^0 production followed by the decay $H^0 \rightarrow b\bar{b}$, obtained using the PYTHIA Monte Carlo program and a full detector simulation, is shown in Fig. 2 for M_{H^0} = 110 GeV/c^2.

TABLE I. The predicted numbers of tagged $W + n$ jet events from QCD backgrounds ($Wb\bar{b}$, $Wc\bar{c}$, mistags, Wc, and other small backgrounds) and top production ($t\bar{t}$ and single top) and the number of events observed.

	W + 1 jet	W + 2 jet	W + 3 jet	W + ≥4 jet
Before tagging	10 135	1527	232	67
Events with single tag				
QCD	65 ± 13	22.4 ± 4.5	4.9 ± 1.1	1.4 ± 0.4
Top	2.2 ± 0.7	7.2 ± 1.4	11.0 ± 1.7	11.6 ± 3.0
QCD + top	67 ± 13	30 ± 5	16 ± 2	13 ± 3
Observed (e + jets)	36	22	4	5
Observed (μ + jets)	30	14	7	7
Events with double tag				
QCD	0	1.6 ± 0.4	0.3 ± 0.1	0.15 ± 0.03
Top	0	1.4 ± 0.4	3.3 ± 0.5	5.0 ± 1.1
QCD + top	0	3.0 ± 0.6	3.6 ± 0.6	5.2 ± 1.1
Observed (e + jets)	0	2	3	2
Observed (μ + jets)	0	4	3	0

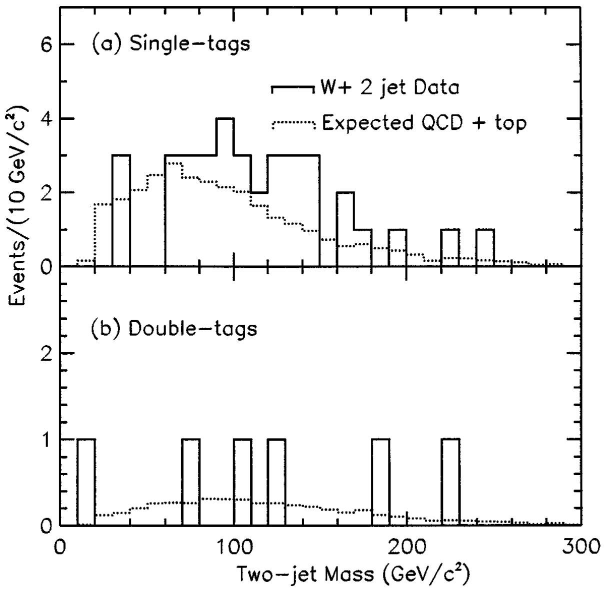

FIG. 1. The measured two-jet mass distribution in data along with background expectations from (a) single-tagged events and (b) double-tagged events.

We set an upper limit on the production cross section times branching ratio of $p\overline{p} \rightarrow WX$ as a function of the mass of X by using the numbers of events in the $W + 2$ jet samples and the shape of the two-jet mass distributions. We assume the single-tagged and double-tagged two-jet mass distributions consist of QCD, top, and WX events. We then use a binned maximum-likelihood technique to estimate the number of WX signal events by constraining the numbers of QCD and top events to the expected values, within the statistical and systematic uncertainties on the acceptance and background calculations. The expected number of events (μ) in each mass bin is

$$\mu = f_{QCD}N_{QCD} + f_{top}N_{top} + f_{WX}[\epsilon \mathcal{L}\, \sigma_{WX}B(X \rightarrow b\overline{b})],$$

where f_{QCD}, f_{top}, and f_{WX} are the expected fractions of events in a given mass bin predicted by Monte Carlo calculations, and N_{QCD}, N_{top}, ϵ, $\mathcal{L}$, and $\sigma_{WX}B(X \rightarrow b\overline{b})$ are, respectively, the expected numbers of QCD and top events, and the detection efficiency, integrated luminosity, and unknown WX production cross section times branching ratio of X decaying into $b\overline{b}$. The likelihood is

$$L = G(\mathcal{L}; \overline{\mathcal{L}}, \sigma_{\mathcal{L}})G(N_{QCD}; \overline{N}_{QCD}, \sigma) \times G(N_{top}; \overline{N}_{top}, \sigma)G(\epsilon; \overline{\epsilon},)T_{single}T_{double}\,,$$

where T_{single} and T_{double} are of the form $T = \prod_i P(N_i; \mu)$. Here $G(x; \overline{x}, \sigma)$ is Gaussian in x, with mean $\overline{x}$ and width σ, and $P(n; \mu)$ is the Poisson probability for n observed events with expected mean μ.

The fit yields $\sigma_{WX}B(X \rightarrow b\overline{b})$ in the range from $0.2^{+4.7}_{-0.0}$ to $5.7^{+4.2}_{-3.0}$ pb for a new particle of mass between 70 and 120 GeV$/c^2$, statistically compatible with no signal. The corresponding 95% confidence level upper limits range from 14 to 19 pb and are shown in Fig. 3. We have studied additional systematic effects, including uncertainties in the b-jet energy corrections and the $Wb\overline{b}$

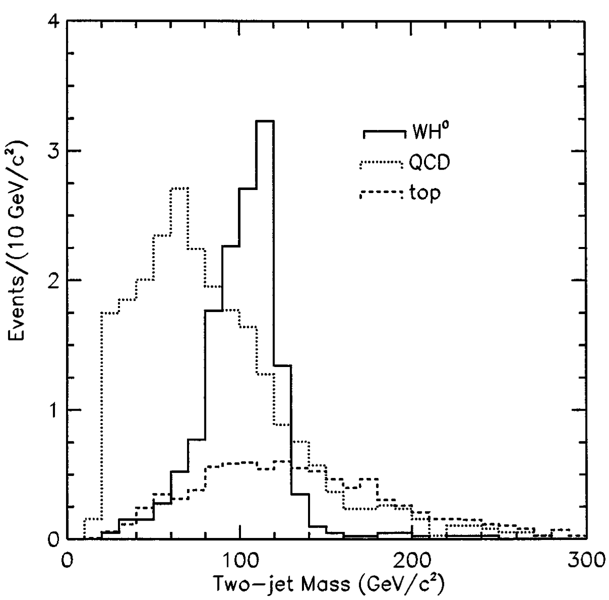

FIG. 2. The expected sum of single- and double-tagged two-jet mass distributions from QCD (dotted), 175 GeV$/c^2$ top (dashed), and standard model WH^0 production (solid) with $M_{H^0} = 110$ GeV$/c^2$. The WH^0 distribution has been scaled up by a factor of 50.

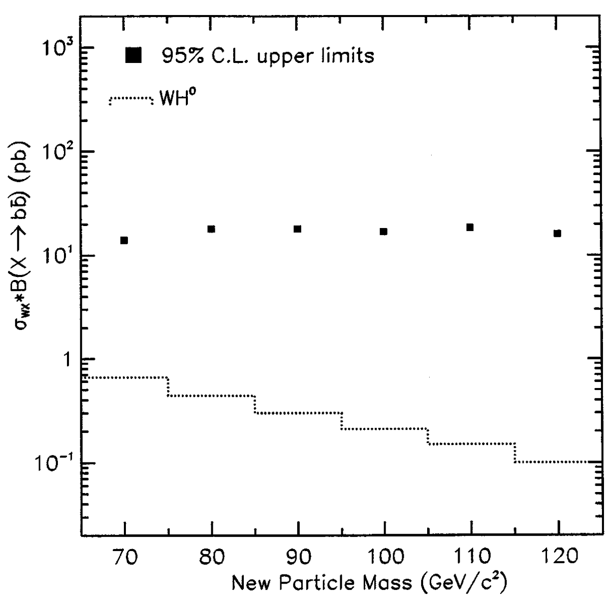

FIG. 3. The 95% C.L. upper limit (filled squares) on the WX production cross section times branching ratio of X decaying into $b\overline{b}$ as a function of new particle mass. Also shown is the theoretical cross section (dotted) for the production of a standard model Higgs boson in association with a W boson.

and $t\bar{t}$ two-jet mass spectra; these have a negligible effect on the upper limits.

The sensitivity of the present search is limited by statistics to a cross section approximately 2 orders of magnitude higher than the predicted cross section for standard model Higgs production [14], although comparable to some models of Technicolor production [15]. Additional sensitivity can be obtained in the channel in which the vector boson decays hadronically. An analysis of this channel is in preparation. For the next Collider run, we hope for a factor of 2 improvement in the double b-tagging efficiency and an approximately 20-fold increase in total integrated luminosity.

In conclusion, we have performed a search for new particles that decay into $b\bar{b}$ and are produced in association with a W boson at CDF. The two-jet mass spectrum shows no significant peak for either single- or double-tagged events. Using standard model WH^0 production as a model, we set a 95% confidence level upper limit in the range from 14 to 19 pb on the production cross section times branching ratio for new particles of mass between 70 and 120 GeV/c^2.

We thank the Fermilab staff and the technical staffs of the participating institutions for their contributions. This work was supported by the U.S. Department of Energy and National Science Foundation, the Italian Istituto Nazionale di Fisica Nucleare, the Ministry of Science, Culture, and Education of Japan, the Natural Sciences and Engineering Research Council of Canada, the National Science Council of the Republic of China, and the A. P. Sloan Foundation.

*Visitor.

[1] J. Gunion *et al.*, *The Higgs Hunter's Guide* (Addison-Wesley, New York, 1990).
[2] E. Eichten and K. Lane, Phys. Lett. B **388**, 803 (1996).
[3] In the CDF coordinate system, θ and ϕ are the polar and azimuthal angles, respectively, with respect to the proton beam direction. The pseudorapidity η is defined as $-\ln(\tan\frac{\theta}{2})$. The transverse momentum of a particle with momentum P is $P_{\mathrm{T}} = P\sin\theta$. The analogous quantity using energy, defined as $E_{\mathrm{T}} = E\sin\theta$, is called transverse energy. The missing transverse energy $\not{E}_{\mathrm{T}}$ is defined as $|-\Sigma E_{\mathrm{T}}^i \hat{r}_i|$, where $\hat{r}_i$ is a unit vector in the transverse plane pointing to the center of calorimeter cell i and E_{T}^i is the transverse energy deposited in that cell.
[4] F. Abe *et al.*, Phys. Rev. Lett. **74**, 2626 (1995).
[5] F. Abe *et al.*, Nucl. Instrum. Methods Phys. Res., Sect. A **271**, 387 (1988).
[6] D. Amidei *et al.*, Nucl. Instrum. Methods Phys. Res., Sect. A **350**, 73 (1994).
[7] The lepton isolation (I_{cal}) is defined by the additional energy deposited in a calorimeter cone of radius $\Delta R = \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2} = 0.4$ around the lepton. We require I_{cal} to be less than 10% of the lepton momentum.
[8] The track isolation requirement is that the sum P_{T} of all tracks be less than 2.0 GeV/c in a cone of radius $\Delta R = \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2} = 0.4$ around, but excluding, the candidate track.
[9] PYTHIA version 5.7, T. Sjöstrand, Comput. Phys. Commun. **82**, 74 (1994).
[10] M. Smith and S. Willenbrock, Phys. Rev. D **54**, 6696 (1996); T. Stelzer and S. Willenbrock, Phys. Lett. B **337**, 125 (1995).
[11] HERWIG version 5.6, G. Marchesini and B. Webber, Nucl. Phys. **B310**, 461 (1988).
[12] D. Gerdes, in *Proceedings of the XXXIInd Rencontres de Morriond, Electroweak Interactions and Unified Theories, Les Arcs, Savoie, France, March 15–22, 1997*, FERMILAB-CONF-97-166-E.
[13] F. Abe *et al.*, Phys. Rev. D **45**, 1448 (1992).
[14] M. Smith and S. Willenbrock (private communication).
[15] K. Lane (private communication); E. Eichten, K. Lane, and J. Womersley, FERMILAB-PUB-97-116-T.