RECENT RESULTS ON CHARMONIUM PHYSICS AT BES

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Abstract

With 58 million J/ψ events and 14 million $\psi(2S)$ events, Partial Wave Analyses have been performed to study scalar mesons κ and σ. There is evidence for the κ near the $K\pi$ threshold and its pole position is $(760 \sim 840) - i(310 \sim 420)$MeV. The low mass enhancement in $\pi^+\pi^-$ invariant mass spectrum is seen in $J/\psi \to \omega\pi^+\pi^-$ and its pole position has been determined to be $(541 \pm 39) - i(252 \pm 42)$ MeV; in $\psi(2S) \to \pi^+\pi^- J/\psi$, the σ destructively interferes with the background term, which suppress the $\pi\pi$ amplitude near threshold to zero. The σ pole position determined in this channel is consistent with that of $J/\psi \to \omega\pi^+\pi^-$. Many two-body decay channels are studied, which include VP and PP modes. Based on systematical measurements for charmonium decay, 12% rule is tested.

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*on behalf of BES Collaboration

1 Introduction

Charmonium decay continues to present itself as a challenge to our understanding of the strong interaction. Up to 2004, BES collaboration has collected 14 Million (M) $\psi(2S)$ events (corresponding integrated luminosity is 19.72 pb$^{-}1$), 58 M J/ψ events and 6.4 pb^{-1} data taken at 3.65 GeV for continuum study. With all these samples, studies have been made systematically for charmonium decay. Herein the results of $\psi(2S)$ and J/ψ decay include two parts: the scalar meson study on κ and σ and the test of the pQCD 12% rule. The scalar meson are one of the most controversial subjects in hadron physics, especially in case of κ and σ. κ and σ have been carefully studied by performing Partial Wave Analysis(PWA) on many channels of BES data. The results of $\psi(2S)$ and J/ψ decay contain the following topics: decays of $\psi(2S)$ to Vector Pseudoscalar (VP) and Pseudoscalar Pseudoscalar (PP) channels.

2 κ and σ study

2.1 κ in $J/\psi \to \pi^+\pi^-K^+K^-$ and $J/\psi \to k_0^\star(892)k\pi$

Events over all of the 4-body phase space for $J/\psi \to \pi^+\pi^-K^+K^-$ have been fitted. We find evidence for the κ in the process $J/\psi \to K(890)\kappa, \kappa \to (K\pi)_S$. We select a $K^+\pi^-$ pair in the $K^-\pi^+$ invariant mass in the range 892 ± 100MeV to fit.

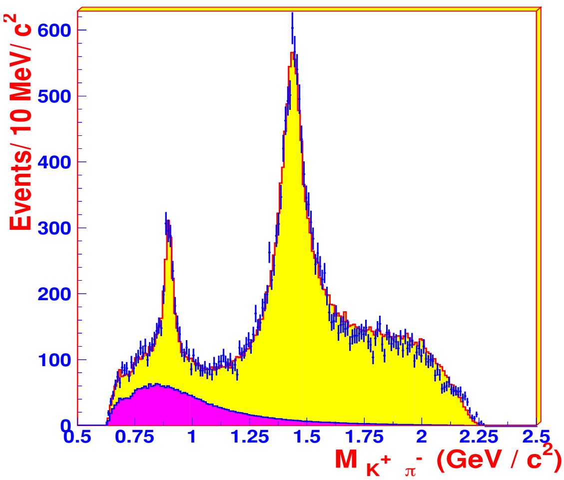

Figure 1: *Fit results of $J/\psi \to K^\star K^+\pi^-$. The figure shows the invariant mass distribution of accompanying $K^+\pi^-$ pairs (crosses). The heavy shaded(purple) region is the κ contribution.*

The data are fitted with a form for the κ containing an Adler zero in the width. The pole position for κ is at $(760 \pm 20(sta) \pm 40(sys)) - i(420 \pm 45(sta) \pm 60(sys))$MeV.

For the $K^*(892)K^+\pi^-$ system in the $K^+K^-\pi^+\pi^-$ data, two independent analyses have been performed. Figure **??** shows the recoil $K^+\pi^-$ invariant mass spectrum against $\bar{K}^*(892)^0$, while the heavy shaded histogram is the κ contribution. Both analyses favor that the low mass enhancement in the $K^+\pi^-$ spectrum is a scalar resonance, which is considered to be the κ particle. Its pole position is determined to be $(841 \pm 30^{+81}_{-73}) - i(309 \pm 45^{+48}_{-72})$MeV.

2.2 σ in $J/\psi \to \omega\pi^+\pi^-$ and $\psi(2S) \to J/\psi\pi^+\pi^-$

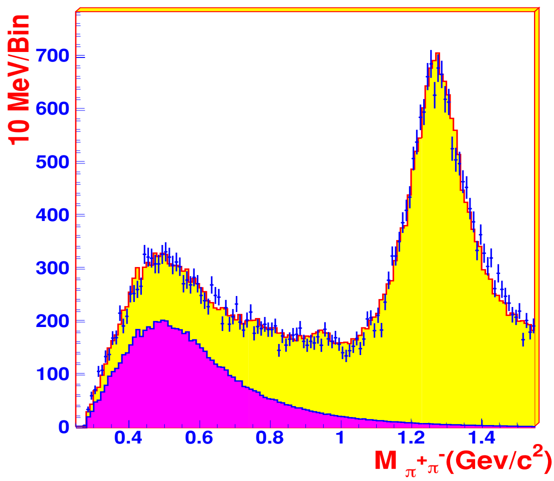

Figure 2: *Data and fit results of $J/\psi \to \omega\pi^+\pi^-$. The figure shows the invariant mass distribution of $\pi^+\pi-$ pair recoiling a reconstructed ω in an event. (crosses for data and histogram for Monte Carlo projection, the heavy shaded(purple) region is the σ contribution).*

In $J/\psi \to \omega\pi^+\pi^-$, a low mass enhancement in the $\pi\pi$ mass spectrum is observed, which is proved to be not coming from background processes, phase space effect or threshold effect. Two independent partial wave analyses have been performed on this channel **?**). In one method, the recoil $\pi^+\pi^-$ mass spectrum in the whole mass region against the ω particle is analyzed. In this analysis the ω decay is considered, and the background is estimated by directly sideband subtraction. In another method, the ω is treated as stable particle. In order to avoid complicity in the higher mass region, only the $\pi\pi$ mass spectrum in the region $M_{\pi\pi} < 1.5$GeV is analyzed, and the background is fitted by a non-interference phase space term in the PWA. In this analysis, the low mass enhancement is proved to be a 0^{++} isoscalar resonance.

Figure **??** shows the $\pi\pi$ invariant mass distribution from $J/\psi \to \omega\pi^+\pi^-$. The full histogram in Figure **??** shows the maximum likelihood fit, the heavy shaded region shows the σ contribution. Four parametrizations for the σ amplitude are tried in the analyses, and the pole position of the σ particle by these parameterizatons are consistent each other. The average pole position is determined to be $(541 \pm 39) - i(252 \pm 42)$ MeV.

Recently, an analysis on $\psi(2S) \to \pi^+\pi^- J/\psi$ channel has been performed to study the structure of $\pi^+\pi^-$ mass spectrum. The Covariant Helicity Amplitude Analysis is performed on the decay process $\psi(2S) \to \pi^+\pi^- J/\psi, J/\psi \to \mu^+\mu^-$.

The $\pi^+\pi^-$ mass spectrum is distinctly different from that of phase space, which suggests the σ production in this process.

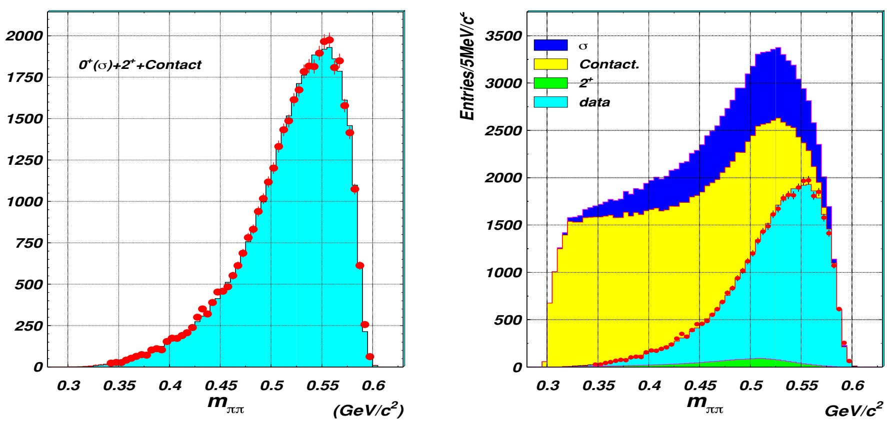

Figure 3: *Fit results of $\psi(2S) \to \pi^+\pi^- J/\psi$. Dot with error bar stands for data and histogram for Monte Carlo. The left is $\pi^+\pi^-$ invariant mass, the right contributions from single components (σ, contact term, d-wave term and data, d-wave is enlarged by a factor of 20.)*

Three types of Breit-Wigner parameterizations for the σ are tried in the fit to the data. With a large destructive interference, the $\pi\pi$ amplitude near the threshold is suppressed to almost zero, which is expected by the chiral theory. In addition, the d-wave only gives a very small contribution. Figure **??** shows the fit results. In the left figure the shaded histogram is the fit and the point with error bar is data, and the right shows the contributions from each component(σ, contact term and d-wave term). The σ pole position are determined to be $(554 \pm 14 \pm 53) - i(242 \pm 5 \pm 24)$MeV, which is consistent with that of $J/\psi \to \omega\pi^+\pi^-$

3 Test of 12% rule with $\psi(2S)$ and J/ψ decay

As it is known, both J/ψ and $(2S)$ decays are expected to be dominated by annihilation into three gluons, with widths that are proportional to the square of the $c\bar{c}$ wave function at the origin [?]. This yields the pQCD expectation(so-called 12% rule) that

$$Q_h = \frac{B_{\psi(2S)\to X_h}}{J/\psi \to X_h} = \frac{B_{\psi(2S)\to e^+e^-}}{B_{J/\psi\to e^+e^-}} = (12.3 \pm 0.7)\% \tag{1}$$

The observation of deviation from 12% rule will provide some new clues concerning the dynamics of charmonium decay.

3.1 VP decay mode of $\psi(2S)$

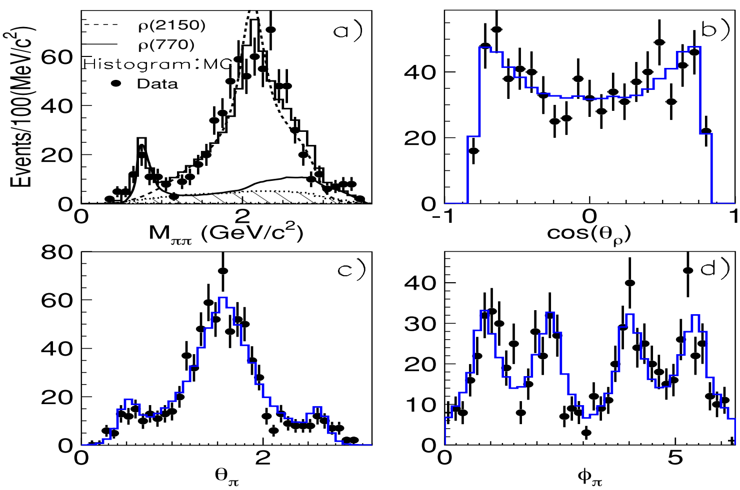

Figure 4: *Comparison between data (dots with error bars) and the final fit (solid histograms) for (a) two pion invariant mass, with a solid line for the $\rho(770)\pi$, a dashed line for the $\rho(2150)\pi$, and a hatched histogram for background; (b) the ρ polar angle in the $\psi(2S)$ rest frame; and (c) and (d) for the polar and azimuthal angles of the designated π in ρ helicity frame.*

The selected $\pi^+\pi^-\pi^0$ events are fitted in the helicity amplitude formalism with an unbinned maximum likelihood method based on MINUIT [?]. The fit shown in Figure **??** describes the data reasonably well, and the $\rho(2150)$ serves as an effective description of the high mass enhancement near 2.15 GeV/c^2 in $\pi\pi$ mass [?]. The branching fractions of $\psi(2S) \to \pi^+\pi^-\pi^0$, $\rho(770)\pi$ and $\rho(2150)\pi \to \pi^+\pi^-\pi^0$ are $(18.1 \pm 1.8 \pm 1.9) \times 10^{-5}$, $(5.1 \pm 0.7 \pm 1.1) \times 10^{-5}$ and $(19.4 \pm 2.5^{+11.5}_{-3.4}) \times 10^{-5}$, respectively, where the first error is statistical and the second one is systematic.

Table 1: *The results of $\psi(2S)$ two-body decay.*

VP channels	$B(\psi(2S) \to) \times 10^{-5}$	$B(J/\psi \to) \times 10^{-4}$	Q_h (%)
$\rho\pi$	$5.1 \pm 0.7 \pm 1.1$	127±9	0.40 ± 0.11
$K^\star(892)^+K^- + c.c.$	$2.9^{+1.3}_{-1.7} \pm 0.4$	50±4	$0.59^{+0.27}_{-0.36}$
$K^\star(892)^0\bar{K}^0 + c.c.$	$13.3^{+2.4}_{-2.8} \pm 1.7$	42±4	3.2 ± 0.8
$\omega\pi$	$1.87^{+0.68}_{-0.62} \pm 0.28$	4.2±0.6	$4.4^{+1.8}_{-1.6}$
$\rho\eta$	$1.78^{+0.67}_{-0.62} \pm 0.17$	1.93±0.23	$9.2^{+3.6}_{-3.3}$
$\rho\eta'$	$1.87^{+1.64}_{-1.11} \pm 0.33$	1.05±0.18	$17.8^{+15.9}_{-11.1}$
$\phi\pi^0$	< 0.41	< 0.068	–
$\phi\eta$	$3.3 \pm 1.1 \pm 0.5$	6.5±0.7	5.1 ± 1.9
$\phi\eta'$	$2.8 \pm 1.5 \pm 0.6$	3.3±0.4	8.5 ± 5.0
$\omega\eta$	< 3.2	15.8±1.6	< 2.0
$\omega\eta'$	$3.1^{+2.4}_{-2.0} \pm 0.7$	1.67±0.25	19^{+15}_{-13}
PP channels	$B(\psi(2S) \to) \times 10^{-5}$	$B(J/\psi \to) \times 10^{-4}$	Q_h (%)
K_SK_L	$5.24 \pm 0.47 \pm 0.48$	$1.82 \pm 0.04 \pm 0.13$	28.8 ± 3.7

For the analysis of electromagnetic decays $\psi(2S) \to \omega\pi, \rho\eta$ and $\rho\eta'$, beside the $\psi(2S)$ data sample, we also analyze 6.42 pb^{-1} of continuum data at $\sqrt{s} =$ 3.650GeV, and 17.3 pb^{-1} at the $\psi(3770)$. Table **??** lists the cross sections of $e^+e^- \to \omega\pi, \rho\eta$ and $\rho\eta'$; the branching fractions of $\psi(2S) \to \omega\pi, \rho\eta$ and $\rho\eta'$ [?] are listed in Table **??**.

For $\psi(2S) \to K^\star(892)\bar{K}^- + c.c.$, we study its final state $K^0_s K^\pm\pi^\mp \to \pi^+\pi^-K^\pm\pi^\mp$ [?]. A large isospin-violation between the charge and neutral mode has been observed. The other decay modes are studied with ϕ decays to K^+K^-, ω to $\pi^+\pi^-\pi^0$, η' to $\eta\pi^+\pi^-$ or $\gamma\pi^+\pi^-$, and π^0 and η to 2γ [?]. The results are also listed in Table **??**.

3.2 PP decay mode of $\psi(2S)$

The decay $\psi(2S) \to K_S K_L$ is observed using 14 million $\psi(2S)$ events; the branching fraction is determined to be $B(\psi(2S) \to K_S K_L)$=$(5.24 \pm 0.47 \pm 0.48)\times 10^{-5}$ [?]. Compared with $J/\psi \to K_S K_L$ [?], the $\psi(2S)$ branching fraction is enhanced by more than 4σ relative to the prediction of the perturbative QCD "12%" rule.

4 Summary

Partial wave analyses have been performed on BES data to study the scalar mesons. The κ near $K\pi$ threshold is needed and the pole position is $(760 \sim 840) - i(310 \sim 420)$MeV. The σ is seen clearly in $J/\psi \to \omega\pi^+\pi^-$ channel and gives an accurate pole position, $(541 \pm 39) - i(252 \pm 42)$MeV. In $\psi(2S) \to \pi^+\pi^- J/\psi$, we can fit the $\pi^+\pi^-$ invariant mass spectrum well through a strong destructive interference between σ and contact term, and the σ pole was determined to be $(554 \pm 14 \pm 53) - i(242 \pm 5 \pm 24)$MeV, which is consistent with that of $J/\psi \to \omega\pi^+\pi^-$.

The Q-values of 12% rule for two kinds of two-body decay, VP and PP, are listed in Table 1. The branching fractions in our measurement are consistent with those of CLEO [?]. It shows clearly the Q-value is enhanced for some channels while suppressed for others. The experimental results show that 12% rule seems to be too simplistic.

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