BES Analysis Memo
Search for $\psi(2S)$ Decays to Vector plus Tensor Mesons

Li Xinhua
email: LIXH@bepc5.ihep.ac.cn

Abstract

The hadronic decays $\psi(2S) \to \omega f_2$ and ρa_2 have been studied in a sample of 3.6×10^6 $\psi(2S)$ events. Measurements of their branching fractions are presented. Both channels violate the "15% *rule*" predicted by perturbative QCD compared with the corresponding J/ψ decays. As vector-tensor pair combinations, they provide the first anomalous example of non-vector-pseudoscalar decays of charmonium.

I. INTRODUCTION

There exists a long standing puzzle in the study of charmonium decays. According to Applequist and Politzer [1], there is a direct parallel between the decay of $\psi(2S)$ and J/ψ to three massless gluons

$$Q_h \equiv \frac{B(\psi(2S) \to ggg)}{B(J/\psi \to ggg)} = \frac{B(\psi(2S) \to e^+e^-)}{B(J/\psi \to e^+e^-)} = (14.7 \pm 2.3)\%$$

where the updated values of leptonic branching fractions from PDG [2] are used.

The Mark II first revealed unexpected small values for the ratios of $\psi(2S)$ to J/ψ branching fractions for decays to $\rho\pi$ and $K^{*\pm}K^{\mp}$. With a data sample of 1.02×10^6 produced $\psi(2S)$ events, it was found that $Q_{\rho\pi} < 0.63\%(90\%\ C.L.)$ and $Q_{K^{*\pm}K^{\mp}} < 2.07\%$(90% C.L.) [3].

Following Mark II, several radiative decays were measured by the Crystal Ball experiment [4]. Radiative decays of $\psi(2S)$ to the tensor f_2 was observed but neither to the η nor the η'. These results, in combination with the Mark II results, immediately led to a conclusion that the suppressed modes are just vector-pseudoscalar decays of $\psi(2S)$. Ever since it becomes popular in the literature to refer to the puzzle as "$vector - pseudoscalar\ puzzle$".

A number of theoretical models [5], [6], [7], [8], [9] have been suggested to explain the puzzle, but none of them works well.

This paper extends to the observation of vector-tensor combination decays, $\psi(2S) \to \omega f_2$ and ρa_2. Data were taken during 1993-1995 at BEPC. The total event number of $\psi(2S)$ is $3.6(1 \pm 10\%) \times 10^6$ got by calculating the total number of J/ψ in the inclusive decay $\psi(2S) \to \pi^+\pi^-J/\psi$ and using the branching fraction of $\psi(2S) \to \pi^+\pi^-J/\psi$ of PDG [2].

II. $\psi(2S) \to \pi^+\pi^-\pi^+\pi^-\pi^0$ SELECTION

Events with four charged tracks in the polar angle region $\mid \cos\theta \mid < 0.8$ and with zero net charge have been selected. MFIT=2, -9, or -19 is required in track fit and transverse momentum larger than 70 MeV/c for each track. Electrons are kicked out by requirung $E_{SC}/P < 0.8$ for each track with momentum greater than 1 GeV/c and $E_+ + E_- < 1.5GeV$ for every two opposite charged tracks. Muons are excluded by requiring at most one good hit layer in μ counter where a good hit layer is required to be within 3σ both on XY plane and in Z direction. The σ is got from the data sample $e^+e^- \to \mu^+\mu^-$ of the $\psi(2S)$ data running. The dE/dx and TOF measurements are used to Kick out kaon by requiring $\mid \chi(\pi) \mid < \mid \chi(K) \mid$ when any track's momentum is less than 0.6GeV/c, and also proton by requiring $\mid \chi(\pi) \mid < \mid \chi(P) \mid$ when any track's momentum is less than 1 GeV/c.

In addition, at least two neutral BSC energy clusters have been selected to be photons with each has $\mid \cos\theta \mid < 0.75$ and $E_{BSC} > 50MeV$. The angle between a photon and the nearest charged track is larger than 16^o. Each photon hits at least 2 layers of shower counter, it starts before 4th layer or else from 4th or 5th layer when the energy deposited in each layer is higher than 40MeV. To exclude fake photon signal made by the coincidence of noise in shower counter, we also require the angle between the photon entering shower counter and its cluster going through shower counter to be less than 20^o. In order to reconstruct π^0 with two selected photons, $\theta_{\gamma\gamma} > 3\sigma_\theta$ and $\mid M_{\gamma\gamma} - M_{\pi^0} \mid < 3\sigma_M$ are required, where the angular resolution σ_θ and mass resolution σ_M are calculated by using three independent parameters, θ, ϕ, and energy, given by the reconstruction of neutral track. In practice, both values of σ_θ and σ_M vary with each pair of photons. Among the whole $\psi(2S)$ data sample their values are around 1^o and $45MeV/c^2$, respectively. In case of three or more photon candidates, two photons with minimum $\mid M_{\gamma\gamma} - M_{\pi^0} \mid / \sigma_M$ are selected.

Furthermore, no $\pi^+\pi^-$ combination is allowed to recoil to J/ψ within $50MeV/c^2$ to exclude the background $\psi(2S) \to \pi^+\pi^- J/\psi$ with J/ψ decaying to $\pi^+\pi^-\pi^0$ or any pair of e, μ, π, K and P. $\mid ERRE \mid < 200MeV$ is required to select $2(\pi^+\pi^-)\pi^0$ candidates, where ERRE is defined as

$$ERRE = E_{cm} - \sum_{i=1}^{4} \sqrt{P_i^2 + m_{\pi^\pm}^2} - \sqrt{P_{miss}^2 + m_{\pi^0}^2}$$

and P_{miss} is the missing momentum of four charged tracks. Corrections are made for energy loss and multiple Coulomb scattering by the charged particles in the material before they enter the drift volume in BES inner detector. So are photon directions entering shower counter for beam position dispersion in the colliding zone. Events are kinematically $4C2\gamma$ fitted and its probability is required to be greater than 0.01. The π^0 is selected by requiring the invariant mass of two photons to be $85 < M_{\gamma\gamma} < 185\ MeV/c^2$.

III. ANALYSIS OF $\psi(2S) \to \omega\pi^+\pi^-$

The $\pi^+\pi^-\pi^0$ mass spectrum 1 shows significant ω signal. The mass distribution is fitted to a Breit-Wigner curve with width fixed to PDG [2] and float mass added to a quaduatical background. Mass resolution is 13.4 MeV got by Monte Carlo simulation. The fit gives

93.5 ± 12.5 events and mass of ω $(783 \pm 2) MeV/c^2$ well consistent with PDG [2]. The efficiency is 5.41% calculated by Monte Carlo simulation with uniform phase space distribution. The branching fraction is obtained as

$$B(\psi(2S) \to \omega\pi^+\pi^-) = (5.41 \pm 0.72 \pm 1.07) \times 10^{-4},$$

where the first error is statistical and second systematic. The systematic error mainly dues to kinematic fit probability cut and π^0 mass band selection, it also contains signal fit to different background line, the simulation of analysis efficiency, total number of $\psi(2S)$, and the branching fraction of $\omega \to \pi^+\pi^-\pi^0$ given by PDG [2]. So are calculated for the other systematic errors in this memo.

The $\omega\pi^+\pi^-$ candidates are selected by requiring $\mid m_{\pi^+\pi^-\pi^0} - m_\omega \mid < 40\ MeV/c^2$. The $\omega\pi^\pm$ mass spectrum 2 shows a clean $b_1^\pm$ signal owing to the proximity of the phase space limit. The measurement for the branching fraction of $b_1^\pm\pi^\mp$ is in processing.

In order to investigate the decay $\psi(2S) \to \omega f_2$, another cut at $M_{\omega\pi} > 1400\ MeV/c^2$ is made to eliminate background coming from $b_1\pi^\pm$. This cut lose 20% efficiency and the result is shown in figure 3. f_2 signal is visible on the plot and its statistic significance is 1.7σ where σ is the standard deviation. Statistic significance in this memo is regarded to the difference of logarithm liklihoods between two fits, one is fitted to signal, the other is to set no signal at all. The f_2 signal has been fitted to a Breit-Wigner curve with width fixed to PDG [2] and float mass added to a linear background. Mass resolution is 12.3 MeV got by simulation. The fit leads to 6.4 ± 4.2 events and gives f_2 mass $(1266 \pm 54) MeV/c^2$ agreeing with PGD [2]. At the 90% confidence level the event number is less than 13.4. The efficiency is 5.31% calculated by simulation with uniform phase space distribution. The branching fraction

$$B(\psi(2S) \to \omega f_2) = (6.7 \pm 4.4 \pm 2.8) \times 10^{-5}$$

is obtained by adopting an isospin ratio 2:1 for f_2 decays into $\pi^+\pi^-$ or $\pi^0\pi^0$. The first error is statistical and the second systematic, where the later is calculated in the samw way as $\omega\pi^+\pi^-$, and it also contains ω mass band selection and $M_{\omega\pi^\pm}$ cut. Alternatively, one also gets the upper limit

$$B(\psi(2S) \to \omega f_2) < 1.5 \times 10^{-4} \qquad \text{(C.L.=90\%)}$$

IV. ANALYSIS OF $\psi(2S) \to \rho A_2$

This decay channel is analyzed in $\rho^0\rho^\pm\pi^\mp$ combination which decayes to $\pi^+\pi^-\pi^+\pi^-\pi^0$ final state. The best $\rho^0\rho^\pm\pi^\mp$ combination is selected by minimizing the quantity

$$[(m_\rho - m_{\pi^+\pi^-})^2 + (m_\rho - m_{\pi^\pm\pi^0})^2]^{1/2}$$

and a cut at 150 MeV/c^2 is applied to select $\rho^\pm\pi^\mp\rho^0$ candidates. a_2 signal is visible on the combining $\rho^0\pi^\pm$ and $\rho^\pm\pi^\mp$ mass plot 4 with 2.9σ statistical significance. A fit to a float mass Breit-Wigner distribution with width fixed to PDG [2] over a quadratic background yields ρa_2 event number 28.4 ± 13.7. Mass of a_2 $1307 \pm 20\ MeV/c^2$ agrees with PDG [2]. Simulation with uniform phase space distribution gives 5.49% detection efficiency. Assuming an isospin ratio of $a_2^+\rho^- : a_2^-\rho^+ : a_2^0\rho^0 = 1:1:1$ for $\psi(2S)$ decay, one calculates

$$B(\psi(2S) \to \rho a_2) = (3.1 \pm 1.5 \pm 1.1) \times 10^{-4},$$

where the first error is statistical, the second systematic. The later is calculted similar to $\omega\pi^+\pi^-$ and also contains $\rho^\pm\pi^\mp\rho^0$ candidate selection.

V. SUMMARY AND DISCUSSION

The decay of $\psi(2S)$ into $2(\pi^+\pi^-)\pi^0$ has been studied from a high statistics constrained and fully reconstructed events. Two vector-tensor combinations, ωf_2 and ρa_2, are measured in $\psi(2S)$ decays. Moreover, the branching fraction of $\psi(2S)$ decay to $K^{*0}K_2^{*0}$ has also been measured by another BES analysis memo in $\psi(2S) \to \pi^+\pi^-K^+K^-$ channel [10]. Table I summarizes the results of branching ratio measured for $\psi(2S)$ decays into vector plus tensor sombinations and also the PDG [2] values for the corresponding J/ψ decays. All three channels give values of the ratio of branching fractions of the $\psi(2S)$ to the J/ψ much lower than the prediction of perturbative QCD. As vector-tensor combinations, their suppressions provide a striking deviation from the naive expectation [1] and as yet there is no theoretical explanation.

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FIGURES

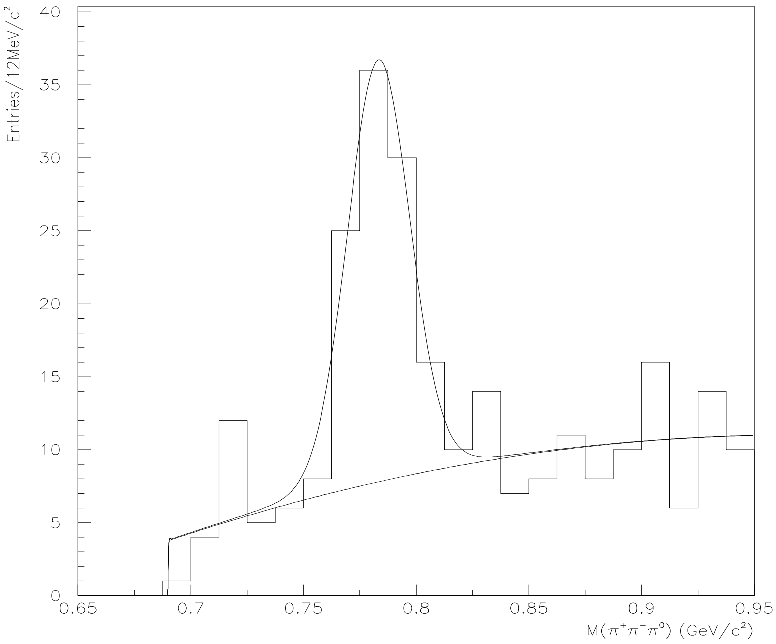

FIG. 1. Fit result of $\pi^+\pi^-\pi^0$ invariant mass

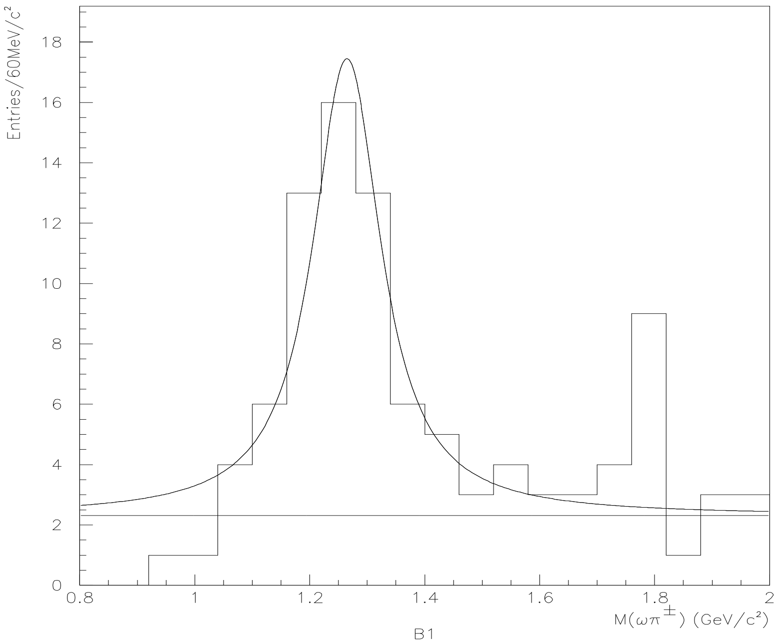

FIG. 2. $\omega\pi^\pm$ invariant mass

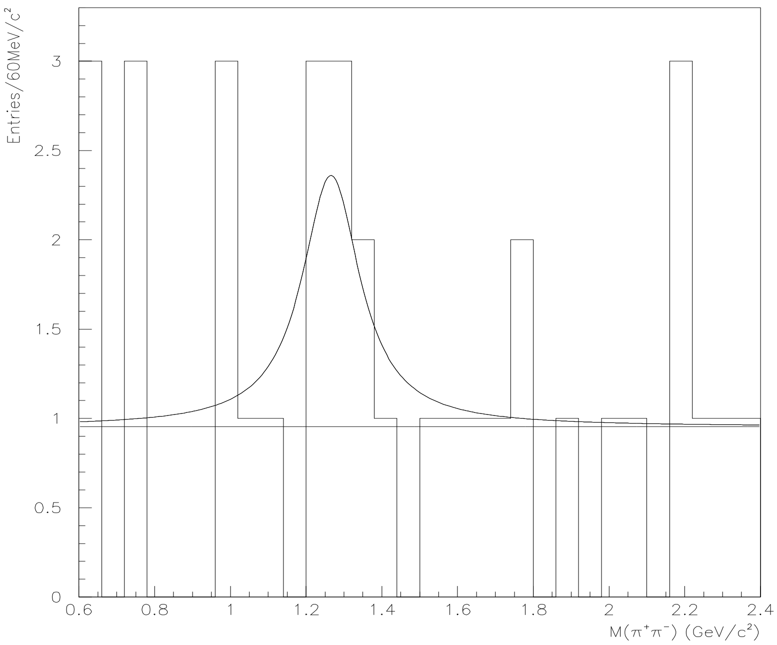

FIG. 3. Fit to the mass recoilling to ω

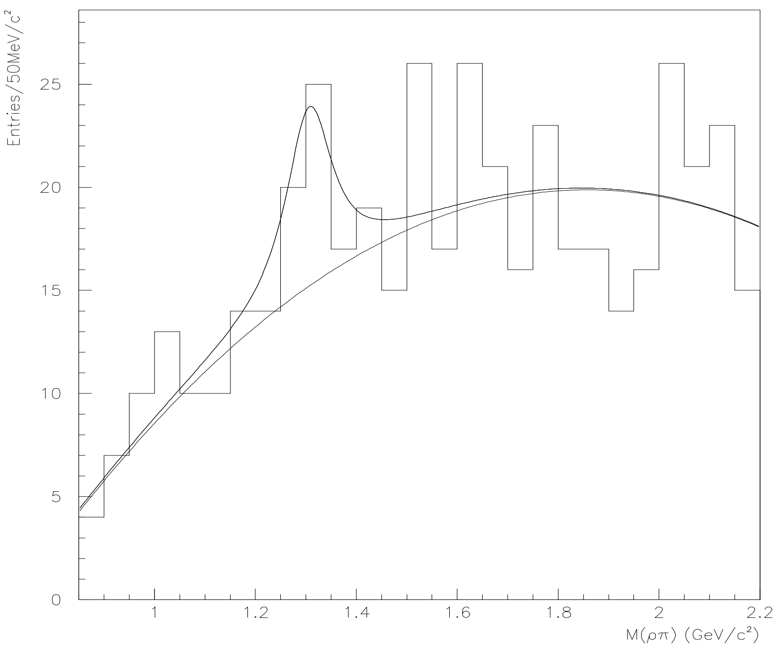

FIG. 4. Fit result of $\rho\pi$ invariant mass

TABLES

Channel	$B(\psi(2S))$	$B(J/\psi)$	$B(\psi(2S))/B(J/\psi)$
$\omega\pi^+\pi^-$	$(5.41 \pm 0.72 \pm 1.07) \times 10^{-4}$	$(7.2 \pm 1.0) \times 10^{-3}$	$(7.5 \pm 2.1)\%$
ωf_2	$< 1.5 \times 10^{-4}$	$(4.3 \pm 0.6) \times 10^{-3}$	$< 3.5\%$
ρa_2	$(3.1 \pm 1.5 \pm 1.1) \times 10^{-4}$	$(10.9 \pm 2.2) \times 10^{-3}$	$(2.8 \pm 1.8)\%$
$K^{*0} K_2^{*0} + c.c.$	$< 1.79 \times 10^{-4}$	$(6.7 \pm 2.6) \times 10^{-3}$	$< 2.8\%$

TABLE I. Experimental ratios of $\psi(2S)$ compared to J/ψ (upper limits are at 90% confidence level).