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Rare B and D Decays at CDF

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The confidence level limits of the CDF search for the D^0, B_s^0 and $B_d^0 \to \mu^+\mu^-$ rare decays are presented. The branching ratio measurements of B_d^0, B^+ and $B_s^0 \to \mu^+\mu^- h$ $(h = K^+, K^{*0}, \phi)$ and first observation of $B_s^0 \to \mu^+\mu^-\phi$ are shown. The first measurements at a hadron collider of the forward backward asymmetry in the B^+ and B_d^0 decays are also presented.

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1. Introduction

Rare decays are sensitive to beyond the Standard Model (SM) physics which may enter in the box or penguin diagrams by which they decay. The searches for the D^0, B_d^0 and $B_s^0 \to \mu^+\mu^-(h)$ rare decays at the Tevatron are strong indirect tests of the SM. Here we present measurements in these decay modes.

2. Search for $B_d^0, B_s^0 \to \mu^+\mu^-$

In the SM, the flavour changing neutral current decays $B \to \mu^+\mu^-$ ($B = B_s^0$ or B_d^0) proceed through loop diagrams and are thus heavily suppressed. The predicted branching ratio of the $B_s^0 \to \mu^+\mu^-$ is $(3.4 \pm 0.5) \times 10^{-9}$ and the $B_d^0 \to \mu^+\mu^-$ decay is further CKM suppressed[1] to $(1.00 \pm 0.14) \times 10^{-10}$. These branching ratios are both below the sensitivity of the Tevatron experiments, and so an observation of these decay modes would call into question the SM branching ratio prediction, independently of any model interpretation.

The experimental challenge of a search for $B \to \mu^+\mu^-$ is the large combinatorial background present in a hadron collider. The key elements of the analysis are to select discriminating variables in order to reject background, to determine the efficiencies for observing these decays and to estimate the remaining background contribution.

The CDF collaboration has searched for $B \to \mu^+\mu^-$ in 3.7fb^{-1} of data. This is an update of the published analysis [2] and is documented in [3]. Oppositely charged μ pairs are sought in both the B_s^0 and B_d^0 mass windows.

The analysis begins by reconstructing the normalisation mode, $B^+ \to J/\Psi K^+$ with which a relative branching ratio for the $B \to \mu^+\mu^-$ is obtained. The B^+ candidates are shown in figure 1. CDF has dedicated rare B decay triggers which require two muons in a pseudorapidity region of $|\eta| \leq 1.0$. The analysis is divided into two types of muon pair, central-central (CMU-CMU), where central corresponds to $|\eta| \leq 0.6$, and central-extension (CMU-CMX), where extension corresponds to $0.6 < |\eta| \leq 1.0$.

A neural network is constructed to select the $B \to \mu^+\mu^-$ signal and suppress backgrounds. Rather than make a cut on the neural network output value, results are combined from several bins with the choice of bins optimised for the best expected limit on the branching ratio. The remaining expected background is assessed by extrapolating from sideband regions, and the relative efficiency and acceptance for the $B \to \mu^+\mu^-$ with respect to the normalisation mode are obtained from Monte Carlo simulations and data. Then, the branching ratio is obtained relative to the control sample, $B^+ \to J/\Psi K^+$:

$$BR(B_s^0 \to \mu^+\mu^-) = \frac{N_{B_s}}{N_{B^+}} \frac{\alpha_{B^+}\varepsilon_{B^+}^{base}}{\alpha_{B_s}\varepsilon_{B_s}^{base}} \frac{1}{\varepsilon_{B_s^0}^{NN}} \frac{f_u}{f_s} \times BR(B^+ \to J/\Psi K^+) \times BR(J/\Psi \to \mu^+\mu^-) \qquad (2.1)$$

Here, N_{B^+} is the yield of $B^+ \to J/\Psi K^+$ in the control sample, N_{B_s} is the yield of $B_s^0 \to \mu^+\mu^-$ decays, α_{B^+,B^0} are the acceptances and $\varepsilon_{B^+,B^0}^{base}$ are the efficiencies of the preselection for the decay modes and $\varepsilon_{B_s^0}^{NN}$ is the efficiency of the neural network to select the signal. The yields, N_{B^+} and N_{B_s}, are corrected by the relative production fractions, f_u and f_s, and the branching ratios of the control

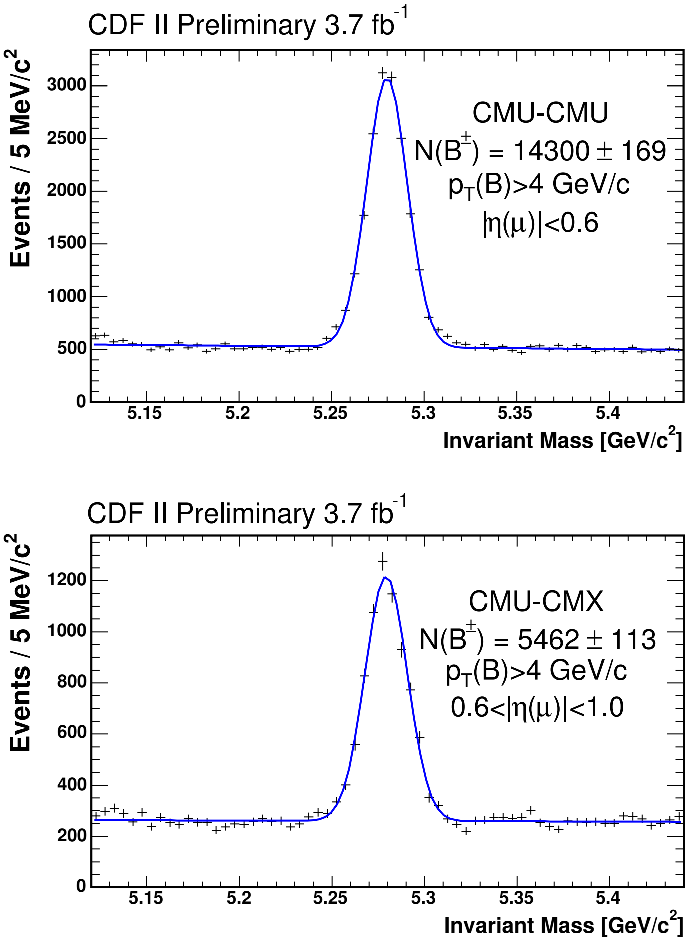

Figure 1: Invariant mass of control channel $B^+ \to J/\Psi K^+$ candidates.

sample are incorporated. In the B_d^0 analysis the calculation is made in the same way, dropping the f_u/f_s term.

Three variables are employed to distinguish signal from background. First, the pointing angle, α, is defined as the difference in ϕ angle between the B momentum direction and the B direction as given by the three dimensional vertexing procedure. Second, the isolation of the B meson is defined by

$$Iso = \frac{p_t(B)}{pt(B) + \sum_i p_t^i(\Delta R < 1.0)} \tag{2.2}$$

where the sum is over all tracks within a cone of $\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$ of 1.0. The third variable is the proper decay length which is defined by $\lambda = cLM(B)/p(B)$ where L is the 3d decay length.

The discriminating variables are combined into a neural network discriminant using probability density functions of the discriminating variables taken from data sidebands for the background distribution and Pythia Monte Carlo samples for the signal distribution. The signal and background neural net distributions are shown in figure 2. An optimisation of the binning of the neural net out-

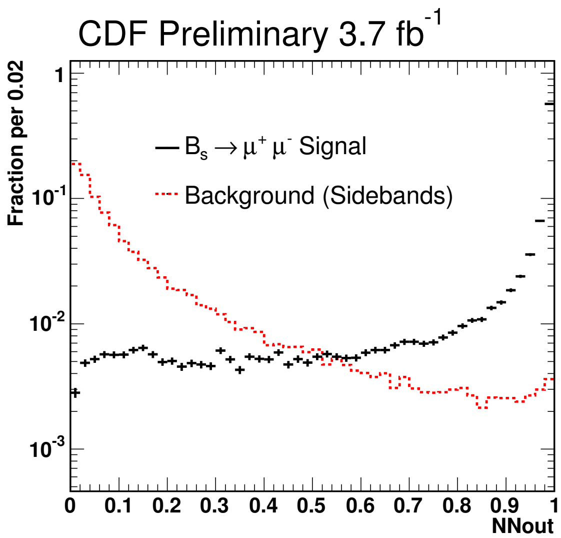

Figure 2: Neural network discriminant for signal and background regions.

	B_s^0 (B_d^0)	
	CMU-CMU	CMU-CMX
Expected Bkg	4.00±1.00(5.30±1.00)	2.08±0.78(2.78±0.78)
Observed	3 (5)	4 (3)
90%C.L. Limit	3.6×10^{-8} (6.0×10^{-9})	
95%C.L. Limit	4.3×10^{-8} (7.6×10^{-9})	

Table 1: Summary of expected and observed events and resulting limits.

put is then performed to achieve the best 90% confidence level limit. A Bayesian approach is used for this optimisation which takes into account statistical and systematic errors.

The expected background in the B signal region is obtained by extrapolating the number of sideband events into the signal region. The expected background values are shown in table 1. The background estimate compares well with the number of events found in several control regions.

The unblinded invariant mass versus the neural network output of the dimuon candidate is shown in figure 3. The expected and observed number of events and the resulting limits are shown in table 1.

3. Branching ratios of B_d^0, B^+ and $B_s^0 \to \mu^+\mu^- h$ and forward backward asymmetry of B_d^0 and B^+

The $b \to s\mu^+\mu^-$ processes are flavour changing neutral currents which are forbidden at tree level in the SM but allowed through highly suppressed internal loops. New physics could manifest itself in a larger branching fraction or in angular distributions of the decay products which are different from those predicted by the SM. The branching ratios of the processes $B_d^0 \to \mu^+\mu^- K^{*0}$,

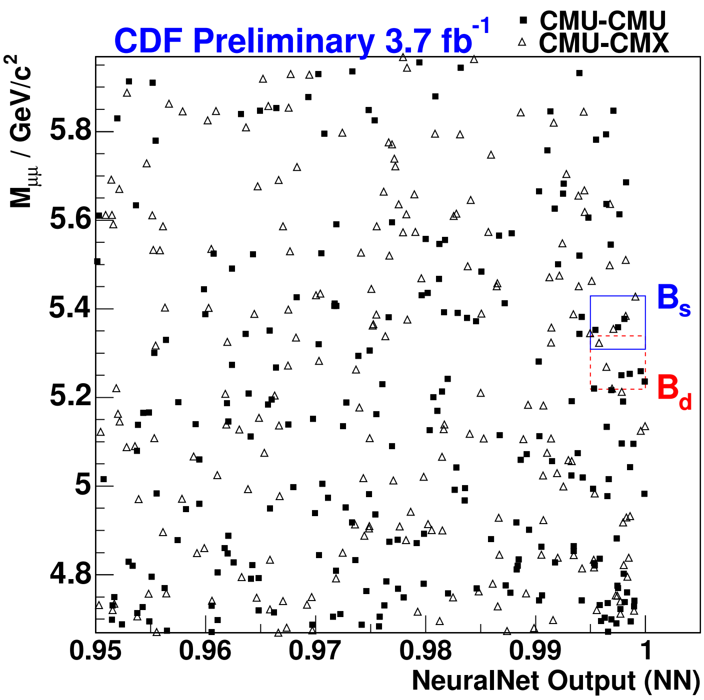

Figure 3: Invariant mass of $B \to \mu^+\mu^-$ candidates.

$B^+ \to \mu^+\mu^- K^+$ and $B_s^0 \to \mu^+\mu^-\phi$ have been measured in 4.4fb$^-$1 of CDF Run II data relative to the equivalent $B \to J/\psi h$ decay ($h = K^{*0}/K^+/\phi$). Many systematic uncertainties cancel in the relative branching ratios:

$$BR(B \to \mu^+\mu^- h) = \frac{N^{NN}_{\mu^+\mu^- h}}{N^{loose}_{J/\psi h}} \frac{\varepsilon^{loose}_{J/\psi h}}{\varepsilon^{loose}_{\mu^+\mu^- h}} \frac{1}{\varepsilon^{NN}_{\mu^+\mu^- h}} \times BR(B \to J/\Psi h) \times BR(J/\Psi \to \mu^+\mu^-) \quad (3.1)$$

The event selection proceeds by requiring a pair of muon candidates that satisfy the trigger requirements and which together with the hadron candidate form a single vertex in three dimensional space to form a B candidate. The χ^2 probability of the vertex fit is required to be greater than 10^{-3}. The hadron, h, is required to have transverse momentum greater than 1GeV/c and the B candidate greater than 4 GeV/c. The distance of closest approach between the B flight path and the beam line must be less than 120 μm to reduce combinatorial background. Normalisation mode candidates are identified by requiring a dimuon invariant mass within 50 MeV/c^2 of the J/ψ mass. Contributions from B decays to charm are reduced by several vetoes on invariant mass ranges. A loose selection is applied to obtain the normalisation modes and their invariant mass distributions are shown in figure 4. A neural network is used to distinguish signal and background in the selection of the rare decay modes and its efficiency is taken from Monte Carlo simulations. The absolute branching ratio measurements are: BR($B^+ \to \mu^+\mu^- K^+$)= [0.38±0.05(stat)±0.03(syst)]$\times 10^{-6}$; BR($B_d^0 \to \mu^+\mu^- K^{*0}$)= [1.06±0.14(stat)±0.09(syst)]$\times 10^{-6}$; BR($B_s^0 \to \mu^+\mu^-\phi$)=[1.44±0.33(stat)±0.46(syst)]$\times 10^{-6}$. This measurement constitutes the first observation of the $B_s^0 \to \mu^+\mu^-\phi$ decay.

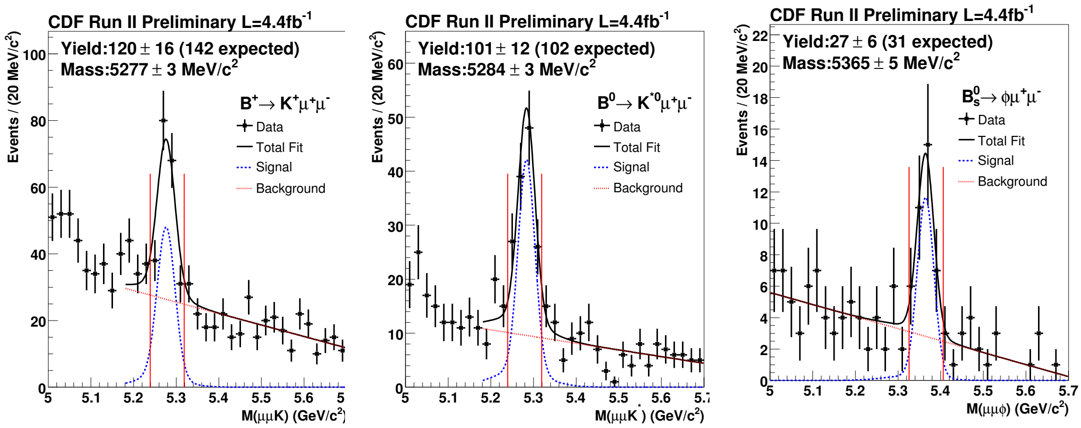

Figure 4: Invariant mass distributions of the control modes.

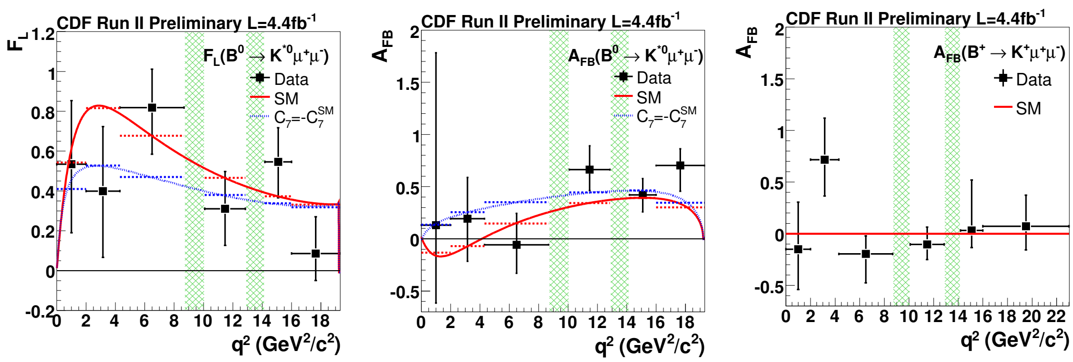

Figure 5: F_L and A_{FB} results for six q^2 bins for $B^0 \to \mu^+\mu^-K^{*0}$ and $B^+ \to \mu^+\mu^-K^+$.Hatched regions are charmonium vetoes.

The forward backward asymmetry and K^{*0} longitudinal polarisation (F_L) are extracted from $\cos\theta_\mu$ and $\cos\theta_K$ distributions where θ_μ is the helicity angle between the μ^+ (μ^-) direction and the opposite of the B ($\overline{B}$) direction in the dimuon rest frame and θ_K is the angle between the kaon and the direction opposite the B meson in the K^{*0} rest frame. An unbinned likelihood fit is made to extract A_{FB} and F_L:

$$\mathscr{L} = \Pi(f_{sig}\mathscr{P}_{sig}(M_B)\mathscr{F}_{sig}(\cos\theta) + (1-f_{sig})\mathscr{P}_{bg}(M_B)\mathscr{F}_{bg}(\cos\theta)) \tag{3.2}$$

where f_{sig} is the signal fraction, $\mathscr{P}_{sig}$ ($\mathscr{P}_{bg}$) is the signal (background) PDF of the B mass shape and $\mathscr{F}_{sig}$ ($\mathscr{F}_{bg}$) is the signal (background) PDF of the angular shape. Angular acceptances are considered as binned histograms which are obtained from phase space signal Monte Carlo. The fit is performed in both $B^0 \to \mu^+\mu^-K^{*0}$ and $B^+ \to \mu^+\mu^-K^+$ samples and compared to expectation. The results are shown in figure 5 with SM and non-SM expectations overlaid [4].

Background source	CMU-CMU
Combinatorial	0.040±0.007
$D^0 \to \pi\pi$ double fakes	0.53±0.005
$D^0 \to K\pi$ double fakes	<0.01
Semimuonic D^0 decays	<0.36
Semimuonic B decays	0.54 ± 0.06
Cascade semimuonic B decays	3.8±1.3
Total	4.9±1.3

Table 2: Background contributions to $D^0 \to \mu^+\mu^-$ search.

4. Search for $D^0 \to \mu^+\mu^-$

The decay $D^0 \to \mu^+\mu^-$ is highly suppressed, with an expected branching ratio of approximately 4×10^{-13}. Its cross section could be enhanced in R parity violating SUSY by up to seven orders of magnitude. A search for this decay has been conducted in 0.36 fb^{-1} of CDF Run II data. The branching ratio is measured relative to the control channel $D^0 \to \pi^+\pi^-$ in order to cancel systematic uncertainties. The relative efficiency is obtained from MC. Muon fake rates are obtained from tagged $D^{*-} \to D^0\pi^-$ samples with $D^0 \to K^+K^-$ in order to obtain clean kaon samples. The main backgrounds to this channel come from B decays with cascade semileptonic D decays. The background contributions are shown in table 2 and the resulting limits are BR($D^0 \to \mu^+\mu^-$)< 3.0 $\times 10^{-7}$ at 95% confidence level and <2.1 $\times 10^{-7}$ at 90% confidence level [5].

5. Conclusions

The $D^0, B_d^0, B_s^0 \to \mu^+\mu^-$ rare decays are a powerful probe of new physics and the Tevatron is currently yielding the world's best limits on their branching ratios with which new SO(10) and mSUGRA space can be excluded. The first observation of $B_s^0 \to \mu^+\mu^-\phi$ and the first measurements at a hadron collider of the forward backward asymmetry in $B_d^0 \to \mu^+\mu^-K^{*0}$ and $B^+ \to \mu^+\mu^-K^+$ have been shown.

References

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