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The charm semileptonic decays $D^+ \to \eta e^+\nu_e$ and $D^+ \to \eta' e^+\nu_e$ are studied with a sample of e^+e^- collision data corresponding to an integrated luminosity of $2.93\,\mathrm{fb}^{-1}$ collected at $\sqrt{s} = 3.773\,\mathrm{GeV}$ with the BESIII detector. We measure the branching fractions for $D^+ \to \eta e^+\nu_e$ to be $(10.74 \pm 0.81 \pm 0.51) \times 10^{-4}$, and for $D^+ \to \eta' e^+\nu_e$ to be $(1.91 \pm 0.51 \pm 0.13) \times 10^{-4}$, where the uncertainties are statistical and systematic, respectively. In addition, we perform a measurement of the form factor in the decay $D^+ \to \eta e^+\nu_e$. All the results are consistent with those obtained by the CLEO-c experiment.

Keywords: BESIII, charm semileptonic decay, form factor

I. INTRODUCTION

Charm semileptonic (SL) decays involve both the c-quark weak decay and the strong interaction. In the Standard Model, the Cabibbo-Kobayashi-Maskawa (CKM) matrix [1] describes the mixing among the quark flavors in the weak decay. The strong interaction effects in the hadronic current are parameterized by a form factor, which is numerically calculable with Lattice Quantum Chromodynamics (LQCD). The differential decay rate for the charm SL decay $D^+ \to \eta e^+\nu_e$, neglecting the positron mass, is given by

$$\frac{\mathrm{d}\Gamma(D^+ \to \eta e^+\nu_e)}{\mathrm{d}q^2} = \frac{G_F^2|V_{cd}|^2}{24\pi^3}|\vec{p}_\eta|^3|f_+(q^2)|^2, \quad (1)$$

where G_F is the Fermi constant, V_{cd} is the relevant CKM matrix element, $\vec{p}_\eta$ is the momentum of the η meson in the D^+ rest frame, and $f_+(q^2)$ is the form factor parametrizing the strong interaction dynamics as a function of the squared four-momentum transfer q^2, which is the square of the invariant mass of the e^+-ν_e pair. Precise measurements of the SL decay rates provide input to constrain the CKM matrix element V_{cd} and to test the theoretical descriptions of the form factor. LQCD calculations of the form factor can be tested by comparing to the ones determined from the partial branching fraction (BF) measurements, once the CKM matrix element V_{cd} is known.

Moreover, the mixing η-η' or η-η'-G, where G stands for a glueball, is of great theoretical interest, because it concerns many aspects of the underlying dynamics and hadronic structure of pseudoscalar mesons and glueballs [2]. The SL decay $D^+ \to \eta^{(\prime)} e^+\nu_e$ can be used to study the η-η' mixing in a much cleaner way than in hadronic processes due to the absence of final-state interaction [3].

Based on a data sample with an integrated luminosity of $818\,\mathrm{pb}^{-1}$ collected at $\sqrt{s} = 3.77\,\mathrm{GeV}$, the CLEO collaboration measured the BF for $D^+ \to \eta e^+\nu_e$ and $D^+ \to \eta' e^+\nu_e$ to be $\mathcal{B}_{\eta e^+\nu_e} = (11.4 \pm 0.9 \pm 0.4) \times 10^{-4}$ and $\mathcal{B}_{\eta' e^+\nu_e} = (2.16 \pm 0.53 \pm 0.07) \times 10^{-4}$ [4], respectively. In this paper, we present new measurements of these BFs, using $D\bar{D}$ meson pairs produced near threshold at $\sqrt{s} = 3.773\,\mathrm{GeV}$ with an integrated luminosity of $2.93\,\mathrm{fb}^{-1}$ [5] collected with the BESIII detector [6]. In addition, the modulus of the form factor $f_+(q^2)$ in $D^+ \to \eta e^+\nu_e$ is measured.

II. THE BESIII DETECTOR

The Beijing Spectrometer (BESIII) detects e^+e^- collisions produced by the double-ring collider BEPCII. BESIII is a general-purpose detector [6] with 93 % coverage of the full solid angle. From the interaction point (IP) to the outside, BESIII is equipped with a main drift chamber (MDC) consisting of 43 layers of drift cells, a time-of-flight (TOF) counter with double-layer scintillator in the barrel part and single-layer scintillator in the end-cap part, an electromagnetic calorimeter (EMC) composed of 6240 CsI(Tl) crystals, a superconducting solenoid magnet providing a magnetic field of 1.0 T along the beam direction, and a muon counter containing multi-layer resistive plate chambers installed in the steel flux-return yoke of the magnet. The MDC spatial resolution is about $135\,\mu$m and the momentum resolution is about 0.5 % for a charged track with transverse momentum of $1\,\mathrm{GeV}/c$. The energy resolution for electromagnetic showers in the EMC is 2.5 % at 1 GeV. More details of the spectrometer can be found in Ref. [6].

III. MC SIMULATION

Monte Carlo (MC) simulation serves to estimate the detection efficiencies and to understand background components. High statistics MC samples are generated with a GEANT4-based [7] software package, which includes simulations of the geometry of the spectrometer and interactions of particles with the detector materials. KKMC is used to model the beam energy spread and the initial-state radiation (ISR) in the e^+e^- annihilations [8]. The 'inclusive' MC samples consist of the production of $D\overline{D}$ pairs with consideration of quantum coherence for all neutral D modes, the non-$D\overline{D}$ decays of $\psi(3770)$, the ISR production of low mass ψ states, and continuum process-