Revisiting the Vector Dominance Model in Radiative Vector-Meson Decays

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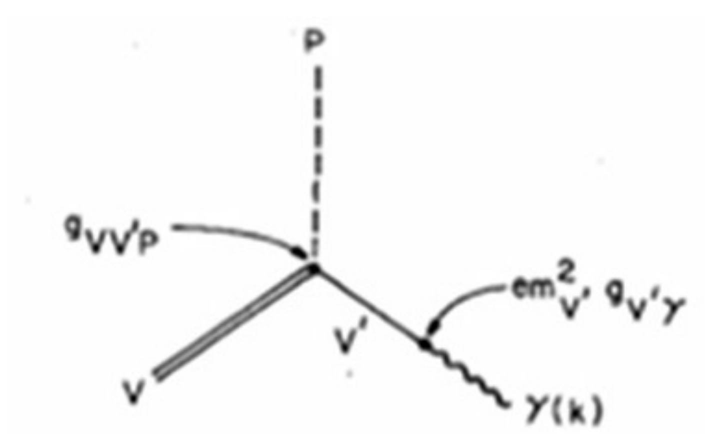
Vector Dominance Model (VDM) and Hadronic Physics

Hadrons are particles made up of quarks and gluons. To investigate their quark-gluon structure, we can study the decay properties of hadrons. When these decays result in a gamma ray or photon, they are called radiative decays. By examining different wavelengths of the outgoing photon, which correlate to the momentum dependence, the structure of the decay process can be investigated. A baseline theoretical model for describing radiative decays is the Vector Dominance Model (VDM)[1].



Here we focus on decays of vector-mesons (V) into a pseudoscalar-meson (P) (relatively stable particle) and photons (γ(k)). It's also possible for the photon to decay further into a pair of leptons ($e^+ e^-$, $\mu^+ \mu^-$, etc.), in which case the mass range of the leptons is used to probe the hadronic structure.

The VDM is distinguished by its coupling: characterised by the incoming meson decaying into a pseudoscalar and an intermediate vector-meson (V'). This intermediate vector-meson gives rise to the VDM form factor. Radiative Decays that have been studied using the VDM include: ω -> πγ, ρ -> πγ, ω -> ηγ, ρ -> ηγ, η -> $\mu^+\mu^-\gamma$.

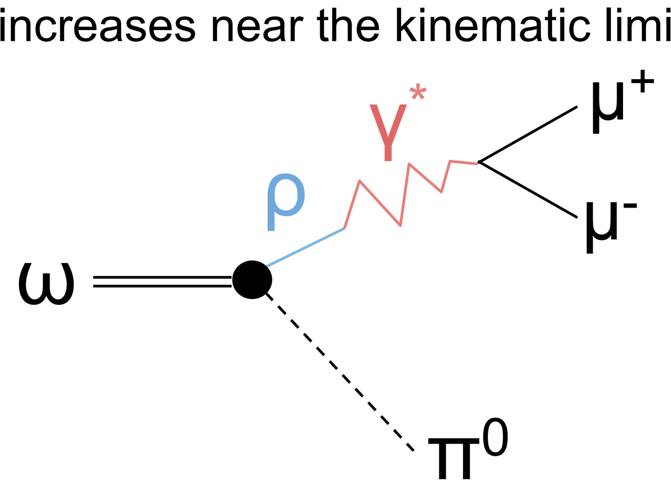
In this work we focus on the Dalitz decay ω -> $\mu^+\mu^-\pi^0$

The ω Anomaly

$u\bar{u}$

$d\bar{d}$

The ω-meson is made of an up and anti-up quark pair or a down and anti-down quark pair. It turns out that the radiative decay of the ω-meson significantly deviates from the expectation of the VDM, see Fig. 1A, especially after recent experiments[2] where this process was measured more precisely. The expectation of the VDM differs from the experimental spectra by a factor of ~10 as the momentum increases near the kinematic limit of the decay.



Our goal is to revisit the results of the VDM for this ω decay mode. We approached this problem by simulating the finite size of the ωρπ vertex with a hadronic form factor.

Form Factors and Calculations

In the VDM, only the intermediate vector-meson contributes to the form factor. For our ω -> $\mu^+\mu^-\pi^0$ decay it is given by:

$$|F_{VDM}|^2 = |D_\rho|^2 |m_\rho|^4$$

where V' = ρ, m_ρ is the ρ mass, and D_ρ is the ρ propagator,

$$D_\rho = \frac{1}{M^2 - m_\rho^2 + iM\Gamma_\rho} \quad \text{with} \quad \Gamma_\rho = \Gamma_\rho^{(0)} \left(\frac{|\vec{p}|}{|\vec{p_0}|}\right)^3 \left(\frac{m_\rho}{M}\right)^2$$

This represents the width and momentum components of the ρ: Γ_ρ, a schematic mass dependent ρ width and M, the invariant mass of the muon pair (virtual photon).

Next, we included a hadronic form factor on top of the baseline VDM,

$$|F_\omega|^2 = |D_\rho|^2 |m_\rho|^4 |F_{\omega\rho\pi}|^2$$

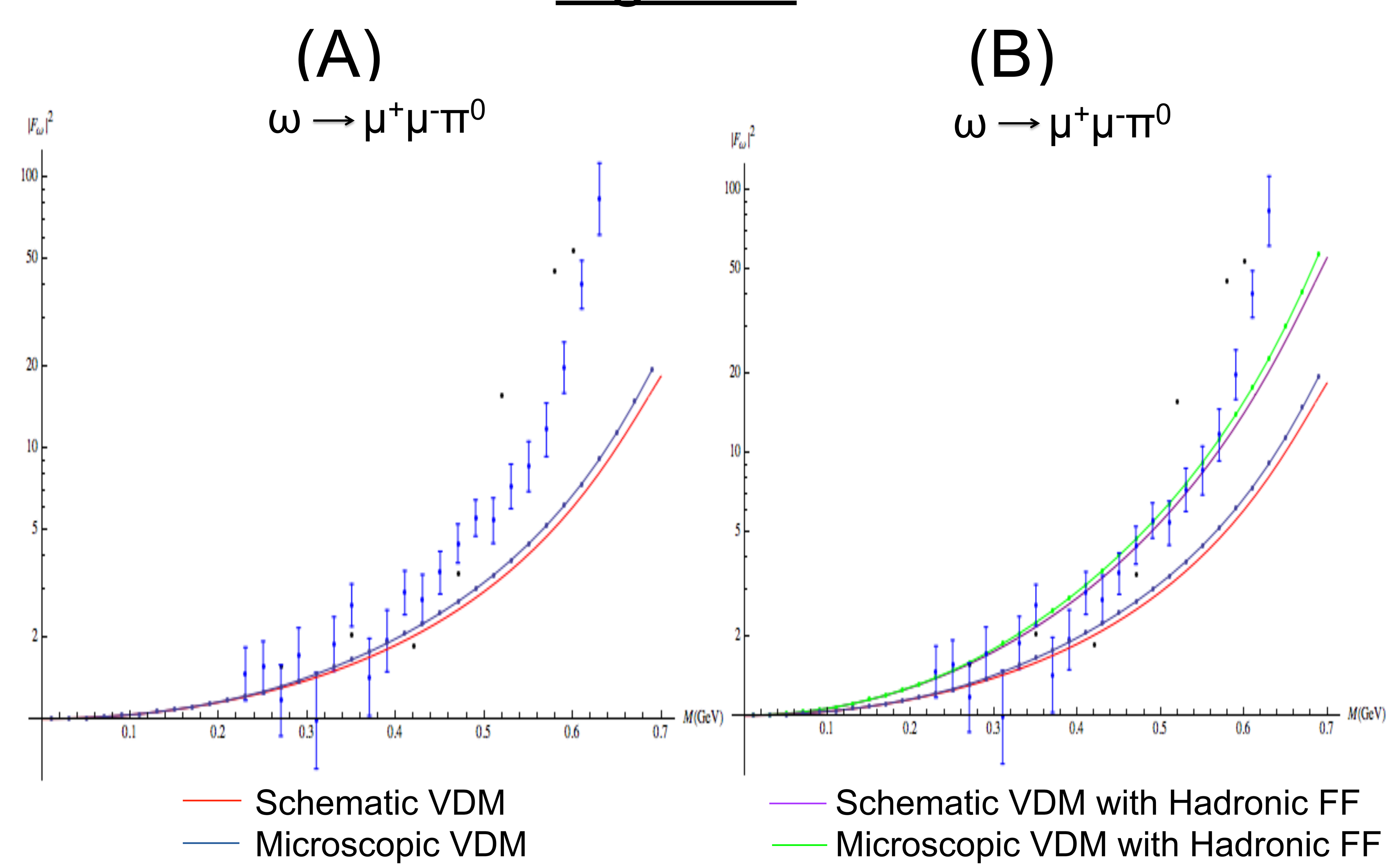
The hadronic form factor, $F_{\omega\rho\pi}$ was introduced previously[3] for the ω -> πγ decay as:

$$F_{\omega\rho\pi} = \left(\frac{2\Lambda_{\rho\pi}^2 + m_\omega^2}{2\Lambda_{\rho\pi}^2 + [\omega_\rho(q_{cm}) + \omega_\pi(q_{cm})]^2}\right)^2$$

where the cutoff parameter, $\Lambda_{\rho\pi}$= 1 GeV, encodes the size of the VV'P decay vertex.The effect of the hadronic form factor on the baseline VDM is shown by Fig. 1B.

Results

Figure 1



Data from the Lepton-G[5] experiment and the CERN-SPS NA60 Collaboration[2] compared to the VDM calculations. A) Shows the bare VDM (red line) and the VDM with the microscopic ρ width. B) Shows the improvement in the VDM with the addition of the hadronic form factor.

Discussion

The baseline VDM (Fig. 1A) begins to underestimate the NA60 data at M > 0.45 GeV. We achieved a small improvement by replacing the schematic ρ width with a microscopic model of the ρ in the vacuum.

Since the ρ, ω, and π are all composite particles, the vertex between them should have structure, which is modeled by the hadronic form factor, $F_{\omega\rho\pi}$.

With the addition of the hadronic form factor, the bare VDM is significantly improved, especially as the invariant mass of the muon pair approaches the kinematic limit, M = (m_ω - m_π) = 0.647 GeV.

Conclusion

In summary, our work shows that hadronic form factors are a useful tool in accounting for the structure of radiative decays, and it helps to recover the description of these decays with the VDM.

References

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