CEBAF-TH-96-10

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Comment on "Confirmation of the Sigma Meson"

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We question the viability of the proposed interpretation of the $I = 0$, $\frac{1}{2}$, and 1 pseudoscalar-pseudoscalar scattering data given in Ref. [1] since t-channel forces have been ignored in apparent conflict with the data in the closely related exotic $I = \frac{3}{2}$ and 2 channels.

In a recent Letter [1], Törnqvist and Roos reported on a reanalysis of $\pi\pi$ S-wave phase shifts using a coupled channel formalism in which the dynamics is totally determined by s-channel resonances. They found in their solution a broad $\frac{1}{\sqrt{2}}(u\bar{u} + d\bar{d})$-type scalar meson at 400 MeV which they associate with the long-controversial σ meson. They also drew from their analysis certain conclusions about the controversial $f_0(980)$ and $a_0(980)$ scalar states.

While we accept some of the elements of their analysis, we wish to point out why we have reached very different conclusions in our independent analyses [2,3] which included both the complete nonet of s-channel resonance poles *and* strong t-channel forces. In particular, we find that:

1) Most of the broad rise of the S-wave $\pi\pi$ phase shifts is to be associated with t-channel attractive forces. As a result our fits do not require a low mass scalar σ meson.

2) Our t-channel forces are dominant in producing the attractive forces in the $K\bar{K}$ channels that create the $f_0(980)$ and $a_0(980)$. Thus, while Refs. [1,2,3] all agree that these two states are dominantly $K\bar{K}$ states, we [2,3] reach a very different conclusion on the

physics behind their formation.

We begin with a quick review of the essential elements of the three analyses [1,2,3] under discussion. The analysis of Törnqvist and Roos assumes that pseudoscalar-pseudoscalar scattering is controlled by its s-channel resonances, and focuses on the resonances' running mass functions $m^2(s) = m_0^2 + \Pi(s)$, with $\Pi(s)$ determined from a model for resonance $\rightarrow$ pseudoscalar-pseudoscalar $\rightarrow$ resonance loop graphs. The distinctive feature of their approach is the use of very strong couplings to the $K\bar{K}$ channel to produce a cusp-like downward spike in $\Pi(s)$ which allows the real part of $m^2(s)$ to intersect $\Pi(s)$ *twice*. In this picture their $f_0(1300)$, a dominantly $s\bar{s}$ state, creates *two* poles: one being a mainly $K\bar{K}$ state just below $K\bar{K}$ threshold (the $f_0(980)$) and one around 1300 MeV corresponding to a "standard" $s\bar{s}$ state. When the strengths of the loop graphs are arranged to produce this behaviour, they naturally also produce the broad, low-mass σ meson highlighted in Ref. [1].

Our approaches [2,3], while distinct, have in common the very important role assigned to t-channel forces. Refs. [2] grew out of a study of $qq\bar{q}\bar{q}$ systems which focussed on the forces between two mesons arising from quark exchange. In the earlier of Refs. [2] it was suggested that the $f_0(980)$ and $a_0(980)$ were "$K\bar{K}$ molecules" entirely bound by such forces (including both the diagonal $K\bar{K} \rightarrow K\bar{K}$ potential and its associated quark-exchange transition potentials like $K\bar{K} \rightarrow \eta\eta$ and $K\bar{K} \rightarrow \eta\pi$). In the most recent of Refs. [2], a broader look at meson-meson forces led to the conclusion that s-channel resonances were also important. When incorporated, they led to a reduced (but still dominant) role for t-channel forces in both the "$K\bar{K}$ molecules" and in the low energy $\pi\pi$ phase shifts, but a better understanding of phase shifts above $K\bar{K}$ threshold.

Ref. [3] studied meson-meson interactions in an effective Lagrangian approach incorporating scalar, pseudoscalar, and vector mesons. In this approach it is mainly the vector mesons which produce very strong t-channel forces. While differing in detail from Ref. [2], this analysis also concludes that the $f_0(980)$ and $a_0(980)$ are $K\bar{K}$ bound states dominated by t-channel forces, and that the strong low energy $\pi\pi$ attraction is also dominantly due to t-channel forces and not a low mass σ meson. Note that all these approaches [1,2,3] use

unitary scattering equations, so the different conclusions arising from [1] versus [2] and [3] are due to differences in the underlying dynamics. Figures 1 show the fits to the $\pi\pi$ phase shifts from Refs. [2] and [3] to underline the fact that these approaches provide a quite acceptable description of the data.

The main purpose of this comment is to suggest that the neglect of t-channel forces *of some kind* in Ref. [1] is untenable, and that this neglect therefore calls into question whether the interpretation of the data given in Ref. [1] is indeed an acceptable alternative to ours. The critical oversight of Ref. [1] is its neglect of the "exotic" $I = \frac{3}{2}$ and $I = 2$ pseudoscalar-pseudoscalar scattering channels. In a pure s-channel-resonance-driven picture, the phase shifts in these channels would be zero. In Refs. [2] and [3] these channels are therefore used to set the scale of t-channel forces by using the data in these channels to fix the values of various crucial parameters (see Fig. 1). Indeed, one can view both Refs. [2] and [3] as having used the exotic channels to determine the t-channel forces, and then used various relations internal to the model (*e.g.*, in Refs. [2] these are $SU(6)$ spin-flavor Clebsch-Gordan coefficients, while in Ref. [3] they are $SU(3)$ relations between coupling constants) to fix the t-channel forces in the $I = 0, \frac{1}{2}$, and 1 channels. For example, in Ref. [3], below 600 MeV the t-channel interactions dominate the phase shifts and are extremely attractive in the $I = 0$ $K\bar{K}$ channel because not only the ρ, but also the ω and ϕ mesons, add *coherently* to the attraction as demanded by $SU(3)$. In Refs. [2] this attraction is somewhat weaker, but comparable. In both Refs. [2] and [3] the s-channel scalar resonances in the 1300 MeV region contribute further binding to the "$K\bar{K}$ molecule" but are not dominant.

It has also been shown explicitly in Ref. [3] that the t-channel ρ exchange (and not an s-channel σ meson) gives rise to a very broad pole (on the "bottom-top" sheet [bt]) at a complex energy $ReE \sim 400$ MeV, $ImE \sim \pm 300$ MeV. The critical physical difference from Ref. [1] is that this pole arises from attractive forces in the $\pi\pi$ channel which are *independent* of the s-channel resonances. It is thus a "dynamical pole" that arises from the degrees of freedom already present in the meson-meson continuum, and not an "intrinsic pole" that arises from the insertion of a new degree of freedom into the dynamics [4]. In contrast, the higher-lying state near 1300 MeV in the analysis of Ref. [3] *is* an intrinsic state. (We note in passing that the fundamental nature of this state is otherwise unclear: it could be a phenomenological representation of many elements including the singlet and octet piece of the scalar nonet and a scalar glueball). In any event, both the t-channel-generated threshold effect on the [bt] sheet and the 1300 MeV state form a background to the rapid phase motion associated with the $f_0(980)$.

We should mention that there are some similarities between our work [2,3] and that of Ref. [1]. We all agree that the $f_0(980)$ and $a_0(980)$ are dominated by their $K\bar{K}$ content. We also all find that it is important to take into account the running meson masses $m^2(s)$ when there are strong channel couplings.

We are, however, not prepared to consider the interpretation of the scalar resonances given in Ref. [1] as a viable alternative until their study is broadened to include in a systematic way the exotic $I = \frac{3}{2}$ and 2 channels. We are convinced that on doing so it will be discovered that the low energy attraction in $\pi\pi$ and $K\bar{K}$ are dominated by t-channel forces and not by an intrinsic low mass σ meson. We also believe that it will emerge that the attractions in the $K\bar{K}$ channels leading to the $f_0(980)$ and $a_0(980)$, while not without important contributions from the s-channel resonances, are also dominated by ordinary t-channel "effective potentials".

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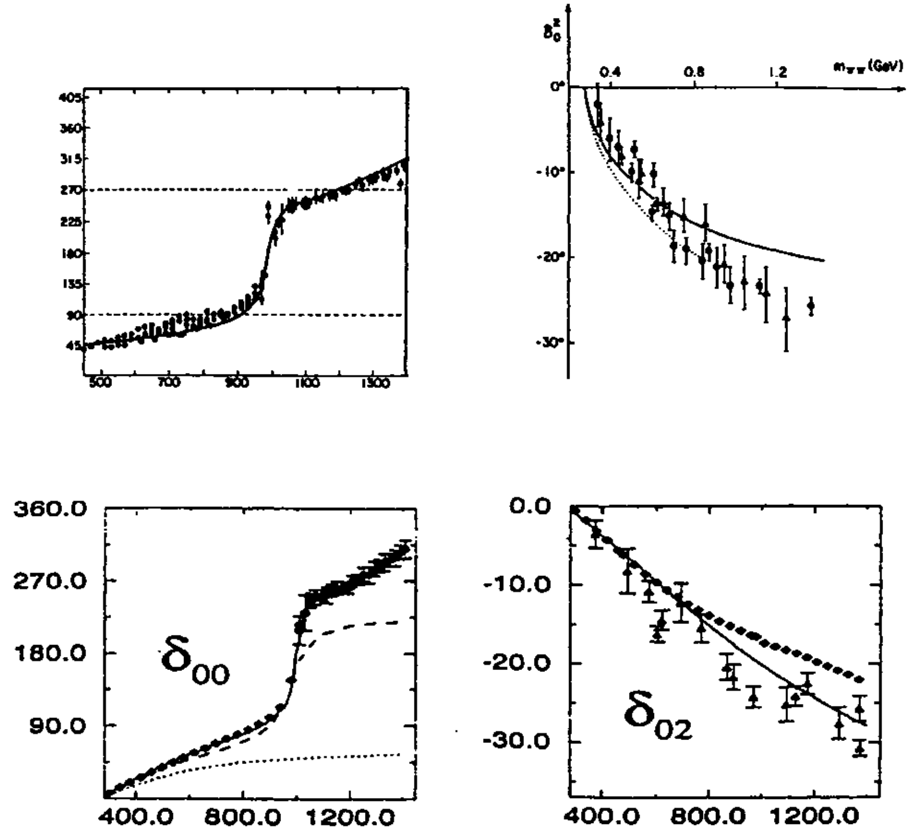

Figure 1: Fits to the $I = 0$ and $I = 2$ $\pi\pi$ phase shifts from Refs. [2] and [3]. The upper two graphs are the phase shifts from Ref. [2], while the lower two are from Ref. [3].