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Search for Flavor-Changing Neutral Current B Meson Decays in $p\bar{p}$ Collisions at $\sqrt{s} = 1.8\,\mathrm{TeV}$

F. Abe,[14] H. Akimoto,[32] A. Akopian,[27] M. G. Albrow,[7] S. R. Amendolia,[23] D. Amidei,[17] J. Antos,[29] C. Anway-Wiese,[4] S. Aota,[32] G. Apollinari,[27] T. Asakawa,[32] W. Ashmanskas,[15] M. Atac,[7] F. Azfar,[22] P. Azzi-Bacchetta,[21] N. Bacchetta,[21] W. Badgett,[17] S. Bagdasarov,[27] M. W. Bailey,[19] J. Bao,[35] P. de Barbaro,[26] A. Barbaro-Galtieri,[15] V. E. Barnes,[25] B. A. Barnett,[13] E. Barzi,[8] G. Bauer,[16] T. Baumann,[9] F. Bedeschi,[23] S. Behrends,[3] S. Belforte,[23] G. Bellettini,[23] J. Bellinger,[34] D. Benjamin,[31] J. Benlloch,[16] J. Bensinger,[3] D. Benton,[22] A. Beretvas,[7] J. P. Berge,[7] J. Berryhill,[5] S. Bertolucci,[8] A. Bhatti,[27] K. Biery,[12] M. Binkley,[7] D. Bisello,[21] R. E. Blair,[1] C. Blocker,[3] A. Bodek,[26] W. Bokhari,[16] V. Bolognesi,[7] D. Bortoletto,[25] J. Boudreau,[24] L. Breccia,[2] C. Bromberg,[18] N. Bruner,[19] E. Buckley-Geer,[7] H. S. Budd,[26] K. Burkett,[17] G. Busetto,[21] A. Byon-Wagner,[7] K. L. Byrum,[1] J. Cammerata,[13] C. Campagnari,[7] M. Campbell,[17] A. Caner,[7] W. Carithers,[15] D. Carlsmith,[34] A. Castro,[21] D. Cauz,[23] Y. Cen,[26] F. Cervelli,[23] H. Y. Chao,[29] J. Chapman,[17] M.-T. Cheng,[29] G. Chiarelli,[23] T. Chikamatsu,[32] C. N. Chiou,[29] L. Christofek,[11] S. Cihangir,[7] A. G. Clark,[23] M. Cobal,[23] M. Contreras,[5] J. Conway,[28] J. Cooper,[7] M. Cordelli,[8] C. Couyoumtzelis,[23] D. Crane,[1] D. Cronin-Hennessy,[6] R. Culbertson,[5] J. D. Cunningham,[3] T. Daniels,[16] F. DeJongh,[7] S. Delchamps,[7] S. Dell'Agnello,[23] M. Dell'Orso,[23] L. Demortier,[27] B. Denby,[23] M. Deninno,[2] P. F. Derwent,[17] T. Devlin,[28] J. R. Dittmann,[6] S. Donati,[23] J. Done,[30] T. Dorigo,[21] A. Dunn,[17] N. Eddy,[17] K. Einsweiler,[15] J. E. Elias,[7] R. Ely,[15] E. Engels, Jr.,[24] D. Errede,[11] S. Errede,[11] Q. Fan,[26] I. Fiori,[2] B. Flaugher,[7] G. W. Foster,[7] M. Franklin,[9] M. Frautschi,[31] J. Freeman,[7] J. Friedman,[16] T. A. Fuess,[1] Y. Fukui,[14] S. Funaki,[32] G. Gagliardi,[23] S. Galeotti,[23] M. Gallinaro,[21] M. Garcia-Sciveres,[15] A. F. Garfinkel,[25] C. Gay,[9] S. Geer,[7] D. W. Gerdes,[17] P. Giannetti,[23] N. Giokaris,[27] P. Giromini,[8] L. Gladney,[22]

D. Glenzinski,[13] M. Gold,[19] J. Gonzalez,[22] A. Gordon,[9] A. T. Goshaw,[6] K. Goulianos,[27] H. Grassmann,[23] L. Groer,[28] C. Grosso-Pilcher,[5] G. Guillian,[17] R. S. Guo,[29] C. Haber,[15] E. Hafen,[16] S. R. Hahn,[7] R. Hamilton,[9] R. Handler,[34] R. M. Hans,[35] K. Hara,[32] A. D. Hardman,[25] B. Harral,[22] R. M. Harris,[7] S. A. Hauger,[6] J. Hauser,[4] C. Hawk,[28] E. Hayashi,[32] J. Heinrich,[22] K. D. Hoffman,[25] M. Hohlmann,[1,5] C. Holck,[22] R. Hollebeek,[22] L. Holloway,[11] A. Hölscher,[12] S. Hong,[17] G. Houk,[22] P. Hu,[24] B. T. Huffman,[24] R. Hughes,[26] J. Huston,[18] J. Huth,[9] J. Hylen,[7] H. Ikeda,[32] M. Incagli,[23] J. Incandela,[7] G. Introzzi,[23] J. Iwai,[32] Y. Iwata,[10] H. Jensen,[7] U. Joshi,[7] R. W. Kadel,[15] E. Kajfasz,[7a] T. Kamon,[30] T. Kaneko,[32] K. Karr,[33] H. Kasha,[35] Y. Kato,[20] T. A. Keaffaber,[25] L. Keeble,[8] K. Kelley,[16] R. D. Kennedy,[28] R. Kephart,[7] P. Kesten,[15] D. Kestenbaum,[9] R. M. Keup,[11] H. Keutelian,[7] F. Keyvan,[4] B. Kharadia,[11] B. J. Kim,[26] D. H. Kim,[7a] H. S. Kim,[12] S. B. Kim,[17] S. H. Kim,[32] Y. K. Kim,[15] L. Kirsch,[3] P. Koehn,[26] K. Kondo,[32] J. Konigsberg,[9] S. Kopp,[5] K. Kordas,[12] W. Koska,[7] E. Kovacs,[7a] W. Kowald,[6] M. Krasberg,[17] J. Kroll,[7] M. Kruse,[25] T. Kuwabara,[32] S. E. Kuhlmann,[1] E. Kuns,[28] A. T. Laasanen,[25] N. Labanca,[23] S. Lammel,[7] J. I. Lamoureux,[3] T. LeCompte,[11] S. Leone,[23] J. D. Lewis,[7] P. Limon,[7] M. Lindgren,[4] T. M. Liss,[11] N. Lockyer,[22] O. Long,[22] C. Loomis,[28] M. Loreti,[21] J. Lu,[30] D. Lucchesi,[23] P. Lukens,[7] S. Lusin,[34] J. Lys,[15] K. Maeshima,[7] A. Maghakian,[27] P. Maksimovic,[16] M. Mangano,[23] J. Mansour,[18] M. Mariotti,[21] J. P. Marriner,[7] A. Martin,[11] J. A. J. Matthews,[19] R. Mattingly,[16] P. McIntyre,[30] P. Melese,[27] A. Menzione,[23] E. Meschi,[23] S. Metzler,[22] C. Miao,[17] G. Michail,[9] R. Miller,[18] H. Minato,[32] S. Miscetti,[8] M. Mishina,[14] H. Mitsushio,[32] T. Miyamoto,[32] S. Miyashita,[32] Y. Morita,[14] J. Mueller,[24] A. Mukherjee,[7] T. Muller,[4] P. Murat,[23] H. Nakada,[32] I. Nakano,[32] C. Nelson,[7] D. Neuberger,[4] C. Newman-Holmes,[7] M. Ninomiya,[32] L. Nodulman,[1] S. H. Oh,[6] K. E. Ohl,[35] T. Ohmoto,[10] T. Ohsugi,[10] R. Oishi,[32] M. Okabe,[32] T. Okusawa,[20] R. Oliver,[22] J. Olsen,[34] C. Pagliarone,[2] R. Paoletti,[23] V. Papadimitriou,[31] S. P. Pappas,[35] S. Park,[7] A. Parri,[8] J. Patrick,[7] G. Pauletta,[23] M. Paulini,[15] A. Perazzo,[23] L. Pescara,[21] M. D. Peters,[15] T. J. Phillips,[6] G. Piacentino,[2] M. Pillai,[26] K. T. Pitts,[7] R. Plunkett,[7] L. Pondrom,[34] J. Proudfoot,[1] F. Ptohos,[9] G. Punzi,[23] K. Ragan,[12] A. Ribon,[21] F. Rimondi,[2] L. Ristori,[23] W. J. Robertson,[6] T. Rodrigo,[7a] S. Rolli,[23] J. Romano,[5]

L. Rosenson,[16] R. Roser,[11] W. K. Sakumoto,[26] D. Saltzberg,[5] A. Sansoni,[8] L. Santi,[23] H. Sato,[32] V. Scarpine,[30] P. Schlabach,[9] E. E. Schmidt,[7] M. P. Schmidt,[35] A. Scribano,[23] S. Segler,[7] S. Seidel,[19] Y. Seiya,[32] G. Sganos,[12] A. Sgolacchia,[2] M. D. Shapiro,[15] N. M. Shaw,[25] Q. Shen,[25] P. F. Shepard,[24] M. Shimojima,[32] M. Shochet,[5] J. Siegrist,[15] A. Sill,[31] P. Sinervo,[12] P. Singh,[24] J. Skarha,[13] K. Sliwa,[33] F. D. Snider,[13] T. Song,[17] J. Spalding,[7] P. Sphicas,[16] F. Spinella,[23] M. Spiropulu,[9] L. Spiegel,[7] L. Stanco,[21] J. Steele,[34] A. Stefanini,[23] K. Strahl,[12] J. Strait,[7] R. Ströhmer,[9] D. Stuart,[7] G. Sullivan,[5] A. Soumarokov,[29] K. Sumorok,[16] J. Suzuki,[32] T. Takada,[32] T. Takahashi,[20] T. Takano,[32] K. Takikawa,[32] N. Tamura,[10] F. Tartarelli,[23] W. Taylor,[12] P. K. Teng,[29] Y. Teramoto,[20] S. Tether,[16] D. Theriot,[7] T. L. Thomas,[19] R. Thun,[17] M. Timko,[33] P. Tipton,[26] A. Titov,[27] S. Tkaczyk,[7] D. Toback,[5] K. Tollefson,[26] A. Tollestrup,[7] J. Tonnison,[25] J. F. de Troconiz,[9] S. Truitt,[17] J. Tseng,[13] N. Turini,[23] T. Uchida,[32] N. Uemura,[32] F. Ukegawa,[22] G. Unal,[22] S. C. van den Brink,[24] S. Vejcik, III,[17] G. Velev,[23] R. Vidal,[7] M. Vondracek,[11] D. Vucinic,[16] R. G. Wagner,[1] R. L. Wagner,[7] J. Wahl,[5] C. Wang,[6] C. H. Wang,[29] G. Wang,[23] J. Wang,[5] M. J. Wang,[29] Q. F. Wang,[27] A. Warburton,[12] T. Watts,[28] R. Webb,[30] C. Wei,[6] C. Wendt,[34] H. Wenzel,[15] W. C. Wester, III,[7] A. B. Wicklund,[1] E. Wicklund,[7] R. Wilkinson,[22] H. H. Williams,[22] P. Wilson,[5] B. L. Winer,[26] D. Wolinski,[17] J. Wolinski,[18] X. Wu,[23] J. Wyss,[21] A. Yagil,[7] W. Yao,[15] K. Yasuoka,[32] Y. Ye,[12] G. P. Yeh,[7] P. Yeh,[29] M. Yin,[6] J. Yoh,[7] C. Yosef,[18] T. Yoshida,[20] D. Yovanovitch,[7] I. Yu,[35] L. Yu,[19] J. C. Yun,[7] A. Zanetti,[23] F. Zetti,[23] L. Zhang,[34] W. Zhang,[22] and S. Zucchelli[2]

(CDF Collaboration)

[1] *Argonne National Laboratory, Argonne, Illinois 60439*

[2] *Istituto Nazionale di Fisica Nucleare, University of Bologna, I-40126 Bologna, Italy*

[3] *Brandeis University, Waltham, Massachusetts 02254*

[4] *University of California at Los Angeles, Los Angeles, California 90024*

[5] *University of Chicago, Chicago, Illinois 60637*

[6] *Duke University, Durham, North Carolina 27708*

[7] *Fermi National Accelerator Laboratory, Batavia, Illinois 60510*

[8] *Laboratori Nazionali di Frascati, Istituto Nazionale di Fisica Nucleare, I-00044 Frascati, Italy*

[9] *Harvard University, Cambridge, Massachusetts 02138*

[10] *Hiroshima University, Higashi-Hiroshima 724, Japan*

[11] *University of Illinois, Urbana, Illinois 61801*

[12] *Institute of Particle Physics, McGill University, Montreal H3A 2T8, and University of Toronto, Toronto M5S 1A7, Canada*

[13] *The Johns Hopkins University, Baltimore, Maryland 21218*

[14] *National Laboratory for High Energy Physics (KEK), Tsukuba, Ibaraki 305, Japan*

[15] *Lawrence Berkeley Laboratory, Berkeley, California 94720*

[16] *Massachusetts Institute of Technology, Cambridge, Massachusetts 02139*

[17] *University of Michigan, Ann Arbor, Michigan 48109*

[18] *Michigan State University, East Lansing, Michigan 48824*

[19] *University of New Mexico, Albuquerque, New Mexico 87131*

[20] *Osaka City University, Osaka 588, Japan*

[21] *Universita di Padova, Istituto Nazionale di Fisica Nucleare, Sezione di Padova, I-35131 Padova, Italy*

[22] *University of Pennsylvania, Philadelphia, Pennsylvania 19104*

[23] *Istituto Nazionale di Fisica Nucleare, University and Scuola Normale Superiore of Pisa, I-56100 Pisa, Italy*

[24] *University of Pittsburgh, Pittsburgh, Pennsylvania 15260*

[25] *Purdue University, West Lafayette, Indiana 47907*

[26] *University of Rochester, Rochester, New York 14627*

[27] *Rockefeller University, New York, New York 10021*

[28] *Rutgers University, Piscataway, New Jersey 08854*

[29] *Academia Sinica, Taipei, Taiwan 11529, Republic of China*

[30] *Texas A&M University, College Station, Texas 77843*

[31] *Texas Tech University, Lubbock, Texas 79409*

[32] *University of Tsukuba, Tsukuba, Ibaraki 305, Japan*

[33] *Tufts University, Medford, Massachusetts 02155*

[34] *University of Wisconsin, Madison, Wisconsin 53706*

[35] *Yale University, New Haven, Connecticut 06511*

We report on a search for the flavor-changing neutral current decays $B^0_{d,s} \to \mu^+\mu^-$, $B^+ \to \mu^+\mu^- K^+$ and $B^0 \to \mu^+\mu^- K^{*0}$ using data from $p\bar{p}$ collisions at $\sqrt{s} = 1.8\,\mathrm{TeV}$, collected with the Collider Detector at Fermilab during the 1992–1993 running period. We find no indication of such decays and we set the following 90% confidence level upper limits on branching ratios: $\mathrm{BR}(B^0 \to \mu^+\mu^-) < 1.6 \times 10^{-6}$, $\mathrm{BR}(B^0_s \to \mu^+\mu^-) < 8.4 \times 10^{-6}$, $\mathrm{BR}(B^+ \to \mu^+\mu^- K^+) < 1.0 \times 10^{-5}$ and $\mathrm{BR}(B^0 \to \mu^+\mu^- K^{*0}) < 2.5 \times 10^{-5}$.

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In the Standard Model of electroweak interactions, rare decays of B mesons involving flavor-changing neutral currents (FCNC) are forbidden at tree level and proceed only through higher order processes. The predicted rates for these decays [1] are $\mathrm{BR}(B^0 \to \mu^+\mu^-) = (0.6{-}1.9)\times 10^{-10}$, $\mathrm{BR}(B^0_s \to \mu^+\mu^-) = (1.5{-}4.5)\times 10^{-9}$, $\mathrm{BR}(B^+ \to \mu^+\mu^- K^+) = (2{-}5)\times 10^{-7}$ and $\mathrm{BR}(B^0 \to \mu^+\mu^- K^{*0}) = (2-5) \times 10^{-6}$. The largest uncertainties in the theoretical calculations come from the unknown B meson decay constant, the uncertainty in the B meson lifetime, and, for the latter two decay channels, the choice of form factors [2]. Deviations from Standard Model physics, such as the existence of a charged Higgs boson or an anomalous magnetic moment of the W boson, can increase these rates significantly [3].

We use data collected by the CDF detector at the Fermilab Tevatron proton-antiproton Collider. The CDF detector has been described in detail elsewhere [4]. The most relevant components of the detector for this analysis are the muon chambers and the charged particle tracking system. The muon system is composed of drift chambers outside the hadron calorimeter, allowing the reconstruction of track segments for penetrating particles. The tracking system consists in part of the silicon vertex detector (SVX) and the Central Tracking Chamber (CTC), both inside a 1.4 T solenoidal magnetic field. The CTC is a cylindrical drift chamber containing 84 layers grouped into nine alternating superlayers of axial and stereo wires. It covers the pseudorapidity range $|\eta| < 1.1$ [5]. The SVX consists of four layers of silicon microstrip detectors located at radii between 3.0 and 7.9 cm from the beam line. The SVX provides measurements in the $r-\phi$ plane resulting in a track impact parameter resolution of $(13 + 40/p_T)$ μm where p_T is the momentum of the track (in GeV/c) perpendicular to the beam line.

The data sample consists of 17.8 $\pm$ 0.6 pb^{-1} of $p\bar{p}$ collisions collected using dimuon triggers in the CDF three-level trigger system. The Level 1 dimuon trigger requires two track segments in the muon chambers, separated by at least 0.09 radians in azimuth. The trigger efficiency for each muon at Level 1 rises from 50% at $p_T = 1.6$ GeV/c to 90% at $p_T = 3.1$ GeV/c with a plateau of 94%. The Level 2 trigger requires that at least one of the muon track segments is matched in ϕ to a track found in the CTC by the CFT [6], a hardware processor. The efficiency for finding a track with the CFT rises from 50% at $p_T = 2.7$ GeV/c to 90% at $p_T = 3.1$ GeV/c and reaches a plateau of 93%. The Level 3 trigger requires a pair of oppositely-charged muons after full track reconstruction.

Both muons are required to satisfy CTC-muon chamber matching requirements. To remain in the region of good trigger efficiency, both muons in this analysis are required to have $p_T(\mu) > 2.0$ GeV/c, whereas one muon is required to have $p_T > 2.5$ GeV/c.

For the $B^+ \to \mu^+\mu^-K^+$ and $B^0 \to \mu^+\mu^-K^{*0}$ [7] analyses, we use all dimuons within the mass range kinematically available to B decays (i.e. $m(\mu\mu) < 4.6$ GeV/c^2). The only exceptions are dimuons in the mass regions 2.9–3.3 and 3.6–3.8 GeV/c^2, which are dominated by resonant decays involving the J/ψ and $\psi(2S)$, and are therefore excluded from the FCNC decay search.

For $B^+ \to \mu^+\mu^-K^+$ all reconstructed charged particle tracks (except for the two muons) with $p_T > 2.0$ GeV/c are assigned the kaon mass. For $B^0 \to \mu^+\mu^-K^{*0}$, K^{*0} mesons are reconstructed using the $K^{*0} \to K^+\pi^-$ decay channel. All oppositely charged pairs of particle tracks are assigned the kaon and pion masses. The $K\ \pi$ particle assignment with invariant mass closest to the K^{*0} mass is used. The resulting K^{*0} candidates are required to be within

100 MeV/c^2 of the K^{*0} mass and to have $p_T > 2.0$ GeV/c. The two muons and the K^+ or K^{*0} candidates are constrained to come from a common point subject to the further constraint that the transverse displacement of the B decay point from the beamline be parallel to the B momentum. Only B candidates with $p_T > 6.0$ GeV/c are considered in order to remain in the region of good kinematic acceptance.

To reduce combinatoric backgrounds, the proper decay distance of all B candidates in the plane transverse to the beam is required to be greater than 100 μm. In addition, B decay products are expected to carry the majority of the transverse momentum in a cone around the B direction. We define the isolation I as the transverse momentum of the B candidate divided by the scalar sum of the transverse momenta of all charged tracks, including the tracks which make up a B candidate, in an η-ϕ cone of radius 1.0 ($\sqrt{\Delta\eta^2 + \Delta\phi^2} < 1.0$) around the B direction. The optimal isolation requirement, $I > 0.6$, was determined from a signal to background study of fully reconstructed B candidates using the $J/\psi K^+$ and $J/\psi K^{*0}$ modes. The efficiency of this requirement is $92 \pm 6\%$.

Additional background rejection is achieved by fitting the tracks forming B candidates in the mass region 5.23–5.33 GeV/c^2 with the added constraint that the system have the B meson mass. Tracks forming B candidates in the sideband regions 5.13–5.23 and 5.33–5.63 GeV/c^2 cannot be fit to the B mass. Instead, the sidebands are split into four 100 MeV/c^2 bins and the candidates in each bin are constrained to the central mass value of the bin. Imposing a confidence level of 10% on the overall fit results in the dimuon mass spectra shown in Figures 1a and 1c for $B^+ \to \mu^+\mu^- K^+$ and $B^0 \to \mu^+\mu^- K^{*0}$ events in the B signal region. The dimuon mass distributions from the B sidebands are displayed in Figures 1b and 1d.

The background in the B signal region is estimated from the number of events from the B sideband region, scaled by the relative size of the B signal and sideband regions. For the decay $B^+ \to \mu^+\mu^- K^+$ ($B^0 \to \mu^+\mu^- K^{*0}$) three (seven) candidate events are found in the non-resonant signal region consistent with the background estimate of 5.0 ± 1.2 (7.2 ± 1.5) events.

We set a limit on the relative branching ratio of the non-resonant $B^+ \to \mu^+\mu^- K^+$ and $B^0 \to \mu^+\mu^- K^{*0}$ to the resonant $B^+ \to J/\psi K^+$ and $B^0 \to J/\psi K^{*0}$ decays because of the cancellation of systematic uncertainties due to the B meson production cross section, the trigger and reconstruction efficiencies and the luminosity measurement. Resonant decays from $B^+ \to J/\psi K^+$ and $B^0 \to J/\psi K^{*0}$ are identified using the dimuon mass region from 3.062 to 3.132 GeV/c^2. In the resonant region there are 34.2 ± 6.3 $B^+ \to J/\psi K^+$ and 29.7 ± 6.0 $B^0 \to J/\psi K^{*0}$ events above background [8]. The relative efficiencies between non-resonant and resonant events, determined from a Monte Carlo calculation based on reference [9], are $\epsilon(\mu\mu K)/\epsilon(J/\psi K) = 1.03 \pm 0.05$ and $\epsilon(\mu\mu K^{*0})/\epsilon(J/\psi K^{*0}) = 0.93 \pm 0.05$.

An upper limit is calculated using the method of reference [10]. Uncertainties on the relative efficiency and on the background estimated from the B sidebands are treated as Gaussian and convoluted with the Poisson distribution. The results for the B^+ and B^0 mesons are:

$$\frac{\mathrm{BR}(B^+ \to \mu^+\mu^- K^+, \mathrm{partial})}{\mathrm{BR}(B^+ \to J/\psi K^+, J/\psi \to \mu^+\mu^-)} < 0.13 \quad \text{at} \quad 90\% \text{ C.L.}$$

$$\frac{\mathrm{BR}(B^0 \to \mu^+\mu^- K^{*0}, \mathrm{partial})}{\mathrm{BR}(B^0 \to J/\psi K^{*0}, J/\psi \to \mu^+\mu^-)} < 0.20 \quad \text{at} \quad 90\% \text{ C.L.}$$

The designation *partial* indicates the dimuon mass region used for the signal, *i.e.* excluding the J/ψ and $\psi(2S)$ mass regions. The above limits are converted to those for the full dimuon mass region by multiplying the partial branching ratios by 1.23 for $B^+ \to \mu^+\mu^- K^+$ and 1.29 for $B^0 \to \mu^+\mu^- K^{*0}$, obtained from the Monte Carlo calculation. Using $\mathrm{BR}(B^+ \to J/\psi K^+, J/\psi \to \mu^+\mu^-) = (6.1 \pm 0.9) \times 10^{-5}$ and $\mathrm{BR}(B^0 \to J/\psi K^{*0}, J/\psi \to \mu^+\mu^-) = (9.4 \pm 1.7) \times 10^{-5}$ [11], the limits on the total branching ratio for non-resonant decays, taking into account the uncertainty on the $J/\psi K$ branching ratios, are $\mathrm{BR}(B^+ \to \mu^+\mu^- K^+) < 1.0 \times 10^{-5}$ at 90% C.L. and $\mathrm{BR}(B^0 \to \mu^+\mu^- K^{*0}) < 2.5 \times 10^{-5}$ at 90% C.L.

The $B^0_{d,s} \to \mu^+\mu^-$ search proceeds along the same lines as the $B^+ \to \mu^+\mu^- K^+$ analysis, with the exception of elements related to the K^+. The two muons are constrained to come from a common point with a confidence level greater than 1% and the proper decay distance of the dimuon system in the transverse plane is required to be greater than 100 μm. The background is higher than in the $B^+ \to \mu^+\mu^- K^+$ search because the constraint of a common point on two tracks is less stringent than on three or more tracks. To compensate, $B^0_{d,s} \to \mu^+\mu^-$ candidates are required to satisfy a tighter isolation requirement of $I > 0.7$. The efficiency for the $I > 0.7$ requirement is $83 \pm 6\%$. Additionally, in order to normalize to the B meson production cross section measured in CDF data, only B candidates with $p_T > 6$ GeV/c are considered.

The mass distribution of $B^0_{d,s} \to \mu^+\mu^-$ candidates is shown in Figure 2. We define the signal regions to be within 75 MeV/c^2 around the measured masses of the B mesons [11]. In these mass windows there are no B_d candidates and one B_s candidate. The number of candidates is consistent with the rate of background events seen outside the mass windows.

The upper limit on the branching fractions is calculated from the formula

$$\mathrm{BR}(B^0_{d,s} \to \mu^+\mu^-) < \frac{N_{\mathrm{limit}}}{2\sigma(B^0_{d,s}) \cdot \mathcal{L} \cdot \epsilon} \quad ,$$

where N_{limit} is the number of candidates allowed at 90% C.L., $\sigma(B^0_{d,s})$ is the production cross section for each B meson species in the kinematic region $p_T(B) > 6$ GeV/c and $|y(B)| < 1$, ϵ is the total reconstruction efficiency in this same kinematic region, and $\mathcal{L}$ is the integrated luminosity of the data sample. $\sigma(B^0_{d,s})$ is obtained from the measured cross section for B^+ only, *i.e.* excluding B^-, $\sigma(B^+; p_T(B) > 6; |y(B)| < 1) = 2.39 \pm 0.54$ μb [12] with the assumption $\sigma(B^+) = \sigma(B^0) = 3\sigma(B^0_s)$. To be conservative, N_{limit} is computed assuming that the single B^0_s candidate is a signal event. The efficiency of the kinematic cuts on the muons is determined from Monte Carlo simulation. Single b quarks are generated according to the QCD calculation of Nason, Dawson and Ellis [13] and are subsequently fragmented using Peterson fragmentation [14] with $\epsilon_B = 0.006$. Mesons satisfying the kinematic requirements $p_T(B) > 6$ GeV/c and $|y(B)| < 1$ are decayed into dimuon pairs which are then passed through the CDF detector simulation.

The efficiency of the requirement on the confidence level of the vertex constraint is measured in $J/\psi \to \mu^+\mu^-$ events. The efficiency of the isolation requirement is obtained from fully reconstructed $B^0 \to J/\psi K^{*0}$ decays. The efficiencies for the mass window and proper decay length requirements are determined from a Monte Carlo calculation. The combined acceptance and efficiency for detection of this decay with our selection cuts is $1.8 \pm 0.2\%$, with most of the uncertainty coming from the efficiency of the isolation and mass window requirements.

The uncertainties in the cross section and the reconstruction efficiency are treated as Gaussian and are convoluted with the Poisson distribution for the number of observed events. The final 90% C.L. limits are $\mathrm{BR}(B^0 \to \mu^+\mu^-) < 1.6 \times 10^{-6}$ and $\mathrm{BR}(B_s^0 \to \mu^+\mu^-) < 8.4 \times 10^{-6}$.

In conclusion, no signal has been observed for FCNC decays. The resulting limits for $B^+ \to \mu^+\mu^- K^+$ and $B^0 \to \mu^+\mu^- K^{*0}$ are consistent with previous results from the CLEO experiment [15]. The $B^0 \to \mu^+\mu^-$ limit is a significant improvement over previously published results [16,17]. The $B_s^0 \to \mu^+\mu^-$ limit is the first result on this mode.

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[1] A. Ali and T. Mannel, Phys. Lett. B **264**, 447 (1991). Erratum, Phys. Lett. B **274**, 526 (1992).

[2] N. Isgur and M. B. Wise, Phys. Lett. B **232**, 113 (1989); **237**, 527 (1990). C. A. Dominguez, N. Paver, and Riazuddin, Z. Phys. C., **48**, 55 (1990). A. Ali and T. Mannel, Phys. Lett. B

264, 447 (1991).

[3] N. G. Deshpande, K. Panose and J. Trampetić, Phys. Lett. B, **308** 322 (1993).

[4] F. Abe *et al.*, Nucl. Instrum. Methods Phys. Res., Sect. A **271**, 376 (1988), and references therein. The silicon vertex detector is described in F. Abe *et al.*, Phys. Rev. D**50**, 2966 (1994).

[5] In CDF, the positive z axis lies along the proton direction, r is the radius from this axis, θ is the polar angle and ϕ is the azimuthal angle. The pseudorapidity, η, is defined as $-\ln\left[\tan(\theta/2)\right]$.

[6] G. Foster *et al.,* Nucl. Instrum. Methods Phys. Res., Sect. A **269**, 93 (1988).

[7] In this paper references to a specific charge state imply the charge-conjugate state as well.

[8] The number of fully reconstructed B mesons is lower in this analysis than in previous CDF publications (e.g. [12]) because of the tighter cuts applied in the current analysis. The selection of these tighter requirements was the result of an optimization of the signal to noise in the expected non-resonant channels.

[9] G. Baillie, Z. Phys. C, **61**, 667 (1994).

[10] O. Helene, Nucl. Instrum. Methods Phys. Res., Sect. A **212**, 319 (1982); G. Zech, Nucl. Instrum. Methods Phys. Res., Sect. A, **277**, 608 (1989).

[11] L. Montanet *et al.*, Phys. Rev. D **50**, 1173 (1994).

[12] F. Abe *et al.,* Phy. Rev. Lett. **75**, 1451 (1995).

[13] P. Nason, S. Dawson and R.K. Ellis, Nucl. Phys. B **303**, 607 (1988); B **327**, 49 (1989); B **335**, 260 (1990).

[14] C. Peterson, D. Schlatter, I. Schmitt, P. M. Zerwas, Phys. Rev. D **27**, 105 (1983).

[15] R. Balest *et al.*, CLEO-CONF 94-4, submission to ICHEP94 conference, Glasgow (1994).

[16] R. Ammar *et al.*, Phys. Rev. D**49**, 5701 (1994).

[17] C. Albajar *et al.*, Phys. Lett. B**262**, 163 (1991).

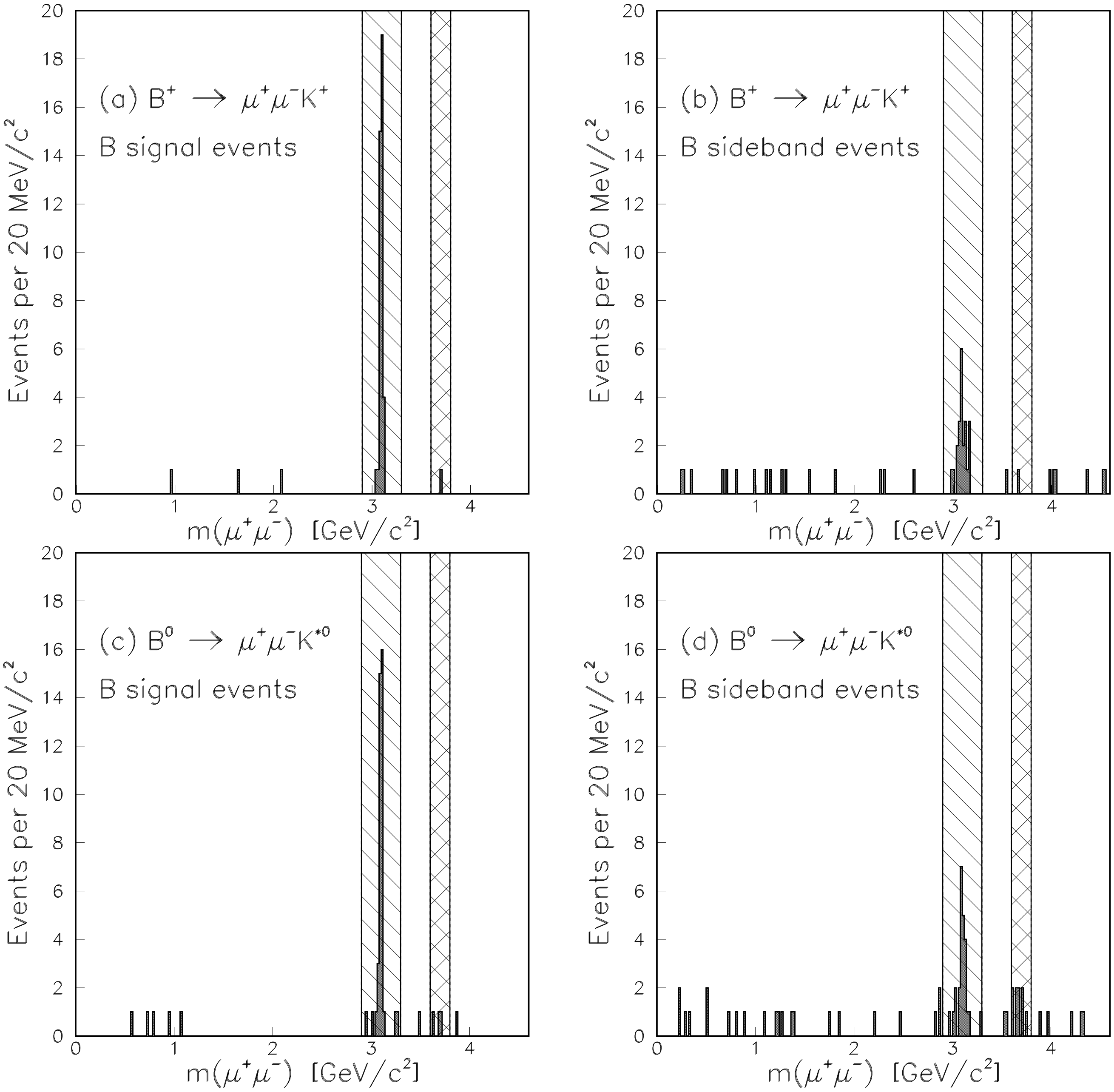

FIG. 1. Invariant mass distribution of the dimuon pair in $B^+ \to \mu^+\mu^- K^+$ candidates: (a) for events in the B^+ mass range and (b) for events in the B^+ sideband mass region. The regions excluded from the non-resonant search are hatched. The mass range 3.062–3.132 GeV/c^2 inside the singly–hatched region is used for $B^+ \to J/\psi K^+$ events. Figures (c) and (d) are the respective distributions for the $B^0 \to \mu^+\mu^- K^{*0}$ candidates.

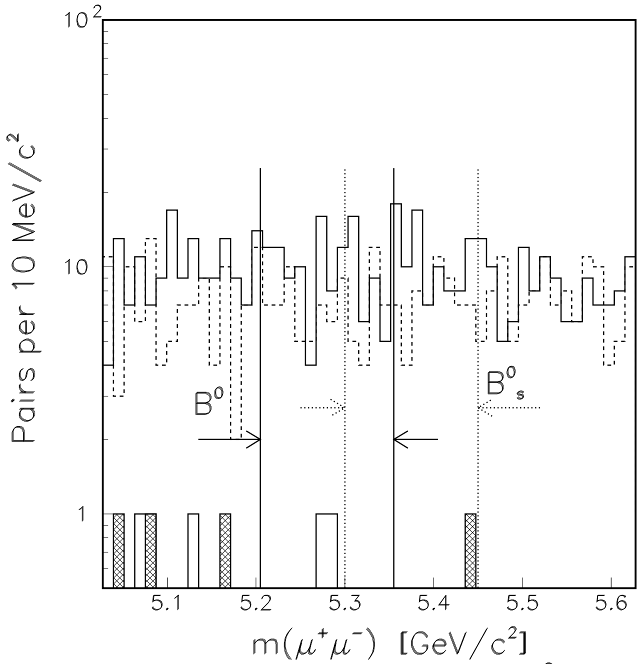

FIG. 2. Invariant mass distribution of the dimuon pair in $B^0_{d,s} \to \mu^+\mu^-$ candidates. The unshaded solid (dashed) line is the spectrum of the unlike (like) sign dimuons before the requirements on the transverse proper decay length and the isolation of the B candidate. The shaded (unshaded) histogram is the final spectrum for unlike (like) sign candidates. The windows for the B_d (B_s) candidates are indicated with the solid (dashed) lines.