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Study of Decays $B_d \to J/\psi + K^*$ and $B_s \to J/\psi + \phi$ with the D0 detector

Phillip GUTIERREZ[*†]
University of Oklahoma
E-mail: `pgutierrez@ou.edu`

We present measurements of the linear polarization amplitudes and the strong relative phases that describe the flavor-untagged decays $B_d \to J/\psi K^*$ and $B_s \to J/\psi\phi$ in the transversity basis. We also measure the mean lifetime of the B_s mass eigenstates and the lifetime ratio. The analyses are based on approximately 2.8 fb^{-1} of data recorded with the D0 detector. From our measurements of the angular parameters we conclude that there is no evidence for a deviation from flavor SU(3) symmetry for these decays and that the factorization assumption is not valid for the $B_d \to J/\psi K^*$ decay.

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[*] Speaker.
[†] On behalf of the D0 collaboration.

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1. Introduction

Among the most important results from the Tevatron experiments are those associated with the B_s meson; mixing and CP-violation. These measurements probe the origins of the matter/antimatter asymmetry in the universe, which at the present time cannot be fully explained within the context of the standard model (SM). In this presentation, we discuss recent results [1, 2] from the D0 experiment [3] for the two color-suppressed decays $B_d \to J/\psi + K^*$ and $B_s \to J/\psi + \phi$ ($B_q \to J/\psi + V_q$ where $\{B_q, V_q\}$ denotes either $\{B_d, K^*\}$ or $\{B_s, \phi_s\}$). We start with a comparison of the two decays in order to extract information about strong interaction dynamics and then move on to the measurement of the CP-violating phase ϕ_s and lifetime difference $\Delta\Gamma_s$ of the B_s mass eigenstates.

The measurements are performed using 2.8 fb^{-1}of data collected using the D0 detector [3] at the Fermilab Tevatron $p\bar{p}$ collider operating at a center of mass energy $\sqrt{s} = 1.96$ TeV. These analyses take advantage of the large muon acceptance $|\eta| \leq 2$ of the detector, the 25% improvement in the proper lifetime resolution from the addition of the layer zero silicon vertex detector, which was installed after the first ≈ 1.3 fb^{-1}, and the $\approx 90\%$ data taking efficiency.

For this measurement, the observables are parametrized using the time-dependent angular distribution in the transversity basis [4]

$$\frac{d^4\mathscr{P}}{d\vec{\omega}dt} = \sum_{i=1}^{6} g_i(|A|, \delta, \phi_s, \Gamma, \Delta M; t)\, f_i(\vec{\omega}) \tag{1.1}$$

where $|A_i|$ represents the magnitude of the three linear polarization amplitudes, $|A_0|$ where both decay products are longitudinally polarized, $|A_{||}|$ ($|A_\perp|$) where both are transversely polarized and polarized parallel (perpendicular) to each other, δ_i are the phases of the three linear polarization amplitudes of which one is arbitrary and the remaining two are given in terms of the CP-conserving strong phases as $\delta_1 = \delta_\perp - \delta_{||}$ and $\delta_2 = \delta_\perp$, Γ_i are the decay widths of the two CP eigenstates in the B_s system, ΔM is the mass difference of the two mass eigenstates, ϕ_s is the CP-violating phase, and finally $\vec{\omega}$ are the three transversity angles [4] $\{\theta, \varphi, \psi\}$ needed to define the orientation of the decay products.

2. Untagged Analysis

For the untagged analysis [2] we do not determine the initial flavor (B_q or $\bar{B}_q$) of the reconstructed B_q-meson. This simplifies the analysis for the B_s by making Eq. 1.1 independent of ΔM and its dependence on δ_i is only through the difference of the two $\delta_2 - \delta_1 = \delta_{||}$. In addition, this analysis assumes that the CP-violating phase $\phi_s = 0$. The primary goal is to determine whether factorization holds for the two color-suppressed decays and also to determine if SU(3) symmetry holds. For factorization to hold, the decay amplitude must be factorizable into two independent currents. This is true if the strong phases are zero $\bmod \pi$. In addition, if the linear polarization amplitudes and the lifetimes are equal for the two color-suppressed modes, then SU(3) symmetry also applies; the d and s quarks are interchangeable.

To extract the $B_s \to J/\psi + \phi_s$ signal, events with two muons each with $p_T > 1.5$ GeV, $|\eta| \leq 2$ and dimuon invariant mass of $2.9 \leq M_{\mu^+\mu^-} \leq 3.3$ GeV are selected defining our sample of J/ψ

candidates. The J/ψ candidates in these events are combined with a $\phi \to K^+K^-$ candidate having a ϕ meson $p_T > 1.5$ GeV, a $K^\pm$ meson $p_T > 0.7$ GeV and $1.01 \leq M_{K^+K^-} \leq 1.03$ GeV. The B_s candidates are defined as $5.0 \leq M_{J/\psi\phi} \leq 5.8$ GeV with $p_T > 6.0$ GeV and the J/ψ and ϕ originating from a common vertex (see fig. 1). The background to these events is modeled using prompt and non-prompt sources. To understand the background modeling of the mass distribution, the largest source of systematic error, the fit was varied between the nominal exponential model and a first order polynomial model. Using an unbinned maximum likelihood fit, the extracted parameters are given in Table 1.

The $B_d \to J/\psi + K^*$ signal is extracted in a similar manner, except that for the $K^* \to K^\pm + \pi^\mp$ we must account for inverting $K^\pm$ and $\pi^\mp$ ($\approx$ 13% of the time) and add additional terms in the angular distribution to account for the P- and S-wave interference in the $K^\pm\pi^\mp$ amplitudes [5]. The results of this analysis are given in Table 1. Comparing the magnitudes of the linear polarization amplitudes and the lifetimes for the two mesons, we conclude that within errors they are the same, therefore SU(3) symmetry holds. In addition, δ_1 is 3.5 standard deviations away from zero, which indicates that factorization may not hold for $B_d \to J/\psi + K^*$.

Parameter	B_d^0	B_s^0	Units
$\|A_0\|^2$	$0.587 \pm 0.011 \pm 0.013$	$0.555 \pm 0.027 \pm 0.006$	–
$\|A_{\|\|}\|^2$	$0.230 \pm 0.013 \pm 0.025$	$0.244 \pm 0.032 \pm 0.014$	–
$\bar{\tau}_s/\tau_d$	$1.053 \pm 0.061 \pm 0.015$		
δ_1	$-0.38 \pm 0.06 \pm 0.090$	–	rad
δ_2	$3.21 \pm 0.06 \pm 0.06$	–	rad

Table 1: The results for the untagged $B_q \to J/\psi + V_q$ analyses under the assumption of no CP-violation in the B_s system. The B_s lifetime ($\bar{\tau}_s$) is given as the average of the lifetimes of the two mass eigenstates.

3. Tagged Analysis

The goals of the tagged analysis [2] are the measurement of the CP-violating phase and the lifetime difference of the two mass eigenstates in the B_s system. In the B_s system, CP-violation occurs through the interference of the direct decay $B_s \to J/\psi + \phi$ and the mixed decay $B_s \to \overline{B}_s \to J/\psi + \phi$, which is proportional to $\sin\phi_s$. To extract $\sin\phi_s$ and $\Delta\Gamma$, the two CP eigenstates need to be separated. Since $J/\psi + \phi$ is a CP eigenstate with eigenvalues $(-1)^\ell$, ℓ being the orbital angular momentum, the CP eigenstates are extracted through the angular distribution, since it is tied to the orbital angular momentum. The CP even eigenstate corresponds to the even orbital angular momenta, which correspond to the linear polarization amplitudes A_0 and $A_{||}$, and the CP odd eigenstate corresponds to $A_\perp$. In addition, since ϕ_s is expected to be small in the SM, the mass and CP eigenstates are approximately the same, $\Delta\Gamma_s = \Delta\Gamma_{CP}\cos\phi_s \approx \Delta\Gamma_{CP}$.

The event selection for the tagged analysis is similar to the event selection for the untagged analysis. The tagging of the initial flavor uses both a same side tag, which relies on the fact that the associated $K^\pm$ meson sign is correlated with the flavor of the B_s as described in [6], and an opposite side tag, which relies on the charge correlation of the $b\bar{b}$ quark pair produced in the event as described in [7]. Two discriminating variables are derived for the same side tags and three for

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the opposite side tag. These are combined in a likelihood ratio, which is found to have a tagging power of $\mathscr{P} = \varepsilon\mathscr{D}^2 = (4.68 \pm 0.54)\%$. The parameters of the angular distribution are fitted to the data with ΔM constrained to the value measured in Ref. [8]. In addition, we consider two cases for the value of the strong phases. In one case they are fixed to the world average measured at the *B*-factories [9] with a Gaussian constraint of width $\pi/8$ allowing for some level of SU(3) symmetry violation, and in the second case they are free parameters. The results of the constrained fit are shown in Fig. 2, which show a deviation from the SM at a confidence level of $\gtrapprox 90\%$.

4. Summary

We have shown that SU(3) symmetry holds and that final-state strong interactions cannot be ignored in the B_q mesons. In addition, we have measured the CP-violating phase and the decay width difference for the B_s system. We are currently improving these measurements with the accumulated > 6 fb^{-1} of data.

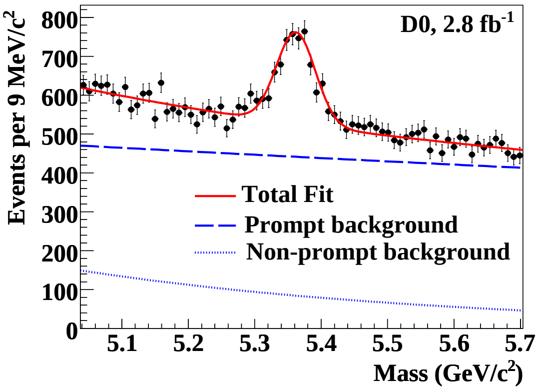

Figure 1: The invariant mass distribution of J/ψ and ϕ for B_s candidates. The points with error bars are the data points and the curves are the likelihood fit projections of the invariant mass for prompt and non-prompt backgrounds and the total sample.

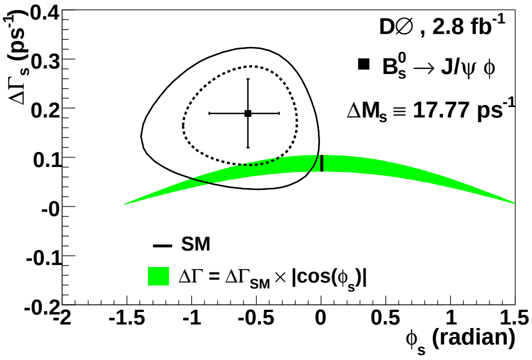

Figure 2: The best fit values of $\Delta\Gamma_s$ and ϕ_s for the constrained fit with the 68.3% and 90% confidence level contours. Also shown is the SM prediction with expected behavior of possible deviations.

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