# HPQCD: shining a light on decay rates

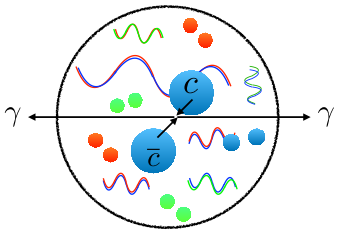


**Figure 1. An $\eta_c$ meson can annihilate to 2 real photons, each with energy one half the $\eta_c$ mass.**

A major success of lattice QCD has been the accurate determination of the decay constants of mesons, bound states of a quark and antiquark held together by the strong interaction. The decay constants parameterise the rate at which the meson (if it has appropriate spin and quark content) annihilates to a virtual photon or W boson and thence to leptons. Because the process is such a simple one, comparison to accurate experimental results allows stringent tests of QCD and the Standard Model of particle physics (see C. Davies, section 4.7 in *50 years of quantum chromodynamics*, arXiv:2212.11107). Another such decay process is the annihilation of a spin-zero meson to 2 real photons, parameterised by a form factor, F(0,0) (see Figure 1). Theorists in the HPQCD collaboration recently calculated an accurate value for the first time for this form factor for the $\eta_c$ meson, a bound state of a charm-anticharm quark pair. The calculation used DiRAC@Cambridge, ideal because of its flexibility for the multiple stages of workflow here.

Our result (arXiv:2305.06231) for the rate of $\eta_c \to \gamma\gamma$ decay has an uncertainty below 1%. The experimental result can be obtained from the decay chain $J/\psi \to \gamma(\eta_c \to \gamma\gamma)$. Because we also calculate the decay rate for $J/\psi \to \gamma\eta_c$, we can determine the product of branching fractions for the decay chain, to compare directly to experiment (Figure 2). Our result is more accurate, but it agrees well with the 2013 value from the BESIII experiment in China. Of theoretical interest is the ratio of F to the decay constant, f, for the $J/\psi$ meson. In the limit of infinite quark mass, the ratio f/(F(0,0)M²) would take the value 0.5. Finite-mass corrections to this value for the c quark can be as large as 30%, making a determination of the ratio impossible without lattice QCD. We find (see Figure 3) that the ratio is in fact surprisingly close to 0.5, implying a lot of cancellation between the different corrections. Ongoing HPQCD work extends this to bottom quarks and $\eta_b \to \gamma\gamma$ decay ahead of upcoming results from the Belle II experiment in Japan.

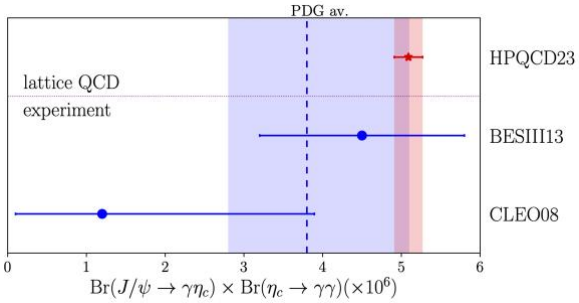


**Figure 2. The red band shows HPQCD's result (with its uncertainty) for the combined branching fractions of $J/\psi \to \gamma\eta_c$ followed by $\eta_c \to \gamma\gamma$ decay compared to experimental results. The experimental average is given by the blue band.**

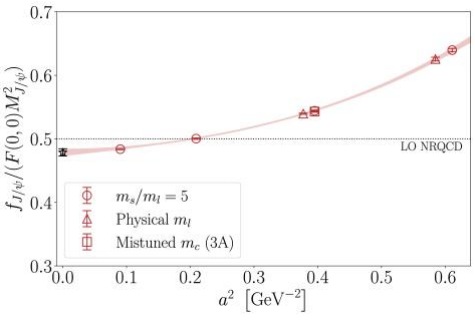


**Figure 3. Our results for the ratio of $J/\psi$ decay constant to $\eta_c$ form factor multiplied by the square of the $J/\psi$ mass as a function of lattice spacing, a. We extrapolate to a=0 for a physical result (black star), surprisingly close to the infinite mass value of 0.5.**