

# Production of $\eta_c(1S, 2S)$ in $e^+e^-$ and $pp$ collisions

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We derive the light-front wave function (LFWF) representation of the  $\gamma^*\gamma^* \rightarrow \eta_c(1S), \eta_c(2S)$  transition form factor  $F(Q_1^2, Q_2^2)$  for two virtual photons in the initial state. For the LFWF, we use different models obtained from the solution of the Schrödinger equation for a variety of  $c\bar{c}$  potentials. We compare our results to the BaBar experimental data for the  $\eta_c(1S)$  transition form factor, for one real and one virtual photon. We observe that the onset of the asymptotic behaviour is strongly delayed and discuss applicability of the collinear and/or massless limit. We present some examples of two-dimensional distributions for  $F(Q_1^2, Q_2^2)$ . A factorization breaking measure is proposed and factorization breaking effects are quantified and shown to be almost model independent. Factorization is shown to be strongly broken, and a scaling of the form factor as a function of  $\bar{Q}^2 = (Q_1^2 + Q_2^2)/2$  is obtained. In addition, we present a thorough analysis of  $\eta_c(1S, 2S)$  quarkonia hadroproduction in  $k_\perp$ -factorisation in the framework of the light-front potential approach for the quarkonium wave function. The off-shell matrix elements for the  $g^*g^*\eta_c(1S, 2S)$  vertices are derived. We discuss the importance of taking into account the gluon virtualities. We present the transverse momentum distributions of  $\eta_c$  for several models of the unintegrated gluon distributions. Our calculations are performed for four distinct parameterisations for the  $c\bar{c}$  interaction potential consistent with the meson spectra. We compare our results for  $\eta_c(1S)$  to measurements by the LHCb collaboration and present predictions for  $\eta_c(2S)$  production.

References:

- 1.) I. Babiarez, V.P. Goncalves, R. Pasechnik, W. Schöfer and A. Szczurek, "The  $\gamma^*\gamma^* \rightarrow \eta_c(1S, 2S)$  transition form factors for spacelike photons", *Phys.Rev. D* **100** 054018 (2019)
- 2.) I. Babiarez, R. Pasechnik, W. Schöfer and A. Szczurek, "Prompt hadroproduction of  $\eta_c(1S, 2S)$  in the  $k_T$ -factorization approach," *JHEP* **2002**, 037 (2020) [arXiv]

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## Secondary track (number)

**Primary authors:** SZCZUREK, Antoni (Institute of Nuclear Physics); BABIARZ, Izabela (IFJ PAN Krakow); SCHAEFER, Wolfgang (Institute of Nuclear Physics PAN)

**Presenter:** BABIARZ, Izabela (IFJ PAN Krakow)

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