EXPERIMENTAL RESULTS OF THE ANNIHILATIONS $\bar{p}p \to K + K + 2\pi$ AT REST

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The Saclay 81 cm hydrogen bubble chamber has been exposed to beams of slow $\bar{p}$'s from the CERN proton synchrotron and the following set of four-body annihilations of stopped $\bar{p}$'s obtained:

$$\bar{p} + p \to K_1^0 K_1^0 \pi^+ \pi^-, \text{ 720 events;} \quad (1)$$

$$\bar{p} + p \to K_1^0 (K^0) \pi^+ \pi^-, \text{ 2025 events;} \quad (2)$$

$$\bar{p} + p \to K_1^0 K^\pm \pi^\mp \pi^0, \text{ 2340 events} \quad (3)$$

where (K^0) means a K^0 or $\bar{K}^0$ not seen.

An analysis of reaction (1) has already been published [1]. In this communication we present the results for the other reaction and consider the group as a whole.

EXPERIMENTAL FACTS

$\bar{p}p \to K_1^0 K_1^0 \pi^+ \pi^-$

The various two and three particle effective mass combinations in the final state of reaction (1) have been studied. The $(K_1^0 \pi^\pm)$ effective mass spectrum does not exhibit any peak at 988 MeV (K^*) which is pronounced in the other reactions. The effective mass spectrum shows a striking deviation from pure phase space. The $(K_1^0 \pi^+ \pi^-)$ effective mass spectrum (two combinations per event), Fig. 1, shows an enhancement around 1230 MeV. We have explained [1] why we attribute this to a $(K\pi\pi)$ resonant state, called C^0 with the following mass and width:

$$M = 1215 \pm 15 \text{ MeV/c}^2,$$

$$\Gamma = 60 \pm 15 \text{ MeV/c}^2.$$

A Dalitz plot of the $(K\pi\pi)$ system in the C region shows an accumulation of events with large $(\pi^+\pi^-)$ effective mass, although in the rest system of the C^0 there is insufficient energy to produce normal ϱ^0 (750) and K^0, the following results are observed:

a) 60% of reaction (1) goes via the channel

$$\bar{p}p \to C^0 K_1^0;$$

b) 80 to 90% of the C^0 decays via the reaction

$$C^0 \to K_1^0 \varrho^0.$$

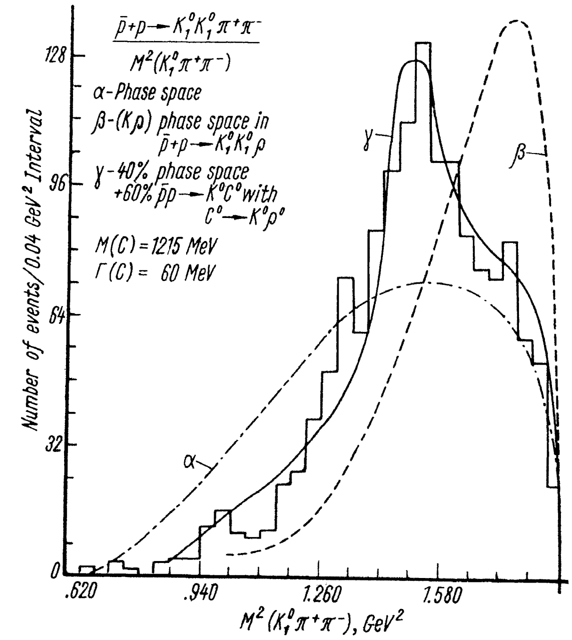

Fig. 1. $(K_1^0\pi^+\pi^-)$-effective squared mass spectrum in $\bar{p}p \to K_1^0 K_1^0 \pi^+ \pi^-$.

Indeed, a detailed study of the Dalitz plot indicated that we observe

450 C^0 's decaying into $K_1^0 \varrho^0$;

80 C^0 's decaying into $K^{*\pm}\pi^\mp$.

If we define the charge conjugation of the K_1^0 to be -1 then the C^0 observed has $C = +1$.

$$p + \bar{p} \rightarrow K_1^0 K_2^0 \pi^+ \pi^-$$

Reaction (2) contains events of the type $K_1^0 K_2^0 \pi^+ \pi^-$ and $K_1^0\ (K_1^0)\pi^+\pi^-$ where one K_1^0 decay is missed because (a) it decays via the $(\pi^0\pi^0)$ mode or (b) it escapes from the chamber before decaying $(\pi^+\pi^-)$.

The latter are few and can be corrected for by suitable weighting. To eliminate the $(\pi^0\pi^0)$ mode we subtract from the spectra of reaction (2) one half of the spectra of reaction (1).

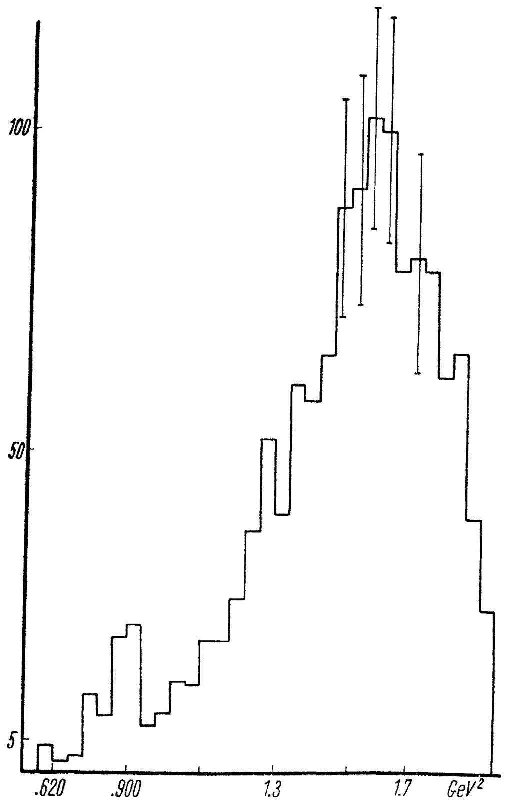

Fig. 2. $(K_2^0\pi^+\pi^-)$-effective squared mass spectrum in $\bar{p}p \rightarrow K_1^0 K_2^0 \pi^+\pi^-$.

After such subtraction we find that the $(K\pi)$ effective mass spectra is dominated by the K^* (888), but the $(\pi\pi)$ and (KK) effective mass spectra are compatible with phase space. The $(K_2^0\pi^+\pi^-)$ and $(K_1^0\pi^+\pi^-)$ effective mass spectra show the same features as the $(K_1^0\pi^+\pi^-)$ system in reaction (1), i. e. an enhancement in the C^0 vicinity (Fig. 2). We have analyzed the Dalitz plot for all $(K\pi\pi)$ combinations falling in the region of the C^0 and find about 640 C^0's decaying into $K^{*\pm}\pi^\mp$ with the subsequent decay of $K^{*\pm}$ into $K_1^0\pi^\mp$ or $K_2^0\pi^\pm$. The number of C^0's decaying into $\varrho^0 K_1^0$ or $\varrho^0 K_2^0$ is compatible with zero.

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

The study of two and three particle effective mass combinations show: a) the strong production of K^* (888) in all possible types of combinations; b) a deviation of the $(\pi^\pm\pi^0)$ effective mass distribution from phase space with an accumulation towards large values of $(\pi^\pm\pi^0)$ mass; c) a $(K^\pm\pi^\mp\pi^0)$ effective mass distribution, Fig. 3, similar to that observed in the annihilation into $K_1^0 K_1^0 \pi^+\pi^-$. The deviation from phase space can be explained by the presence of a C^0 resonant state; d) the charged three-body system $(K_1^0\pi^\pm\pi^0)$ also shows a deviation from phase space, Fig. 3, but the enhancement is now central at 1320 MeV/c². This mass difference seems too large to identify this enhancement as the charged counterpart of the C^0.

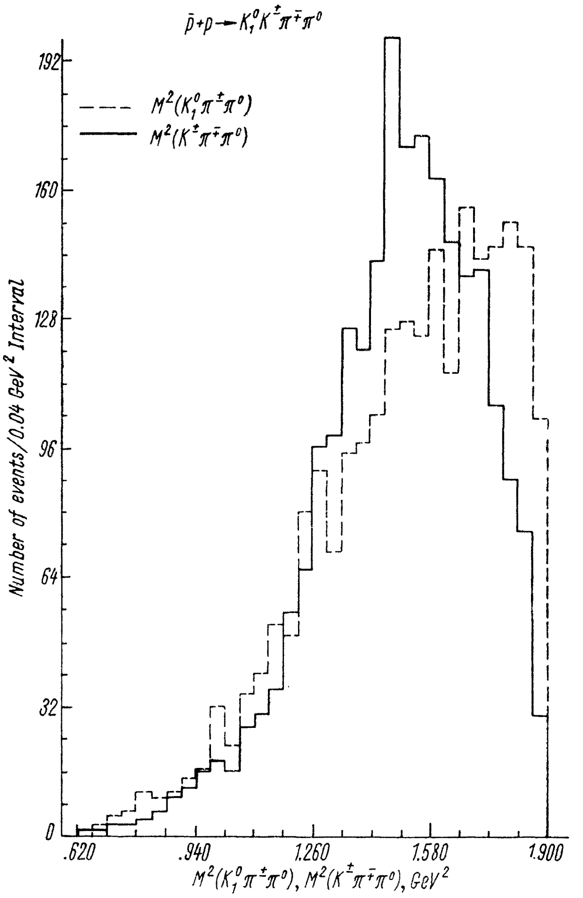

Fig. 3. $(K_1^0\pi^\pm\pi^0)$- and $(K^\pm\pi^\mp\pi^0)$-effective squared mass spectra in $\bar{p}p \rightarrow K_1^0 K^\pm\pi^\mp\pi^0$.

We will only discuss here the characteristics of the neutral system ($K^{\pm}\pi^{\mp}\pi^0$).

The Dalitzs plot in the C^0 region, Fig. 4, shows an accumulation of events both in the K^* (888) bands and in the large ($\pi\pi$) effective mass region. A detailed study yields: 370 C's decaying into $\varrho^{\pm}K^{\mp}$, 200 C^0's decaying into $K^*\pi$, of which 105 into charged K^* and 95 into neutral K^*.

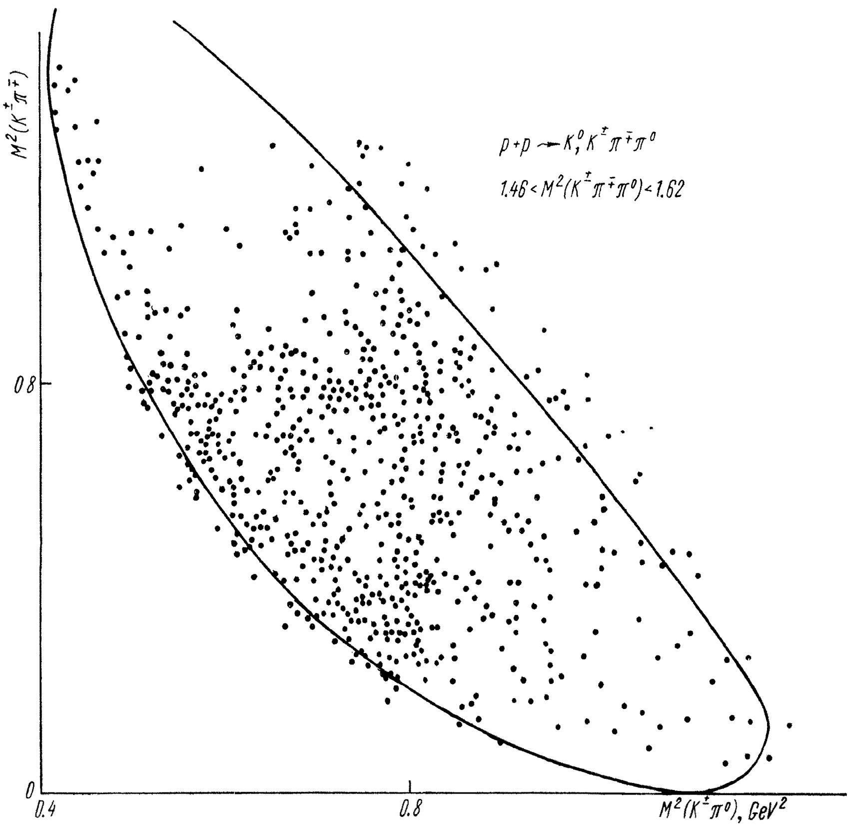

Fig. 4. Dalitz plot of the ($K^{\pm}\pi^{\mp}\pi^0$)-system in $\bar{p}p \to K_1^0K^{\pm}\pi^{\mp}\pi^0$ in the limits: $1{,}46 < M^2(K\pi\pi) < 1{,}62$ (GeV/c^2)^2.

DISCUSSION

The production of the C represents 60% of the total channel for reaction (1), it is respectively 50% for reaction (2b)

$$\bar{p}p \to K_1^0K_2^0\pi^+\pi^- \tag{2b}$$

and 25% for reaction (3).

The analysis of the decaying Dalitz plot shows that, for reaction (1), the C decay mainly into $K\varrho$ (85%), although the energy available in the rest frame of the C does not allow a well shaped ϱ-production: there is also some evidence for K^*_π decay mode, limited to 15%.

For reaction (2b) we don't observe ($K\varrho$) decay mode, but only $K^*\pi$, and for reaction (3), both decay modes are observed: 65% of $K\varrho$ and 35% of $K^*\pi$.

The fact that the ($\pi\pi$) system is in a P state in reaction (1), and, apparently, in an S state in reaction (2b) can be understood if, as if seems, $\bar{p}p$ capture occurs in S state [2]: then by J and P conservation one can show that mainly $^3S_1$ contribute to reactions (1) and (2b) and by charge conjugation conservation the ($\pi\pi$) system must be in odd l states for reaction (1) and even l states for reaction (2); this is also confirmed by the absence of events of the type:

$$\bar{p}p \to K_1^0K_1^0\pi^0\pi^0.$$

These are experimental observations. Of course, the C cannot be considered as a resonance until its quantum numbers are properly defined. In attempting to determine them, we are met with serious difficulties: when we try to determine the isospin, we come accross this trouble: in $(K^*\pi)$ decay mode of the C the predicted branching ratios for isotopic spin $^1/_2$ and $^3/_2$ for the C, and the experimental results are the following (Table).

	$T=1/2$	$T=3/2$	Exp.
$(K^*\to K^{\pm}\pi^{\mp})/(K^*\to K^{\mp}\pi^0)$	1	4	0.91
$(K^*\to K_2^0\pi^{\mp})/(K^*\to K^{\mp}\pi^0)$	1	1	3.1
$(K^*\to K_2^0\pi^{\mp})/(K^*\to K_1^0\pi^{\mp})$	1	1	3.9

On the other hand, for $(K\varrho)$ decay mode

$$(C\to K^0\varrho^0)/(C\to K^{\pm}\varrho^{\mp}) \quad 1/2 \quad 2/1 \quad 1.25$$

If we introduce SU_3 the disagreement is even worse. Again, when we try to determine the spin and parity, i. e. we look at the angular distributions available we observe strong interference effects.

These interference are explained, in reaction (1) by the 2 possibilities to form a C^0, with the $2K^0$ and the $(\pi\pi)$ system, in reaction (2b) and (3), the interference effects are due to the crossing fo the $(K^*\pi)$ system with the K^* which can be formed with the K which is outside the C.

We believe, nevertheless, that the observation of an enhancement occuring at the same place and with the same width in 3 different $(K\pi\pi)$ mass distributions testifies to the validity of the physical phenomenon, which has to be explained whether one calls it a resonance or a Pierls — Nauenberg's mechanism.

REFERENCES

1. A r m e n t e r o s R. et al. Phys. Lett., 9, 207 (1964).
2. A r m e n t e r o s R. et al. International Conference on High Energy Physics at CERN, 1962, p. 351.

DISCUSSION

J. B a l l a m.

Could you please explain the difference between $K_1K_1\pi^+\pi^-$ and $K_1K_2\pi^+\pi^-$ behaviours especially as regards the difference in the amount of K^* in the decay of the $K\pi\pi$?

L. M o n t a n e t.

The 2 differences we mentioned are about K^* and ϱ production in

$$p\bar{p}\to K_1^0K_1^0\pi^+\pi^-, \qquad (1)$$

$$p\bar{p}\to K_1^0K_2^0\pi^+\pi^-. \qquad (2b)$$

The production of K^* in (1) is smaller than in (2b), where it is very abundant: we have no esplanation for this difference.

For the ϱ production, we expect to observe it in reaction (1) and not in reaction (2b), if, as it seems, $p\bar{p}$ annihilation occurs mainly in $^3S_1$ state.