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The $\gamma^*\gamma^* \to \eta_c(1S, 2S)$ transition form factor from quarkonium wave functions

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We discuss $\gamma^*\gamma^* \to \eta_c(1S)$, $\eta_c(2S)$ transition form factor for both virtual photons. The general formula is given. We use different models for the $c\bar{c}$ wave function obtained from the solution of the Schr\"odinger equation for different $c\bar{c}$ potentials: harmonic oscillator, Cornell, logarithmic, power-law, Coulomb and Buchm\"uller-Tye. We compare our results to the BaBar experimental data for $\eta_c(1S)$, for one real and one virtual photon. We discuss approaching of $Q_1^2 F(Q_1^2, 0)$ or $Q_2^2 F(0, Q_2^2)$ to their asymptotic value $\frac{8}{3} f_{\eta_c}$ predicted by Brodsky and Lepage formalism. We discuss applicability of the collinear and/or massless limit and delayed onset of asymptotic behaviour.
We present some examples of two-dimensional distributions for $F_{\gamma^*\gamma^* \to \eta_c}(Q_1^2, Q_2^2)$. A scaling in $\omega = (Q_1^2 = Q_2^2)/(Q_1^2 + Q_2^2)$ was obtained. A factorization breaking measure is proposed and factorization breaking effects are quantified and shown to be weakly model dependent.

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