Physics Letters B 738 (2014) 391–396

Contents lists available at ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

Measurement of $J/\psi \to \gamma\eta_c$ decay rate and η_c parameters at KEDR

V.V. Anashin [a], V.M. Aulchenko [a,b], E.M. Baldin [a,b], A.K. Barladyan [a], A.Yu. Barnyakov [a,b], M.Yu. Barnyakov [a,b], S.E. Baru [a,b], I.Yu. Basok [a], I.V. Bedny [a], A.E. Blinov [a,b], V.E. Blinov [a,b,c], A.V. Bobrov [a], V.S. Bobrovnikov [a], A.V. Bogomyagkov [a,b], A.E. Bondar [a,b], A.R. Buzykaev [a], S.I. Eidelman [a,b,*], Yu.M. Glukhovchenko [a], V.V. Gulevich [a], D.V. Gusev [a], S.E. Karnaev [a], G.V. Karpov [a], S.V. Karpov [a], T.A. Kharlamova [a,b], V.A. Kiselev [a], S.A. Kononov [a,b], K.Yu. Kotov [a], E.A. Kravchenko [a,b], V.F. Kulikov [a,b], G.Ya. Kurkin [a,c], E.A. Kuper [a,b], E.B. Levichev [a,c], D.A. Maksimov [a], V.M. Malyshev [a,*], A.L. Maslennikov [a], A.S. Medvedko [a,b], O.I. Meshkov [a,b], S.I. Mishnev [a], I.I. Morozov [a,b], N.Yu. Muchnoi [a,b], V.V. Neufeld [a], S.A. Nikitin [a], I.B. Nikolaev [a,b], I.N. Okunev [a], A.P. Onuchin [a,c], S.B. Oreshkin [a], I.O. Orlov [a,b], A.A. Osipov [a], S.V. Peleganchuk [a], S.G. Pivovarov [a,c], P.A. Piminov [a], V.V. Petrov [a], A.O. Poluektov [a], G.E. Pospelov [a], V.G. Prisekin [a], O.L. Rezanova [a,b], A.A. Ruban [a], V.K. Sandyrev [a], G.A. Savinov [a], A.G. Shamov [a], D.N. Shatilov [a], B.A. Shwartz [a,b], E.A. Simonov [a], S.V. Sinyatkin [a], A.N. Skrinsky [a], V.V. Smaluk [a,b], A.V. Sokolov [a], A.M. Sukharev [a], E.V. Starostina [a,b], A.A. Talyshev [a,b], V.A. Tayursky [a], V.I. Telnov [a,b], Yu.A. Tikhonov [a,b], K.Yu. Todyshev [a,b], G.M. Tumaikin [a], Yu.V. Usov [a], A.I. Vorobiov [a], A.N. Yushkov [a], V.N. Zhilich [a], V.V. Zhulanov [a,b], A.N. Zhuravlev [a,b]

[a] *Budker Institute of Nuclear Physics, 11, Lavrentiev prospect, Novosibirsk, 630090, Russia*
[b] *Novosibirsk State University, 2, Pirogova street, Novosibirsk, 630090, Russia*
[c] *Novosibirsk State Technical University, 20, Karl Marx prospect, Novosibirsk, 630092, Russia*

ARTICLE INFO

Article history:
Received 1 July 2014
Received in revised form 3 September 2014
Accepted 30 September 2014
Available online 6 October 2014
Editor: M. Doser

Keywords:
Charmonium
Radiative decays

ABSTRACT

Using the inclusive photon spectrum based on a data sample collected at the J/ψ peak with the KEDR detector at the VEPP-4M e^+e^- collider, we measured the rate of the radiative decay $J/\psi \to \gamma\eta_c$ as well as η_c mass and width. Taking into account an asymmetric photon lineshape we obtained $\Gamma^0_{\gamma\eta_c} = 2.98 \pm 0.18^{+0.15}_{-0.33}$ keV, $M_{\eta_c} = 2983.5 \pm 1.4^{+1.6}_{-3.6}$ MeV/c^2, $\Gamma_{\eta_c} = 27.2 \pm 3.1^{+5.4}_{-2.6}$ MeV.

1. Introduction

$J/\psi \to \gamma\eta_c$ decay is a magnetic dipole radiative transition in charmonium with the most probable photon energy ω_0 of about 114 MeV and a fairly large branching fraction of $(1.7 \pm 0.4)\%$ [1]. This is a transition between $1S$ states of the charmonium system and its rate can be easily calculated in potential models. In the nonrelativistic approximation, the magnetic dipole amplitudes between S-wave states are independent of a specific potential model, because the spatial overlap equals one for states within the same multiplet. A simple calculation in the nonrelativistic approximation yields the result [2] $\mathcal{B}(J/\psi \to \gamma\eta_c) = 3.05\%$. It is reasonable to assume that relativistic corrections are of order $20 \div 30\%$, similarly to the case of the electric dipole transitions in the charmonium (see, for example, the reviews [3,4]). However, in 1986 the Crystal Ball Collaboration measured this branching fraction in the inclusive photon spectrum and obtained a much smaller value

* Corresponding authors.
E-mail addresses: S.I.Eidelman@inp.nsk.su (S.I. Eidelman), V.M.Malyshev@inp.nsk.su (V.M. Malyshev).

http://dx.doi.org/10.1016/j.physletb.2014.09.064

$(1.27 \pm 0.36)\%$ [5]. There are a lot of theoretical predictions for this decay rate [6–13], based on QCD sum rules, lattice QCD calculations and so on, but as a rule they lead to values approximately twice as large as the Crystal Ball result.

This discrepancy remained unchanged for more than twenty years. During this period no new measurements of this branching fraction were performed, and the PDG average [14] was based on the single Crystal Ball result. Only in 2009 the CLEO Collaboration published the result of a new measurement [15], in which 12 exclusive decay modes of the η_c were analyzed. The obtained value $\mathcal{B}(J/\psi \to \gamma\eta_c) = (1.98 \pm 0.09 \pm 0.30)\%$ is closer to theoretical predictions. Combining the Crystal Ball and CLEO results, PDG obtained $\mathcal{B}(J/\psi \to \gamma\eta_c) = (1.7 \pm 0.4)\%$ [1] with a scale factor of 1.6. In this work we report the result of a new independent measurement performed using the inclusive photon spectrum.

2. Photon spectrum

The spectrum of detected photons in $J/\psi \to \gamma\eta_c$ decay is given by the formula [3]

$$\frac{d\Gamma(\omega)}{d\omega} = \frac{4}{3}\alpha\frac{e_c^2}{m_c^2}\omega^3|M|^2\,\mathrm{BW}(\omega). \tag{1}$$

Here ω is a photon energy, α is the fine structure constant, e_c and m_c are c-quark charge (in electron charge units) and mass, $M = \langle\eta_c|j_0(\omega r/2)|J/\psi\rangle$ is the matrix element of the transition (without relativistic corrections), $j_0(x) = \sin(x)/x$, $\mathrm{BW}(\omega)$ is a Breit–Wigner function. A typical momentum transfer inside the charmonium bound state is about 700 to 800 MeV [16] (this is of the order of the inverse size of the system), so the matrix element is almost constant (close to one) up to such photon energies. Therefore, in this energy range the decay spectrum $\frac{d\Gamma(\omega)}{d\omega} \sim \omega^3\,\mathrm{BW}(\omega)$. Since $\mathrm{BW}(\omega) \sim \omega^{-2}$ at $\omega \gg \omega_0$, the decay probability grows as ω when ω increases. If a resonance width is not small, it can give a noticeable tail in the photon spectrum at photon energies $\omega \gg \omega_0$. For the $J/\psi \to \gamma\eta_c$ transition we have $\frac{\Gamma_{\eta_c}}{\omega_0} \approx \frac{30\text{ MeV}}{114\text{ MeV}} \approx \frac{1}{4}$. This value is not small, therefore we should take into account this tail. It should be also noted that in theoretical calculations of the decay rate this effect is as a rule neglected, and, assuming a small width of the resonance, ω is replaced with ω_0 in (1).

At the same time it is known that the usual form of the Breit–Wigner function is applicable only in the close vicinity of a resonance and gives an overestimated value far from it. For example, in the theory of atomic transitions a photon absorption lineshape has the same functional form as a (non-relativistic) Breit–Wigner function, but with $\Gamma(\omega) \sim \omega^3$ [17], so $\mathrm{BW}(\omega) \sim \omega^{-3}$ at $\omega \gg \omega_0$. Also, it should be taken into account that this function gives a correct description of the resonance in the limit of its zero width only. Given this, the photon lineshape in the decay $J/\psi \to \gamma\eta_c$ has the form

$$\frac{d\Gamma(\omega)}{d\omega} \sim \omega^3 f(\omega)\,\mathrm{BW}(\omega), \tag{2}$$

where the correction factor $f(\omega)$ is about one near the resonance and falls far from the resonance.

Due to the ω^3 factor and a fairly large η_c width, the photon lineshape in this decay is asymmetric, and this is confirmed experimentally. The Crystal Ball did not consider this issue in their publication, noting only that the ω^3 factor was used in the fit of the spectrum in the convolution of the detector response function with the η_c Breit–Wigner resonance shape. However, because of the large background, such an asymmetry cannot be revealed using the data collected at the Crystal Ball.

The CLEO Collaboration used exclusive decay modes of the η_c, that allows one to suppress background strongly. As a result, it was found that the photon lineshape of this transition is really asymmetric. The Breit–Wigner function alone, traditionally used to describe resonances, provides a poor fit to data. Its modification with the ω^3 factor improves the fit around the peak, but gives a great tail at higher photon energies, as it was noted above. To suppress this tail, CLEO used $|M|^2 = \exp(-\frac{\omega^2}{8\beta^2})$ in their fit with $\beta = 65$ MeV. However, such a form of matrix element is valid for harmonic oscillator wave functions only. Also, the value of β used in the fit is too small for the charmonium system and gives very fast fall of the matrix element with the photon energy increase. In addition, in their analysis CLEO did not consider interference effects, which may be not small for exclusive spectra.

When measuring the branching fraction $\mathcal{B}(J/\psi \to \gamma\eta_c)$, one should separate the events of $J/\psi \to \gamma\eta_c$ decays from the background events. This requires either a knowledge of the photon lineshape or a background measurement with sufficient accuracy. As a rule, the latter is a difficult task, especially for inclusive decays, because of the small signal to background ratio. Therefore, to determine the number of signal events, during the data fitting one has to specify the explicit form of the resonance. However, considering that exact ω dependence of the $f(\omega)$ factor in (2) is unknown, we can conclude that the measurement of $\mathcal{B}(J/\psi \to \gamma\eta_c)$ will be inevitably model-dependent, until the photon lineshape will be measured or calculated theoretically with a sufficient accuracy. In this work we assume that the photon lineshape has the form (2) wherein $f(\omega)$ is chosen under the assumption that the spectrum tail at photon energies $\omega - \omega_0 > 4\Gamma_{\eta_c}$ can be neglected: at $\omega - \omega_0 < 2\Gamma_{\eta_c}$ the factor $f(\omega) = 1$, at $\omega - \omega_0 > 4\Gamma_{\eta_c}$ the factor $f(\omega) = 0$, and in the region $2\Gamma_{\eta_c} < \omega - \omega_0 < 4\Gamma_{\eta_c}$ the decay probability falls linearly.

3. KEDR data

The experiment was performed at the KEDR detector [18] of the VEPP-4M collider [19]. It operates at a peak luminosity of about $1.5 \times 10^{30}\ \mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ near the J/ψ resonance energy. The luminosity is measured using single Bremsstrahlung online and small-angle Bhabha scattering offline. Two methods of a beam energy determination are used: a resonant depolarization with an accuracy of $8 \div 30$ keV and an IR-light Compton backscattering with an accuracy of ~ 100 keV [20].

The view of the KEDR detector is shown in Fig. 1. Subsystems are listed in the figure. Detector includes a tracking system consisting of a vertex detector and a drift chamber, a particle identification (PID) system of aerogel Cherenkov counters and scintillation time-of-flight counters, and an electromagnetic calorimeter based on liquid krypton (in the barrel part) and CsI crystals (endcap part). The superconducting solenoid provides a longitudinal magnetic field of 0.6 T. A muon system is installed inside the magnet yoke. The detector also includes a high-resolution tagging system for studies of two-photon processes.

Charged tracks are reconstructed in the drift chamber (DC) and vertex detector (VD). DC has a cylindrical shape, with a 1100 mm length and an outer radius of 535 mm, and is filled with pure dimethyl ether. DC cells form seven concentric layers: four axial layers and three stereo layers to measure track coordinates along the beam axis. The coordinate resolution averaged over drift length is 100 μm. VD is installed between the vacuum chamber and DC and increases a solid angle accessible to the tracking system to 98%. VD consists of 312 cylindrical drift tubes aligned in 6 layers. It is filled with an Ar + 30% CO_2 gas mixture and has a coordinate resolution of 250 μm. The momentum resolution of the tracking system is $\sigma_p/p = 2\% \oplus (4\% \times p[\mathrm{GeV}])$.

Scintillation counters of the time-of-flight system (TOF) are used in a fast charged trigger and for identification of the charged