# Recent Results From BESIII

Rong-Gang Ping (for the BES Collaboration)
*Institute of High Energy Physics, Chinese Academy of Sciences, P.O. Box 918-1, Beijing 100049, China*

We present recent results from the BES experiment on the observation of the $Y(2175)$ in $J/\psi \to \phi f_0(980)\eta$, and $\eta(2225)$ in $J/\psi \to \gamma\phi\phi$, and $X(1440)$ in $J/\psi$ hadronic decays, together with the new observation of $\psi(2S)$ radiative decays and hadronic decays into $nK_S^0\bar{\Lambda} + c.c.$, $\Lambda\bar{\Lambda}\pi^0$, $\Lambda\bar{\Lambda}\eta$. The effort to search for $J/\psi$ decays into $\gamma\gamma$ and invisible decays are also reported.

## 1. Introduction

The analyses reported in this talk were performed using either a sample of $58 \times 10^6$ $J/\psi$ events or a sample of $14 \times 10^6$ $\psi(2S)$ events collected with the upgraded Beijing Spectrometer (BESII) detector [1] at the Beijing Electron-Positron Collider (BEPC).

## 2. Light hadron spectroscopy

### 2.1. The $Y(2175)$ in $J/\psi \to \phi f_0(980)\eta$ [2]

A new structure, denoted as $Y(2175)$ and with mass $m = 2.175 \pm 0.010 \pm 0.015$ GeV/$c^2$ and width $\Gamma = 58 \pm 16 \pm 20$ MeV/$c^2$, was observed by the BaBar experiment in the $e^+e^- \to \gamma_{ISR}\phi f_0(980)$ initial-state radiation process [3, 4]. This observation stimulated some theoretical speculation that this $J^{PC} = 1^{--}$ state may be an $s$-quark version of the $Y(4260)$ since both of them are produced in $e^+e^-$ annihilation and exhibit similar decay patterns [5, 6].

Here we report the observation of the $Y(2175)$ in the decays of $J/\psi \to \eta\phi f_0(980)$, with $\eta \to \gamma\gamma$, $\phi \to K^+K^-$, $f_0(980) \to \pi^+\pi^-$. A four-constraint energy-momentum conservation kinematic fit is performed to the $K^+K^-\pi^+\pi^-\gamma\gamma$ hypothesis for the selected four charged tracks and two photons. $\eta \to \gamma\gamma$ candidates are defined as $\gamma$-pairs with $|M_{\gamma\gamma} - 0.547| < 0.037$ GeV/$c^2$, a $\phi$ signal is defined as $|m_{K^+K^-} - 1.02| < 0.019$ GeV/$c^2$, and in the $\pi^+\pi^-$ invariant mass spectrum, candidate $f_0(980)$ mesons are defined by $|m_{\pi^+\pi^-} - 0.980| < 0.060$ GeV/$c^2$. The $\phi f_0(980)$ invariant mass spectrum for the selected events is shown in Fig. 1, where a clear enhancement is seen around 2.18 GeV/$c^2$. Fit with a Breit-Wigner and a polynomial background yields $52 \pm 12$ signal events and the statistical significance is found to be $5.5\sigma$ for the signal. The mass of the structure is determined to be $M = 2.186 \pm 0.010$ $(stat) \pm 0.006$ $(syst)$ GeV/$c^2$, the width is $\Gamma = 0.065 \pm 0.023$ $(stat) \pm 0.017$ $(syst)$ GeV/$c^2$, and the product branching ratio is $\mathcal{B}(J/\psi \to \eta Y(2175)) \cdot \mathcal{B}(Y(2175) \to \phi f_0(980)) \cdot \mathcal{B}(f_0(980) \to \pi^+\pi^-) = (3.23 \pm 0.75\ (stat) \pm 0.73\ (syst)) \times 10^{-4}$. The mass and width are consistent with BaBar's results.

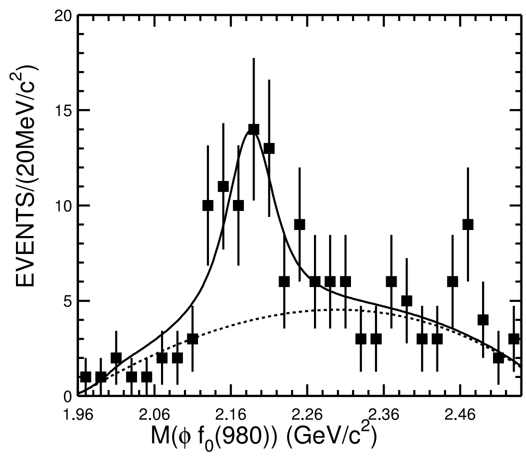


Figure 1: The $\phi f_0(980)$ invariant mass distribution of the data (points with error bars) and the fit (solid curve) with a Breit-Wigner function and polynomial background; the dashed curve indicates the background function.

### 2.2. The $\eta(2225)$ in $J/\psi \to \gamma\phi\phi$ [7]

Structures in the $\phi\phi$ invariant-mass spectrum have been observed by several experiments both in the reaction $\pi^-p \to \phi\phi n$ [8] and in radiative $J/\psi$ decays [9–11]. The $\eta(2225)$ was first observed by the MARK-III collaboration in $J/\psi$ radiative decays $J/\psi \to \gamma\phi\phi$. A fit to the $\phi\phi$ invariant-mass spectrum gave a mass of 2.22 GeV/$c^2$ and a width of 150 MeV/$c^2$ [9]. An angular analysis of the structure found it to be consistent with a $0^{-+}$ assignment. It was subsequently observed by the DM2 collaboration, also in $J/\psi \to \gamma\phi\phi$ decays [10, 11].

We present results from a high statistics study of $J/\psi \to \gamma\phi\phi$ in the $\gamma K^+K^-K_S^0K_L^0$ final state, with the $K_L^0$ missing and reconstructed with a one-constraint kinematic fit. After kinematic fit, we require both the $K^+K^-$ and $K_S^0K_L^0$ invariant masses lie within the $\phi$ mass region ($|M(K^+K^-) - m_\phi| < 12.5$ MeV/$c^2$ and $|M(K_S^0K_L^0) - m_\phi| < 25$ MeV/$c^2$). The $\phi\phi$ invariant mass distribution is shown in Fig. 2. There are a total of 508 events with a prominent structure around 2.24 GeV/$c^2$.

A partial wave analysis of the events with $M(\phi\phi) < 2.7$ GeV/$c^2$ was performed. The two-body decay

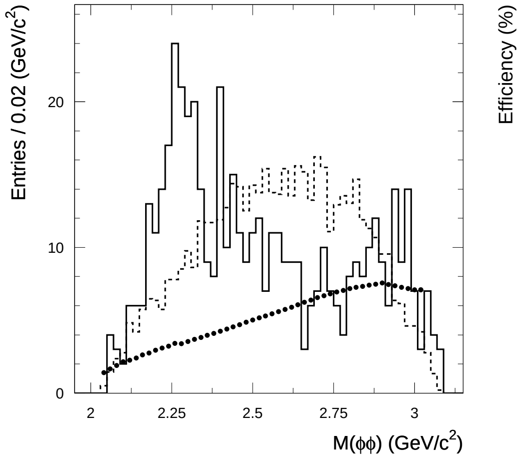


Figure 2: The $K^+K^-K^0_SK^0_L$ invariant mass distribution for $J/\psi \to \gamma\phi\phi$ candidate events. The dashed histogram is the phase space invariant mass distribution, and the dotted curve indicates how the acceptance varies with the $\phi\phi$ invariant mass.

amplitudes in the sequential decay process $J/\psi \to \gamma X, X \to \phi\phi$, $\phi \to K^+K^-$ and $\phi \to K^0_SK^0_L$ are constructed using the covariant helicity coupling amplitude method. The intermediate resonance $X$ is described with the normal Breit-Wigner propagator $BW = 1/(M^2 - s - iM\Gamma)$, where $s$ is the $\phi\phi$ invariant mass-squared and $M$ and $\Gamma$ are the resonance's mass and width. When $J/\psi \to \gamma X$, $X \to \phi\phi$ is fitted with both the $\phi\phi$ and $\gamma X$ systems in a $P$-wave, which corresponds to a pseudoscalar $X$ state, the fit gives $196\pm19$ events with mass $M = 2.24^{+0.03+0.03}_{-0.02-0.02}$ GeV/$c^2$, width $\Gamma = 0.19 \pm 0.03^{+0.04}_{-0.06}$ GeV/$c^2$, and a statistical significance larger than $10\sigma$, and a product branching fraction of: $\mathcal{B}(J/\psi \to \gamma\eta(2225)) \cdot \mathcal{B}(\eta(2225) \to \phi\phi) = (4.4 \pm 0.4 \pm 0.8) \times 10^{-4}$.

The presence of a signal around 2.24 GeV/$c^2$ and its pseudoscalar character are confirmed, and the mass, width, and branching fraction are in good agreement with previous experiments.

## 2.3. The $X(1440)$ in $J/\psi$ hadronic decays [12]

A pseudoscalar gluonium candidate, the so-called $E/\iota(1440)$, was observed in $p\bar{p}$ annihilation in 1967 [13] and in $J/\psi$ radiative decays in the 1980's [14–16]. The study of the decays $J/\psi \to \{\omega, \phi\}K\bar{K}\pi$ is a useful tool in the investigation of quark and possible gluonium content of the states around 1.44 GeV/$c^2$. Here we investigate the possible structure in the $K\bar{K}\pi$ final state in $J/\psi$ hadronic decays at around 1.44 GeV/$c^2$.

In this analysis, $\omega$ mesons are observed in the $\omega \to \pi^+\pi^-\pi^0$ decay, $\phi$ mesons in the $\phi \to K^+K^-$ decay, and other mesons are detected in the decays: $K^0_S \to \pi^+\pi^-$, $\pi^0 \to \gamma\gamma$. $K\bar{K}\pi$ could be $K^0_SK^\pm\pi^\mp$ or $K^+K^-\pi^0$.

Figures 3 and 4 show the $K^0_SK^\pm\pi^\mp$ and $K^+K^-\pi^0$ invariant mass spectra after $\omega$ selection ($|m_{\pi^+\pi^-\gamma\gamma} - m_\omega| < 0.04$ GeV/c$^2$) or $\phi$ signal selection ($|m_{K^+K^-} - m_\phi| < 0.015$ GeV/$c^2$). Clear $X(1440)$ signal is observed recoiling against the $\omega$, and there is no significant signal recoiling against a $\phi$.

The $K^0_SK^\pm\pi^\mp$ invariant mass distribution in $J/\psi \to \omega K^0_SK^\pm\pi^\mp$ (Fig. 3(b)) is fitted with a BW function convoluted with a Gaussian mass resolution function ($\sigma = 7.44$ MeV/$c^2$) to represent the $X(1440)$ signal and a third-order polynomial background function. The mass and width obtained from the fit are $M = 1437.6\pm3.2$ MeV/$c^2$ and $\Gamma = 48.9\pm9.0$ MeV/$c^2$, and the fit yields $249\pm35$ events. Using the efficiency of 1.45% determined from a uniform phase space MC simulation, we obtain the branching fraction to be $\mathcal{B}(J/\psi \to \omega X(1440)) \cdot \mathcal{B}(X(1440) \to K^0_SK^+\pi^- + c.c.) = (4.86 \pm 0.69 \pm 0.81) \times 10^{-4}$, where the first error is statistical and the second one systematic.

For $J/\psi \to \omega K^+K^-\pi^0$ mode, by fitting the $K^+K^-\pi^0$ mass spectrum in Fig. 3(c) with same functions, we obtain the mass and width of $M = 1445.9 \pm 5.7$ MeV/$c^2$ and $\Gamma = 34.2\pm18.5$ MeV/$c^2$, and the number of events from the fit is $62 \pm 18$. The efficiency is determined to be 0.64% from a phase space MC simulation, and the branching fraction is $\mathcal{B}(J/\psi \to \omega X(1440))\cdot\mathcal{B}(X(1440) \to K^+K^-\pi^0) = (1.92\pm0.57\pm0.38)\times10^{-4}$, in good agreement with the isospin symmetry expectation from $J/\psi \to \omega K^0_SK^\pm\pi^\mp$ mode.

The distribution of $K^0_SK^\pm\pi^\mp$ and $K^+K^-\pi^0$ invariant mass spectra recoiling against the $\phi$ signal are shown in Fig. 4, and there is no evidence for $X(1440)$. The upper limits on the branching fractions at the 90% C.L. are $\mathcal{B}(J/\psi \to \phi X(1440) \to \phi K^0_SK^+\pi^- + c.c.) < 1.93 \times 10^{-5}$ and $\mathcal{B}(J/\psi \to \phi X(1440) \to \phi K^+K^-\pi^0) < 1.71 \times 10^{-5}$.

In conclusion, the mass and width of the $X(1440)$ are measured, which are in agreement with previous measurements; the branching fractions we measured are also in agreement with the DM2 and MARK-III results. The significant signal in $J/\psi \to \omega K\bar{K}\pi$ mode and the missing signal in $J/\psi \to \phi X$ mode may indicate the $s\bar{s}$ component in the $X(1440)$ is not significant.

# 3. New observations in $J/\psi$ and $\psi(2S)$ decays

## 3.1. $\psi(2S)$ radiative decays

Besides conventional meson and baryon states, QCD also predicts a rich spectrum of glueballs, hybrids, and multi-quark states in the 1.0 to 2.5 GeV/$c^2$ mass region. Therefore, searches for the evidence of these exotic states play an important role in testing

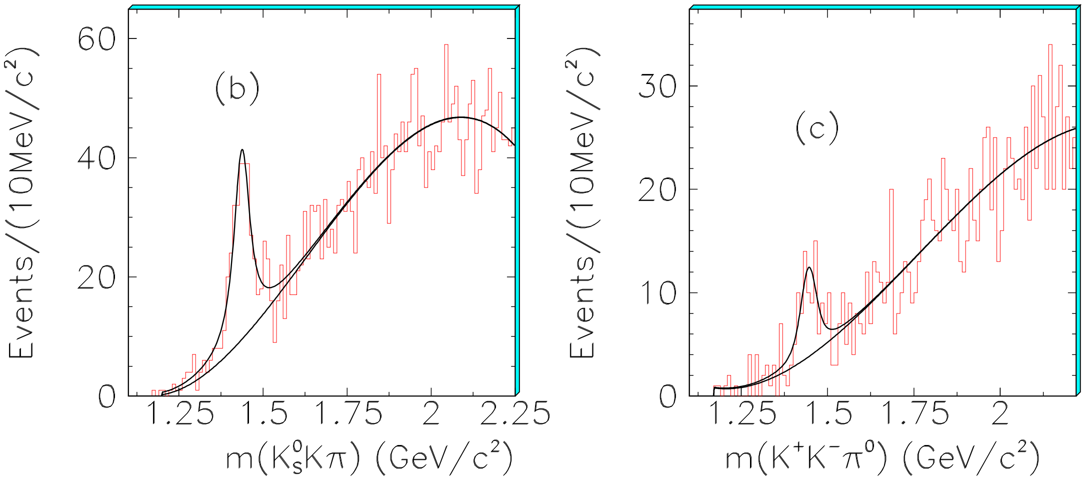


Figure 3: The $K\bar{K}\pi$ invariant mass distribution for $J/\psi \to \omega K_S^0 K^\pm \pi^\mp$ (b) and $\omega K^+K^-\pi^0$ (c) candidate events. The curves are the best fit.

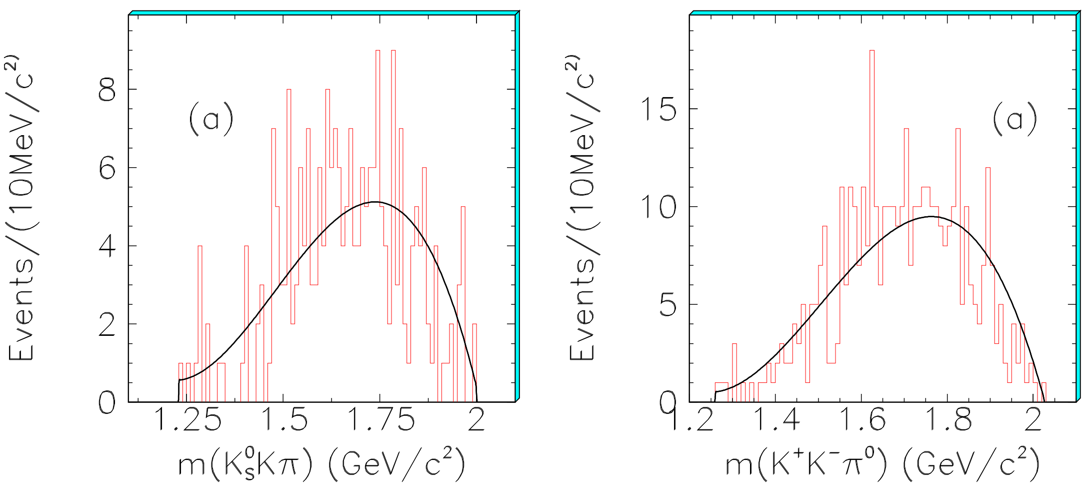


Figure 4: The $K_S^0 K^\pm \pi^\mp$ (left) and $K^+K^-\pi^0$ (right) invariant mass recoiling against the $\phi$ in $J/\psi \to \phi K\bar{K}\pi$ mode.

QCD. The radiative decays of $\psi(2S)$ to hadrons are expected to contribute about 1% to the total $\psi(2S)$ decay width [17]. However, the measured channels only sum up to about 0.05% [18].

We measured the decays of $\psi(2S)$ into $\gamma p\overline{p}$, $\gamma 2(\pi^+\pi^-)$, $\gamma K_S^0 K^+\pi^- + c.c.$, $\gamma K^+K^-\pi^+\pi^-$, $\gamma K^{*0}K^-\pi^+ + c.c.$, $\gamma K^{*0}\bar{K}^{*0}$, $\gamma\pi^+\pi^- p\overline{p}$, $\gamma 2(K^+K^-)$, $\gamma 3(\pi^+\pi^-)$, and $\gamma 2(\pi^+\pi^-)K^+K^-$, with the invariant mass of the hadrons ($m_{hs}$) less than 2.9 GeV/$c^2$ for each decay mode [19]. The differential branching fractions are shown in Fig. 5. The branching fractions below $m_{hs} < 2.9$ GeV/$c^2$ are given in Table I, which sum up to 0.26% of the total $\psi(2S)$ decay width. We also analyzed $\psi(2S) \to \gamma\pi^+\pi^-$ and $\gamma K^+K^-$ modes to study the resonances in $\pi^+\pi^-$ and $K^+K^-$ invariant mass spectrum. Significant signals for $f_2(1270)$ and $f_0(1710)$ were observed, but the low statistics prevent us from drawing solid conclusion on the other resonances [20].

### 3.2. $J/\psi,\ \psi(2S) \to nK_S^0\bar{\Lambda} + c.c.,\ \Lambda\bar{\Lambda}\pi^0,\ \Lambda\bar{\Lambda}\eta$

The $X(2075)$ was first reported by BESII near the threshold of the invariant mass spectrum of $p\bar{\Lambda}$ in $J/\psi \to pK^-\bar{\Lambda}$ decays. The mass, width, and product branching fraction of this enhancement are $M = 2075 \pm 12$ (stat.) $\pm$ 5 (syst.) MeV/$c^2$, $\Gamma = 90 \pm 35$ (stat.) $\pm$ 9 (syst.) MeV/$c^2$ [21], and $B(J/\psi \to$

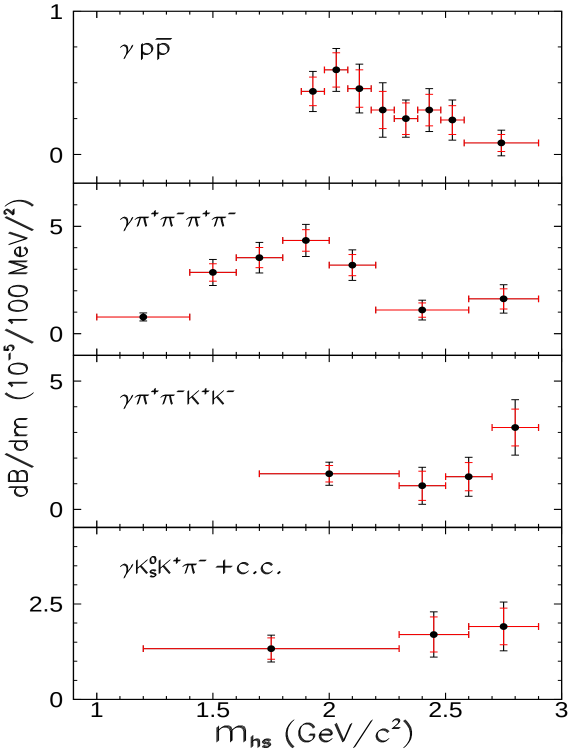


Figure 5: Differential branching fractions for $\psi(2S) \to \gamma p\bar{p}$, $\gamma 2(\pi^+\pi^-)$, $\gamma K^+K^-\pi^+\pi^-$, and $\gamma K_S^0 K^+\pi^- + c.c.$. Here $m_{hs}$ is the invariant mass of the hadrons. For each point, the smaller longitudinal error is the statistical error, while the bigger one is the total error.

$K^-X)B(X \to p\bar{\Lambda} + c.c.) = (5.9 \pm 1.4 \pm 2.0) \times 10^{-5}$, respectively. The study of the isospin conjugate channel $J/\psi \to nK_S^0\bar{\Lambda}$ is therefore important not only in exploring new decay modes of $J/\psi$ but also in understanding the $X(2075)$.

The invariant mass spectra of $\Lambda K_S^0$, $nK_S^0$, and $\bar{\Lambda}n(\Lambda\bar{n})$, as well as the Dalitz plot for all selection requirements are shown in Fig. 6. In the $\Lambda K_S^0$ invariant mass spectrum, an enhancement near $\Lambda K_S^0$ threshold is evident, as is found in the $\Lambda K$ mass spectrum in $J/\psi \to pK^-\bar{\Lambda}$ [22]. If the enhancement is fitted with an acceptance weighted S-wave Breit-Wigner function and a function $f_{bg}(\delta)$ describing the phase space "background" contribution, the fit leads to M=1.648±0.006GeV/$c^2$ and $\Gamma = 61 \pm 21$MeV/$c^2$, respectively. Here the errors are only statistical. The systematic uncertainties are not included since more accurate measurements of the mass and width should come from a full PWA involving interferences among $N^*$ and $\Lambda^*$ states. The fitted mass and width are consistent with those obtained from a partial wave analysis of $J/\psi \to pK^-\bar{\Lambda}$ [22]. The $X(2075)$ signal which was seen in the $p\bar{\Lambda}$ invariant mass spectrum in $J/\psi \to pK^-\bar{\Lambda}$ is not significant here. Using a

Table I Branching fractions for $\psi(2S) \to \gamma + hadrons$ with $m_{hs} < 2.9$ GeV/$c^2$, where the upper limits are determined at the 90% C.L.

| Mode | $\mathcal{B}(\times 10^{-5})$ |
|---|---|
| $\gamma p\bar{p}$ | 2.9±0.4±0.4 |
| $\gamma 2(\pi^+\pi^-)$ | 39.6±2.8±5.0 |
| $\gamma K_S^0 K^+\pi^- + c.c.$ | 25.6±3.6±3.6 |
| $\gamma K^+K^-\pi^+\pi^-$ | 19.1±2.7±4.3 |
| $\gamma K^{*0}K^+\pi^- + c.c.$ | 37.0±6.1±7.2 |
| $\gamma K^{*0}\bar{K}^{*0}$ | $24.0 \pm 4.5 \pm 5.0$ |
| $\gamma\pi^+\pi^- p\bar{p}$ | 2.8±1.2±0.7 |
| $\gamma K^+K^-K^+K^-$ | $< 4$ |
| $\gamma 3(\pi^+\pi^-)$ | $< 17$ |
| $\gamma 2(\pi^+\pi^-)K^+K^-$ | $< 22$ |

Bayesian approach [23] and fixing the mass and width of $X(2075)$ to 2075 MeV/$c^2$ and 90 MeV/$c^2$ respectively, the upper limit on the number of events observed $N_{obs}^{UL}$ is 54 events at the 90% C.L.

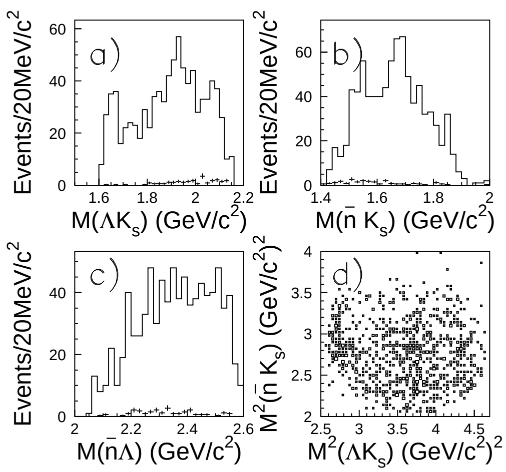


Figure 6: The invariant mass spectra of (a) $\Lambda K_S^0$, (b) $\bar{n}K_S^0$, and (c) $\bar{n}\Lambda$, as well as (d) the Dalitz plot for candidate events after all selection criteria. The crosses show the sideband backgrounds.

The decays of $J/\psi$ and $\psi(2S)$ to $nK_S^0\bar{\Lambda}+c.c.$ are observed for the first time, and their branching fractions are:

$$B(J/\psi \to nK_S^0\bar{\Lambda} + c.c.) = (6.46 \pm 0.20 \pm 1.07) \times 10^{-4},$$
$$B(J/\psi \to nK_S^0\bar{\Lambda}) = (3.09 \pm 0.14 \pm 0.58) \times 10^{-4},$$
$$B(J/\psi \to \bar{n}K_S^0\Lambda) = (3.39 \pm 0.15 \pm 0.48) \times 10^{-4},$$
$$B(\psi(2S) \to nK_S^0\bar{\Lambda}+c.c.) = (0.81 \pm 0.11 \pm 0.14) \times 10^{-4}.$$

The isospin violating process $J/\psi \to \Lambda\bar{\Lambda}\pi^0$ has been studied by DM2 [24] and BESI [25], and its average branching fraction is determined to be $\mathcal{B}(J/\psi \to \Lambda\bar{\Lambda}\pi^0) = (2.2 \pm 0.6) \times 10^{-4}$ [26]. However, the isospin conserving process $J/\psi \to \Lambda\bar{\Lambda}\eta$ has not been reported, and there are no measurements for $\Lambda\bar{\Lambda}\pi^0$ and $\Lambda\bar{\Lambda}\eta$ decays of $\psi(2S)$.

Table II lists the results for $J/\psi$ and $\psi(2S)$ decay into $\Lambda\bar{\Lambda}\pi^0$ and $\Lambda\bar{\Lambda}\eta$, as well as $J/\psi \to \Sigma^+\pi^-\bar{\Lambda} + c.c.$. We also list the total branching fraction for the conjugate modes, where the common systematic errors have been taken out. Except for $J/\psi \to \Lambda\bar{\Lambda}\pi^0$ and $J/\psi \to \Sigma^+\pi^-\bar{\Lambda} + c.c.$, the results are first measurements. Interestingly, the result of $J/\psi \to \Lambda\bar{\Lambda}\pi^0$ presented here is much smaller than those of DM2 and BESI [24, 25]. In previous experiments, the large contaminations from $J/\psi \to \Sigma^0\pi^0\bar{\Lambda} + c.c.$ and $J/\psi \to \Sigma^+\pi^-\bar{\Lambda} + c.c.$ were not considered, resulting in a large value of branching fraction for $J/\psi \to \Lambda\bar{\Lambda}\pi^0$. The small branching fraction of $J/\psi \to \Lambda\bar{\Lambda}\pi^0$ and relatively large branching fraction of $J/\psi \to \Lambda\bar{\Lambda}\eta$ measured here indicate that the isospin violating decay in $J/\psi$ decays is suppressed while isospin conserving decays are favored, which is consistent with expectation.

## 4. Search for $J/\psi$ rare decays via $\psi(2S) \to \pi^+\pi^- J/\psi$

Search for $J/\psi$ rare decays, e.g. $C$-parity violation or invisible decays, suffers from removing the QED backgrounds from the direct annihilation of $e^+e^-$. Using the $J/\psi$ sample produced from $\psi(2S) \to \pi^+\pi^- J/\psi$, the QED background can be strongly suppressed. The direct decay $J/\psi \to \gamma\gamma$ was previously measured to be $Br(J/\psi \to \gamma\gamma) < 5 \times 10^{-4}$. BES studies the decay $J/\psi \to \gamma\gamma$ using $J/\psi \to \pi^+\pi - J/\psi$, and the upper limit for the branching ratio is measured to be $Br(J/\psi \to \gamma\gamma) < 2.2 \times 10^{-5}$ at 90% confidence level, which is about 20 times lower than previous measurements.

Invisible decays of quarkonium states offer a window into what may lie beyond the standard model. In standard model (SM), the predicted branching fraction for $J/\psi \to \nu\nu$ is $Br(J/\psi \to \nu\nu) = 4.54 \times 10^{-7} \times Br(J/\psi \to e^+e^-)$ with a small uncertainty (2%-3%). However, new physics beyond the SM might enhance the branching fraction of $J/\psi$ invisible decays. One possibility is the decay into light dark matter particles mediated by a new, electrically neutral spin-1 gauge boson $U$, which could significantly increase the invisible decay rate [27]. It is of interest to search for such light invisible particle in collider experiments. Using $\psi(2S) \to \pi^+\pi^- J/\psi$ decays, a search for the decay of the $J/\psi$ to invisible final states is performed. The $J/\psi$ peak in the distribution of masses recoiling against the $\pi^+\pi^-$ is used to tag $J/\psi$ invisible decays. No signal is found, and an upper limit at the 90% confidence level is determined to be $1.2 \times 10^{-2}$ for the ratio $\frac{\mathcal{B}(J/\psi \to \text{invisible})}{\mathcal{B}(J/\psi \to \mu^+\mu^-)}$. This is the first search for $J/\psi$ decays to invisible final states.

## 5. Summary

Using the 58 M $J/\psi$ and 14 M $\psi(2S)$ event samples taken with the BESII detector at the BEPC storage ring, BES experiment provided many interesting results in charmonium decays, including the observation of the $Y(2175)$, $\eta(2225)$, $X(1440)$, and many $\psi(2S)$ radiative decays. The effort to search for rare decays, e.g. $J/\psi$ decays into $\gamma\gamma$ and invisible decays are also reported. These results shed light on the understanding of role played by strong interactions in charmonium decays.

## Acknowledgments

This work is supported in part by the National Natural Science Foundation of China under contracts Nos. 10491300, 10225524, 10225525, 10425523,10625524, 10521003.

## References

[1] J. Z. Bai *et al.* [BES Collaboration], Nucl. Instr. Meth. A **458**, 627 (2001).
[2] M. Ablikim *et al.* [BES Collaboration], Phys. Rev. Lett. **100**, 102003 (2008).
[3] B. Aubert *et al.* [BABAR Collaboration], Phys. Rev. D **74**, 091103 (2006).
[4] B. Aubert *et al.* [BABAR Collaboration], Phys. Rev. D **76**, 012008 (2007).
[5] B. Aubert *et al.* [BaBar Collaboration], Phys. Rev. Lett. **95**, 142001 (2005).
[6] C. Z. Yuan *et al.* [Belle Collaboration], Phys. Rev. Lett. **99**, 182004 (2007).
[7] M. Ablikim *et al.* [BES Collaboration], Phys. Lett. B **662**, 330 (2008).
[8] A. Etkin *et al.*, Phys. Lett. B **201**, 568 (1988).
[9] Z. Bai *et al.* [MARK-III Collaboration], Phys. Rev. Lett. **65**, 1309 (1990).
[10] D. Bisello *et al.* [DM2 Collaboration], Phys. Lett. B **179**, 294 (1986).
[11] D. Bisello *et al.* [DM2 Collaboration], Phys. Lett. B **241**, 617 (1990).
[12] M. Ablikim *et al.* [BES Collaboration], Phys. Rev. D **77**, 032005 (2008).
[13] P. H. Baillon *et al.*, NC 50A, 393 (1967).
[14] D. L. Scharre *et al.*, Phys. Lett. B **97**, 329 (1980).
[15] C. Edwards *et al.*, Phys. Rev. Lett. **49**, 259 (1982); Phys. Rev. Lett. **50**, 219 (1982).

Table II Measured branching fractions or upper limits at 90% confidence level (C.L.) for all the studied channels. Here, $\mathcal{B}(\Lambda \to \pi^- p) = 63.9\%$, $\mathcal{B}(\Sigma^+ \to \pi^0 p) = 51.6\%$ and $\mathcal{B}(\eta \to \gamma\gamma) = 39.4\%$ are taken from the PDG.

| Channels | Number of events | MC efficiency(%) | Branching fraction ($\times 10^{-4}$) |
|---|---|---|---|
| $J/\psi \to \Lambda\bar{\Lambda}\pi^0$ | $< 11.2$ | 0.75 | $< 0.64$ |
| $J/\psi \to \Lambda\bar{\Lambda}\eta$ | $44 \pm 10$ | 1.8 | $2.62 \pm 0.60 \pm 0.44$ |
| $\psi(2S) \to \Lambda\bar{\Lambda}\pi^0$ | $< 7.0$ | 2.5 | $< 0.49$ |
| $\psi(2S) \to \Lambda\bar{\Lambda}\eta$ | $< 7.6$ | 2.9 | $< 1.2$ |
| $J/\psi \to \Sigma^+\pi^-\bar{\Lambda}$ | $335 \pm 22$ | 2.3 | $7.70 \pm 0.51 \pm 0.83$ |
| $J/\psi \to \bar{\Sigma}^-\pi^+\Lambda$ | $254 \pm 19$ | 1.8 | $7.47 \pm 0.56 \pm 0.76$ |
| $J/\psi \to \Sigma^+\pi^-\bar{\Lambda} + c.c.$ | | | $15.17 \pm 0.76 \pm 1.59$ |


[16] J. E. Augustin *et al.* [DM2 Collaboration], Phys. Rev. D **42**, 10 (1990).

[17] P. Wang, C. Z. Yuan, and X. H. Mo, Phys. Rev. D **70**, 114014 (2004).

[18] W.-M. Yao *et al.* [Particle Data Group], J. Phys. G **33**, 1 (2006).

[19] M. Ablikim *et al.* [BES Collaboratio], Phys. Rev. Lett. **99**, 011802 (2007).

[20] M. Ablikim *et al.* [BES Collaboration], arXiv:0710.2324 [hep-ex].

[21] BES collaboration, M. Ablikim, et. al., Phys. Rev. Lett. 93(2004) 112002.

[22] H. X. Yang, for BES Collaboration Int. J. Mod. Phys. A 20(2005) 1985.

[23] G. J. Feldman, R. D. Cousins, Phys. Rev. D57 (1998) 3873.

[24] DM2 Collaboration, P. Henrard *et al.*, Nucl. Phys. B **292**, 670 (1987).

[25] BES Collaboration, J. Z. Bai *et al.*, Phys. Lett. B **424**, 213 (1998).

[26] Particle Physics Group, W. M. Yao *et al.*, J. Phys. G **33**, 1 (2006).

[27] C. Boehm and P. Fayet. Nucl. Phys. **B 683**, 219 (2004); C. Boehm and D. Hooper, J. Silk, M. Casse, and J. Paul, Phys. Rev. Lett. **92**, 101301 (2004); P. Fayet. Phys. Rev. D **70**, 023514 (2004); P. Fayet, Phys. Lett. **B 95**, 285 (1980); P. Fayet, Nucl. Phys. **B 187**, 184 (1981); S. H. Zhu, Phys. Rev. **D 75**, 115004 (2007).