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Measurements of Inclusive and Exclusive B Decays to Charmonium with *BABAR*

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Abstract

Using 8.5M $B\overline{B}$ events recorded by the *BABAR* detector the yield of inclusive J/ψ, the branching ratios of $\psi(2S)$ and χ_c are presented. Combining the charmonium state with either a $K^{\pm}$,K^0_S, $K^{*\pm}$ or K^{*0} exclusive B decays are reconstructed and their branching ratios determined. Using the fully reconstructed decays, both the B^0 and $B^{\pm}$ masses and their difference is measured. Finally the contributions of CP even and odd amplitudes in the decay $B \to J/\psi\, K^*$are determined from an angular analysis.

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1 Introduction

Observation of charmonium mesons in B decays is a crucial component of the measurement of time-dependent CP-violating asymmetries[1].

For the analyses described here, a sample of 7.7 fb^{-1} collected at the $\Upsilon(4S)$ resonance with an additional 1.2 fb^{-1} collected below the $B\overline{B}$ threshold are used. The number of $B\overline{B}$ events is determined by counting the number of hadronic events selected both on and off resonance. The continuum contribution to the on-resonance sample is estimated by rescaling the number of off-resonance hadronic events by the ratio of the number of observed $\mu^+\mu^-$ events in the two samples. This procedure yields a total of $8.46 \pm 0.14 \cdot 10^6$ selected $B\overline{B}$ events.

2 Inclusive decays of B to Charmonium

Events containing a J/ψ are selected by requiring two identified leptons of opposite charge. Electrons are selected by requiring the observed energy in the calorimeter to match the measured momentum, the shape of the calorimeter cluster and the observed ionization in the tracking detectors. Muons are identified by requiring a minimum ionizing signal in the calorimeter and by their penetration into and observed cluster shape in the instrumented flux return. The number of J/ψ events is determined by fitting the invariant mass distribution to a pdf obtained from a simulation which includes both final state radiation and bremsstrahlung. The fits yield $4920 \pm 100 \pm 180$ $J/\psi \to e^+e^-$ and $5490 \pm 90 \pm 90$ $J/\psi \to \mu^+\mu^-$ signal events.

Events containing $\psi(2S)$ decays are reconstructed in both the leptonic decays of the $\psi(2S)$ and its decays to $J/\psi\,\pi^+\pi^-$. In case of the former, the number of signal events is extracted in similar fashion to the J/ψ; for the latter, a fit to the mass difference between the $\psi(2S)$ and the J/ψ candidates is performed. We find $131 \pm 29 \pm 2$ decays to e^+e^-, 125 ± 19 to $\mu^+\mu^-$, 126 ± 44 to $J/\psi\,(\mu^+\mu^-)\pi^+\pi^-$ and 162 ± 23 to $J/\psi\,(e^+e^-)\pi^+\pi^-$.

The χ_{c1} and χ_{c2} are reconstructed by combining a J/ψ candidate with a photon. The signal yield is determined by fitting the mass difference between the χ_c and J/ψ candidates. We fit simultaneously for a χ_{c1} and possible χ_{c2} component. The shape of the signal is taken from the simulation, and the mass difference between the χ_{c1} and χ_{c2} is fixed to the PDG value[4]. We find $129 \pm 26 \pm 13$ χ_{c1} and 3 ± 21 χ_{c2} candidates in which $J/\psi \to e^+e^-$ and $204 \pm 47 \pm 12$ χ_{c1} and 47 ± 21 χ_{c2} candidates in which $J/\psi \to \mu^+\mu^-$.

The branching ratios of $B \to \psi(2S)X$ and $B \to \chi_{c1}X$ are determined[2] by measuring their rates relative to the measured J/ψ yield, and a limit is set on the decay to $\chi_{c2}X$. The results are summarized in Table 1.

Table 1: Measured Inclusive Branching Ratios

Mode	Br ($\times 10^{-2}$)
$\psi(2S)$	$0.25 \pm 0.02 \pm 0.02$
χ_{c1}	$0.39 \pm 0.04 \pm 0.04$
χ_{c2}	< 0.24 (90%CL)

3 Exclusive decays of B to Charmonium

As the exclusive decays in general have very little background, lepton identification is required for only one of the two J/ψ decay products. After including photons compatible with bremsstrahlung from one of the leptons, the charmonium states are selected in a window around their expected mass[4], and the observed momenta are refined by a kinematic fit constraining the charmonium masses.

The charmonium candidates are then combined with either a K^+, a K^0_S (either $\pi^+\pi^-$ or $\pi^0\pi^0$), K^{*0} (either $K^+\pi^-$ or $K^0_S\pi^0$) or K^{*+} (either $K^0_S\pi^+$ or $K^+\pi^0$) to form a B candidate. The two most significant observables used to identify the signal are ΔE, the difference in energy between the reconstructed B decay and $\sqrt{s}/2$, and the energy-substituted B mass,

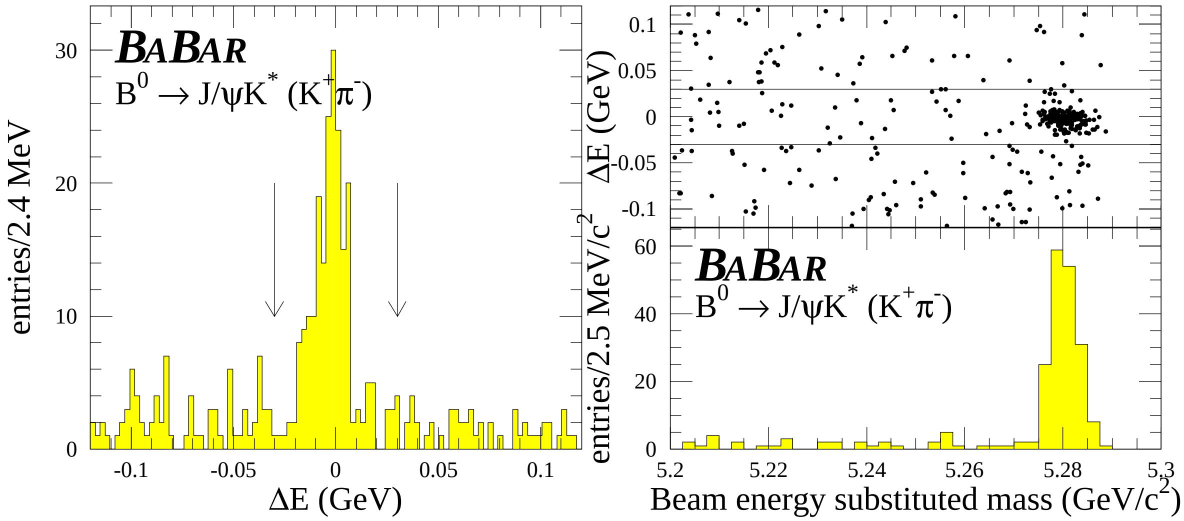

Figure 1: Example of the ΔE (left) and $m_{\rm ES}$ (right) distributions for the decay $B\to J/\psi\, K^*(K^+\pi^-)$.

$m_{\rm ES} = \sqrt{(\sqrt{s}/2)^2 - {P_B^*}^2}$ where P_B^* is the center of mass momentum of the B candidate. An example of these distributions is shown in figure 1. In the case of multiple candidates per event, only the candidate with the smallest $|\Delta E|$ is selected.

The signal yields are determined by fitting the $m_{\rm ES}$ distribution with the sum of a Gaussian and an ARGUS function[5]; for the K^* modes a likelihood fit is performed to all modes simultaneously, taking into account the cross-feed between the decays.

Systematic uncertainties considered include the number of produced B events (3.6%), the signal fit (0.9–8.6%), uncertainties on the measured tracking (2.5% per track), neutral (0.6–11%) and particle ID (2.5–8.8%) efficiencies, the tracking resolution (0.6–2.6%), the branching ratios of secondary decays (2.2–13.1%) and MC statistics (0.5–5.8%). The observed yields and branching ratios[3] are summarized in Table 2.

Table 2: Measured Exclusive Branching Ratios

Mode	Yield	Br $(\times 10^{-4})$
$B^\pm\to J/\psi\, K^{*\pm}$	126 ± 12	$13.2 \pm 1.4 \pm 2.1$
$B^0\to J/\psi\, K^{*0}$	188 ± 14	$13.8 \pm 1.1 \pm 1.8$
$B^\pm\to J/\psi\, K^\pm$	445 ± 21	$11.2 \pm 0.5 \pm 1.1$
$B^0\to J/\psi\, K^0$		
$K^0_S\to\pi^+\pi^-$	93 ± 10	$10.2 \pm 1.1 \pm 1.3$
$K^0_S\to\pi^0\pi^0$	14 ± 4	$7.5 \pm 2.0 \pm 1.2$
$B^\pm\to\psi(2S)K^\pm$	73 ± 8	$6.3 \pm 0.7 \pm 1.2$
$B^0\to\psi(2S)K^0$		
$K^0_S\to\pi^+\pi^-$	23 ± 5	$8.8 \pm 1.9 \pm 1.8$
$B^\pm\to\chi_{c1}K^\pm$	44 ± 9	$7.7 \pm 1.6 \pm 0.9$

4 Measurement of B meson masses

The masses of the B mesons are measured using fully reconstructed decays of $B^0\to J/\psi\, K^0_S(\pi^+\pi^-)$, $B^0\to J/\psi\, K^{*0}(K^+\pi^-)$ and $B^\pm\to J/\psi\, K^\pm$. These modes are chosen for their small backgrounds and good knowledge of the masses of their decays products.

The invariant mass of the B candidates is derived by fitting the decay products to a common vertex, constraining the J/ψ and K^0_S masses to their nominal values. Uncertainties in the magnetic field and the alignment of the tracking detectors could introduce a bias in the momentum measurement. Their effect is quantified by comparing the reconstructed J/ψ and K^0_S masses with the PDG values[4]. The effect of background on the measurement has been estimated by removing separately the N events with the smallest and the largest mass, where N is the number of background events determined from the sidebands.

The resulting masses[3] are:

$$m(B^0) = 5279.0 \pm 0.8 \pm 0.8\,\mathrm{MeV/c^2}$$
$$m(B^\pm) = 5278.8 \pm 0.6 \pm 0.4\,\mathrm{MeV/c^2}$$

where the first error is the quadratic sum of the statistical and uncorrelated systematic errors and the second error is the correlated systematic error.

The mass difference between B^0 and $B^\pm$ mesons is evaluated by fitting the m_{ES} distributions of the three above-mentioned channels. The use of m_{ES} has the advantage that it reduces the uncertainty in the momentum scale, whilst the uncertainty due to the beam energy cancels in the difference. The mass difference is determined[3] to be:

$$m(B^0) - m(B^\pm) = 0.28 \pm 0.21 \pm 0.04\,\mathrm{MeV/c^2}.$$

5 Angular analysis of $B \to J/\psi\, K^*$

The decay of $B \to J/\psi\, K^*$ proceeds through two CP even amplitudes $(A_0, A_{\|})$ and one CP odd amplitude $(A_\perp)$. The contribution of $A_\perp$ must be known before a value of $\sin 2\beta$ can be determined from this decay channel.

The relative contributions of the three amplitudes are determined using an unbinned extended likelihood fit to the decay angles, imposing the constraint $|A_0|^2 + |A_{\|}|^2 + |A_\perp|^2 = 1$. The CP odd fraction is found to be $|A_\perp|^2 = 0.13 \pm 0.06 \pm 0.02$ whereas the longitudinal polarization Γ_L/Γ is given by $|A_0|^2 = 0.60 \pm 0.06 \pm 0.04$. Sources of systematic uncertainties include the knowledge of the background, the acceptance corrections, the cross-feed amongst $B \to J/\psi\, K^*$ modes and the contribution from heavier K^* mesons.

References

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