Study of η and η′ physics at BES-III *

JI Qing-Ping(姬清平)[1,2] ZHANG Lei(张雷)[2,3] CHEN Shen-Jian(陈申见)[3]
LI Hai-Bo(李海波)[2;1)] LU Gong-Ru(鲁公儒)[1]

[1] Department of Physics, Henan Normal University, Xinxiang 453007, China
[2] Institute of High Energy Physics, P.O.Box 918, Beijing 100049, China
[3] Department of Physics, Nanjing University, Nanjing 210093, China

Abstract Decays of both η and η′ provide very useful information in our understanding of low-energy QCD, and experimental signatures for these decays would be extremely helpful at BES-III. The rare decays of the η and η′ mesons could serve as a low-energy test of the Standard Model and its beyond. The sensitivities of the measurements of η and η′ decays are discussed at BES-III, in which the η and η′ mesons are produced in the ψ decays.

Key words BES-III, mesons, QCD, ChPT

PACS 14.40.Aq, 13.20.Jf, 12.38.Qk

1 Introduction

Quantum chromodynamics (QCD), which is a field theory of strong interaction, cannot be directly applied in low energy since the strong coupling α_s is large enough [1, 2]. In this case one must resort to alternative model-independent approaches, such as lattice QCD, and chiral perturbation theory (ChPT). The η and η′ mesons play an important role in understanding the low energy QCD. They are isoscalar members of the nonet of the lightest pseudoscalar mesons. Decays of η and η′ are investigated within a $U(3)$ chiral unitary approach based on the ChPT [3–5]. Precision measurements on η and η′ would be very helpful, and provide useful information in our understanding of low energy QCD. In particular, the $\eta\to 3\pi$ process is very interesting for verifying the description of isospin violation in ChPT. The situation has never been clear on this mechanism. A precise analysis of the corresponding Dalitz plot parameters would be very helpful.

The rare decays of η and η′ mesons also serve as a test of the Standard Model (SM) at low energy. In this paper, we are trying to give a review of η and η′ physics at BES-III by using the decay of ψ.

2 Production of η and η′ at BES-III

Beginning in mid-2008, the BEPC-II/BES-III was operated at center-of-mass (CM) energies corresponding to $\sqrt{s}$ = 2.0–4.6 GeV. The designed luminosity over this energy region ranges from 1×10^{33} cm^{-2}·s^{-1} down to about 0.6×10^{33} cm^{-2}·s^{-1} [6], yielding around 5 fb^{-1} each year at ψ(3770) above the $D_s^+D_s^-$ threshold and 3 fb^{-1} at J/ψ peak in one year's running with full luminosity [6]. These integrated luminosities correspond to samples of 2.0 million $D_s^+D_s^-$, 30 million $D\overline{D}$ pairs and 10×10^9 J/ψ decays. Table 1 summarizes the data set per year at BES-III [7]. In this paper, the sensitivity studies are based on 3 fb^{-1} luminosity at the J/ψ or ψ(2S) peak for η and η′ physics.

In Tables 2 and 3, the dominant decay channels of J/ψ or ψ(2S) decaying into final states involving η or η′ mesons are listed. With one year's luminosity at J/ψ (ψ(2S)) peak, we expect to obtain about 63 million η decays and 61 million η′ decays, respectively. At BEPC-II, the background is small and the event topology is simple compared with the other experiments. The decays of η and η′ can be studied with these clean samples, it will be especially helpful for studying η′ physics.

Received 6 May 2009, Revised 24 July 2009

* Supported by National Natural Science Foundation of China (10575108, 10521003, 10735080, 10821063, 10835001), 100 Talents Program of CAS and Knowledge Innovation Project of CAS (U-612 and U-530 (IHEP))

1) E-mail: lihb@ihep.ac.cn; Li Hai-Bo is corresponding author

Table 1. τ-charm productions at BEPC-Ⅱ in one year's running (10^7 s).

data sample	central-of-mass/MeV	# events per year
J/ψ	3097	10×10^9
$\tau^+\tau^-$	3670	12×10^6
$\psi(2S)$	3686	3.0×10^9
$D^0\bar{D}^0$	3770	18×10^6
D^+D^-	3770	14×10^6
$D_s^+D_s^-$	4030	1.0×10^6
$D_s^+D_s^-$	4170	2.0×10^6

Table 2. The production of η meson at BES-III in charmonium decays by assuming that 10×10^9 J/ψ and 3.0×10^9 $\psi(2S)$ events can be collected per year.

decay mode	combined BR($\times10^{-4}$)	# events per year
$J/\psi\to\gamma\eta$	9.8 ± 1.0	9.8×10^6
$J/\psi\to\phi\eta(\phi\to K^+K^-)$	3.69 ± 0.39	3.69×10^6
$J/\psi\to\omega\eta(\omega\to\pi^+\pi^-\pi^0)$	15.5 ± 1.8	15.5×10^6
$J/\psi\to\rho\eta(\rho\to\pi^+\pi^-)$	1.93 ± 0.23	1.93×10^6
$J/\psi\to p\bar{p}\eta$	20.9 ± 1.8	20.9×10^6
$\psi(2S)\to\eta J/\psi(J/\psi\to l^+l^-)$	37.5 ± 0.8	11.25×10^6
total		63.1×10^6

Table 3. The production of η′ meson at BES-III in charmonium decays by assuming that 10×10^9 J/ψ and 3.0×10^9 $\psi(2S)$ events can be collected per year.

decay mode	combined branching fraction ($\times10^{-4}$)	# events per year
$J/\psi\to\gamma\eta'$	47.1 ± 2.7	47.1×10^6
$J/\psi\to\phi\eta'(\phi\to K^+K^-)$	1.97 ± 0.34	1.97×10^6
$J/\psi\to\omega\eta'(\omega\to\pi^+\pi^-\pi^0)$	1.62 ± 0.19	1.62×10^6
$J/\psi\to\rho\eta'(\rho\to\pi^+\pi^-)$	1.05 ± 0.18	1.05×10^6
$J/\psi\to p\bar{p}\eta'$	9.0 ± 4.0	9.0×10^6
total		60.74×10^6

3 Hadronic decays of η and η′

Hadronic decays of η, $\eta'\to\pi^+\pi^-\pi^0$ and $\pi^0\pi^0\pi^0$ can be utilized to extract m_d-m_u. The 3π-decay of η or η′ violates iso-spin invariance. In case of the $\pi^0\pi^0\pi^0$ system the two pions can have $I_{2\pi}=0, 1, 2$ but coupling with the remaining pion to $I_{3\pi}=0$ is only possible if $I_{2\pi}=1$. However, the $(\pi^0\pi^0)_{I=1}$ does not exist and as a consequence the decay $\eta(\eta')\to\pi^0\pi^0\pi^0$ has to violate isospin. In the case of the $\eta(\eta')\to\pi^+\pi^-\pi^0$ decay one can write [8]:

$$(3\pi)_{I=0} = \sqrt{\frac{1}{3}}[(\pi^+\pi^0)_{I=1}|\pi^-\rangle-(\pi^+\pi^-)_{I=1}|\pi^0\rangle+(\pi^-\pi^0)_{I=1}|\pi^+\rangle], \quad (1)$$

where

$$(\pi^+\pi^0)_{I=1}=\sqrt{\frac{1}{2}}[|\pi^+\rangle|\pi^0\rangle-|\pi^0\rangle|\pi^+\rangle],$$

$$(\pi^+\pi^-)_{I=1}=\sqrt{\frac{1}{2}}[|\pi^+\rangle|\pi^-\rangle-|\pi^-\rangle|\pi^+\rangle],$$

and

$$(\pi^-\pi^0)_{I=1}=\sqrt{\frac{1}{2}}[-|\pi^-\rangle|\pi^0\rangle+|\pi^0\rangle|\pi^-\rangle],$$

one can obtain the full wave function for the 3π system as:

$$(3\pi)_{I=0} = \sqrt{\frac{1}{6}}[|\pi^+\rangle|\pi^0\rangle|\pi^-\rangle-|\pi^0\rangle|\pi^+\rangle|\pi^-\rangle-|\pi^+\rangle|\pi^-\rangle|\pi^0\rangle+|\pi^-\rangle|\pi^+\rangle|\pi^0\rangle-|\pi^-\rangle|\pi^0\rangle|\pi^+\rangle+|\pi^0\rangle|\pi^-\rangle|\pi^+\rangle], \quad (2)$$

which is always antisymmetric against any exchange of pions. In particular, we have $C(3\pi)_{I=0}=-(3\pi)_{I=0}$, while it is $C=+1$ for $\eta(\eta')$. Therefore the decay $\eta(\eta')\to\pi^+\pi^-\pi^0$ violates C or I. On the other hand there exists a G operator which is constructed from the C parity and isospin I_2 operators as $G=Ce^{i\pi I_2}$, and the decay $\eta(\eta')\to\pi^+\pi^-\pi^0$ should also violate the G parity.

According to Sutherland's theorem, electromagnetic contributions to the process are very small [9] and the decay is induced dominantly by the strong interaction via the u, d mass difference. Based on the following two assumptions: (1) the decay $\eta'\to\pi^0\pi^+\pi^-$ proceeds entirely via $\eta'\to\eta\pi^+\pi^-$ followed by $\pi^0-\eta$ mixing; (2) both decay amplitudes are "essentially constant" over phase space on the Dalitz plot, Gross, Treiman and Wilczek claimed that [10]

$$r=\frac{\Gamma(\eta'\to\pi^0\pi^+\pi^-)}{\Gamma(\eta'\to\eta\pi^+\pi^-)}=(16.8)\frac{3}{16}\left(\frac{m_d-m_u}{m_s}\right)^2. \quad (3)$$

However recently Borasoy et al. claimed that the light quark masses cannot be extracted from the ratio [11] since the results from the full chiral unitary approach are in plain disagreement with these two assumptions. It turns out that more precise experimental data on η and η′ decays are needed. An improvement of the experimental situation is foreseen in the near future due to the upcoming data from WASA-at-COSY [12], MAMI-C [13] and KLOE [14]. Here, we would address the clean data samples from ψ decays at BES-III [6].

The $\eta/\eta' \to 3\pi$ is an ideal laboratory for testing ChPT. From a fit to the Dalitz plot density distribution one can make precise determinations of the parameters that characterize the decay amplitude. One can choose two of the pion energies (T_+, T_-, T_0) in the η rest frame, two of the three combinations of the two-pion masses squared (m^2_{+-}, m^2_{-0}, m^2_{0+}) are also called (s, t, u). The Dalitz plot distribution for the charged decay channel is described by the following two variables:

$$X = \sqrt{3}\,\frac{T_+ - T_-}{Q_c} = \frac{\sqrt{3}(u-t)}{2m_\eta Q_c},$$

$$Y = \frac{3T_0}{Q_c} - 1 = \frac{3[(m_\eta - m_{\pi^0})^2 - s]}{2m_\eta Q_c} - 1, \qquad (4)$$

where $Q_c = T_0 + T_+ + T_- = m_\eta - 2m_\pi - m_{\pi^0}$. For the neutral decay channel it is convenient to use one fully symmetrized coordinate:

$$Z = \frac{2}{3}\sum_{i=1}^{3}\left(\frac{3T_i}{Q_n} - 1\right)^2 = X^2 + Y^2, \qquad (5)$$

with $Q_n = m_\eta - 3m_{\pi^0}$, in order to reflect symmetry in all Mandelstam variables.

The squared absolute values of the two decay amplitudes are expanded around the center of the corresponding Dalitz plot for $\eta/\eta' \to \pi^0\pi^+\pi^-$ in order to obtain the Dalitz slope parameters [16]:

$$|A_c(X,Y)|^2 = |\mathcal{N}_c|^2[1 + aY + bY^2 + cX + dX^2 + eXY + \cdots], \qquad (6)$$

while for the decays into three identical particles Bose symmetry dictates the form

$$|A_n(X,Y)|^2 = |\mathcal{N}_n|^2[1 + 2\alpha Z + \cdots], \qquad (7)$$

For the charged channel odd terms in X are forbidden due to charge conjugation symmetry. The parameters (a, b, c, d, e and α) can be obtained from fits to the observed Dalitz plot density, and can be computed by the theory.

In Table 4, we estimate the produced number of events for various hadronic η and η′ decays at BES-III with one year's data taking. There are about 14 million $\eta \to \pi^0\pi^+\pi^-$ and 0.23 million $\eta' \to \pi^0\pi^+\pi^-$ events produced each year, respectively. We assume the selection efficiency for $\eta/\eta' \to \pi^0\pi^+\pi^-$ is 30%, and is constant over the Dalitz plots. Thus the expected observed number of events in the Dalitz plot is about $N_{\rm exp} = 4.2$ million for $\eta \to \pi^0\pi^+\pi^-$ decay or $N_{\rm exp} = 0.07$ million for $\eta' \to \pi^0\pi^+\pi^-$ decay. At KLOE, about 6.6 million of $\eta \to \pi^0\pi^+\pi^-$ decays should be selected after considering the selection efficiency in 2.5 fb^{-1} data [14]. We expect that the Dalitz parameter can be measured almost at the same level of sensitivity for the η decay at BES-III.

Table 4. The production of $\eta(\eta') \to 3\pi$ decay at BES-III in charmonium decays by assuming that 10×10^9 J/ψ and 3.0×10^9 ψ(2S) events can be collected per year.

decay mode	branching fraction (%)	# events per year
$\eta \to \pi^0\pi^+\pi^-$	22.73 ± 0.28	14.3×10^6
$\eta \to \pi^0\pi^0\pi^0$	32.56 ± 0.23	20.5×10^6
$\eta' \to \eta\pi^+\pi^-$	44.6 ± 1.4	27.2×10^6
$\eta' \to \eta\pi^0\pi^0$	20.7 ± 1.2	12.6×10^6
$\eta' \to \pi^0\pi^+\pi^-$	$0.37^{+0.11}_{-0.09} \pm 0.04$ [15]	0.23×10^6
$\eta' \to \pi^0\pi^0\pi^0$	0.154 ± 0.026	0.09×10^6

Some specific integrated asymmetries as defined in Ref. [17] are very sensitive in assessing the possible contributions to C-violation in amplitudes with fixed ΔI. In particular the left-right asymmetry tests C-violation with no specific ΔI constraint. One can calculate the left-right asymmetry as

$$A_{\rm LR} = \frac{N_+ - N_-}{N_+ + N_-}, \qquad (8)$$

where N_+ is the number of events for which π^+ has greater energy than π^-, and N_- is the number of events for which the π^- has the greater energy in the η rest system. One can also measure the quadrant asymmetry A_Q and sextant asymmetry A_S as defined in Ref. [17]. The quadrant asymmetry is sensitive to an $I = 2$ final state, while the sextant asymmetry is sensitive to an $I = 0$ C-invariance-violating final state [18, 19]. With 4.2 million $\eta \to \pi^0\pi^+\pi^-$ events at BES-III, the sensitivity of these asymmetry could be 7.0×10^{-4}, which is one order higher than the current PDG measurements [20].

For the neutral channel $\eta/\eta' \to \pi^0\pi^0\pi^0$ decay, assuming that the averaged selection efficiency is 20%, we should expect that about 4.1 million of $\eta \to 3\pi^0$ and 0.02 million $\eta' \to 3\pi^0$ decays can be selected in the Dalitz plots at BES-III. With these high statistics and low background samples, one can make a more precise measurement of the slope parameter α as shown in Formula (7). The best measurement of α is $\alpha = -0.032 \pm 0.003$ which is from the Crystal Ball at MAMI-C [21] by using about 3 million η decay events.

For the $\eta' \to \eta\pi^+\pi^-$ and $\eta' \to \eta\pi^0\pi^0$ decays, about 27 million and 12 million decay events could be detected at BES-III each year, respectively. Since the mass of η′ meson is large enough, in this case, the contributions of σ, a_0 and $f_0(980)$ resonances and their interference on the Dalitz plots dominate [22]. It will be very interesting to study the ηπ and ππ scattering in these decay modes at BES-III with the huge data set.

4 Rare decays of η and η′

Decays of η and η′ mesons into a lepton-antilepton pairs, $\eta/\eta' \to l^+l^-$, represent a potentially important channel for looking for effects of new physics [23]. The dominant mechanism within the SM is a second order electromagnetic process, additionally suppressed by helicity conservation, involving two virtual photons $\eta \to \gamma^*\gamma^*$, which is sensitive to the form factor [24]. The imaginary part of the decay amplitude can be uniquely related to the decays width of the $\eta \to \gamma\gamma$ decay. The experimental value of the $\Gamma(\eta \to \gamma\gamma)$ leads to a lower limit (the unitarity bound) of the branching ratio: $BR(\eta \to e^+e^-) \geqslant 1.7\times10^{-9}$ and $BR(\eta \to \mu^+\mu^-) \geqslant 4.4\times10^{-6}$ when the real part of the decay amplitude is neglected [23, 25]. The measured branching fraction, $BR(\eta \to \mu^+\mu^-) = (5.7\pm0.8)\times10^{-6}$ [20], is consistent with this limit.

The real part of the amplitude of the $\eta \to e^+e^-$ decay can be estimated using the measured value of $BR(\eta \to \mu^+\mu^-)$ [26–29]. The assumption that the ratio between Im and Re parts of the amplitudes for the $\eta \to e^+e^-$ and $\eta \to \mu^+\mu^-$ is the same leads to the prediction $BR(\eta \to e^+e^-) \approx 6\times10^{-9}$. The limit for $\eta \to e^+e^-$ is much lower than that for other decays of π^0 and η into lepton-antilepton pairs. This makes the $\eta \to e^+e^-$ decay rate sensitive to a possible exotic contribution. The best experimental upper limit for the $BR(\eta \to e^+e^-)$ comes from the CLEO-II as listed in Table 5. By the way, the decays $\pi^0 \to e^+e^-$, $\eta \to \mu^+\mu^-$ and e^+e^- are also important in order to estimate long range contribution to the decay $K_L \to \mu^+\mu^-$ [27].

Recently, the KTeV experiment at Fermilab has firstly observed the $\pi^0 \to e^+e^-$ decay rate to be [30]:

$$BR(\pi^0 \to e^+e^-) = (7.49\pm0.29\pm0.25)\times10^{-8}, \quad (9)$$

which is 3 standard deviations higher than the theoretical prediction [31–33]. It is interesting to search for the other neutral pseudoscalar meson decays into lepton pairs and to compare with theoretical predictions. These probes will offer a way to study long-distance dynamics in the Standard Model. At BES-III, leptonic decays $\eta/\eta' \to e^+e^-$, $\mu^+\mu^-$, $e^+e^-e^+e^-$, $\mu^+\mu^-\mu^+\mu^-$ and $e^+e^-\mu^+\mu^-$ can be measured with sensitivities at 10^{-7} as listed in Tables 5 and 6. Most of the limits will be improved by one or two orders by using data with one year luminosity in J/ψ and ψ(2S) decays. We will also test C-invariance by improving the upper limits on the C-forbidden decays $\eta/\eta' \to \pi^0e^+e^-$, $\pi^0\mu^+\mu^-$, 3γ and $\eta' \to \eta e^+e^-$, $\eta\mu^+\mu^-$. We will test CP-invariance by searching for $\eta/\eta' \to \pi\pi$ and $4\pi^0$ decays [34]. The first experimental run at J/ψ and ψ(2S) peaks has been conducted at BES-III/BEPC-II. We expect to obtain more data so that the sensitivities listed in Tables 5 and 6. can be reached.

Table 5. The sensitivity of η rare and forbidden decays at BES-III. The expected sensitivities are estimated by considering the detector efficiencies for different decay mode at BES-III. We assume no background dilution and the observed number of signal events is zero. The BES-III limit refers to a 90% confidence level.

decay mode	best upper limits 90% CL	BES-III limit with one year's luminosity
$\eta \to e^+e^-$	7.7×10^{-5}	0.7×10^{-7}
$\eta \to \mu^+\mu^-$	$(5.8\pm0.8)\times10^{-6}$	0.8×10^{-7}
$\eta \to e^+e^-e^+e^-$	6.9×10^{-5}	0.9×10^{-7}
$\eta \to \mu^+\mu^-\mu^+\mu^-$	–	1.5×10^{-7}
$\eta \to \pi^+\pi^-e^+e^-$	$(4.2\pm1.2)\times10^{-4}$	1.3×10^{-7}
$\eta \to \pi^+\pi^-\mu^+\mu^-$	–	1.4×10^{-7}
$\eta \to \pi^0\mu^+\mu^-$	5×10^{-6}	1.5×10^{-7}
$\eta \to \pi^0e^+e^-$	4×10^{-5}	1.3×10^{-7}
$\eta \to \pi^0\gamma$	9×10^{-5}	1.2×10^{-7}
$\eta \to \pi^0\pi^0$	3.5×10^{-4}	1.8×10^{-7}
$\eta \to \pi^+\pi^-$	1.3×10^{-5}	0.8×10^{-7}
$\eta \to \mu^+e^-+\mu^-e^+$	6×10^{-6}	0.8×10^{-7}
$\eta \to$ invisible	6×10^{-4}	60×10^{-7}

The $\eta(\eta') \to \pi^+\pi^-e^+e^-$ decay is interesting as a test of CP violation, which is motivated by the corresponding test in K_L decays. A recent prediction and observations were made of an asymmetry in the distribution of angles between the $\pi^+\pi^-$ and e^+e^- production planes in $K_L \to \pi^+\pi^-e^+e^-$ decay [35]. These observations have triggered theoretical speculations that a similar observation in $\eta \to \pi^+\pi^-e^+e^-$ decay might reveal unexpected mechanisms of CP violation in flavor conserving processes [36, 37]. At BES-III, we can observe a CP-violating asymmetry in the CP and T-odd variable $\sin\phi\cos\phi$,

$$A = \frac{N_{\sin\phi\cos\phi>0.0} - N_{\sin\phi\cos\phi<0.0}}{N_{\sin\phi\cos\phi>0.0} + N_{\sin\phi\cos\phi<0.0}}\ , \quad (10)$$

where ϕ is the angle between the e^+e^- and $\pi^+\pi^-$ planes in the η center of mass system. This asymmetry implies, with the mild assumption of unitarity to avoid exotic CPT violation [36], time reversal symmetry violation. The quantity $\sin\phi\cos\phi$ is given by

$(\hat{n}_{ee}\times\hat{n}_{\pi\pi})\cdot\hat{z}(\hat{n}_{ee}\cdot\hat{n}_{\pi\pi})$, where the $\hat{n}$'s are the unit normals and $\hat{z}$ is the unit vector in the direction of the $\pi\pi$ in the η center of mass system. The measured branching fraction is $BR(\eta\to\pi^+\pi^-e^+e^-)=(4.2\pm1.2)\times10^{-4}$. About 26 thousand events are expected to be produced at BES-III. Assuming that the efficiency is about 30%, we expect that the sensitivity to measure the CP asymmetry is about 1%. A measurement done with a sensitivity better than 10^{-2} for the asymmetry will provide a stringent constraint for new physics proposed by D. N. Gao [37].

Table 6. The sensitivity of η' rare and forbidden decays at BES-III. The expected sensitivities are estimated by considering the detector efficiencies for a different decay mode at BES-III. We assume no background dilution and the observed number of signal events is zero. The BES-III limit refers to a 90% confidence level.

decay mode	best upper limits 90% CL	BES-III limit with one year's luminosity
$\eta'\to e^+e^-$	2.1×10^{-7}	0.7×10^{-7}
$\eta'\to\mu^+\mu^-$	–	0.8×10^{-7}
$\eta'\to e^+e^-e^+e^-$	–	0.9×10^{-7}
$\eta'\to\mu^+\mu^-\mu^+\mu^-$	–	1.6×10^{-7}
$\eta'\to\pi^+\pi^-e^+e^-$ [15]	$(25^{+12}_{-9}\pm5)\times10^{-4}$	1.4×10^{-7}
$\eta'\to\pi^+\pi^-\mu^+\mu^-$ [15]	2.4×10^{-4}	1.5×10^{-7}
$\eta'\to\pi^0\mu^+\mu^-$	6.0×10^{-5}	1.6×10^{-7}
$\eta'\to\pi^0e^+e^-$	1.4×10^{-3}	1.3×10^{-7}
$\eta'\to\pi^0\gamma$	–	1.2×10^{-7}
$\eta'\to\pi^0\pi^0$	9.0×10^{-4}	1.9×10^{-7}
$\eta'\to\pi^+\pi^-$	2.9×10^{-3}	0.8×10^{-7}
$\eta'\to\mu^+e^-+\mu^-e^+$	4.7×10^{-4}	0.8×10^{-7}
$\eta'\to$ invisible	9.5×10^{-4} [15]	140×10^{-7}
$\eta'\to\eta e^+e^-$	2.4×10^{-3}	2.4×10^{-7}
$\eta'\to\eta\mu^+\mu^-$	1.5×10^{-5}	3.1×10^{-7}

Invisible decays of η and η' mesons offer a window into what may lie beyond the Standard Model [38–40]. The reason is that apart from neutrinos, the Standard Model includes no other invisible final particles that these states can decay into. It is such a window that we intend to further explore by presenting here the first experimental limits on invisible decays of the η and η', which complement the limit of 2.7×10^{-7} recently established in Ref. [41] for the invisible decays of the π°.

Theories beyond the Standard Model generally include new physics, such as, possibly, light dark matter (LDM) particles [42]. These can have the right relic abundance to constitute the nonbaryonic dark matter of the Universe, if they are coupled to the SM through a new light gauge boson U [43], or exchanges of heavy fermions. It is also possible to consider a light neutralino with coupling to the Standard Model mediated by a light scalar singlet in the next-to-minimal supersymmetric standard model [44].

The BES-II Collaboration searched for the invisible decay modes of η and η' for the first time in $J/\psi\to\phi\eta(\eta')$ using the 58 million J/ψ events at BES II [45]. They obtained limits on the ratio, $\frac{\mathcal{B}(\eta(\eta')\to\text{invisible})}{\mathcal{B}(\eta(\eta')\to\gamma\gamma)}$. The upper limits at the 90% confidence level are 1.65×10^{-3} and 6.69×10^{-2} for $\frac{\mathcal{B}(\eta\to\text{invisible})}{\mathcal{B}(\eta\to\gamma\gamma)}$ and $\frac{\mathcal{B}(\eta'\to\text{invisible})}{\mathcal{B}(\eta'\to\gamma\gamma)}$, respectively, corresponding to upper limits on the rates for $\eta\to$ invisible of 6.0×10^{-4} and for $\eta'\to$ invisible of 1.4×10^{-3}. CLEO-c has almost two times a better limit than that from BES-II for $\eta'\to$ invisible decay as shown in Table 6 [15]. At BES-III, the sensitivity of the invisible decays will be improved by an order of two with high statistic data as listed in Tables 5 and 6.

5 Summary

A mini-review of η and η' physics at BES-III has been done. With one year's luminosity data, about 63 million η decays and 61 million η' decays can be collected at BES-III. The hadronic decays of η and η' can be studied, in particular parameters for the Dalitz decays of η could be extracted from about 4.2 million η events, so that the prediction of ChPT will be tested. The rare and forbidden decays of η and η' could be reached at BES-III, and the sensitivity of these decays is at the level of 10^{-7}. New physics beyond the Standard Model can be probed at low energy. At BES-III, η and η' decay samples are clean, and the event topology is simple so that events can be easily reconstructed. More fruitful results will be seen from BES-III experiment.

The author would like to thank D. N. Gao and M. Z. Yang for their useful discussions.

References

1 Gross D J, Wilczek F. Phys. Rev. Lett., 1973, **30**: 1343
2 Politzer H D. Phys. Rev. Lett., 1973, **30**: 1346
3 Weinberg S. Physica A, 1979, **96**: 327
4 Gasser J, Leutwyler H. Ann. Phys., 1984, **158**: 142
5 Gasser J, Leutwyler H. Nucl. Phys. B, 1985, **250**: 465
6 Asner D M et al. Physics at BES-Ⅲ. Edited by CHAO K T, WANG Y F. arXiv:0809.1869; to be published at International Journal of Modern Physics A
7 LI H B. Nucl. Phys. Proc. Suppl., 2006, **162**: 312
8 Marcin Zielinski. Feasibility Study of the $\eta' \to \pi^0\pi^+\pi^-$ Decay Using WASA-at-COSY Apparatus. Master thesis. arXiv:0807.0576 [hep-ex]
9 Sutherland D G. Phys. Lett. B, 1996, **23**: 384
10 Gross D J, Treiman S B, Wilczek F. Phys. Rev. D, 1979, **19**: 2188
11 Borasoy B et al. Phys. Lett. B, 2006, **643**: 41
12 Adam H H et al (WASA-at-COSY collaboration). arXiv:nucl-ex/0411038
13 Arends H J (A2 collaboration). AIP Conf. Proc., 2006, **870**: 481
14 Capussela T et al (KLOE collaboration). Acta. Phys. Slov., 2005, **56**: 341
15 Naik P et al (CLEO collaboration). Phys. Rev. Lett., 2009, **102**: 061801
16 Borasoy B, Niβler R. Eur. Phys. J. A, 2005, **26**: 383
17 Layter J G et al. Phys. Rev. Lett., 1972, **29**: 316
18 Lee T D. Phys. Rev. B, 1965, **139**: 1415
19 Nauenberg M. Phys. Lett., 1965, **17**: 239
20 Amsler C et al. Phys. Lett. B, 2008, **667**: 1
21 Prakhov S et al. The Crystal Ball Collaboration at MAMI and A2 Collaboration. arXiv:0812.1999 [hep-ex]
22 Beisert N, Borasoy B. Nucl. Phys. A, 2003, **716**: 186
23 Bergstrom L. Zeit. Phys. C, 1982, **14**: 129
24 Drell S D. Nuovo Cimento, 1959, **11**: 693
25 Landsberg L G. Phys. Rept., 1985, **128**: 301
26 Browder T E et al (CLEO collaboration). Phys. Rev. D, 1997 **56**: 5359
27 Gomez Dumm D, Pich A. Phys. Rev. Lett., 1998, **80**: 4633
28 Savage M J, Luke M E, Wise M B. Phys. Lett. B, 1992, **291**: 481
29 Ametller L, Bramon A, Masso E. Phys. Rev. D, 1993, **48**: 3388
30 Abouzaid E et al (KTeV collaboration). Phys. Rev. D, 2007, **75**: 012004
31 Dorokhov A E, Ivanov M A. Phys. Rev. D, 2007, **75**: 114007
32 Dorokhov A E, Ivanov M A. JETP Lett., 2008, **87**: 531
33 Dorokhov A E et al. Eur. Phys. J. C, 2008, **55**: 193
34 MAMI proposal A2/3-05, Testing Chiral Perturbation Theory and C Invariance in η' Decays
35 Alavi-Harati A et al. Phys. Rev. Lett., 2000, **84**: 408
36 Bigi I I, Sanda A I. hep-ph/9904484; Bigi I I. arXiv:hep-ph/0608073
37 GAO Dao-Neng. Mod. Phys. Lett. A, 2002, **17**: 1583
38 HE X G, Tandean J, Valencia G. JHEP, 2008, **0806**: 002 [arXiv:0803.4330]
39 Fayet P. Phys. Lett. B, 1979, **84**: 421; Besson D et al (CLEO). Phys. Rev. D, 1984, **30**: 1433; Fayet P, Kaplan J. Phys. Lett. B, 1991, **269**: 213; McElrath B. Phys. Rev. D, 2005, **72**: 103508
40 Fayet P. Phys. Rev. D, 2005, **72**: 054034
41 Artamonov A V et al (E949). Phys. Rev. D, 2005, **72**: 091102
42 Boehm C, Fayet P. Nucl. Phys. B, 2004, **683**: 219; Boehm C, Hooper D, Silk J, Casse M, Paul J. Phys. Rev. Lett., 2004, **92**: 101301; Fayet P. Phys. Rev. D, 2004, **70**: 023514
43 Fayet P. Phys. Lett. B, 1980, **95**: 285; Fayet P. Nucl. Phys. B, 1981, **187**: 184
44 Ellis J, Gunion J F, Haber H E, Roszkowski L, Zwirner F. Phys. Rev. D, 1989, **39**: 844; Gunion J F, Hooper D, McElrath B. Phys. Rev. D, 2006, **73**: 015011
45 Ablikim M et al (BES collaboration). Phys. Rev. Lett., 2006, **97**: 202002