Recent Charmonium Results from BES

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Abstract
This paper summarizes recent results obtained from the BES 3.8×10^6 $\psi(2S)$ event sample, which is the world's largest.

1. Introduction

The Beijing Spectrometer (BES) experiment takes data at the Beijing Electron Positron Collider (BEPC) which operates in the tau-charm energy range from 2 - 5 GeV. BES is a conventional cylindrical magnetic detector and is described in detail in Ref. [1]. This paper describes recent preliminary results obtained from the $\psi(2S)$ data set, which is the world's largest sample. Details can be found in the references.

2. $\psi(2S) \to \pi^+\pi^- J/\psi$ Distributions

The dynamics of the process $\psi^{'} \to \pi^+\pi^- J/\psi$, which is the largest decay mode of the $\psi(2S)$, can be investigated using the very clean, high statistics sample of $\psi^{'} \to \pi^+\pi^- J/\psi, J/\psi \to$ leptons (~ 23 K). This reaction is thought to occur in a two step process by the emission of two gluons followed by hadronization to pion pairs. Early investigation of this decay by Mark I [2] found that the $\pi^+\pi^-$ mass distribution was strongly peaked towards higher mass values, in contrast to what is expected from phase space. Angular distributions strongly favored S-wave production of $\psi\pi\pi$, as well as an S-wave decay of the $\pi\pi$ system. We observe that the $\cos\theta^*_{\pi^+}$ distribution, which is the cosine of the pion angle relative to the J/ψ direction in the $\pi\pi$ rest frame, is not flat as expected for S-wave decay of the dipion system. Some D-wave contribution is required in addition to the S-wave.

One model that predicts a D-wave component is the Novikov-Shifman model [3]. The pions in this process are very low energy, so the process is nonperturbative. This model uses the scale anomaly and a multipole expansion [4]-[6] to give an amplitude:

$$A \propto \{q^2 - \kappa(\Delta M)^2(1 + \frac{2m_\pi^2}{q^2}) + \frac{3}{2}\kappa[(\Delta M)^2 - q^2](1 - \frac{4m_\pi^2}{q^2})(\cos^2\theta^*_\pi - \frac{1}{3})\},$$

where q^2 is the four-momentum squared of the dipion system, $\Delta M = M_{\psi(2S)} - M_{J/\psi}$, and κ is predicted to be ≈ 0.15 to 0.2. The first terms in the amplitude are the S-wave part, and the last is the D-wave part. Parity and charge conjugation invariance require that the spin be even. Fits using this amplitude are shown in Fig. 1, and the fit results are given in Table 1. Our result for κ based on the $m_{\pi\pi}$ distribution is in good agreement with that of ARGUS [7] using Mark I data for $\psi^{'} \to \pi^+\pi^- J/\psi$: $\kappa = 0.194 \pm 0.010$ with a χ^2/DOF of 38/24.

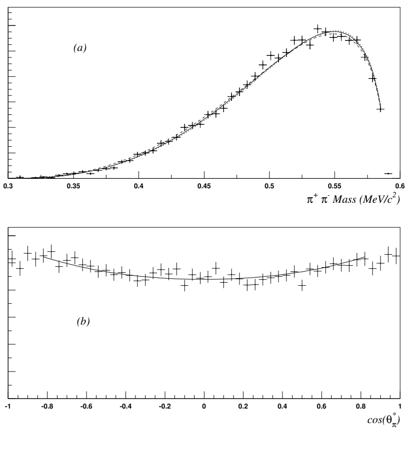

Figure 1. Fits to 1D distributions. **(a)** $m_{\pi\pi}$ distribution (solid curve). **(b)** $\cos\theta^*_\pi$ distribution.

The amount of D wave as a function of $m_{\pi\pi}$ has been fit using $N(\cos\theta) \propto 1.0 + 2(D/S)(\cos^2\theta -$

Table 1. Fit results for κ for the Novikov-Shifman model.

Distribution	κ	χ^2/DOF
$m_{\pi\pi}$	$0.186 \pm 0.003 \pm 0.010$	55/45
$\cos\theta^*_\pi$	$0.210 \pm 0.027 \pm 0.050$	26/40
$m_{\pi\pi}$ vs $\cos\theta^*_\pi$	$0.183 \pm 0.003 \pm 0.005$	1618/1482

$1/3) + (D/S)^2(\cos^2\theta - 1/3)^2$. The last term corresponds to the amount of D-wave, while the middle term corresponds to the interference term. The behavior of $\frac{D}{S}$ as a function of $m_{\pi\pi}$ is shown in Fig. 2, along with the prediction of the Novikov-Shifman model. For more detail, see Ref. [8].

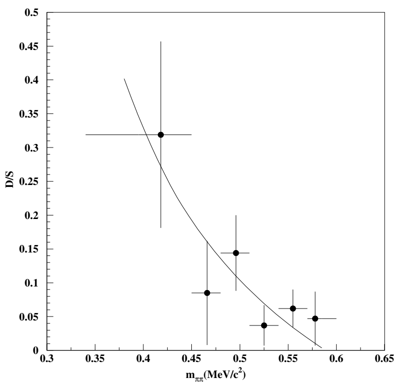

Figure 2. Plot of the interference term, $\frac{D}{S}$, versus $m_{\pi\pi}$. The smooth curve is the prediction of the Novikov-Shifman model for $\kappa = 0.183$.

3. Hadronic $\psi(2S)$ decays

Both J/ψ and $\psi(2S)$ decays are expected to proceed via $\psi \to ggg$, with widths that are proportional to the square of the $c\bar{c}$ wave function at the origin [9]. This yields the expectation that

$$Q = \frac{B(\psi(2S) \to X_h)}{B(J/\psi \to X_h)} \approx \frac{B(\psi(2S) \to e^+e^-)}{B(J/\psi \to e^+e^-)} = (14.7 \pm 2.3)$$

It was first observed by MarkII[10] that the vector-pseudoscalar $\rho\pi$ and $K^*\overline{K}$ channels are suppressed with respect to the 15% expectation - the "$\rho\pi$ puzzle". BES finds a suppression factor of $\sim$60; this and many other results are summarized in Ref. [11].

Here we report some recent preliminary results. Fig. 3 shows the $\pi^+\pi^-$ invariant mass for $\psi(2S) \to \gamma\pi^+\pi^-$. A $f_2(1270)$ peak is seen, along with continuum background from $e^+e^- \to \gamma\rho$ and $e^+e^- \to (\gamma)\mu^+\mu^-$. We subtract this background using our $e^+e^- \to \tau^+\tau^-$ runs [12]. Fitting the peak with a D-wave Breit-Wigner function, we obtain $B(\psi(2S) \to \gamma f_2(1270)) = (2.31 \pm 0.25 \pm 0.42) \times 10^{-4}$. For $\psi(2S) \to \gamma\pi^o\pi^o$, we obtain $Br(\psi(2S) \to \gamma f_2(1270)) = (3.01 \pm 1.12 \pm 1.12) \times 10^{-4}$. Combining, we find $B(\psi(2S) \to \gamma f_2(1270)) = (2.37 \pm 0.25 \pm 0.39) \times 10^{-4}$ and $Q = \frac{B(\psi(2S) \to \gamma f_2(1270))}{B(J/\psi \to \gamma f_2(1270))} = (17.2 \pm 1.8 \pm 2.8)\%$.

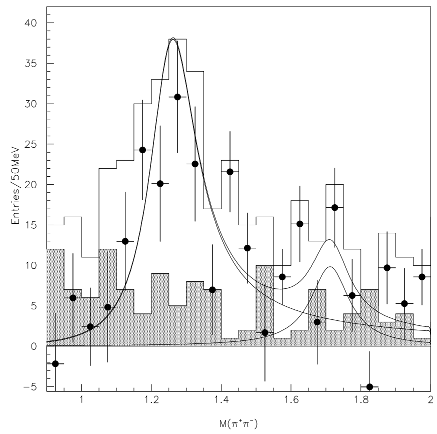

Figure 3. Invariant Mass of $\pi^+\pi^-$ in $\psi(2S)$ (histogram), τ scan data (shaded), and the difference (points).

We have also looked for $\psi(2S) \to \gamma K^+K^-$. An $f_J(1710)$ signal is seen, as indicated in Fig. 4. Subtracting continuum background and fitting with an S-wave Breit-Wigner function, we obtain $B(\psi(2S) \to \gamma f_J(1710)) = (1.24 \pm 0.20 \pm 0.21) \times 10^{-4}$ and $Q = \frac{B(\psi(2S) \to \gamma f_J(1710))}{B(J/\psi \to \gamma f_J(1710))} = (12.8 \pm 2.6 \pm 2.7)\%$. The "15% rule" holds for $\psi(2S)$ radiative decay to $f_2(1270)$ and $f_J(1710)$.

For decay channels of the $\Psi(2S)$ involving an ω or a ϕ, we obtain the branching ratios shown in Table 2. Some satisfy the 15 % Rule, and some do not.

4. $\chi_{c0,1,2}$ and η_c decays

The large sample of $\psi(2S)$ decays permits studies of $\chi_{c0,1,2}$ decays with unprecedented precision ($\sim 1 \times 10^6 \chi$'s). Many BES branching fraction results may be found in Refs. [11],[13],[14]. Many, like $B(\chi_{c0} \to p\bar{p})$, are measured for the first time.

The mass and width of the χ_{co} are not well determined in the PDG [15]. Using $\chi_{c0} \to \pi^+\pi^-$, we find $\Gamma_{\chi_{c0}} = 14.3 \pm 3.6$ MeV [13], which is an

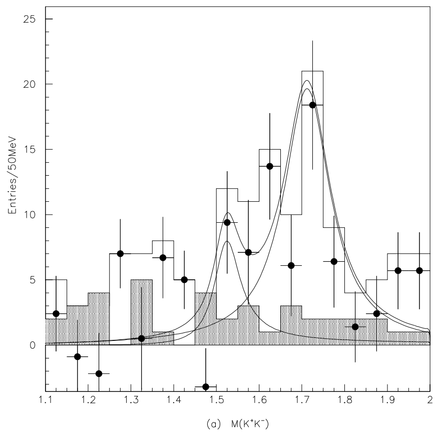

Figure 4. Invariant Mass of K^+K- in $\psi(2S)$ and τ scan data (shaded).

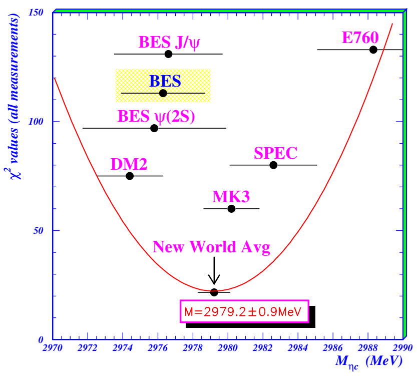

Figure 5. $M_{\eta c}$ Results

Table 2. Measurements of the Ψ(2S) decay Branching Ratios.

Ψ(2S) $\Rightarrow$	Br($\times 10^{-5}$)	Q(%)
$\omega\pi^+\pi^-$	$44.7 \pm 5.7 \pm 5.4$	6.3 ± 1.4
ωK^+K^-	$12.6 \pm 4.3 \pm 3.9$	17.0 ± 9.6
$\phi\pi^+\pi^-$	$17.6 \pm 2.2 \pm 2.4$	22.0 ± 5.3
ϕK^+K^-	$6.10 \pm 1.79 \pm 1.51$	7.3 ± 3.0
ϕf_0	$6.57 \pm 1.68 \pm 0.76$	20.5 ± 8.1
$\omega p\bar{p}$	$6.00 \pm 2.34 \pm 1.41$	4.6 ± 2.2
$\phi p\bar{p}$	$0.86 \pm 0.50 \pm 0.20$	18.9 ± 13.4
$\pi^+\pi^-\pi^0 p\bar{p}$	$38.5{\pm}3.7 \pm 5.5$	16.7 ± 7.1
$\eta\pi^+\pi^- p\bar{p}$	$25.8{\pm}6.8 \pm 7.3$	?
$\eta p\bar{p}$	$8.36{\pm}4.8 \pm 4.8$	4.0 ± 4.0

improvement on the PDG value (14 ± 5 MeV) [15] based on two discrepant measurements.

Using many decay modes of the χ_{c0}, we have determined $M_{\chi_{c0}} = 3414.1 \pm 0.6 \pm 0.8$ MeV [14]. This is a big improvement over the PDG value of 3417.3 ± 2.8 MeV.

The mass of the η_c is also not well determined (CL = 0.001). We have measured the η_c mass using $\eta_c \rightarrow \pi^+\pi^-\pi^+\pi^-$, $\pi^+\pi^-K^+K^-$, $K_sK^\pm\pi^\mp$, and $K^+K^-K^+K^-$, and obtain $M_{\eta_c} = 2975.8 \pm 3.9 \pm 1.2$ MeV. This work is described fully in Ref. [14]. Using the 7.8 M J/ψ data, BES finds a preliminary value of $M_{\eta_c} = 2976.6 \pm 2.9 \pm 1.0$ MeV, which agrees well with the $\psi(2S)$ result. Combining, we obtain $M_{\eta_c} = 2976.3 \pm 2.3 \pm 0.8$ MeV. These and previous results are summarized in Fig. 5.

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