Fermi National Accelerator Laboratory

FERMILAB-Conf-96/253-E
D0

Search for b $\rightarrow$ X $\mu^+\mu^-$ and B$^0 \rightarrow \mu^+\mu^-$ Decays in p$\bar{\text{p}}$ Collisions at $\sqrt{s}$ = 1.8 TeV

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The D0 Collaboration

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August 1996

Submitted to the *28th International Conference on High Energy Physics (ICHEP96)*, Warsaw, Poland, July 25-31, 1996

Operated by Universities Research Association Inc. under Contract No. DE-AC02-76CHO3000 with the United States Department of Energy

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FERMILAB Conf-96/253-E

Search for $b \to X\mu^+\mu^-$ and $B^\circ \to \mu^+\mu^-$ Decays in $p\bar{p}$ Collisions at $\sqrt{s}$ =1.8 TeV

The DØ Collaboration[1]

(July 1996)

We have searched for the flavor-changing neutral current decays $b \to X\mu^+\mu^-$ and $B^\circ \to \mu^+\mu^-$ in $p\bar{p}$ collisions at $\sqrt{s}$ =1.8 TeV with the DØ detector at Fermilab. Using our observed $\mu^+\mu^-$ mass spectrum and the measured b quark production cross section we determine the 90% confidence limit for the branching fraction $\mathrm{B}(b \to s\mu^+\mu^-) < 3.6{\cdot}10^{-5}$. For the exclusive, purely leptonic decay $B^\circ \to \mu^+\mu^-$ we obtain a 90% confidence level limit $\mathrm{B}(B^\circ \to \mu^+\mu^-) < 8.0{\cdot}10^{-6}$.

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[1]Submitted to the 28th International Conference on High Energy Physics, Warsaw, Poland, 25-31 July 1996.

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INTRODUCTION

In the Standard Model (SM) the decay processes $b \to X\mu^+\mu^-$ and $b \to \mu^+\mu^-$ are forbidden at the tree level and are possible only through loop diagrams. The largest contributions come from diagrams involving top quark and therefore these decays are sensitive to the top quark mass. Note that the 'rare' flavor-changing neutral current (FCNC) decays for b quarks are expected to be relatively frequent compared to the case of strange quark decays. The $b \to c$ transition is suppressed by $|V_{bc}| = O(10^{-1})$ while loop corrections are large due to $|V_{tb}| \approx 1$ and large top quark mass, m_t. At m_t= 170 GeV/c^2, the SM expected branching fraction (1) for the semi-inclusive decay $b \to X\mu^+\mu^-$ is $6{\cdot}10^{-6}$. The best limit, set by the UA1 Collaboration (2), is $5{\cdot}10^{-5}$. For the exclusive decay $B^\circ \to \mu^+\mu^-$ the SM prediction is $1.5{\cdot}10^{-10}$ whereas the lowest limit for this decay is $1.6{\cdot}10^{-6}$, set by the CDF (3) Collaboration. Extentions to the minimal Standard Model involving new particles in the loop, such as a fourth generation, charged Higgs or Supersymmetric particles, provide additional possible sources of FCNC. Precision measurements of rare b decay rates extend the new physics discovery potential beyond direct searches. We describe a search for such decays in the data collected by the DØ Collaboration during the 1994-1995 Tevatron collider run.

DATA SELECTION

The data correspond to a total integrated luminosity of 45.7 pb^{-1}. Dimuon events are selected by requiring two muons at both hardware and software trigger levels (4). We select events containing an opposite charge muon pair with the invariant mass $M_{\mu\mu} < 7$ GeV/c^2 and transverse momentum $p_T^{\mu\mu} > 5$ GeV/c. The muons are required to have a transverse momentum $p_T^{\mu} > 3$ GeV/c and the pseudorapidity $|\eta_\mu| < 1.0$ ($\eta_\mu = -\ln[\tan(\theta/2)]$ where θ is the polar angle with respect to the beam axis).

Each muon track must have at least six (out of possible 10) hits in the muon detector, and the two muons must have at least 14 hits total. Both muon trajectories are required to be consistent with the reconstructed vertex position and to have a matching track in the central detector. There must be a track-like object reconstructed in the calorimeter, with positive energy in at least three out of maximum four hadronic layers, consistent with the muon trajectory. The total energy detected in the calorimeter cells traversed by a muon track and their nearest neighbors is required to exceed 1 GeV. The total number of events satisfying the above criteria is 1349.

SEARCH FOR THE DECAY $b \to X\mu^+\mu^-$

The dimuon mass spectrum for events satisfying the selection criteria discussed in the previous section is shown in Fig.1. In the mass range $2 < M_{\mu\mu} < 7$ GeV/c^2 the spectrum is well described by the J/ψ and ψ' resonances and background, parametrized as a superposition of a Gaussian and a constant, simulating the sum of the known physics processes (5): the sequential semileptonic decay $b \to c + \mu$, $c \to \mu$, $b\bar{b}$ and $c\bar{c}$ events with both heavy quarks decaying semileptonically and virtual photon decays (the Drell-Yan process).

We use the ratio N(ψ')/N(J/ψ) =6%, based on the recent results from the CDF collaboration (6) corrected for the dependence of the dimuon detection efficiency on $M_{\mu\mu}$. The ψ' mass is fixed at 3.69 GeV/c^2 and its width is assumed to be 20% higher than the J/ψ width. The mass, width and number of events due to the J/ψ resonance are fit parameters. The best fit gives the J/ψ mass equal 3.05 ± 0.02 GeV/c^2 and the width of the J/ψ signal equal 0.29 ± 0.02 GeV/c^2, or $\approx$10% of the mass. In order to minimize the effects of long-distance, resonance decays $B \to X\ J/\psi$ and $B \to X\ \psi'$, we define the search window above the ψ' mass, $3.9 < M_{\mu\mu} < 4.6$ GeV/c^2. We find no evidence for an excess of events in our search window: we observe 33 events, with 44 ± 4 expected.

We use a Monte Carlo simulation of the $b \to X\mu^+\mu^-$ decay to determine the efficiency of the hardware and software trigger and to estimate the acceptance for kinematic and geometric restrictions on the two muons coming from a decay of a b quark with $p_T(b) >$ 6 GeV/c and $|y(b)| < 1$. Events with b quarks are generated with the ISAJET program. Quarks satisfying the above kinematic requirements are subsequently fragmented according to the Peterson fragmentation model (7). B mesons produced in the b quark fragmentation are forced to produce a pair of muons with the invariant mass spectrum taken from Ref. (8). The calculated spectrum, normalized to unity, is shown in Fig.2(a).

Events that satisfy the muon pseudorapidity cut and muon and dimuon momentum cuts mentioned in the previous section are passed through a detector simulation, trigger and software filter simulation and offline reconstruction programs. (No offline selection cuts are applied at this stage). The simulated spectrum for detected dimuons from the $b \to X\mu^+\mu^-$ decay is shown in Fig.2(b). The integral of the spectrum within our search range gives the the combined effect of the geometric and kinematic acceptance and trigger efficiency for this channel, $\epsilon = 0.0018 \pm 0.0002$. The main sources of the 10% systematic uncertainty is

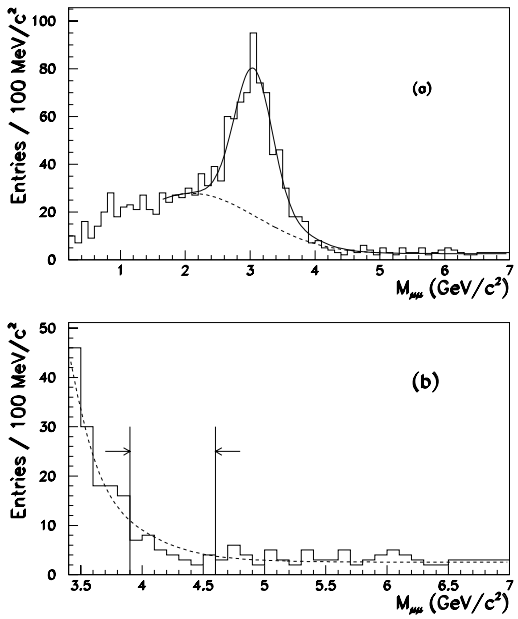

FIG. 1. The invariant mass distribution for dimuons with $p_T^{\mu\mu} > 7$ GeV/c (a), and (b) expanded view of (a). The arrows indicate the search window for the decay $b \to X\mu^+\mu^-$.

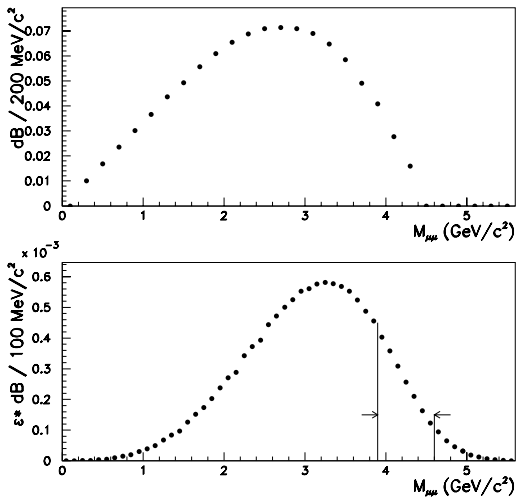

FIG. 2. (a) The calculated differential branching fraction for the decay $b \to X\mu^+\mu^-$, Ref. [8] (b) The simulated invariant mass distribution for dimuons from the decay $b \to X\mu^+\mu^-$ in the DØ detector. The arrows indicate the search window used in this analysis.

a variation of the muon chamber efficiency over the data taking period.

The offline selection efficiency is determined as follows. Monte Carlo studies indicate that the efficiency of the offline selection cuts for a muon pair near $M_{\mu\mu} = 4$ GeV/c^2 is the same as for the J/ψ events. We compare the number of all J/ψ events passing the dimuon trigger, 2573 $\pm$ 170, to the number of triggered J/ψ events that satisfy our selection offline cuts, 448 $\pm$ 39. The resulting offline selection efficiency is $\epsilon_{\rm off}$ =0.17 $\pm$ 0.02.

The inclusive b quark production cross section for $p_T(b) > 6$ GeV/c and $|y(b)| < 1$ is 7.2 $\pm$ 1.5 μb. This estimate is based on a compilation of DØ measurements (9) of the inclusive muon and dimuon production. The 21% uncertainty is related to the procedure of retracing the hadronization and decay processes leading from b quarks to final state containing a muon or a dimuon (12% due to the assumed p_T shape of the b quark distribution, 13% due to the B hadron leptonic branching fraction and decay parameters), and to the estimate of the fraction of muon (dimuon) events due to the b quark decay (12%). Note that uncertainties due to the integrated luminosity and due to the $b \to B$ fragmentation function cancel out in the expression for the branching fraction for the decay $b \to X\mu^+\mu^-$ given below:

$$B(b \to s\mu^+\mu^-) = \frac{N_{\rm limit}}{2 \cdot \sigma(b) \cdot \mathcal{L} \cdot \epsilon \cdot \epsilon_{\rm off}} \tag{1}$$

We obtain a 90% confidence level limit of B($B \to \mu^+\mu^- X$) $< 3.6 \cdot\ 10^{-5}$. To derive the limit, we have applied the Bayesian approach in which the observed number of events is compared to the number of background events in the region of interest. We assume Poisson statistics for the signal and background and account for uncertainty in background and in the estimates of the total cross section and of the dimuon detection effciency.

SEARCH FOR THE DECAY $B^\circ \to \mu^+\mu^-$

For the exclusive decay $B^\circ \to \mu^+\mu^-$ (an unseparated mixture of B_d and B_s decays) we define the search window as $4.8 < M_{\mu\mu} < 5.8$ GeV/c^2. The efficiency for this selection is 0.60 $\pm$ 0.03. In this process, the two muons are expected to carry a large fraction of the energy in a cone around the direction of the parent b quark. To reduce background, we select events with the energy deposition in the calorimeter in a cone $\Delta R <$ 0.6 around each muon being less than 8 GeV. The efficiency of this requirement is 0.80 $\pm$ 0.03. The dimuon mass spectrum for isolated dimuons is shown in Fig.3. We find 13 events in the search region. We assume that all events in the mass range $4.3 < M_{\mu\mu} < 7$ GeV/c^2 are due to the known sources of isolated dimuons, predominantly tails of the J/ψ and ψ' resonances and the Drell-Yan process. The background in the search window is estimated to be 14.5 $\pm$ 2.7 events.

The B° production cross section at $p_T(B) > 6$ GeV and $|y(B)| < 1$, measured by the CDF collaboration (3), is 2.39 $\pm$ 0.54 μb. The combined effect of (1) the acceptance for kinematic and geometric restrictions on the two muons coming from a decay of a B° meson and (2) the efficiency of the hardware and software trigger determined by a Monte Carlo simulation, is $\epsilon = 0.050 \pm 0.003$. As in the case of the $b \to X\mu^+\mu^-$ decay, the efficiency for the offline requirements is found to be the same as for the J/ψ resonance. We obtain a 90% confidence level limit of B($B^o \to \mu^+\mu^-$) $< 8.0 \cdot 10^{-6}$.

CONCLUSIONS

In conclusion, we have conducted a search for the FCNC decays $b \to X\mu^+\mu^-$ and $B^\circ \to \mu^+\mu^-$. We find no evidence for either decay. For the semi-inclusive decay $b \to X\mu^+\mu^-$

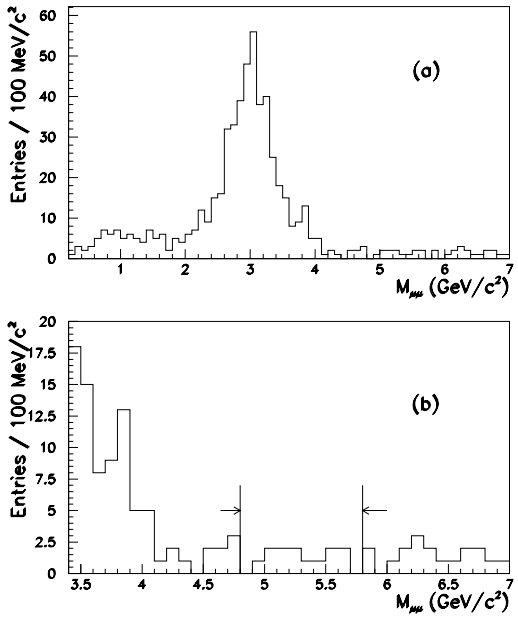

FIG. 3. The invariant mass distribution for isolated dimuons with $p_T^{\mu\mu} > 7$ GeV/c (a), and (b) expanded view of (a). The arrows indicate the search window for the decay $B^\circ \to \mu^+\mu^-$.

we set a 90% confidence limit of $\mathrm{B}(B \to \mu^+\mu^- X) < 3.6 \cdot 10^{-5}$. For the exclusive decay $B^\circ \to \mu^+\mu^-$ (an unseparated mixture of B_d and B_s decays) we obtain a 90% confidence level limit of $\mathrm{B}(B^o \to \mu^+\mu^-) < 8.0 \cdot 10^{-6}$.

ACKNOWLEDGMENTS

We thank the staffs at Fermilab and the collaborating institutions for their contributions to the success of this work, and acknowledge support from the Department of Energy and National Science Foundation (U.S.A.), Commissariat à L'Energie Atomique (France), Ministries for Atomic Energy and Science and Technology Policy (Russia), CNPq (Brazil), Departments of Atomic Energy and Science and Education (India), Colciencias (Colombia), CONACyT (Mexico), Ministry of Education and KOSEF (Korea), CONICET and UBACyT (Argentina), and the A.P. Sloan Foundation.

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6. Preliminary CDF results on the ratio of ψ' and J/ψ production rates are available on WWW at http://www-cdf.fnal.gov/physics/new/bottom/cdf3561/cdf3561.html. CDF has measured the ratio of branching fractions of $B \to J/\psi$ and $B \to \psi'$ as ≈ 0.033 and the ratio of the cross section for directly produced J/ψ and ψ' as ≈ 0.046. Taking these ratios in the proportion 1:2 and accounting for the dimuon detection efficiency at DØ proportional to $M^2_{\mu\mu}$ we obtain the expected ratio of the number of events of ψ' and J/ψ in our sample to be ≈ 0.06.
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