Recent BES results in Charmonium Physics

Li Xinhua [a] (on behalf of the BES Collaboration)

[a] Institute of High Energy Physics, Chinese Academy of Sciences
P.O.Box 918 (1-1), Beijing 100039, P R China

Results on $\psi(2S)$ physics at BES are presented. They are based on 3.79×10^6 events collected at the BEPC in 1993-95. These results include measurements of the J/ψ leptonic branching fractions, the χ_c decay widths, and the decays of $\psi(2S)$ to vector pseudoscalar and vector tensor final states.

1. Introduction

Running at the BEPC e^+e^- storage ring, the BES detector has collected $(3.788 \pm 0.009 \pm 0.309) \times 10^6$ $\psi(2S)$ events, so far the largest $\psi(2S)$ sample in the world. This report presents the recent results obtained by BES in the field of charmonium physics.

The BES is a conventional solenoidal magnet detector that is described in detail elsewhere [1]. We summarize the most essential points. Charged particles are tracked using a 40-layer cylindrical drift chamber in a 0.4 Tesla magnetic field with a momentum resolution $\sigma_p/p = 1.7\%\sqrt{1+p^2(GeV/c)}$. 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 the TOF are an electromagnetic calorimeter with resolution $\sigma_E/E = 0.22/\sqrt{E(GeV)}$, $\sigma_\phi = 4.5$ mrad, $\sigma_\theta = 12$ mrad, and an array of μ counters that are interspersed inside the steel plates that return the solenoid's magnetic flux.

2. Determination of J/ψ leptonic branching fractions via $\psi(2S) \to \pi^+\pi^- J/\psi$

A precise measurement of the J/ψ leptonic branching fractions is based on a comparison of the rates for $\psi(2S) \to \pi^+\pi^- J/\psi$, $J/\psi \to l^+l^-$ and $J/\psi \to anything$, which is independent of the luminosity determination and free of the QED contaminations. Figure 1 shows the $m^{recoil}_{\pi^+\pi^-}$ distribution for the $\psi(2S) \to \pi^+\pi^- J/\psi$, a) $J/\psi \to l^+l^-$ events and b) $J/\psi \to anything$ events. The results are $B(J/\psi \to e^+e^-) = (5.90 \pm 0.05 \pm 0.10)\%$ and $B(J/\psi \to \mu^+\mu^-) = (5.84 \pm 0.06 \pm 0.10)\%$, where the first error is statistical and the second is systematic. These values are consistent with and improve on the precision of the world averages [2]. The close equality of B_{ee} and $B_{\mu\mu}$ is a verification of e–μ universality:

$$\frac{B(J/\psi \to e^+e^-)}{B(J/\psi \to \mu^+\mu^-)} = 1.011 \pm 0.013 \pm 0.016. \quad (1)$$

3. Study of $\psi(2S)$ hadronic decays

One expects that the J/ψ and $\psi(2S)$ decays into light hadrons via ggg, or γ^*, or γgg. In either case, the partial width for the decay is proportional to $\mid \Psi(0) \mid^2$, where $\psi(0)$ is the wave function at the origin in the non-relativistic quark model for $c\bar{c}$. Thus it is reasonable to expect [3] on the basis of perturbative QCD that, for any hadronic final state h,

$$Q_h \equiv \frac{B(\psi(2S) \to h)}{B(J/\psi \to h)} = \frac{B(\psi(2S) \to \mu^+\mu^-)}{B(J/\psi \to \mu^+\mu^-)} \quad (2)$$
$$= 0.146 \pm 0.022,$$

where the leptonic branching fractions from PDG [2] are used. In order to test the above relation, which is referred to as the "15% *rule*", systematic studies of $\psi(2S)$ exclusive hadronic decays have been carried out at the BES in years. Table 1 summarizes the results of branching fraction measurements for all decay modes of the $\psi(2S)$ studied. The table includes the data for the corresponding J/ψ decays [4] as well as the ratios of branching fractions of the $\psi(2S)$ to the J/ψ. Some outstanding features are found.

Table 1
Branching fractions measured for the $\psi(2S)$ decays. Results for the corresponding J/ψ branching fractions [4] are also given as well as the ratios $Q_h \equiv B(\psi(2S))/B(J/\psi)$. All limits are at the 90% confidence level.

Channel	$B(\psi(2S))$ ($\times 10^{-4}$)	$B(J/\psi)$ ($\times 10^{-3}$)	Q_h (%)
$\rho\pi$ (preliminary)	< 0.29	12.8 ± 1.0	< 0.23
$\omega\pi^0$	$0.36 \pm 0.16 \pm 0.06$	0.42 ± 0.06	8.6 ± 4.5
$K^+\overline{K^*}(892)^- + c.c$	< 0.23	5.0 ± 0.4	< 0.46
$K^0\overline{K^*}(892)^0 + c.c.$	$1.30 \pm 0.34 \pm 0.16$	4.2 ± 0.4	3.1 ± 1.0
$K^{*0}\overline{K_2^{*0}} + c.c.$	< 1.4	6.7 ± 2.6	< 2.2
$\phi f_2'$	< 0.47	$1.23 \pm 0.06 \pm 0.20$	< 5.9
ρa_2	< 2.7	10.9 ± 2.2	< 2.5
ωf_2	< 1.8	4.3 ± 0.6	< 4.2
γf_2 (preliminary)	$1.59 \pm 0.34 \pm 0.41$	1.38 ± 0.14	11.5 ± 4.0
$\gamma\eta$	$0.53 \pm 0.31 \pm 0.08$	0.86 ± 0.08	6.2 ± 3.8
$\gamma\eta'$	$1.54 \pm 0.31 \pm 0.20$	4.31 ± 0.30	3.6 ± 0.9

3.1. $\psi(2S)$ decays to vector pseudoscalar (VP) mesons

One of the most intriguing puzzle in charmonium physics was reported in 1983 by MARK II [5]: Two hadronic channels, $\rho\pi$ and $K^{*+}\overline{K^-} + c.c.$, which are dominant in J/ψ decays, are missing in $\psi(2S)$ decays. The limits at 90% confidence level on the ratio of $\psi(2S)$ to J/ψ decay rates are more than an order of magnitude below the "15% *rule*".

Our analyses confirm the MARK II measurements at much higher levels of sensitivity. The upper limits on the branching fractions of $\psi(2S) \to \rho\pi$ and $\psi(2S) \to K^{*+}\overline{K^-} + c.c.$ are found to be more than a factor of 60 and 20, respectively, lower than the "15% *rule*" expectations.

It is of interest to note that the rate of the isospin-violating decay $\psi(2S) \to \omega\pi^0$ is at least as large as that of the isospin-conserving decay $\psi(2S) \to \rho\pi$. This fact, along with the large isospin violating difference observed between the branching fractions for the charged and neutral $\psi(2S) \to K^*\overline{K}$ decay modes, implies that the strong interacting $\psi(2S) \to VP$ processes are suppressed to the level of electromagnetic processes, while this kind of suppression does not occur for J/ψ decays.

3.2. New suppression found in vector tensor (VT) decays

We extend for the first time the study of $\psi(2S)$ hadronic decays beyond the VP final states. The $\psi(2S) \to \omega f_2$ decay channel is analyzed in the $\pi^+\pi^-\pi^+\pi^-\pi^0$ final state. The $\pi^+\pi^-\pi^0$ mass spectrum of selected $\pi^+\pi^-\pi^+\pi^-\pi^0$ events, shown in Fig. 2, has a clear ω signal with a mass resolution $\sigma = 13.4$ MeV. Candidate ω mesons are required to have a $\pi^+\pi^-\pi^0$ combination with an invariant mass in the range $740 < m_{\pi^+\pi^-\pi^0} < 820$ MeV. Figure 3 shows the invariant mass spectrum for $\pi^+\pi^-$ pairs recoiling against candidate ω mesons. There is no obvious signal in the region of the $f_2(1270)$ meson. All observed four VT final states are suppressed with respect to "15% *rule*" expectations. In contrast to the case for the VP modes, these decays are allowed by the QCD theorem that the total hadron helicity is conserved in high-momentum transfer exclusive processes [6]. Noting that the tensor meson is a P-wave state, a suppression of $m^2(J/\psi)/m^2(\psi(2S)) \sim 0.71$ is involved in the ratio $B(\psi(2S))/B(J/\psi)$, which seems not large enough to account for the observed data. This finding of new suppression poses an additional challenge to current understanding of charmonium physics.

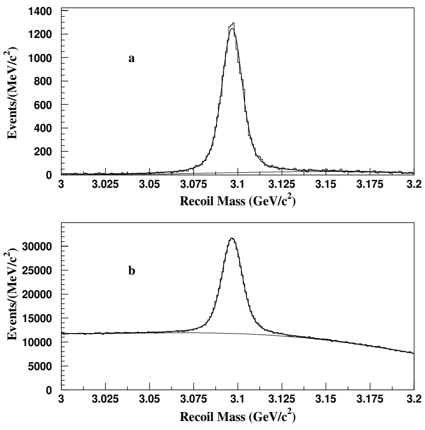

Figure 1. a) Number of events versus $m^{recoil}_{\pi^+\pi^-}$, the mass recoiling against the $\pi^+\pi^-$, for $\psi(2S) \to \pi^+\pi^- J/\psi$, $J/\psi \to l^+l^-$ events. The histogram is data, and the smooth curve is a BWG (*"signal"*) plus a third order polynomial (*"background"*). b) Number of events versus $m^{recoil}_{\pi^+\pi^-}$ for inclusive events. The histogram is data, and the smooth curve is a BWG (*"signal"*) with parameters determined from a) plus a fourth order polynomial (*"background"*).

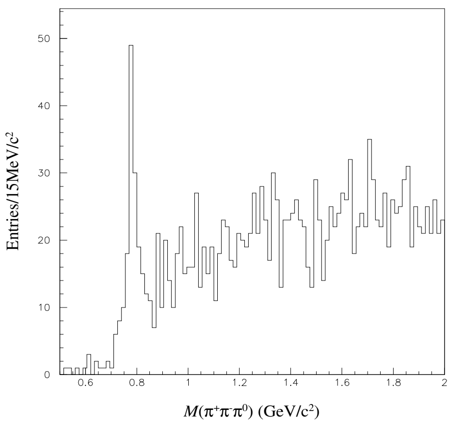

Figure 2. The $\pi^+\pi^-\pi^0$ invariant mass distribution for $\psi(2S) \to \pi^+\pi^-\pi^+\pi^-\pi^0$ events (4 entries/event).

3.3. $\psi(2S)$ radiative decays

Results on the $\psi(2S)$ radiative decays are also listed in Table 1. The $\gamma\rho^0$ mass spectrum, shown in Figure 4, has a clear η' signal in the $\psi(2S) \to \gamma\eta'$ decays. The new measurement for the $\gamma\eta'$ is consistent with the PDG [2] upper limit; and the other two decays are measured for the first time. One sees that the radiative VT final state γf_2 observes the "15% *rule*" contrary to the hadronic VT final state ωf_2. It is also noted that a suppression relative to the "15% *rule*" occurs for the $\gamma\eta$ and $\gamma\eta'$ channels but not as strong as $\rho\pi$. The $\psi(2S) \to \gamma\eta'$ result is consistent with the expectation of a model [7] that proposes the η' - $\eta_c(2S)$ mixing as the dominant mechanism for this OZI forbidden radiative charmonium decays, $B(\psi(2S) \to \gamma\eta') = (1.8 \pm 0.9) \times 10^{-4}$. Another model [8] relates the process $\psi(2S) \to \gamma\eta'$ to the hindered M1 transition $\psi(2S) \to \gamma\eta_c$, leading to a prediction $Q_{\gamma\eta'} = 0.002$, which is well below our measured value.

4. χ_{cJ} physics

The hadronic decay rates of the P-wave quarkonium states provide important tests of QCD. Recently, a systematic approach to the treatment of the infrared ambiguities in the calculation of the production and decays of these states has been developed [9]. However, existing experimental information on the triplet charmonium χ_c states is not adequate for testing the predictions of this new theory.

The total width of the χ_{c0} has been determined at the BES from a careful analysis of exclusive $\psi(2S) \to \gamma\pi^+\pi^-$ and γK^+K^- decays. The χ_{c0} as well as the χ_{c2} signals, shown in figure 5 for the $\pi^+\pi^-$ invariant mass distribution, and figure 6 for the K^+K^- invariant mass distribution, respectively, are free of distortions coming from possible contamination of the χ_{c1} and η_c' states, since the decays of the χ_{c1} and η_c' to $\pi^+\pi^-$ or K^+K^- are forbidden by parity conservation. Strong χ_{c2} signals provide a direct experimental determination of the mass resolution

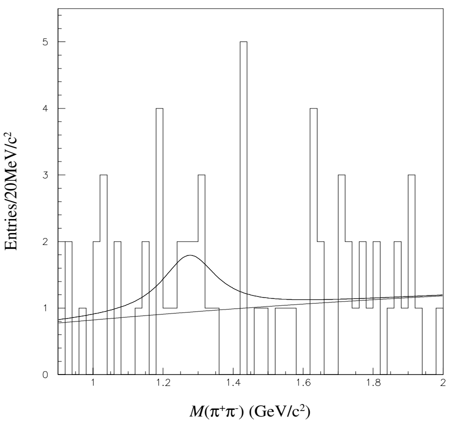

Figure 3. The invariant mass distribution of $\pi^+\pi^-$ pairs recoiling against candidate ω mesons for events of the type $\psi(2S) \to \omega\pi^+\pi^-$. The curve shows a fit to quadratic background plus f_2 resonance with mass and width fixed at the PDG values.

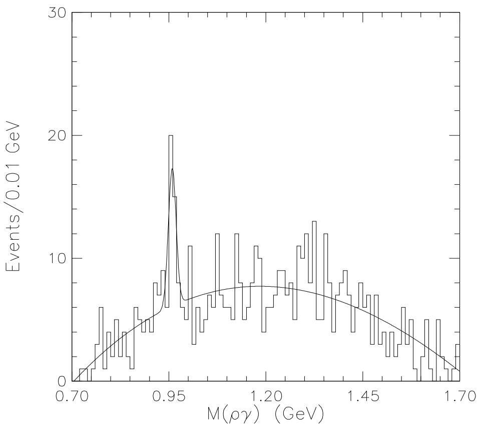

Figure 4. The $\pi^+\pi^-\gamma$ invariant mass distribution for selected $\psi(2S) \to \gamma\gamma\pi^+\pi^-$ events. The curve is the result of a fit to the mass spectrum with the η' represented as a Gaussian and a third-order polynomial background function

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at the χ_{c2}; MC simulations are then used to determine how the resolution changes from χ_{c2} to χ_{c0}. The total width of the χ_{c0} thus obtained is $14.3 \pm 2.0 \pm 3.0\ MeV$, where the first error is statistical and the second is systematic. This result is consistent with but more precise than the PDG [2] value, which is a combination of two measurements having large errors and only marginal consistency [10]. Recent calculations involving new factorization schemes with high order QCD corrections [11] are in good agreement with our measurement.

The branching fractions of $\chi_{c0,2} \to 0^-0^-$ mesons have been measured.

$$B(\chi_{c0} \to \pi^+\pi^-) = (4.79 \pm 0.27 \pm 0.73) \times 10^{-3}$$

$$B(\chi_{c0} \to K^+K^-) = (5.82 \pm 0.36 \pm 0.94) \times 10^{-3}$$

$$B(\chi_{c2} \to \pi^+\pi^-) = (1.52 \pm 0.15 \pm 0.24) \times 10^{-3}$$

$$B(\chi_{c2} \to K^+K^-) = (0.81 \pm 0.14 \pm 0.14) \times 10^{-3}$$

These results are somewhat lower than the previous measurements [2]. The recent calculations [12], which include color-octet contributions in exclusive χ_{cJ} decays, are in generally good agreement with our measurements.

5. Summary

The $\psi(2S)$ is a unique laboratory to systematically study charmonium family members and investigate QCD. With 3.79 million $\psi(2S)$ data, the J/ψ leptonic branching fractions and χ_c decay widths are measured at high precision, and the upper limits are set for the $\psi(2S)$ hadronic decay rates to VP and VT final states. The $''\rho\pi$ $puzzle''$ still persists at higher sensitivity and also extends to VT hadronic decays. The isospin violating is seen in J/ψ and $\psi(2S)$ decays. Contrary to expectations, $\psi(2S)$ hadronic decays are interesting.

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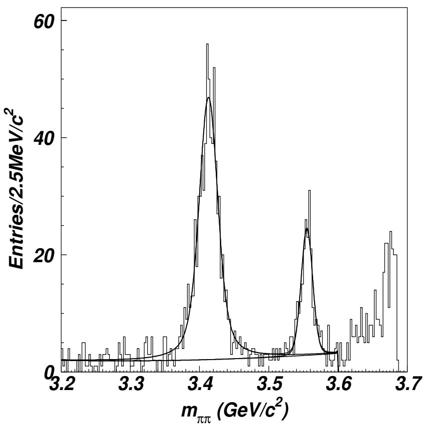

Figure 5. The $\pi^+\pi^-$ mass distribution for selected $\psi(2S) \to \gamma\pi^+\pi^-$ events. The curve shows a fit to the distribution.

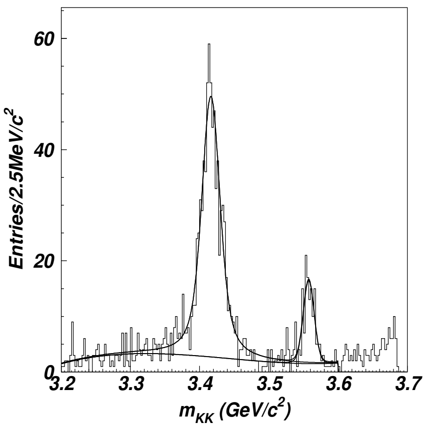

Figure 6. The K^+K^- mass distribution for selected $\psi(2S) \to \gamma K^+K^-$ events. The curve shows a fit to the distribution.

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REFERENCES

1. BES Collab., J.Z.Bai et al., Nucl. Instr. Methods, A344 (1994) 319.
2. Particle Data Group, R.M.Barnett et al., Phys. Rev. D54, 1(1996).
3. S.J.Brodsky and M.Karliner, Phys. Rev. Lett. **78**, 468 (1997); Yu-Qi Chen and Eric Braaten, Phys. Rev. Lett. **80**, 5060 (1998); and references therein.
4. For the $J/\psi \to \phi f_2'$ decay rate, 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 $f_J(1710)$. For the other decay channels, we use the PDG [2] recommended values of the J/ψ branching fractions.
5. M.E.B.Franklin et al., Phys. Rev. Lett. 51, 963(1983).
6. Y.F.Gu and S.F.Tuan, Mod. Phys. Lett., A10, 615(1995).
7. K.T.Chao, Nucl. Phys., B317, (1989)597; B335, (1990)101.
8. S.S.Pinsky, Phys. Lett. B 236 (1990) 479.
9. G.T.Bodwin, E.Braaten, and G.P.Lepage, Phys. Rev. D 51 (1995) 1125.
10. F.E.Gaiser er al., Phys. Rev. D34, (1986)711
11. Han-Wen Huang and Kuang-Ta Chao, Phys. Rev. D54, 6850(1996); M.L.Mangano and A.petrelli, Phys. Lett. B 352, (1995) 445; A.Petrelli, Phys. Lett. B380 (1996) 159.
12. J.Bolz, P.Kroll and G.A.Schuler, Phys. Lett. B 392 (1997) 198.