Does the quark cluster model predict a $J^P=0^-$ isospin-2 dibaryon resonance?

E. Moro,[1] A. Valcarce,[1,3] H. Garcilazo,[2] and F. Fernández[1]
[1]*Grupo de Física Nuclear, Universidad de Salamanca, E-37008 Salamanca, Spain*
[2]*Escuela Superior de Física y Matemáticas, Instituto Politécnico Nacional, Edificio 9, 07738 México D.F., Mexico*
[3]*Institut für Theoretische Physik, Universität Tübingen, D-72076 Tübingen, Germany*
(Received 10 October 1995)

We use a nonlocal nucleon-Δ interaction, based on a quark cluster model for the nonstrange sector, to analyze the possible existence of a resonance in the $J^P=0^-$ channel with isospin 2. The employed quark cluster model has been successfully applied to the one and two nonstrange baryon properties. The nonlocal potential results to be attractive enough to generate a resonance although with a mass and width larger than the experimental predictions. There is a strong correlation between the mass and the width of the resonance due to the proximity of the nucleon-Δ threshold. [S0556-2813(96)05110-2]

PACS number(s): 24.85.+p, 12.39.Pn, 13.75.Cs, 14.20.Pt

A $J^P=0^-$ resonance has been proposed in Ref. [1] to explain the sharp peak seen 50 MeV above the pion threshold on the pionic double charge exchange cross section in several nuclei from ^{14}C to ^{48}Ca. The narrow width of these peaks (around 5 MeV) suggested that the resonance must have isospin even, otherwise decay into nucleon-nucleon (NN) would be allowed causing a much larger width. Besides, based on QCD string models, it was assumed that the resonance has isospin zero. However, in Refs. [2,3] it was pointed out that the narrow width of this structure could be related with the vicinity of the nucleon-Δ ($N\Delta$) threshold and therefore the resonance most likely must have isospin 2 (the $N\Delta$ system cannot be coupled to isospin zero).

The existence of πNN bound states (negative pions and neutrons, pineuts) was predicted theoretically years ago [4]. A system of neutrons and negative pions gives rise to a structure similar to an ordinary nucleus, where the protons have been replaced by negative pions. Since these systems can only decay through weak interactions, they should be stable and have lifetimes comparable to that of the pion. Then, a question arises immediately as to if one could observe even the simplest of these possible pineuts, a bound state of a pion and two neutrons.

This problem has been studied from the theoretical point of view by means of different methods [3–5] and with different conclusions, but never definitively excluding the possibility of a resonance. A recent calculation [3] based on a local approximation of the quark cluster model does not show any resonance with isospin 2, although the 0^- channel is the most attractive. However, due to the quark substructure of baryons, baryon-baryon potentials become nonlocal. Therefore, a possible source of the lack of attraction within the calculation of Ref. [3] could be due to having neglected the nonlocal terms of the $N\Delta$ interaction.

The purpose of the present investigation is to study the influence of the nonlocalities of the quark-model-based potential. For this purpose, we have constructed a $N\Delta$ interaction using the quark-cluster model of Ref. [6]. In this model, the constituent quark mass is a consequence of the chiral symmetry breaking. This fundamental symmetry of the QCD Lagrangian is restored by the introduction of the exchange of a pseudoscalar (pion) and a scalar (sigma) boson between quarks. Besides, a perturbative contribution is obtained from the nonrelativistic reduction of the one-gluon exchange diagram in QCD.

Therefore, the ingredients of the quark-quark interaction are the confining potential (CON), the one-gluon exchange (OGE), the one-pion exchange (OPE), and the one-sigma exchange (OSE):

$$V_{\rm CON}(\vec r_{ij})=-a_c\vec\lambda_i\cdot\vec\lambda_j r_{ij}^2, \tag{1}$$

$$V_{\rm OGE}(\vec r_{ij})=\frac{1}{4}\alpha_s\vec\lambda_i\cdot\vec\lambda_j\left\{\frac{1}{r_{ij}}-\frac{\pi}{m_q^2}\left[1+\frac{2}{3}\vec\sigma_i\cdot\vec\sigma_j\right]\delta(\vec r_{ij})-\frac{3}{4m_q^2r_{ij}^3}S_{ij}\right\}, \tag{2}$$

$$V_{\rm OPE}(\vec r_{ij})=\frac{1}{3}\alpha_{ch}\frac{\Lambda^2}{\Lambda^2-m_\pi^2}m_\pi\left\{\left[Y(m_\pi r_{ij})-\frac{\Lambda^3}{m_\pi^3}Y(\Lambda r_{ij})\right]\vec\sigma_i\cdot\vec\sigma_j+\left[H(m_\pi r_{ij})-\frac{\Lambda^3}{m_\pi^3}H(\Lambda r_{ij})\right]S_{ij}\right\}\vec\tau_i\cdot\vec\tau_j, \tag{3}$$

$$V_{\rm OSE}(\vec r_{ij})=-\alpha_{ch}\frac{4m_q^2}{m_\pi^2}\frac{\Lambda^2}{\Lambda^2-m_\sigma^2}m_\sigma\left[Y(m_\sigma r_{ij})-\frac{\Lambda}{m_\sigma}Y(\Lambda r_{ij})\right]. \tag{4}$$

All the parameters of the model are fixed to reproduce the nucleon-nucleon phenomenology (scattering phase shifts and deuteron binding energy) and the nonstrange baryon spectrum. Moreover, as the fundamental vertex of the model (qq meson) is independent of the baryon to which the quarks are coupled, the generalization of the NN interaction to any other nonstrange baryonic system is straightforward, and in particular to the $N\Delta$ system. The parameters of the model are those of Ref. [3].

In Ref. [3] it was found that the $J^P=0^-$ partial wave is the most attractive one and therefore the best candidate to possess a resonance. In this channel the two baryons move in a relative P wave and therefore the centrifugal barrier suppresses the short range part of the interaction, minimizing the effects of the fluctuations of the center of mass motion. Therefore, it can be assumed that the interbaryon distance has the sharp value R, and one can use the Born-Oppenheimer approximation. The nonlocal nucleon-Δ potential can be obtained from the quark-quark interaction [7] as the expectation value of the energy of the six-quark system minus the self-energies of the two clusters, which can be computed as the energy of the six-quark system when the two quark clusters do not interact:

$$V_{N\Delta(LST)\rightarrow N\Delta(L'S'T)}(R,R') = \xi_{LST}^{L'S'T}(R,R') - \xi_{LST}^{L'S'T}(\infty,\infty), \tag{5}$$

where

$$\xi_{LST}^{L'S'T}(R,R') = \frac{\langle \Psi_{N\Delta}^{L'S'T}(\vec{R}')|\Sigma_{i<j=1}^{6} V_{qq}(\vec{r}_{ij})|\Psi_{N\Delta}^{LST}(\vec{R})\rangle}{\sqrt{\langle \Psi_{N\Delta}^{L'S'T}(\vec{R}')|\Psi_{N\Delta}^{L'S'T}(\vec{R}')\rangle}\sqrt{\langle \Psi_{N\Delta}^{LST}(\vec{R})|\Psi_{N\Delta}^{LST}(\vec{R})\rangle}}. \tag{6}$$

To study the character of the $J^P=0^-$ partial wave with the nonlocal potential, we calculate Argand diagrams between a stable and an unstable particle using the formalism of Ref. [8]. That means we will solve the Lippmann-Schwinger equation

$$T_{ij}(q,q_0) = V_{ij}(q,q_0) + \sum_k \int_0^\infty q'^2 dq' V_{ik}(q,q') G_0(E,q') T_{kj}(q',q_0). \tag{7}$$

The two-body propagator is

$$G_0(S,q) = \frac{2m_\Delta}{s - m_\Delta^2 + i m_\Delta \Gamma_\Delta(s,q)}, \tag{8}$$

where S is the invariant mass squared of the system, while s is the invariant mass squared of the πN subsystem (those are the decay products of the Δ). The width of the Δ is taken to be [8]

$$\Gamma_\Delta(s,q) = \frac{2}{3} 0.35 p_0^3 \frac{\sqrt{m_N^2+q^2}}{m_\pi^2 \sqrt{s}}, \tag{9}$$

where p_0 is the pion-nucleon relative momentum.

We compare in Fig. 1 the phase shifts obtained for the 0^- channel to those of Ref. [3]. As can be seen from this figure, this partial wave is attractive in both cases, however, the attraction is only strong enough to produce a resonance with the nonlocal potential (it reaches 90°). The resulting Argand diagram shows a resonancelike behavior (Fig. 2). This resonance lies at 2145.6 MeV and has a width of 148.12 MeV for the mass of the sigma predicted by chiral symmetry requirements $m_\sigma \sim 675$ MeV.

The peak seen in the pionic double charge exchange cross sections has been explained by means of a resonance with a mass of 2065 MeV and a very small width of 0.51 MeV. The most striking feature of this structure is its very tiny width. Although the resonance predicted by our model is of higher

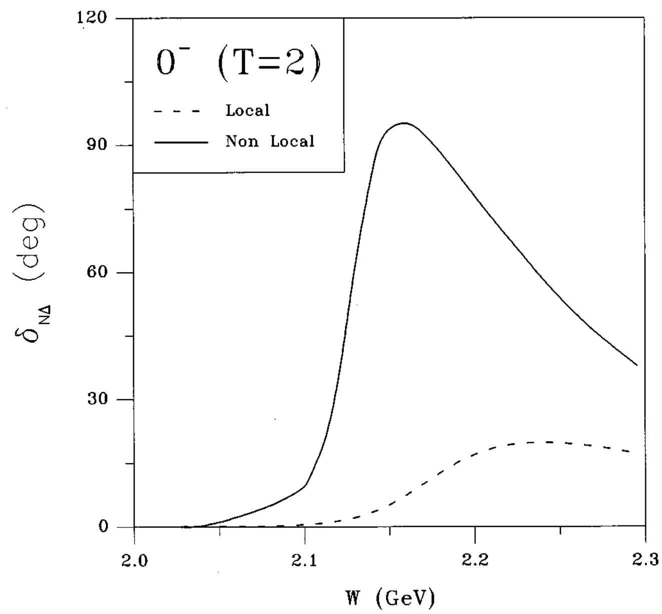

FIG. 1. Comparison between the phase shifts of the 0^- nucleon-Δ channel predicted by the local and the nonlocal quark model based potentials as a function of the invariant mass $W=S^{1/2}$.

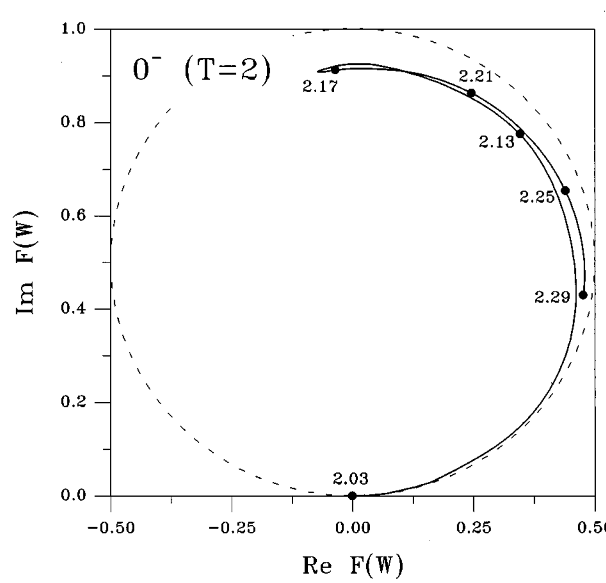

FIG. 2. Argand diagrams of the $^3P_0$ nucleon-Δ partial wave. The numbers correspond to the invariant mass of the πNN system in GeV.

TABLE I. Mass and width of the 0^- resonance with the corresponding mass of the sigma meson using the nonlocal nucleon-Δ potential based on the constituent quark model.

m_σ (MeV)	M_{res} (MeV)	Γ_{res} (MeV)
675.0	2145.7	148.13
493.0	2099.8	13.17
434.0	2071.4	3.30
420.0	2063.2	1.73
395.0	2046.7	0.37

mass and wider, it is interesting to study the possibility of such a structure in the present model. Following Ref. [3], we have increased artificially the amount of attraction in the model by decreasing the mass of the sigma meson. We show in Table I the mass and width of the resonance and the corresponding mass of the sigma meson necessary to generate it. As explained in Ref. [3], the width of the resonance drops dramatically when its mass approaches the πNN threshold (2017 MeV). When the mass of the sigma is taken to reproduce the predicted mass of the resonance (2065 MeV) the width is very narrow, which is in very good agreement with the predictions extracted by Bilger and Clement [1]. Let us note that the mass of the sigma needed to reproduce the width of the resonance in the medium (5 MeV) is of the order of the one predicted by the Brown-Rho [9] scaling law. Therefore, one could attribute the decreasing on the mass of the sigma to medium effects.

As a summary, we have studied the nucleon-Δ system in the 0^- channel with isospin 2, within the quark cluster model of the baryon-baryon interaction using the nonlocal potential. We found that the nonlocal effects generate additional attraction, although not enough to reproduce the resonance predicted in Ref. [1]. However, due to the proximity of the nucleon-Δ threshold, if the resonance is forced to reach its experimentally predicted mass, its width is in very good agreement with the data extracted in Ref. [1]. This tuning of the mass of the resonance could be justified by the scaling of the mass of the sigma in the medium. It would be an interesting further experimental effort to disentangle the existence of this resonance.

This work was partially funded by EU Project No. ERBCHBICT941800, DGICYT Contract No. PB91-0119, and by COFAA-IPN (Mexico).

[1] R. Bilger, H. A. Clement, and M. G. Schepkin, Phys. Rev. Lett. **71**, 42 (1993); **72**, 2972 (1994).
[2] H. Garcilazo and L. Mathelitsch, Phys. Rev. Lett. **72**, 2971 (1994).
[3] A. Valcarce, H. Garcilazo, and F. Fernández, Phys. Rev. C **52**, 539 (1995).
[4] H. Garcilazo, Phys. Rev. Lett. **50**, 1567 (1983).
[5] W. A. Gale and I. M. Duck, Nucl. Phys. **B8**, 109 (1968); G. Kalbermann and J. M. Eisenberg, J. Phys. G **5**, 35 (1977); H. Garcilazo and L. Mathelitsch, Phys. Rev. C **34**, 1425 (1986); F. Wang, J. Ping, G. Wu, L. Teng, and T. Goldman, *ibid.* **51**, 3411 (1995).
[6] F. Fernández, A. Valcarce, U. Straub, and A. Faessler, J. Phys. G **50**, 2246 (1993).
[7] E. Moro, Diploma thesis, University of Salamanca, unpublished.
[8] H. Garcilazo and M. T. Peña, Phys. Rev. C **44**, 2311 (1991).
[9] G. E. Brown and M. Rho, Phys. Rev. Lett. **66**, 2720 (1991).