Scalar-isoscalar states in the large-N_c Regge approach

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Scalar-isoscalar states ($J^{PC} = 0^{++}$) are investigated within the large-N_c Regge approach. We elaborate on the consequences of including the lightest $f_0(600)$ scalar-isoscalar state into such an analysis, where the position of $f_0(600)$ fits very well into the pattern of the radial Regge trajectory. Furthermore, we point out that the pion and nucleon spin-0 gravitational form factors, recently measured on the lattice, provide valuable information on the low-mass spectrum of the scalar-isoscalar states on the basis of the scalar-meson dominance in the spin-0 channel. Through the fits to these data we find $m_\sigma = 450 - 600$ MeV. We compare the predictions of various fits and methods. An analysis of the QCD condensates in the two-point correlators provides further constraints on the parameters of the scalar-isoscalar sector. We find that a simple two-state model suggests a meson nature of $f_0(600)$, and a glueball nature of $f_0(980)$, which naturally explains the ratios of various coupling constants. Finally, we note that the fine-tuned condition of the vanishing dimension-2 condensate in the Regge approach with infinitely many scalar-isoscalar states yields a reasonable value for the mass of the lighest glueball state.

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I. INTRODUCTION

The history and status of the σ-meson has been quite vacillating (for reviews see e.g. [1–3] and references therein). A scalar-isoscalar state with a mass of $\sim$ 500 MeV was originally proposed in the fifties [4] as an ingredient of the nucleon-nucleon force providing saturation and binding in nuclei. Along the years, there has always been some arbitrariness in the "effective" or "fictitious" σ meson mass and the coupling constant to the nucleon, partly due to the lack of other sources of information. For instance, in the very successful Charge Dependent (CD) Bonn NN-potential [5], any partial wave $^{2S+1}L_J$-channel is fitted with a different scalar-isoscalar meson mass and coupling. The σ-meson was also introduced as the chiral partner of the pion to account for spontaneous breaking of the chiral symmetry [6]. The lack of confidence in its existence motivated taking its mass to infinity, yielding the non-linear sigma model [7], which is the modern starting point for the Chiral Perturbation Theory [8].

During the last decade, the situation has steadily changed, and the σ-meson has been finally resurrected [9], culminating with the inclusion of the 0^{++} resonance in the Particle Data Group review (PDG) [10] as the $f_0(600)$ state, seen as a $\pi\pi$ resonance. It has widespread values for the mass, $400 - 1200$ MeV, and for the width, $600 - 1200$ MeV [11]. A rigorous definition of the σ as a $\pi\pi$ resonance requires that it be a pole of the $\pi\pi$ scattering amplitude in the $(J,T) = (0,0)$ channel in the second Riemann sheet in the Mandelstam variable s. Within such a framework, the uncertainties have recently been narrowly sharpened with a benchmark determination based on the Roy equations with constraints from the chiral symmetry [12], yielding the value [1]

$$m_\sigma - i\Gamma_\sigma/2 = 441^{+16}_{-8} - i272^{+9}_{-12} \text{ MeV}. \qquad (1)$$

The analysis of Ref. [13] yields a result with somewhat higher m_σ, $473 \pm 6 \pm 11 - i257 \pm 5 \pm 2$ MeV (with the errors statistical and systematic, respectively), while the unitarized Chiral Perturbation Theory (χPT) gives a bit lower value of the mass, $401^{+12}_{-16} - i277^{+23}_{-26}$ MeV [14]. Nevertheless, various determinations of the pole mass agree with the values (1) within the uncertainties. These accurate determinations make somewhat tricky the original question on *what* σ mass should be used *a priori* within a meson-exchange picture, due to the very large width of the resonance. Moreover, the determinations mentioned above do not imply necessarily the standard assignment of the linear sigma-model where one takes $(\sigma, \vec{\pi})$ as chiral partners in the $(\frac{1}{2}, \frac{1}{2})$ representation of the chiral $SU(2)_R \otimes SU(2)_L$ group. A priori, the σ state

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[1] We use this definition for the pole mass in the $\sqrt{s}$ variable. A better one is $s_\sigma = m_\sigma^2 - i\Gamma_\sigma m_\sigma$, which coincides with the previous one in the narrow resonance limit.