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On the $J/\psi \to \gamma\eta_c \to \gamma X$ line-shape in pNRQCD

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The $J/\psi \to \gamma\eta_c$ branching fraction was first measured in 1986 by the Crystal Ball Collaboration in the inclusive photon spectrum and the value $calB(J/\psi \to \gamma\eta_c \to \gamma X) = (1.27 \pm 0.36)\%$ was obtained. There are many theoretical predictions for this decay rate, based on potential models, QCD sum rules, nonrelativistic EFTs and lattice QCD, but as a rule they lead to values approximately twice as large as the Crystal Ball result. No new measurements of this branching fraction were performed until 2009 when the CLEO Collaboration reported a value $calB(J/\psi \to \gamma\eta_c) = (1.98 \pm 0.09 \pm 0.30)\%$, closer to theoretical predictions. Combining the Crystal Ball and CLEO results, PDG obtained $calB(J/\psi \to \gamma\eta_c) = (1.7{\pm}0.4)\%$. More recently the KEDR Collaboration measured the transition and reported a much higher figure, $(3.40{\pm}0.33)\%$, triggering questions on the actual value of this branching fraction and on possible issues when extracting it experimentally.

One of the crucial ingredients in the determination of the branching fraction from experimental measurements is the photon spectrum line-shape used in the analysis. The CLEO Collaboration observed for the first time a clear asymmetry in the photon energy spectrum line-shape due to phase-space and energy-dependent terms in the $J/\psi \to \gamma\eta_c$ transition matrix element. In order to obtain a good fit to the data, the photon spectrum line-shape was constructed with a relativistic Breit-Wigner distribution modified by a factor k^3, where k is the photon energy. However, adding this factor led to a divergent tail at large photon energies and an {\it ad hoc} damping function was included in order to suppress this behaviour, arguing that it modeled the overlap between the charmonium wave functions. Nevertheless, such damping factor does not appear in the theoretical studies of the same branching fraction and thus it is not well justified. The analysis by the KEDR Collaboration followed a similar approach incorporating a different, non-theoretically motivated, damping function, and found that the sensitivity of its branching ratio measurement with respect the damping function is actually quite large.

We calculate the photon spectrum line-shape for the $J/\psi \to \gamma\eta_c \to \gamma X$ process using a well suited effective field theory approach called weakly-coupled pNRQCD. We argue that the large energy tail of the line-shape is due to either polynomially or logarithmically divergent terms. Integrating the line-shape over the photon energy using DR, an analytical expression for the widths of the $J/\psi \to \gamma\eta_c \to \gamma X$ and $J/\psi \to \gamma\eta_c$ processes are obtained. Upon integration in DR, the polynomially divergent terms give no contribution and the logarithmically divergent term produces an UV divergence than can be subtracted in $\overline{\text{MS}}$ scheme and renormalized.

We propose to analyze CLEO's data using a photon spectrum line-shape in which the UV divergent terms are subtracted in a manner consistent with the calculation of the decay width in DR and $\overline{\text{MS}}$ scheme. The signal over background ratio depends on the tail of the line-shape at large photon energies. Using either an unsubtracted line-shape or a hard cut-off in its integration, the large energy tail leads to a determination of a branching fraction which is incompatible with the above theoretical estimate and with the PDG's average value. The subtracted line-shape shows a suppression at large photon energies that leads to compatible experimental and theoretical determinations of the branching fractions for the processes $J/\psi \to \gamma\eta_c \to \gamma X$ and $J/\psi \to \gamma\eta_c$.

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