Vol. 29 (1998) *ACTA PHYSICA POLONICA B* No 11

PSEUDOSCALAR MESON-PHOTON TRANSITION FORM FACTORS *

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(Received June 5, 1998)

I discuss the perturbative calculation of $P\gamma$ transition form factors, with $P = \pi^0, \eta, \eta', \eta_c$.

PACS numbers: 13.40.Gp, 13.60.Le, 14.70.Bh

The investigation of exclusive reactions in $\gamma\gamma$ collisions is useful in order to gain information about the hadronic properties and to test our present understanding of QCD [1]. The processes[1] $\gamma\gamma^* \to P$, where P is a pseudoscalar meson, may be described by the corresponding meson-photon transition form factors $F_{P\gamma}(Q^2)$ with Q^2 being the (space-like) virtuality of one of the photons. For large values of Q^2, or (in the case of the η_c) large quark masses, these form factors can be calculated from a convolution of process-independent hadronic (light-cone) wave functions Ψ, a perturbatively calculable hard-scattering amplitude T and (eventually) a Sudakov form factor $\mathcal{S}$ (for details see [2–5]).

In this so-called modified hard scattering approach (mHSA) the $\pi\gamma$ transition form factor reads

$$F_{\pi\gamma}(Q^2) = \int_0^1 \mathrm{d}x \int \frac{\mathrm{d}^2 b}{4\pi}\, \hat{\Psi}_\pi(x,\vec{b})\, \hat{T}_\pi(x,\vec{b},Q)\, \exp\left[-\mathcal{S}(x,\vec{b},Q)\right] . \qquad (1)$$

Here $\hat{\Psi}_\pi(x,\vec{b}) = f_\pi\, \phi(x)\, \Sigma(x,\vec{b})/2\sqrt{6}$ is the wave function of the leading $u\bar{u} - d\bar{d}$ Fock state of the pion with x being the usual parton momentum fraction and $\vec{b}$ the quark-antiquark separation, canonically conjugated to the transverse momentum, and $f_\pi = 131$ MeV. It turns out (see Fig. 1) that the distribution of the quarks inside the light pseudoscalars can be

* Presented at the Meson'98 and Conference on the Structure of Meson, Baryon and Nuclei, Cracow, Poland, May 26–June 2, 1998.

1 In the following we consider the case where one of the photons is (almost) real.

chosen close to the asymptotic form [6, 7], $\phi_{\rm AS}(x) = 6\,x\,(1-x)$. For the transverse shape of the wave function $\Sigma(x,\vec{b})$ it is usually sufficient to assume a Gaussian with a transverse size parameter fixed by the anomalous decay $\pi \to \gamma\gamma$. From (1) it follows that asymptotically the form factor takes the value $Q^2 F_{\pi\gamma}(Q^2) \to \sqrt{2}\, f_\pi = 185$ MeV. Transverse momenta and Sudakov effects determine the curvature of the form factor at intermediate values of Q^2 which fits perfectly with the experimental data (see Fig. 1).

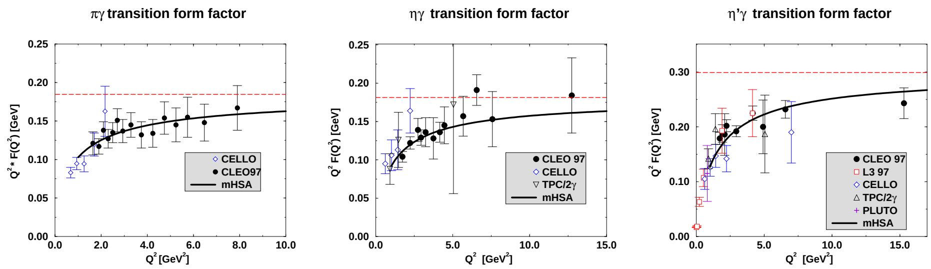

Fig. 1. Results for the scaled form factor $Q^2\,F_{P\gamma}(Q^2)$ with $P = \pi^0, \eta, \eta'$ in the mHSA with asymptotic distribution amplitudes. The straight lines indicate the asymptotic limit. Data are taken from [13].

The $\eta(\eta')\gamma$ transition form factors can be treated in the same manner as the pion one. However, one has to take into account properly the η-η' mixing induced by $\mathrm{SU}(3)_F$ breaking and the $\mathrm{U}(1)_A$ anomaly. The main effect in comparison with the pion are different charge factors and decay constants (*i.e.* wave functions at the origin). In the quark flavor mixing scheme advocated in [8], the asymptotic values of the form factors take the following values (see also [9])

$$Q^2 F_{\eta\gamma}(Q^2) \;\to\; \frac{5\sqrt{2}}{3}\, f_q\, \cos\phi - \frac{2}{3}\, f_s\, \sin\phi = 181 \text{ MeV}$$
$$Q^2 F_{\eta'\gamma}(Q^2) \;\to\; \frac{5\sqrt{2}}{3}\, f_q\, \sin\phi + \frac{2}{3}\, f_s\, \cos\phi = 299 \text{ MeV} \qquad (2)$$

where $f_q \simeq 1.07\, f_\pi$ and $f_s \simeq 1.34\, f_\pi$ denote the decay constants of $u\bar{u} + d\bar{d}$ and $s\bar{s}$ basis states, respectively, and $\phi \simeq 39^\circ$ their mixing angle. The Q^2-dependence of the form factors at intermediate values of momentum transfer is well described if the same distribution amplitudes and transverse size parameters are used as for the pion (see Fig. 1).

For the $\eta_c\gamma$ for factor the situation is a bit different: At values of the momentum transfer up to $Q^2 = 10$ GeV^2, where one expects experimental data in the near future [1], one has to take into account the heavy charm quark mass, which provides the large scale in the perturbative calculation. The distribution amplitude for heavy quarks is expected to be concentrated around $x = 1/2$, and one therefore chooses a Bauer–Stech–Wirbel [10] type of wave function $\phi_{BSW}(x) \propto \exp[-a^2\, M_{\eta_c}^2\, (x - 1/2)^2]$. Reasonable values for the size parameter a can be obtained by relating it to the probability $P_{c\bar{c}}$ of finding a $c\bar{c}$ Fock state inside the η_c meson which should be close to one. For $P_{c\bar{c}} = 0.8$ one finds $a \simeq 1/\text{GeV}$ [11]. Finally, for heavy quarks the Sudakov factor can be set to unity, and up to corrections of order $1/m_c^4$ one finds the approximate formula [11]

$$F_{\eta_c\gamma}(Q^2) \;\simeq\; \frac{F_{\eta_c\gamma}(0)}{1 + \frac{Q^2}{M_{\eta_c}^2 + 1/a^2}} \tag{3}$$

which reveals that, to a very good approximation, the shape of the form factor is rather insensitive to the details of the wave function. The value of the form factor at zero momentum transfer is related to the decay of the η_c into two real photons $\Gamma[\eta_c \to \gamma\gamma] = \pi\, \alpha^2\, M_{\eta_c}^3\, |F_{\eta_c\gamma}(0)|^2/4$, the experimental value of which still suffers from large uncertainties [12]. On the other hand, in the non-relativistic limit one has $F_{\eta_c\gamma}(0) = 4\, e_c^2\, f_{\eta_c}$ with $f_{\eta_c} \simeq f_{J/\psi} = 405 \pm 15$ MeV [12]. However, α_s and relativistic corrections are large. It is to be mentioned that for large momentum transfers $Q^2 \gg M_{\eta_c}^2$ also the distribution amplitude of the η_c meson evolves into the asymptotic one, and consequently the form factor behaves asymptotically as $Q^2\, F_{\eta_c\gamma}(Q^2) \to 8\, f_{\eta_c}/3$.

REFERENCES

[1] P. Aurenche *et al.*, (1996), hep-ph/9601317.

[2] G.P. Lepage, S.J. Brodsky, *Phys. Rev.* **D22**, 2157 (1980).

[3] I.V. Musatov, A.V. Radyushkin, *Phys. Rev.* **D56**, 2713 (1997).

[4] J. Botts, G. Sterman, *Nucl. Phys.* **B325**, 62 (1989).

[5] M. Dahm, R. Jakob, P. Kroll, *Z. Phys.* **C68**, 595 (1995).

[6] P. Kroll, M. Raulfs, *Phys. Lett.* **B387**, 848 (1996).

[7] T. Feldmann, P. Kroll, hep-ph/9711231, to be published in *Eur. Phys. J.* **C**.

[8] T. Feldmann, P. Kroll, B. Stech, hep-ph/9802409 (1998), submitted to *Phys. Rev.* **D**.

[9] T. Feldmann, P. Kroll, hep-ph/9805294 (1998), to be published in *Phys. Rev.* **D**.

[10] M. Wirbel, B. Stech, M. Bauer, *Z. Phys.* **C29**, 637 (1985).

[11] T. Feldmann, P. Kroll, *Phys. Lett.* **B413**, 410 (1997).

[12] Particle Data Group, R.M. Barnett *et al.*, *Phys. Rev.* **D54**, 1 (1996).

[13] CLEO collaboration, J. Gronberg *et al.*, *Phys. Rev.* **D57**, 33 (1998); L3 collaboration, M. Acciarri *et al.*, preprint CERN-PPE/97-110 (1997); CELLO collaboration, H.J. Behrend *et al.*, *Z. Phys.* **C49**, 401 (1991); TPC/2γ collaboration, H. Aihara *et al.*, *Phys. Rev. Lett.* **64**, 172 (1990); PLUTO collaboration, C. Berger *et al.*, *Phys. Lett.* **142B**, 125 (1984).