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Study of Charmonium Production and Electroweak Penguins with BABAR

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STUDY OF CHARMONIUM PRODUCTION AND ELECTROWEAK PENGUINS WITH BABAR

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We report measurements of charmonium resonances (J/ψ, $\psi(2S)$, χ_{c1}) using about 25 fb^{-1} of data collected by the BABAR detector around the $\Upsilon(4S)$ resonance. We present measurements of inclusive charmonium production of charmonium in B decays and from the continuum, as well as exclusive branching ratios of B mesons into charmonium final states. We present also a measurement of the $B^0 \to K^{0*}\gamma$ branching ratio and a search for the decay $B^0 \to \gamma\gamma$.

1 Introduction

We present measurements of charmonium production and processes involving electroweak penguins in e^+e^- collisions at the $\Upsilon(4S)$ resonance, using data taken by the BABAR detector [1] at the PEP-II B factory in 1999 and 2000, which consist of $20.7\,\text{fb}^{-1}$ accumulated at the $\Upsilon(4S)$ resonance, and $2.6\,\text{fb}^{-1}$ taken off-resonance at an energy 0.04 GeV below the peak. This sample corresponds to $22.7 \cdot 10^6$ $\Upsilon(4S) \to B\bar{B}$ decays.

2 Charmonium production

We reconstruct decays of the charmonium resonances J/ψ, $\psi(2S)$ and χ_{c1}. We reconstruct J/ψ and $\psi(2S)$ through their decay into two electrons or two muons; $\psi(2S)$ is also reconstructed through the decay $J/\psi\pi^+\pi^-$, while χ_{c1} is reconstructed through the decay into $J/\psi\,\gamma$. As examples, the signals for the decays $J/\psi \to e^+e^-$, $\chi_{c1} \to J/\psi\,\gamma$ ($J/\psi \to \mu^+\mu^-$) and $\psi(2S) \to J/\psi\pi^+\pi^-(J/\psi \to e^+e^-)$ are shown in Fig. 1.

2.1 Inclusive Charmonium studies

Charmonium mesons may be produced: a) as a product of a B meson decay; b) as a direct product of the decay of $\Upsilon(4S)$; c) in the fragmentation process of a continuum $e^+e^- \to q\bar{q}$ event (prompt production); d) through Inital State Radiation (ISR).

We isolate charmonium mesons from B decays by looking at $B\bar{B}$-like events and by requiring the charmonium momentum in the center of mass frame, p^*, to be below the kinematic limit for B decays, less than 2 GeV/c for J/ψ and less than 1.6 GeV/c for $\psi(2S)$. Results for inclusive branching ratios of B mesons into charmonium mesons are listed in Table 1.

We mesure the J/ψ polarization by fitting the helicity distribution. The helicity angle, Θ_H, is the angle, measured in the J/ψ rest frame, between the positively charged lepton and the

Meson	$\mu\mu/ee$	$\mathcal{B}(\mathcal{B} \to$ Meson X) [%]
J/ψ	0.995 ± 0.036	$1.044 \pm 0.013 \pm 0.028$
J/ψ direct	0.999 ± 0.045	$0.789 \pm 0.010 \pm 0.034$
$\psi(2S)$	0.93 ± 0.15	$0.275 \pm 0.020 \pm 0.029$
χ_{c1}	1.09 ± 0.21	$0.378 \pm 0.034 \pm 0.026$
χ_{c1} direct	1.11 ± 0.23	$0.353 \pm 0.034 \pm 0.024$
χ_{c2}	0.78 ± 0.68	$0.137 \pm 0.058 \pm 0.012$
χ_{c2} limit		< 0.21 at 90% C.L.

Table 1: Inclusive Branching Ratios of B mesons into charmonium mesons.

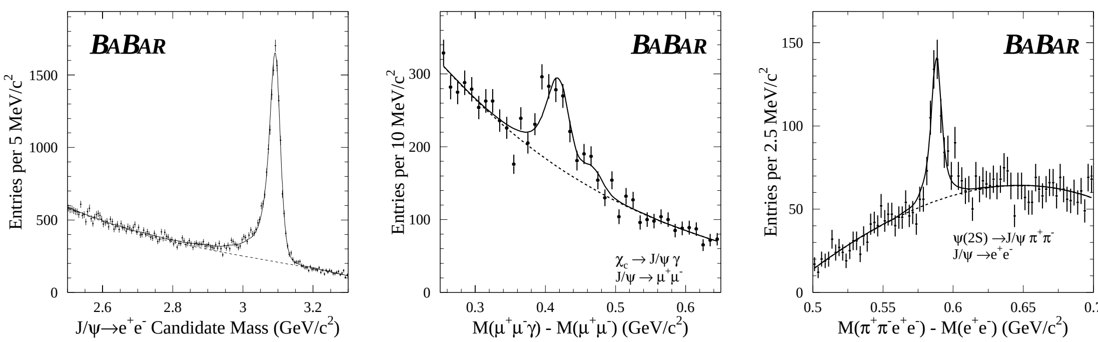

Figure 1: Charmonium signals, from left to right: $M(e^+e^-)$ for $J/\psi\ toe^+e^-$ candidates, $M(\mu\mu\gamma) - M(\mu\mu)$ for $\chi_{c1} \to J/\psi(\mu\mu)\gamma$ candidates and $M(e^+e^-\pi^+\pi^-) - M(e^+e^-)$ for $\psi(2S) \to J/\psi(e^+e^-)\pi^+\pi^-$ candidates.

J/ψ flight direction in the B meson rest frame[a]. The distribution of $u = \cos\Theta_H$ can be written in terms of a polarization parameter α: $h(u) = 3(1 + \alpha u^2)/[2(\alpha + 3)]$, where $\alpha = 0$ indicates the distribution is unpolarized, $\alpha = 1$ is transversely polarized and $\alpha = -1$ is longitudinally polarized. We find $\alpha = -0.424 \pm 0.023$ for J/ψ mesons from B decays.

The J/ψ production in the continuum is of particular interest due to the possible contribution of $c\bar{c}$ pairs created in a color octet state, which would enhance prompt J/ψ production [2,3]. To eliminate background from $B \to J/\psi X$ in the on-peak data sample, we require the J/ψ momentum in the $\Upsilon(4S)$ rest frame to be greater than 2 GeV/c. To suppress ISR production of J/ψ and $\psi(2S)$ and two photon production of χ_{c2}, we require at least 3 quality tracks with $0.41 < \theta < 2.54$, the visible energy of the event be greater than 5 GeV and the ratio of the second to the zeroth Fox-Wolfram moment, R_2, to be smaller than 0.5. We then study the production and decay properties of these prompt J/ψ mesons. The distribution of the signal in $\cos\Theta^*$ has been extracted and fit with $1 + A\cos^2\Theta^*$. Color octet and color singlet models have very different predictions for the value of A: at high p^* values, color octet models predict $0.6 < A < 1.0$ while the color singlet model predicts $A \approx -0.8$ [4]. We measure $A = 1.5 \pm 0.6$ for p^*> 3.5 GeV/c, clearly favoring the presence of color octet contributions. We also measure the polarization for prompt J/ψ to be $\alpha = -0.73 \pm 0.09$.

2.2 Exclusive Charmonium decays

We look for candidate B mesons by combining the reconstructed charmonium mesons with light meson candidates. Two kinematic variables are used to isolate the B meson signal: the difference ΔE between the reconstructed energy of the candidate and the beam energy in the $\Upsilon(4S)$ rest

[a] The B meson rest frame is approximated by the $\Upsilon(4S)$ rest frame.

Channel		BF / 10^{-4}
$B^0 \to J/\psi K^0$	$K_S^0 \to \pi^+\pi^-$	$8.5 \pm 0.5 \pm 0.6$
	$K_S^0 \to \pi^0\pi^0$	$9.6 \pm 1.5 \pm 0.7$
	K_L^0	$6.8 \pm 0.8 \pm 0.8$
	All	$8.3 \pm 0.4 \pm 0.5$
$B^+ \to J/\psi K^+$		$10.1 \pm 0.3 \pm 0.5$
$B^0 \to J/\psi \pi^0$		$0.20 \pm 0.06 \pm 0.02$
$B^0 \to J/\psi K^{*0}$		$12.4 \pm 0.5 \pm 0.9$
$B^+ \to J/\psi K^{*+}$		$13.7 \pm 0.9 \pm 1.1$
$B^0 \to \psi(2S) K^0$		$6.9 \pm 1.1 \pm 1.1$
$B^+ \to \psi(2S) K^+$		$6.4 \pm 0.5 \pm 0.8$
$B^0 \to \chi_{c1} K^0$		$5.4 \pm 1.4 \pm 1.1$
$B^+ \to \chi_{c1} K^+$		$7.5 \pm 0.8 \pm 0.8$
$B^0 \to \chi_{c1} K^{*0}$		$4.8 \pm 1.4 \pm 0.9$

Table 2: Measured branching fractions for exclusive decays of B mesons involving charmonium. The first error is statistical and the second systematic.

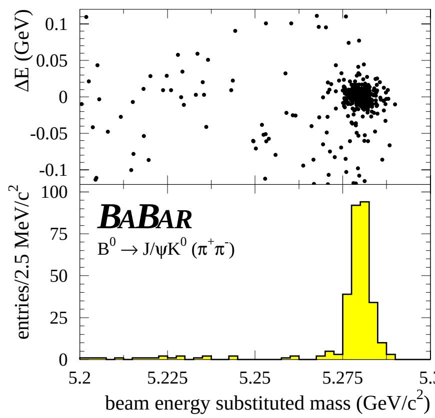

Figure 2: Energy difference ΔE vs energy substituted mass m_{ES} for the golden CP channel $B^0 \to J/\psi K_S^0(\pi^+\pi^-)$.

frame , and the beam energy substituted mass m_{ES}, defined as $m_{ES} = \sqrt{E_{beam}^{*\,2} - p_B^{*\,2}}$, where p_B^* is the momentum of the reconstructed B candidate in the $\Upsilon(4S)$ rest frame. We determine branching fractions for 14 exclusive B meson charmonium decay modes[6], listed in Table 2. We report, in particular, the first observation of the decay $B^0 \to \chi_{c1} K^{*0} (\to K^+\pi^-)$.

3 Electroweak Penguins

Electroweak penguins could be particularly sensitive to the presence of new physics and they could be low energy probes of new phenomena at a much higher energy scale. We present in the following the measurement of the decay $B \to K^*\gamma$ and a search for the decay $B^0 \to \gamma\gamma$.

3.1 Decay $B \to K^*\gamma$

The decay $B \to K^*\gamma$ proceeds by the electroweak penguin transition $b \to s\gamma$. We reconstruct this decay in the mode $K^* \to K^+\pi^-$. The radiative photon candidate is found by looking for a cluster in the electromagnetic calorimeter consistent with a photon shower and with an energy between 1.5 and 4.5 Gev in the laboratory, and 2.30 and and 2.85 Gev in the center of mass frame. The K^+ and π^- candidates are identified thanks to the DIRC, an internally-reflecting ring-imaging Cherenkov detector (DIRC), requiring that the cone of light must be consistent with the pion or kaon hypothesis, which leads in a correct K/π assignment in 97% of the cases.

The main background is from continuum $q\bar{q}$ production with the high-energy photon originating from initial state radiation or from π^0 or η decays. We exploit event topology differences between signal and background to reduce the continuum contribution. The first variable used to achieve that is $|\cos\Theta_T^*|$, where Θ_T^* is the angle, measured in the center of mass frame, between the photon candidate and the thrust vector of the event excluding the B daughter candidates. While the distribution of $|\cos\Theta_T^*|$ is flat between 0 and 1 for the signal, it is peaked at 1 for the continuum background. Thus, we require $|\cos\Theta_T^*| < 0.8$. We further suppress backgrounds using the angle of the B candidate's direction with respect to the beam axis, Θ_B^*, and the helicity angle of the K^* decay, Θ_H^*, defined as the angle between the $K^\pm$ momentum vector computed in the rest frame of the K^* and the K^* momentum vector in the parent B menson rest frame. This distribution follows a $\sin^2\Theta_H^*$ distribution for signal and is approximately flat for $q\bar{q}$ background. The same is true for the B candidate direction with respect to the beam axis. We

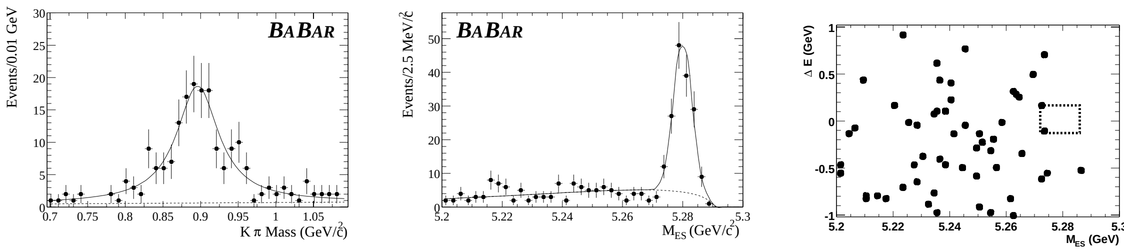

Figure 3: The fist two plots, from left to right, show the $K\pi$ mass and the energy susbstituted mass for $B \to K^*\gamma$ candidates; the third plot shows ΔE and m_{ES} for the $B^0 \to \gamma\gamma$ candidates.

require $|\cos\Theta^*_B| < 0.80$ and $|\cos\Theta^*_H| < 0.75$. The signal is shown in Fig. 3 We find a yield of 139 ± 13 events and we derive the branching fraction $\mathcal{B}(B^0 \to K^*\gamma) = (4.39 \pm 0.41 \pm 0.27) \cdot 10^{-5}$.

This sample is used to search for CP violating charge asymmmetries by constructing $A_{CP} = [(\bar{B} \to \bar{K}^*\gamma) - (B \to K^*\gamma)]/[(\bar{B} \to \bar{K}^*\gamma) + (B \to K^*\gamma)]$. The flavour of the underlying b quark is tagged by the charge of the $K^\pm$ in the decay. We constrain $A_{CP} = -0.035 \pm 0.094 \pm 0.022$.

3.2 Decay $B^0 \to \gamma\gamma$

In the Standard Model, the decay $B^0 \to \gamma\gamma$ proceeds via a second order weak transition including gluonic penguings, followed by annihilation. Standard Model predictions for the branching fraction of these effective flavor-changing neutral current processes range from 0.1 to $2.3 \cdot 10^{-8}$ [8]. Physics beyond the Standard Model could enhance this branching ratio by as much as two orders of magnitude[9]. To look for this decay, we look for events with two isolated photon candidates with energies consistent with photons coming from the decay $B \to \gamma\gamma$. As for the $B \to K^*\gamma$ mode, the main backgrounds are continuum events, and we use similar requirements to eliminate the background [7]. For the purpose of determining number of events and efficiencies, a rectangular signal region in the $(m_{ES}, \Delta E)$ plane is defined. Its size is determined by the ΔE and m_{ES} resolution. The overall efficiency for $B^0 \to \gamma\gamma$ events, as determined from Monte Carlo simulation, is $(10.7 \pm 0.2)\%$. We find one event in the signal box, with an expected background of $0.9^{+0.4}_{-0.3}$ events. We choose to quote a conservative upper limit on the branching fraction, assuming that the observed event is signal, and set the limit $\mathcal{B}(B^0 \to \gamma\gamma) < 2.4 \cdot 10^{-6}$ at the 90% confidence level . This improves the previous limit[10] by a factor twenty.

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