Eur. Phys. J. A 4, 327–328 (1999)

THE EUROPEAN
PHYSICAL JOURNAL A

Short Note

η'q$\bar{\text{q}}$ and η'NN vertex suppression in effective theories

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Received: 8 January 1999
Communicated by W. Weise

Abstract. In an effective theory containing only quark degrees of freedom, such as the extended Nambu–Jona–Lasinio model, the influence of the axial anomaly can be incorporated by a self-interaction of the 't Hooft determinant type. I will show that despite the threshold problem related to the η' meson this leads to a significant suppression of the η' coupling $g_{\eta'\mathrm{q}\bar{\mathrm{q}}}$ to dynamical quarks which suggests a suppression of the η'NN vertex as compared to the ηNN vertex.

PACS. 13.75-n Hadron-induced low- and intermediate-energy reactions and scattering – 14.40.Cs Other mesons with S=C=0, mass < 2.5 GeV – 12.39-x Phenomenological quark models

The recent experimental efforts in η' electro- and photoproduction in facilities like ELSA, JLAB, DAΦNE, and GRAAL as well the recent close to threshold pp $\rightarrow$ ppη' production results of COSY-11 [1] have increased the interest in η' interaction properties. So far, only little is known about the η'NN vertex, both theoretically and experimentally. In effective meson theories the vertex is *parametrized* through a single coupling constant $g_{\eta'\mathrm{NN}}$ ($1.9 \leq g_{\eta'\mathrm{NN}} \leq 6.2$, see e.g. [2]) rather than predicted from an underlying dynamics.

As is well-known, the η' meson differs significantly in its mass from the pseudo-scalar octet mesons. This comes about, since the η' is predominantly a flavor-singlet, and the axial anomaly of QCD breaks the axial U(1) symmetry, preventing the η' from being a pseudo-Goldstone boson unlike its octet counterparts. It is therefore very likely that the axial anomaly has also a significant influence on the interaction properties of the η' particle, e.g. on the η'NN vertex.

Since a direct calculation of the coupling in QCD is presently not feasable, one has to resort to specific models. A model that has proven both tractable and phenomenologically successful in describing properties of low-lying mesons is the three flavor extended Nambu–Jona–Lasinio (ENJL) model (see e.g. [3–5] for a review). It not only exhibits the chiral symmetry breaking aspects of the pseudo-scalar octet mesons but also allows a direct inclusion of the $\mathrm{U}(1)_\mathrm{A}$ breaking effects of the axial anomaly. The later is taken into account by an additional local six-fermion self-interaction of the 't Hooft determinant type [7] and turned out to be of crucial importance for the η and η' mesons. While the ENJL model has been successfully applied to the η meson, see e.g. [8], it has rarely been applied to the flavor singlet η', since the lack of confinement, one of the major shortcomings of the model, will cause the η' meson to lie above the q$\bar{\text{q}}$ threshold when realistic parameters are chosen. This results in unphysical decay modes $\eta' \rightarrow$ q$\bar{\text{q}}$. Thus, care is needed to identify the pole on the second Riemann sheet reasonably well, see e.g. [9,10].

In [11] it has been shown that due to the 't Hooft interaction the η'-quark coupling $g_{\eta'\mathrm{q}\bar{\mathrm{q}}}$ is significantly suppressed compared to the other pseudo-scalar mesons. However, no particular attention has been paid to the theshold problem. When realistic parameters are chosen, quite some imaginary part is obtained in $g_{\eta'\mathrm{q}\bar{\mathrm{q}}}$ which reflects the unphysical decay mode $\eta' \rightarrow$ q$\bar{\text{q}}$. The main result of this note is to demonstrate that the observed suppression is indeed physically sensible and not just a threshold artifact. For that purpose I investigated [6] a chirally symmetric version of the model with a dynamical quark mass of 407 MeV. Here a wide η' mass range of about 800 MeV can be covered *without* encountering threshold effects. The results shown in Fig. 1 conclusively support the singlet ($g_{\eta'\mathrm{q}\bar{\mathrm{q}}}$) suppression compared to the (constant) octet coupling. A threshold artifact thus seems to be ruled out.

We have to be aware that the observed η' suppression *a priori* depends crucially on our model choice. It is therefore essential to discuss in how far this is believed to hold in QCD as well. To this end, note that the origin of the $g_{\eta'\mathrm{q}\bar{\mathrm{q}}}$ suppression in the ENJL model is a destructive interference between the attractive part of the

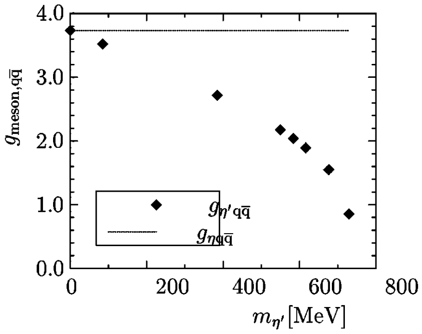

Fig. 1. Suppression of the $\eta'q\bar{q}$ coupling (diamonds) in dependence of the η' mass in the chirally symmetric ENJL model. The line indicates the constant value for the octet mesons. (Data taken from [6])

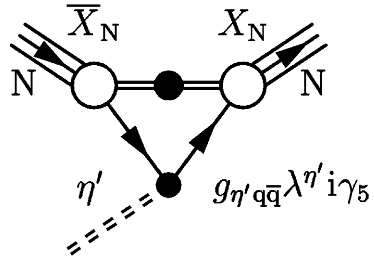

Fig. 2. Leading contribution to the η'NN vertex in an effective meson-quark theory. The double line denotes the scalar diquark propagator, while X_{N} and $\overline{X}_{\mathrm{N}}$ are nucleon-quark-diquark vertices

standard four-fermion interaction and the (in the flavor-singlet channel) *repulsive* 't Hooft interaction. In the octet sector in contrast, the 't Hooft interaction acts attractive, conspiring with the four-fermion interaction to fulfill Goldstone's theorem in the chiral limit.[1] A destructive interference mechanism, however, strongly supports the *model independence* of my conclusions, since in any description of the pseudo-scalar meson sector the axial anomaly will contribute repulsively in the singlet ($\approx \eta'$) channel to account for the η' mass, while an attractive part is most likely present and responsible for the binding of the flavor-octet pseudo-Goldstone bosons and essentially compensates the large constituent quark masses. The suppression is important for the physically observable η'NN vertex, which may be calculated within the ENJL model to leading order as shown in Fig. 2. The nucleon can be described by solving the relativistic Faddeev equations in the quark-diquark picture with a quark-exchange interaction, following the approaches of [12,13]. An even simpler approximation consists in the static approximation [6,14], i.e. assuming the exchanged quark to be infinitely heavy. Since the nucleon-quark-diquark vertices are not sensitive neither to the 't Hooft interaction nor to the meson channel, the ratio of η'NN and ηNN vertices is in leading order determined by the ratio of meson-quark couplings,

$$\frac{\mathcal{V}_{\eta'\mathrm{NN}}}{\mathcal{V}_{\eta\mathrm{NN}}} = \frac{g_{\eta' q\bar{q}}}{g_{\eta q\bar{q}}} \frac{\sqrt{\frac{2}{3}}\cos\theta_{\eta'} + \sqrt{\frac{1}{3}}\sin\theta_{\eta'}}{-\sqrt{\frac{2}{3}}\sin\theta_{\eta} + \sqrt{\frac{1}{3}}\cos\theta_{\eta}} \approx 0.30 + 0.22\,\mathrm{i}\,. \quad (1)$$

A comparison of η' vs. π^0 productions is of similar magnitude,

$$\frac{\mathcal{V}_{\eta'\mathrm{NN}}}{\mathcal{V}_{\pi\mathrm{NN}}} \approx 0.21 - 0.15\,\mathrm{i}\ . \quad (2)$$

A suppression of the η'NN vertex conforms with claims in the literature, e.g. in the the context of the EMC effect ("spin crisis"), see [15–17,11] or at finite density [18].

[1] Of course, the axial U(1)-breaking also induces a singlet-octet mixing term, which in the absence of flavor-symmetry complicates the argumentation slightly without spoiling it.

Its a pleasure to thank F. Lenz and K. Yazaki for fruitful discussions and U.-G. Meissner and R. H. Lemmer for helpful hints. This work was supported by the Bundesministerium für Bildung und Forschung (BMBF) under grant 06 ER 809.

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