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POSSIBLE INTRUSION OF A GLUEBALL-CONFIGURATION IN THE SCALAR–ISOSCALAR MESON SPECTRUM * **

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We determine the hadronic two-body decay modes of the scalar–isoscalar $f_0(1370)$, $f_0(1500)$ and $f_0(1710)$ states as resulting from the mixture of the lowest lying scalar glueball with the isoscalar states of the ground state $^3P_0$ quark–antiquark ($Q\bar{Q}$) nonet. In addition we study the production properties of the f_0 states in proton–antiproton ($p\bar{p}$) annihilation reactions of the type $p\bar{p} \to \pi^0 f_0$. The quantitative predictions both for the decay and the production emphasize the role of the gluonic components in the f_0 states and its observable consequences.

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1. Introduction

The discussion on a possible evidence for the emergence of the glueball ground state has been dominantly centered on the scalar–isoscalar resonance $f_0(1500)$ [1]. This state has been clearly established by Crystal Barrel at LEAR [2] in proton–antiproton annihilation, and is also seen in central pp collisions and J/Ψ decays [3]. The main interest in the $f_0(1500)$ as a candidate reflecting the possible intrusion of a glueball state in the scalar–isoscalar meson spectrum rests on several observations. The $f_0(1500)$ is produced

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in gluon rich production mechanisms, whereas no signal is seen in $\gamma\gamma$ collisions [3]. Lattice QCD, in the quenched approximation, predicts the lightest glueball state (G_0) to be a scalar ($J^{PC} = 0^{++}$) lying in the mass range of $1.4 - 1.8$ GeV [4]. Although the decay pattern of the $f_0(1500)$ into two pseudoscalar mesons is compatible with a quarkonium state $n\bar{n} \equiv 1/\sqrt{2}\,(u\bar{u}+d\bar{d})$ in the scalar $Q\bar{Q}$ nonet, the observed total width of $\Gamma \approx 120$ MeV is in conflict with naive quark model expectations of $\Gamma \geq 500$ MeV [1,5]. Moreover, it is now believed [2], that the $f_0(1370)$ state occupies the corresponding position in the scalar nonet. In the analysis of the partial decay widths into two pseudoscalar mesons, several schemes have been proposed to attribute at least partial glueball nature to the $f_0(1500)$ state [1,6,7], although quantitative predictions for its glueball content differ sizably. In a minimal scenario originally proposed by Ref. [1] the pure glueball is mixed with the $n\bar{n}$ and $s\bar{s}$ states of the scalar ${}^3P_0$ nonet leading to three scalar states, identified with the $f_0(1370)$, $f_0(1500)$ and an additional state around 1700 MeV, which can possibly be the $f_{J=0,2}(1710)$. One decisive test of the proposed mixing schemes is the full analysis of the strong decay modes of the observed f_0 states.

2. Decay modes and production rates

In the decay analysis [5] we have taken into account the coupling of the quarkonia ($Q\bar{Q}$) and glueball (G_0) components of the f_0 states to the $Q\bar{Q}$ components of the two-meson final state, where the decay dynamics is guided by strong coupling QCD [1]. The coupling of the $Q\bar{Q}$ component of the f_0 states is described in the framework of the ${}^3P_0$ pair creation model (see Fig. 1). In next-to-leading order we obtain a direct coupling of the G_0

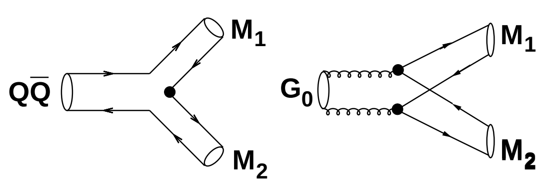

Fig. 1. Effective quark/gluon line diagrams for the decay of the $Q\bar{Q}$ and G_0 components into the final state $M_1\,M_2$.

component of the f_0 states to the quarkonia component of the decay channel (see Fig. 1). The corresponding transition $G_0 \rightarrow (Q\bar{Q})\;(Q\bar{Q})$ is modelled by resorting to a scalar digluonium wave function for G_0 as given by cavity QCD. Decay patterns resulting from the individual decay mechanisms of Fig. 1, that is coupling to the $Q\bar{Q}$ and G_0 components of the $f_0(1500)$, are qualitatively very different. Whereas the $Q\bar{Q}$ decay is in line with the two-pseudoscalar decays of the $f_0(1500)$, the gluonic component strongly influences the decay channels $\sigma\sigma$, $\rho\rho$, $\pi^\star\pi$ and $a_1\pi$ feeding the 4π final states. For example, the $\rho\rho$ decay channel is experimentally known to be strongly suppressedin conflict with a pure $Q\bar{Q}$ interpretation, and hints at a sizable influence of the G_0 contribution [5]. Our full fit to the known $f_0(1500)$ decays results in the state vectors

$$\begin{pmatrix} |f_0(1370)> \\ |f_0(1500)> \\ |f_0(1710)> \end{pmatrix} = \begin{pmatrix} 0.94 & 0.07 & -0.34 \\ 0.31 & -0.58 & 0.75 \\ 0.15 & 0.81 & 0.57 \end{pmatrix} \begin{pmatrix} |n\bar{n}> \\ |s\bar{s}> \\ |G_0> \end{pmatrix} , \quad (1)$$

where the G_0 strength is dominant in $f_0(1500)$.

To further quantify the possible influence of the G_0 component we estimate branching ratios for the production of f_0 states in $N\bar{N}$ annihilation [9]. With the effective graphs of Fig. 2 both the coupling to the $Q\bar{Q}$ and the G_0

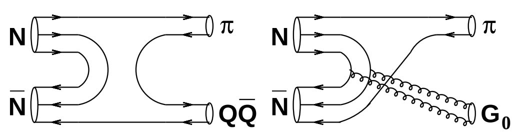

Fig. 2. Effective quark line diagrams for $N\bar{N}$ annihilation into the final states $\pi(Q\bar{Q})$ and πG_0.

components of the f_0 states for the annihilation channel πf_0 are taken into account. The respective strengths of the transitions are fixed by usual two-meson production (here $p\bar{p} \to \pi^0 f_2(1270)$) and by the G_0 decay graph of Fig. 1. For annihilation from atomic S-states we obtain for the ratio

$$R \equiv \frac{\mathrm{BR}(p\bar{p} \to f_0(1500)\pi^0)\mathrm{BR}(f_0 \to \eta\eta)}{\mathrm{BR}(p\bar{p} \to f_0(1370)\pi^0)\mathrm{BR}(f_0 \to \eta\eta)} = 0.3\ (Q\bar{Q}),\ 3.0(Q\bar{Q} + G_0)\ , \quad (2)$$

where $R = 0.3$ is obtained by taking into account the $Q\bar{Q}$ component of the f_0 state only. The result $R = 3.0$ includes the coupling to the G_0 component, assuming maximal interference between the production graphs. This should be compared to the experimental number of $R \approx 1.6$ [2]. Similarly, for the production branching ratio, including both annihilation graphs of Fig. 2, we obtain $\mathrm{BR}(p\bar{p} \to f_0(1500)\pi^0)\mathrm{BR}(f_0(1500) \to \eta\eta) = 5.5 \times 10^{-4}$ compared to the measured result of $(5.5 \pm 1.3) \times 10^{-4}$ [2].

Known decay modes and $p\bar{p}$ production rates of the $f_0(1500)$ state are qualitatively consistent with the presence of a sizable glueball component and cannot be explained by a pure $Q\bar{Q}$ interpretation. In turn, the corresponding predictions [5] for the partner states $f_0(1370)$ and $f_0(1710)$ provide a stringent test for the scenario of Eq. (1) which can be tested by future experimental results.

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