Electromagnetic Transition Form Factors of Mesons

Carla Terschlüsen

Department of Physics and Astronomy
Uppsala University

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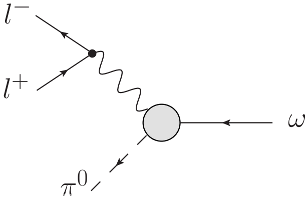
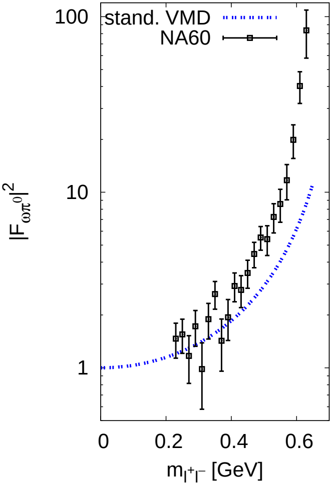
Motivation

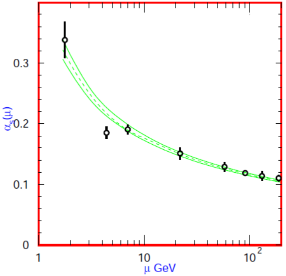




R. Arnaldi *et al* (NA60), Phys.Lett. **B677**, 260 (2009)

Standard vector meson dominance (VMD) fails to describe the data

Problem in QCD



PDG, J. Phys. **G33**, 1 (2006)

Running coupling constant in QCD

- high energies:
  can use perturbation theory
- low energies:
  cannot use perturbation theory

Possible solution:

effective theories
$\hookrightarrow$ hadrons as relevant degrees of freedom

Effective theories for light mesons

Calculation of hadronic reactions and decays:

- low-energy region: Chiral perturbation theory (ChPT)
  - Goldstone bosons (π, K, η) only active degrees of freedom
  - vector mesons are heavy

  $\Rightarrow$ not applicable for energy range of hadronic resonances (ρ, ω, K^*, ϕ)

- energy range of hadronic resonances:

  so far only phenomenologically successful models

Aim: effective field theories for higher energy range

New counting scheme for Goldstone bosons and light vector mesons

- masses of both vector mesons and pseudoscalar mesons are treated as soft, i.e. $\sim q$
- decays: all involved momenta are smaller than the mass of the decaying meson, i.e. $\sim q$

Possible justification:

other low-lying mesons are dynamically generated from interactions of Goldstone bosons and light vector mesons (hadrogenesis conjecture)

Leading-order Lagrangian

Leading-order chiral Lagrangian for the decay $V \to P\gamma^{(*)}$:

$$\mathcal{L}_{\text{indir.}} = -\frac{1}{16f} h_A \, \varepsilon^{\mu\nu\alpha\beta} \, \text{tr}\{[V_{\mu\nu}, (\partial^\tau V_{\tau\alpha})]_+ \, \partial_\beta \Phi\} - \frac{1}{16f} b_A \, \varepsilon^{\mu\nu\alpha\beta} \, \text{tr}\{[V_{\mu\nu}, V_{\alpha\beta}]_+ \, [\Phi, \chi_0]_+\} - \frac{e_V m_V}{4} \, \text{tr}\{V^{\mu\nu} Q \, \partial_\mu A_\nu\}$$

$\Rightarrow$ only decays via virtual vector mesons allowed

Decay photon into dilepton: usual QED

Uncertainties of our method

Rough estimate: one particular next-to-leading-order term

$$\mathcal{L}_{\text{dir.}} = -\frac{1}{4fm_V}\, e_A\, \varepsilon^{\mu\nu\alpha\beta}\, \text{tr}\{[Q, (\partial^\tau V_{\tau\alpha})]_+\, \partial_\beta \Phi\, \partial_\mu A_\nu\}$$

$\Rightarrow$ direct decay $V \to P\gamma^{(*)}$

Parameters fixed by two-body decays $V \to P\gamma$

$\hookrightarrow$ parameter sets (P1) with $e_A = 0$ and (P2) with $e_A \neq 0$

For decays into dileptons: no additional parameters needed

$\Rightarrow$ predictive power

Decay $\omega \to \pi^0 \, l^+ l^-$

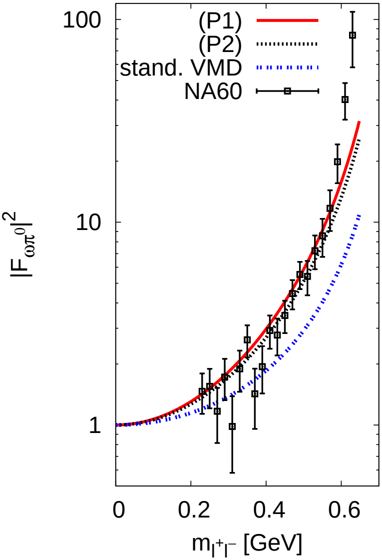
Isospin conservation: decay only possible via virtual ρ^0-meson

$\Rightarrow$ standard VMD (with invariant mass $|q|$ of the dilepton):

$$F^{\mathrm{VMD}}_{\omega\pi^0}(q) = \frac{m_\rho^2}{m_\rho^2 - q^2}$$

$\hookrightarrow$ our calculations yield an additional constant term:

$$F_{\omega\pi^0}(q) \sim -h_A + \frac{\left(m_\omega^2 + m_\rho^2\right) h_A - 8\, b_A\, m_\pi^2}{m_\rho^2 - q^2}$$



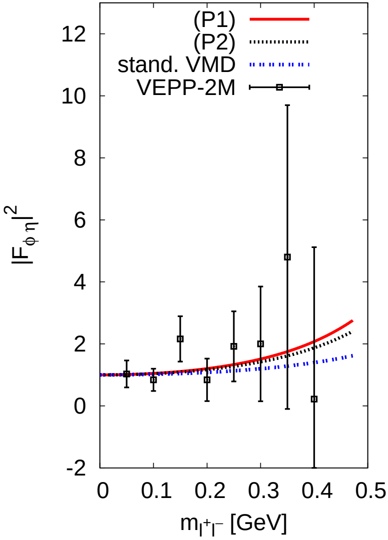
- data taken by NA60 for decay $\omega \to \pi^0 \mu^+ \mu^-$
- standard VMD fails to explain data
- our calculations miss only the last three data points

$$\Gamma_{\omega\to\pi^0\mu^+\mu^-} = (9.85 \pm 0.58) \cdot 10^{-7}\,\text{GeV}$$
$$\Gamma^{\text{exp.}}_{\omega\to\pi^0\mu^+\mu^-} = (8.15 \pm 2.13) \cdot 10^{-7}\,\text{GeV}$$

$$\Gamma_{\omega\to\pi^0 e^+e^-} = (6.93 \pm 0.09) \cdot 10^{-6}\,\text{GeV}$$
$$\Gamma^{\text{exp.}}_{\omega\to\pi^0 e^+e^-} = (6.54 \pm 0.54) \cdot 10^{-6}\,\text{GeV}$$

Data: R. Arnaldi *et al* (NA60), Phys.Lett. **B677**, 260 (2009)
Theory: C.T., S. Leupold, Phys. Lett. **B691**, 191 (2010)

Decay $\phi \to \eta e^+ e^-$



Relatively large error bars
$\rightarrow$ no assessment possible

$$\Gamma_{\phi\to\eta e^+e^-} = (4.64 \pm 0.26)\cdot 10^{-7}\ \text{GeV}$$
$$\Gamma^{\text{exp.}}_{\phi\to\eta e^+e^-} = (4.90 \pm 0.47)\cdot 10^{-7}\ \text{GeV}$$

Prediction:

$$\Gamma_{\phi\to\eta\mu^+\mu^-} = (2.75 \pm 0.29)\cdot 10^{-8}\ \text{GeV}$$

Data: M.N. Achasov *et al.*, Phys.Lett. **B504**, 275 (2001)
Theory: C.T., S. Leupold, Phys. Lett. **B691**, 191 (2010)

Summary and Outlook

Transition $\omega \to \pi^0$ and $\phi \to \eta$:

- form factor data well described
  $\hookrightarrow$ $\omega \to \pi^0$ form factor much better described than with VMD
- widths agree well with experimental ones

Outlook:

- systematic inclusion of η' meson
- next-to-leading-order calculations

Thanks for your attention.

Backup

$$V_{\mu\nu} = \begin{pmatrix} \rho^0_{\mu\nu} + \omega_{\mu\nu} & \sqrt{2}\rho^+_{\mu\nu} & \sqrt{2}K^+_{\mu\nu} \\ \sqrt{2}\rho^-_{\mu\nu} & -\rho^0_{\mu\nu} + \omega_{\mu\nu} & \sqrt{2}K^0_{\mu\nu} \\ \sqrt{2}K^-_{\mu\nu} & \sqrt{2}\bar{K}^0_{\mu\nu} & \sqrt{2}\Phi_{\mu\nu} \end{pmatrix}$$

$$\Phi = \begin{pmatrix} \pi^0 + \frac{1}{\sqrt{3}}\eta_8 & \sqrt{2}\pi^+ & \sqrt{2}K^+ \\ \sqrt{2}\pi^- & -\pi^0 + \frac{1}{\sqrt{3}}\eta_8 & \sqrt{2}K^0 \\ \sqrt{2}K^- & \sqrt{2}\bar{K}^0 & -\frac{2}{\sqrt{3}}\eta_8 \end{pmatrix} + \sqrt{\frac{2}{3}}\eta_1 I_{3\times 3}$$

$$\chi_0 = \begin{pmatrix} \bar{m}_\pi^2 & 0 & 0 \\ 0 & \bar{m}_\pi^2 & 0 \\ 0 & 0 & 2\bar{m}_K^2 - \bar{m}_\pi^2 \end{pmatrix}$$

$$Q = \begin{pmatrix} \frac{2}{3} & 0 & 0 \\ 0 & -\frac{1}{3} & 0 \\ 0 & 0 & -\frac{1}{3} \end{pmatrix}$$

Form factor for the $\phi \to \eta$ transition:

$$f_{\phi\eta}(q) = \frac{2m_\phi}{3\sqrt{6} f m_V e} \left[-e_A - 2b_A e_V m_V^2 \frac{2\bar{m}_K^2 - \bar{m}_\pi^2}{m_\phi^2} S_\phi(q^2) \right. \\ \left. + \frac{1}{4} e_V h_A m_V^2 \left(1 + \frac{q^2}{m_\phi^2} \right) S_\phi(q^2) \right]$$

Results

Decay of vector mesons (predictions):

$$\omega \to \eta\mu^+\mu^- :$$
$$\Gamma^{\text{calc}} = (8.51 \pm 0.01) \cdot 10^{-12} \text{ GeV}$$

$$\omega \to \eta e^+e^- :$$
$$\Gamma^{\text{calc}} = (2.72 \pm 0.09) \cdot 10^{-8} \text{ GeV}$$

$$\phi \to \eta\mu^+\mu^- :$$
$$\Gamma^{\text{calc}} = (2.75 \pm 0.29) \cdot 10^{-8} \text{ GeV}$$