Multiple generation of pions in colliding electron-positron beams

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It is shown that the experimentally observed ρ' meson is a quasinuclear $^3S_1$ state of the $N\bar{N}$ system. The existence of one more relatively narrow resonant maximum ($\Gamma \lesssim 10$ MeV) in multiple generation of an even number of pions is predicted, with an energy close to two nucleon masses.

The experimental data[1] point to a noticeable increase of the cross section for the production of four and six pions in e^+e^- colliding beams, when the energy of the colliding particles reaches values on the order of two nucleon masses. The observed correlation of the energy dependence of the multiple-generation cross section with the threshold of the nucleon-antinucleon pair production calls for an explanation, since much less energy suffices for the production of several pions.

In the present article we explain this phenomenon as being due to the production of a virtual quasinucleon meson—a bound state of a nucleon (N) and an antinucleon ($\bar{N}$) with a nonrelativistic mass defect (see[2]). Since the $N\bar{N}$ annihilation proceeds predominantly via multipion channels, the considered mechanism should contribute to the observed effect.

The idea of the participation of quasinuclear mesons in the processes of multiple generation of pions in colliding e^+e^- beams was first advanced in.[3] The quantitative results obtained in that reference call, however, for a review and a certain refinement.

The considered mechanism of multiple pion generation corresponds to the diagram of Fig. 1. The light circle in the diagram denotes the amplitude of the photon → quasinuclear meson transition. It is equal to $\sqrt{\alpha}g(s)$, where $\alpha = 1/137$ and $g(s)$ is a function of the energy variable s. This function is conveniently parametrized by separating the constant and the term linear in s:

$$g(s) = c_0 + c_1 s + F(s). \tag{1}$$

The analytic function $F(s)$ contains all the singularities of the amplitude, including also the threshold singularities.

The cross section of the reaction $e^+e^- \to n\pi$ ($n > 2$ is the number of pions), corresponding to diagram 1, obviously has a resonance at the point $s = M^2$, where M is the mass of the quasinuclear meson. Denoting the partial (for the $n\pi$ channel) and the total widths of this meson by $\Gamma_{n\pi}$ and Γ, we can express the cross section in the form

$$\sigma(e^+e^- \to n\pi) = \frac{4\pi\alpha^2 M |g(s)|^2}{s^2} \frac{\Gamma_{n\pi}}{(s - M^2)^2 + M^2\Gamma^2}. \tag{2}$$

Figure 2 shows the experimental points for the energy dependence of the cross section of the reaction $e^+e^- \to 2\pi^+2\pi^-$, which have been investigated more thoroughly than the others (see[4]). These data can be reconciled with formulas (1) and (2) (dashed curve) at the following values of the parameters

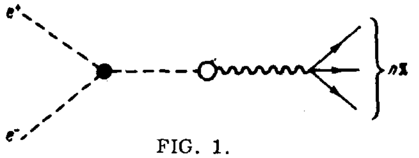

FIG. 1.

$$|(c_0 + F)/c_1 M^2| \leqslant 0.1,$$

$$M = 1650 \text{ MeV} \qquad \Gamma = 350 \text{ MeV}$$

The referred-to resonance ρ' should have the same quantum numbers as the ρ meson. It is of interest to compare the constant c_1 for the ρ' and ρ mesons. The absolute value of the constant $c_1(\rho')$ can be determined from data on the total cross section of the annihilation of e^+e^- into an even number of pions.[1] This yields

$$c_1^{-2}(\rho') = 9 \pm 3.$$

If we use for $c_1(\rho)$ the value given in[4] [$c_1^{-2}(\rho) = 2.36 \pm 0.25$], then

$$\frac{c_1^2(\rho')}{c_1^2(\rho)} = 4.0 \pm 1.4.$$

Thus, the orders of magnitude of the constants $c_1(\rho')$ and $c_1(\rho)$ are the same.

According to the quasinuclear model (see[2]), the resonance ρ' should be connected with the isovector $^3S_1$ state of the nucleon and antinucleon (with a possible d-wave admixture). Its width should be of the order of 100 MeV and the mass about 1700 MeV.

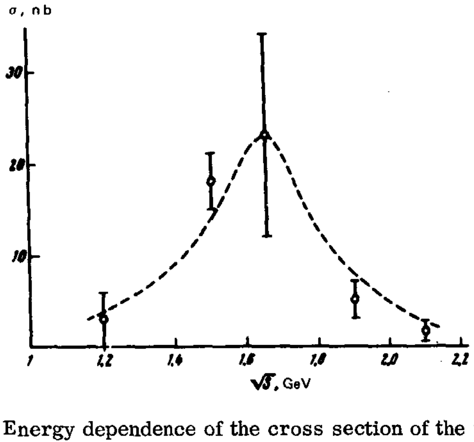

FIG. 2. Energy dependence of the cross section of the reaction $e^+e^- \to 2\pi^+2\pi^-$.

Channel		$\pi^+\pi^-$	$2\pi^+2\pi^-$	$\pi^+\pi^-2\pi^0$	$3\pi^+3\pi^-$	$2\pi^+2\pi^-2\pi^0$	$\pi^+\pi^-\pi^0$	$2\pi^+2\pi^-\pi^0$	$\pi^+\pi^-3\pi^0$
σ_{theor}	1 = 1	0.02	0.4	0.5	0.11	0.88	0.26	0.74	0.89
(nb)	1 = 0	0.01	0.22	0.31	0.07	0.54	0.16	0.45	0.54
σ_{expt} (nb)	–	–	5 ± 2	–	3.5 ± 1.5	7 ± 3	—	5 ± 3	—

As follows from the foregoing, the main contribution to the amplitude $g(s)$ should be made by the term linear in s. All the threshold singularities of this amplitude are contained in the term $F(s)$ (see formula (1)], which should be small. It is hardly possible to calculate the value of $F(s)$ purely theoretically, but a certain part of this quantity, determined by the intermediate states with the $N\bar{N}$ pair, can be estimated within the framework of the quasinuclear model. If the analysis given above for the multiple pion generation in e^+e^- collisions is correct, then the amplitude corresponding to the production of the virtual unbound $N\bar{N}$ pair should be much smaller than the linear term in $g(s)$ (otherwise it would be necessary to assume strong cancellation of the contributions from different intermediate states). An estimate of the term $\alpha(F)$ that is quadratic in F in the cross section (2) was obtained in.[3] As shown in that reference,

$$\sigma(F) = \frac{12\pi}{4M^2} W_e W_\pi , \tag{3}$$

where W_e and W_π are the relative probabilities of the annihilation of the resting N and $\bar{N}$ into e^+e^- and $n\pi$. These quantities can be estimated from the experimental data. The figures for $\sigma(F)/\sigma$, reviewed in accordance with the latest data (see[5]), are shown in the table. As seen from the table, $\sigma(F)/\sigma$ amounts to about 1% in the region of the ρ' resonance.[1)]

We note in conclusion that the quasinuclear model predicts the existence of one more vector state $N\bar{N}$ with positive G-parity and with unity isospin. This state is predominantly a $^3d_1$ wave in the relative motion $N\bar{N}$. Its mass is approximately 1850 MeV, and the total width can be much smaller than the width of the ρ' meson (owing to the centrifugal barrier that prevents N and $\bar{N}$ from coming together to distances of the order of the Compton length of the nucleon, which are typical of annihilation). The $N\bar{N}$ bound state $^3d_1$ (1850) has apparently been observed experimentally from the annihilation of $\bar{p}$ in a deuterium bubble chamber (see the experimental data in[6] and the theoretical discussion in[6]). The two isoscalar NN bound states with the quantum numbers of the photon and with negative G parities, have much smaller masses according to.[2]

Thus, according to the quasinuclear scheme, one should expect the presence of one more relatively narrow resonant maximum (with a possible width on the order of 10 MeV) in multiple generation of an even number of pions in colliding e^+e^- beams. The maximum should correspond to an energy close to two nucleon masses. At the same time, the model predicts the absence of resonances in multiple pion channels with negative G parity at energies in the region of or larger than the ρ' mass.

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[1)] The cross sections given in the table are large by approximately one order of magnitude than the values obtained in.[3] This difference is due to the fact that the contributions of the channels with the required isospin and B-parity to the total annihilation cross section were separated in the given paper in the calculation of W_π.

[1] G. Bacci *et al.*, Phys. Lett. 38 B, 551 (1972); G. Barbarino *et al.*, LNC 3, 369 (1972).
[2] L.D. Dal'karov, V.B. Mandel'tsveig, V.A. Khoze, ZhETF Pis. Red. 14, 131 (1971) [JETP Lett. 14, 87 (1971).
[3] D. Benaskas *et al.*, Phys. Lett. 39 B, 289 (1972).
[4] Symposium on Nucleon-Antinucleon Annihilation, Chexbres, Switzerland, 27—29 March, 1972.
[5] L. Gray, P. Hagerty, and T. Kalogeropoulos, Phys. Rev. Lett. 26, 1491 (1971).
[6] L.N. Bogdanova, O.D. Dalkarov, and I.S. Shapiro, Phys. Rev. Lett. 28, 1418 (1972).