Impact of γV-vertex corrections on the $\omega\pi^0\gamma$ and $\phi\pi^0\gamma$ transition form factors

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The aim of the present work is to present an effective field theory description of the conversion transition of the vector meson V into the pseudoscalar P and the lepton pair l^+l^-. The lepton pair is produced by the virtual photon γ^*: $V \to P\gamma^* \to Pl^+l^-$. The most recent information on the former process comes from the CERN SPS experiment NA 60 [1]. The knowledge given by Novosibirsk experiment CMD-2 [2] is less precise. The measured quantity is the transition form factor $\mathcal{F}_{V\to P\gamma^*}(Q^2)$ as a function of the lepton-pair invariant mass $Q^2 \equiv M_{l^+l^-} \equiv M_{\gamma^*}$. The most recent theoretical advances in the modeling of the $VP\gamma^*$ transition form factors [3-5] were partly motivated by a drastic discrepancy between a novel CERN SPS NA 60 experiment data and a naive VMD ansatz prediction for the $\omega \to \pi^0\gamma^*$ transition form factor. We would like to remark that new precise data from KLOE experiment will appear soon [6] and serve as an important test of the models.

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Effective Lagrangian

For the odd-intrinsic-parity interactions of vector mesons we use chiral Lagrangian in vector formulation for spin-1 fields [7, 8]. The Lagrangian terms relevant for the calculation of $\mathcal{F}_{V\to P\gamma^*}(Q^2)$:

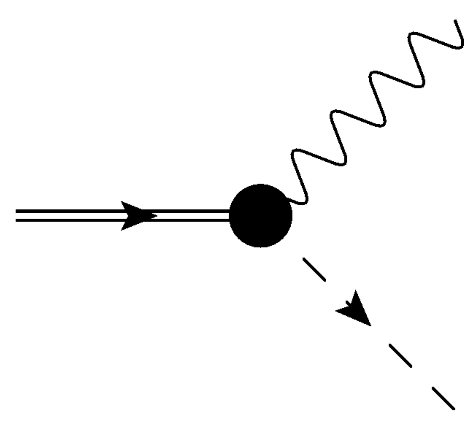
- $\mathcal{L}_{\gamma V} = -ef_V\partial^\mu B^\nu(\tilde{\rho}^0_{\mu\nu} + \frac{1}{3}\tilde{\omega}_{\mu\nu} - \frac{\sqrt{2}}{3}\tilde{\phi}_{\mu\nu})$,

  where $\tilde{V}_{\mu\nu} \equiv \partial_\mu V_\nu - \partial_\nu V_\mu$;
- $\mathcal{L}_{V\gamma\pi^0} = -\frac{4\sqrt{2}eh_V}{3f_\pi}\epsilon^{\mu\nu\alpha\beta}\partial_\mu B_\nu \times(\rho^0_\alpha + 3\omega_\alpha + 3\epsilon_{\omega\phi}\phi_\alpha)\partial_\beta\pi^0$;
- $\mathcal{L}_{\omega\rho^0\pi^0} = -\frac{4\sigma_V}{f_\pi}\epsilon^{\mu\nu\alpha\beta}\partial_\mu\omega_\nu\pi^0\partial_\alpha\rho^0_\beta$,

  where $\epsilon^{\mu\nu\alpha\beta}$ is the totally antisymmetric Levi-Civita tensor,
  $f_\pi = 92.4$ MeV is the pion decay constant.
- Short-distance constraint [9]:

$$\sqrt{2}h_V - \sigma_V f_V = 0\,.$$

Radiative decays $V \to \pi^0\gamma$



- These decays provide an access to the value of the model parameter h_V via the partial width:

$$\Gamma(\omega \to \pi^0\gamma) = \frac{4\alpha M_\omega^3 {h_V}^2}{3f_\pi^2}\left(1 - \frac{m_\pi^2}{M_\omega^2}\right)^3$$

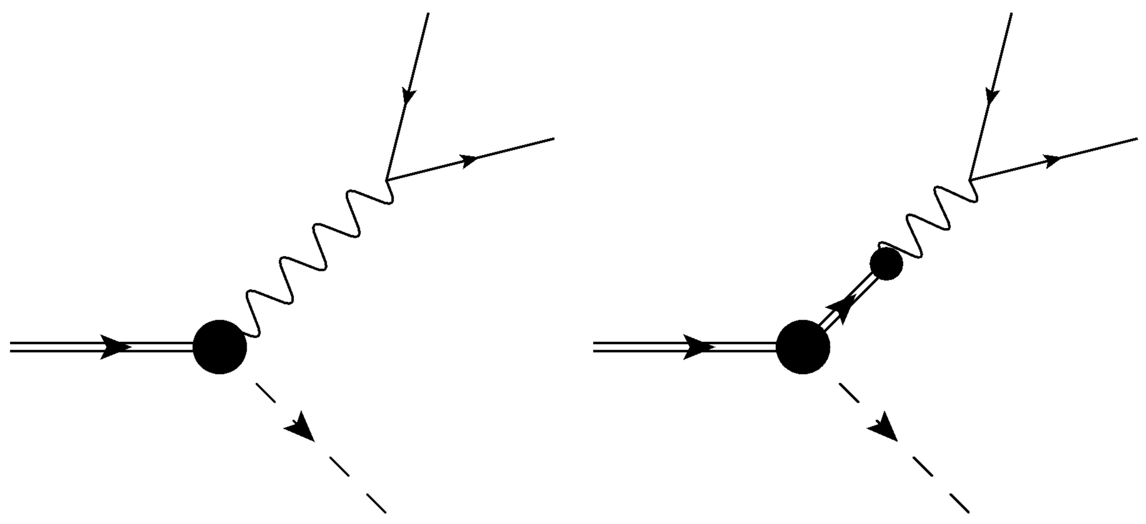
- The PDG value for widths [10]
  $\Gamma(\rho^0 \to \pi^0\gamma) = (89.46 \pm 11.94)$ keV
  $\Gamma(\omega \to \pi^0\gamma) = (702.97 \pm 24.67)$ keV
  roughly follow the SU(3) prediction of its ratio.
  The extracted coupling constant is

$$h_V = 0.041 \pm 0.003.$$

OZI-forbidden process

- The $\phi \to \pi^0\gamma$ decay width vanishes as long as the ϕ-meson is a pure $s\bar{s}$ state. The measured width $\Gamma(\phi \to \pi^0\gamma) = (5.41 \pm 0.26)$ keV is, however, significantly different from zero.
- Thus $\omega\phi$-mixing ansatz may be assumed and compared with the data. Estimated mixing parameter: $\varepsilon_{\omega\phi} = (5.79 \pm 0.17) \times 10^{-2}$.

Conversion decays $V \to \pi^0\gamma^* \to \pi^0 l^+l^-$



- The transition form factors can be extracted from the lepton-pair invariant mass spectrum $\frac{d\Gamma(V\to P\gamma^*)}{dQ^2}$, where $\sqrt{Q^2} \equiv M_{\gamma^*} \equiv M_{l^+l^-}$.
- Experimentally only the normalized FF's are known:

$$F_{V\to P\gamma^*}(Q^2) = \frac{\mathcal{F}_{V\to P\gamma^*}(Q^2)}{\mathcal{F}_{V\to P\gamma^*}(0)}\,.$$

- We include the direct $\omega\pi^0\gamma$-coupling and subsequent $\rho\gamma$ conversion contributing to the **Dalitz decay** $\omega \to \pi^0\mu^+\mu^-$. According to the Lagrangian terms, the form factor:

$$F_{\omega\pi^0\gamma^*}(Q^2) = 1 - \frac{\sigma_V f_\rho(Q^2)}{\sqrt{2}h_V}Q^2 D_\rho(Q^2)\,.$$

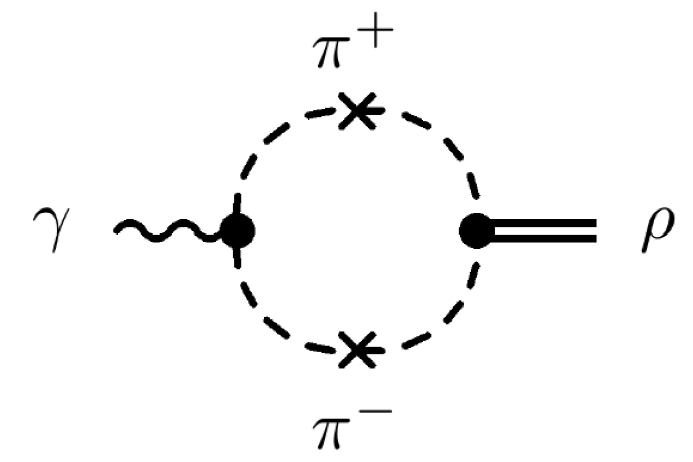
- An additional energy dependence of the EM coupling $f_\rho(Q^2)$ arises due to higher-order corrections. The ρ-meson propagator is

$$D_\rho(Q^2) = \left[Q^2 - M_\rho^2 - \Pi_\rho(Q^2)\right]^{-1},$$

  where $\Pi_\rho(Q^2)$ is the self-energy operator.

EM vertex modification

- In the region of interest the most important contribution to $\Pi_\rho(Q^2)$ consist of the pion loop vertex correction to $\gamma\rho$ coupling [11]:



- In the following we include only the **imaginary** part of the loop contribution. This will be the dominant term for the energy-dependent width

$$\Gamma_{tot,\rho}(Q^2) = -M_\rho^{-1}\,\mathrm{Im}\,\Pi_\rho(Q^2)\,.$$

- The equation for the modified EM coupling:

$$f_\rho(Q^2) = f_V - \frac{\imath}{e\,Q^2}\sum_c \mathrm{Im}\Pi_{\gamma(\pi\pi)\rho}(Q^2)\,,$$

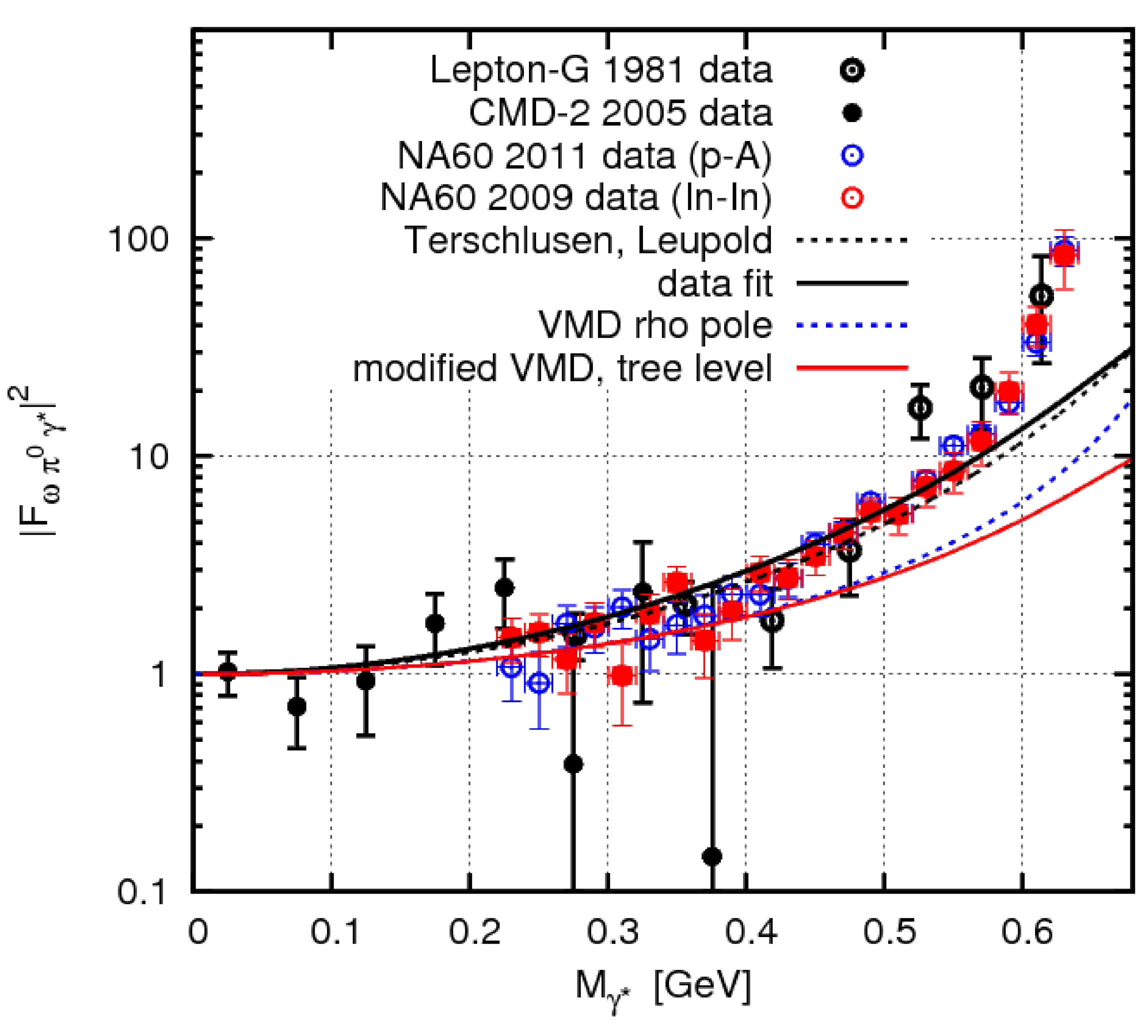
  The coupling constant f_V could be found from

$$\Gamma(\rho^0 \to e^+e^-) = \frac{e^4 M_\rho}{12\pi}\left[f_\rho(Q^2 = M_\rho^2)\right]^2.$$

  According to the PDG value for the width:

$$f_V = 0.20173 \pm 0.00086.$$

Results



Summary

- Strong contradiction with the data in the region of $M^*_\gamma > 0.4$ GeV. The γV vertex modification does not improve the result.
- We look forward to develop a more realistic model.