Recent $J/\psi$ Results from BESII

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The studies on the multi-quark candidates, light scalar mesons and excited baryon states at BES are presented, based on $5.8 \times 10^7$ $J/\psi$ data collected with BESII detector. The measurements of some $J/\psi$ and $\eta_c$ decays are presented too. We also report the searches for the lepton flavor violation and pentaquark states in $J/\psi$ decays.

Keywords: multiquark state; $J/\psi$ decay; scalar meson, branching ratio; baryon

1. Introduction

BES, as described in ref. [1], is a large general purpose solenoidal detector at the Beijing Electron Positron Collider (BEPC). Since 1998, the BES detector has been upgraded to BESII. The $5.8 \times 10^7$ $J/\psi$ events have been accumulated with BESII since then, which provides a good laboratory for the study of the non-$q\bar{q}$ states and hadron spectroscopy.

2. Study of the multiquark candidates

2.1. Near $p\bar{p}$ threshold enhancement in $J/\psi \to \gamma p\bar{p}$

There is an accumulation of evidence for anomalous behavior in the $p\bar{p}$ system near $2m_p$ mass threshold. We analyze $J/\psi \to \gamma p\bar{p}$ with BESII $J/\psi$ data [2]. Fig. 1 shows the $p\bar{p}$ invariant mass distribution for selected events. Except for a peak near $M_{p\bar{p}} = 2.98$ GeV/$c^2$ that is consistent in mass, width, and yield with expectations for $J/\psi \to \gamma \eta_c$, $\eta_c \to p\bar{p}$ [3] and a broad enhancement around $M_{p\bar{p}} \sim 2.2$ GeV/$c^2$, there is a narrow, low-mass peak near the $p\bar{p}$ mass threshold.

![Fig. 1. The $p\bar{p}$ invariant mass distribution in $J/\psi \to \gamma p\bar{p}$ decays.](image-url)
The low mass region of the $p\bar{p}$ distribution is fitted by an acceptance-weighted S-wave Breit-Wigner (BW) function and $f_{bkg}(\delta)$ which represent the low-mass enhancement and the background, respectively. The fit yields 928 ± 57 events in the BW function with a peak mass of $M = 1859^{+3}_{-10} +5^{+25}_{-10}$ MeV/$c^2$ and a full width of $\Gamma < 30$ MeV/$c^2$ at a 90% confidence level (CL).

2.2. The anomalous enhancements near the $m_p + M_\Lambda$ and $m_K + M_\bar{\Lambda}$ mass thresholds in $J/\psi \rightarrow pK^-\bar{\Lambda} + c.c.$ decays

The decay of $J/\psi \rightarrow pK^-\bar{\Lambda} + c.c.$ are studied. Fig. 2 (left) shows the $p\Lambda$ invariant mass spectrum for the selected events, where an enhancement is evident near the mass threshold. The $pK^-\bar{\Lambda}$ Dalitz plot is shown in Fig. 2 (right). In addition to bands for the well established $\Lambda^*(1520)$ and $\Lambda^*(1690)$, there is a significant $N^*$ band near the $K^-\bar{\Lambda}$ mass threshold, and a $p\Lambda$ mass enhancement in the right-upper part of the Dalitz plot, isolated from the $\Lambda^*$ and $N^*$ bands.

This enhancement can be fitted with an acceptance weighted S-wave Breit-Wigner together with a function $f_{PS}(\delta)$ describing the phase space contribution. The fit gives a peak mass of $m = 2075 \pm 12$ MeV, a width $\Gamma = 90 \pm 35$ MeV and a branching ratio

$$BR(J/\psi \rightarrow K^-X)BR(X \rightarrow p\bar{\Lambda}) = (5.9 \pm 1.4) \times 10^{-5}.$$
Recent $J/\psi$ Results from BESII

3. Light scalar mesons

3.1. The $\sigma$ and $\kappa$

There have been hot debates on the existence of $\sigma$ and $\kappa$. The decay of $J/\psi \rightarrow \omega \pi^+\pi^-$, with the $\omega$ decaying to $\pi^+\pi^-\pi^0$, is studied for $\sigma$.

Fig. 4 (left) shows the $\pi^+\pi^-$ invariant mass spectrum recoiling against the $\omega$ for the selected $J/\psi \rightarrow \omega \pi^+\pi^-$ events. The Dalitz plot of this channel is shown in Fig. 4 (right). At low $\pi\pi$ masses, a broad enhancement which is due to the $\sigma$ pole is clearly seen. This peak is evident as a strong band along the upper right-hand edge of the Dalitz plot.

Two independent Partial wave analyses (PWA) have been performed on this channel. Different analysis methods and four parametrizations of the $\sigma$ amplitude give consistent results for the $\sigma$ pole. The average $\sigma$ pole position is determined to be $(541 \pm 39) - i(252 \pm 42)$ MeV.

The $\kappa$ is studied from $J/\psi \rightarrow \bar{K}^*(892)K^+\pi^-$ and $K^+K^-\pi^+\pi^-$ decays through partial wave analysis. Three independent analyses have been performed and different parametrizations of $\kappa$ pole are used. The preliminary results show the evidence of $\kappa$ near the $K\pi$ threshold. Its pole position is around $(760 \sim 840) - i(310 \sim 420)$ MeV.

3.2. $J/\psi \rightarrow \omega K^+K^-$

Fig. 5 shows the $K^+K^-$ invariant mass distribution from $J/\psi \rightarrow \omega K^+K^-$. The crosses are data and the shaded area indicates background events from the $\omega$ side-band estimation. A dominant feature of this channel is the structure around 1.74 GeV, denoted as $f_0(1710)$. A partial wave analysis (PWA) shows that the $J^P$ of
this structure favors $0^+$ and the mass and width are optimized at $M = 1738 \pm 30$ MeV, $\Gamma = 125 \pm 20$ MeV.

\[ M = 1738 \pm 30 \text{ MeV}, \quad \Gamma = 125 \pm 20 \text{ MeV}. \]

In $J/\psi \rightarrow \omega \pi^+ \pi^-$, there is no definite evidence for the presence of $f_0(1710)$. Therefore, we find at the 95% confidence level

\[ \frac{BR(f_0(1710) \rightarrow \pi\pi)}{BR(f_0(1710) \rightarrow K\bar{K})} < 0.11. \]

### 3.3. $J/\psi \rightarrow \phi \pi^+ \pi^-$ and $J/\psi \rightarrow \phi K^+ K^-$ (preliminary)

Fig. 6 (a) and (b) show the $\pi^+ \pi^-$ and $K^+ K^-$ invariant mass distributions from $J/\psi \rightarrow \phi \pi^+ \pi^-$ and $\phi K^+ K^-$, respectively. The shaded histograms correspond to the backgrounds estimated from $\phi$ sidebands.

The $\phi \pi^+ \pi^-$ and $\phi K^+ K^-$ data are fitted simultaneously by using partial wave analysis, constraining resonance masses and widths to be the same in both sets of data. The full histograms in Fig. 6 (left) and (right) show the maximum likelihood fit.

The $f_0(980)$ is observed clearly in both sets of data. The Flatté form:

\[ f = \frac{1}{M^2 - s - i(g_1 \rho_{\pi\pi} + g_2 \rho_{KK})}. \]

has been used to fit the $f_0(980)$ amplitude. Here $\rho$ is Lorentz invariant phase space, $2k/\sqrt{s}$, $k$ refers to $\pi$ or $K$ momentum in the rest frame of the resonance. The present
Recent J/ψ Results from BESII

5

data offer the opportunity to determine the parameters of f_0(980) accurately:
\[ M = 965 \pm 8_{\text{sta}} \pm 6_{\text{sys}} \text{ MeV}, \ g_1 = 165 \pm 10_{\text{sta}} \pm 15_{\text{sys}} \text{ MeV}, \ g_2/g_1 = 4.21 \pm 0.25_{\text{sta}} \pm 0.21_{\text{sys}}. \]

The \( \phi \pi \pi \) data also exhibit a strong peak centered at \( M = 1335 \text{ MeV} \). It may be fitted with \( f_2(1270) \) and a dominant 0\(^+\) signal made from \( f_0(1370) \) interfering with a smaller \( f_0(1500) \) component. The Mass and width of \( f_0(1370) \) are determined to be:
\[ M = 1350 \pm 50 \text{ MeV} \text{ and } \Gamma = 265 \pm 40 \text{ MeV}. \]

There is also a signal at around 1.79 GeV in \( J/\psi \rightarrow \phi \pi \pi + \pi^- \) with \( M = 1790^{+40}_{-30} \) MeV and \( \Gamma = 270^{+60}_{-30} \) MeV. The spin 0 is prefered over spin 2.

3.4. \( J/\psi \rightarrow \gamma \pi \pi \) (preliminary)

The \( \pi^+ \pi^- \) and \( \pi^0 \pi^0 \) invariant mass distributions from \( J/\psi \rightarrow \gamma \pi^+ \pi^- \) and \( \gamma \pi^0 \pi^0 \) are shown in Fig. 7 (left) and (right). The partial wave analyses are carried out in the 1.0-2.3 GeV \( \pi \pi \) mass range. Two 0\(^+\) states exist in the mass lower than 1.8 GeV. The first one peaks at 1466 \( \pm 6 \pm 16 \) MeV with a width of 108\(^+14_{-11}\) \pm 21 MeV, which is approximately consistent with \( f_0(1500) \). Due to the large interference between S-wave states, a possible contribution from \( f_0(1370) \) cannot be excluded.

The second 0\(^+\) peaks at around 1.75 GeV. If it is the same state with that observed in \( J/\psi \rightarrow \gamma K \bar{K} \) \[4\], we obtain the ratio of decaying to \( \pi \pi \) and \( K \bar{K} \) as \( 0.41^{+0.08}_{-0.15} \).

4. Study of the excited baryon states from \( J/\psi \rightarrow p \bar{n} \pi^- + c.c \)

The \( \pi N \) system in decays of \( J/\psi \rightarrow \bar{N}N \pi \) is limited to be isospin 1/2 by isospin conservation. This provides a big advantage in studying \( N^* \rightarrow \pi N \) compared with \( \pi N \) and \( \gamma N \) experiments which mix isospin 1/2 and 3/2 for the \( \pi N \) system. Fig. 8 shows the \( \pi N \) invariant mass spectrum from \( J/\psi \rightarrow \bar{p}n \pi^- \). Besides two well known \( N^* \) peaks at 1500 MeV and 1670 MeV, there are two new, clear \( N^* \) peaks in the \( p \pi \) invariant mass spectrum around 1360 MeV and 2030 MeV. They are the first direct observation of the \( N^*(1440) \) peak and a long-sought "missing" \( N^* \) peak above 2 GeV in the \( \pi N \) invariant mass spectrum. A simple Breit-Wigner fit gives the mass and width for the \( N^*(1440) \) peak as 1358 \( \pm 6 \pm 16 \) MeV and 179 \( \pm 26 \pm 50 \) MeV, and for the new \( N^* \) peak above 2 GeV as 2068 \( \pm 3^{+15}_{-40} \) MeV and 165 \( \pm 14 \pm 40 \) MeV, respectively.
5. Other Results

The mass, width of $\eta_c$, as well as some of its decay branching ratios are measured with BESII $5.8 \times 10^7 J/\psi$ events. The $J/\psi \rightarrow \gamma f_2(1270)f_2(1270)$ decay is first observed and measured. We also present much improved measurements on $J/\psi \rightarrow \pi^+\pi^-\pi^0 K_s K L$ and $p\bar{p}$ decays.

The lepton flavor violation (LFV) is searched for from $J/\psi \rightarrow e\mu, \mu\tau$ and $e\tau$ decays, the LFV processes. The observed signal events are consistent with the background level. The upper limits of the decay branching fractions are set [10].

We also search for the pentaquark state $\Theta(1540)$ in $J/\psi \rightarrow K_0^0 pK^-\bar{n}$ and $K_0^0 pK^+n$ final states with $K_0^0$ decaying to $\pi^+\pi^-$. No clear $\Theta$ signal is observed. The upper limits are set [11].

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