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e^+e^- ANNIHILATION INTO $\overline{N}N$ PAIRS*

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The reactions of electron-position annihilation into nucleon-antinucleon pairs have been studied in a nonperturbative quark model. The work suggests that the two-step process, in which the primary $\overline{q}q$ pair forms first a meson and then the meson decays into a baryon pair, is dominant over the one-step process in which the primary $\overline{q}q$ pair is directly dressed by two additional $\overline{q}q$ pairs to form a baryon pair. The experimental data indicates that there exists a vector meson with quantum numbers $I^G(J^{PC}) = 0^-(1^{--})$ and a mass around 2 GeV.

1. Introduction

Experimental data on the reaction $e^+e^- \to \overline{n}n$ from the FENICE collaboration[1] and the earlier data on the reaction $e^+e^- \to \overline{p}p$ [2] and also the data on the time-reversed reaction $\overline{p}p \to e^+e^-$ [3] indicate in Fig. 1 that $\sigma(e^+e^- \to \overline{n}n)/\sigma(e^+e^- \to \overline{p}p) > 1$ at energies around the threshold $E_{cm} \sim 2$ GeV. Averaging over the available data on both the direct and time-reversed reactions, one finds

$$\frac{\sigma(e^+e^- \to \overline{p}p)}{\sigma(e^+e^- \to \overline{n}n)} = 0.66^{+0.16}_{-0.11}. \quad (1)$$

It is puzzling that the ratio is less than one.

In a naive perturbative description of e^+e^- annihilation into baryons the virtual time-like photon first decays into a $\overline{q}q$ pair, then the $\overline{q}q$ pair is dressed by two additional quark-antiquark pairs excited out of the vacuum to form a baryon pair. The dressing process does not distinguish between u and d quarks at high momentum transfers in the description of perturbative QCD since gluon couplings are flavor

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blind. In the conventional perturbative picture, theorefore, the only difference between the proton and neutron productions comes from the different electric charges of the primary $\bar{q}q$ pairs. One expects to get

$$\frac{\sigma(e^+e^- \to \bar{p}p)}{\sigma(e^+e^- \to \bar{n}n)} > 1 \tag{2}$$

at large momentum transfers if it is true that the u contribution dominates in the proton and the d in the neutron.

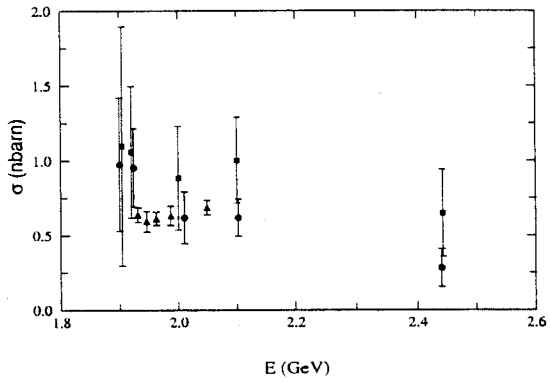

Fig. 1. Experimental data on the reaction $e^+e^- \to \overline{N}N$, where the squares for $e^+e^- \to \bar{n}n$, the circles for $e^+e^- \to \bar{p}p$ and the triangles for $\bar{p}p \to e^+e^-$.

In this work we study the reactions in a nonperturbative quark model, considering both one-step process (the primary $\bar{q}q$ pair is produced by the virtual photon and dressed by two additional quark-antiquark pairs to form a baryon pair) and two-step process (the primary $\bar{q}q$ pair forms first a meson, then the meson decays into a baryon pair).

2. e^-e^+ to $\overline{N}N$ in One-step Process

We consider here the process that an e^-e^+ pair annihilates into a virtual time-like photon which then decays into a $\bar{q}q$ pair, and finally the $\bar{q}q$ pair is dressed by two additional quark-antiquark pairs excited out of the vacuum to form a baryon pairs. The transition amplitude for e^-e^+ annihilation into $\overline{N}N$ in the one-step process takes the form

$$T = \langle \overline{N}N|\hat{V}(^3P_0)|\bar{q}q\rangle\langle\bar{q}q|\hat{S}|e^+e^-\rangle \tag{3}$$

where $\langle\bar{q}q|\hat{S}|e^+e^-\rangle$ is simply the transition amplitude of e^-e^+ to a primary quark pair while $\langle\overline{N}N|\hat{V}(^3P_0)|\bar{q}q\rangle$ denotes the amplitude of the process of a $\bar{q}q$ pair to a nucleon-antinucleon pair. $\hat{V}(^3P_0)$ is the effective vertex for creation and destruction of a quark-antiquark pair in the $^3P_0$ nonrelativistic quark model.[4] As for the wave function $|\overline{N}N\rangle$, we approximate the nucleon/antinucleon as three-quark/antiquark bound state in the harmonic oscillator interaction and neglect the interactions between the nucleon and antinucleon.[4] There is a free parameter, the harmonic length a in the wave function $|\overline{N}N\rangle$, subject to experimental data.

A detailed calculation of the amplitude in Eq. (3) results in

$$\frac{\sigma(e^+e^- \to \overline{p}p)}{\sigma(e^+e^- \to \overline{n}n)} \approx 3.0 \tag{4}$$

for $E_{cm} \sim 2M_N$ and $a = 3.1$ GeV^{-1}, a value widely used in the studies of nucleon-antinucleon annihilation to two and three mesons.[5]

3. e^-e^+ to $\overline{N}N$ in Two-step Process

We turn to the two-step process that an e^-e^+ pair annihilates into a virtual time-like photon which then decays into a $\overline{q}q$ pair, then the $\overline{q}q$ pair forms a virtual vector meson, and finally the virtual vector meson decays into a baryon pairs. The meson $\rho(2150)$ with the quantum number $I^G(J^{PC}) = 1^+(1^{--})$ is a good candidate for such an intermediate state.

The transition amplitude in such a process takes the form

$$T = \langle\overline{N}N|\hat{V}(^3P_0)|\rho\rangle\langle\rho|G|\rho\rangle\langle\rho|\overline{q}q\rangle\langle\overline{q}q|\hat{S}|e^+e^-\rangle \tag{5}$$

Here $\langle\rho|\overline{q}q\rangle$ is simply the wave function of the intermediate meson $\rho(2100)$ as mentioned before, $\langle\rho|G|\rho\rangle$ the Green function describing the propagation of the intermediate meson, and $\langle\overline{N}N|\hat{V}(^3P_0)|\rho\rangle$ the transition amplitude of the $\rho(2100)$ meson decays into nucleon-antinucleon pairs.

The ρ mesons can be in states with the orbital angular momentum even like S, D and G due to its negative parity. Since it is likely that the $1S$, $2S$ and $1D$ states have been occupied,[6,7] the $\rho(2100)$ could be either a $3S$ or $2D$ state. In the harmonic oscillator approximation, the $3S$ and $2D$ states take the forms

$$\Phi_s(\vec{p}) = N_s \exp\left(-\frac{1}{2}b^2p^2\right)\left(\frac{15}{4} - 5b^2p^2 + b^4p^2\right)\left[\frac{1}{2}^{(1)} \otimes \frac{1}{2}^{(2)}\right]_1 \tag{6}$$

and

$$\Phi_p(\vec{p}) = N_d \exp\left(-\frac{1}{2}b^2p^2\right)(bp)^2\left(\frac{7}{2} - b^2p^2\right)\left[\left(\frac{1}{2}^{(1)} \otimes \frac{1}{2}^{(2)}\right)_1 \otimes Y_2(\hat{p})\right]_1 \tag{7}$$

respectively. Here $\vec{p}$ is the relative momentum with $\vec{p} = \frac{1}{2}(\vec{p}_1 - \vec{p}_2)$, and the normalization factors $N_s = \left(\frac{2b^3}{15\pi^{3/2}}\right)^{1/2}$, and $N_d = \left(\frac{32b^3}{105\pi^{1/2}}\right)^{1/2}$

It is natural to argue that the intermediate mesons could be both ρ like and ω like since an e^+e^- pair could be in states of isospin singlet and triplet. Considering that the confirmed ρ and ω mesons[6] always appear in pairs with almost the same masses, we introduce a vector meson of isospin singlet with a mass around 2100 MeV and a width around 300 MeV, say $\omega(\sim 2100)$. With e^-e^+ annihilation into nucleon-antinucleon pairs through the intermediate vector mesons $\rho(2100)$ and $\omega(\sim 2100)$, we have

$$\frac{\sigma(e^+e^- \to \overline{p}p)}{\sigma(e^+e^- \to \overline{n}n)} = \frac{|T(e^+e^- \to \rho \to \overline{N}N) + T(e^+e^- \to \omega \to \overline{N}N)|^2}{|T(e^+e^- \to \rho \to \overline{N}N) - T(e^+e^- \to \omega \to \overline{N}N)|^2} \quad (8)$$

A detailed study results in

$$\frac{\sigma(e^+e^- \to \overline{p}p)}{\sigma(e^+e^- \to \overline{n}n)} \approx 3.3 \quad (9)$$

for both the $\rho(2150)$ and $\omega(\sim 2100)$ in $3S$ state, and

$$\frac{\sigma(e^+e^- \to \overline{p}p)}{\sigma(e^+e^- \to \overline{n}n)} \approx 0.64 \quad (10)$$

for both the $\rho(2150)$ and $\omega(\sim 2100)$ in $2D$ state. Note that the results above are independent of the parameter a, b and effective strength λ of the vertex $^3P_0$.

4. Discussions

The reactions of electron-position annihilation into nucleon-antinucleon pairs have been studied in the $^3P_0$ nonperturbative quark model. The work suggests that the two-step process, in which the primary $\overline{q}q$ pair forms first a meson then the meson decays into a baryon pair, is dominant over the one-step process in which the primary $\overline{q}q$ pair is directly dressed by two additional $\overline{q}q$ pairs to form a baryon pair.

It is interesting to have a close look at the Particle Table [6] to check how the ρ and ω mesons come in pairs. For each ρ meson except for $\rho(2150)$, one always has

Table 1. ρ and ω mesons come in pairs.

1S	$\rho(770)$	$\omega(782)$
2S	$\rho(1450)$	$\omega(1420)$
1D	$\rho(1700)$	$\omega(1650)$
3S or 2D	$\rho(2150)$	$\omega(2100)$?

one ω around with the similar mass, see Table 1. The work here strongly supports the argument that there exists an ω meson in the $2D$ state with mass around 2100 MeV and width around 300 MeV.

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April 15, 2003

Ref.: Dr. Yan's One-Lecturer-One-Project

To Whom It May Concern

Dear Sir/Madam:

This is to ask for your understanding of the change of the project title.

I had initially planned to publish a paper on *Decay of Roper Resonance*. However, it was found that the project needs at least two years. The research on this topic has still been going on and we expect to have a big paper in about one year. Instead, I would like to have another publication on *Electron-Position Annihilation to Nucleon Pairs* to be the project.

Sincerely yours

Yupeng Yan