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FURTHER STUDY OF THE $I=1$ $K\bar{K}$ STRUCTURE NEAR THRESHOLD

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We summarize the present experimental evidence for an $I=1$ $(K\bar{K})$ enhancement in $\bar{p}p$ annihilations at rest and at 1.2 GeV/c. We propose different possible interpretations for the enhancement.

In this letter we are not going to discuss the $I=0$ $K\bar{K}$ system near threshold, which is now relatively well understood with the presence of the $\varphi(1020)$ in the $C=-1$ channel and good evidences for a $C=+1$ resonance around 1050 MeV [1-4].

We shall instead discuss briefly the present experimental situation as known from the results obtained with $\bar{p}p$ annihilations at rest and at 1.2 GeV/c on the $I=1$ $K\bar{K}$ system near threshold.

We shall show the observed effect cannot be explained in terms of interference effects or reflections of known resonances, and discuss its interpretation.

We shall first consider the 3-body annihilations at rest

$$\bar{p}p \rightarrow K_1^0 K^{\pm}\pi^{\mp}$$

for which a detailed analysis has been achieved [5] and has given the best evidence for a genuine $I=1$ $K\bar{K}$ structure near threshold. This analysis shows that the coherent addition of $K^*(890)$, $K\bar{K}(1280)$ and S-wave $(K\pi)$ amplitudes gives a good interpretation of the Dalitz plot apart from the $K\bar{K}$ threshold region. The $K^*(890)$ and $K\bar{K}(1280)$, which may be identified to the A_2-meson, appear clearly on the $K_1^0K^{\pm}\pi^{\mp}$ production Dalitz plot. We have to introduce, in addition, S-wave $(K\pi)$ amplitudes, parametrized by rather small scattering lengths, to take into account the general tendency of the Dalitz plot to be depopulated at the centre. One may then ask if these S-wave $(K\pi)$ amplitudes are not responsible for the accumulation of events in the $(K\bar{K})$ threshold region. Fig. 1 shows that attempts made to reproduce this structure with interfering $(K\pi)$ amplitudes parametrized by scattering lengths ranging from -0.4 fm to 0.4 fm, have failed.

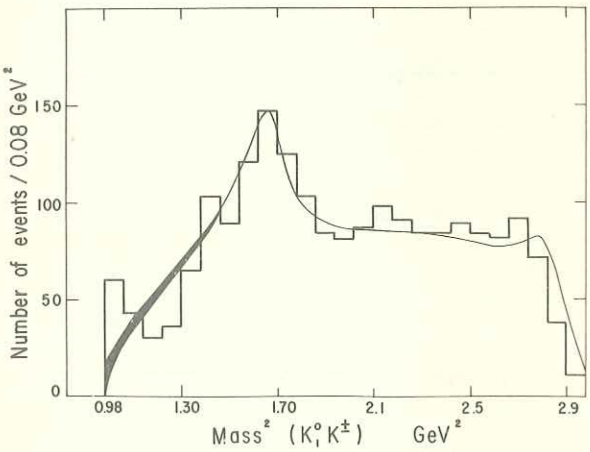

Fig. 1. $(K_1^0K^{\pm})$ effective mass squared spectrum for $\bar{p}p \rightarrow K_1^0K^{\pm}\pi^{\mp}$ at rest. The curves represent the theoretical distributions as given by the fit when no $K\bar{K}$ threshold effect is introduced. The curves are in good agreement with the experimental data for effective mass squared sufficiently far from the threshold region. Near threshold, the hatched region corresponds to the domain of expected distributions for different values of $a_{\frac{1}{2}}$ and $a_{\frac{3}{2}}$ (the S-wave scattering lengths of the $(K\pi)$ systems). It is clear that none of these theoretical distributions can reproduce the accumulation at threshold in the $(K\bar{K})$ system.

Fig. 2, where $K^*(890)$ events have been re-

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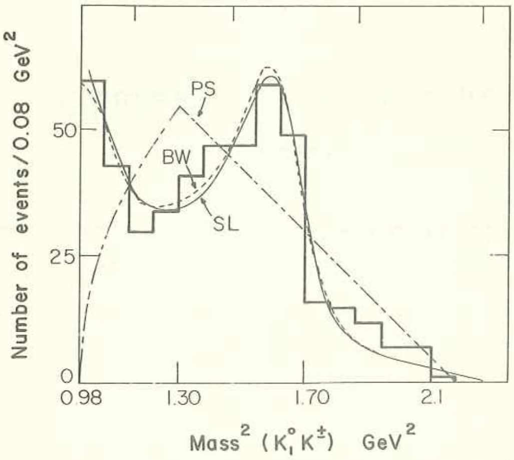

Fig. 2. $(K_1^0K^{\pm})$ effective mass squared for $\bar{p}p \rightarrow K_1^0K^{\pm}\pi^{\mp}$ at rest when $M^2(K\pi) > 0.9$ GeV^2. This cut is to remove K*(891) contributions. Curve "PS" represents the phase space. The accumulation of events at 990 MeV is clearly visible. The 1280 MeV enhancement is analyzed in ref. 5. Curve "SL" represents the theoretical distribution as given by the fit when a S-wave scattering length of 2.0 fm is introduced for the $K\bar{K}$ threshold effect. Curve "BW" represents the theoretical distribution as given by the fit when a Breit-Wigner form factor is introduced for the $K\bar{K}$ threshold effect.

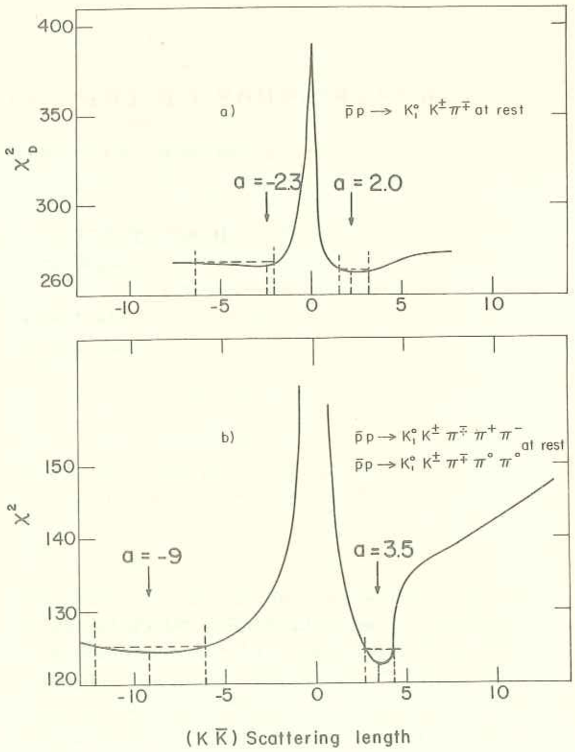

Fig. 3. $\chi^2 = f(a_0)$ for the 3 and 5 body annihilations at rest.
a) $\bar{p}p \rightarrow K_1^0K^{\pm}\pi^{\mp}$: The χ_D^2 is given for the fit of the Dalitz plot ($\langle\chi^2\rangle = 175$).
b) $\bar{p}p \rightarrow K_1^0K^{\pm}\pi^{\mp}\pi^+\pi^-$ and $\bar{p}p \rightarrow K_1^0K^{\pm}\pi^{\mp}\pi^0\pi^0$. The χ^2 refers to a simultaneous fit of $M^2(K\bar{K})$, $M^2(K\pi)$, and the decay angular distribution of the $K\bar{K}$ system for 1.84 GeV$^2 < M^2(K\bar{K}\pi)^0 < 2.14$ GeV^2 (this selection defines the E-meson) [6].

moved, shows that this $K\bar{K}$ effect is not due to a reflection of K*(890).

We are then led to introduce a specific $K\bar{K}$ effect near 1000 MeV. Two parametrizations have been tried: a scattering length amplitude $1/(1 - iaq)$ and a Breit-Wigner amplitude $1/(m_{K\bar{K}}^2 - m_0^2 + iq\gamma)$. We have used this form for the Breit-Wigner amplitude, rather than the "classical one": $1/(m_{K\bar{K}}^2 - m_0^2 + im_0\Gamma)$, to obtain a satisfactory comportment of the amplitude at threshold. In these expressions, q is the momentum of the K in the $K\bar{K}$ system; $m_{K\bar{K}}^2$ is the invariant mass squared of the $K\bar{K}$ system; a, m_0 and γ are the parameters to be fitted.

For the scattering length, we first try a real length a, in the zero effective range approximation. Fig. 3 shows that two solutions must be considered:

$$a = +2.0^{+1.0}_{-0.5}\ \text{fm} \qquad \chi_D^2 = 262 \qquad \langle\chi_D^2\rangle = 175$$

$$a = -2.3^{+0.3}_{-4.0}\ \text{fm} \qquad \chi_D^2 = 266 \qquad \langle\chi_D^2\rangle = 175$$

The fit is performed on the Dalitz plot; the distribution of the cells for which the contribution to the χ_D^2 is the largest, does not show a systematic arrangement, but for the interference regions of the K*'s and the $K\bar{K}(1280)$ resonances. It gives us confidence in the fits obtained for the $K\bar{K}$ system near threshold. The errors given for the scattering lengths correspond to $\Delta\chi_D^2 = 1$; they may be slightly under estimated.

Although the absolute value found for this scattering length is relatively small, this amplitude reproduces quite well the experimental $K\bar{K}$ spectrum (fig. 2) because of the presence of strong interference effects between the $K\bar{K}$ and $K\pi$ amplitudes in the $I = 0\ {}^1S_0\ \bar{p}p$ initial state.

An alternative way is to consider a Breit-Wigner amplitude, which suggests the existence of a resonant state in the $K\bar{K}$ system above threshold. This Breit-Wigner amplitude gives a fit of comparable quality to the fits obtained with the scattering length parametrization (fig. 2). The following mass and width are obtained:

$m_0 = 1016 \pm 6$ MeV $\quad \chi^2_D = 260 \quad \langle\chi^2_D\rangle = 175$

$\gamma = 200 \pm 40$ MeV

In the limit of a narrow resonance far from threshold, this width γ may be related to the more classical "constant width" Γ by the relation $\Gamma = q\gamma/m_0$, which, in the present case, leads to $\Gamma \sim 25$ MeV.

The analysis of the reaction $\bar{p}p \to K_1^0 K_1^0 \pi^0$ gives results compatible with the above conclusions.

Although the main information on the $I=1$ $K\bar{K}$ system comes from the study of the reaction $\bar{p}p \to K_1^0 K^\pm \pi^\mp$ at rest, it seems interesting to examine the other annihilations in which the same effect may be present.

The reaction $\bar{p}p \to K\bar{K}\pi\pi$ at rest shows an abundant production of ρ, K*(890) and $K\pi\pi$ resonances. The analysis is still in progress and not complete enough to present a satisfactory interpretation of the $K\bar{K}$ spectrum.

In the reaction $\bar{p}p \to K\bar{K}3\pi$ at rest, the $K\bar{K}$ effect is important and associated with the decay of the E meson [6]. Indeed, the quantum numbers of the E meson ($I^G J^P = 0^+0^-$) are identical to the quantum numbers of the $\bar{p}p$ initial state $^1S_0$, $I=0$ contributing to the production of the $K\bar{K}$ enhancement in the reaction $\bar{p}p \to K\bar{K}\pi$. Moreover, the observed decay mode of the E is: $E \to K\bar{K}\pi$. In these conditions, it may be expected that the analysis of the E-decay and of the reaction $\bar{p}p \to K\bar{K}\pi$ leads to comparable conclusions.

When a $K\bar{K}$ S-wave scattering length is introduced to interpret the decay Dalitz of the E, two solutions are equally probable (fig. 3)

$a = 3.5 \pm 1$ fm $\quad \chi^2 = 122 \quad \langle\chi^2\rangle = 122$

$a = -9.0 \pm 3$ fm $\quad \chi^2 = 123 \quad \langle\chi^2\rangle = 122$

The Breit-Wigner amplitude leads to a fit of comparable quality.

In the 1.2 GeV/c $\bar{p}p$ annihilation experiment, only two channels can be fully analyzed for the $I=1$ $K\bar{K}$ system near threshold, the others being less significant from the statistical point of view.

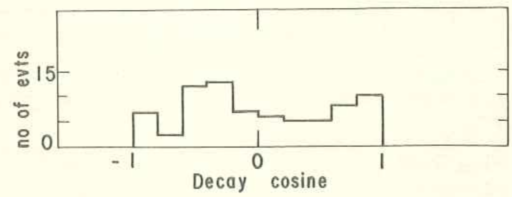

Fig. 4. Decay distribution of the $K\bar{K}$(990) in $\bar{p}p \to K_1^0 K^\pm \pi^\mp$.

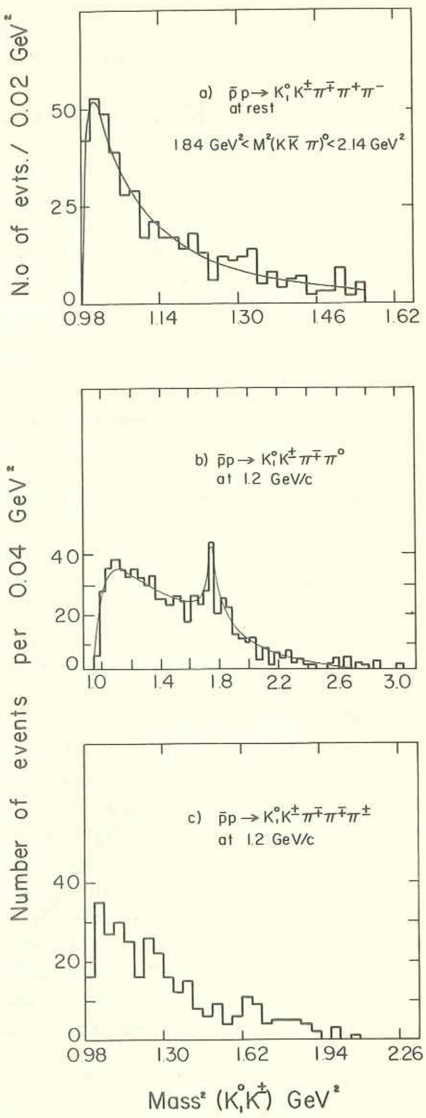

Fig. 5. $(K_1^0K^\pm)$ effective mass squared spectra for different $\bar{p}p$ reactions:
a) $\bar{p}p \to K_1^0 K^\pm \pi^\mp \pi^+ \pi^-$ for annihilation at rest.
b) $\bar{p}p \to K_1^0 K^\pm \pi^\mp \pi^0$ for annihilations at 1.2 GeV/c.
c) $\bar{p}p \to K_1^0 K^\pm \pi^\mp \pi^+ \pi^-$ for annihilations at 1.2 GeV/c.

In the channel $\bar{p}p \to K\bar{K}\pi\pi$ [3], a real scattering length must be introduced in the $K\bar{K}$ system to explain the $K\bar{K}$ spectrum near threshold: the results of the fit give:

$$|a| = 2.5 \pm 1 \text{ fm} .$$

In this case, the interpretation of the $K\bar{K}$ spectrum has been obtained by the introduction of an incoherent addition of K*(891), ρ(765) and S-wave

$K\overline{K}$ effects, the last one being parametrized in the following way: $1/(1+a^2q^2)$.

We have therefore no access to the sign of the scatteringlength a.

In the reaction $\overline{p}p \to K\overline{K}3\pi$, the $K\overline{K}$ effect is also observed near threshold, but it may be explained, partially, by the reflections of the K*(890) resonance. It seems also present in the D-meson decay [7]. The quantum numbers of the D-meson being not well known, it is difficult to decide whether the $K\overline{K}$ effect is genuine or an effect of the matrix elements of the D. Assuming $J^P(D) = 0^-$, a good fit is obtained with a scattering length of 2.5 fm.

Finally, one can also notice that a $K\overline{K}$ enhancement at threshold has been observed at higher $\overline{p}p$ annihilation energies.

It has been interpreted, for annihilations at 3.7 GeV/c, with the help of a scattering length ranging from 2 to 6 fm [8].

All the experimental results presented above are compatible with one of the following interpretations:

1) The $I=1$ $K\overline{K}$ channel is dominated in this energy region by an amplitude parametrized by a positive real scattering length of 2.5 ± 1 fm.

2) The $K\overline{K}$ enhancement is due to the presence of a resonance with $m_0 \sim 1016 \pm 10$ MeV and $I^GJ^P = 1^-0^+$. The spin-parity assignment is suggested by the position of this resonance near threshold and the decay angular distribution of the $K\overline{K}$ system in the reaction $\overline{p}p \to K_1^0K^{\pm}\pi^{\mp}$ (fig. 4). With these assignments, it is impossible to identify this resonance with the φ, or with the so-called S*, H^0 and $\delta^{\pm}(970)$ enhancements. We have therefore to assume, in this case, that we are in the presence of a new object, which could also decay into $\eta\pi$. No such object has yet been observed. The preliminary results of the analysis of the annihilation $\overline{p}p \to \eta\pi^+\pi^-$ seems to exclude a branching ratio $\eta\pi/K\overline{K}$ larger than [5] ‡.

3) The $I=1$ $K\overline{K}$ channel is dominated, at threshold, by a virtual bound state resonance [9]. This resonance may be coupled, in particular, to the $\eta\pi$ channel. To take into account this possibility, we have tried a fit with a complex scatteringlength $a + ib$. The result: $b = 0^{+0.5}_{-0.0}$ fm suggests that the width of this resonance is probably narrow. In these conditions, the value $a = -2.3$ fm corresponds to a narrow resonance with a mass $m = 975^{+15}_{-10}$ MeV.

If this interpretation is correct, it is tempting to identify this narrow resonance, at 975 MeV, to the relatively well established $\delta^{\pm}$ resonance. Then, our results lead to the following quantum number assignment for the δ-meson: $I^GJ^P = 1^-0^+$. However this interpretation presents a difficulty if one takes seriously the indication that the width of this scalar resonance should be relatively small. If, for some unexplained reason, the strong $\eta\pi$ decay mode was depressed, the electromagnetic decays would be in competition.

‡ 40 000 two-prong and an equivalent number of four-prong are being measured by the CERN-College de France Collaboration, and allow the study of the reaction $\overline{p}p \to \eta\pi^+\pi^-$ [10].

We should like to express our thanks to Drs. R. Armenteros and J. Prentki for stimulating discussions.

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