EVIDENCE ON $qqq\bar{q}$ HADRON SPECTRUM
FROM $\gamma\gamma \to$ vector meson vector meson REACTIONS

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Abstract

The $\gamma\gamma \to \rho^0\rho^0 \to 4\pi$ reaction shows a broad "resonance" at 1.5 GeV with no counterpart in the $\rho^+\rho^-$ channel. This $(J^P, J_z) = (2^+, 2)$, $I = 0$ and $2$ resonance is considered as a candidate for a $qqq\bar{q}$ state. We show, however, that it can also be explained by potential scattering of $\rho^0\rho^0$ via the $\sigma-$ exchange.

1. The Motivation

After many successes of quark models to describe a single meson or baryon, their predictive power in the two-hadron sector remains questionable. A fair description of the nucleon-nucleon interaction was accompanied with the prediction of a rich dibaryon spectrum which has never been observed. It is interesting to see how different quark models perform in the two-meson sector, as compared to mesonic models. We are also motivated by our experimental colleagues in Ljubljana (ARGUS coll.[1],[2]).

2. The Experimental "Puzzle"

The $\gamma\gamma \to \rho\rho$ reaction [1],[2] has a large and broad peak near the nominal threshold in the $\rho^0\rho^0$, $(2^+2)$ channel and a much smaller cross section in other $\rho^0\rho^0$ channels as well as in the $\rho^+\rho^-$ channel. Since so far the quark models [3] covered more features simultaneously than the effective mesonic models [4],

\[^1\]Talk presented at the International Conference on Quark Confinement and the Hadron Spectrum, Como, 20.-24.6.1994. To be published in the Proceedings.
the opinion prevails that explicit quark degrees of freedom (a \(qq\bar{q}\bar{q}\) molecule) are essential. Here we challenge this view.

3. The Hypothesis

The peak near the nominal threshold and its strong spin dependence are reminiscent of the p-n scattering at low energy. There the S=0 channel has a very high cross section while in the S=1 chanel it is much lower, because in the S=0 state the potential well contains almost exactly 1/4 wavelength of the relative wavefunction.

We hypothesize that a similar trick of nature is played also in \(\rho\rho\) scattering. We assume that both photons are converted in \(\rho\) via vector dominance, and both \(\rho\) then interact by a scalar isoscalar potential which is just strong enough to (almost) bind them for one spin orientation and fails to do so for the others. Also, an isoscalar potential cannot exchange charges and does not lead to the \(\rho^+\rho^-\) final state.

4. A Toy Potential Model

To illustrate this idea, we choose a Yukawa-type \(\sigma\)-exchange potential with the same parameters as in the Bonn potential for the nucleon-nucleon system \((g^2/4\pi = 7.07, m_\sigma = 0.55\ \text{GeV})\), but multiplying it with a factor \((\frac{3}{4})^2\) (two quarks rather than three at each vertex). Solving the nonrelativistic Schrödinger equation we showed that with a very plausible hard core \((r_c = 0.17\ \text{fm})\) a weakly bound or antibound state at \(E \sim 0\) can be obtained. If the potential is assumed to be slightly spin dependent one spin channel will have a state close to zero and other spin channels will miss it. This demonstrates that the proposed hypothesis can be realized.

5. A Relativistic Potential Model

Our starting Lagrangian is gauge invariant and respects vector dominance:

\[
\mathcal{L} = -\frac{1}{4}(\partial_\mu B_\nu - \partial_\nu B_\mu)^2 - \frac{1}{4}(\partial_\mu \rho_\nu - \partial_\nu \rho_\mu)^2 + \frac{1}{2}m_\rho^2 \rho_\mu^2 + \frac{1}{2}(\partial_\mu \sigma)^2 - \frac{1}{2}m_\sigma^2 \sigma^2 - \frac{1}{2}(\rho_\mu - \frac{e}{g} B_\mu)^2 + \frac{g_s}{2}\sigma(\partial_\mu \rho_\nu - \partial_\nu \rho_\mu)^2. \tag{1}
\]

The amplitude was calculated with the Bethe-Salpeter equation in the leading order of \(e/g\) with the \(\sigma\) exchange kernel given from Eq. (1). After the Blankenbecler-Sugar reduction \(\boxed{\text{[image]}\)} and the partial wave expansion \(\boxed{\text{[image]}\)} the integral equations for different channels were solved with the matrix inversion method \(\boxed{\text{[image]}\)}\), taking 16 points for the magnitude of the relative three-momentum from 0 to the cutoff \(\Lambda\). Assuming that the effect of different off-shellness of the
final $\rho$ is small, we got the cross section by weighing the amplitude squared with Breit-Wigner factors.

We choose for the vector dominance factor $e/g = 0.036$, which is consistent with the value obtained within a larger model from the $\rho$ and $a_1(1260)$ decay widths. The mass in the two-body propagator was chosen $m = 0.692$ GeV instead of $m = m_\rho = 0.77$ GeV, since the $\rho$ meson is broad. The results proved to be relatively insensitive to the choice of the $\sigma$ mass, so that we will report only the case $m_s = 0.5$ GeV.

The results are shown in fig. 1, for different choices of the paramaters $\Lambda$ and $g_s$ together with the experimental values. A combination of the two parameters in a reasonable range exists, which reproduces quite well the experimental results.

Some models predict, that the enhancement in the $(2^+, 2)$ channel is a universal feature of $\gamma \gamma \rightarrow 2$ vector mesons. Experimentally, there are too few events to judge. Due to the sensitivity to potential parameters in our models we predict that such enhancement is very difficult to appear in more than one case.

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FIGURES

Figure 1: Cross sections for various channels in the relativistic potential model with scalar exchange: — ($\Lambda = 2.0$ GeV, $g_s = 12.0$ GeV$^{-1}$); · · · ($\Lambda = 2.2$ GeV, $g_s = 10.4$ GeV$^{-1}$); - - ($\Lambda = 2.4$ GeV, $g_s = 9.13$ GeV$^{-1}$); experiments: • ARGUS [3], ○ ARGUS [2].
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