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Fireballs in the mass region of the g meson

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Threshold enhancements predicted by the statistical bootstrap for the $\rho\rho$ and $A_2\pi$ channels in the region of the g meson account for the observed signal in these channels, but do not explain the strong $g(1680)$ signal seen in the $\pi\pi$ channel. We conclude that the g meson decays principally into the $\pi\pi$ channel, and hence belongs to that small class of particles which have a preferred decay mode in violation of the statistical bootstrap. Other examples of the phenomenon are given, and a dynamical scheme which incorporates these exceptional decays is outlined.

I. INTRODUCTION

It is pointed out that though most high-mass hadrons decay into many different channels in agreement with the statistical bootstrap, there is a small class of particles which have a preferred decay into a single channel. Examples are the $f'(1514)$, the $F_1(1540)$, and the $f(1270)$. The broad threshold enhancements such as the A_1, which appear to decay into one mode, are an incoherent sum of several resonances, each of which decays statistically, and are not to be counted in the above.

The threshold enhancements seen in the $\rho\rho$ and $A_2\pi$ channels have been interpreted as decay modes of the g meson. It is shown in Sec. II that these enhancements agree well in spectral shape and relative strength with the predictions of the statistical bootstrap model for an incoherent sum of several resonances. With this interpretation, the g meson appears to highly favor the $\pi\pi$ decay mode.

In Sec. III a dynamical scheme is presented which allows for favored decay modes for some resonances and statistical decays for others. The scheme is based on the quark model, in which quarks combine to form the low-lying baryon and meson octets. There are high-mass excitations of bound quark states whose decay modes are governed by quark dynamics. These states do not decay statistically.

On the other hand, hadrons may bind together to form composites in the manner prescribed by the statistical bootstrap. These states decay statistically and give rise to the threshold enhancements.

II. THRESHOLD ENHANCEMENTS IN THE g REGION

Statistical models predict threshold enhancements in the mass spectra of systems of particles produced by diffraction dissociation,[1-3] Regge exchange, and in some cases of direct production.[4] These enhancements are due to competition effects; as energy increases more channels become kinematically allowed, and the cross section for a particular channel shows a corresponding decrease. Using the statistical bootstrap of Hagedorn[5] and Frautschi,[6] the following formula can be derived for the distribution in the invariant mass M for the production of two particles of mass M_a and M_b as shown in Fig. 1 (see Refs. 1 and 4):

$$\frac{d\sigma_{ab}}{dM}=\frac{A(M,S)\Gamma(M,M_a,M_b)\lambda^{1/2}(M^2,M_a{}^2,M_b{}^2)}{M\rho(M)}\,. \tag{1}$$

$A(M,S)$ is determined by the production mechanism, which can be evaluated for $1\ \mathrm{GeV}^2 < M < S$ by Mueller's theorem.[7] Since we work over a limited range of M at fixed S, we take A to be constant. Γ and λ are defined by

$$\Gamma(M,M_a,M_b)=[M^4-(M_a{}^2-M_b{}^2)^2]/4M^2\,, \tag{2}$$

$$\lambda(M,M_a,M_b)=[M^2-(M_a-M_b)^2]\times[M^2-(M_a+M_b)^2]\,. \tag{3}$$

$\rho(M)$ is the density of states, given by the statistical bootstrap formula[6,8]

$$\rho(M)=CM^{-3}\exp(M/T)\,, \tag{4}$$

where C is a constant and T is the ultimate tem-

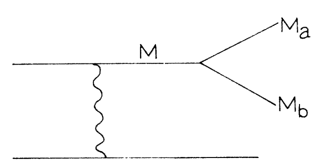

FIG. 1. The production of particles with mass M_a and M_b through diffractive or Reggeon exchange. A fireball of mass M is produced, which decays into particles a and b.

perature which is in the range from 140 MeV to 170 MeV.

As shown in Ref. 1, formula (1) gives a good representation of the threshold enhancements seen in the A region of the $\rho\pi$ spectrum, the A_3 region of the $f\pi$ spectrum, the Q region of the $K^*(890)\pi$ spectrum, the L region of the $K^*(1420)\pi$ spectrum, as well as the $\Delta\pi$ and $n\pi$ threshold enhancements. This is not to say that the above enhancements are not resonances, but rather that the enhancements arise from an incoherent sum of several resonances which decay with branching ratios determined statistically into the various allowed channels. Indeed, formula (1) has been derived as an incoherent sum of Breit-Wigner amplitudes with partial widths inversely proportional to the density of channels.[4]

In Fig. 2 the prediction of Eq. (1) for the $\rho^0\rho^-$ mass distribution is compared with experimental data for the reaction $\pi^-p\to\pi^+\pi^-\pi^-\pi^0p$ at 9.1 GeV/c. Predictions for the $A_2^-\pi^0$ channel are compared with the data in Fig. 3. Data are from Ref. 9. Although these enhancements have been interpreted to be decay modes of the g meson, agreement between the data and theoretical curves is excellent. For the curves shown A/C $=(2.38\times10^5$ events/50 MeV)/MeV. The shapes of the distributions are correctly predicted, as well as the relative normalization of the two channels. We take $T=140$ MeV.

It should be noted that in the above comparisons Eq. (1) has been multiplied by factors of 9 and 5 for the respective $\rho\rho$ and $A_2\pi$ modes. These factors arise because a factor of $(2J+1)$ must be included for each particle of spin J to ensure proper counting in statistical models.

We conclude that the enhancements seen in the $\rho\rho$ and $A_2\pi$ channels are threshold enhancements similar to those mentioned above. These enhancements are due to an incoherent sum of several states which decay statistically into allowed channels, rather than being decay modes of the $g(1680)$ meson seen in the $\pi\pi$ mode.

The $g(1680)$ meson seen in the $\pi\pi$ channel is not due to an incoherent sum of resonance states, but is a single resonance. If formula (1) is used to calculate a mass distribution for the $\pi\pi$ channel, the peak occurs around 700 MeV rather than 1700 MeV. Of course, formula (1) is not valid unless the mass is sufficiently high for several resonances to contribute to the cross section at a given energy, which is above 1 GeV. Still, the effects of an incoherent sum of resonances in the $\pi\pi$ channel show up below the g region, and has been seen, for example, in the reaction $\gamma Be\to(\pi\pi)Be$.[10] This enhancement is too broad to explain the g signal in the $\pi\pi$ channel, and peaks at too low a mass.[11]

We interpret these facts in the following manner. The enhancements seen in the $\rho\rho$ and $A_2\pi$ mass distributions around 1.7 GeV are the threshold enhancements predicted by the statistical bootstrap, arising from an incoherent sum of several resonances which decay statistically. The enhancement seen in the $\pi\pi$ channel, however, is due to the presence of a single resonance (the g meson) which strongly favors the $\pi\pi$ decay mode and stands out above a background which includes the decay of these other resonances into the $\pi\pi$ channel.

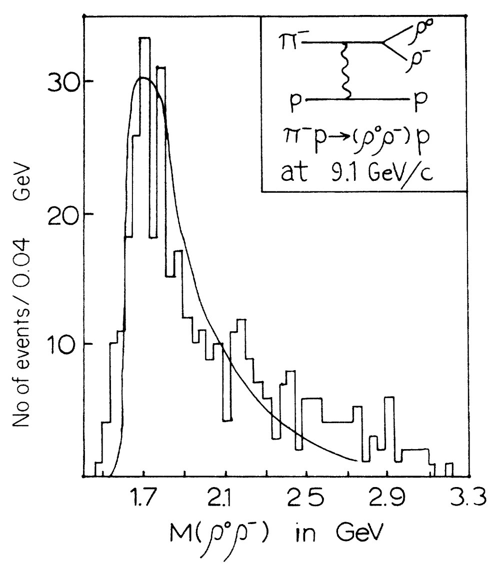

FIG. 2. The predictions of the statistical model, discussed in the text for the $\rho\rho$ threshold enhancement, produced by the mechanism shown in the insert, is compared with experimental data of Ref. 9 for the reaction $\pi^-p\to\pi^+\pi^-\pi^-\pi^0p$ at 9.1 GeV/c.

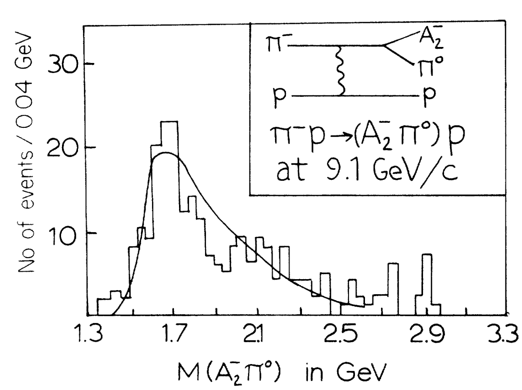

FIG. 3. The $A_2\pi$ threshold enhancement, as seen in the data for $\pi^-p\to\pi^+\pi^-\pi^-\pi^0p$ at 9.1 GeV/c, is compared with the predictions of the statistical bootstrap. Good agreement in shape, as well as in the relative strength of $\rho\rho$ and $A_2\pi$ modes, is obtained.

Most hadronic resonances with mass above 1 GeV decay into many channels,[12] as expected from statistical considerations. Hamer[13] has recently shown that the elastic branching ratios of resonances on the N^γ and Δ^δ trajectories decrease exponentially with resonance mass, in agreement with the predictions of the statistical model. There are, however, exceptions to this rule.[14] The $f(1270)$ meson has a branching ratio into the $\pi\pi$ channel of 0.83, versus a statistical-model prediction of 0.56. The $f'(1514)$ is only seen in the $\bar{K}K$ mode, and the $F_1(1540)$ only appears in the $K^*\bar{K}+\bar{K}^*K$ mode.[12] From the considerations above, the g meson strongly favors the $\pi\pi$ mode and is one of the exceptional resonances.

Clearly, though the statistical model correctly predicts the branching ratios of most resonances, as well as the shapes and strengths of the threshold enhancements due to an incoherent superposition of several resonance states, there are resonances which for dynamical reasons do not decay statistically, but prefer a particular channel. A dynamical scheme capable of incorporating these facts is presented in the next section.

We close this Section with a comment on the A_2 meson. The A region of the $\rho\pi$ spectrum is well explained as a statistical enhancement above the $\rho\pi$ threshold. The A_2 peak, however, is distinct above the continuous spectrum and has a very distinct spin and parity assignment. We argue that it is a discrete state with a preferred decay into the $\rho\pi$ channel, similar to the $g\rightarrow\pi\pi$.

III. FIREBALLS AS HADRONIC MOLECULES

To explain the existence of high-mass states which decay into preferred channels in violation of the statistical bootstrap, the following scheme is proposed. There are quarks which are the fundamental constituents of hadrons. The quarks form composite systems, the particles, which may be stable or unstable for decay into other particles. Fireballs may then be formed, which are composite systems of particles and other fireballs. The statistical bootstrap gives a theory for predicting the decay of fireballs, but calculating branching ratios of particles lies in the domain of quark dynamics.

A loose analogy exists between this scheme and the situation in atomic physics, with fireballs being hadronic molecules and particles being hadronic atoms, while the quarks as fundamental constituents correspond to electrons and nuclei. This correspondence is outlined in Table I. It must be emphasized that this analogy cannot be taken literally.

The necessity for this scheme goes beyond the fact that there are particles whose decay branching ratios violate the statistical bootstrap. To calculate the density of states using the Frautschi equa-

TABLE I. Comparison is made between the hierarchy of states in atomic physics and that of hadrons as presented in the text. Quarks form states whose decay characteristics are not statistical in nature, while fireballs, which are composites of particles and lower mass fireballs, exhibit statistical behavior in agreement with the Hagedorn-Frautschi statistical bootstrap.

	Atomic physics	Hadronic physics
Fundamental constituent	Electrons and nuclei	Quarks
Composites of fundamental constituent	Atoms (bound states of electrons and nuclei)	Particles (three quark and quark-antiquark bound states) Examples: $\frac{1}{2}^+$, $\frac{3}{2}^+$, ... baryon octets 0^-, 1^-, ... meson octets $f'(1270)$, $f'(1514)$, $F_1(1540)$ $g(1680)$, A_2, ...
Composite of composites of fundamental constituent	Molecules (composites of atoms)	Fireballs (composites of particles *and* lower-mass fireballs) Examples: The many resonances whose incoherent sums make up the A_1, B, A_3, Q, ... threshold enhancements seen in the $\rho\pi$, $\omega\pi$, $f\pi$, $K^*(890)\pi$, ... channels. N^γ and Δ^δ trajectories.

tion, one needs an input spectrum of particles, the low-mass SU(3) multiplets. The statistical bootstrap is unable to generate the input spectrum or predict its properties. Hence one needs a more fundamental scheme such as the quark model to generate the input spectrum for the statistical bootstrap.

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