Searches for New Physics in Bottom Hadron Decays at the Tevatron

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Measurements of flavor changing neutral current processes play a key role in the search for new physics beyond the Standard Model. New physics could also impact the decay amplitudes of hadronic two-body charmless decays of neutral B hadrons with new particles entering in penguin diagrams. We present recent analysis results from the CDF and D0 collaborations, including observation of Λ_b and B_s^0 $b \to s\mu^+\mu^-$ transitions, an updated search for $B_s^0 \to \mu^+\mu^-$ decays, and relevant measurements of CP-violation in B_s^0 mixing and B hadron decays using the full (≈ 10 fb^{-1}) data sample available at the Tevatron.

1 Introduction

The standard model (SM) has a highly distinctive flavour structure, with no tree-level flavor changing neutral currents (FCNC), and quark mixing described by the Cabibbo-Kobayashi-Maskawa (CKM) matrix [1,2] involving only a single source of CP violation. The Tevatron $p\bar{p}$ collider, which exploited collisions at $\sqrt{s} = 1.96$ TeV, was a suitable environment to test the SM, potentially revealing new physics effects in the flavor sector. At the Tevatron, b quarks are pair-produced with large cross section [3] and generate all sorts of b hadrons. This provided access to SM-suppressed processes such as FCNC transitions and CP violation in B hadron decays. In this paper we focus on recent studies of $b \to s\mu^+\mu^-$ transitions, $B_s^0 \to \mu^+\mu^-$ decays, and CP-violation in B_s^0 mixing and B hadron decays performed by the CDF and D0 collaborations.

2 Rare Decays

In the SM framework, $b \to s\mu^+\mu^-$ transitions are dominated by FCNC processes mediated by electroweak-box and penguin-type diagrams. Many relevant new-physics processes could enhance the decay amplitude and might be observed from the interference with the SM amplitude. CDF measures various observables expected to be sensitive to possible new interactions, namely branching ratios, polarizations, forward-backward asymmetries, and the isospin asymmetry, between neutral and charged B mesons. CDF selects two oppositely-charged muon candidates with a momentum transverse to the beamline, p_T, greater than 1.5 or 2.0 GeV/c, depending on the trigger selection. The $H_b \to h\mu^+\mu^-$ events are reconstructed as signal candidates and $H_b \to J/\psi h$ events as normalization channels, where H_b represents B^0, B^+, B_s^0, or Λ_b^0 hadrons and h stands for K^+, $K^{\star 0(+)}$, K_S^0, ϕ or Λ hadrons. For the $K^{\star 0}$, $K^{\star +}$, ϕ, and Λ hadrons, CDF reconstructs $K^+\pi^-$, $K_S^0\pi^+$, K^+K^- and $p^+\pi^-$ final states, respectively. The K_S^0 meson is reconstructed in the $\pi^+\pi^-$ decay mode. To enhance separation of signal from background CDF employs an artificial neural network (NN) technique. The signal yield is obtained by an unbinned maximum log-likelihood fit of the H_b invariant mass distribution. With 9.6 fb^{-1} of data [4], CDF

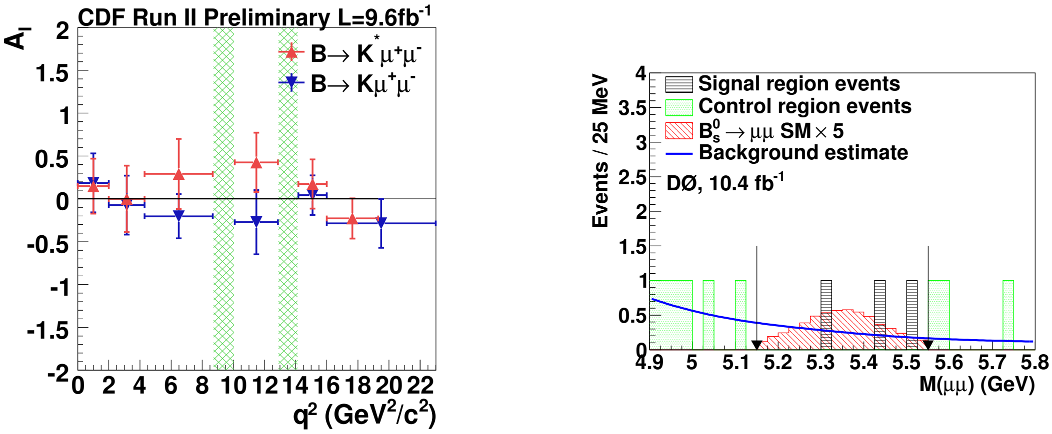

Figure 1: Left: Isospin asymetry of $B \to K\mu^+\mu^-$ and $B \to K^\star\mu^+\mu^-$. Only the statistical uncertainty is shown. Hatched regions are charmonium veto regions. Right: D0 Dimuon invariant mass distribution after un-blinding.

obtains 323 ± 24 ($B^+ \to K^+\mu^+\mu^-$), 228 ± 20 ($B^0 \to K^{\star 0}\mu^+\mu^-$), 32 ± 8 ($B^0 \to K^0_S\mu^+\mu^-$), 24 ± 6 ($B^+ \to K^{\star +}\mu^+\mu^-$), 62 ± 9 ($B^0_s \to \phi\mu^+\mu^-$) and 51 ± 8 ($\Lambda^0_b \to \Lambda\mu^+\mu^-$) signal events, with 15.6σ, 16.8σ, 4.6σ, 4.2σ, 8.9σ and 7.6σ statistical significances, respectively. This is the first observation of the $\Lambda^0_b \to \Lambda\mu^+\mu^-$ mode. Obtained yields are consistent with world average values and theoretical expectations. CDF also measures a number of observables more sensitive to NP. We report here only the results of isospin asymmetry (see Fig. 1) between neutral and charged B mesons, $A_I(B \to K\mu^+\mu^-) = [-0.11 \pm 0.13(stat) \pm 0.05(syst)] \times 10^{-6}$ and $A_I(B \to K^\star\mu^+\mu^-) = [0.16 \pm 0.14(stat) \pm 0.06(syst)] \times 10^{-6}$ which are consistent with the SM prediction, see ref. [4] for more details.

The $B^0_s \to \mu^+\mu^-$ decays are also dominated by FCNC processes, with rates further suppressed by the helicity factor, $(m_\mu/m_B)^2$. The SM expectation for the branching fraction is $\mathcal{B}(B^0_s \to \mu^+\mu^-) = (3.42 \pm 0.54) \times 10^{-9}$ [5]. As many new physics models can enhance the $\mathcal{B}$ significantly, these decays are among the most sensitive probes for NP. D0 selects two high-quality muon candidates with opposite-charge and a dimuon mass range of $4.0 < m_{\mu^+\mu^-} < 7.0$ GeV/c^2. Muon candidates are required to have $p_T > 1.5$ GeV/c, pseudorapidity $|\eta| < 2$ and to form a good three-dimensional vertex well separated from the primary $p\bar{p}$ interaction. These loose criteria maintain high signal efficiency, with further discrimination provided by Boosted Decision Tree, BDT. The event selection is checked with control samples of $B^\pm \to J/\psi K^\pm$ decays. This analysis is performed with the relevant dimuon mass region (4.9 and 5.8 GeV/c^2) blinded until all analysis procedures were final (see Fig. 1). D0 expects a SM signal of 1.23 ± 0.13 events and a background of 4.0 ± 1.5 events. After unblinding D0 observes 3 events, compatible with the background, and an upper limit on the branching fraction is set to $\mathcal{B}(B^0_s \to \mu^+\mu^-) < 1.5 \times 10^{-8}$ at the 95% C.L.[6] These results along with final CDF results[7], are the final Tevatron measurements on the search for $B^0_s \to \mu^+\mu^-$ decays.

3 CP violation in charmless decays

Non-leptonic two-body charmless decays of neutral B mesons ($B \to hh'$, where h is a charged pion or kaon) allow measurements and constraints on the parameters of the CKM matrix, providing also sensitivity to NP. Asymmetries up to about 10% are predicted for $\Lambda^0_b \to pK^-$ and $\Lambda^0_b \to p\pi^-$ decays in the SM[8,9], and are accessible with the current CDF data set, corresponding to an integrated luminosity of 9.3 fb^{-1}. CDF selects pairs of oppositely-charged particles with $p_T > 2$ GeV/c and $p_T(1) + p_T(2) > 5.5$ GeV/c, that form B candidates. The trigger requires also a transverse opening angle $20^\circ < \Delta\phi < 135^\circ$ between the two tracks for background rejection. In addition, both charged particles are required to originate from a displaced vertex with a large impact parameter ($0.1 < d_0(1,2) < 1$ mm), while the b-hadron candidate is required to be produced in the primary $\bar{p}p$ interaction ($d_0 < 140$ μm) and to have travelled a transverse distance $L_T > 200$ μm. A maximum likelihood fit, including kinematic and PID information, is performed to disentangle the different compontents of the resulting mass peak (Fig. 2, left). Signal yields are calculated from the fractions returned by the fit. To determine the physical asymmetries these yields are corrected for detector-induced charge asymmetries extracted from control samples in data. The result $\mathcal{A}_{CP}(B^0 \to K^+\pi^-) = -0.083 \pm 0.013 \pm 0.003$, is consistent with current results from asymmetric e^+e^- colliders [10] and LHCb [11]. The result $\mathcal{A}_{CP}(B^0_s \to K^-\pi^+) = 0.22 \pm 0.07 \pm 0.02$ confirms the LHCb observation [11]. The observed asymmetries in $\Lambda^0_b \to pK^-$ decays, $\mathcal{A}_{CP}(\Lambda^0_b \to p\pi^-) = 0.07 \pm 0.07 \pm 0.03$, and in $\Lambda^0_b \to p\pi^-$ decays, $\mathcal{A}_{CP}(\Lambda^0_b \to pK^-) = -0.09 \pm 0.08 \pm 0.04$, are consistent with zero. The limited experimental precision does not allow a conclusive discrimination between the standard model prediction (8%) and much-suppressed values (0.3%) expected in R-parity violating supersymmetric scenarios.

4 CPV B^0_s mixing

The study of neutral B meson oscillations, which are mediated by the box-diagram weak interaction, can provide a sensitive probe for CP violation processes. An observation of anomalously large CP violation in B^0_s oscillations can indicate the existence of physics beyond the standard model.[12]. Measurements of the like-sign dimuon asymmetry by the D0 Collaboration [13] show evidence of large CP-violating effects using data corresponding to ≈9 fb^{-1} of integrated luminosity. Assuming that this asymmetry originates from mixing of neutral B mesons, the measured value is $A^b_{sl} = C_d a^d_{sl} + C_s a^s_{sl} = [-0.787 \pm 0.172(stat) \pm 0.021(syst)]\%$ where $a^{s(d)}_{sl}$ is the time-integrated flavor-specic semileptonic charge asymmetry in $B^0_s(B^0_d)$ decays that have undergone flavor mixing and $C_s(C_d)$ is the fraction of $B^0_s(B^0_d)$ events. The SM predicts a tiny value of $a^s_{sl} = (1.9 \pm 0.3) \times 10^{-5}$ [12], which is negligible compared with current experimental precision. However the value extracted from the A^b_{sl} measurement is found to be $a^s_{sl} = (-1.81 \pm 1.06)\%$ [13]. D0 performs also an independent measurement of a^s_{sl} using the decay $B^0_s \to D^-_s\mu^+X$ where $D^-_s \to \phi\pi^-$ and $\phi \to K^+K^-$. The flavor of the B^0_s meson at the time of decay is identified using the charge of the associated muon, and no use of initial-state tagging is made. The fraction of mixed events integrated over time is extracted using simulations. D0 assumes that any CP violation only occurs in mixing. The analysis strategy is to extract a^s_{sl} by counting the number of reconstructed $B^0_s \to \mu^+D^-_sX$ decays, corrected for detector-related asymmetries and by the fraction of reconstructed $D^-_s \to \phi\pi^-$ decays (F^{osc}) that originate from the decay of a B^0_s meson after oscillation in its antiparticle, $a^s_{sl} = (A - A_{det})/F^{osc}$. The data are collected with a suite of single and dimuon triggers. The selection and reconstruction of $\mu^+D^-_sX$ decays requires tracks and muons with standard good quality requirements. In addition, muons are required to match tracks reconstructed in the central tracking system, with momentum $p > 3$ GeV/c and $2 < p_T < 25$ GeV/c. The $\phi(\to K^+K^-)$ meson, coming form the $D^-_s \to \phi\pi^-$ decay is reconstructed if two tracks with $p_T > 0.7$ GeV/c, opposite charge, and a mass $M(KK) < 1.07$ GeV/c^2 are reconstructed in the kaon hypothesis. D0 than requires a third track with $0.5 < p_T < 25$ GeV/c to be consistent with a charged pion and to have opposite charge to the muon's one. The three tracks are combined to create a common D^-_s decay vertex[14]. D0 requires this vertex to be displaced in the transverse plane from the $p\bar{p}$ interaction vertex, with a significance (L_T/σ_{L_T}) of at least 4 standard deviations. Kinematic requirements assure that the trajectories of the muon and D^-_s candidates originate from a common vertex (assumed to be the B^0_s decay vertex). D0 requires an effective mass consistent with B^0_s semileptonic decays, $2.6 < M(\mu^+D^-_s) < 5.4$ GeV/c^2. A $L_T/\sigma_{L_T} > 4\sigma$ requirement on the B^0_s decay vertex is also imposed. A likelihood ratio combining several discriminating variables, improves the significance of the B^0_s selection. The number of events is extracted by fitting the $M(KK\pi)$ data distribution to an appropriate model using a χ^2 fit. The resulting time-integrated flavor-specific semileptonic charge asym-

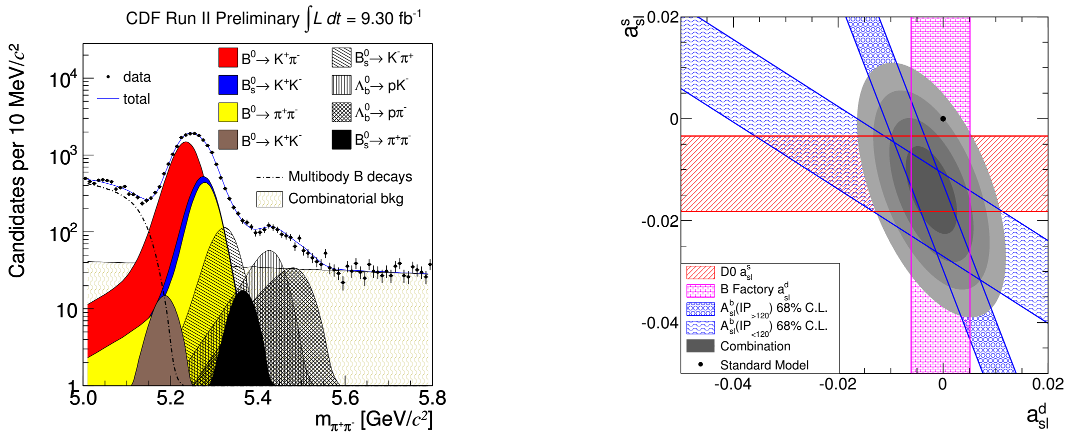

Figure 2: Left: Mass distribution of reconstructed $B \to hh'$ candidates. The charged pion mass is assigned to both tracks. The total fit projection is overlaid on the data distribution. Right: Combination of $a_{sl}^{s(d)}$ measurements. The error bands represent the ± 1 standard-deviation uncertainties on each individual measurement. The ellipses represent the 1, 2, 3, and 4 standard deviation two-dimensional C.L. regions, respectively, in the a_{sl}^{s} and a_{sl}^{d} plane.

metry is found to be $a_{sl}^{s} = [-1.12 \pm 0.74(stat) \pm 0.17(syst)]\%$, superseding the previous D0 measurement[13], and in agreement with the SM prediction. A combination with measurements of a_{sl}^{d} from B factories and di-muon asymmetries from D0 [13] is shown in Fig. 2(right). The results are $a_{sl}^{s} = (-1.42 \pm 0.57)\%$ and $a_{sl}^{d} = (-0.21 \pm 0.32)\%$ with a correlation of -0.53, which is a significant improvement on the previous measurement precision[13]. These results have a probability of agreement with the SM of 0.28×10^{-2} , which corresponds to a 3.0 standard deviations discrepancy. Up to date, this discrepancy is not confirmed by measurement of mixing-induced CP violation in $B_s^0 \to J/\psi\phi$ decays as preformed by the CDF, D0 and LHCb collaborations [15].

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