Search for $\psi(2s) \to$ Vector + Pseudoscalar Decays[?]

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Abstract

A search is made for $\psi(2s)$ decays into $\rho\pi$, $K^*\overline{K} + c.c.$ and $\gamma\eta'$ based on 1.3×10^6 produced $\psi(2s)$ events collected by the BES detector at the Beijing Electron Positron Collider. No convincing evidence for a signal in either of these channels are found.New Upper limits at 90% confidence level are set on the branching fraction into $\rho\pi$ of 3.6×10^{-5}, into $K^{*+}K^- + c.c.$ of 2.4×10^{-5}, into $K^{*0}\overline{K^0} + c.c.$ of 1.2×10^{-4}, and into $\gamma\eta'$ of 1.7×10^{-4}. We see a large discrepancy between the ratios of $\psi(2s)$ to J/ψ branching fractions into these decays and the predictions of PQCD.

I. INTRODUCTION

There has been a long-standing puzzle in the J/ψ and $\psi(2s)$ decays into vector plus pseudoscalar exclusive final states. As early as 1983, measuring the branching fractions of the J/ψ and $\psi(2s)$ to several hadronic final states, the MARK II Collaboration first found two final states,$\rho\pi$ and $K^{*\pm}K^{\mp}$, unobservable in $\psi(2s)$ decays, while both of them have a large branching fraction in J/ψ decays[1]. It has been noted that the ratios of branching fractions of $\psi(2s)$ and J/ψ to these two final states[2]

$$Q_{\rho\pi} < 0.0063; \;\; Q_{K^{*}\overline{K}} < 0.011$$

badly violated the expectation of PQCD that, for any final hadronic state h, the ratio Q_h scales as the ratio of the 3 gluon widths which are proportional to the leptonic widths divided by the full widths:

$$Q_h \equiv \frac{B(\psi' \to h)}{B(J/\psi \to h)} = \frac{B(\psi' \to ggg)}{B(J/\psi \to ggg)} = \frac{B(\psi' \to e^+e^-)}{B(J/\psi \to e^+e^-)} = (14.7 \pm 2.3)\%$$

where the updated values of leptonic branching fractions from Particle Data Table[2] are used. More recently, the Crystal Ball experiment observed another two decays of the $\psi(2s)$ into VP final states, $\gamma\eta$ and $\gamma\eta'$, where the vector is a photon, that are anomalously suppressed[3]. However, the Crystal Ball results have never been formally published, and the MARK II measurements of $\psi(2s)$ decays have not been renewed so far. In this paper we present a new search for $\psi(2s)$ decays in a data sample of 1.3×10^6 produced $\psi(2s)$ events taken with the BES detector at the Beijing Electron Positron Collider.

II. BES DETECTOR

The BES is a conventional cylindrical detector, which has been described in detail in Ref. 4. A four layer central drift chamber (CDC) surrounding the beampipe provides trigger information. Outside the CDC, the forty-layer main drift chamber (MDC) provides tracking and energy loss (dE/dx) information on charged tracks over 85% of the total solid angle. The momentum resolution is $\sigma_P/P = 0.017\sqrt{1+P^2}$ (P in GeV/c), and the dE/dx resolution is 11% for hadron tracks. An array of 48 scintillation counters surrounds the MDC and measures the time-of-flight (TOF) of charged tracks with a resolution of 450 ps for hadrons. Outside the TOF system, a 12 radiation length, lead-gas barrel shower counter (BSC), operating in self-quenching streamer mode, measures the energies of electrons and photons over 80% of the total solid angle. The energy resolution is $\sigma_E/E = 0.22/\sqrt{E}$ (E in GeV), and the spatial resolution $\sigma_\phi = 4.5$ mrad, $\sigma_Z = 2$ cm. Surrounding the BSC is a solenoidal magnet providing a 0.4 Tesla magnetic field in the central tracking region of the detector. Three double layers of muon counters instrument the magnet flux return, and serve to identify muons of momentum greater than 0.5 GeV/c. Endcap time-of-flight and shower counters extend coverage to the forward and backward regions.

III. EVENT SELECTION AND ANALYSIS

The analyses of the individual channels have common features. Each analysis requires events to have the correct number of charged tracks with the sum of their charges equal to zero, and at least the required number of showers. Each track must be well-reconstructed and consistent with an origin in the interaction region (candidate pions from K_s^0 decay need not satisfy the latter requirement). Spurious photon candidates, arising from the interactions of charged tracks in the shower counters, are minimized by rejecting showers which fall near a charged track and by imposing a minimum-energy requirement. Also eliminated are two showers with small invariant mass and angle of separation. For events containing a π^0, a kinematic cut on variable ERRE is used; the ERRE is defined as $ERRE = E_{cm} - \sum_i \sqrt{P_i^2 + m_{\pi^\pm}^2} - \sqrt{P_{miss}^2 + m_{\pi^0}^2}$. For events only containing one shower, a cut on the "missing-neutral-energy" variable U is used; the U is defined as $U = E_{cm} - \sum_i \sqrt{P_i^2 + m_{\pi^\pm}^2} - |\vec{P}_{miss}|$. ($\vec{P}_{miss}$ is the total momentum of all charged tracks.

The selected events are kinematically fitted by imposing energy and momentum constraints. This improves the momentum measurement and suppresses events with the wrong charge-particle assignment. The ability of the kinematic fit to discriminate between signal and background is important in the present analyses, as it partially makes up for insufficient TOF information. When the number of showers in an event exceeds the minimum, the showers are ordered in decreasing energy, all combinations of two showers are fitted, and the combination with the minimum χ^2 is retained. Detection efficiencies are calculated by Monte Carlo simulation.

The decay $\psi(2s) \to \rho\pi(\pi^+\pi^-\pi^0)$ is observed in the $\pi^+\pi^-\gamma\gamma$ final state. Events with two oppositely charged tracks and at least two photons are selected. Possible backgrounds from different sources have been estimated by Monte Carlo simulation. Two parallel hypotheses are examined, representing the signal of interest $\psi(2s) \to \pi^+\pi^-\gamma\gamma$ as well as the largest background $\psi(2s) \to K^+K^-\gamma\gamma$; $\chi^2_{\pi^+\pi^-\gamma\gamma} < \chi^2_{K^+K^-\gamma\gamma}$ is required.

Fig.1a shows the $\gamma\gamma$ invariant mass distribution for events which are consistent with the $\pi^+\pi^-\gamma\gamma$ hypothesis. A clear π^0 signal is observed, providing evidence for the decay $\psi(2s) \to \pi^+\pi^-\pi^0$. A Gaussian fit yields 29 $\pi^+\pi^-\pi^0$ candidates. Assuming all the three-pion events are non-resonant, we obtain then, using the detection efficiency of 13.9%,

$$B(\psi(2s) \to \pi^+\pi^-\pi^0) = (1.7 \pm 0.3 \pm 0.3) \times 10^{-4}$$

where the first error is statistical and the second systematic. Fig.1b shows the $\pi\pi$ invariant mass distribution after the π^0 mass cut $| M_{\gamma\gamma} - M_{\pi^0} | < 50\ MeV/c^2$. A fit with a Breit-Wigner line shape plus a linear background with the fixed mass and width of ρ yields no $\rho\pi$ events. The event number is less than 5.7 at the 90% confidence level. Using a Monte Carlo calculated efficiency of 12.8%, we are able to calculate an upper limit at 90% confidence level for the branching ratio of

$$B(\psi(2s) \to \rho\pi) < 3.6 \times 10^{-5}$$

This is more than a factor of two improvement on the MARK II result. Using the PDG average of $B(J/\psi \to \rho\pi) = (1.28 \pm 0.10)\%$[2], we set a limit on the ratio of branching fractions:

$$Q_{\rho\pi} < 0.0028$$

which is more than a factor of 50 below the theoretically expected value.

The decay $\psi(2s) \to K^{*+}K^- + c.c.$ is observed in two decay modes of the $K^{*\pm}$. For the $K^{*\pm} \to K^\pm\pi^0$ mode, the final state $K^+K^-\gamma\gamma$ is selected. The $\gamma\gamma$ invariant mass is required to be consistent with a π^0 $(0.09 < M_{\gamma\gamma} < 0.18GeV/c^2)$. Any possible $K^\pm\pi^0$ combinations consistent with $K^{*\pm}$ $(0.78 < M_{K\pi} < 1.05GeV/c^2)$ are considered. In the absence of a signal, we set limit on the branching fraction

$$B(\psi(2s) \to K^{*+}K^- + c.c.) < 4.8 \times 10^{-5}$$

at 90% confidence level. The detection efficiency is 11.6%. For the $K^{*\pm} \to K_s^0\pi^\pm$ mode, the final state $K^\pm\pi^\mp\pi^+\pi^-$ is selected. The K_s^0 is seen in the $\pi^+\pi^-$ decay mode and is identified by the distance between the primary vertex and secondary vertex and the cosine of the angle between the momentum of the K_s and its vertex direction which is expected to be close 1. The momentum of the kaon is required to be greater than 1.5 GeV/c. No event is found in the vicinity of $K^*(892)^\pm$. Using the detection efficiency of 10.7%, we set a 90% confidence level upper limit on

$$B(\psi(2s) \to K^{*+}K^- + c.c.) < 5.1 \times 10^{-5}$$

Combining both measurement for the two decay modes of the $K^{*\pm}$, we are able to obtain a better upper limit at 90% confidence level

$$B(\psi(2s) \to K^{*+}K^- + c.c.) < 2.4 \times 10^{-5}$$

This is again more than a factor of two improvement on the MARK II result[2]. Using the PDG average of $B(J/\psi \to K^{*+}K^- + c.c.) = (5.0 \pm 0.4) \times 10^{-3}$, we set a limit on the ratio of branching fractions

$$Q_{K^{*\pm}K^\mp} < 0.0048$$

This is a factor of 30 deviation from the theory.

The decay $\psi(2s) \to K^{*0}\overline{K}^0 + c.c.$ is observed in the $K^\pm\pi^\mp\pi^+\pi^-$ final state. Fig.2 show the $K^\pm\pi^\mp$ invariant mass distribution. Two events are found in the K^{*0} mass region. We set a 90% confidence level upper limit of 5.3 events, yielding a 90% C.L. limit on the branching fraction of

$$B(\psi(2s) \to K^{*0}\overline{K}^0 + c.c.) < 1.2 \times 10^{-4},$$

where the detection efficiency is 10.5%. This is the first measurement of this decay mode. Using the PDG average of $B(J/\psi \to K^{*0}\overline{K}^0 + c.c.) = (4.2 \pm 0.4) \times 10^{-3}$,we set a limit on the ratio of branching fractions

$$Q_{K^{*0}K^0} < 0.028$$

The $\psi(2s)$ decay appears to be suppressed by a factor of at least five compared to theory.

The decay $\psi(2s) \to \gamma\eta'$ is observed in the $\eta' \to \gamma\rho$ decay mode of the η'.The final state $\pi^+\pi^-\gamma\gamma$ is selected.The π^0 is rejected by $M_{\gamma\gamma}$ cut. A Gaussian fit to the $\gamma\rho$ invariant mass spectrum shown in Fig. 3 by fixing the mass of the η' and by using the mass resolution determined by Monte Carlo simulation for the width yields 0.44 events. We set a 90% C.L. upper limit of 5.4 events, yielding a 90% C.L. limit on the branching fraction of

$$B(\psi(2s) \to \gamma\eta') < 1.7 \times 10^{-4},$$

where the MC determined efficiency is 8.3%.This result,being comparable to the Crystal Ball result of $B(\psi(2s) \to \gamma\eta') < 1.4 \times 10^{-4}$ at 90% C.L., is an improvement on the limit for the branching fraction given by PDG. Using the present result and the PDG value of

$$B(J/\psi \to \gamma\eta') = (4.31 \pm 0.30) \times 10^{-3},$$

we set a limit on the ratio of branching fractions

$$\frac{B(\psi(2s) \to \gamma\eta')}{B(J/\psi \to \gamma\eta')} < 0.039$$

This is about a factor of 4 suppression compared to theory.

IV. SUMMARY AND DISCUSSION

In conclusion,using 1.3×10^6 produced $\psi(2s)$ events collected by the BES experiment,we have searched for two-body decays of the $\psi(2s)$ into a vector and a pseudoscalar meson. New upper limits are set on the branching fraction for the $\psi(2s)$ decays into $\rho\pi$,$K^{*\pm}\overline{K}^{\mp}$, $K^{*0}K^0$, and $\gamma\eta'$.These results are summarized in Tab. 1. We found that all these decays are substantially suppressed in the $\psi(2s)$ decays compared to the PQCD prediction relative to the corresponding J/ψ decays. Our results confirm the previous searches from Mark II and Crystal Ball experiments;no compelling explanation currently exists.

V. ACKNOWLEDGEMENTS

This work is supported by the National Natural Science Foundation of China, the Chinese Academy of Sciences, the U.S. Dept. of Energy, the U.S. National Science Foundation and the Texas National Research Laboratory Commission. We would like to thank the staffs of the BEPC accelerator, the Computing Center at the Institute of High Energy Physics (Beijing), and the Texas High Performance Computing Center.

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† Work supported in part by the National Natural Science Foundation of China under Contract No. 19290400 and the Chinese Academy of Sciences under contract No. KJ85 (IHEP); by the Department of Energy under Contract Nos. DE-FG02-91ER40676 (Boston University), DE-FG03-92ER40701 (Caltech), DE-FG03-93ER40788 (Colorado State University), DE-AC02-76ER03069 (MIT), DE-AC03-76SF00515 (SLAC), DE-FG03-91ER40679 (UC Irvine), DE-FG03-94ER40833 (U Hawaii), DE-FG05-92ER40736 (UT Dallas), DE-AC35-89ER40486 (SSC Lab); by the U.S. National Science Foundation, Grant No. PHY9203212 (University of Washington); and by the Texas National Research Laboratory Commission under Contract Nos. RGFY91B5, RGFY92B5 (Colorado State), and RCFY93-316H (UT Dallas).

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TABLES

TABLE I. Experimental Ratios of vector-pseudoscalar mode

- $\psi(2s)$ data are from this paper,
- J/ψ data are from PDG[2],
- Upper limits are at 90% confidence level.

Mode	$B(\psi')(\times 10^{-4})$	$B(J/\psi)(\times 10^{-3})$	$B(\psi')/B(J/\psi)$
$\rho\pi$	< 0.36	12.8 ± 1.0	< 0.0028
$K^{*\pm}K^{\mp}$	< 0.24	5.0 ± 0.4	< 0.0048
$K^{*0}K^{0}$	< 1.2	4.2 ± 0.4	< 0.028
$\gamma\eta'$	< 1.7	4.31 ± 0.30	< 0.039