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Towards the understanding of the meson spectra

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We present a quark-quark interaction for the complete study of the meson spectra, from the light to the heavy sector. We compare the quark model predictions against well-established $q\bar{q}$ experimental data. This allows to identify discrepancies between quark model results and experiment that may signal physics beyond conventional hadron spectroscopy.

Keywords: nonrelativistic quark models; meson spectrum; scalar mesons

1. SU(3) chiral constituent quark model

Since the origin of the quark model hadrons have been considered as bound states of constituent (massive) quarks. The constituent quark mass appears as a consequence of the spontaneous breaking of the original $SU(3)_L \otimes SU(3)_R$ chiral symmetry at some momentum scale. This symmetry breaking also generates Goldstone modes that are exchanged between the constituent quarks. Explicit expressions and details of these potentials can be found elsewhere[1]. In the heavy quark sector, chiral symmetry is explicitly broken and therefore Goldstone modes do not appear.

Above the chiral symmetry breaking scale quarks still interact through gluon exchanges. Following de Rújula *et al.*[2] the one-gluon-exchange (OGE) interaction can be taken as a standard color Fermi-Breit potential. To obtain a unified description of light, strange and heavy mesons a running strong coupling constant has to be used[3]. The perturbative expression for $\alpha_s(Q^2)$ diverges when $Q \to \Lambda_{QCD}$ and therefore the coupling constant has to be frozen at low energies. This behavior is parametrized by means of an effective scale dependent strong coupling constant[1,4]. The spin-spin interaction of the OGE presents a contact term that has to be regularized in order to avoid an unbound spectrum from below. For a coulombic system the size scales with the reduced mass, what suggests to use a flavor-dependent regularization $r_0(\mu) = \hat{r}_0/\mu$[1]. Moreover the Schrödinger equation cannot be solved numerically for potentials containing $1/r^3$ terms. This is why the noncentral terms of the OGE are also regularized.

Finally, potential models have to include other nonperturbative property of QCD, confinement. Lattice QCD studies show that $q\bar{q}$ systems are well reproduced at short distances by a linear potential that it is screened at large distances due to pair creation[5]. One important question is the covariance property of confinement. While the spin-orbit splittings in heavy quark systems suggest a scalar confining potential[6], Szczepaniak and Swanson [7] showed that the Dirac structure of confinement is of vector nature in the heavy quark limit of QCD. Therefore, we write the confining interaction as an arbitrary combination of scalar and vector terms.

Using this model we have studied more than 110 states from the light to the heavy sector[1], obtaining a rather good description. We have analyzed in detail several states reported in the charm sector which do not seem to fit into a $q\bar{q}$ structure. The same applies for the light scalar sector which does not seem possible to be described using only $q\bar{q}$ states.

2. New results on charmonium physics

During the last year several new results of the $\eta_c(2S)$ mass have been reported. They are significantly larger than most predictions of constituent quark models and the previous experimental value of the PDG: $M[\eta_c(2S)] = 3594 \pm 5$ MeV[8]. We find for this state an energy of 3627 MeV, close to the new experimental value quoted by the PDG, 3637.7 ± 4.4 MeV.

BaBar has reported a narrow state near 2317 MeV called $D^*_{sJ}(2317)$[9]. This state has been confirmed by CLEO[10] together with another possible resonance around 2460 MeV. Both experiments interpret these resonances as $J^P = 0^+$ and 1^+ states. The most striking aspect of these two resonances is that their masses are much lower than expected. Our results are 2470 MeV for the $D^*_{sJ}(2317)$ and 2550 for the $D^*_{sJ}(2460)$. The other open-charm states agree reasonably well with the values of the PDG, but the two new D_s states reported by Belle and CLEO do not fit into a $q\bar{q}$ scheme.

The most recent state discovered in the charm sector is the $X(3872)$, which was reported by Belle[11] with a mass of $3872.0 \pm 0.6 \pm 0.5$ MeV and confirmed by CDF[12]. One of its most interesting features is that its energy is within the error bars of the $D^0 D^{0*}$ threshold, 3871.5 ± 0.5 MeV. Due to its experimental decays the most probable assignment for this state would be an $L = 2$ $c\bar{c}$ state, however most of the quark models predict a somewhat lower mass[13]. Our model gives 3790 MeV for the 2^{--}, 3803 MeV for the 3^{--} and 3793 MeV for the 2^{-+}, which are too low to be identified with it. Another possibility is that this state could be an excited 1^{++} $P-$wave[14], but again our prediction, 3913 MeV, does not match the experimental energy.

3. The light scalar sector

With respect to the isovector state, we find a candidate for the $a_0(980)$, the ${}^3P_0$ member of the lowest ${}^3P_J$ isovector multiplet, with and energy of 983 MeV. However, in spite of the correct description of the mass of the $a_0(980)$, the model predicts a pure light-quark content, what seems to contradict some of the observed decays. In the case of the isoscalar states, one finds a candidate for the $f_0(600)$ with a mass of 413 MeV, in the lower limit of the experimental error bar, but the $f_0(980)$ cannot be found for any combination of the parameters of the model. Concerning the $I = 1/2$ sector our model predicts a mass for the lowest 0^{++} state 200 MeV greater than the $a_0(980)$ mass. Therefore the $\kappa(800)$ cannot be explained as a $q\bar{q}$ pair.

It is worth to notice that similar conclusions has been achieved using approaches as different as chiral perturbation theory[15] or an extended Nambu-Jona-Lasinio model in an improved ladder approximation of the Bethe-Salpeter equation[16]. This seems to indicate that other corrections would not improve the situation and the conclusions remain model independent.

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