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CHIRAL SYMMETRY RESTORATION IN EXCITED MESONS

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Abstract

Recently the Crystal Barrel Collaboration has found many new states in the excited light meson spectrum analyzing the experimental data on proton-antiproton annihilation in the range $1.9 - 2.4\,GeV$. A large degeneracy on these states has been found and interpreted by some authors as a signal of chiral symmetry restoration . In this work we show how this large degeneracy can be reproduce in the framework of a constituent quark model with a screened confinement potential. Observables that could discriminate our model from those which explicitly restore the chiral symmetry are proposed.

Chiral symmetry and confinement are two of the most important properties of QCD to describe the hadron spectra. The absence of chiral multiplets in the low-lying hadron spectrum is a signal that chiral symmetry is spontaneously broken. In recent years it has been suggested that the physics of the excited part of the meson spectrum seems to be quite different. The partial wave analysis of the proton-antiproton annihilation into mesons at LEAR in the range 1.9-2.4 GeV has shown a large degeneracy on the spectra of the angularly and radially excited resonances [1,2]. The new results along with the well established states from the PDG [3] are shown in Fig. 1(a). One can see that as far as we move to higher excitation energy the different states become more and more degenerated. This phenomena has been shown to be compatible with a chiral symmetry restoration scenario and for some authors is a signal that chiral symmetry is effectively restored in high excited states. The spectrum has also been analyzed within a nonrelativistic description based on the relation $M^2 \sim L + n$ and can also be understood in this scenario, although different predictions for missing states from the chiral symmetry restoration scenario are found [4].

The present calculation has been performed in the framework of the constituent quark model of Ref. [5] where an extensive study of the meson spectra

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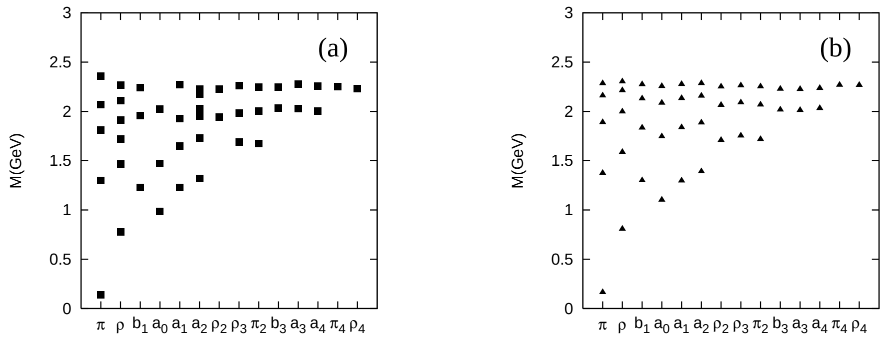

Figure 1: Light meson experimental (a) and theoretical (b) spectrum.

has been done. As a consequence of the spontaneous breaking of the original QCD $SU(3)_L \otimes SU(3)_R$ chiral symmetry, quarks acquire a dynamical mass and interact through Goldstone modes. For higher momenta perturbative QCD effects are present and we assume that quarks interact through gluon exchanges.

Lattice calculations in the quenched approximation and for heavy quarks derived a confining interaction linearly dependent on the interquark distance [6]. The consideration of sea quarks apart from valence quarks (unquenched approximation) suggests a screening effect on the potential when increasing the interquark distance. String breaking has been recently confirm in a $n_f = 2$ lattice QCD calculation [7]. The color screening can be parametrized by the potential [8]

$$V_{CON}(\mathbf{r}_{ij}) = \{-a_c\,(1 - e^{-\mu_c\, r_{ij}}) + \Delta\}(\lambda^{\mathbf{c}}{}_i \cdot \lambda^{\mathbf{c}}{}_j) \tag{1}$$

At short distances this potential presents a linear behavior with an effective confinement strength $a = -a_c\,\mu_c\,(\lambda^{\mathbf{c}}{}_i \cdot \lambda^{\mathbf{c}}{}_j)$ while it becomes constant at large distances.

Table 1: Contribution in MeV to the mass of the high excited states from the different potential pieces.

	$\pi_0(4S)$	$\rho_1(4S)$	$\pi_4(1F)$	$\rho_4(1F)$
Goldstone bosons	-7.23	-1.29	0.16	0.50
Confinement	-416.70	-330.61	-370.02	-368.76

We have taken the parameters for the quark-quark interaction from [5] except those corresponding to the confinement potential which has been fine tuned to obtain the experimental threshold. The product μa_c has not been modified to guarantee the good description of the low lying spectrum. In Fig. 1 we compare our calculation (b) with the excited state meson spectrum with isospin $I = 1$. One can see that the pattern of the degeneracy is very well reproduced using the values $a_c = 498.9\, MeV$ and $\mu = 0.603\, fm^{-1}$.

Although chiral symmetry is still broken, since no changes in the dynamical quark mass has been made, it is irrelevant on the dynamics since, as seen in Table 1, the contribution of the Goldstone bosons is almost negligible compared with those from the confinement potential.

Models in the Chiral Symmetry Restoration scenario are based on the assumption that increasing the excitation energy of an hadron one also increases the typical momentum of the valence quarks. Therefore the quark wave function is shifted to the high momentum region [9]. In our approach degeneracy comes about from the gradual decreases of the confinement potential slope and so the wave function range in coordinate space increases as the excitation energy increases.

We calculate the electronic widths using the Van Royen-Weisskopf formula with the QCD corrections taken into account [10]. The width is proportional to the wave function (w.f.) at the origin $|R_n(0)|^2$. If the typical momentum of quarks increase above the chiral symmetry breaking scale one should expect that the w.f at the origin should also increase, getting much higher leptonic widths for excited mesons.

Table 2: The leptonic widths (in keV) of highly excited states in charmonium and light mesons. Experimental data are from Ref. [3] ($\psi(2S)$) and Ref. [12].

		$\psi(nS)$	
	$2S$	$3S$	$4S$
Theory	1.71	1.07	0.74
Exp	2.10 ± 0.15	0.89±0.08	0.71 ±0.10

		$\pi(nS)$			$\rho(nS)$	
	$2S$	$3S$	$4S$	$2S$	$3S$	$4S$
Theory	0.984	0.269	0.104	0.081	0.030	0.012

In our model the behavior of the wave function at the origin is just the opposite and the leptonic widths will decrease as the excitation energy increases. This behavior is observed in the leptonic widths of heavy quarkonia and explained by the flattening of the confinement potential at distances

$r \geq 1,2fm$. [11]. In Table 2 we show the agreement of our results for the charmonium electronic widths with the experimental data. In this Table we also give our predictions for the high excitations of light mesons. The measurement of these widths in the new PANDA experiment at FAIR may give definitive arguments about the possible restoration of chiral symmetry on the high excited meson spectrum.

Acknowledgments

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