Measurement of higher-order multipole amplitudes in $\Psi(3686) \to \gamma \chi_{c1,2}$ with $\chi_{c1,2} \to \gamma J/\Psi$ and search for the transition $\eta_c(2S) \to \gamma J/\Psi$

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INTRODUCTION

106 million $\psi(3686)$ events are collected with the BESIII detector

amplitudes for the decay $\Psi(3686) \to \gamma\chi_{c1.2} \to \gamma\gamma J/\Psi$ beyond the dominant electric-dipole amplitudes

normalized magnetic-quadrupole amplitude for $\Psi(3686) \to \gamma\chi_{c1.2} \to \gamma\gamma J/\Psi$

normalized electric-quadrupole amplitude for $\Psi(3686) \to \gamma\chi_{c2}, \chi_{c2} \to \gamma J/\Psi$

superscript representing $\chi_{c1.2}$

$\Psi(3686) \to \gamma_1\chi_{c1.2}$

$\chi_{c1.2} \to \gamma_2 J/\Psi$

normalized M2 contributions ($b_2^{1,2}$ and $a_2^{1,2}$) are predicted to be related to the mass of the charm quark, m_c and κ

dominated by electric-dipole (E1) amplitudes

INTRODUCTION

$$b_2^1 = \frac{E_{\gamma_1}[\psi(3686) \to \gamma_1 \chi_{c1}]}{4m_c}(1+\kappa) = 0.029(1+\kappa),$$

$$a_2^1 = -\frac{E_{\gamma_2}[\chi_{c1} \to \gamma_2 J/\psi]}{4m_c}(1+\kappa) = -0.065(1+\kappa),$$

$$b_2^2 = \frac{3}{\sqrt{5}} \frac{E_{\gamma_1}[\psi(3686) \to \gamma_1 \chi_{c2}]}{4m_c}(1+\kappa) = 0.029(1+\kappa),$$

$$a_2^2 = -\frac{3}{\sqrt{5}} \frac{E_{\gamma_2}[\chi_{c2} \to \gamma_2 J/\psi]}{4m_c}(1+\kappa) = -0.096(1+\kappa),$$

$$\frac{b_2^1}{b_2^2} = 1.000 \pm 0.015$$

$$\frac{a_2^1}{a_2^2} = 0.676 \pm 0.071$$

BESIII found evidence for the M2 contribution in $\Psi(3686) \to \gamma\chi_{c2}$ with $\chi_{c2} \to \pi^+\pi^-/K^+K^-$

report on a measurement of the higherorder multipole amplitudes in the processes of $\Psi(3686) \to \gamma_1\chi_{c2}, \chi_{c2} \to \gamma_2 J/\Psi$, where the J/ψ is reconstructed in its decay modes $J/\Psi \to l^+l^-$.

EVENT SELECTION

- $\psi(3686)$ resonances are produced by the event generator KKMC
- The signal decay $\psi(3686) \to \gamma_1\chi_{c0,1,2}(\eta_c(2S)) \to \gamma_1\gamma_2 J/\psi$, $J/\psi \to \ell^+\ell^-$ (ℓ = e, μ) consists of two charged tracks and two photons. Events with exactly two oppositely charged tracks and from two up to four photon candidates are selected.
- Charged tracks are required to originate from the run-dependent interaction point within 1 cm in the direction perpendicular to and within $\pm$10 cm along the beam axis and should lie within the polar angular region of $|\cos\theta| < 0.93$
- The momentum p of each track must be larger than 1 GeV/c.
- Tracks with $E < 0.4$ GeV are taken as muons, and those with $E/p > 0.8$ c are identified as electrons.
- The energy of each photon shower is required to be larger than 25 MeV. The shower timing information is required to be in coincidence with the event start time with a requirement of
- $0 \leq t \leq 700$ ns to suppress electronic noise and showers unrelated to the event.
- $3.08 < M^{4C}(\ell+\ell-) < 3.12$ GeV/c^2
- $\chi^2_{4C} < 60$
- $0.11 < M^{4C}(\gamma\gamma) < 0.15$ GeV/c^2, $M^{4C}(\gamma\gamma) > 0.51$ GeV/c2 are rejected

EVENT SELECTION

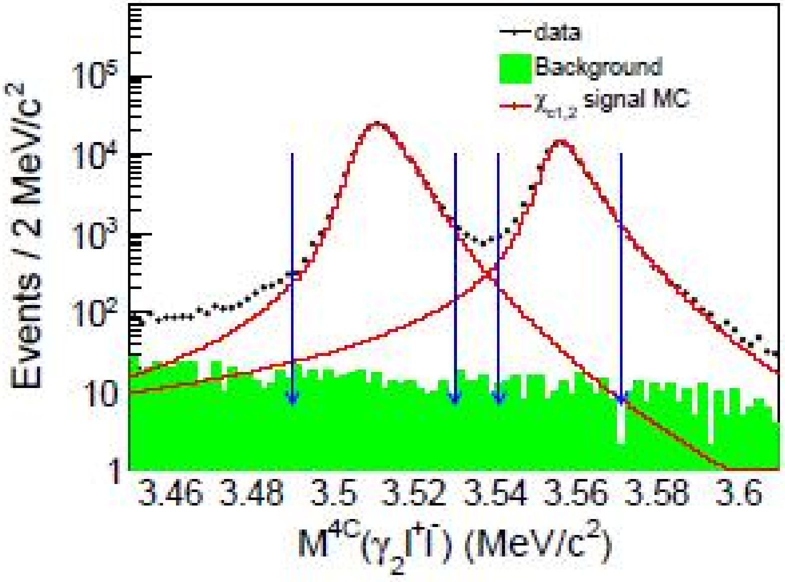

FIG. 1. Mass distributions of $M^{4C}(\gamma_2\ell^+\ell^-)$ for events in the $\chi_{c1,2}$ region. Black dots correspond to data, and red histograms are obtained from the signal MC samples scaled by the maximum bin. The green dashed histogram is the background contribution obtained from the inclusive MC samples. The arrows denote the signal regions.

Events in the signal regions are used to determine the higher-order multipole amplitudes in the ψ(3686) → γ1χc1,2 → γ1γ2J/ψ radiative transitions. The normalized M2 contributions for the channels ψ(3686) → γ1χc1,2 and χc1,2 → γ2J/ψ are denoted as $b^{1,2}_2$ and $a^{1,2}_2$, respectively.

In the χ_{c2} decays, the E3 transition is also allowed. The corresponding normalized E3 amplitudes are indicated as b^2_3 and a^2_3 for ψ(3686) → $\gamma_1\chi_{c2}$ and χ_{c2} → γ_2J/ψ, respectively.

FIG.1. shows the $M^{4C}(\gamma_2\ell^+\ell^-)$ invariantmass distribution for the selected $\chi_{c1,2}$ candidates.

FIT

By minimizing $-\ln L_s$, the best estimates of the high-order multipole amplitudes can be obtained.

$$L_s = \ln L - \ln L_b$$

$$L = \prod_{i=1}^{N} F_{\chi c1,2}(i)$$

$$F = \frac{W_{\chi cJ}(\theta_1, \theta_2, \phi_2, \theta_3, \phi_3, a^J_{2,3}, b^J_{2,3})}{\overline{W_{\chi cJ}(a^J_{2,3}, b^J_{2,3})}}$$

TABLE I. Fit results for $a^J_{2,3}$ and $b^J_{2,3}$ for the process of $\psi(3686) \to \gamma_1\chi_{c1,2} \to \gamma_1\gamma_2 J/\psi$; the first uncertainty is statistical, and the second is systematic. The $\rho^J_{a_{2,3}b_{2,3}}$ are the correlation coefficients between $a^J_{2,3}$ and $b^J_{2,3}$.

χ_{c1}	$a^1_2 = -0.0740 \pm 0.0033 \pm 0.0034$, $b^1_2 = 0.0229 \pm 0.0039 \pm 0.0027$ $\rho^1_{a_2b_2} = 0.133$
χ_{c2}	$a^2_2 = -0.120 \pm 0.013 \pm 0.004$, $b^2_2 = 0.017 \pm 0.008 \pm 0.002$ $a^2_3 = -0.013 \pm 0.009 \pm 0.004$, $b^2_3 = -0.014 \pm 0.007 \pm 0.004$ $\rho^2_{a_2b_2} = -0.605$, $\rho^2_{a_2a_3} = 0.733$, $\rho^2_{a_2b_3} = -0.095$ $\rho^2_{a_3b_2} = -0.422$, $\rho^2_{b_2b_3} = 0.384$, $\rho^2_{a_3b_3} = -0.024$

RESULT

Based on 106 million $\psi(3686)$ decays, we measure the higher-order multipole amplitudes for the decays $\psi(3686) \rightarrow \gamma_1\chi_{c1,2} \rightarrow \gamma_1\gamma_2 J/\psi$ channels. The statistical significance of nonpure E1 transition is 24.3σ and 13.4σ for the χ_{c1} and χ_{c2} channels, respectively. The normalized M2 contribution for $\chi_{c1,2}$ and the normalized E3 contributions for χ_{c2} are listed in Table I.

The ratios of M2 contributions of χc1 to χc2 are independent of the mass mc and the anomalous magnetic moment κ of the charm quark at leading order in Eγ/mc. They are determined to be $b^1{}_2/b^2{}_2$= 1.35 ± 0.72, $a^1{}_2/a^2{}_2$= 0.617 ± 0.083. The corresponding theory predictions are $(b^1{}_2/b^2{}_2)$th =1.000 ± 0.015 and $(a^1{}_2/a^2{}_2)$th = 0.676 ± 0.071.

THANKS