PROCEEDINGS OF SCIENCE

η and η' Physics at BESIII

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With a sample of 225 million J/ψ events collected with the BESIII detector at BEPCII, the recent results on η/η' decays are presented, including the Dalitz plot analysis of $\eta' \to \pi^+\pi^-\eta$, measurement of the braching fractions of $\eta' \to \pi\pi\pi$ and $\eta' \to \pi^+\pi^- l^+ l^-$, and the search for rare decays of $\eta/\eta' \to \pi\pi$ and $\eta/\eta' \to$ *invisible*.

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1. Introduction

Although the main decay modes of η and η' were well measured by different experiments, the study of their decays still attracts considerable efforts from both theory and experiment, which offers a unique tool to test the well known low QCD theory, the Chiral Perturbation theory, and search for new physics beyond the standard model.

BESIII/BEPCII, a major upgrade of the BESII/BEPC experiment, is designed to study τ-charm physics, light hadron spectroscopy and charmonium decays. Since the production rates of η and η' in J/ψ radiative decays are at a level of 10^{-3}, the recorded sample J/ψ events collected at the BESIII detector also provides an important source of η and η' mesons to study their decay dynamics. In this talk, with the 225 million J/ψ events accumulated at the BESIII detector, we present the recent results on η and η' decays via J/ψ radiative decays.

2. Study of $\eta' \to \pi^+\pi^-\eta(\eta \to \gamma\gamma)$ [1]

In addition to test the predictions of the chiral theory, the study of $\eta' \to \pi^+\pi^-\eta$ helps us to understand the gluon components on the dynamics of η' decays. Based on the 225 million J/ψ events, the branching fraction of $J/\psi \to \gamma\eta'$ is measured to be $(4.84 \pm 0.03 \pm 0.24) \times 10^{-3}$. After that, with the largest sample of η' decays produced via J/ψ radiative decays, the distribution of X and Y, two the Dalitz plot variables defined as $X = \frac{\sqrt{3}}{Q}(T_{\pi^+} - T_{\pi^-})$ and $Y = \frac{m_\eta + 2m_\pi}{m_\pi}\frac{T_\eta}{Q} - 1$, are shown in Fig. 1.

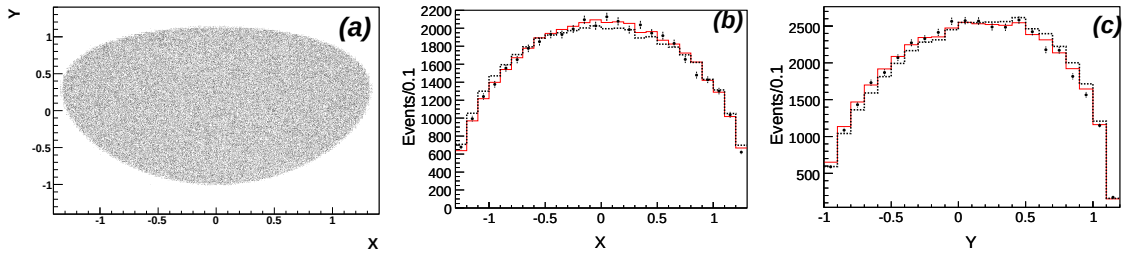

Figure 1: (a) The experimental Dalitz diagram for the decay $\eta' \to \pi^+\pi^-\eta$ in terms of the variables X and Y with the $\pi^+\pi^-\eta$ mass in the η' mass region. The corresponding projections on variables X and Y are shown in (b) and (c), respectively, where the dashed histograms are from MC signal sample with $\eta' \to \pi^+\pi^-\eta$ events produced with phase space and the solid histograms are the fitted results described in the text.

Two different representations are used to used to extract the parameters of the Dalitz plot and the results are summarized in Table 1. We can see that the values of some parameters are not in agreement with previous work; α representing the gluon effect in η' decays and "c" defined for C parity violation are consistent with zero within 2 standard deviations.

3. Search for CP violation in $\eta(\eta') \to \pi\pi$ [7]

In the standard model, these processes can proceed via the weak interaction with a branching fraction of order 10^{-27} according to Ref. [6]. Therefore $\eta/\eta' \to \pi\pi$ offer an excellent laboratory

Table 1: Experimental and theoretical values of the parameters of the matrix element squared for $\eta' \to \pi^+\pi^-\eta$ in the general parametrization (second, third and fourth columns) and in the linear parametrization (sixth, seventh and eighth columns).

Par.	VES [2]	Theory [3]	This work	Par.	CLEO [4]	VES [5]	This work
a	-0.127 ± 0.018	-0.116 ± 0.011	-0.047 ± 0.012	Re(α)	-0.021 ± 0.025	-0.072 ± 0.014	-0.033 ± 0.006
b	-0.106 ± 0.032	-0.042 ± 0.034	-0.069 ± 0.021	Im(α)	0.000 (fixed)	0.000 ± 0.100	0.000 ± 0.050
c	$+0.015 \pm 0.018$	–	$+0.019 \pm 0.012$	c	0.000 (fixed)	$+0.020 \pm 0.019$	$+0.018 \pm 0.010$
d	-0.082 ± 0.019	$+0.010 \pm 0.019$	-0.073 ± 0.013	d	0.000 (fixed)	-0.066 ± 0.034	-0.059 ± 0.013

for testing P and CP invariance. In this analysis, the *CP* and *P* violating decays of $\eta/\eta' \to \pi^-\pi^-$ and $\pi^0\pi^0$ are searched for in J/ψ radiative decays.

The mass spectra of $\pi^+\pi^-$ and $\pi^0\pi^0$ are shown in Fig. 2 and Fig. 3, respectively. No significant η or η' signal is observed. Using the Bayesian method, the 90% confidence level upper limits are determined to be $\mathscr{B}(\eta \to \pi^+\pi^-) < 3.9 \times 10^{-4}$, $\mathscr{B}(\eta' \to \pi^+\pi^-) < 5.5 \times 10^{-5}$, $\mathscr{B}(\eta \to \pi^0\pi^0) < 6.9 \times 10^{-4}$ and $\mathscr{B}(\eta' \to \pi^0\pi^0) < 4.5 \times 10^{-4}$.

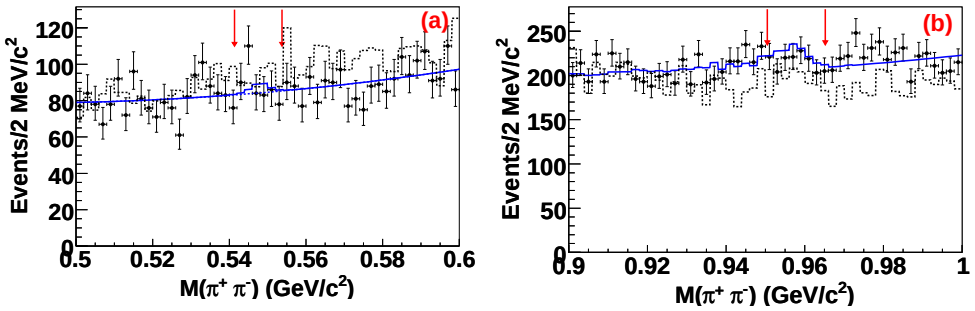

Figure 2: The $\pi^+\pi^-$ invariant mass distributions of the final candidate events, (a) η mass region, (b)η' mass regions. The dots with error bars are data, the solid lines are the fit described in the text, and the dashed histograms are the sum of all the simulated normalized backgrounds. The arrows show mass regions which contain around 95% of the signal according to MC simulations.

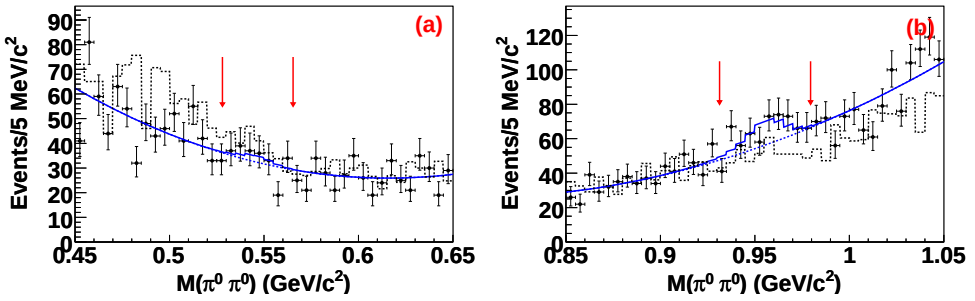

Figure 3: The $\pi^0\pi^0$ invariant mass distributions of the final candidate events, (a) η mass region, (b) η' mass regions. The dots with error bars are data, the solid lines are the fit described in the text, and the dashed histograms are the sum of all the simulated normalized backgrounds. The arrows show mass regions which contain around 95% of the signal according to MC simulations.

4. Branching fraction measurement of $\eta' \to \pi^+\pi^-\pi^0, \pi^0\pi^0\pi^0$ [8]

These are two isospin violation decay modes, which provides valuable information about the light quark mass. The uncertainty of the branching fractions from the previous work are quite large, which motivate us to study these two decay modes via J/ψ radiative decays.

The mass spectra of $\pi^+\pi^-\pi^0$ and $\pi^0\pi^0\pi^0$ are shown in Fig. 4(a) and Fig. 4(b), where the clear η' signals are observed. The branching fractions are measured to be $\mathscr{B}(\eta' \to \pi^+\pi^-\pi^0) = (3.83 \pm 0.15 \pm 0.39) \times 10^{-3}$ and $\mathscr{B}(\eta' \to \pi^0\pi^0\pi^0) = (3.56 \pm 0.22 \pm 0.34) \times 10^{-3}$. For the decay $\eta' \to \pi^+\pi^-\pi^0$, the branching fraction that we measured is consistent with the CLEO-c measurement [9], and the precision is improved by a factor of four, while it is two times larger than the world average value [10] for $\eta' \to 3\pi^0$.

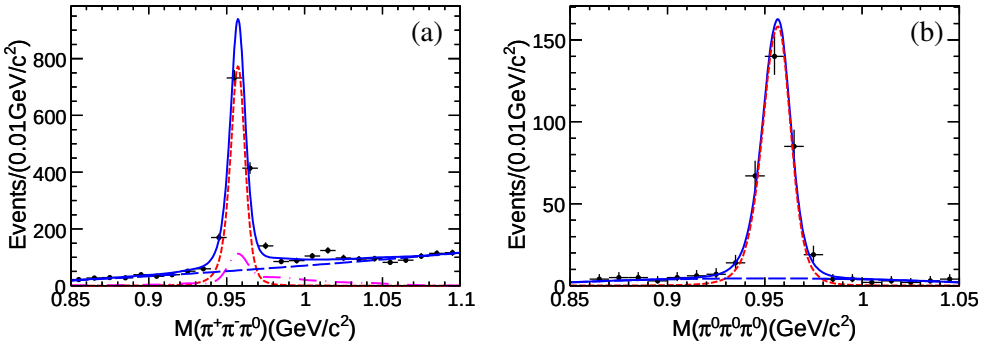

Figure 4: Results of the fit of the $\pi^+\pi^-\pi^0$ and $\pi^0\pi^0\pi^0$ mass spectra. The solid curve in the result of the fit as described in the text. The dotted curve is the η' signal. The dashed curves denote the background polynomial and the dash-dotted curve in (a) is the peaking backgrounds.

5. Preliminary results: Search for the invisible decays of η and η'

The invisible decays of η, η' and other mesons allow us to search for new physics beyond the Standard Model. In this analysis, we performed the search for the invisible decays of η and η' via the two-body decays $J/\psi \to \phi\eta$ and $\phi\eta'$ since the narrow resonance ϕ is easy to tag with the two charged kaons,

Figure 5(a) shows $M_{K^+K^-}$, where a clear ϕ peak, while no evident η or η' signal is observed in the mass spectrum recoiling against ϕ shown in Figure 5(b). To reduce the systematic uncertainty, the branching fraction of $\eta(\eta') \to \gamma\gamma$ is also determined in $J/\psi \to \phi\eta(\eta')$, in order to obtain the ratio of $\mathscr{B}(\eta(\eta') \to invisible)$ to $\mathscr{B}(\eta(\eta') \to \gamma\gamma)$. Finally the invisible decays of η and η' and obtain upper limits at the 90% C.L. of 3.37×10^{-4} and 2.39×10^{-2} for $\frac{\mathscr{B}(\eta \to invisible)}{\mathscr{B}(\eta \to \gamma\gamma)}$ and respectively. Using the branching fraction values of η and $\eta' \to \gamma\gamma$ from the PDG [10], we determine the invisible decay rates to be $\mathscr{B}(\eta \to invisible) < 1.32 \times 10^{-4}$ and $\mathscr{B}(\eta' \to invisible) < 5.31 \times 10^{-4}$ at the 90% confidence level.

6. Preliminary Results: Branching fraction measurement of $\eta' \to \pi^+\pi^-l^+l^-$

This process is expected to proceed the internal photon conversion, $\eta' \to \pi^+\pi^-\gamma^* \to \pi^+\pi^-l^+l^-$.

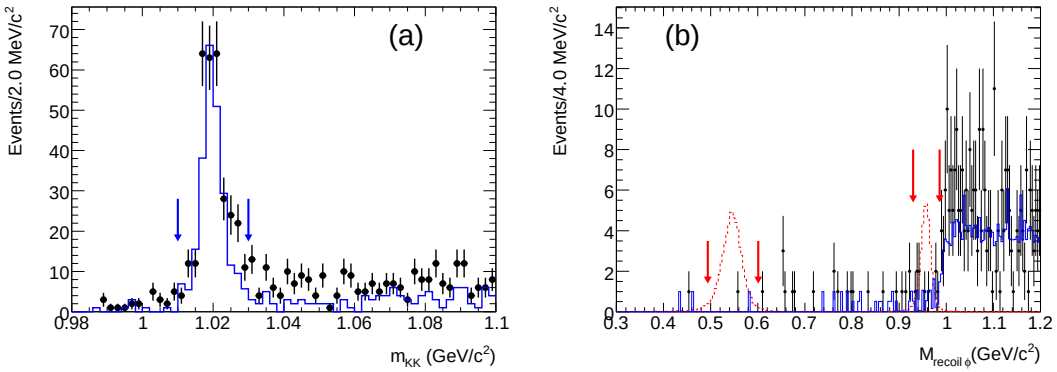

Figure 5: (a) The m_{KK} distribution for candidate events in data. The arrows on the plot indicate the signal region of ϕ candidates. Points with error bars are data; the (blue) histogram is expected background. (b) Recoil mass distribution against ϕ candidates, M_{ϕ}^{recoil}, for events with 1.01 GeV/c^2 $< m_{KK} <$ 1.03 GeV/c^2 in (a). Points with error bars are data; the (blue) solid histogram is the sum of the expected backgrounds; the dashed histograms (with arbitrary scale) are signals of η and η' invisible decays from MC simulations; the arrows on the plot indicate the signal regions of the η and $\eta' \to$ *invisible*.

Of interesting is this process could be used to probe the η' structure, search for CP violation and test the predictions based on the Vector Meson Dominance (VMD) and Chiral Perturbation Theory.

Figure 6 displays the e^+e^- mass spectrum by requiring $|M(\pi^+\pi^-e^+e^-) - m(\eta')| < 0.02$ GeV/c^2, where the background from $\gamma\pi^+\pi^-$ conversions could be easily distinguished. The enhancement close to e^+e^- mass threshold corresponds to the signal from the decay of $\eta' \to \pi^+\pi^-e^+e^-$ and the clear peak around 0.015 GeV/c^2 comes from the background events of $\eta' \to \gamma\pi^+\pi^-$.

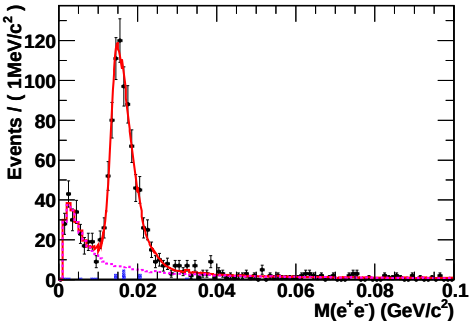

Figure 6: The invariant mass spectrum of e^+e^- on data (dots with error bars) after all the selection criteria are applied. The solid line represents the fit result, the dotted histogram is MC signal shape and the shaded histogram is for backgrounds obtained from η' sideband events.

Figure 7 shows the invariant mass of $\pi^+\pi^-\mu^+\mu^-$, where no evident η' signal is observed. The remaining events in the η' mass region is consistent with the contributions from the background events estimated with MC simulations.

Here we present the preliminary results for these two decay modes. The branching fraction of $\eta' \to \pi^+\pi^-e^+e^-$ is measured to be $\mathscr{B}(\eta' \to \pi^+\pi^-e^+e^-) = (2.13 \pm 0.13(stat)) \times 10^{-3}$, which is in good agreement with theoretical predictions and the previous measurement. No η' signal

is found in the mass spectrum of $\pi^+\pi^-\mu^+\mu^-$, and the upper limit is determined to be $\mathscr{B}(\eta' \to \pi^+\pi^-\mu^+\mu^-) < 2.65 \times 10^{-5}$ at 90% confidence level.

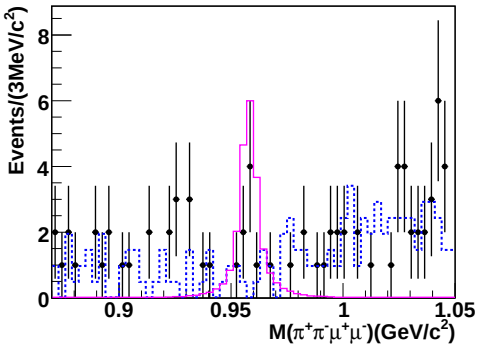

Figure 7: The invariant mass distribution of $\pi^+\pi^-\mu^+\mu^-$ between data and MC samples with all the selection criteria applied. Dots with error bars represent the data, the solid histogram is MC signal, and the dashed line indicates inclusive MC.

7. Summary and Outlook

In summary, with a sample of 225 million J/ψ events, the recent results on η/η' decays at BESIII are presented. We can see that there is a rich field to be explored in η/η' decays, which motivates us to make a good understanding of their decay dynamics and search for new physics beyond the Standard Model in the future. In 2012 about 1 billion J/ψ events were taken at the BESIII, which offers an unique opportunity to search for rare or forbidden decays of η/η'.

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