PROCEEDINGS OF SCIENCE

η and η' physics at BESIII

Liqing QIN[*†]
School of Physics, Shandong University
Jinan 250100, P. R. China
E-mail: qinlq@ihep.ac.cn

Based on the 225.3 million J/ψ events accumulated with the BESIII detector at the BEPCII, the recent results on η and η' decays are presented in this paper. The Dalitz study of $\eta' \to \pi^+\pi^-\eta$ is performed in a new level of precision and the C-parity violation is not evident . Decays of $\eta' \to \pi^+\pi^- l^+ l^-$ ($(l^\pm = e^\pm, \mu^\pm)$) are also studied via $J/\psi \to \gamma\eta'$. The branching fraction is measured to be $\mathscr{B}(\eta' \to \pi^+\pi^- e^+ e^-) = (2.11 \pm 0.12\ (stat.) \pm 0.14\ (syst.)) \times 10^{-3}$, which is in good agreement with theoretical predictions and the previous measurement, but is determined with much higher precision. No η' signal is found in the $\pi^+\pi^-\mu^+\mu^-$ mass spectrum, and the branching fraction upper limit is set. A search for P and CP violation decays of $\eta/\eta' \to \pi^+\pi^-, \pi^0\pi^0$ is performed as well as the invisible decays and the semileptonic weak decay.

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[*]Speaker.
[†]On behalf of the BESIII collaboration

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1. Introduction

Since the η and η' were discovered four decades ago, there has been considerable interest in their decays both theoretically and experimentally because of their special roles in low energy scale Quantum Chromodynamics theory. Their main decay modes, including hadronic and radiative decays, have been well measured, but the study of their anomalous decays is still an open field. At BESIII a sample of $(225.3 \pm 2.8) \times 10^6$ J/ψ events was collected in 2009, and offers a unique opportunity to study η and η' decays via $J/\psi \to \gamma\eta(\eta')$ or $J/\psi \to \phi\eta(\eta')$.

2. Measurement of the matrix element for the decay $\eta' \to \pi^+\pi^-\eta$ [1]

In this analysis, the η' is identified by its decay into $\eta\pi^+\pi^-$ with $\eta \to \gamma\gamma$ in J/ψ radiative decays. The invariant mass distribution of $\eta\pi^+\pi^-$ candidate events are shown in Figure 1 (a), from which a very clear η' signal is observed. Figure 1 (b) shows the experimental form of the Dalitz plot for the decay $\eta' \to \eta\pi^+\pi^-$ in terms of the variables X and Y with the $\eta\pi^+\pi^-$ mass in the 0.93-0.98 GeV/c^2 mass region. The Dalitz plot parameters are determined in a generalized and a linear representation (as shown in Fig. 2) with a new level of precision. In general the results are in reasonable agreement with the previous measurements and the C-parity violation is not evident. The statistical error of the parameters are still quite large, much more data are strongly needed to provide a more stringent test of the chiral theory.

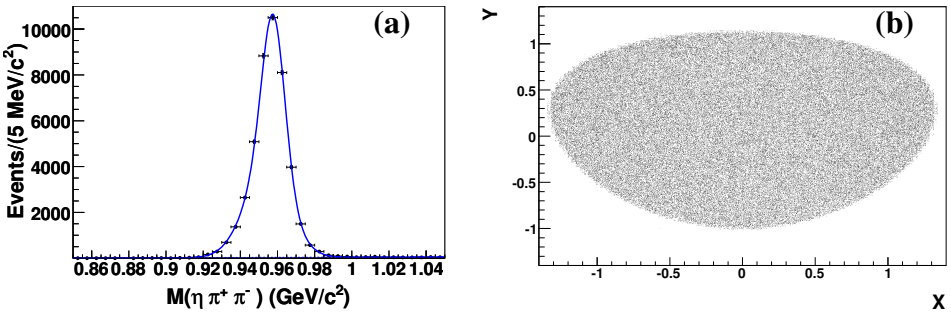

Figure 1: (a) The $\eta\pi^+\pi^-$ invariant mass distribution of the final candidate events. The dots with error bars represent data, and the solid curve is the result of the fit with a double-Gaussian function for the η' signal and a linear function for the background shape; (b) The experimental Dalitz plot for the decay $\eta' \to \eta\pi^+\pi^-$ in terms of the variables X and Y with the $\eta\pi^+\pi^-$ mass in the η' mass region.

3. Search for CP violation in $\eta/\eta' \to \pi\pi$ [2]

This is a blind analysis with the background estimated beforehand. Figure 3 shows the $\pi^+\pi^-$, $\pi^0\pi^0$ invariant mass distributions of the final candidate events in the η, η' mass regions after removal of the blinded boxes, where dots with error bars are data and the dashed histograms are all the normalized background events estimated by a Monte-Carlo (MC) simulation. No evident η, η' signals were observed, and then the branching fraction upper limits (as shown in Table 1) are presented at the 90% confidence level. For comparison, we also list the best upper limits on these processes from PDG [3]. Except for $\mathscr{B}(\eta \to \pi\pi)$, where the KLOE and GAMS-4π Collaborations

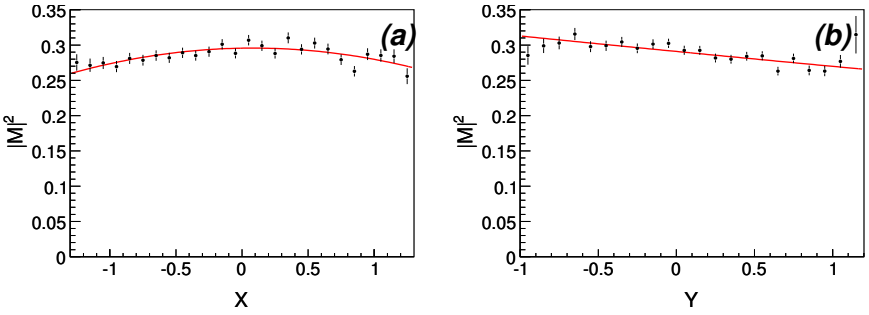

Figure 2: Dependence of the square of the η' decay matrix element on the Dalitz variables X and Y. The solid lines are the fit results of the data with a linear parametrization.

have huge η samples providing the lowest upper limits for $\eta \to \pi^+\pi^-$ and $\eta \to \pi^0\pi^0$, our upper limits are the lowest.

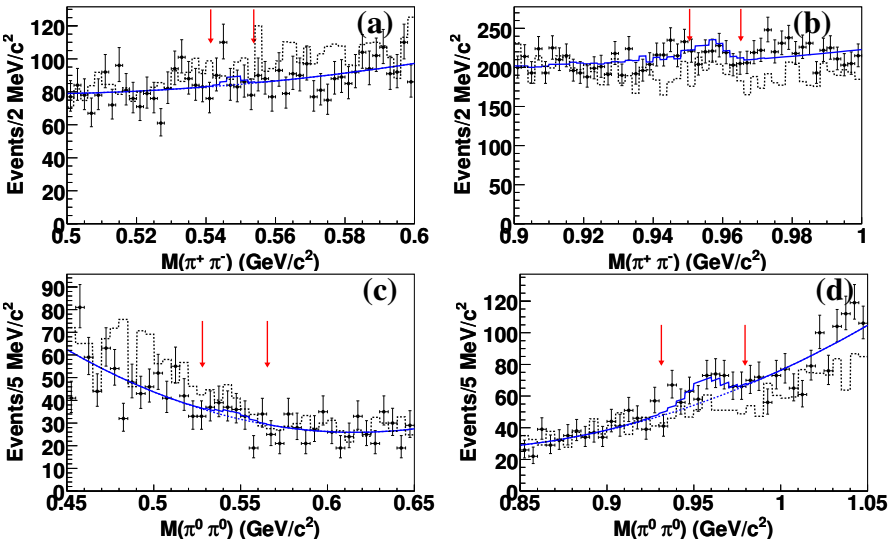

Figure 3: (a)-(d): The $\pi^+\pi^-$, $\pi^0\pi^0$ invariant mass distributions of the final candidate events in the η, η' mass regions, respectively. The dots with error bars are data, the solid lines are the fit described in the text, and the dashed histograms are the sum of all the normalized background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

4. Measurement of $\eta' \to \pi^+\pi^- l^+ l^-$ ($(l^\pm = e^\pm, \mu^\pm)$) [4]

The decays of $\eta' \to \pi^+\pi^- e^+ e^-$, $\eta' \to \pi^+\pi^-\mu^+\mu^-$ are studied via $J/\psi \to \gamma\eta'$. A clear η' signal is observed in the $\pi^+\pi^- e^+ e^-$ mass spectrum. The dominant background comes from $J/\psi \to \gamma\eta'$, $\eta' \to \gamma\pi^+\pi^-$ with the η' photon subsequently converted into an electron-positron pair, which can be easily distinguished from the e^+e^- mass spectrum (as shown in Figure 4(a)). The enhancement close to e^+e^- mass threshold corresponds to the signal from the $\eta' \to \pi^+\pi^- e^+ e^-$ decay, and the clear peak around 0.015 GeV/c^2 comes from the background events of $\eta' \to \gamma\pi^+\pi^-$ where the photon undergoes conversion to an e^+e^- pair and the electron (positron)'s momentum is improperly reconstructed assuming that all the charged tracks are from the interaction point. The branch-

Process	$N_{\rm sig}^{\rm UP}$	ε (%)	$\sigma_{\rm sys}$(%)	S	$\mathscr{B}^{\rm UP}$	$\mathscr{B}^{\rm UP}_{PDG}$
$\eta \to \pi^+\pi^-$	48	54.28	7.3	0.8σ	3.9×10^{-4}	1.3×10^{-5}
$\eta' \to \pi^+\pi^-$	32	53.81	8.6	0.1σ	5.5×10^{-5}	2.9×10^{-3}
$\eta \to \pi^0\pi^0$	36	23.75	8.6	0.6σ	6.9×10^{-4}	3.5×10^{-4}
$\eta' \to \pi^0\pi^0$	110	23.18	8.5	2.6σ	4.5×10^{-4}	9×10^{-4}

Table 1: Summary of the limits on η/η' decays to $\pi^+\pi^-$ and $\pi^0\pi^0$ states. $N_{\rm sig}^{\rm UP}$ is the upper limit on the number of signal events, ε is the efficiency, $\sigma_{\rm sys}$ is the total systematic error, S is the number of statistical significance, $\mathscr{B}^{\rm UP}$ is the upper limit at the 90% C.L. on the decay branching fraction of η/η' to $\pi^+\pi^-$ or $\pi^0\pi^0$, and $\mathscr{B}^{\rm UP}_{PDG}$ is the upper limit on the decay branching fraction from PDG [3].

ing fraction is measured to be $\mathscr{B}(\eta' \to \pi^+\pi^- e^+e^-) = (2.11 \pm 0.12\ (stat.) \pm 0.14\ (syst.)) \times 10^{-3}$, which is in good agreement with theoretical predictions [5] and the previous measurement [6], but is determined with much higher precision. Figure 4 (b) shows the $\pi^+\pi^-\mu^+\mu^-$ mass spectrum. Although a few events accumulate in the η' mass region, they are not significant. The upper limit is determined to be $\mathscr{B}(\eta' \to \pi^+\pi^-\mu^+\mu^-) < 2.9\times10^{-5}$ at the 90% confidence level.

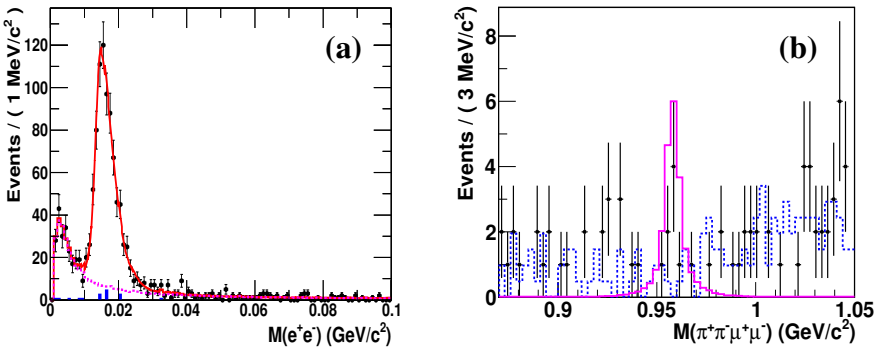

Figure 4: The e^+e^-, $\mu^+\mu^-$ invariant mass spectra of data (dots with error bars) after all selection criteria are applied. For (a), the solid line represents the fit result, the dotted histogram is the simulated events by MC study and the shaded histogram is background obtained from η' sideband events; for (b) the solid histogram is events estimated in the MC simulation, and the dashed line indicates the background estimated with the inclusive MC J/ψ events.

5. Search for the invisible and weak decays of η, η' [7] [8]

The BESII experiment obtained a first upper limit $\mathscr{B}(\eta(\eta') \to \text{invisible})/\mathscr{B}(\eta\,(\eta') \to \gamma\gamma) < 1.65\times10^{-3}\ (6.69\times10^{-2})$, corresponding to $\mathscr{B}(\eta\,(\eta') \to \text{invisible}) < 6.5\times10^{-4}\ (1.5\times10^{-3})$ [9]. Complementally IceCube set $\mathscr{B}(\eta \to \nu_{e,\tau}\bar{\nu}_{e,\tau}) < 6.1\times10^{-4}$ [10] for η decays into SM neutrinos. Updated results of searches for the invisible decays at BESIII are presented here. Both invisible and weak decays are tried to search for via $J/\psi \to \phi\eta$ and $J/\psi \to \phi\eta'$. The ϕ signals, which are reconstructed in K^+K^- final states, are used to tag η and η' decays. Since ϕ and $\eta(\eta')$ are given strong boosts in the J/ψ decay, the invisible decays of the η and η' were investigated with the

mass spectra recoiling against ϕ. No signal above background were found for the invisible decays of η and η'. To reduce the systematic uncertainty, the upper limits of the ratios, $\frac{\mathscr{B}(\eta\to invisible)}{\mathscr{B}(\eta\to\gamma\gamma)} < 2.6\times10^{-4}$ and $\frac{\mathscr{B}(\eta'\to invisible)}{\mathscr{B}(\eta'\to\gamma\gamma)} < 2.4\times10^{-2}$ were obtained first at the 90% confidence level. Using the branching fractions of $\eta(\eta')\to\gamma\gamma$, the upper limits on the branching fraction at the 90% confidence level were calculated to be $\mathscr{B}(\eta(\eta')\to$invisible$) < 1.0\times10^{-4}(5.3\times10^{-4})$. For the first time a search for the semileptonic weak decays $\eta(\eta')\to\pi^+e^-\bar{\nu}_e$ was performed and no signal was observed. At the 90% confidence level, the semileptonic weak rates were given to be $\mathscr{B}(\eta\to\pi^+e^-\bar{\nu}_e+c.c.) < 1.7\times10^{-4}$ and $\mathscr{B}(\eta'\to\pi^+e^-\bar{\nu}_e+$ c.c.$) < 2.2\times10^{-4}$.

6. Summary

Based on the 225.3 million J/ψ events, we report the recent results on η and η' decays in this talk. To precisely test the fundamental symmetries and theoretical predictions, the larger statistics of $\eta(\eta')$ decays are strongly needed. In 2012 the BESIII detector collected about 1 billion J/ψ events, four times larger than the sample taken in 2009, which allow us to update the study of η', including the Dalitz plot analysis, the search for new decays, as well as the test to the fundamental symmetries. We believe that more interesting results will be coming soon in the near future.

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