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η/η' decays at BESIII

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Decays of both η and η' mesons provide an unique laboratory to study and understand low-energy QCD, and search for physics beyond the Standard Model. We present the latest η and η' related results, which are obtained using 1.3×10^8 J/ψ events collected with the BESIII detector at the BEPCII. Dalitz plot analysis of $\eta\to\pi^+\pi^-\pi^0$ and $\eta/\eta'\to\pi^0\pi^0\pi^0$ decays are performed, and the matrix elements measured. We also present results from amplitude analysis of $\eta'\to\pi^+\pi^-\pi^0$ and $\eta'\to\pi^0\pi^0\pi^0$ decays. A significant P-wave contribution from $\eta'\to\rho^\pm\pi^\mp$ is observed for the first time in the $\eta'\to\pi^+\pi^-\pi^0$ channel, and the corresponding branching fraction is determined. The doubly radiative decay $\eta'\to\gamma\gamma\pi^0$ are studied and the preliminary branching fraction measurements of the inclusive and non-resonant η' decays are determined for the first time.

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1. Introduction

The field theory of strong interaction, Quantum Chromodynamics (QCD), cannot be directly applied at low energy due to the large value of the strong coupling α_s [1, 2]. In this case, alternative model-dependent approaches are used, such as lattice QCD and chiral perturbation theory (ChPT). The η/η' mesons play an important role in the understanding of the low energy QCD. Discovered more than 50 years ago [3, 4], they are isoscalar members of the nonet of the lightest pseudoscalar mesons. The decays of η and η' are investigated within the $U(3)$ chiral unitary approach based on the ChPT [5, 6], and precise measurements of branching fractions, as well as Dalitz plot and amplitude analyses, provide important information in our understanding of the low energy regime.

In this report, we present a selection of the latest η/η' results obtained using a sample of 1.31×10^9 J/ψ events collected with the BESIII detector at the BEPCII [7]. Radiative $J/\psi\to\gamma\eta^{(\prime)}$ decays are then exploited to access the η and η' mesons.

2. Matrix elements for the decays $\eta\to\pi^+\pi^-\pi^0$ and $\eta/\eta'\to\pi^0\pi^0\pi^0$

The decay $\eta/\eta'\to\pi\pi\pi$ is an isospin-violating process. Since the electromagnetic contribution is strongly suppressed [8, 9], they are induced predominately by the strong interaction via chiral symmetry breaking. Therefore, it offers an unique opportunity to investigate fundamental symmetries and test the ChPT approach.

The precise measurement of the matrix elements and decay widths for $\eta\to\pi^+\pi^-\pi^0$ and $\eta/\eta'\to\pi^0\pi^0\pi^0$ performed at BESIII [10] allows to disentagle between several theoretical approaches. For the three-body decay $\eta\to\pi^+\pi^-\pi^0$, the square of the decay amplitude can be parametrized as a function of two independent Dalitz plot variables X and Y as $|A|^2=N(1+aY+bY^2+cX+dX^2+eXY+fY^3+...)$, where

$$X=\frac{\sqrt{3}}{Q}(T_{\pi^+}-T_{\pi^-}) \qquad Y=\frac{3T_{\pi^0}}{Q}-1. \tag{2.1}$$

T_π refers to the kinetic energy of a given pion in the η rest frame, $Q=m_\eta-m_{\pi^+}-m_{\pi^-}-m_{\pi^0}$, $m_{\eta,\pi}$ are the nominal mass from PDG [11], and N is the normalization factor. The extracted Dalitz plot parameters $a, b, c, ...$ are used to test several theoretical models (a non-zero value of odd powers in X implies the violation of the charge conjugation).

In the decay $\eta/\eta'\to\pi^0\pi^0\pi^0$ we have three identical bosons in the final state, and hence it is more convenient to use one fully symmetrized variable $Z=X^2+Y^2$. In this case, the square amplitude is parametrized as $|A|^2=N(1+2\alpha Z+...)$, where a non-zero value of the slope parameter α indicates final-state interaction.

From radiative $J/\psi\to\gamma\eta$ decay, we reconstruct and select 79625 $\eta\to\pi^+\pi^-\pi^0$ candidate events. Figure 1(a) shows the invariant mass spectrum of $\pi^+\pi^-\pi^0$. A clear signal is observed over a small background component, which is estimated to be of the order of 0.2% from η sidebands. The projection of the Dalitz plot variables X and Y from data and MC events are reported in Fig. 1(b) and (c). The phase space MC distributions differ visibly from those in the data sample, which indicates that could be a large contribution from higher-order terms in ChPT.

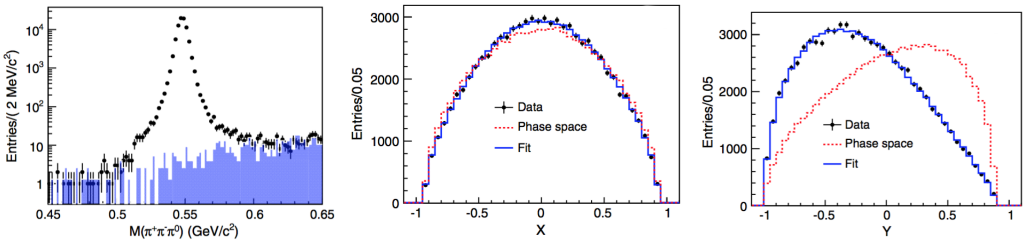

Figure 1: (a) Invariant mass spectrum of $\pi^+\pi^-\pi^0$ after event and track selection for data (black dots) and background events from sidebands (shaded histogram). (b) and (c) show the projection of the Dalitz plot X and Y, respectively, obtained from data (dots), and phase space MC sample (dashed lines). The fit results is represented by solid lines.

The Dalitz plot matrix elements are obtained from an unbinned maximum likelihood fit of the decay amplitude, in which the resolution and detector efficiency are taken into account. The parameters a, b, c, d are extracted, and they result in good agreement with the most recent experimental results and consistent with predictions of dispersive approach [12] and ChPT. The parameters c and e are found to be consistent with zero, and hence no significant symmetry breaking effect is observed.

For the decay $\eta \to \pi^0\pi^0\pi^0$ a very clean η signal is observed, with a background level of the order of 0.3% under the signal region, while a larger background contamination (11.2%) is estimated for the $\eta' \to \pi^0\pi^0\pi^0$ decay.

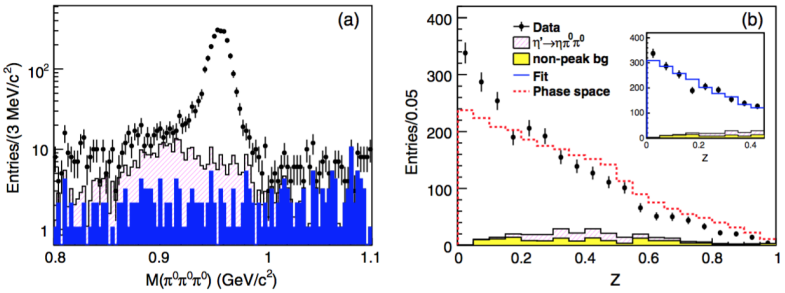

Figure 2: (a) Invariant mass spectrum of $\pi^0\pi^0\pi^0$ for $\eta' \to \pi^0\pi^0\pi^0$ from data (dots), from inclusive MC sample (shaded histogram), and from $\eta' \to \eta\pi^0\pi^0$ MC events. (b) Distribution of the kinematic variable Z for $\eta' \to \pi^0\pi^0\pi^0$ from data (dots), MC phase space (dashed line), and η' sideband (shaded histograms). The fit results is shown in the insert by the solid line.

The invariant mass of $3\pi^0$ for the $\eta' \to \pi^0\pi^0\pi^0$ decay is shown in Fig. 2(a), while the Z distribution in Fig. 2(b). Note that the MC phase space clearly deviates from data. For both $\eta/\eta' \to \pi^0\pi^0\pi^0$ the slope parameter α is extracted from an unbinned maximum likelihood fit, taking into account detection efficiency and resolution. The fit is performed only in the region where the phase space Z distribution is flat. We found $\alpha_{\eta\to 3\pi^0} = -0.055 \pm 0.014 \pm 0.004$, which is compatible with other experimental results [10], and $\alpha_{\eta'\to 3\pi^0} = -0.640 \pm 0.046 \pm 0.047$, which is consistent but more precise than previous results [10]. In particular, the last one is in agreement with prediction done in Ref. [13], where a chiral unitary approach is used.

3. $\eta' \to \pi^+\pi^-\pi^0$ and $\eta' \to \pi^0\pi^0\pi^0$ amplitude analysis

Three pions decay of η' meson allows determination of the $u-d$ quark mass difference by means of the ratio $r_\pm = \mathscr{B}(\eta' \to \pi^+\pi^-\pi^0)/\mathscr{B}(\eta' \to \pi^+\pi^-\eta)$ and $r_0 = \mathscr{B}(\eta' \to \pi^0\pi^0\pi^0)/\mathscr{B}(\eta' \to \pi^0\pi^0\eta)$ [14, 15]. For the charged channel, final state interaction is expected to be very important. In Ref. [13], for example, is predicted a significant $\eta' \to \rho^\pm\pi^\mp$ P-wave contribution for the $\eta' \to \pi^+\pi^-\pi^0$ decay, while it is forbidden by Bose symmetry in three neutral pions decay.

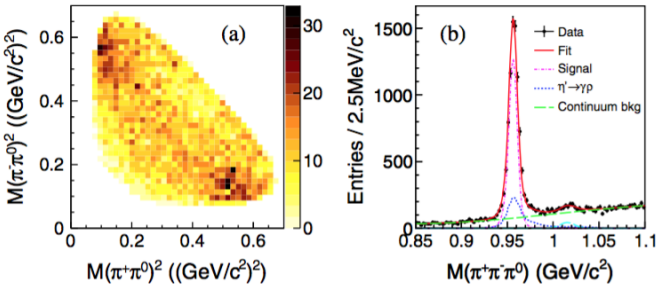

Figure 3: (a) Dalitz plot for selected $\eta' \to \pi^+\pi^-\pi^0$ candidate events from data and (b) $\pi^+\pi^-\pi^0$ invariant mass distribution.

A flat Dalitz plot distribution for $\eta' \to \pi^+\pi^-\pi^0$ decay was observed for the first time by CLEO-c experiment [16] with $20.2^{+6.1}_{-4.8}$ events, and a branching fraction of $\mathscr{B}(\eta' \to \pi^+\pi^-\pi^0) = (37 \pm 11) \times 10^{-4}$ is measured. A more recent BESIII analysis confirms CLEO-c branching fraction [17], but no Dalitz plot analysis was reported. In a even more recent BESIII analysis, here summarized, a model-dependent analysis combining $\eta' \to \pi^+\pi^-\pi^0$ and $\eta' \to \pi^0\pi^0\pi^0$ events was carried out [18]. After event and track selection, a sample of 8267 events is selected, and the corresponding Dalitz plot is shown in Fig. 3(a), where two clusters corresponding to the decay $\eta' \to \rho^\pm\pi^\mp$ are clearly visible. A clear signal η' signal is observed, and the $\pi^+\pi^-\pi^0$ invariant mass spectra is shown in Fig. 3(b). For the neutral channel 2237 events are selected with a very low background contribution. The Dalitz plot and the $\pi^0\pi^0\pi^0$ invariant mass distribution are reported in Ref. [18].

The resonant π-π S-wave and P-wave amplitudes are described following the formalism described in Ref. [19]. The branching fraction $\mathscr{B}(\eta' \to \rho^\pm\pi^\mp)$ is determined to be $(7.44 \pm 0.60 \pm 1.26 \pm 1.84) \times 10^{-4}$. In addition to the non resonant S-wave, the resonant π-π S-wave, interpreted as the broad σ meson, plays an fundamental role in the $\eta' \to \pi\pi\pi$ decays. However, due to the large interference between the resonant and non-resonant component, only the sum is used to describe the S-wave contribution. The extracted branching fractions are summarized in Table 1. For the $\eta' \to \pi^0\pi^0\pi^0$ decay a 5σ discrepancy is observed with respect to previous measurements. This results in a change of a factor two to the ratio r_0, which should be properly considered by theory before any attempt to extract the $u-d$ mass difference [18].

4. Doubly radiative decay $\eta' \to \gamma\gamma\pi^0$

Recently, it have been demonstrated that the contribution from Vector Meson Dominance (VDM) are dominant in the doubly radiative decay $\eta' \to \gamma\gamma\pi^0$ [21]. For the first time, we measure

the branching fraction of the inclusive $\eta' \to \gamma\gamma\pi^0$, which includes all possible intermediate contributions from the ρ- and ω- mesons and the non-resonant contributions [20]. A fit to the $\gamma\gamma\pi^0$

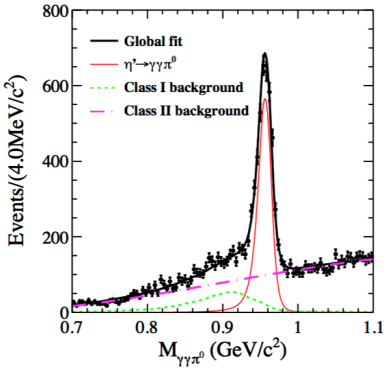

Figure 4: Invariant mass of $\gamma\gamma\pi^0$ distribution and fit result. Class I background are from η' decays into final states other than the signal one, while Class II are from J/ψ decays to final state without the η'.

invariant mass distribution is performed to extract the inclusive signal yield. The fit result is shown in Fig. 4, and the corresponding branching fraction are reported in Table 1. Assuming that the inclusive decay $\eta' \to \gamma\gamma\pi^0$ can be attributed to the vector meson ρ and ω, the branching fraction for the non-resonant contribution can be extracted by fitting the $\gamma\pi^0$ invariant mass distribution, which is reported in Table 1 and agrees with the upper limit measured by the GAMS-2000 experiment [22]. In this fit, the ρ-ω interference is considered, while are neglected possible interferences with the non-resonant component. In addition, as validation of the fit, the product branching fraction with the ω intermediate state is measured, and its value is consistent with the PDG one [11].

Decay mode	$\mathscr{B}(\times 10^{-4})$	Ref.
$\eta' \to \pi^+\pi^-\pi^0$	$35.91 \pm 0.54(\text{stat.}) \pm 1.74(\text{syst.})$	[18]
$\eta' \to \rho^\pm\pi^\mp$	$7.44 \pm 0.60(\text{stat.}) \pm 1.26(\text{syst.}) \pm 1.84(\text{model})$	[18]
$\eta' \to (\pi^+\pi^-\pi^0)_S$	$37.63 \pm 0.77(\text{stat.}) \pm 2.22(\text{syst.}) \pm 4.48(\text{model})$	[18]
$\eta' \to \pi^0\pi^0\pi^0$	$35.22 \pm 0.82(\text{stat.}) \pm 2.60(\text{syst.})$	[18]
$\eta' \to (\gamma\gamma\pi^0)_{incl.}$	$32.0 \pm 0.7(\text{stat.}) \pm 2.3(\text{syst.})$	[20]
$\eta' \to (\gamma\gamma\pi^0)_{NR}$	$6.16 \pm 0.64(\text{stat.}) \pm 0.67(\text{syst.})$	[20]
$\eta' \to \gamma\omega,\ \omega \to \gamma\pi^0$	$23.7 \pm 1.4(\text{stat.}) \pm 1.8(\text{syst.})$	[20]

Table 1: Summary of some recent BESIII results on η' branching fractions.

5. Conclusions

In this report, we summarize a selection of recent BESIII results on η/η' decays. A large statistics is necessary to study fundamental symmetries and test theoretical prediction. Despite their discovery being made more than 50 years ago, there are still a lot η/η' aspects still not well understood. Several BESIII η/η' related analysis are ongoing, and more interesting results will be coming soon in the near future.

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