SLAC-TN-11-014

Investigation of novel decay $B^+ \rightarrow \psi(2S)\omega K^+$ at BaBar

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August 18, 2010

Prepared in partial fulfillment of the requirements of the Office of Science, Department of Energy's Science Undergraduate Laboratory Internship under the supervision of Arafat Gabareen Mokhtar at the BaBar Collaboration, SLAC National Laboratory. I would like to thank the United States Department of Energy, the SLAC National Accelerator Laboratory, and the directors and administrators of the SULI internship program for making this research possible. I would also like to thank his mentor Arafat Mokhtar as well as the entire SULI community.

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Work supported in part by US Department of Energy contract DE-AC02-76SF00515.

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I. Abstract

We investigate the undocumented B meson decay, $B^+ \rightarrow \psi(2S)\omega K^+$. The data were collected with the BaBar detector at the SLAC PEP-II asymmetric-energy e^+e^- collier operating at the $\gamma(4S)$ resonance, a center-of-mass energy of 10.58 GeV/c^2[1]. The $\gamma(4S)$ resonance primarily decays to pairs of B-mesons.

II. Introduction

The BaBar collaboration at the PEP-II ring was located at the SLAC National Accelerator Laboratory and was designed to study the collisions of positrons and electrons. The $e^- e^+$ pairs collide at asymmetric energies, resulting in a center of mass which is traveling at relativistic speeds. The resulting time dilation allows the decaying particles to travel large distances through the detector before undergoing their rapid decays, a process that occurs in the in the center of mass frame over extremely small distances. As they travel through silicon vertex trackers, a drift chamber, a Cerenkov radiation detector and finally an electromagnetic calorimeter, we measure the charge, energy, momentum, and particle identification in order to reconstruct the decays that have occurred.

While all well understood mesons currently fall into the qq model, the quark model has no a priori exclusion of higher configuration states such as qqqq which has led experimentalists and theorists alike to seek evidence supporting the existence of such states. Currently, there are hundreds of known decay modes of the B mesons cataloged by the Particle Data Group, but collectively they only account for approximately 60% of the B branching fraction and it is possible that many more exist [2].

In this note we attempt to establish evidence for a novel B meson decay mode $B^+ \rightarrow \psi(2S)\omega K^+$. We examine resonant features in the energy regimes of the B-meson itself (5.279 GeV/c^2), the ω-meson (0.782 GeV/c^2), and the $\psi(2S)$-meson (3.686 GeV/c^2). The $\psi(2S)$ is reconstructed in this analysis in four decay modes: $\psi(2S)$: $\psi(2S)\rightarrow e^+e^-$, $\psi(2S)\rightarrow\mu^+\mu^-$, $\psi(2S)\rightarrow J/\psi(\mu^+\mu^-)\pi^+\pi^-$, and $\psi(2S)\rightarrow J/\psi(e^+e^-)\pi^+\pi^-$

[3]. The first two have low branching fractions, (0.752±0.017% and 0.75±0.05% respectively). The latter two have significantly higher branching fractions, (both 1.93±0.06%)[3]. Note that in this analysis, the use of charge conjugated reactions is implied, so we analyze $B^- \rightarrow \psi(2S)\omega K^-$ along with $B^+ \rightarrow \psi(2S)\omega K^+$.

III. Methods

Events were selected for the presence of significant signals at the B, ψ(2S) and ω resonances. Primarily we are searching for structure in the ψ(2S)ω mass range. While we are looking for a direct three body decays, structure in the ψ(2S)ω invariant mass would suggest that this is instead a two body decay, first decaying $B^+ \rightarrow XK^+$ and then $X \rightarrow \psi(2S)\omega$, where X represents an intermediate state. While we identify the Kaon (K), the B^+ , ψ(2S), and ω must be observed indirectly, through their decay products. To improve the B^+ mass resolution we use the energy substituted mass, m_{ES}, which uses the beam energy information to reconstruct the mass of the B^+ meson[4].

In order to quantitatively analyze these events, first attempt to determine an instrument resolution function as a function of energy and its most accurate parametrization. This enables us to determine which portion of our signal width is attributable to instrument resolution limitations, and which are actual signal. Furthermore, we perform additional fits to parametrize the background and measure the signal size in the resonant ranges of interest. We utilize ROOT, a robust, software package designed specifically for high energy physics data analysis.

The selection criterion for the B-signal is shown in Table 1. To extract the B-signal, we fit m_{ES}. For the background contamination, we use an Argus function while for the signal we use a single Gaussian function. The total number of B-candidates from the fit is 138±25. The fit of the m_{ES} is shown in Figure 1, and a satisfactory fit is observed.

In order to examine ω events, we examine the 3π-mass distribution. The 3π-mass distribution is fitted with a polynomial background function and a Breit Wigner function convolved with a Gaussian resolution function for the signal. The signal size is 240±45 events. Note that we assumed 10 MeV/c^2 resolution when fitting the 3π-mass distribution. The histogram and fit of the 3π-mass distribution is shown in figure 2.

The selection criterion for the ψ(2S)-meson are shown in Table 2. Figure 3 shows the mass of dileptons, and $J/\psi\pi^+\pi^-$, for the decays of the ψ(2S) meson. In all decays, clear ψ(2S)mass resonances are observed. A summed histogram of these contributions represents the total ψ(2S) signal and is shown in Figure 4.

V. Results and Conclusion

We performed fits for two histograms: one at the $m_{3\pi}$ invariant mass, and one in the energy substituted mass, $m_{ES.}$ We examine four histograms in the region of common decays of the ψ(2S) meson. There is a one-to-one correlation between the B-signal (i.e. m_{ES} signal), ψ(2S)-signal, and ω-signal. As such, the number of signal events in all distributions should be similar[5].

We have searched for the decay of $B^+ \rightarrow \psi(2S)\omega K^+$ using the full BaBar data sample. Clear signal in B^+, ψ(2S), and ω-mesons were observed. Therefore, we found definite evidence for this novel decay mode. This result is new and will be added to the Particle Data Group list of B-meson decay modes. No new structure has been observed in the ψ(2S)ω mass distribution.

VI. Tables and Figures

Selection Category	Criterion
$J/\psi \to \mu^+\mu^-$ mass (GeV/c^2)	$3.06 < m_{\mu\mu} < 3.14$
$J/\psi \to e^+e^-$ mass (GeV/c^2)	$2.95 < m_{ee} < 3.14$
K_S mass (GeV/c^2)	$0.472 < m_{\pi\pi} < 0.522$
π^0 mass (GeV/c^2)	$0.115 < m_{\gamma\gamma} < 0.150$
ω signal region (GeV/c^2) (B^+)	$0.7695 < m_{3\pi} < 0.7965$
ω signal region (GeV/c^2) (B^0)	$0.7605 < m_{3\pi} < 0.8055$
ΔE (GeV) (B^+)	$\|\Delta E\| < 0.020$
ΔE (GeV) (B^0)	$\|\Delta E\| < 0.015$
m_{ES} (GeV/c^2)	$5.274 < m_{ES} < 5.284$
B helicity angle θ_B	$\|\cos\theta_B\| < 0.9$
Photon helicity angle θ_γ	$\cos\theta_\gamma < 0.95$
$\psi(2S)$ veto (GeV/c^2)	$3.661 < M_{J/\psi\pi\pi} < 3.711$

Table 1. Principal criteria used to select B candidates [5]

Selection Category	criterion
$\psi(2S) \to e^+e^-$	$3.44 < m_{e^+e^-} < 3.74$ GeV/c^2
$\psi(2S) \to \mu^+\mu^-$	$3.655 < m_{\mu^+\mu^-} < 3.715$ GeV/c^2
$\psi(2S) \to J/\psi(e^+e^-)\pi^+\pi^-$	$3.64 < m_{J/\psi(e^+e^-)\pi^+\pi^-} < 3.74$ GeV/c^2
$\psi(2S) \to J/\psi(\mu^+\mu^-)\pi^+\pi^-$	$3.655 < m_{J/\psi(\mu^+\mu^-)\pi^+\pi^-} < 3.715$ GeV/c^2

Table 2. For decay modes with ψ(2S) in the final state, in addition to the selection criteria in table 1, we apply the mass requirements shown above in table 3[5].

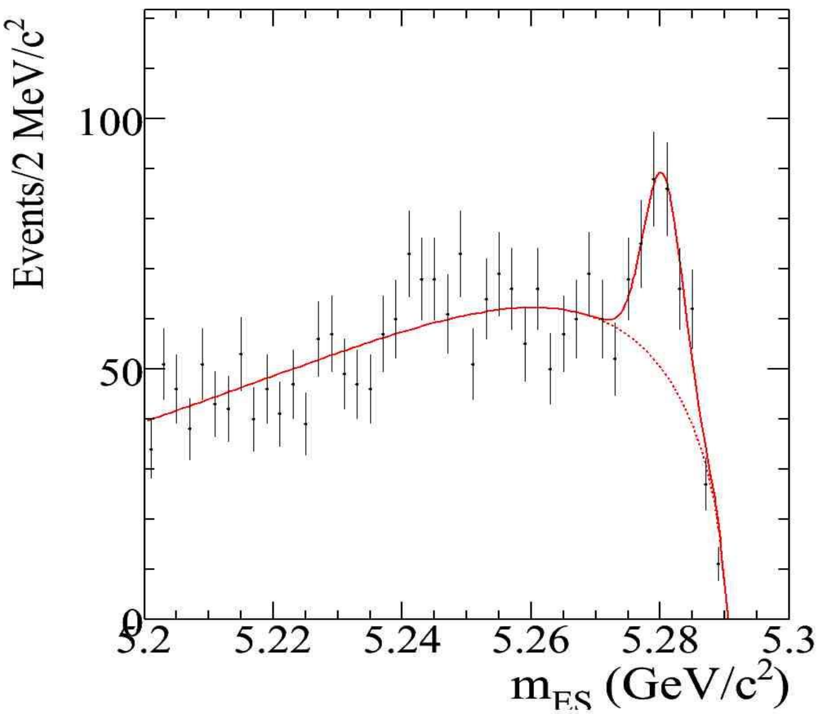

Figure 1. A fit of the B meson resonant feature near the kinematic limit. The data are shown by the filled circles and the solid (dotted) line shows the fit result of the fit (background).

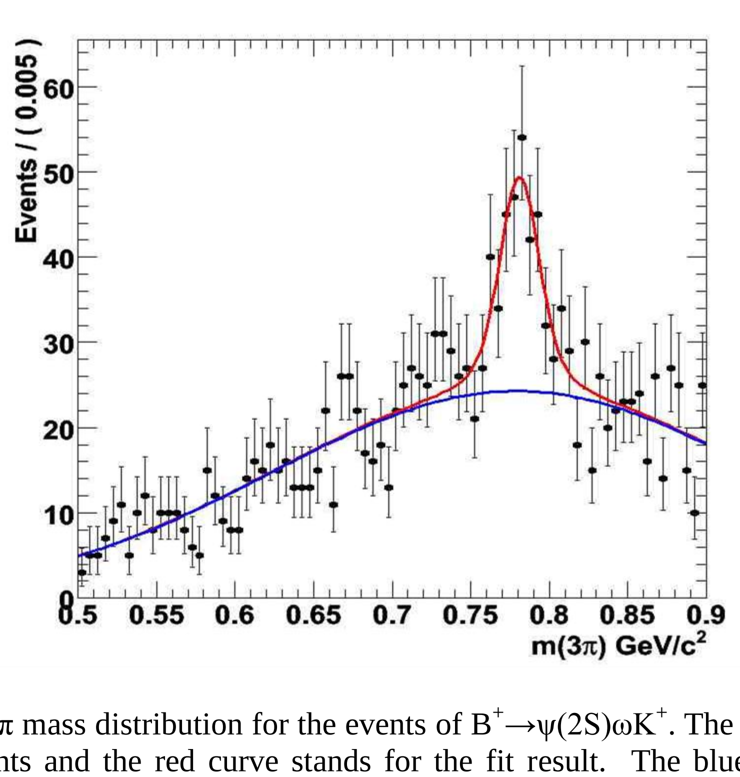

Figure 2. The 3π mass distribution for the events of $B^+ \rightarrow \psi(2S)\omega K^+$. The filled circles show the data points and the red curve stands for the fit result. The blue curve represents the background contamination in the fit.

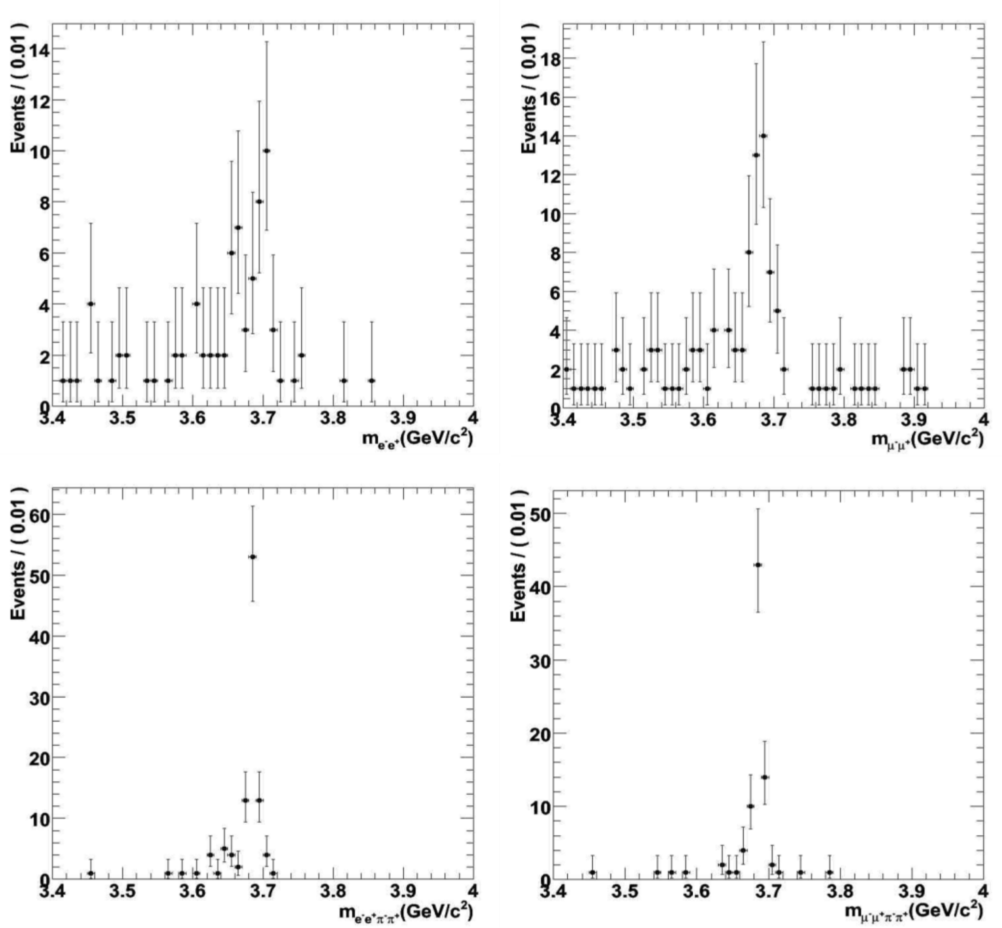

Figure 3. Histograms of the four measured contributions to the $\psi(2S)$ resonance clockwise from the top left, the first histogram corresponds to $\psi(2S)\rightarrow e^+e^-$, the second to $\psi(2S)\rightarrow\mu^+\mu^-$, the third $\psi(2S)\rightarrow J/\psi(e^+e^-)\pi^+\pi^-$. and the last to $\psi(2S)\rightarrow J/\psi(\mu^+\mu^-)\pi^+\pi^-$.

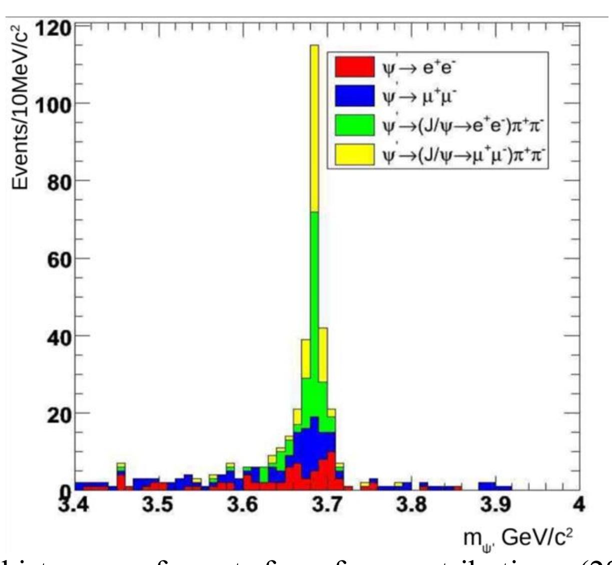

Figure 4. A summed histogram of events from four contributing $\psi(2S)$ decay modes.

VII. References

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