PROCEEDINGS OF SCIENCE

Light meson decay at BESIII

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Due to the high production rate of light mesons in J/ψ decays, the hight statistics sample of 1.3 billion of J/ψ events provides an ideal laboratory to investigate the decay dynamics of light mesons, in particular for η and η' mesons. Recently, the BESIII experiment made significant progresses in η and η' decays, including their hadronic and rare decays investigation, which will be discussed in this proceeding.

40th International Conference on High Energy physics - ICHEP2020
July 28 - August 6, 2020
Prague, Czech Republic (virtual meeting)

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1. Introduction

Quantum Chromodynamics (QCD), the theory of strong interaction, cannot be applied at low energy due to the large value of the strong coupling α_s [1, 2]. Alternative model-dependent approaches are used, such as lattice QCD and chiral perturbation theory (ChPT). In this context, the η and η' mesons play an important role in the understanding of low energy QCD. The decays of η and η' are investigated within the $U(3)$ chiral unitary approach based on the ChPT [3, 4], and precise measurements of branching fractions, as well as the hadronic transition and rare decays, 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 Beijing Electron Positron Collider II (BEPCII) [5], where radiative $J/\psi \to \gamma\eta$ and $J/\psi \to \gamma\eta'$ decays are then exploited to access the η and η' mesons, respectively.
BEPCII is a double-ring e^+e^- collider working at center-of-mass energies from 2.0 to 4.9 GeV (recently updated). The BESIII experiment is a general purpose detector with a geometrical acceptance of 93% of the 4π solid angle. From the inner to the outer side, it consists of a multilayer drift chamber (MDC) for measuring the momentum and ionization loss of charged particles, a plastic-scintillator-based time-of-flight (TOF) detector for the identification of charged particles, and an electromagnetic calorimeter (EMC) used to measure the energy of the neutral showers and identify electrons. These systems are encapsulated in a magnetic field of 1 T provided by a superconducting solenoid. Finally, a resistive-plate-chamber-based muon counters are interleaved between the flux-return yoke of the magnet. More details about the BESIII detector can be found in ref. [6].

2. Precision measurements of Branching Fractions of η' decays

The excellent momentum resolution of charged tracks and photon conversion to e^+e^- pairs provide a unique tool to reconstruct inclusive photon spectrum form J/ψ radiative decays. This allows to tag the η' inclusive decays and then to measure the absolute branching fraction (BF) $\mathcal{B}(J/\psi \to \gamma\eta')$, where the energy resolution of radiative photon is improved by a factor 3 using photon conversion events. After the inclusive measurement of η' events, precision measurements of η' exclusive decays to $\gamma\pi^+\pi^-$, $\eta\pi^+\pi^-$, $\eta\pi^0\pi^0$, $\gamma\omega$, and $\gamma\gamma$ (denoted with X) are obtained by means of radiative photon directly detected in the EMC in order to improve the statistics. The exclusive BF for each η' exclusive decay is calculated as:

$$\mathcal{B}(\eta' \to X) = \frac{N^{\text{obs}}_{\eta'\to X}}{\epsilon_{\eta'\to X}} \frac{\epsilon}{N^{\text{obs}}_{J/\psi\to\gamma\eta'}} f, \tag{1}$$

where $N^{\text{obs}}_{J/\psi\to\gamma\eta'}$ is the observed η' yield, $N^{\text{obs}}_{\eta'\to X}$ the number of signal events obtained form a fit to data, ϵ is the detection efficiency obtained from MC simulation for $J/\psi \to \gamma\eta'$ and $\eta' \to X$ event selections, and f is a correction factor to account for the difference in the photon conversion efficiencies between data and MC simulation. The invariant mass spectra of $\gamma\pi^+\pi^-$, $\eta\pi^+\pi^-$, $\eta\pi^0\pi^0$, $\gamma\omega$ and $\gamma\gamma$ are shown in figure 1, and the corresponding signal yields are obtained by performing the extended maximum likelihood fit to those spectra.

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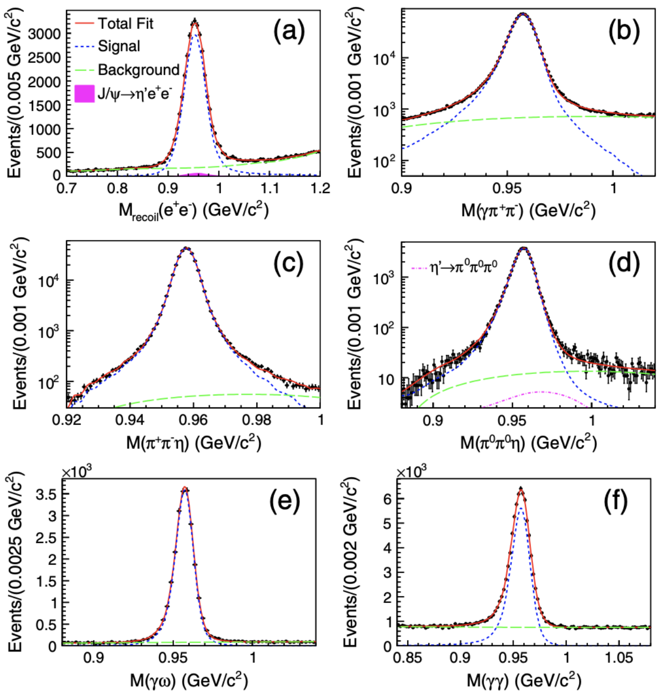

Figure 1: Unbinned maximum likelihood fit to the invariant mass spectra [7]. The pink histogram in (a) is peaking background form $J/\psi \to \eta' e^+e^-$, while the dashed pink line in (d) is the peaking background from $\eta' \to \pi^0\pi^0\pi^0$.

According to Eq. (1), the BF for these five dominant decays of η' are measured independently for the first time [7] and their values are: $\mathcal{B}(\eta' \to \gamma\pi^+\pi^-) = (29.90 \pm 0.03 \pm 0.55)\%$, $\mathcal{B}(\eta' \to \eta\pi^+\pi^-) = (41.24 \pm 0.08 \pm 1.24)\%$, $\mathcal{B}(\eta' \to \eta\pi^0\pi^0) = (21.36 \pm 0.10 \pm 0.92)\%$, $\mathcal{B}(\eta' \to \gamma\omega) = (2.489 \pm 0.018 \pm 0.074)\%$, and $\mathcal{B}(\eta' \to \gamma\pi^+\pi^-) = (2.331 \pm 0.012 \pm 0.035)\%$, where the first and second uncertainties are statistical and systematic, respectively. The results are in agreement with CLEO's results [8] within two standard deviations, but with an improved precision by a factor between 2 to 4.

3. Search for the rare decay $\eta' \to \pi^0\pi^0\pi^0\pi^0$

The $\eta' \to \pi^0\pi^0\pi^0\pi^0$ decay is a highly suppressed due to the S-wave CP-violation. Higher order contributions, involving a D-wave pion loop or the production of two f_2 tensor mesons, provide a CP-conserving route through which the decay can occur. Prediction based on ChPT and Vector Meson Dominant model (VDM) predicts a branching fraction of the order of 10^{-8} [9]. In order to verify the validity of theoretical models, in BESIII we searched for the decay $\eta' \to \pi^0\pi^0\pi^0\pi^0$, which is not observed so far.

Figure 2 shows the $4\pi^0$ invariant mass spectrum ($M(4\pi^0)$) after the event selection described in reference [10]. No η' signal is observed, and a Bayesian approach was used to determine an upper limit on the branching fraction of $\eta' \to 4\pi^0$. Taking into account statistical and systematic uncertainties, we have found the upper limit of $\mathcal{B}(\eta' \to 4\pi^0) < 4.94 \times 10^{-5}$ at 90% C.L. This limit

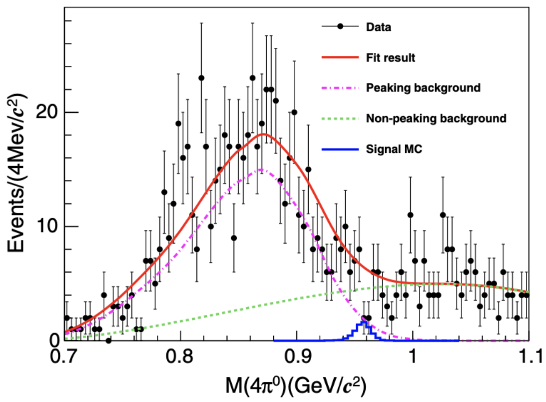

Figure 2: Fit result to the $M(4\pi^0)$ invariant mass distribution. The shape of the $J/\psi\gamma\eta'$, $\eta' \to \pi^0\pi^0\eta$, $\eta \to \pi^0\pi^0\pi^0$ peaking background is obtained from dedicated MC simulation, while non-peaking background is described by a third-order Chebychev function.

is approximately a factor 6 smaller than the previous most stringent result [11], but still far from theoretical prediction [9]. The new sample of 10^{10} J/ψ events collected at BESIII will allow for even more sensitive searches to be performed.

4. Search for $\eta' \to \gamma\gamma\eta$ decay

Within the framework of the linear σ model and VDM model, the branching fractions of $\eta' \to \gamma\gamma\pi^0$ and $\eta' \to \gamma\gamma\eta$ are predicted to be $3.8{\times}10^{-3}$ and $2.0{\times}10^{-4}$ [12], respectively. Using $1.31{\times}10^9$ J/ψ , BESIII determined for the first time the branching fraction $\mathcal{B}(\eta' \to \gamma\gamma\pi^0) = (32.0 \pm 0.7 \pm 2.3) \times 10^{-4}$ [13] and extracted the non resonant branching fraction $(6.16 \pm 0.64 \pm 0.67) \times 10^{-4}$, which confirmed the theoretical prediction and indicated that this decay was dominated by the VDM processes (ω and ρ contributions dominate). In a more recent analysis, BESIII also reported the search for $\eta' \to \gamma\gamma\eta$ in the J/ψ radiative decay [14], which has not been observed to date.

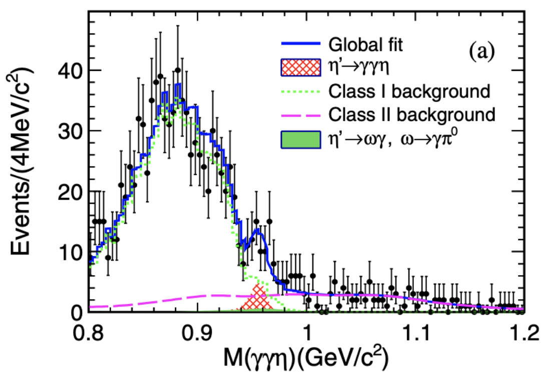

Figure 3: Fit result to $M(\gamma\gamma\eta)$ invariant mass. Black dots with error bars refer to data, Class I background refers to $J/\psi \to \gamma\eta'$, $\eta' \to \pi^0\pi^0\eta$ events, Class II background refers to J/ψ decays without η' in the final states. The peaking background, $\eta' \to \omega\gamma$ and $\eta' \to \pi^0\gamma$, is shown by the green histogram.

After the event and track selection described in reference [14], the resulting $\gamma\gamma\eta$ invariant mass distribution ($M(\gamma\gamma\eta)$) is shown in figure 3, and an unbinned maximum likelihood fit to $M(\gamma\gamma\eta)$ was performed in order to determine the $\eta' \to \gamma\gamma\eta$ signal yield. The extracted signal corresponds to a BF of $(8.25 \pm 3.41 \pm 0.72) \times 10^{-5}$ with a statistical significance of 2.6σ. Since no significant η' peak is observed, a Bayesian approach was used to extract the upper limit. Taking into account statistical and systematic uncertainties, the branching fraction upper limit at 90% C.L. was found to be 1.33×10^{-4}. This result seems in tension with theoretical prediction [12], but more data are needed in order to draw a final conclusion.

5. Dalitz plot analysis of $\omega \to \pi^+\pi^-\pi^0$ decay

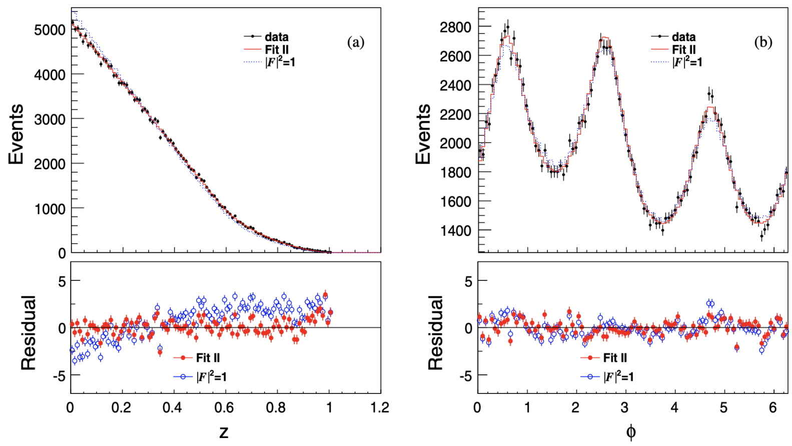

Figure 4: Data and fit results for z and ϕ distributions in the ω rest frame.

Dalitz plot analysis of $\omega \to \pi^+\pi^-\pi^0$ provides further constraints to the calculation of electromagnetic transition form factor of $\omega \to \pi^0\gamma^*$, it is useful to test prediction from dispersive theory [15], and to estimate the so-called crossed-channel effect [16]. The ω meson is abundantly produced in J/ψ decays, and by means of a sample of about 1.3×10^9 J/ψ events collected at BESIII, a Dalitz plot analysis of $\omega \to \pi^+\pi^0 - \pi^0$ via $J/\psi \to \omega\eta$ was performed [17]. Following reference [18], two dimensionless polar coordinate z and ϕ were built, and the Dalitz plot density was studied by performing an unbinned maximum likelihood fit. The fit results are shown in figure 4, where different parametrization of $|\mathcal{F}|^2$ were used. In particular, for the simplest case, $|\mathcal{F}|^2 = 1$ if there is no final state interaction and the decay amplitude is distributed like $P-$wave phase space. In this case, discrepancies are clearly visible between the fitted projections and data (see figure 4(a)) which indicate that the fit is not able to describe well the data. Taking into account more terms for the $|\mathcal{F}|^2$ parameterization, such as $|\mathcal{F}|^2 = 1 + 2\alpha z + 2\beta z^{3/2}\sin 3\phi$, the fit quality is improved and the α and β parameters extracted: $\alpha = (120.2 \pm 7.1 \pm 3.8) \times 10^{-3}$ and $\beta = (29.5 \pm 8.0 \pm 5.3) \times 10^{-3}$. The first and second uncertainties are statistical and systematic ones, respectively. The fitted parameter values are consistent with the theoretical predictions [16, 19] without incorporating crossed channel effects. More details can be found in reference [17].

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6. Conclusions

As shown in this report, J/ψ decays provide an excellent laboratory to study light meson physics. In particular, the new data collected by BESIII at the J/ψ center-of-mass energy, about 10 billion of new data collected, will allow the study of light meson decays with unprecedented statistics, and so many new results are expected in the near future.

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