

BUMPS AND POLES IN THE S-MATRIX  
A SYSTEMATIC STUDY OF  $0^{++}$  AND  $2^{++}$  MESONS PLUS A MOLECULE APPROACH TO THE  
 $E(1420)$  IN THE  $K\bar{K}$  SYSTEM\*

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BUMPS AND POLES IN THE S-MATRIX  
 A SYSTEMATIC STUDY OF  $0^{++}$  AND  $2^{++}$  MESONS PLUS A MOLECULE APPROACH TO THE  
 $E(1420)$  IN THE  $K\bar{K}\pi$  SYSTEM

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The goal of Hadron Spectroscopy is to find the spectrum of states formed by color singlet arrangements of quarks and gluons. Ideally these spectral states are associated with poles of the scattering matrix of hadrons which are the decay channels of the states. For example the  $\rho$  meson is the lowest  $q\bar{q}$  s-wave, spin one color singlet state and decays into  $\pi^+\pi^-$ . Since the  $\rho$  decays in a relative p-wave, one finds the  $\rho$  pole in the  $I = 1$  p-wave  $\pi\pi$  phase shifts.

There are forces between quarks and gluons which do not manifest themselves as true resonances and thus cannot be described by a Breit-Wigner pole. I will give some examples that are not Breit-Wigner poles of the scattering matrix but are important bumps in meson production.

**Threshold  $\pi\pi$  bump**

One sees a very pronounced threshold  $\pi\pi$  bump coming from the reaction  $\gamma\gamma \rightarrow \pi^+\pi^-$  and pomeron pomeron  $\rightarrow \pi^+\pi^-$  (see Figs. 1 and 2). If one tries to describe this threshold bump by a new s-wave  $\pi\pi$  resonance, one runs into a contradiction

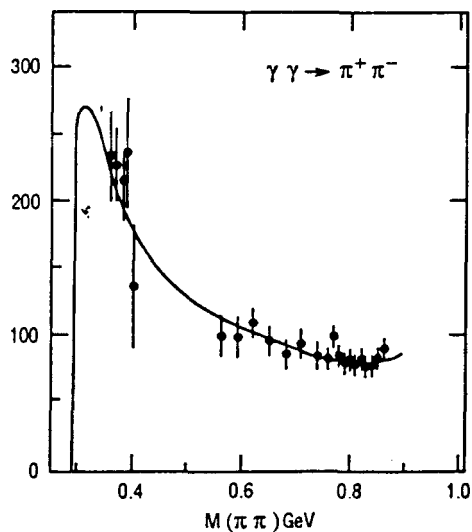


Fig. 1 Cross section in mb from Ref. 1 for  $|z| \leq 0.6$ .

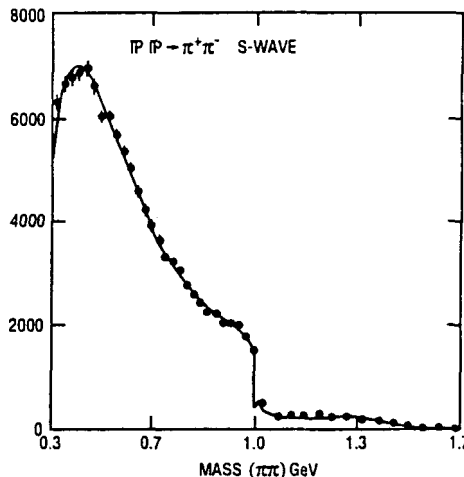


Fig. 2 Events per 25 MeV from Ref. 2. Curve from systematic study.

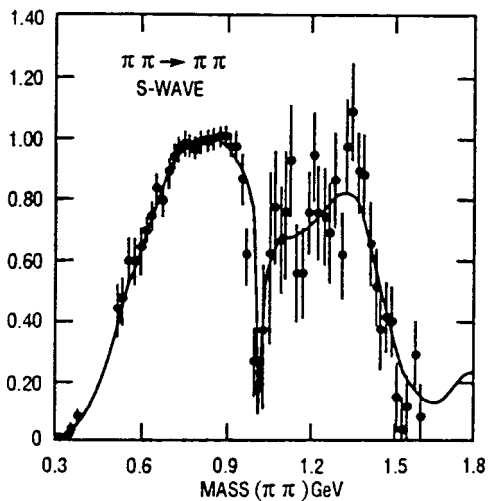


Fig. 3 S-wave Argand plot units from Ref. 3. Curve from systematic study.

with the known  $\pi\pi$  phase shifts and unitarity. The s-wave  $\pi\pi$  phase shift shown in Fig. 3 shows no resonance near threshold and by unitarity, if there was such a resonance, it would have to show up in  $\pi\pi$  scattering and reach the magnitude of unity as the phase shift actually does around 0.8 GeV. Morgan and Pennington [4] show that this threshold bump is due to a Born term of  $\gamma\pi$  scattering which gives a one over mass squared falloff, with, of course, the usual rise at threshold.

### The E(1420) as a threshold bump in $K^*\bar{K}$

The E(1420) is an axial vector isoscalar  $J^{PC} = 1^{++}$  bump which has a width of around 60 MeV. For many years the E(1420) was thought to belong to the  $S\bar{S}$  member of the  $J^{PC} = 1^{++}$  nonet. However Ref. 5 has analyzed the reaction  $K^-p \rightarrow K\bar{K}\Lambda^0$  and did not find the E(1420), but found the  $D'(1530)$ , which is now believed to be the  $S\bar{S}$  member of the  $J^{PC} = 1^{++}$  nonet. Thus it appears that the E(1420) is an extra member in the  $1^{++}$  system. Its mass is either too low or its quantum numbers are wrong to be either a glueball [6] or a hybrid [7].

R.L. Jaffe predicts a  $q\bar{q}q\bar{q}$  state around 1.6 GeV which decays into  $K\bar{K}\pi$ [8]. Later work by R.L. Jaffe and F.E. Low showed that such four quark states are very broad and would not give a 60 MeV width [9]. We were able to show that a final state rescattering mechanism based on K and  $\bar{K}$  s-channel exchange Born terms leads to an enhancement at the E(1420)[9]. The subsequent sum of Born terms is analogous to a  $\pi$  orbiting in a p-wave around a  $K\bar{K}$  system interacting through s-wave at the center.

Reference 10 shows that a phenomenological analysis of all  $K\bar{K}\pi$  data arising from hadroproduction is consistent with the above picture. Figure 4 shows the threshold enhancement plotted against Refs. 11 and 12. The dashed curve is the threshold enhancement without the final state interaction. Figure 5 shows the  $1^{++}$  signal from Ref. 5, where one sees a small threshold enhancement plus a bigger  $D'(1530)$ . Reference 9 shows that the threshold enhancement is confined entirely to the  $K^*\bar{K}$  system, while Ref. 5 shows that the  $D'(1530)$  is also mainly decaying into  $K^*\bar{K}$ . If one views the  $1^{++}$  signal as a measurement of  $K^*\bar{K}$  elastic scattering, one can extract the phase shift plotted in Fig. 6 and

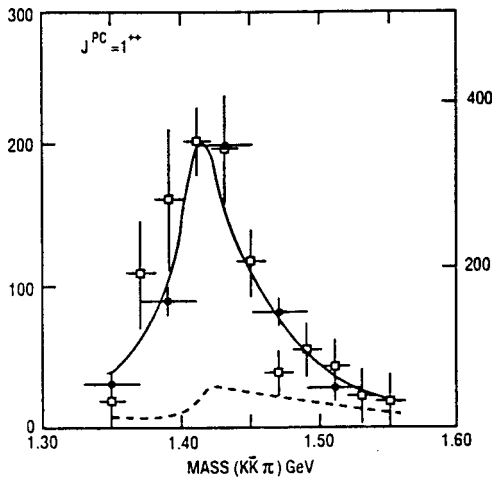


Fig. 4 Left hand scale events per 40 MeV from Ref. 11, and right hand scale events per 20 MeV from Ref. 12. Curves described in Ref. 10 and text.

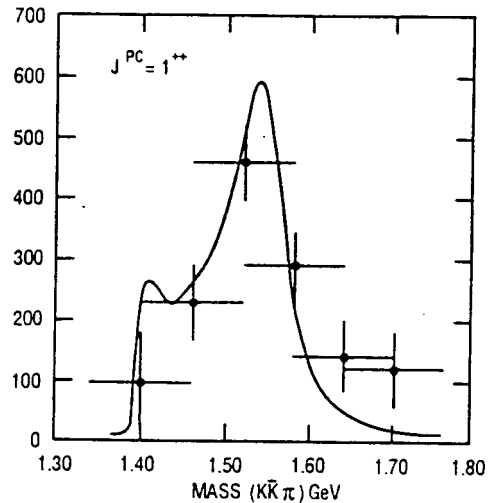


Fig. 5 Events per 50 MeV from Ref. 5. Curve described in Ref. 10.

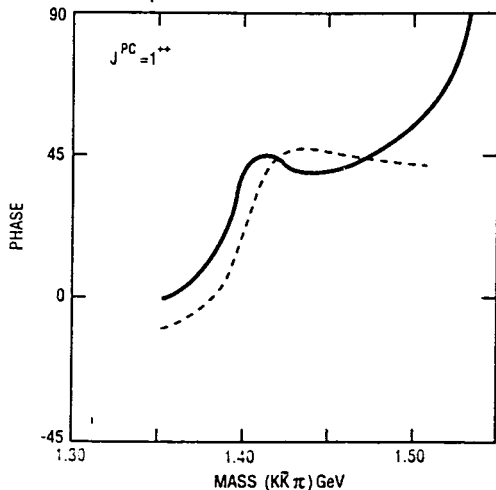


Fig. 6 Phase in degrees of curve in Fig.5 as  $K\bar{K}$  elastic scattering (solid) plus Phase from Ref. 10 (dashed).

compare it to the phase shift calculated in Ref. 10. Since both are in good agreement, we see that the bump or molecule has 1/4 of the phase motion associated with a resonance. This fact is the key ingredient in the success of the fit to phase information of Ref. 12.

#### A Systematic Study of $0^{++}$ and $2^{++}$ Mesons

For a pion scattering on a proton which is then changed into a neutron, the low  $|t'|$  scattering is dominated by one pion exchange (OPE). Using the standard OPE extrapolation [13], one obtains the S-Matrix Argand amplitudes for each of the partial waves. For the following S-Matrix analysis we have used the following processes:  $\pi\pi \rightarrow \pi\pi$ ,  $\pi\pi \rightarrow K\bar{K}$ ,  $\pi\pi \rightarrow \eta\eta$  [14-15],  $\pi\pi \rightarrow \eta\eta'$  [16]. We can also add the reaction  $K\bar{K} \rightarrow K\bar{K}$  [5] by assuming that the unnatural exchange for  $M = 0$  amplitude for  $K^-\bar{p} \rightarrow K\bar{K}\Lambda^0$  is pure K exchange. The channels  $J/\psi \rightarrow \gamma\pi^+\pi^-$ ,  $J/\psi \rightarrow \gamma K^+K^-$ ,  $J/\psi \rightarrow \gamma K_S^0 K_S^0$ ,  $J/\psi \rightarrow \gamma\eta$ ,  $J/\psi \rightarrow \gamma\eta'$  [17] were also fitted because they only have  $I^G = 0^+$  and  $J^{PC} = 0^{++}$  and  $2^{++}$  below a mass of 2.0 GeV. Finally we fit the double pomeron data for  $pp \rightarrow p\pi\pi p$  and  $pp \rightarrow pK\bar{K}p$  [2]. We choose to describe the T-matrix by a sum of complex coupled Breit-Wigners.

At this time we find that we need three  $2^{++}$  poles [ $f_2(1270)$ ,  $f_2(1520)$ ,  $f_2(1850)$ ] and five  $0^{++}$  poles ( $f_0(1024)$ ,  $f_0(1300)$ ,  $f_0(1411)$ ,  $f_0(1734)$ ,  $f_0(2213)$ ] in order to describe the above data. It is very interesting to note that three important glueball candidates are not in the above fit and we have fitted the data that there existent was derived from.

Reference 18 claims that at the  $K\bar{K}$  threshold there exist two  $0^{++}$  resonances that are almost degenerate in mass [ $f_0(988)$  and  $f_0(991)$ ]. They claim that the existence of the two states depends solely upon the double Pomeron data of Ref. 2. We had no problem fitting the same data with just one Breit-Wigner which interfere with the other broad states and backgrounds (Fig. 2 and Fig. 7). New data presented at this conference ( $J/\psi \rightarrow \phi\pi^+\pi^-$  and  $J/\psi \rightarrow \phi K^+K^-$  [19]) may help clarify the threshold resonance situation in our fit.

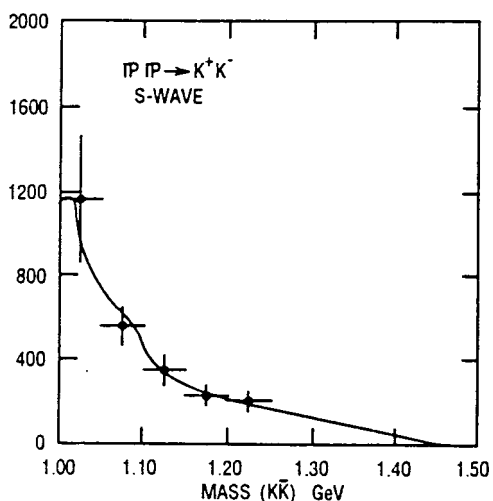


Fig. 7 Events per 50 MeV from Ref. 2. Curve from systematic study.

The  $f_2(1720)$  resonance has been seen in  $J/\psi$  radiative decay [17] and double pomeron production [20]. The spin parity analysis is still not completely certain and it could very well be that these experiments are observing the  $f_0(1734)$  that is seen in  $\pi$  production [21]. We have used this assumption and have achieved a good fit to  $J/\psi$  radiative decay data [17] which includes the separation of the  $0^{++}$  cross section. Reference 20 is plagued by systematic problems due to the fact that they are not at high enough cm

energy to cleanly get at pure double pomeron. Our fit does have a problem with assuming only a single  $f_0(1734)$  for  $\pi\pi$ ,  $K\bar{K}$ , and  $J/\psi$  radiative decay. This problem occurs in the  $\pi\pi \rightarrow \pi\pi$  channel. The  $J/\psi$  radiative decay ties down the branching ratio of  $f_0(1734)$  into  $\pi\pi$  and  $K\bar{K}$  and this ratio is not small if one wants to explain the  $\pi\pi$  scattering data (Fig. 8). If on the other hand we introduced the  $f_2(1720)$  in addition to the  $f_0(1734)$  and let the  $f_0(1734)$  account for all of the  $\pi\pi$  bump in  $J/\psi$  radiative decay one could correct this problem. We have shown in an earlier publication that the  $f_2(1720)$  most couple to  $\pi\pi$  at a rate of 4% or less [14]. Reference 5 shows that the  $f_2(1720)$  cannot couple to  $K\bar{K}$  at more than a 20% level, thus if the  $f_2(1720)$  really exist it must have other decay channels.

The  $f_0(1590)$  resonance has been seen in  $\pi\pi \rightarrow n\bar{n}$  [14-15] and  $n\bar{n}'$  [16]. It is also seen in double pomeron production [22]. In our fit to the above  $\pi\pi$  scattering data, we are able to fit the  $n\bar{n}$  and the  $n\bar{n}'$  decay modes with the

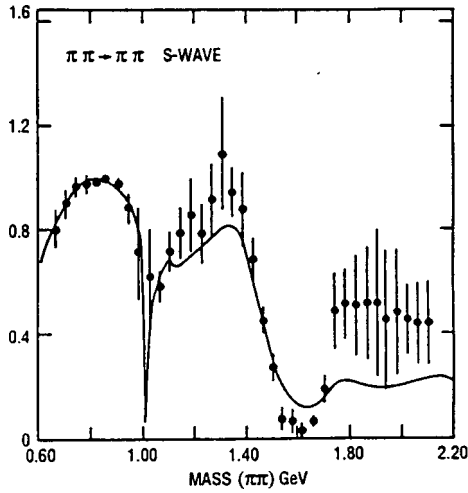


Fig. 8 S-wave Argand plot units from Ref. 14. Curve from systematic study.

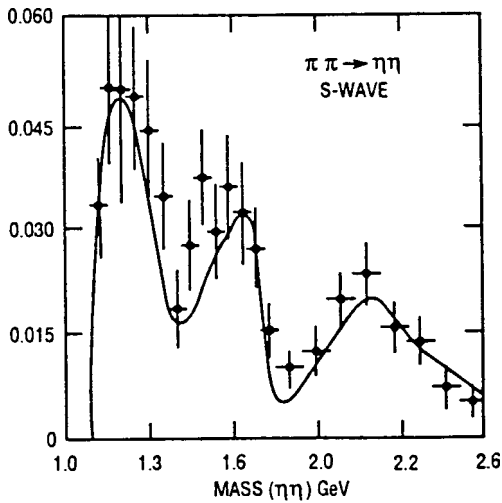


Fig. 9 S-wave Argand plot units from Ref. 15. Curve from systematic study.

$f_0(1411)$  and the  $f_0(1734)$  (Fig. 9). We see from Fig. 10 that the  $J/\psi$  radiative decay also supports this fit. One needs to test the double pomeron production which would require that one has separated s and d-wave for the  $\pi\pi$ ,  $K\bar{K}$ ,  $\eta\eta$  and  $\eta\eta'$  channels. Until one finds a need to add the  $f_0(1590)$ , its independent existence is in question.

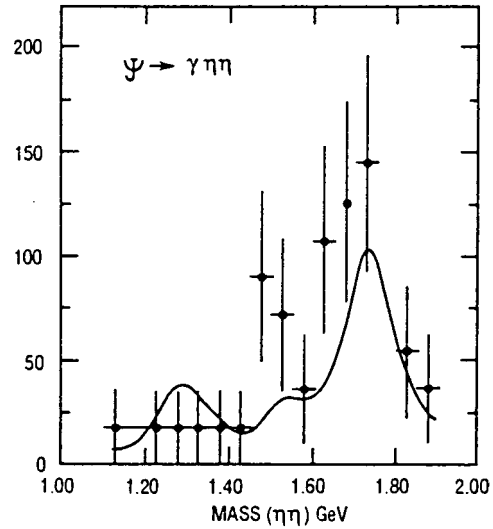


Fig. 10 Events per 50 MeV from Ref. 17. Curve from systematic study.

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