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BRANCHING FRACTIONS AND CP ASYMMETRIES IN TWO-BODY NONLEPTONIC CHARMLESS b-HADRON DECAYS

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Relative branching fractions of $B^0_{d,s} \to h^+ h'^-$ decays (where $h, h' = K$ or π) and the direct CP asymmetry $\mathcal{A}_{CP}$ in the $B^0_d \to K^+ \pi^-$ mode are measured with 179 ± 11 pb^{-1} of data collected at $\sqrt{s} = 1.96$ TeV using the CDF II detector at the Fermilab Tevatron $p\bar{p}$ collider. The first branching-fraction measurement of a B^0_s meson to two pseudoscalars, $\mathcal{B}(B^0_s \to K^+ K^-)$, and a search for the baryon mode $\Lambda^0_b \to p^+ h^-$ are also presented, in addition to branching-fraction limits on the rare channels $B^0_s \to K^+ \pi^-$, $B^0_d \to K^+ K^-$, and $B^0_s \to \pi^+ \pi^-$.

Keywords: CP asymmetry; B^0_d meson; B^0_s meson; Λ^0_b baryon; CDF.

1. Introduction

Two-body charmless hadronic decays of neutral b hadrons can provide insight into both the CKM matrix and possible new physics phenomena. The CDF II experiment[1] can reconstruct significant samples of these decay modes by virtue of the high yields of b-quark production at the Fermilab Tevatron $p\bar{p}$ collider and the use of a dedicated trigger on impact parameters of charged-particle tracks.

Whereas B^0_d decays are also under intense scrutiny at the $e^+ e^- \to \Upsilon(4S)$ factories, studies of the B^0_s-meson and b-baryon channels are presently unique to the Tevatron. Properties of the heavier hadron states complement and extend measurements in the B^+_u and B^0_d-meson sectors, *e.g.*, by constraining hadronic parameters that are difficult to calculate[2,3,4].

In this paper, I report new results on analyses of two-body charmless hadronic decays of B^0_d, B^0_s, and Λ^0_b hadrons[a] in a sample with time-integrated luminosity 179 ± 11 pb^{-1} collected by the CDF II detector between February 2002 and September 2003 at a center-of-mass energy of $\sqrt{s} = 1.96$ TeV.

[a]Except in the case of $\mathcal{A}_{CP}$, charge-conjugate modes are implied throughout.

2. Event Selection

Data are collected using CDF's hadronic B triggers, which are designed to select events containing track pairs originating from a common displaced vertex. At the lowest trigger levels, pairs of oppositely charged tracks are required to have each transverse momenta $p_T \geq 2.0$ GeV/c and total $p_T \geq 5.5$ GeV/c, impact parameters >150 μm, and an azimuthal opening angle between 20° and 135°. Candidate b hadrons are then reconstructed from the track pairs and required to have a transverse decay length greater than 300 μm, their total momenta point back to within 80 μm of the primary vertex, and an invariant mass between 4.0 and 6.0 GeV/c^2.

Additional optimized cuts are applied offline to confirm the trigger selection. An isolation criterion, defined as $\frac{p_T(b)}{p_T(b)+\sum_i p_T(\mathrm{track}_i)} \geq 0.5$, where the sum is over all the non-b tracks i within a cone of radius = 1 in pseudorapidity-azimuth space around the candidate b-hadron direction, is imposed to effect a 4× background rejection factor while retaining a signal efficiency of ∼85%. Specific ionization (dE/dx) information measured in CDF's drift chamber is used statistically in the fit to distinguish K from π mesons with a separation of 1.39σ and 1.43σ for negative and positive tracks, respectively. This resolution suffices to provide a separation between K and π mesons that is ∼60% of what a perfect particle identification scheme would achieve.

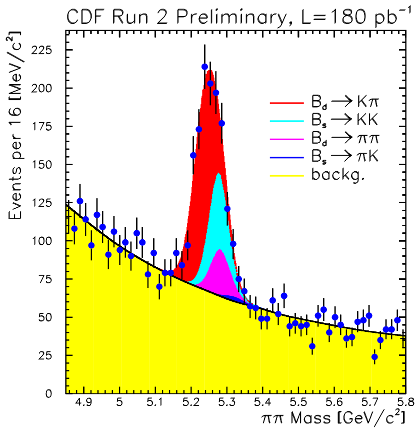

Fig. 1. The $M_{\pi\pi}$ invariant mass distribution of the $B^0 \to h^+ h'^-$ candidates after all selection criteria have been applied. Overlaid are the fit results in this variable for the individual signal modes and the background component.

The di-track invariant mass distribution, where the world-average π-meson mass[5] is assigned to each daughter regardless of dE/dx information, is depicted by the points in Fig. 1. A clear signal of $893 \pm 47\,(\mathrm{stat.})$ events is observed.

3. Separation of Signal Modes and Background

An unbinned maximum likelihood fit that combines 'dipion' mass $M_{\pi\pi}$, additional kinematic (kin), and dE/dx particle identification (PID) information is used to discriminate between the two B_d^0 modes, the two B_s^0 modes, and the background component. The likelihood function used is $\mathcal{L} = \prod_{j=1}^{N} \mathcal{L}_j$, where the index j runs over the N events and $\mathcal{L}_j$ has contributions from signal (sig) and background (bkg): $\mathcal{L}_j = b \cdot \mathcal{L}^{\mathrm{bkg}} + (1-b) \cdot \mathcal{L}^{\mathrm{sig}}$, where b is the background fraction.

The signal likelihood function is given by $\mathcal{L}^{\mathrm{sig}} = \sum_k \xi_k \cdot \mathcal{L}_k^{\mathrm{kin}} \cdot \mathcal{L}_k^{\mathrm{PID}}$, where the index k runs over the six distinct $B_{d,s}^0$ decay-mode and charge-state combinations, and the parameters ξ_k represent their relative fractions determined by the fit. The background likelihood function is expressed as $\mathcal{L}^{\text{bkg}} = \mathcal{L}^{\text{kin}}_{\text{bkg}} \cdot \mathcal{L}^{\text{PID}}_{\text{bkg}}$.

In addition to $M_{\pi\pi}$, the other kinematic variable used is the charge-signed momentum imbalance, defined as $\alpha \equiv Q_1 \cdot \left(1 - \frac{p_1}{p_2}\right)$, where $p_1(p_2)$ is the modulus of the smaller(larger) momentum of the two tracks and Q_1 is the charge sign of the track assigned to p_1. Analytic expressions for the $M_{\pi\pi}$ dependence on α exhibit discriminating shape differences between particles and antiparticles; self tagging is thereby facilitated in the fit.

4. Summary of Results

The branching-fraction ratio of the B^0_d modes is measured to be

$$\frac{\mathcal{B}(B^0_d \to \pi^+\,\pi^-)}{\mathcal{B}(B^0_d \to K^+\,\pi^-)} = 0.24 \pm 0.06\,(\text{stat.}) \pm 0.05\,(\text{syst.}), \tag{1}$$

which is in agreement with the current world average[5].

The direct CP asymmetry, $\mathcal{A}_{CP}$, is measured to be

$$\frac{N(\overline{B}{}^0_d \to K^-\pi^+) - N(B^0_d \to K^+\pi^-)}{N(\overline{B}{}^0_d \to K^-\pi^+) + N(B^0_d \to K^+\pi^-)} = -0.04 \pm 0.08\,(\text{stat.}) \pm 0.01\,(\text{syst.}), \tag{2}$$

which is compatible with both zero and recent evidence for a finite asymmetry reported by the BaBar and Belle collaborations[6].

In the B^0_s sector, two ratios of fragmentation fractions (f_d, f_s) and branching fractions are measured:

$$\frac{f_s \cdot \mathcal{B}(B^0_s \to K^+\,K^-)}{f_d \cdot \mathcal{B}(B^0_d \to K^+\,\pi^-)} = 0.50 \pm 0.08\,(\text{stat.}) \pm 0.09\,(\text{syst.}) \tag{3}$$

$$\frac{f_d \cdot \mathcal{B}(B^0_d \to \pi^+\,\pi^-)}{f_s \cdot \mathcal{B}(B^0_s \to K^+\,K^-)} = 0.48 \pm 0.12\,(\text{stat.}) \pm 0.07\,(\text{syst.}), \tag{4}$$

where in both cases the following assumptions are made: $\Gamma_s = \Gamma_d$, the CP content of $B^0_s \to K^+\,K^-$ is 100% dominated by the CP-even short-lived component, and[7] $\Delta\Gamma_s/\Gamma_s = 0.12 \pm 0.06$. The quantity $\Delta\Gamma_s/\Gamma_s$ is assumed because this CP B^0_s eigenstate may not possess a lifetime identical to the average B^0_s lifetime measured using other modes, including semileptonic decays. The uncertainty on $\Delta\Gamma_s/\Gamma_s$ is included in the systematics in Eqs. 3 and 4. Combining Eqs. 3 and 4 with world-average results[5] for the light B mesons provides a first measure of the branching fraction

$$\mathcal{B}(B^0_s \to K^+\,K^-) = [34.3 \pm 5.5\,(\text{stat.}) \pm 5.2\,(\text{syst.})] \times 10^{-6}, \tag{5}$$

which is almost twice that for the $B^0_d \to K^+\,\pi^-$ mode[5]. The branching-fraction comparison between these two modes, which differ only by flavor of spectator quark, is compatible with expectations from QCD sum-rule calculations[4,8].

The other B^0_s channel for which an accessible branching fraction is expected, $B^0_s \to K^+\pi^-$, is not observed and a limit is therefore set:

$$\frac{f_s \cdot \mathcal{B}(B^0_s \to K^+\,\pi^-)}{f_d \cdot \mathcal{B}(B^0_d \to K^+\,\pi^-)} < 0.11\ (90\%\ CL), \tag{6}$$

which translates[5] to $\mathcal{B}(B_s^0 \to K^+ \pi^-) < 7.5 \times 10^{-6}$ (90% CL), near the lower end of current expectations[3].

Other rare modes, thought to be dominated by annihilation and exchange processes and exhibiting branching fractions in an expected range[3,9] of 10^{-8} to 10^{-7}, were sought by adding contribution components for them to the likelihood expression. Since the fit parameters changed negligibly after their inclusion, no evidence for these modes was established, and the following limits were set:

$$\frac{\mathcal{B}(B_d^0 \to K^+ K^-)}{\mathcal{B}(B_d^0 \to K^+ \pi^-)} < 0.17 \text{ (90\% } CL), \tag{7}$$

or[5] $\mathcal{B}(B_d^0 \to K^+ K^-) < 3.1 \times 10^{-6}$ (90% CL). The current best limit measurement[5] for this mode is 0.6×10^{-6}. Also,

$$\frac{\mathcal{B}(B_s^0 \to \pi^+ \pi^-)}{\mathcal{B}(B_s^0 \to K^+ K^-)} < 0.10 \text{ (90\% } CL), \tag{8}$$

which takes the assumption that both modes have the same average lifetime and translates to $\mathcal{B}(B_s^0 \to \pi^+ \pi^-) < 3.4 \times 10^{-6}$ (90% CL). This represents a significant improvement over the previous best limit measurement[5] of 170×10^{-6}.

Our data sample was also used separately to search for the charmless two-body baryon decays[10] $\Lambda_b^0 \to p\,\pi^-$ and $\Lambda_b^0 \to p\,K^-$ by counting the number of candidates populating a search region with invariant mass between[11] 5.415 and 5.535 GeV/c^2. No evidence for these modes was found, and an upper limit is therefore presented:

$$\left[\mathcal{B}(\Lambda_b^0 \to p\,\pi^-) + \mathcal{B}(\Lambda_b^0 \to p\,K^-)\right] < 22 \times 10^{-6} \text{ (90\% } CL), \tag{9}$$

which improves upon the previous limit[5] of $\mathcal{B}(\Lambda_b^0 \to p\,h^-) < 50 \times 10^{-6}$.

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