For Publisher's use

SEARCHES FOR FCNC DECAYS $B_{S(D)} \to \mu^+\mu-$

M. HERNDON FOR THE CDF AND D0 COLLABORATIONS

Dr. Matthew Herndon, Fermi National Accelerator Laboratory, Johns Hopkins University Group, CDF - M.S. 318, PO Box 500 Batavia, IL 60510, USA

E-mail: herndon@fnal.gov

We report on a search for $B_s^0 \to \mu^+\mu^-$ and $B_d^0 \to \mu^+\mu^-$ decays in $p\overline{p}$ collisions at $\sqrt{s} = 1.96$ TeV using 171 pb^{-1} and 240 pb^{-1} of data collected respectively by the CDF and D0 experiments at the Fermilab Tevatron Collider. The decay rates of these rare processes are sensitive to contributions from physics beyond the Standard Model. The results from the two experiments are a combined branching fraction limit of $\mathcal{B}(B_s^0 \to \mu^+\mu^-) < 2.7 \times 10^{-7}$ and a limit from the CDF experiment of $\mathcal{B}(B_d^0 \to \mu^+\mu^-) < 1.5 \times 10^{-7}$ at 90% confidence level.

1 Introduction

We report on a search for $B_s^0 \to \mu^+\mu^-$ [1] and $B_d^0 \to \mu^+\mu^-$ decays using the upgraded CDF II and D0 detectors at the Tevatron $p\overline{p}$ collider. More detailed explanations of the analysis can be found in Refs.[2].

The rare flavor-changing neutral previously decay $B_s^0 \to \mu^+\mu^-$ is one of the most sensitive probes to physics beyond the Standard Model (SM)[3 4 5 6]. The decay has not been observed and is currently limited to $\mathcal{B}(B_s^0 \to \mu^+\mu^-) < 2.0 \times 10^{-6}$ at 90% confidence level (CL) [7], while the SM prediction is $(3.5 \pm 0.9) \times 10^{-9}$ [8]. The limit on the related branching ratio, $\mathcal{B}(B_d^0 \to \mu^+\mu^-) < 1.6 \times 10^{-7}$ [9], is approximately 1000 times larger than its SM expectation. The $\mathcal{B}(B_s^0 \to \mu^+\mu^-)$ can be significantly enhanced in various supersymmetric (SUSY) extensions of the SM. Minimal supergravity models at large $\tan\beta$ [4 5 6] predict $\mathcal{B}(B_s^0 \to \mu^+\mu^-) \leq \mathcal{O}(10^{-7})$ in regions of parameter space consistent with the observed muon $g-2$ [10] and also with the observed relic density of cold dark matter [11]. $SO(10)$ models [12], which naturally accommodate neutrino masses, predict a branching ratio as large as 10^{-6} in regions of parameter space consistent with these same experimental constraints. R-parity violating SUSY models can also accommodate $\mathcal{B}(B_s^0 \to \mu^+\mu^-)$ up to 10^{-6} [5]. Correspondingly, the $\mathcal{B}(B_d^0 \to \mu^+\mu^-)$ can be enhanced by the same models. Even modest improvements to the experimental limits can significantly restrict the available parameter space of these models.

2 Detectors

The CDF II detector consists of a magnetic spectrometer surrounded by calorimeters and muon chambers and is described in detail in Ref.[13]. Critical components of the CDF II detector for this analysis are a five-layer silicon microstrip detector (SVX II) which provides precise tracking information near the beamline[14], a large area drift chamber(COT) with 96 measurement layers[15], and four layers of planar drift chambers (CMU)[16] which detect muons in the psudorapidity range $\eta < 0.6$ and an additional four layers of planar drift chambers (CMP) which instrument 0.6 m of steel outside the magnet return yoke[17]. The D0 detector is similarly designed, though with a smaller tracking volume and more extensive angular muon and tracking coverage[18]. The D0 central tracking system consists of a silicon microstrip tracker(SMT) and a central fiber track(CFT). The muon detector consists of tracking detectors and scintillation trigger counters in front of toroidal magnets, followed by two more similar layers, after the toroids, which track muons in the psudorapidity range $\eta < 2.0$

3 Trigger and Preselection

The CDF experiment uses data corresponding to an integrated luminosity of $\mathcal{L} = 171 \pm 10$ pb^{-1}[19] while the D0 uses $\mathcal{L} = 240\text{pb}^{-1}$. The data used in this analysis in both experiments are selected by dimuon triggers. The CDF and D0 analysis use multiple trigger paths that are subdivided by the detector subsystem which trigger the muons. An example of a typical trigger is the CDF detectors two CMU muon trigger where the muon candidates must have transverse momentum, $p_T > 1.5$ GeV/c. In addition, the two tracks must originate from the same vertex, be oppositely charged, and have an opening angle inconsistent with a cosmic ray event. Finally, the invariant mass of the muon pair must satisfy $M_{\mu^+\mu^-} < 6$ GeV/c^2.

Both experiments apply a preselection to the triggered data to form a reduced dataset for the analysis. CDF requires the muon candidates to have $p_T > 2$ GeV/c, the vector sum of the muon momenta must satisfy $|\vec{p}_T^{\mu^+\mu^-}| > 6$ GeV/c and applies quality cuts to the muon chamber hit to track matching and the two track vertex. Similarly D0 requires the muon candidates to have $p_T > 2.5$ GeV/c, $|\vec{p}_T^{\mu^+\mu^-}| > 5$ GeV/c and applies muon hit to track matching and vertex quality cuts.

4 Optimization of Analysis Cuts

Both experiments use a 'blind" analysis technique is used to determine the optimal selection criteria. In each case a set of selection criteria are optimized base on simulated signal events and data sideband events. The selection criteria used in the CDF analysis are: the invariant mass of the muon pair ($M_{\mu^+\mu^-}$); the B-candidate proper decay length (λ); the opening angle ($\Delta\Phi$) between

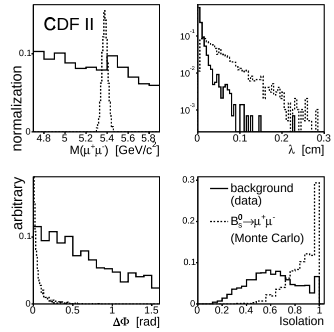

Figure 1. Arbitrarily normalized distributions of the discriminating variables for events in our background-dominated data sample (solid) compared to Monte Carlo $B_s^0 \to \mu^+\mu^-$ events (dashed).

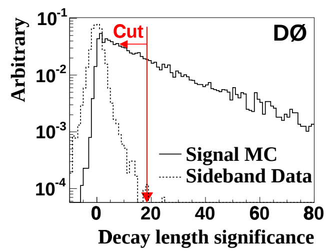

Figure 2. L_{xy} significance after the preselection for signal MC an data events from the sidebands. The arrow indicates the cut value that was obtained after optimization. The normalization is done on the number of signal MC an sideband events after preselection.

the B-hadron flight direction (estimated as the vector $\vec{p}_T^{\mu^+\mu^-}$) and the vector $\vec{L}_T$; and the B-candidate track isolation (I)[20](see figure 1). D0 uses a similar set of variables only replacing λ with transverse decay length significance $L_{xy}/\delta L_{xy}$(see figure 2). In optimizing the selection variables CDF optimizes the uncorrelated variables separately while D0 uses a random grid search over all variables.

The optimal selection criteria in the CDF analysis are determined to be a ± 80 MeV/c^2 search window around the B_s^0 mass, $\lambda > 200$ μm, $\Delta\Phi < 0.10$ rad and $I > 0.65$. The criteria used in the D0 analysis are a ± 180 MeV/c^2 search window around the B_s^0 mass, $L_{xy}/\delta L_{xy} > 18.47$ μm, $\Delta\Phi <$

0.203 rad and $I > 0.56$. The expected background in the signal window is 1.1 ± 0.3 and 3.7 ± 1.1 for the CDF and D0 analysis respectively.

5 Results

With these criteria one event survives the CDF analysis(see fig. 3) and 4 events survive the D0 analysis(see fig. 4) consistent with the background expectations. The CDF events lies in both the B_s^0 and B_d^0 search windows. We derive 90% (95%) CL limits of $\mathcal{B}(B_s^0 \rightarrow \mu^+\mu^-) < 5.8 \times 10^{-7}$ (7.5×10^{-7}) and $\mathcal{B}(B_d^0 \rightarrow \mu^+\mu^-) < 1.5 \times 10^{-7}$ (1.9×10^{-7}) for CDF and $\mathcal{B}(B_s^0 \rightarrow \mu^+\mu^-) < 3.8 \times 10^{-7}$ (4.6×10^{-7}) for D0. The CDF limits used an older value of f_s. Using the same value as used by D) the CDF limit would be $\mathcal{B}(B_s^0 \rightarrow \mu^+\mu^-) < 5.4 \times 10^{-7}$ (7.1×10^{-7}). The two $\mathcal{B}(B_s^0 \rightarrow \mu^+\mu^-)$ limits can be combined using a Bayesian technique giving a combined limit of $\mathcal{B}(B_s^0 \rightarrow \mu^+\mu^-) < 2.7 \times 10^{-7}$ (3.4×10^{-7}) which is considerably better than the single limits. The new $B_s^0 \rightarrow \mu^+\mu^-$ combined limit improves the previous limit[7] by a factor of eight and significantly reduces the allowed parameter space of R-parity violating and $SO(10)$ SUSY models[5,12]. The $B_d^0 \rightarrow \mu^+\mu^-$ limit is slightly better than the recent published limit from the Belle Collaboration[9]. We expect significant improvements to this analysis as we work to increase the signal acceptance and reduce background contributions. In addition both experiments already have collected significantly more data.

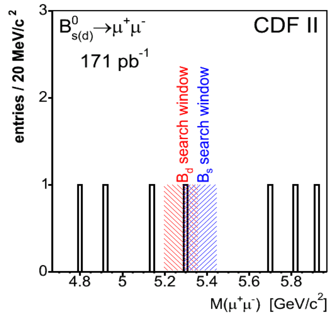

Figure 3. The $\mu^+\mu^-$ invariant mass distribution of the events in the sideband and search regions satisfying all requirements.

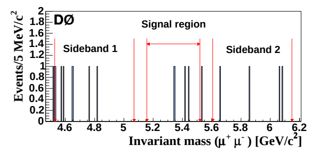

Figure 4. Invariant mass of the remaining events of the full data sample after optimized requirements on the discrimination variables.

References

1. Throughout this paper inclusion of charge conjugate modes is implicit.
2. CDF Collaboration, D. Acosta *et al.*, Phys. Rev. Let. 93, 032001 (2004; D0 Collaboration, V.M. Abazov *et al.*, FERMILAB-Pub-04/215-E.
3. S. R. Choudhury and N. Gaur, Phys. Lett. **B451**, 86 (1999); K.S. Babu and C. Kolda, Phys. Rev. Lett. **84**, 228 (2000); P.H. Chankowski and L. Slawianowska, Phys. Rev. D **63**, 054012 (2001); C. Bobeth *et al.*, Phys. Rev. D **64**, 074014 (2001); A.J. Buras *et al.*, Phys. Lett. **B546**, 96 (2002); S. Baek, P. Ko, and W.Y. Song, Phys. Rev. Lett. **89**, 271801 (2002); A. Dedes and A. Pilaftsis, Phys. Rev. D **67**, 015012 (2003); G.L. Kane, C. Kolda, and J.E. Lennon, `hep-ph/0310042`.
4. A. Dedes, H.K. Dreiner, and U. Nierste, Phys. Rev. Lett. **87**, 251804 (2001).
5. R. Arnowitt *et al.*, Phys. Lett. **B538**, 121 (2002).
6. H. Baer *et al.*, JHEP **07**, 050 (2002).
7. CDF Collaboration, F. Abe *et al.*, Phys. Rev. D **57**, 3811 (1998).
8. G. Buchalla and A.J. Buras, Nucl. Phys. **B398**, 285 (1993); *ibid.* Nucl. Phys. **B400**, 225 (1993); *ibid.* Nucl. Phys. **B548**, 309 (1999); M. Misiak and J. Urban, Phys. Lett. **B451**, 161 (1999).

9. Belle Collaboration, M.C. Chang *et al.*, Phys. Rev. D **68**, 111101(R) (2003).
10. Muon g-2 Collaboration, G.W. Bennett *et al.*, Phys. Rev. Lett. **92**, 161802 (2004).
11. D.N. Spergel *et al.*, Astrophys. J. Suppl. **148**, 175 (2003).
12. R. Dermisek *et al.*, JHEP **04**, 037 (2003); D. Auto *et al.*, JHEP **06**, 023 (2003).
13. CDF II Collaboration, R. Blair *et al.*, FERMILAB-PUB-96/390-E (1996).
14. A. Sill *et al.*, Nucl. Instrum. Meth. A **447**, 1 (2000).
15. T. Affolder *et al.*, Nucl. Instrum. Meth. A **526**, 249 (2004).
16. G. Ascoli *et al.*, Nucl. Instrum. Meth. A **268**, 33 (1988).
17. T. Dorigo *et al.*, Nucl. Instrum. Meth. A **461**, 560 (2001).
18. V. Abazov, *et al.*, in preperation for submission to Nucl. Inftrum. Methods Phys. Res. A; T. Leccompte and H.T. Diehl, "The CDF and D0 Upgrades for Run II, Ann. Rev. Nucl. Part. Sci, **50**, 71 (2000).
19. D. Acosta *et al.*, Nucl. Instrum. Meth. A **494**, 57 (2002); S. Klimenko, J. Konigsberg, and T.M. Liss, FERMILAB-FN-0741 (2003).
20. The B-candidate isolation is defined as $I = |\vec{p}_T^{\,\mu^+\mu^-}|/(\sum_i p_T^i + |\vec{p}_T^{\,\mu^+\mu^-}|)$, where the sum is over all tracks within an η-ϕ cone radius of 1, centered on $\vec{p}_T^{\,\mu^+\mu^-}$ and satisfying standard track quality requirements; ϕ is the azimuthal angle defined in the plane transverse to the beamline.