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O.D. DALKAROV, K.V. PROTASOV

ON THE NEW VECTOR STATE IN e^+e^- ANNIHILATION NEAR 2 GeV

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Abstract

Experimental data obtained recently have confirmed the predicted possibility for an appearence of minimum in behaviour of the e^+e^--annihilation into six pions near $\bar{N}N$ threshold. From the theoretical analysis of the observed irregularity in the framework of coupled channel model existence of narrow vector state corresponding to $2^{33}S_1$-state in $\bar{N}N$ system with the mass about 1800 MeV and the width 15 MeV is followed.

Experimental study of e^+e^- annihilation into hadrons reveals a structure in manypionic channels near $\bar{N}N$ threshold[1]. The behaviour of the cross section $e^+e^- \to 2\pi^+2\pi^-2\pi^0$ is shown in Fig. 1. Well pronounced minimum is seen to coincide within several tens MeV with the mass of two nucleons. Possible existence of such structure caused by vicinity of $\bar{N}N$ channel was predicted earlier[2]. In this work using most common properties of the $\bar{N}N$ interaction (strong attraction between $\bar{N}$ and N, and shortrangness of annihilation) the unmonotonic behaviour of the e^+e^- annihilation was predicted. Such a phenomenon should be observed in manypionic modes which corresponds to main channels of $\bar{N}N$ annihilation.

e^+e^- annihilation into hadrons near $\bar{N}N$ threshold was considered in the work[2] as a coupled channel model: e^+e^-, $\bar{N}N$, and $n\pi$ (in these calculations for simplicity one two-boson channel with ρ and ε-mesons was taken into account). This process can be described using the Feynman graphs in Fig. 2. The reaction amplitude corresponding to the diagram (a) is proportional to

$$M \sim T_0 \, G_{\bar{N}N} \, V_{Nh} \, , \tag{1}$$

here $G_{\bar{N}N}$ is $\bar{N}N$ Green function (dotted block in Fig. 2(a)), T_0 is the amplitude for $e^+e^- \to \bar{N}N$ (without $\bar{N}N$ final state interaction), V_{Nh} is the short range potential realizing connection between $\bar{N}N$ and $n\pi$ channels. The diagram 2(b) corresponds to unpotential contribution into $e^+e^- \to n\pi$ annihilation and is considered as background one. Using a short-range character of T_0 and V_{Nh} the amplitude M can be rewritten in the following form

$$M \sim -\frac{|\varphi(0)|^2}{|\varepsilon_b| + \mathcal{E} + i\eta} + \int \frac{d\,\vec{k}\,|\varphi_k(0)|^2}{k^2/M - \mathcal{E} - i\eta} \, , \tag{2}$$

where $\varphi_k(\vec{r})$ and $\varphi(\vec{r})$ are the $\bar{N}N$ wave functions of continuum spectrum and discrete one, ε_b is the binding energy of $\bar{N}N$ level, existence of which is caused by the strong attraction between $\bar{N}$ and N,

$\mathcal{E} = \sqrt{s} - 2M$ is $\bar{N}N$ kinetic energy in c.m.s. It is easy to see that the integral over continuum at $\mathcal{E} < 0$ is positive everywhere while the pole contribution corresponding to bound state changes sign at $\mathcal{E} = -|\mathcal{E}_b|$ point. Therefore the exact compensation of these two terms is possible. An appearence of zero in Green function in corresponding brackets leads to elimination of the $e^+e^- \to n\pi$ amplitude without background (the exact position of this zero depends obviously on relative contribution of pole term and integral over continuum i.e. on $\bar{N}N$ interaction dynamics). In the region $\mathcal{E} < -|\mathcal{E}_b|$ one may be await the growth of the annihilation cross-section due to constructive interference between both terms in formula (2). Let us note that the statements mentioned above do not depend on the number of annihilation channels and concrete form of annihilation interaction, but depend on the fact of existance of the bound state and smallness of annihilation radius in comparison with quasinuclear state one.

There is another instructive example, in which transition amplitude discussed here can be calculated analytically. Let us consider $\bar{N}N$ nuclear interaction and annihilation one (transiton potential from $\bar{N}N$ into $n\pi$ channel) in seperable form: $V_{\bar{N}N} = g\,|1\rangle\langle 1|$ and $V_{ann} = \lambda\,|2\rangle\langle 2|$ correspondingly. In this case the amplitude for e^+e^- annihilation has the form

$$M \sim \frac{\lambda[(1 - g\,G_{111})G_{e12} + g\,G_{112}\,G_{e11}]\,\langle 2|}{(1 - g\,G_{111})(1 - \lambda^2 G_{222}\,G_{212}) - \lambda^2 g\,G_{112}\,G_{222}\,G_{212}}, \quad (3)$$

where $G_{ijk} = \langle i|G_j|k\rangle$, $i,j,k = 1,2$, G_1 is the free Green function in the $\bar{N}N$ channel, G_2 is one in the $n\pi$ channel, $G_{eik} = T_0\,G_i|k\rangle$. Zero of the amplitude M in (3) corresponds to zero of expression in the square brackets. Consider the form-factors $|1\rangle$ and $|2\rangle$ in the following Yukawa-like form $\langle i|\vec{r}\rangle = \sqrt{\beta_i/2\pi}\,\exp(-\beta_i r)/r$ $(i = 1, 2)$. For such form-factors we have

$$g\, G_{111} = \tilde{g} \frac{\beta_1^2}{(k + i\beta_1)^2} \quad ;$$

$$g\, G_{112} = \tilde{g} \frac{2\beta_1 \beta_2 \beta_1^2}{(\beta_1 + \beta_2)(k + i\beta_1)(k + i\beta_2)} \quad ,$$

where $\tilde{g}$ is dimentionless constant $g = (\beta_1^2/M)\tilde{g}$, M is the nucleon mass, k is the momentum in the $\bar{N}N$ channel. Also we have

$$G_{e12}/G_{e11} = \sqrt{\beta_2/\beta_1}\, \frac{k + i\beta_1}{k + i\beta_2} .$$

In taking imaginary momentum $k \to i\,q$ it is easy to determine the zero of M in (3):

$$q_{zero} = \beta_1 \left[\sqrt{\frac{\beta_2 - \beta_1}{\beta_2 + \beta_1}}\sqrt{\tilde{g}} - 1\right] . \qquad (4)$$

This zero lies on real axis of momentum if $\frac{\beta_2 - \beta_1}{\beta_2 + \beta_1} . \tilde{g} > 1$ and $\beta_2 > \beta_1$. Compare this expression with one for pole position in the nuclear $V_{\bar{N}N}$ potential, which is given by the solution of the equation

$$1 - g\, G_{111} = 0.$$

For the form-factor considered above we have

$$q_{pole} = \beta_1 \left[\sqrt{\tilde{g}} - 1\right]. \qquad (5)$$

From comparison of the expressions (4) and (5) we conclude:

1) The zero of M exists only in case, when the nuclear potential $V_{\bar{N}N}$ has a bound state. This zero lies between the pole and $\bar{N}N$ threshold.

2) For appearing of this zero smallness of the annihilation range in comparison with the nuclear forces range (i.e. $\beta_2 \gg \beta_1$) is of vital importance. In opposite case this zero does not exist.

Other method to prove the existence of Green function zero which is followed from the common properties of transition amplitude with $\lambda \to \infty$ was considered in ref.[2].

In present numerical calculations the annihilation $e^+e^- \to n\bar{n}$

near $\bar{N}N$ threshold is considered in the realistic coupled channel model. This model was used earlear[3] for description of all up to date experimental data on the low energy $\bar{N}N$ interaction. The connection between $\bar{N}N$ and e^+e^- channels was realised using -function potential $V_0 \cdot \delta(\vec{r})$, whereas direct transition from e^+e^- into $n\pi$ was absent, i.e. e^+e^- and annihilation channels are connected only through the $\bar{N}N$ one (diagram in Fig. 2(a)).The value V_0 was choosen the same as in calculations of the nucleon electromagnetic formfactor near $\bar{N}N$ threshold in the frame of this model[4](note that the absolute value and energy behaviour of proton electromagnetic formfactor are in good agreement with experimental data[5]). Finally the amplitude for $e^+e^- \rightarrow 2\pi^+2\pi^-2\pi^0$ process can be written in the foloving form

$$M = M_{eff} + M_{bg} \tag{6}$$

where M_{eff} is the amplitude calculated using coupled channel model, M_{bg} is background one corresponding to the direct annihilation $e^+e^- \rightarrow 2\pi^+2\pi^-2\pi^0$(diagram in Fig.2(b)). The background amplitude was fitted by smooth polinomial curve and normalized at the $\sqrt{s}$ = 2 Gev point where its contribution is dominant. The factor $(s/4M^2)^2$ taking into account the dependence of six pionic annihilation on the mass of annihilating $\bar{N}N$ system was included to the calculated amplitude M_{eff}. The relative phase of these amplitudes was fixed from a condition of best agreement with the experimental data and is equal to $\varphi = -\pi/4$.

The results of calculations for the cross-section of annihilation $e^+e^- \rightarrow 2\pi^+2\pi^-2\pi^0$ are shown in Fig. 1 (solid curve).It is seen that the main qualitative characteristics mentioned above are proved by exact calculations in the realistic model. Let's emphasize that the $e^+e^- \rightarrow \bar{N}N \rightarrow 6\pi$ annihilation can take place only from the $^{33}S_1$ state of $\bar{N}N$ system (isospin and spin of $\bar{N}N$ pair are equal to 1). It follows from the definite G-parity (G = + 1) and from the limitation of S-wave only (due to short range character of δ-functional $e^+e^- \to \bar{N}N$ potential). The analysis of the discrete spectrum in $^{33}S_1$-state carried out after describing of the experimental data has shown that in this partial wave the bound state with binding energy $|\varepsilon_b| = 90$ MeV and the width 15 MeV exists. This state corresponds to the exited $2^{33}S_1$ state in $\bar{N}N$ system. Such level should manifest itself as a narrow ($\Gamma \simeq 15$ MeV) vector meson ($J^{PC} = 1^{--}$) with the mass $M = 1790$ MeV. It is necessary to note that the existence of a narrow level causes sufficiently wider anomaly due to specific nature (zero of Green function) of the energy structure observed in $e^+e^- \to 6\pi$ annihilation.

The direct observation of predicted narrow vector state is possible in the experiment with deuterium target i.e. $\bar{p}d \to$ $\to p + 2\pi^+3\pi^-\pi^0$. It is interesting that in the ref.[6] first indication on the existence of meson state with the mass 1794 MeV and width 15 MeV in (4+6)-pionic mode for $\bar{p}d$ annihilation was obtained. Other method of experimental investigation could be a study of γ-spectra in $\bar{p}p$-annihilation at rest with gaseous hydrogen target. In this case $\bar{p}p$-annihilation (due to suppression of Stark effect) corresponds to one from P-state of protonium and relative probability of E1-transition from 2P-state of $\bar{p}p$-atom to $2^{33}S_1$ quasinuclear $\bar{N}N$ state could be equal of the order of $10^{-2} \div 10^{-3}$ which is possible to study in the experiments planned now at LEAR.

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Figure captions

Fig. 1 Annihilation $e^+e^- \rightarrow 2\pi^+2\pi^-2\pi^0$ in the mass region 1.5 - 2.5 GeV. Experimental data were taken from ref.[1]. Solid curve is the theoretical calculation.

Fig. 2 The Feynman diagrams for annihilation $e^+e^- \rightarrow n\pi$.

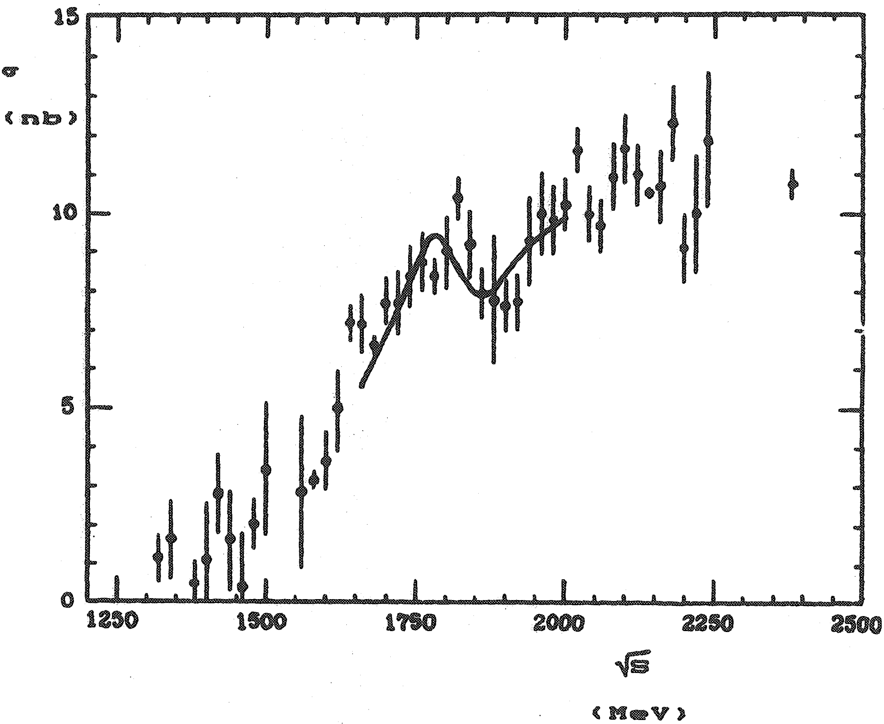

Fig. 1

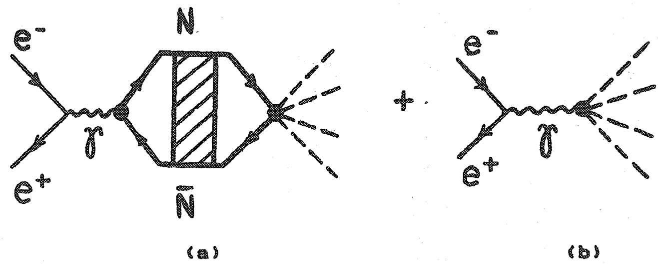

Fig. 2

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