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Phenomena related to CP violation at CDF

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Abstract. We report recent CDF results on CP violation in $B^- \to DK^-$ modes, where D goes to Cabibbo suppressed ($\pi\pi$, KK) or doubly cabibbo suppressed ($K^+\pi^-$) modes, which are related to CKM angle gamma. We also describe direct CP violation measurements in charmless two-body decays of $B_s^0 \to K\pi$ and $\Lambda_b^0 \to pK$, $p\pi$ modes, which are unique to the CDF experiment. We also report on CP violation measurements in $D^0 \to h^+h^-$ modes.

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INTRODUCTION

The decay modes of B mesons into pairs of charmless pseudo-scalar mesons are effective probes of the quark-mixing (CKM) matrix and sensitive to potential new physics effects. The branching fraction of $B_s^0 \to K^-\pi^+$ decay mode could be used to measure γ [1] and the measurement of its direct CP asymmetry could be a powerful model-independent test of the source of direct CP asymmetry in the B system [2]. CP violation asymmetries in $\Lambda_b^0 \to p\pi^-$ and $\Lambda_b^0 \to pK^-$ decay modes may reach significant size $O(10\%)$ in the Standard Model [3]. Measurements of asymmetries and branching fractions of these modes would rule out (or allow) some extension of the Standard Model [4].

The measurement of the partial widths of $B^- \to DK^-$ modes allows a theoretically clean extraction of the CKM angle γ. This can be obtained in several ways, using different choices of D decay channels [5, 6, 7, 8]. Comparing the determination of γ obtained from $B^- \to DK^-$ modes, where it enters at tree-level, with the determinations from processes where γ appears in higher order diagrams, is a good way to test for the presence of non-standard-model CP-violating effects [9, 10].

CHARMLESS TWO-BODY DECAY MODES $B_{(s)}^0 \to h^+h^-$

CDF reconstructed a sample of about 14500 $H_b^0 \to h^+h'^-$ decay modes (where $H_b^0 = B^0, B_s^0$ or Λ_b^0 and $h = K$ or π) in 1 fb^{-1}. The $\pi\pi$-mass distributions (Fig. 1) show a clean signal of $H_b^0 \to h^+h'^-$ decays. In spite of a good mass resolution ($\sim$ 22 MeV/c^2), the various $H_b^0 \to h^+h'^-$ modes overlap into an unresolved mass peak.

The resolution in invariant mass and in particle identification (dE/dx) is not sufficient for separating the individual $H_b^0 \to h^+h'^-$ decay modes on an event-by-event basis, therefore an unbinned maximum likelihood fit was performed. This combines kinematic and particle identification information to statistically determine both the contribution of

each mode, and the relative contributions to the CP asymmetries.

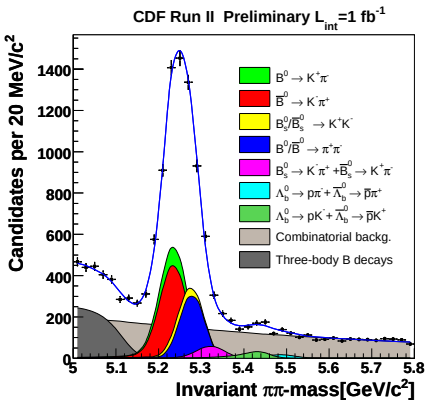

FIGURE 1. Invariant mass distributions of $H_b^0 \to h^+h'^-$ candidates using a pion mass assumption for both decay products. Comulative projections of the likelihood fit for each mode are overlaid.

We report the observation of three new charmless decays $B_s^0 \to K^-\pi^+$, $\Lambda_b^0 \to p\pi^-$ and $\Lambda_b^0 \to pK^-$ with a significance respectively of 8.2, 6.0 and 11.5 σ.

The CP asymmetries are listed in Table 1. The direct CP asymmetry of the $B_s^0 \to K^-\pi^+$ is 2.5σ different from 0 and is in agreement with the standard model expectation ($A_{CP}(B_s^0 \to K^-\pi^+) \sim 0.37$) obtained comparing the direct CP asymmetry in $B_s^0 \to K^-\pi^+$ and in $B^0 \to K^+\pi^-$ decays [1, 2]. The measurements of the direct CP violating asymmetries in the b-baryon decays, presented here, are the first such measurements in this sector. The statistical uncertainty dominates the resolution and prevents a statement on the presence of the asymmetry, whose measured value deviates from 0 to 2.1 σ in the $\Lambda_b^0 \to pK^-$ decay mode and is fully consistent with 0 in the $\Lambda_b^0 \to p\pi^-$ decay mode.

TABLE 1. CP asymmetries results.

Quantity	Measurement
$A_{CP}(B^0 \to K^+\pi^-)$	$-0.086 \pm 0.023(stat) \pm 0.009(syst)$
$A_{CP}(B_s^0 \to K^-\pi^+)$	$0.39 \pm 0.15(stat) \pm 0.03(syst)$
$A_{CP}(\Lambda_b^0 \to pK^-)$	$0.37 \pm 0.17(stat) \pm 0.03(syst)$
$A_{CP}(\Lambda_b^0 \to p\pi^-)$	$0.03 \pm 0.17(stat) \pm 0.05(syst)$

Assuming the PDG value $f_{baryon}/f_d = 0.230 \pm 0.052$ we measured the absolute branching fractions $BR(\Lambda_b^0 \to pK^-) = (5.6 \pm 0.8(stat) \pm 1.5(syst)) \times 10^{-6}$ and $BR(\Lambda_b^0 \to p\pi^-) = (3.5 \pm 0.6(stat) \pm 0.9(syst)) \times 10^{-6}$. These values are in agreement with standard model expectations and exclude $O(10^{-4})$ values indicated for R-parity violating Minimal Supersymmetric extensions of the Standard Model [4].

$B^- \to DK^-$ MODES

We report the first measurement of branching ratios and CP asymmetries of $B^- \to DK^-$ modes performed in hadron collisions, based on an integrated luminosity of 1 fb^{-1} collected by CDF. Events where the D meson decays to the flavor specific mode $K^-\pi^+$

(D^0_f), or one of the CP-even modes K^-K^+ and $\pi^-\pi^+$ are reconstructed. From these modes, the following observables can be defined [5, 6]:

$$A_{CP+} = \frac{\mathscr{B}(B^- \to D_{CP+}K^-) - \mathscr{B}(B^+ \to D_{CP+}K^+)}{\mathscr{B}(B^- \to D_{CP+}K^-) + \mathscr{B}(B^+ \to D_{CP+}K^+)}, \tag{1}$$

$$R_{CP+} = 2\frac{\mathscr{B}(B^- \to D_{CP+}K^-) + \mathscr{B}(B^+ \to D_{CP+}K^+)}{\mathscr{B}(B^- \to D^0_f K^-) + \mathscr{B}(B^+ \to \overline{D}^0_f K^+)}. \tag{2}$$

These quatities are related to the CKM angle γ by the equations $R_{CP+} = 1 + r^2 + 2r\cos\delta\cos\gamma$ and $A_{CP+} = 2r\sin\delta\sin\gamma/R_{CP+}$, where r is the magnitude of the ratio of the amplitudes of the processes $B^- \to \overline{D}^0K^-$ and $B^- \to D^0K^-$, and δ is their relative strong phase. For every $B^- \to Dh^-$ candidate, a nominal invariant mass is evaluated by assigning the charged pion mass to the particle h^- coming from the B decay. The distributions obtained for the $B^- \to [K^+K^-]h^-$ are reported in Fig. 2. An unbinned likelihood fit, exploiting kinematic and particle identification information provided by the dE/dx, is performed to statistically separate the $B^- \to DK^-$ contributions from the $B^- \to D\pi^-$ signals and from the combinatorial background.

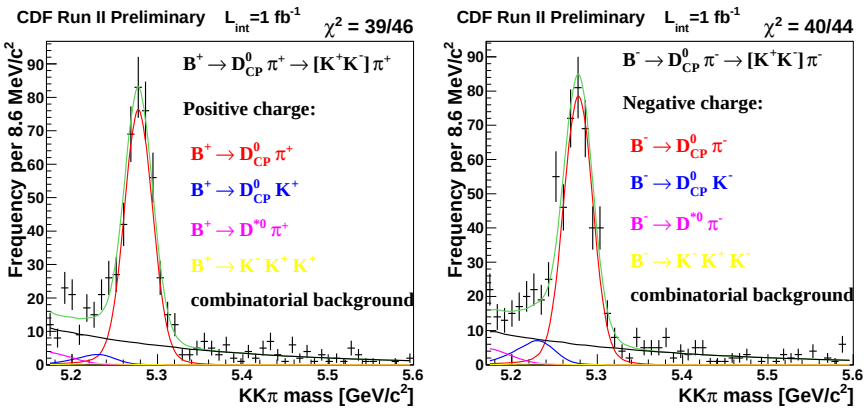

FIGURE 2. Invariant mass distributions of $B^- \to [K^+K^-]h^-$ candidates. The pion mass is assigned to the track from the direct B decay. The projections of the likelihood fit are overlaid for each mode.

CDF has measured the double ratio of CP-even to flavor eigenstate branching fractions $R_{CP+} = 1.30 \pm 0.24(\text{stat}) \pm 0.12(\text{syst})$ and the direct CP asymmetry $A_{CP+} = 0.39 \pm 0.17(\text{stat}) \pm 0.04(\text{syst})$. These results are in agreement with previous measurements from $\Upsilon(4S)$ decays [11, 12], and have comparable uncertainties. They can be combined with other $B^- \to DK^-$ decay parameters to improve the determination of the CKM angle γ. For example CDF reconstruct also the $B^- \to D_{DCS}h^-$ where D_{DCS} is the double Cabibbo suppressed D^0 decay ($D_{DCS} \to K^+\pi^-$). The invariant mass distribution of $B^- \to D_{DCS}\pi^-$ based on 2.4 fb^{-1} is shown in Fig. 3. CDF observed 34 $B^- \to D_{DCS}\pi^-$ events with a significance of 3.8 σ and we expect an asymmetry resolution of $\sim 30\%$ that we can compare with the resolution obtained by Belle ($A_{ADS}(\pi) = -0.023 \pm 0.218(stat) \pm 0.071(syst)$) [13].

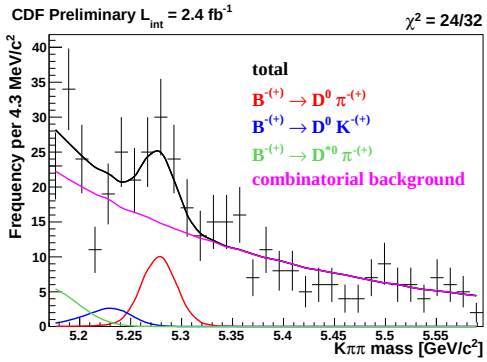

FIGURE 3. Invariant mass distributions of $B^- \to D_{DCS}h^-$ candidates. The pion mass is assigned to the track from the direct B decay. The projections of the likelihood fit are overlaid for each mode.

$D^0 \to h^+h^-$ MODES

CDF has today the world's largest charm samples. This provides the opportunity to pursue a rich analysis program that includes access to direct CP violating asymmetries, branching fractions, mixing and mixing-induced CP violation. All these are possible windows to physics beyond the Standard Model. As an example, in the first 2.9 fb^{-1} of collected data (today we have more than 5 fb^{-1}) we reconstruct a huge sample of $D^* \to D^0\pi$ candidates: 4×10^6 D^* with $D^0 \to K^-\pi^+$, 170×10^3 D^* with $D^0 \to \pi^-\pi^+$, and 360×10^3 D^* with $D^0 \to K^-K^+$.

Taking into account only the number of events we estimate we can make the most precise measurement to date of the CP violating asymmetries in Cabibbo-suppressed D0 decays, $D^0 \to \pi^+\pi^-$ and $D^0 \to K^+K^-$. As an example, we calculate the expected statistical resolution on the measurement of the $\pi\pi$ asymmetry ($\sigma(A_{CP}(\pi\pi)) = 0.24$) that is much better than the most recent results from B-factories ($\sigma(A_{CP}(\pi\pi)) = 0.52$) [14, 15], and similar results we estimate for the K^+K^- decay channel.

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