# Measurement of $\psi(2S)$ Hadronic Decays to Vector Tensor Final States

BES Collaboration
*Contact: LIXH@bepc5.ihep.ac.cn; GUYF@bepc5.ihep.ac.cn*
(April 8, 1998)

## Abstract

The $\psi(2S)$ decays into vector tensor final states have been studied for the first time using a sample of $3.7\times10^6$ produced $\psi(2S)$ events. The upper limits on branching fractions for the $\psi(2S)$ decays into $\omega f_2$, $\rho a_2$, $K^{*0}\overline{K_2}^{*0}+c.c.$, and $\phi f_2'(1525)$ are obtained. The ratios of $\psi(2S)$ to $J/\psi$ branching fractions for the four hadronic decays are significantly smaller than the theoretical prediction of perturbative QCD. The long-standing puzzle of $J/\psi$ and $\psi(2S)$ hadronic decays extends beyond the vector pseudoscalar channels.

One of the most dramatic problems confronting the standard picture of charmonium decays is the long-standing puzzle involving the strong suppression of $\psi(2S)\to\rho\pi$ and $K^*\overline{K}+c.c.$ decays. One expects $J/\psi(\psi(2S))$ to decay to hadrons via three gluons or, occasionally, via a single direct photon. In either case the decay proceeds via $\mid\Psi(0)\mid^2$, where $\Psi(0)$ is the wave function at the origin in the nonrelativistic quark model for $c\bar{c}$. Thus it is reasonable to expect on the basis of perturbative QCD that for any final hadronic state h, we have [1]

$$Q_h\equiv\frac{B(\psi(2S)\to h)}{B(J/\psi\to h)}\cong\frac{B(\psi(2S)\to e^+e^-)}{B(J/\psi\to e^+e^-)}=(14.6\pm2.2)\%,$$

where the leptonic branching fractions from PDG [2] are used. It was first observed by the Mark II experiment [3] that, while this is true for a number of exclusive hadronic decay channels, it is badly violated for two vector pseudoscalar (VP) final states, $\rho\pi$ and $K^*\overline{K}+c.c.$. The experimental limits on $Q_{\rho\pi}$ and $Q_{K^*\overline{K}+c.c.}$ show order-of-magnitude discrepancies with the expected rate [2]. This anomaly, called the $\rho\pi$ puzzle, has generated considerable interest; a number of theoretical explanations have been proposed [1]. However, there was meagre progress in experiment, which has hindered the resolution of the puzzle. Until very recently, no further examples of differences between $J/\psi$ and $\psi(2S)$ hadroinc decays have been documented [2].

In this letter we extend the study of $\psi(2S)$ decays into vector tensor (VT) final states and present measurements of the branching fractions for $\psi(2S)$ decays into $\omega f_2$, $\rho a_2$, $K^{*0}\overline{K_2}^{*0}+c.c.$, $\phi f_2'(1525)$. The data were taken with the BES detector at the BEPC $e^+e^-$ storage ring located at the IHEP, Beijing. The data sample corresponds to 3.7 million produced $\psi(2S)$ events. The BES detector has been described in detail elsewhere [4]. Charged particles are tracked using a 40-layer cylindrical drift chamber in a 0.4 Tesla magnetic field with a momentum resolution $\sigma_P/P = 2.1\%\sqrt{1+P^2(GeV/c)}$. The tracking chamber is surrounded by an array of 48 time-of-flight (TOF) counters with resolution of about 450 ps for hadrons. Radially outside of TOF are an electromagnetic calorimeter with resolution $\sigma_E/E = 0.22/\sqrt{E(GeV)}$, $\sigma_\phi = 4.5$ mrad, $\sigma_\theta = 12$ mrad, as well as an array of $\mu$ counters.

The decays $\psi(2S) \to \omega f_2$, $\rho a_2$, $K^{*0}\overline{K_2}^{*0} + c.c.$ and $\phi f_2'$ have been observed in the final states $\pi^+\pi^-\pi^+\pi^-\pi^0$, $\pi^+\pi^-K^+K^-$ and $K^+K^-K^+K^-$, respectively. Each analysis requires events to have four charged tracks with total charge zero and at least two photons in the case of $\pi^+\pi^-\pi^+\pi^-\pi^0$. Particle identification is accomplished by combining the specific ionization measurement from the drift chamber with TOF information, whenever available, to derive probabilities for each charged track to be consistent with the pion or kaon mass hypothesis. Tracks compatible with electrons in electromagnetic calorimeter or muon in muons detector are discarded. A particle species dependent correction for energy loss in the beam pipe is made for all charged tracks. A correction of $-0.42\%$ is also applied to the momentum of each charged track to compensate for a shift in the BES magnetic field. Events are kinematically fitted to energy-momentum constraints and a cut on the probability $> 0.01$ is applied. A neutral pion candidate is formed from a pair of showers detected in the calorimeter which yields a $\gamma\gamma$ invariant mass within $2.5\sigma$ ($\sigma = 14\ MeV/c^2$) of the known $\pi^0$ mass. The analysis efficiency in this letter is calculated using events generated with uniform phase space distribution.

In the selection of the $\pi^+\pi^-\pi^+\pi^-\pi^0$ final state, the background contribution from $\psi(2S) \to \eta J/\psi$, where $\eta$ decays to $\pi^+\pi^-\pi^0$ and $J/\psi$ decays to leptons, is removed by a cut $M_{\pi^+\pi^-} < 2.9\ GeV/c^2$. The contamination of $\psi(2S) \to \pi^+\pi^- J/\psi$ with $J/\psi$ decays into $\pi^+\pi^-\pi^0$ is rejected by requiring the $\pi^+\pi^-\pi^0$ mass not within $50 MeV/c^2$ of known $J/\psi$ mass. The $\pi^+\pi^-\pi^0$ mass distribution of the selected events shows a clean $\omega$ signal owing to the good mass resolution ($\sigma = 13.4\ MeV/c^2$) and the proximity of the phase space limit. The $\omega$ candidate in the $\omega\pi^+\pi^-$ event is selected by requiring that $740 < m_{\pi^+\pi^-\pi^0} < 820\ MeV/c^2$. The decay $\psi(2S) \to \omega f_2$ is searched in the spectrum of $\pi^+\pi^-$ mass recoiling against the $\omega$ (FIG. 1). Taking the expected mass resolution of $f_2$ about 12.3 $MeV/c^2$ into account, a fit to a Breit-Wigner function added to a quadratic background yields $8.8 \pm 9.2$ $\omega f_2$ events. The mass and width of $f_2$ are fixed to PDG [2] values in the fit. Using an isospin ratio 2:1 for $f_2$ decays into $\pi^+\pi^-$ to $\pi^0\pi^0$ and the efficiency of 0.074, one gets an upper limit on the branching fraction

$$B(\psi(2S) \to \omega f_2) < 1.8 \times 10^{-4} \qquad \text{(C.L.=90\%)}$$

The channel $\rho a_2$ is analyzed in $\rho^0\rho^\pm\pi^\mp$ combination which also decays to the $\pi^+\pi^-\pi^+\pi^-\pi^0$ final state. The best $\rho^0\rho^\pm\pi^\mp$ combination is selected by minimizing the quantity [5]

$$\sqrt{(m_{\pi^+\pi^-} - m_{\rho^0})^2 + (m_{\pi^0\pi^\pm} - m_{\rho^\pm})^2}.$$

and a cut at 200 $MeV/c^2$ is applied to select $\rho^0\rho^\pm\pi^\mp$ candidates. Events compatible with the $\omega\pi^+\pi^-$ dynamics are already discarded. The combined mass plot of $\rho^0\pi^\pm$ and $\rho^\pm\pi^\mp$ (FIG. 2) is fitted to a Breit-Wigner line shape over a quadratic background and the number of $\rho a_2$ events is $3.9 \pm 15.7$. The mass and width of $a_2$ are fixed to PDG values [2] in the fit. The expected $a_2$ mass resolution is around 10.3 $MeV/c^2$. Using an isospin ratio of $\rho^+a_2^- : \rho^-a_2^+ : \rho^0a_2^0 = 1:1:1$ and the detection efficiency of 0.074, one calculates

$$B(\psi(2S) \to \rho a_2) < 2.5 \times 10^{-4} \qquad \text{(C.L.=90\%)}.$$

In the selection of $\pi^+\pi^-K^+K^-$ final state, each event has four assignments of $\pi^+$, $\pi^-$, $K^+$, $K^-$ tracks. The TOF, $dE/dx$ measurement and kinematic fit quality are combined to get a combined probability for an assignment. The combined $\chi^2$ is calculated as

$$\chi^2 = \sum_i \chi^2(TOF) + \sum_i \chi^2(dE/dx) + \chi^2(4C - fit).$$

Similarly are the combined degrees of freedom calculated. The track assignment with the largest combined probability is selected for a $\pi^+\pi^-K^+K^-$ candidate. The contamination of $\psi(2S) \to \pi^+\pi^-J/\psi$ is discarded by a cut on the $\pi^+\pi^-$ recoiling mass. The $K^{*0}$ candidate in the $K^{*0}K^\pm\pi^\mp$ event is selected by requiring that $800 < m_{K^\pm\pi^\mp} < 1000$ $MeV/c^2$. The contamination of $\psi(2S) \to \phi\pi^+\pi^-$ with $\phi \to K^+K^-$ is negligible. The plot of $K^\pm\pi^\mp$ mass recoiling against the $K^{*0}$ is fitted with two Breit-Wigner curves of $K^{*0}$ and $K_2^{*0}$ over a quadratic background (figure 3). The mass and width of $K_2^{*0}$ are set to PDG [2]. So is the width of $K^{*0}$. With the expected mass resolution 4.9 $MeV/c^2$ for the $K^{*0}$ and 6.7 $MeV/c^2$ for the $K_2^{*0}$, respectively, the fit yields $1.4 \pm 8.6$ $K^{*0}K_2^{*0}$ events. Applying $K^\pm\pi^\mp : K^0\pi^0 = 2:1$ for both $K^{*0}$ and $K_2^{*0}$ decays and using the efficiency of 0.171, one gets

$$B(\psi(2S) \to K^{*0}\overline{K_2}^{*0} + c.c.) < 1.4 \times 10^{-4} \qquad (C.L. = 90\%).$$

There are 41 events selected as $K^+K^-K^+K^-$ candidates. The $K^+K^-$ mass spectrum shows the $\phi$ signal with mass resolution $\sigma$ =4.1 $MeV/c^2$. The $\phi$ candidate in the $\phi K^+K^-$ event is selected by requiring that $m_{K^+K^-} < 1040$ $MeV/c^2$. FIG. 4 shows the spectrum of the $K^+K^-$ mass recoiling against the $\phi$ where no clear evidence for enhancement at the mass of the $f_2'$ resonance is found. The mass resolution of $f_2'$ is expected to be 6 $MeV/c^2$. There are 3 events in FIG. 4 that fall into 80 $MeV/c^2$ region around the known $f_2'$ mass. Taken all of them as $f_2'$ candidates, at the 90% confidence level the event number is less than 6.68. The branching fraction is calculated by using the efficiency of 0.181 to be

$$B(\psi(2S) \to \phi f_2'(1525)) < 4.7 \times 10^{-5} \qquad \text{(C.L.=90\%)}.$$

Table I summarizes the results of branching fraction measurements for all decay modes of the $\psi(2S)$ analyzed. The table includes the data for the corresponding $J/\psi$ decays [6] as well as the ratios of branching fractions of the $\psi(2S)$ to the $J/\psi$. Those four states, all being vector-tensor meson combinations, appear to be suppressed by a factor of at least three compared to the theoretical expectation of 15% relative to the corresponding $J/\psi$ decays. It is noted that, in a perturbative QCD quark scheme, the hadronic VT decays are allowed by the Hadron Helicity Conservation (HHC) theorem [7], unlike the VP hadronic decays which are forbidden by the same theorem [8]. It thus seems even more puzzling why hadronic $\psi(2S)$ decays to VT mesons are missing in HHC allowed channels while $J/\psi$ decays to VP mesons ($\rho\pi$ and $K^*\overline{K} + c.c.$) are enhanced in HHC forbidden channels. This unusal suppression poses a new challenge to the present theoretical understanding of the charmonium decay mechanism.

In conclusion, we have presented first measurements of $\psi(2S)$ decays into $\omega f_2$, $\rho a_2$, $K^{*0}\overline{K_2}^{*0} + c.c.$, $\phi f_2'(1525)$. The upper limits are set on branching fractions for these decay modes, for which the ratio of $\psi(2S)$ to $J/\psi$ branching fractions is substantially smaller than the theoretical expectation. The puzzle of the hadronic decays of the $J/\psi$ and $\psi(2S)$ extends from the VP decay to the VT decay.

Table I. Branching fractions measured for $\psi(2S)$ decays into vector tensor final states. The data of corresponding $J/\psi$ branching fractions [6] are also given for calculating the ratio of $\psi(2S)$ to $J/\psi$ branching fractions. All limits are set at 90% confidence level.

| Final state | $B(\psi(2S))$ $(\times 10^{-4})$ | $B(J/\psi)$ $(\times 10^{-3})$ | $B(\psi(2S))/B(J/\psi)$ |
|---|---|---|---|
| $\omega f_2$ | $< 1.8$ | $4.3 \pm 0.6$ | $< 0.042$ |
| $\rho a_2$ | $< 2.5$ | $10.9 \pm 2.2$ | $< 0.023$ |
| $K^{*0}\overline{K_2}^{*0} + c.c.$ | $< 1.4$ | $6.7 \pm 2.6$ | $< 0.022$ |
| $\phi f_2'$ | $< 0.47$ | $1.23 \pm 0.06 \pm 0.20$ | $< 0.038$ |

## REFERENCES


[1] W.S.Hou and A.Soni, Phys. Rev. Lett. 50, (1983) 569;
G.Karl and W.Roberts, Phys. Lett. B144, (1984) 243;
S.J.Brodsky et al., Phys. Rev. Lett. 59, (1987) 621;
M.Chaichian et al., Nucl. Phys. B323, (1989) 75;
S.S.Pinsky, Phys. Lett. B236, (1990) 479;
X.Q.Li et al., Phys. Rev. D55, (1997) 1241;
S.J.Brodsky and M.Karliner, Phys. Rev. Lett. 78, (1997) 4682.

[2] Particle Data Group, R.M.Barnett et al., Phys. Rev. D54, (1996) 1.

[3] M.E.B.Franklin et al., Phys. Rev. Lett. 51, (1983) 963.

[4] BES Collab., J.Z.Bai et al., Nucl. Instr. Methods, A344 (1994) 319.

[5] DM2 Collab., J.E.Augustin et al., Nucl. Phys. B320, (1989) 1.

[6] For the first three decays, we use the PDG [2] recommended values of the $J/\psi$ branching fractions. For $J/\psi$ decay to $\phi f_2'$, there is poor consistency between the two existing measurements, MARK II and DM2 [2]. Instead of the PDG average with 50% error, we use the more recent data of DM2, which was a high statistics measurement, giving smaller errors and including the interference with $f_J(1710)$.

[7] Y.F.Gu and S.F.Tuan, Mod. Phys. Lett., A10, (1995) 615.

[8] S.J.Brodsky and G.P.Lepage, Phys. Rev. D24, (1981) 2848.

FIGURES

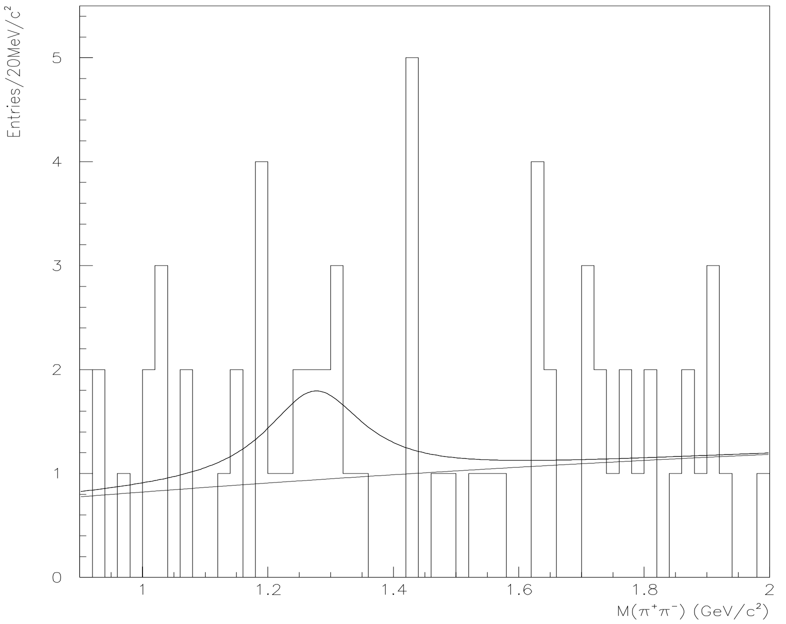


FIG. 1. The $\pi^+\pi^-$ invariant mass recoiling against the $\omega$ for events of the type $\psi(2S) \to \omega\pi^+\pi^-$. The curve shows a fit to quadratic background plus $f_2$ resonance (to see the text).

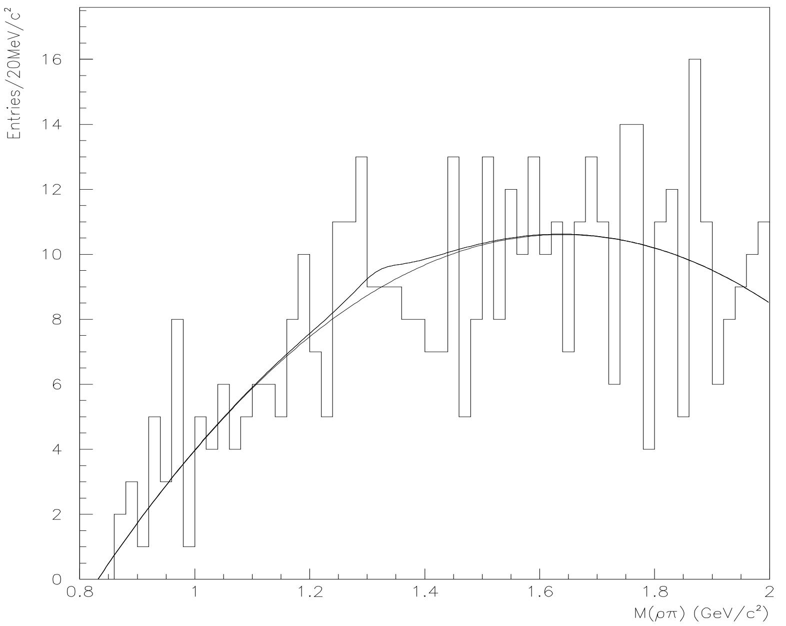


FIG. 2. The $\rho\pi$ invariant mass for events of the type $\psi(2S) \to \rho^0\rho^{\mp}\pi^{\pm}$. The curve shows a fit to quadratic background plus $a_2$ resonance (to see the text).

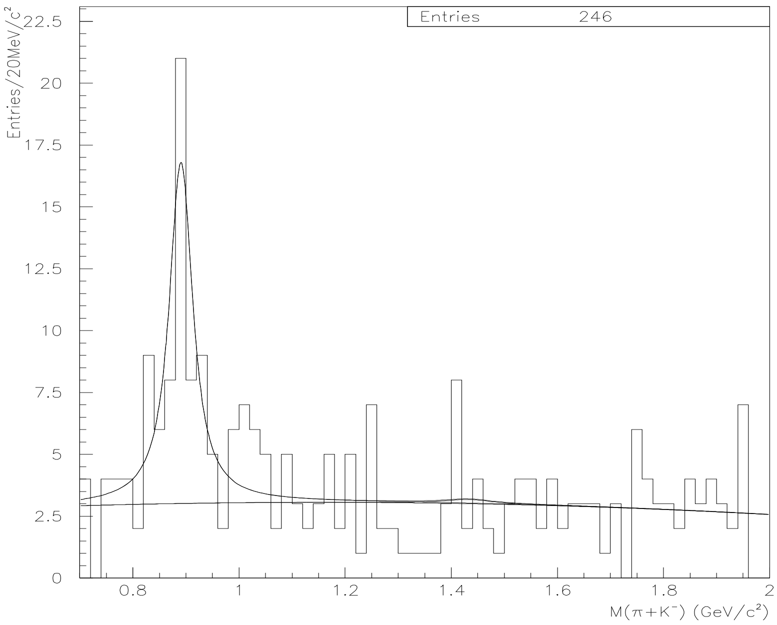


FIG. 3. The $\pi^{\pm}K^{\mp}$ invariant mass recoiling against the $K^{*0}$ for events of the type $\psi(2S) \to K^{*0}\pi^{\pm}K^{\mp}$. The curve shows a fit to quadratic background plus $K^{*0}$ and $K_2^{*0}$ resonances (to see the text).

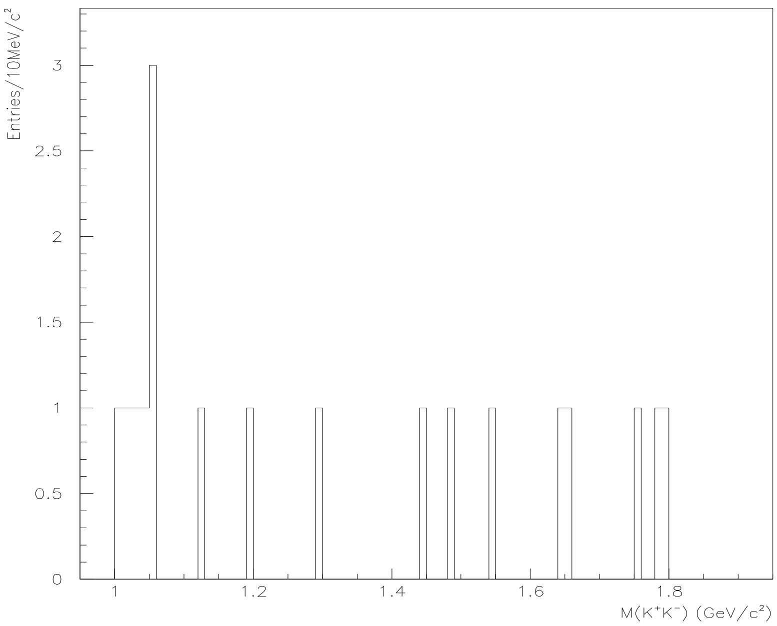


FIG. 4. The $K^+K^-$ invariant mass recoiling against the $\phi$ for events of the type $\psi(2S) \to \phi K^+K^-$. 3 events fall into 80 $MeV/c^2$ region around the known $f_2'$ mass.