Comments

Comments are short papers which comment on papers of other authors previously published in **Physical Review C.** *Each Comment should state clearly to which paper it refers and must be accompanied by a brief abstract.*

Comment on "$\bar{p}p \rightarrow \bar{\Lambda}\Lambda$ reaction in the one-gluon-exchange and the $^3P_0$ models"

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A number of recent papers have compared the $^3P_0$ and $^3S_1$ models for $\bar{N}N$ annihilation. We argue that a more consistent approach is to use both models together because they represent different aspects of quantum chromodynamics. In the approximation of the paper on which this Comment is based, our approach gives better agreement with data.

Burkardt and Dillig[1] have argued that data from the $\bar{p}p \rightarrow \bar{\Lambda}\Lambda$ reaction favor the so-called one-gluon-exchange "$^3S_1$" model over the $^3P_0$ model. We wish to comment on this paper especially, but also on others in which the superiority of one model over the other is debated. [We believe that the name $^3S_1$ is a misnomer because the virtual gluon exchanged between quarks/antiquarks has both transverse ($J^P=1$) and longitudinal ($J^P=0^+$) or Coulomb components. It thus is not a pure ($q\bar{q}$) $^3S_1$ model, and we use quotes for that reason.] We believe that such comparisons should not be made, but rather that a description more consistent with quantum chromodynamics (QCD) and NN scattering models requires the use of a superposition of the $^3P_0$ and "$^3S_1$" models as components of an overall scheme.[2] We point out that the superposition is suggested by $\bar{p}p \rightarrow \bar{\Lambda}\Lambda$ scattering data.

Almost all models of QCD which incorporate quark-gluon degrees of freedom in the description of the NN interaction[3] require two parts: (1) a short-distance one-gluon exchange force and (2) a long-distance scalar confining force. Also, the combination of the one-gluon exchange and a linear confining force reproduces the spectra of heavy quarkonia systems such as $c\bar{c}, b\bar{b}$, and those of one light and one heavy quark such as D^0, D^{0*}.[4] In a field theory approach, crossing symmetry suggests that similar forces should be present in the $\bar{N}N$ system, i.e., a short-range one-gluon exchange and a long-range scalar interaction.

The important features which appear to be present in both nuclear and quark systems is that they are dominated by scalar (or pseudoscalar) and vector interactions. In the NN system these are described, at large distances, by π, σ, ρ, and ω exchanges. In qq and $q\bar{q}$ systems they arise from gluon exchange and the confining force. There is good evidence[5] that confinement is due to a scalar force, independent of flavor, whereas the one-gluon force is clearly a colored-vector exchange one. For light quark (u,d,s) systems confinement is sometimes represented by a harmonic ($\sim r^2$) force; we use this description here.

In low-energy applications of QCD we believe that one-gluon and part of the multigluon exchanges can be represented by the exchange of a colored-vector particle. Indeed, in applications of the "$^3S_1$" model to $\bar{N}N$ (Refs. 6 and 7) and elsewhere, the propagator for the so-called gluon has often been taken to be a constant, which results in a contact interaction. Thus the model advocated here for $\bar{N}N$ annihilation is a superposition of the exchange of a vector particle and of a scalar "particle" (e.g., representing two or more gluons or 0^+ gluonium).

The recent paper by Burkardt and Dillig[1] uses a plane wave Born approximation to compare the $^3P_0$ and "$^3S_1$" models for $\bar{p}p \rightarrow \bar{\Lambda}\Lambda$. We do not believe that the Born approximation is justified, but show that even with this approach, our composite model[2] fits data better than either of the models alone.

The simplest graphs for the "$^3S_1$" and $^3P_0$ mechanisms for $\bar{p}p \rightarrow \bar{\Lambda}\Lambda$ are shown in Fig. 1. Although relevant equations appear in Ref. 1, we repeat the basic ones in our own notation.[2] The matrix element for this reaction is given by

$$\mathcal{M}_{p\bar{p}\rightarrow\Lambda\bar{\Lambda}} \sim \langle \Phi_{\Lambda\bar{\Lambda}}(1'2'3';4'5'6')\phi(1'2'3')\phi(4'5'6') \mid I_v + I_s \mid \phi(123)\phi(456)\Phi_{N\bar{N}}(123;456) \rangle \ , \tag{1}$$

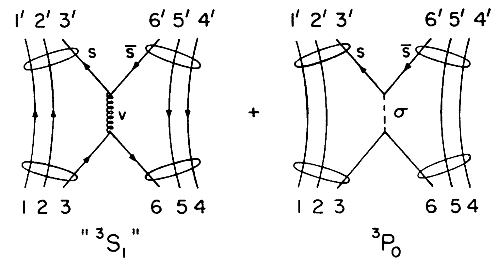

FIG. 1. Lowest order diagrams for $p\bar{p}\to\Lambda\bar{\Lambda}$. The scalar exchange is called σ in analogy to the topological soliton model (Ref. 12).

where $\Phi_{\Lambda\bar{\Lambda}}$ and $\Phi_{N\bar{N}}$ are taken to be plane waves in Born approximation, and ϕ is a harmonic oscillator wave function. In Eq. (1), the operator for I_v, the vector exchange ("$^3S_1$" model), is

$$I_v = g_v \boldsymbol{\sigma}'_3 \cdot \boldsymbol{\sigma}_3 , \tag{2a}$$

and that for I_s, the scalar exchange ($^3P_0$ model), is

$$I_s = g_3 \vec{\sigma}'_3 \cdot \left[\frac{\overleftarrow{\nabla}_{3'} - \overleftarrow{\nabla}_{6'}}{2m_s} \right] \vec{\sigma}_3 \cdot \left[\frac{\vec{\nabla}_3 - \vec{\nabla}_6}{2m} \right] , \tag{2b}$$

where m_s is the strange quark mass. We use $m=m_u=m_d=313$ MeV, $m_s=491$ MeV, and harmonic oscillator bound state wave functions, $\sim e^{-(1/2)\alpha r_i^2}$, for each quark. Results for the angular distribution at $\bar{p}_{\rm lab}=1.5075$ GeV/c are compared to experiment[8] in Fig. 2 for $\alpha_s=1.0$ fm^{-1} and $|I_v|^2$ alone, $|I_s|^2$ alone, and $|I_v+I_s|^2$ with $g_s=-0.6g_v$. This figure demonstrates that the angular distribution of the combined model fits the data somewhat better than either I_v or I_s alone. Burkardt and Dillig show the differential cross section at this momentum only for the vector exchange model. Their best fit to the total cross section, for a radius of 0.8 fm ($\alpha\approx 0.7$ fm^{-1}), is also shown in Fig. 2. We believe the steep rise of their differential cross section at forward angles occurs due to the neglect of the mass difference m_s-m_u. We note that the fit of the scalar term alone (not shown by Burkardt and Dillig) is not nearly as good as our vector term alone, and a destructive interference between the two mechanisms improves the fit to the data.

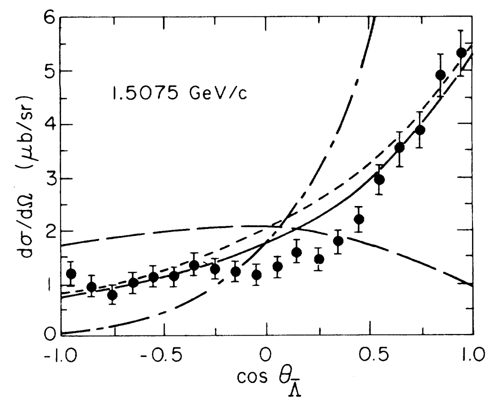

FIG. 2. Differential cross section for $\bar{p}$ lab momentum of 1.5075 GeV/c. The data are taken from Barnes *et al.* (Ref. 8). The short-dashed curve is the "$^3S_1$" (vector) contribution (normalized to fit the data) and the long-dashed curve is the $^3P_0$ (scalar) contribution. The solid curve results from the linear combination $|I_v+I_s|^2$, with $g_s=-0.6g_v$. The short-long-short dashed curve is the "$^3S_1$" calculation of Burkardt and Dillig (Ref. 1).

Kohno and Weise and others[9] have shown that a kaon exchange model with distorted waves gives fair agreement with the data.[8] They[10] and Faessler and colleagues[11] also obtain fair agreement with the data by employing a quark model. Even in Born approximation, we are able to improve the fit to the angular distribution by means of a destructive interference between the $^3P_0$ and "$^3S_1$" terms. Work is in progress to include distortion effects in both initial and final states, so that a comparison with polarization data can be made.

In conclusion, we have argued that the $^3P_0$ and "$^3S_1$" models should be used together and have shown by a simple calculation and by comparison to Burkardt and Dillig that this approach provides an improved fit to $\bar{p}p\to\bar{\Lambda}\Lambda$ data even in Born approximation.

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