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Branching Fractions and Direct CP Asymmetries of Charmless B Decay Modes at CDF

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Abstract. We present new CDF results on the branching fractions and time-integrated direct CP asymmetries for B^0 and B_s^0 decay modes into pairs of charmless charged hadrons (pions or kaons). The data-set for this update amounts to 1 fb^{-1} of $p\overline{p}$ collisions at a center of mass energy 1.96 TeV. We report the first observation of the $B_s \to K^-\pi^+$ mode and a measurement of its branching fraction and direct CP asymmetry. We also observe for the first time two charmless decays of the Λ_b-baryon: $\Lambda_b \to p\pi^-$ and $\Lambda_b \to pK^-$.

PACS. 13.25.Hw Decays of bottom mesons – 14.40.Nd Bottom mesons

1 Introduction

The decay modes of B mesons into pairs of charmless pseudo-scalar mesons are effective probes of the CKM matrix with sensitivity to potential new physics. The production cross section of B hadrons at the Tevatron allows studies of such decays which are competitive to B factories. In addition B hadrons of all kind are produced at the Tevatron and thus making possible to complement the information by studies of decays of B_s mesons and B baryons which is impossible at current B factories.

In this paper we review current results on charmless two body decays of B hadrons from the CDF experiment using 1 fb^{-1} of data. As the CDF detector is not capable to detect π^0 with reasonable precision and efficiency, we only use charged kaons, pions and protons as final state particles. The main results presented here are the first observation of the decay $B_s \to K^-\pi^+$ and measurement of direct CP asymmetries in $B^0 \to K^+\pi^-$ and $B_s \to K^-\pi^+$ decays. More details about the analysis can be found in the Ref. [1].

2 Data sample

We analyze a data sample with an integrated luminosity of 1 fb^{-1} collected by the CDF II detector at Tevatron. Online selection of events requires two oppositely charged tracks, each with $p_T > 2$ GeV/c. The scalar sum $p_T(1) + p_T(2)$ is required to be larger than 5.5 GeV/c and the transverse opening angle between tracks ranges from 20° to 135°. The CDF detector has the unique opportunity to use the silicon detector at trigger level. This allows us to place requirements on the impact parameter d_0 of each track and on the displacement of the secondary vertex L_{xy}. We use 100 μm $< d_0 <$ 1 mm for the two tracks, $d_0 < 140$ μm and $L_{xy} > 200$ μm for the B hadron candidate.

For the offline selection an unbiased optimization is performed. During the optimization, the requirements from the trigger level are tightened. In addition to tightening trigger cuts we add other two discriminating variables, which are the quality of the B secondary candidate vertex fit and the isolation defined as $I(B) = p_T(B)/[p_T(B) + \sum_i p_T(i)]$, where the sum runs over all tracks not associated with the B candidate in a cone of unit radius in the η–ϕ space around the B candidate. As a result we derive two sets of requirements, one optimized for measurements in decay modes with larger yields and the other one for measurements in modes with lower yields. They optimize the sensitivity for the measurement of the CP asymmetry $A_{\rm CP}(B^0 \to K^+\pi^-)$ and for the discovery of the decay $B_s \to K^-\pi^+$.

3 Signal decomposition

In Fig. 1 we show the typical expectation of the invariant mass distribution obtained from simulated events assigning pion mass to both decay products. Despite the excellent mass resolution on the level of 22 MeV/c^2 it is not possible to distinguish different decays as separate peaks in the invariant mass distribution. In addition the particle identification system of the CDF detector does not allow track-by-track identification.

To find out the composition of the signal an unbinned maximum likelihood fit is performed using the invariant $\pi\pi$ mass $M_{\pi\pi}$, dE/dx measurement and momenta of the two tracks. The fit determines fractions of different components, which are then converted to

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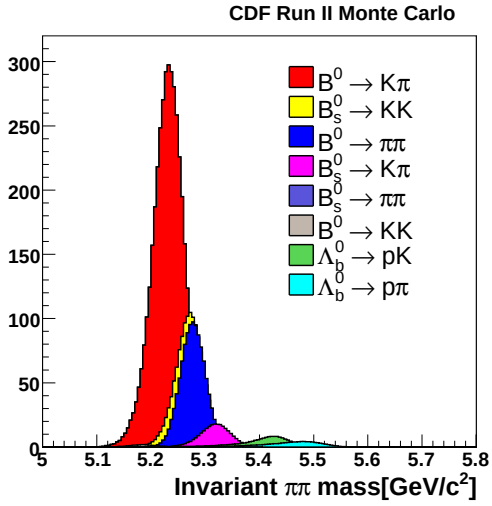

Fig. 1. Expected invariant mass distribution for different charmless two-body decays of B hadrons. In all cases the invariant mass distribution is calculated assigning pion mass to both decay products.

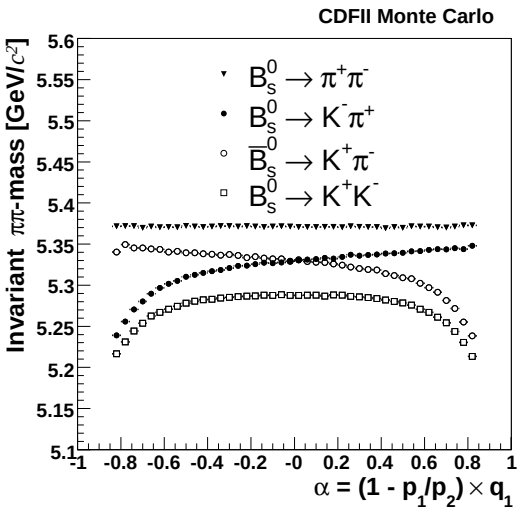

Fig. 2. Average $M_{\pi\pi}$ versus α for simulated B_s decays. Corresponding dependencies for other B hadrons are analogous.

physical quantities like branching fractions and CP asymmetries. The momenta of the two tracks enters in a form of loosely correlated variables $p_{tot} = p_1 + p_2$ and $\alpha = (1-p_1/p_2)q_1$ where index 1 (2) corresponds to particle with lower (higher) momentum. The invariant mass with correct mass assignment to the daughters can be unambiguously calculated from $M_{\pi\pi}$ and momenta of the two daughters. The dependence of the $M_{\pi\pi}$ on the α for B_s decays is shown in Fig. 2. Decays of other three B hadrons have similar dependencies. The likelihood used in the fit has the form

$$\mathcal{L}_i = (1-b)\sum_j f_j \mathcal{L}_j^{\rm kin}\mathcal{L}_j^{\rm PID} + b\left(f_{\rm A}\mathcal{L}_{\rm A}^{\rm kin}\mathcal{L}_{\rm A}^{\rm PID} + (1-f_{\rm A})\mathcal{L}_{\rm E}^{\rm kin}\mathcal{L}_{\rm E}^{\rm PID}\right) \quad (1)$$

where b is a background fraction and indices A and E label physics and combinatorial background. Index j runs over signal B^0, B_s and Λ_b decays modes. $\mathcal{L}^{kin}$ ($\mathcal{L}^{PID}$) denotes the mass (particle identification) part of the likelihood. The background mass distribution is described by an Argus function convoluted with a Gaussian for physics background and an exponential function for combinatorial background.

The high available statistics demands a good description of the signal PDF distributions in the likelihood fit. One of the main effects for the mass description is the inclusion of a tail due to the final state radiation. This is modeled using QED calculations [2]. The result is then convoluted with the resolution function obtained from simulated events. The description is found to be in excellent agreement with $D^0 \to K^-\pi^+$ decays from $D^{*+} \to D^0\pi^+$ decays reconstructed in the data.

For a proper description of the particle identification, we calibrate the $\mathrm{d}E/\mathrm{d}x$ response using a data sample of $D^{*+} \to D^0\pi^+$ with $D^0 \to K^-\pi^+$, which provides a very clean sample of kaons and pions. On this sample we obtain a separation between kaons and pions around 1.4σ. After the calibration we use the same data sample to derive the probability density function for the likelihood. This is the same for signal and background except of fractions of different particles, which are independent for signal and background.

4 Results

The result of the analysis is a refined measurement of several ratios of branching fractions for previously observed decays. More important new decay modes $B_s \to K^-\pi^+$, $\Lambda_b \to pK^-$ and $\Lambda_b \to p\pi^-$ are observed here for the first time. The invariant mass distribution using a set of tighter requirements optimized for the observation of the $B_s \to K^-\pi^+$ is shown in Fig. 3. Measured ratios of the branching fractions for all observed decay modes are summarized in Table 1. The dominant systematic uncertainties are due to the statistical uncertainty on selection efficiency, the uncertainty on the $\mathrm{d}E/\mathrm{d}x$ calibration and parametrization and the uncertainty on the background modeling. In following we will concentrate in more details on the two results, which are the measurement of the $B^0 \to K^+\pi^-$ CP asymmetry and the observation of the $B_s \to K^-\pi^+$ decay and measurement of the corresponding direct CP asymmetry.

4.1 $\mathbf{B^0 \to K^+\pi^-}$ CP asymmetry

As the decay $B^0 \to K^+\pi^-$ is self tagging, one can measure the direct CP asymmetry defined as

$$A_{\rm CP} = \frac{N(\overline{B}^0 \to K^-\pi^+) - N(B^0 \to K^+\pi^-)}{N(\overline{B}^0 \to K^-\pi^+) + N(B^0 \to K^+\pi^-)} \quad (2)$$

The only significant difference between B^0 and $\overline{B}^0$ from the efficiency point of view is the difference in the

Table 1. Results on the data sample optimized to measure $A_{\rm CP}(B^0 \to K^+\pi^-)$ (top) and $\mathcal{B}(B_s^0 \to K^-\pi^+)$ (bottom). Absolute branching fractions are normalized to the the world–average values $\mathcal{B}(B^0 \to K^+\pi^-) = (19.7 \pm 0.6) \times 10^{-6}$ and $f_s = (10.4 \pm 1.4)\%$ and $f_d = (39.8 \pm 1.0)\%$ [3]. The first quoted uncertainty is statistical, the second is systematic. N_s is the number of fitted events for each mode. For rare modes both the systematic and statistical uncertainty on N_s was quoted while for abundant modes only the statistical one. For the Λ_b^0 modes only the ratio $\frac{\mathcal{B}(\Lambda_b^0 \to p\pi^-)}{\mathcal{B}(\Lambda_b^0 \to pK^-)}$ was measured.

Mode	N_s	Quantity	Measurement	$\mathcal{B}(10^{-6})$
$B^0 \to K^+\pi^-$	4045 ± 84	$\frac{\mathcal{B}(\overline{B}^0 \to K^-\pi^+) - \mathcal{B}(B^0 \to K^+\pi^-)}{\mathcal{B}(\overline{B}^0 \to K^-\pi^+) + \mathcal{B}(B^0 \to K^+\pi^-)}$	$-0.086 \pm 0.023 \pm 0.009$	
$B^0 \to \pi^+\pi^-$	1121 ± 63	$\frac{\mathcal{B}(B^0 \to \pi^+\pi^-)}{\mathcal{B}(B^0 \to K^+\pi^-)}$	$0.259 \pm 0.017 \pm 0.016$	$5.10 \pm 0.33 \pm 0.36$
$B_s^0 \to K^+K^-$	1307 ± 64	$\frac{f_s}{f_d}\frac{\mathcal{B}(B_s^0 \to K^+K^-)}{\mathcal{B}(B^0 \to K^+\pi^-)}$	$0.324 \pm 0.019 \pm 0.041$	$24.4 \pm 1.4 \pm 4.6$
$B_s^0 \to K^-\pi^+$	$230 \pm 34 \pm 16$	$\frac{f_s}{f_d}\frac{\mathcal{B}(B_s^0 \to K^-\pi^+)}{\mathcal{B}(B^0 \to K^+\pi^-)}$	$0.066 \pm 0.010 \pm 0.010$	$5.0 \pm 0.75 \pm 1.0$
		$\frac{\mathcal{B}(\overline{B}_s^0 \to K^+\pi^-) - \mathcal{B}(B_s^0 \to K^-\pi^+)}{\mathcal{B}(\overline{B}_s^0 \to K^+\pi^-) + \mathcal{B}(B_s^0 \to K^-\pi^+)}$	$0.39 \pm 0.15 \pm 0.08$	
		$\frac{f_d}{f_s}\frac{\Gamma(\overline{B}^0 \to K^-\pi^+) - \Gamma(B^0 \to K^+\pi^-)}{\Gamma(\overline{B}_s^0 \to K^+\pi^-) - \Gamma(B_s^0 \to K^-\pi^+)}$	$-3.21 \pm 1.60 \pm 0.39$	
$B_s^0 \to \pi^+\pi^-$	$26 \pm 16 \pm 14$	$\frac{f_s}{f_d}\frac{\mathcal{B}(B_s^0 \to \pi^+\pi^-)}{\mathcal{B}(B^0 \to K^+\pi^-)}$	$0.007 \pm 0.004 \pm 0.005$	$0.53 \pm 0.31 \pm 0.40$ (< 1.36 @ 90% CL)
$B^0 \to K^+K^-$	$61 \pm 25 \pm 35$	$\frac{\mathcal{B}(B^0 \to K^+K^-)}{\mathcal{B}(B^0 \to K^+\pi^-)}$	$0.020 \pm 0.008 \pm 0.006$	$0.39 \pm 0.16 \pm 0.12$ (< 0.7 @ 90% CL)
$\Lambda_b^0 \to pK^-$	$156 \pm 20 \pm 11$	$\frac{\mathcal{B}(\Lambda_b^0 \to p\pi^-)}{\mathcal{B}(\Lambda_b^0 \to pK^-)}$	$0.66 \pm 0.14 \pm 0.08$	
$\Lambda_b^0 \to p\pi^-$	$110 \pm 18 \pm 16$			

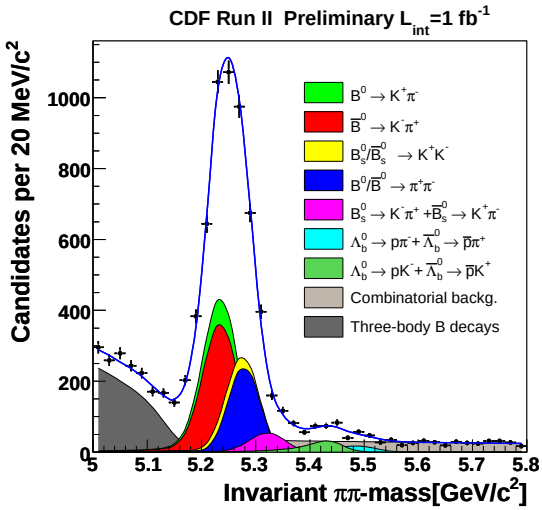

Fig. 3. Invariant mass distribution using selection optimized for $B_s \to K^-\pi^+$ observation. The full line represents result of the fit.

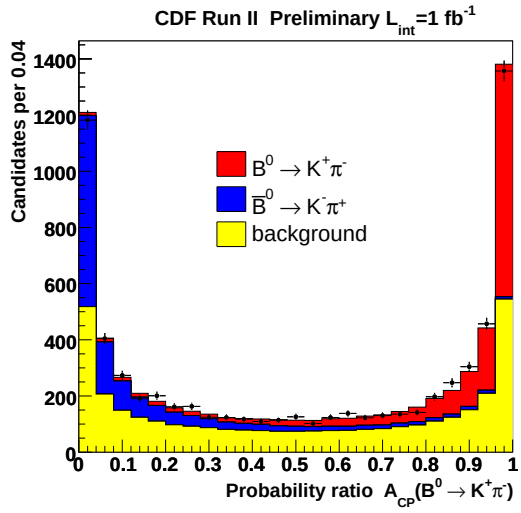

Fig. 4. Distribution of the likelihood ratio $\mathcal{L}_{s1}/(\mathcal{L}_{s1}+\mathcal{L}_{s2})$ where $\mathcal{L}_{s1}$ ($\mathcal{L}_{s2}$) denotes the probability to be B^0 ($\overline{B}^0$). The points show data while histograms represent different fit components.

interaction of K^+ and K^- with detector material. This difference is estimated using a sample of $D^{*+} \to D^0\pi^+$ with $D^0 \to K^-\pi^+$ and results in a $\leq 0.6\%$ shift for the $A_{\rm CP}$ obtained from the fit result. To visualize the difference between B^0 and $\overline{B}^0$ in Fig. 4 we show the distribution of the likelihood ratio $\mathcal{L}_{s1}/(\mathcal{L}_{s1} + \mathcal{L}_{s2})$ where $\mathcal{L}_{s1}$ ($\mathcal{L}_{s2}$) denotes the probability to be B^0 ($\overline{B}^0$). The points show data while histograms represent different fit components. A small difference between B^0 and $\overline{B}^0$ is clearly visible. The result corrected for detector effects is $A_{\mathcal{CP}} = -0.086 \pm 0.023 \pm 0.009$. In Fig. 5 we show a comparison of this measurement to the other existing measurements [4–6]. Our result is in good agreement with other measurements with a precision comparable to the Belle and *BABAR* experiments.

4.2 $B_s \to K^-\pi^+$ branching fraction and CP asymmetry

The most important result obtained here, is the first observation of the decay $B_s \to K^-\pi^+$. We observe $230 \pm 34 \pm 16$ signal events from which we measure

$$\frac{f_s}{f_d}\frac{\mathcal{B}(B_s^0 \to K^-\pi^+)}{\mathcal{B}(B^0 \to K^+\pi^-)} = 0.066 \pm 0.010 \pm 0.010. \quad (3)$$

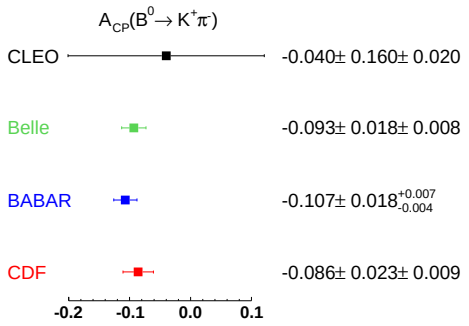

Fig. 5. Comparison of the measured $A_{\rm CP}(B^0 \to K^+\pi^-)$ with other measurements [4–6].

The significance of the observed signal is 8.2σ including systematic uncertainties. Using world average values for f_s, f_d and $\mathcal{B}(B^0 \to K^+\pi^-)$ [3] we obtain for the branching fraction $\mathcal{B}(B_s^0 \to K^-\pi^+) = (5.0 \pm 0.75 \pm 1.0) \cdot 10^{-6}$ which is in agreement with the latest theoretical predictions [7].

As the decay $B_s^0 \to K^-\pi^+$ is a self-tagging decay, we can determine also the direct CP asymmetry. The CDF experiment has the unique opportunity for a model independent test for new physics by comparing $A_{\rm CP}(B^0 \to K^+\pi^-)$ with $A_{\rm CP}(B_s^0 \to K^-\pi^+)$. In the standard model one expects for the decay rate differences [8]

$$\frac{\Gamma(\overline{B}^0 \to K^-\pi^+) - \Gamma(B^0 \to K^+\pi^-)}{\Gamma(B_s \to K^-\pi^+) - \Gamma(\overline{B}_s \to K^+\pi^-)} = 1. \qquad (4)$$

This can be used to predict $A_{\rm CP}(B_s^0 \to K^-\pi^+)$ from the known $A_{\rm CP}(B^0 \to K^+\pi^-)$, ratios of branching fractions and lifetimes. Using world average values provided by HFAG [3] one gets $A_{\rm CP}(B_s^0 \to K^-\pi^+) \approx +37\%$. In Fig. 6 we show the likelihood ratio of being B_s or $\overline{B}_s$. We measure $A_{\rm CP}(B_s^0 \to K^-\pi^+) = +0.39 \pm 0.15 \pm 0.08$ with 2.5σ significance. While not statistically significant, this result starts to indicate for the first time a possible direct CP violation in the B_s system. The size and the sign of the measured asymmetry is in good agreement with the standard model expectation.

5 Conclusions

We presented here the latest result on the charmless two-body decays of B hadrons from the CDF experiment. We measure $A_{\rm CP}(B^0 \to K^+\pi^-)$ which is in agreement with other measurements and has a comparable uncertainty. More important we observed three new decays which are $B_s^0 \to K^-\pi^+$, $\Lambda_b \to pK^-$ and $\Lambda_b \to p\pi^-$. For the decay $B_s^0 \to K^-\pi^+$ we measure also the direct CP asymmetry which for the first time starts to reveal an indication of direct CP violation in the B_s system.

While we already obtained important results, there is lot of progress to be expected in this area. First of all, we already collected 2.5 fb^{-1} of data, which is a substantial increase compared to data used in the presented results. With this increase in the available statistics we expect not only a decrease of the statistical uncertainties, but also the systematic uncertainties as in many cases the dominant systematic uncertainties come from the limited statistics of the control data samples. Finally a large sample of $B_s \to K^+K^-$ decays is interesting for the lifetime measurement and tagged time dependent measurements.

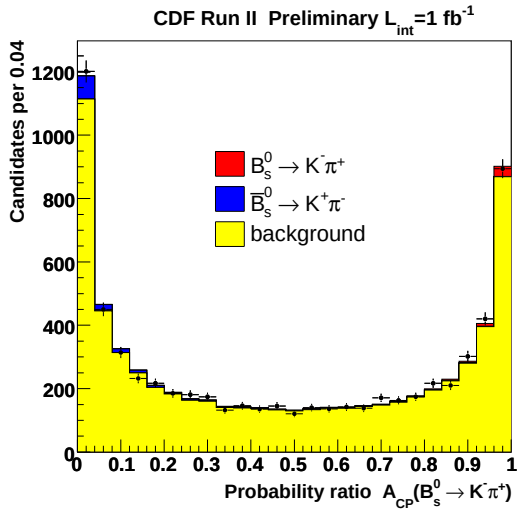

Fig. 6. Distribution of the likelihood ratio $\mathcal{L}_{s1}/(\mathcal{L}_{s1}+\mathcal{L}_{s2})$ where $\mathcal{L}_{s1}$ ($\mathcal{L}_{s2}$) denotes the probability to be B_s ($\overline{B}_s$). The points show data while histograms represent different fit components.

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