Lower Limit on the Top-Quark Mass from Events with Two Leptons in $p\bar{p}$ Collisions at $\sqrt{s}=1.8$ TeV

F. Abe,[9] D. Amidei,[4] G. Apollinari,[16] M. Atac,[4] P. Auchincloss,[15] A. R. Baden,[6] N. Bacchetta,[11] M. W. Bailey,[14] A. Bamberger,[4],[a] B. A. Barnett,[8] A. Barbaro-Galtieri,[10] V. E. Barnes,[14] T. Baumann,[6] F. Bedeschi,[13] S. Behrends,[2] S. Belforte,[13] G. Bellettini,[13] J. Bellinger,[21] D. Benjamin,[20] J. Bensinger,[2] A. Beretvas,[4] J. P. Berge,[4] S. Bertolucci,[5] S. Bhadra,[7] M. Binkley,[4] R. Blair,[1] C. Blocker,[2] V. Bolognesi,[13] A. W. Booth,[4] C. Boswell,[8] G. Brandenburg,[6] D. Brown,[6] E. Buckley-Geer,[17] H. S. Budd,[15] G. Busetto,[11] A. Byon-Wagner,[4] K. L. Byrum,[21] C. Campagnari,[3] M. Campbell,[3] A. Caner,[4] R. Carey,[6] W. Carithers,[10] D. Carlsmith,[21] J. T. Carroll,[4] R. Cashmore,[4],[a] A. Castro,[11] F. Cervelli,[13] K. Chadwick,[4] G. Chiarelli,[5] W. Chinowsky,[10] S. Cihangir,[4] A. G. Clark,[4] D. Connor,[12] M. Contreras,[2] J. Cooper,[4] M. Cordelli,[5] D. Crane,[4] M. Curatolo,[5] C. Day,[4] F. DeJongh,[4] S. Dell'Agnello,[13] M. Dell'Orso,[13] L. Demortier,[2] B. Denby,[4] P. F. Derwent,[3] T. Devlin,[17] D. DiBitonto,[18] M. Dickson,[15] R. B. Drucker,[10] K. Einsweiler,[10] J. E. Elias,[4] R. Ely,[10] S. Eno,[3] S. Errede,[7] B. Esposito,[5] B. Flaugher,[4] G. W. Foster,[4] M. Franklin,[6] J. Freeman,[4] H. Frisch,[3] T. Fuess,[4] Y. Fukui,[9] Y. Funayama,[19] A. F. Garfinkel,[14] A. Gauthier,[7] S. Geer,[4] D. W. Gerdes,[3] P. Giannetti,[13] N. Giokaris,[16] P. Giromini,[5] L. Gladney,[12] M. Gold,[10] K. Goulianos,[16] H. Grassmann,[11] C. Grosso-Pilcher,[3] C. Haber,[10] S. R. Hahn,[4] R. Handler,[21] K. Hara,[19] R. M. Harris,[4] J. Hauser,[4] C. Hawk,[17] T. Hessing,[18] R. Hollebeek,[12] L. Holloway,[7] P. Hu,[17] B. Hubbard,[10] B. T. Huffman,[14] R. Hughes,[12] P. Hurst,[5] J. Huth,[4] J. Hylen,[4] M. Incagli,[13] T. Ino,[19] H. Iso,[19] H. Jensen,[4] C. P. Jessop,[6] R. P. Johnson,[4] U. Joshi,[4] R. W. Kadel,[10] T. Kamon,[18] S. Kanda,[19] D. A. Kardelis,[7] I. Karliner,[7] E. Kearns,[6] L. Keeble,[18] R. Kephart,[4] P. Kesten,[2] R. M. Keup,[7] H. Keutelian,[4] D. Kim,[4] S. Kim,[19] L. Kirsch,[2] K. Kondo,[19] J. Konigsberg,[6] E. Kovacs,[4] S. E. Kuhlmann,[1] E. Kuns,[17] A. T. Laasanen,[14] J. I. Lamoureux,[21] S. Leone,[13] W. Li,[1] T. M. Liss,[7] P. Limon,[4] N. Lockyer,[12] C. B. Luchini,[7] P. Lukens,[4] P. Maas,[21] K. Maeshima,[4] M. Mangano,[13] J. P. Marriner,[4] M. Mariotti,[13] R. Markeloff,[21] L. A. Markosky,[21] R. Mattingly,[2] P. McIntyre,[18] A. Menzione,[13] T. Meyer,[18] S. Mikamo,[9] M. Miller,[3] T. Mimashi,[19] S. Miscetti,[5] M. Mishina,[9] S. Miyashita,[19] Y. Morita,[19] S. Moulding,[2] J. Mueller,[17] A. Mukherjee,[4] L. F. Nakae,[2] I. Nakano,[19] C. Nelson,[4] C. Newman-Holmes,[4] J. S. T. Ng,[6] M. Ninomiya,[19] L. Nodulman,[1] S. Ogawa,[19] R. Paoletti,[13] A. Para,[4] E. Pare,[6] S. Park,[4] J. Patrick,[4] T. J. Phillips,[6] F. Ptohos,[6] R. Plunkett,[4] L. Pondrom,[21] J. Proudfoot,[1] G. Punzi,[13] D. Quarrie,[4] K. Ragan,[12] G. Redlinger,[3] J. Rhoades,[21] M. Roach,[20] F. Rimondi,[4],[a] L. Ristori,[13] T. Rohaly,[12] A. Roodman,[3] W. K. Sakumoto,[15] A. Sansoni,[5] R. D. Sard,[7] A. Savoy-Navarro,[4] V. Scarpine,[7] P. Schlabach,[6] E. E. Schmidt,[4] O. Schneider,[10] M. H. Schub,[14] R. Schwitters,[6] A. Scribano,[13] S. Segler,[4] Y. Seiya,[19] M. Sekiguchi,[19] M. Shapiro,[10] N. M. Shaw,[14] M. Sheaff,[21] M. Shochet,[3] J. Siegrist,[10] P. Sinervo,[12] J. Skarha,[8] K. Sliwa,[20] D. A. Smith,[13] F. D. Snider,[8] L. Song,[12] M. Spahn,[10] R. St. Denis,[6] A. Stefanini,[13] G. Sullivan,[3] R. L. Swartz, Jr.,[7] M. Takano,[19] F. Tartarelli,[13] K. Takikawa,[19] S. Tarem,[2] D. Theriot,[4] M. Timko,[18] P. Tipton,[4] S. Tkaczyk,[4] A. Tollestrup,[4] J. Tonnison,[14] W. Trischuk,[6] N. Turini,[13] Y. Tsay,[3] F. Ukegawa,[19] D. Underwood,[1] S. Vejcik, III,[8] R. Vidal,[4] R. G. Wagner,[1] R. L. Wagner,[4] N. Wainer,[4] J. Walsh,[12] T. Watts,[17] R. Webb,[18] C. Wendt,[21] H. Wenzel,[13] W. C. Wester, III,[10] T. Westhusing,[13] S. N. White,[16] A. B. Wicklund,[1] H. H. Williams,[12] B. L. Winer,[15] J. Wyss,[11] A. Yagil,[4] A. Yamashita,[19] K. Yasuoka,[19] G. P. Yeh,[4] J. Yoh,[4] M. Yokoyama,[19] J. C. Yun,[4] A. Zanetti,[13] F. Zetti,[13] and S. Zucchelli[4],[a]

(CDF Collaboration)

[1]*Argonne National Laboratory, Argonne, Illinois 60439*
[2]*Brandeis University, Waltham, Massachusetts 02254*
[3]*University of Chicago, Chicago, Illinois 60637*
[4]*Fermi National Accelerator Laboratory, Batavia, Illinois 60510*
[5]*Laboratori Nazionali di Frascati, Istituto Nazionale di Fisica Nucleare, Frascati, Italy*
[6]*Harvard University, Cambridge, Massachusetts 02138*
[7]*University of Illinois, Urbana, Illinois 61801*

[8]*The Johns Hopkins University, Baltimore, Maryland 21218*
[9]*National Laboratory for High Energy Physics (KEK), Tsukuba, Ibaraki 305, Japan*
[10]*Lawrence Berkeley Laboratory, Berkeley, California 94720*
[11]*Universita di Padova, Istituto Nazionale di Fisica Nucleare, Sezione di Padova, I-35131 Padova, Italy*
[12]*University of Pennsylvania, Philadelphia, Pennsylvania 19104*
[13]*Istituto Nazionale di Fisica Nucleare, University and Scuola Normale Superiore of Pisa, I-56100 Pisa, Italy*
[14]*Purdue University, West Lafayette, Indiana 47907*
[15]*University of Rochester, Rochester, New York 14627*
[16]*Rockefeller University, New York, New York 10021*
[17]*Rutgers University, Piscataway, New Jersey 08854*
[18]*Texas A&M University, College Station, Texas 77843*
[19]*University of Tsukuba, Tsukuba, Ibaraki 305, Japan*
[20]*Tufts University, Medford, Massachusetts 02155*
[21]*University of Wisconsin, Madison, Wisconsin 53706*
(Received 16 October 1991)

We present results from searches for the top quark in $p\bar{p}$ collisions at the Fermilab Tevatron Collider. The data sample was collected during 1988–89 with the Collider Detector at Fermilab and has an integrated luminosity of 4.1 pb^{-1}. Our previous search for $e\mu$ final states for $t\bar{t} \to e\nu b\mu\nu\bar{b}$ decays has been extended to include the ee and $\mu\mu$ channels. In addition, we have searched in each event with a high-transverse-momentum lepton accompanied by hadron jets for a low-transverse-momentum muon as a tag of a bottom quark in $t\bar{t} \to l\nu bq\bar{q}\bar{b}$ decays. A lower limit on the top-quark mass of 91 GeV/c^2 is obtained at the 95% confidence level, assuming standard model decays.

PACS numbers: 14.80.Dq, 12.15.Ff, 13.85.Qk, 13.85.Rm

The top quark (t) required to complete the three generations of quarks and leptons in the standard model [1,2] has yet to be observed. The forward-backward asymmetry measured in $e^+e^- \to b\bar{b}$ [3] and the absence of flavor-changing neutral currents in bottom-quark (b) decays [4] imply the existence of the isodoublet partner of the b quark. Lower bounds up to 77 GeV/c^2 on the top-quark mass M_{top} have been reported [5–9] and upper limits of about 200 GeV/c^2 have been placed by requiring consistency with the measured W and Z boson masses [10], and with weak-neutral-current data [11].

In a previous Letter, we reported a limit of $M_{top} > 72$ GeV/c^2 (95% C.L.) based on a search with the Collider Detector at Fermilab (CDF) for the decay of $t\bar{t}$ pairs into $e\mu$ pairs: $p\bar{p} \to t\bar{t} \to e\mu + X$ [6]. Here we present an extension of that analysis to include the channels ee and $\mu\mu$. The search has also been extended to include electrons at smaller polar angles relative to the beam. In addition, we have searched in lepton+jets events for a low-transverse-momentum (P_T) muon as a tag of a bottom quark in $t\bar{t} \to W^+bW^-\bar{b}$ decays.

Top quarks are expected to be produced at the Fermilab Collider mainly via the process $p\bar{p} \to t\bar{t} + X$ [12,13]. Each top quark is expected to decay into a W boson and a b quark ($t \to Wb$, where the W is real or virtual depending on the top-quark mass). Each W subsequently decays into either a charged lepton and a neutrino or two quarks. The branching ratio for both W's from a $t\bar{t}$ pair to decay leptonically is $\frac{2}{81}$ for $e\mu$, $\frac{1}{81}$ for ee, and $\frac{1}{81}$ for $\mu\mu$. The cleanest signature for the production and decay of a $t\bar{t}$ pair is the presence of two high-P_T leptons (e or μ) in the final state.

Decay modes of $t\bar{t}$ pairs in which one of the W bosons decays hadronically and the other leptonically have larger branching ratios ($\frac{24}{81}$), but in these channels there are serious backgrounds from W bosons produced in association with jets ($p\bar{p} \to W+$jets). These backgrounds are reduced by looking for a b (or $\bar{b}$) quark in the $t\bar{t} \to W^+bW^-\bar{b}$ decay. The b quark can be tagged by its transition $b \to \mu$. Decay modes of $t\bar{t}$ pairs in which both quarks decay hadronically also have a large branching fraction ($\frac{36}{81}$), but it is difficult to distinguish them from multijet QCD backgrounds.

In the high-P_T dilepton analysis, the P_T threshold has been chosen such that a large portion of the top signal is preserved while the backgrounds, which mostly come from $b\bar{b}$ decays and from particle misidentification, are suppressed. Electrons are detected [7,14] inside the rapidity regions $|\eta| < 1.0$ (central calorimeter) and $1.26 < |\eta| < 2.2$ (plug calorimeter). Muons are identified in the region $|\eta| < 1.2$, but can trigger the apparatus only in the region $|\eta| < 0.6$. Further details of the analysis are presented in Ref. [15].

For events in the signal region, we require that each lepton has $P_T > 15$ GeV/c and that each event has been triggered by at least one of the central electron and muon triggers, which are highly efficient above 15 GeV/c. The subset of $e\mu$ events, in which the electron is in the plug calorimeter and the muon has a rapidity $0.6 < |\eta| < 1.2$, must be triggered by the plug electron trigger. For this subset of events, we require the electron E_T to be higher than 30 GeV to ensure that the trigger is efficient.

After the P_T and lepton identification cuts, there are 4 $e\mu$, 271 ee, and 112 $\mu\mu$ events. Further kinematic and event topology cuts are applied to reject the remaining backgrounds. A back-to-back cut, requiring $\Delta\phi_{ll} < 160°$, where $\Delta\phi_{ll}$ is the dilepton azimuthal opening angle, is placed to suppress a small expected $Z^0 \to \tau\tau$ background. For dielectron and dimuon channels, the $\Delta\phi_{ll}$ cut also reduces large background from Z^0 and Drell-Yan events. These backgrounds are reduced further by a dilepton invariant mass (M_{ll}) cut around the Z^0 peak and a cut on missing transverse energy ($\not\!E_T$). We remove ee and $\mu\mu$ events with $75 < M_{ll} < 105$ GeV/c^2 or with $\not\!E_T < 20$ GeV. In $t\bar{t}$ events, there would be two undetected high-transverse-energy neutrinos, and the two leptons are not expected to be back to back. Therefore, with these cuts, most of the $t\bar{t}$ acceptance is preserved.

Of the 271 ee and 112 $\mu\mu$ events, 50 ee and 15 $\mu\mu$ events survive the invariant mass cut. The distribution of $\Delta\phi_{ll}$ vs $\not\!E_T$ for these events is shown in Fig. 1(a). After imposing the $\Delta\phi_{ll}$ and $\not\!E_T$ cuts, no dielectron or dimuon events remain in the data. Figure 1(b) shows the expected distribution for $t\bar{t} \to ll+X$ events with $M_{\rm top}=90$ GeV/c^2 generated from the ISAJET [16] Monte Carlo program together with a CDF detector simulation. We expect 0.9 ± 0.7 event from the Drell-Yan and Z^0 production processes, and 0.4 ± 0.1 event from fake lepton background.

Three of the four $e\mu$ events are rejected by the $\Delta\phi_{ll}$ cut. The three events also have small $\not\!E_T$, and are consistent with being background events. The remaining event is the same one found in the previous analysis [6], which, however, did not include electrons in the plug calorimeter. Before the $\Delta\phi_{ll}$ cut, we expect 1.4 $e\mu$ events from the process $Z^0 \to \tau\tau$, 0.15 event from WW, 1.5 events from QCD $b\bar{b}$ production, and 1.6 events from fake lepton background [15]. After the $\Delta\phi_{ll}$ cut, we expect 0.2 ± 0.1, 0.12 ± 0.01, 0.3 ± 0.2, and 0.6 ± 0.4 event from the above sources, respectively. Background events from WZ pair production, the decay $Z^0 \to b\bar{b}$, and the Drell-Yan processes are negligible.

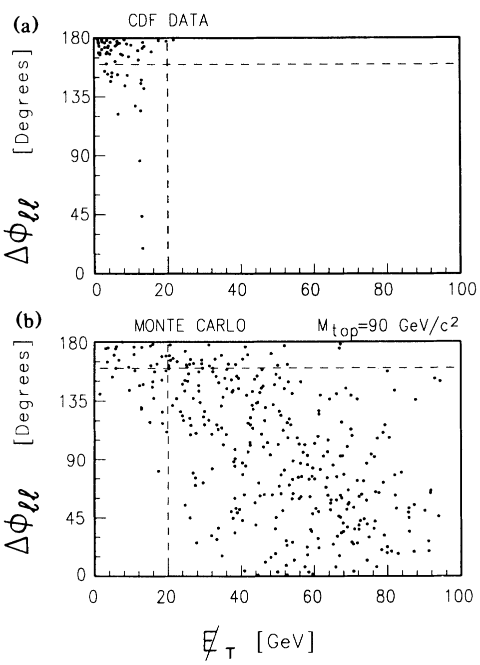

FIG. 1. Distributions of $\not\!E_T$ vs $\Delta\phi_{ll}$. (a) CDF dielectron and dimuon data with integrated luminosity of 4.1 pb^{-1}. (b) Monte Carlo $t\bar{t} \to ll+X$ events for $M_{\rm top}=90$ GeV/c^2 for 600 pb^{-1}. Events with dilepton masses in the range $75 < M_{ll} < 105$ are not included in the figure.

For $M_{\rm top}=90$ GeV/c^2, the total detection efficiency for $t\bar{t}$ pairs from the high-P_T dilepton analysis is $16\% \times \frac{4}{81}$. The direct double semileptonic decays of $t\bar{t}$ into $e\mu$, ee, or $\mu\mu$ account for over 80% of the high-P_T dilepton $t\bar{t}$ signal. The next major contribution to the signal is 12% from events with one lepton from the decay of a τ daughter of one top quark.

In the b tag analysis, we consider events with a high-P_T electron or muon from the decay of a W boson, plus a low-P_T muon from direct or sequential b decays, $t\bar{t} \to l\nu bq\bar{q}\bar{b}$, $b \to \mu$ or $b \to c \to \mu$. For each event, we require an isolated electron or muon with $P_T > 20$ GeV/c, $\not\!E_T > 20$ GeV, and at least two jets of $E_T > 10$ GeV and $|\eta| < 2$. In this analysis, we consider only electrons inside the rapidity region $|\eta| < 1.0$ and muons with $|\eta| < 0.6$. Any event with two lepton candidates that are consistent with being decay products of a Z boson is removed from the sample. The properties of the remaining 104 e+jets and 91 μ+jets events are consistent with expectations for $p\bar{p} \to W$+jets. The background from b semileptonic decays and from misidentified hadrons is estimated from studies of the lepton isolation distribution to be less than 15%. For $M_{\rm top} < 100$ GeV/c^2, the muon from the b decay is expected to have a soft P_T spectrum ($\langle P_T \rangle \approx 3$ GeV/c). We explicitly exclude muons with $P_T(\mu) > 15$ GeV/c to avoid overlap with the high-P_T dilepton analysis described above. Muons with $P_T < 1.6$ GeV/c are stopped in the calorimeter without reaching the muon chambers. Because of uncertainties in the detection efficiency of the lowest-momentum muons, a P_T cutoff of 2 GeV/c is imposed in the search.

If $M_{\rm top}$ is near the W mass, the two most energetic jets in top events usually originate from hadronic W decay or from initial-state radiation, and rarely from the hadronization of the b quarks. Thus, muons from b decays tend to be well separated from the two highest-E_T jets. The background to the muon signal, from decays in flight and hadron-shower leakage in W+jets events, is reduced by eliminating muon candidates with $\Delta R < 0.5$, where $\Delta R = (\Delta\eta^2 + \Delta\phi^2)^{1/2}$ is the η-ϕ distance between the μ candidate and the nearest of the two most energetic jets. The threshold for ΔR was determined from studies of background muon candidates in QCD jet events [15].

The ΔR distribution for muon candidates with $P_T > 2$ GeV/c is shown in Fig. 2. There are no candidate muons with $\Delta R > 0.5$. The expected number of events from the W+jets background, estimated from the number of lepton+jets events and the fake muon probability, is 0.9 ± 0.5.

The detection efficiency for $t\bar{t}$ events for the b tag analysis is determined also from ISAJET and detector simulation. In this Monte Carlo study, the semileptonic

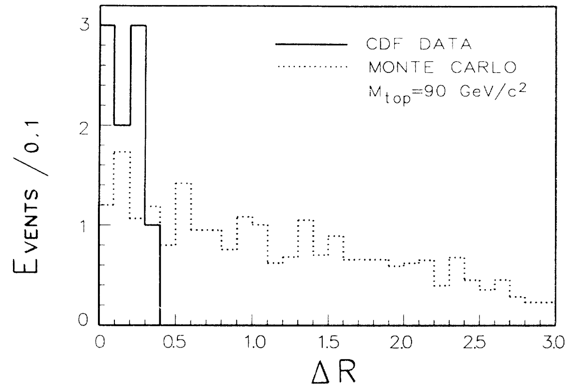

FIG. 2. The η-ϕ distance ΔR to the nearest of the two most energetic jets for low-P_T muon candidates in the lepton+jets sample. Also shown is the 90-GeV/c^2 $t\bar{t}$ Monte Carlo prediction (arbitrary normalization).

branching ratios of bottom and charmed particles and the lepton spectrum from b decays are chosen to agree with the most recent measurements [17,18]. Approximately 30% of reconstructed muons originate from sequential charm decays. The efficiency of the ΔR requirement for top events is greater than 75%. The detection efficiency of the lepton+jets selection for $t\bar{t}$ is $19.5\% \times \frac{24}{81}$ for $M_{top}=90$ GeV/c^2. In 4.5% of these events we expect to detect an additional muon, for an overall efficiency of $(0.26 \pm 0.03)\%$ for the b tag analysis.

The results from the searches in the high-P_T dilepton and the b tag analyses are combined by adding detection efficiencies and yields, and are summarized in Table I. The data yield the one $e\mu$ candidate event described above.

The 95% confidence level (C.L.) upper limit on the cross section can be written as

$$\sigma_{t\bar{t}} < N_{top} \Big/ \int \mathcal{L}\, dt\, \epsilon_{top}, \qquad (1)$$

where N_{top} is the 95% C.L. upper limit on the number of expected top events, $\int \mathcal{L}\, dt$ (=4.1 pb^{-1}) is the integrated luminosity, and ϵ_{top} is the detection efficiency of the analysis for observing top events. With one event detected, the value of N_{top} would be 4.74; however, the uncertainties in $\int \mathcal{L}\, dt$ and ϵ_{top} must be considered. This is done by convoluting the Poisson probability distribution for N_{top} with the uncertainties in $\int \mathcal{L}\, dt$ and ϵ_{top}, which are assumed to be Gaussian.

For the high-P_T dilepton analysis, the total uncertainty in ϵ_{top} is 11%. The largest contributions are from the lepton isolation cuts (8%) and from the lepton identification cuts (5%). In the b tag analysis, the total uncertainty is 13%. The major contributions come from the initial-state radiation assumptions in ISAJET (5%), the limited Monte Carlo statistics (7%), and the uncertainty on the understanding of the jet energy scale (5%) and on the $b \to \mu$ branching ratio (5%). The total uncertainty in ϵ_{top}, taking into account correlations in the uncertainties in the two analyses, is 11%. The uncertainty in the luminosity is 6.8% [14]. Without subtracting the expected 3.6 ± 1.4 background events from the one event observed, we find $N_{top}=4.90$. The 95% C.L. limit on $\sigma_{t\bar{t}}$ varies slightly as a function of M_{top} and is 113 pb for $M_{top}=90$ GeV/c^2.

Using theoretical expectations for $\sigma_{t\bar{t}}$, and assuming standard-model charged-current decays for top quarks, the cross-section limit can be translated into a lower limit on the mass of the top quark. Figure 3 shows the upper limits on $\sigma_{t\bar{t}}$ as a function of M_{top} together with the QCD calculation to order α_s^3 of the heavy-quark production cross section from Refs. [12,13]. The shaded region represents the uncertainty in the calculation based on different choices of the renormalization scale and the QCD scale parameter Λ. To set a lower limit on M_{top}, we find the point at which the experimental curve crosses the lower (more conservative) bound of the theoretical prediction. At the 95% C.L. we find $M_{top} > 85$ GeV/c^2 for the high-P_T dilepton analysis. From the combination of the high-P_T dilepton analysis with the b tag analysis, we obtain $M_{top} > 95$ GeV/c^2 at 90% C.L., and

$M_{top} > 91$ GeV/c^2 at 95% C.L.

TABLE I. Detection efficiencies ϵ_{top} for the high-P_T dilepton and b tag analyses, the predicted central value of $t\bar{t}$ production cross section from Ref. [13], and the total number of events expected.

M_{top} (GeV/c^2)	ϵ_{top} (dilepton) (%)	ϵ_{top} ($t \to b \to \mu$) (%)	$\sigma_{t\bar{t}}$ (pb)	N_{events} (in 4.1 pb^{-1})
80	0.68	0.20	291	10.5
90	0.80	0.26	150	6.5
100	0.83	0.29	94	4.3

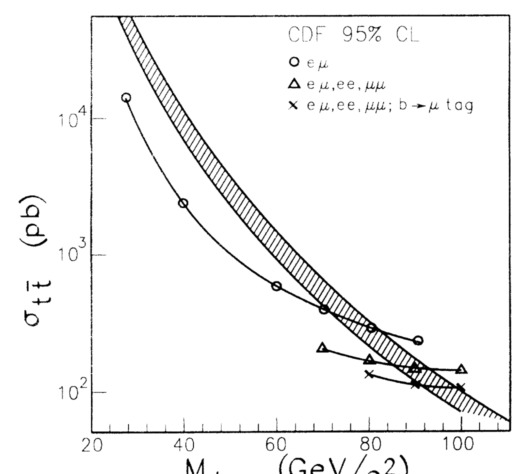

FIG. 3. The 95% C.L. limits on $\sigma_{t\bar{t}}$ compared with a band of theoretical predictions from Ref. [13]. The three sets of experimental limits are (1) from the $e\mu$ analysis of Ref. [6]; (2) from this analysis in the dilepton modes ee, $e\mu$, and $\mu\mu$ and including electrons with $1.26 < |\eta| < 2.2$; (3) from the combination of this high-P_T dilepton analysis with the b tag analysis.

We thank the Fermilab Accelerator Division and the CDF technical and support staffs at each institution for their vital contribution. This work was supported by the U.S. Department of Energy, the National Science Foundation, the Italian Istituto Nazionale di Fisica Nucleare, the Ministry of Science, Culture and Education of Japan, and the A. P. Sloan Foundation.

[a]Visiting.

[1] S. L. Glashow, Nucl. Phys. **22**, 579 (1961); S. Weinberg, Phys. Rev. Lett. **19**, 1264 (1967); A. Salam, in *Elementary Particle Theory,* edited by N. Svartholm (Almqvist and Wiksell, Sweden, 1968), p. 367.

[2] S. L. Glashow, J. Illiopoulos, and L. Maiani, Phys. Rev. D **2**, 1285 (1970); M. Kobayashi and M. Maskawa, Prog. Theor. Phys. **49**, 652 (1973).

[3] W. Bartel *et al.*, Phys. Lett. **146B**, 437 (1984).

[4] A. Bean *et al.*, Phys. Rev. D **35**, 3533 (1987).

[5] H. Albrecht *et al.*, Phys. Lett. B **192**, 245 (1987); M. Artuso *et al.*, Phys. Rev. Lett. **62**, 2233 (1989); G. Altarelli and P. Franzini, Z. Phys. C **37**, 271 (1988); J. Ellis *et al.*, Nucl. Phys. **B304**, 205 (1988).

[6] F. Abe *et al.*, Phys. Rev. Lett. **64**, 147 (1990).

[7] F. Abe *et al.*, Phys. Rev. Lett. **64**, 142 (1990); Phys. Rev. D **43**, 664 (1991).

[8] UA2 Collaboration, T. Åkesson *et al.*, Z. Phys. C **46**, 179 (1990).

[9] UA1 Collaboration, C. Albajar *et al.*, Z. Phys. C **48**, 1 (1990).

[10] CDF Collaboration, F. Abe *et al.*, Phys. Rev. Lett. **63**, 720 (1989); **65**, 2243 (1990); Phys. Rev. D **43**, 2070 (1991); Mark II Collaboration, G. Abrams *et al.*, Phys. Rev. Lett. **63**, 2173 (1989); ALEPH Collaboration, D. Decamp *et al.*, Phys. Lett. B **231**, 519 (1989); DELPHI Collaboration, P. Aarnio *et al.*, Phys. Lett. B **231**, 539 (1989); L3 Collaboration, B. Adeva *et al.*, Phys. Lett. B **231**, 509 (1989); OPAL Collaboration, M. Z. Akrawy *et al.*, Phys. Lett. B **231**, 530 (1989); UA2 Collaboration, J. Alitti *et al.*, Phys. Lett. B **241**, 150 (1990).

[11] W. Marciano and A. Sirlin, Phys. Rev. D **29**, 945 (1984); D. Bardin *et al.*, Z. Phys. C **32**, 121 (1986); U. Amaldi *et al.*, Phys. Rev. D **36**, 1385 (1987); P. Langacker and M. Luo, Phys. Rev. D **44**, 817 (1991); J. R. Carter, in Proceedings of the International Lepton Photon Symposium, CERN, Geneva, 1991 (to be published).

[12] P. Nason, S. Dawson, and R. K. Ellis, Nucl. Phys. **B303**, 607 (1988).

[13] G. Altarelli, M. Diemoz, G. Martinelli, and P. Nason, Nucl. Phys. **B308**, 724 (1988); R. K. Ellis, Fermilab Report No. Fermilab-Pub-91/30-T, 1991 (to be published). We use the $t\bar{t}$ cross sections obtained by Ellis.

[14] F. Abe *et al.*, Phys. Rev. D **44**, 29 (1991).

[15] F. Abe *et al.*, "A Lower Limit on the Top Quark Mass from Proton-Antiproton Collisions at $\sqrt{s}=1.8$ TeV" (to be published).

[16] F. Paige and S. D. Protopopescu, BNL Report No. BNL 38034, 1986 (unpublished). We used version 6.22.

[17] M. A. Worris, in *Proceedings of the Rice Meeting (1990 DPF Meeting)* (World Scientific, Singapore, 1990), p. 470.

[18] Particle Data Group, J. J. Hernandez *et al.*, Phys. Lett. B **239**, 1 (1990).