Scalar and Vector Contributions to $\bar{p}p \to \bar{\Lambda}\Lambda$

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Abstract

A quark model which includes both scalar and vector contributions to the reaction $\bar{p}p \to \bar{\Lambda}\Lambda$ is presented. DWBA calculations of differential cross-sections, polarizations and spin correlation coefficients are compared to experimental results at several energies. The results are sensitive to details of the reaction mechanism and to the parameters of the $\bar{\Lambda}\Lambda$ interaction.

1. Introduction

The exclusive reaction $\bar{p}p \to \bar{\Lambda}\Lambda$ provides a laboratory in which to study the detailed mechanism of $\bar{N}N$ annihilation. The weak decays of the hyperons allow measurement of spin observables that are sensitive to details of the reaction mechanism. We have proposed[1] a quark model for $\bar{N}N$ annihilation which consists of a linear superposition of the so-called $^3P_0$ (scalar) and $^3S_1$ (vector) models. We have argued that this approach is more consistent with QCD and the analogous $\bar{N}N$ system than the use of either model alone. Recent precise measurements[2] of the $\bar{p}p \to \bar{\Lambda}\Lambda$ reaction by the PS185 collaboration at LEAR allow a test of this model. In this paper we present the results of distorted wave calculations for the production of $\bar{\Lambda}\Lambda$; distortion effects due to real and imaginary (absorptive) potentials in both initial and final states are included. Our results at $p_{lab} = 1.5075$ GeV/c, 1.564 GeV/c and 1.695 GeV/c show that the best fits to the differential cross section,

polarization, and spin correlation coefficients are obtained with an interference between scalar and vector terms. The sensitivity of our results to the parameters of the $\bar{\Lambda}\Lambda$ potential indicates that this reaction may be used to provide information about the hyperon-antihyperon interaction, about which very little is known.

2. Reaction Mechanism

Two complementary pictures of the $\bar{p}p \to \bar{\Lambda}\Lambda$ reaction are those of meson exchange[3-6], and quark annihilation. Exchange models include K, K^*, and/or K^{**} exchanges. Such exchanges are of short range, at distances for which quark effects might be expected to play a role. Therefore alternative descriptions[5,7-10] based on constituent quark dynamics have been developed. These models are based on either the $^3P_0$ model, in which a $\bar{u}u$ pair annihilation into the vacuum is followed by an $\bar{s}s$ creation, or the "$^3S_1$" model, in which a virtual vector quantum is exchanged. The simplest graphs for these models are shown in Fig. 1. We have proposed that the correct description for $\bar{N}N$ annihilation consists of a superposition of the $^3P_0$ and "$^3S_1$" mechanisms; the former can be thought to arise from the confining scalar force and the latter describes a vector quantum exchange (e.g., one or more gluons) expected in the $\bar{N}N$ interaction.
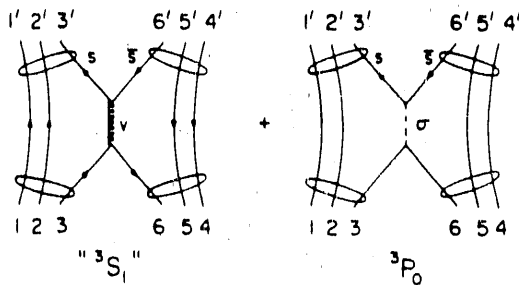

Figure 1
Lowest order diagrams for $\bar{p}p \to \bar{\Lambda}\Lambda$

In our model, the operator for vector exchange is

$$I_v = g_v \overleftarrow{\sigma_3'} \cdot \overrightarrow{\sigma_3}$$

and that for scalar exchange is

$$I_s = g_s \overleftarrow{\sigma_3'} \cdot \left(\frac{\overleftarrow{\nabla}_{3'} - \overleftarrow{\nabla}_{6'}}{2m_s} \right) \overrightarrow{\sigma}_3 \cdot \left(\frac{\overrightarrow{\nabla}_3 - \overrightarrow{\nabla}_6}{2m} \right) ,$$

where m_s and m are the strange and up quark masses respectively. Our matrix element for the reaction is

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

in which $\Phi_{\bar{\Lambda}\Lambda}$ and $\Phi_{\bar{N}N}$ are distorted waves and ϕ is a harmonic oscillator wave-function.

Initial and Final State Interactions

We used the same distorting potentials for $\bar{N}N$ and $\bar{\Lambda}\Lambda$ as Kohno and Weise.[5] For $\bar{N}N$ the real part of the potential is determined by a G-parity transformation of the long-range part of a realistic one-boson exchange potential, with a smooth extrapolation to the origin. The imaginary part, which represents annihilation, is of Gaussian form and is adjusted to produce good fits to $\bar{p}p$ experimental data. For the real part of the $\bar{\Lambda}\Lambda$ interaction Kohno and Weise use the isoscalar boson exchanges of the real part of the $\bar{N}N$ potential. The annihilation term is taken to be of the same form as that for the $\bar{N}N$, but with a strength adjusted to fit total $\bar{p}p \rightarrow \bar{\Lambda}\Lambda$ cross section data.
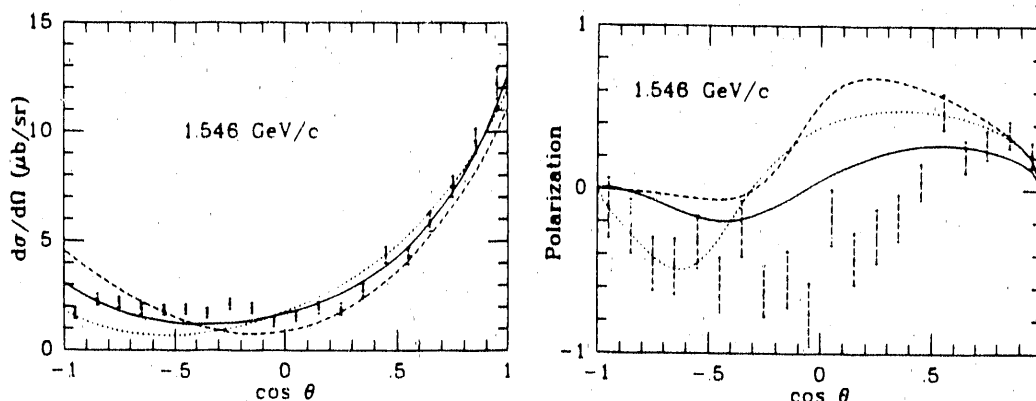
4. Results

Figure 2
Differential cross section and polarization for $\bar{p}$ lab momentum of 1.546 GeV/c. The long-dashed curve is the vector contribution (for $r_0 = .66$ fm) and the short-dashed curve is the scalar contribution (for $r_0 = .63$ fm). The solid curves are the result of a linear combination $(I_v + I_s)$ with $g_v = -.48g_s$ and $r_0 = .57$ fm.

Our results for differential cross sections and polarization at 1.546 GeV/c are shown in Fig. 2. Our best fits (minimum χ^2) to the experimental data[2] are shown for the scalar model alone, the vector model alone, and the superposition. For the scalar and vector models alone we searched on the oscillator radius r_0; for our superposition we searched on r_0 and the ratio g_v/g_s. As seen in Fig. 2, the differential cross section can be fit reasonably well by either term alone or the superposition, but a better fit to the polarization data is obtained by using the combined terms with $r_0 = .89$ fm and $g_v/g_s = -.19$. One characteristic of the polarization data that we, as well

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as other authors, have found difficult to fit is the crossing point, i.e. the angle at which the polarization changes sign. The combined model fits better than either vector or scalar alone, but still does not agree well with the data.

Because not much is known about the $\bar{\Lambda}\Lambda$ interaction, we studied the effect of varying the strengths of the various components of the $\bar{\Lambda}\Lambda$ potential, which includes a real central term, an imaginary central term, and real spin-orbit and tensor terms. We found our results to be very sensitive to the strengths of these terms. We obtained a much better fit to the polarization data at 1.546 GeV/c, as shown in Fig. 3, for a ratio $g_v/g_s = -1.53$, $r_0 = .58$ fm, and by multiplying the other terms in the $\bar{\Lambda}\Lambda$ potential by factors of about 1.5, except for the real central term, which was almost zero. In Fig. 4 we show our results for spin correlation coefficients, which are in reasonable agreement with the data.
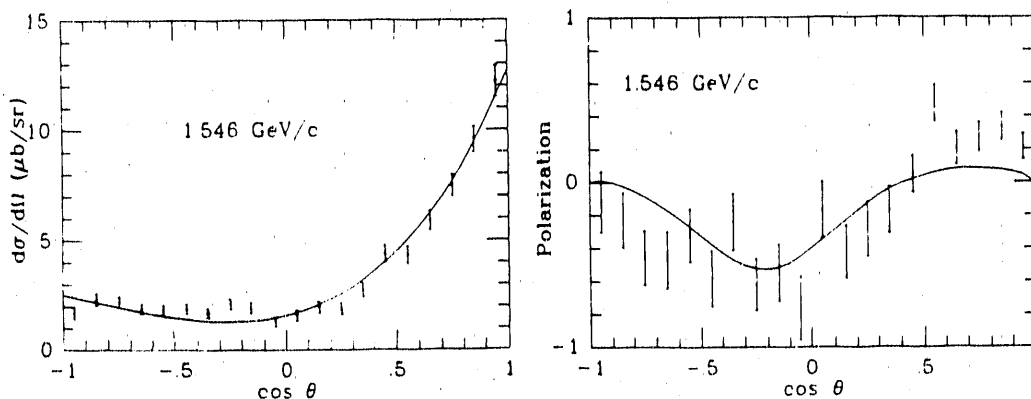

Figure 3

Differential cross section and polarization for $\bar{p}$ lab momentum of 1.546 GeV/c. The solid curves are found by varying the parameters of the $\bar{\Lambda}\Lambda$ potential.

In Fig. 5 we present calculations of the differential cross section and polarization at 1.508 GeV/c and 1.695 GeV/c. The best fit parameters found at 1.546 GeV/c agree moderately well with the cross-section data at the higher momentum, but overestimate the magnitude and distort the shape of the cross section at the lower momentum; the polarization data is well fit at 1.508 GeV/c, but the prediction is very poor at 1.695 GeV/c. We also show the best fits obtained at each momentum. The improvements came mainly from a decrease in vector strength at the lower momentum and a decrease in the tensor and spin-orbit potentials at the higher momentum. This strong dependence of our results on the parameters of the $\bar{\Lambda}\Lambda$ interaction suggests that a fit to the reaction data at all available energies may provide us with information about the various components of this little-known interaction. Such a fit is now in progress.
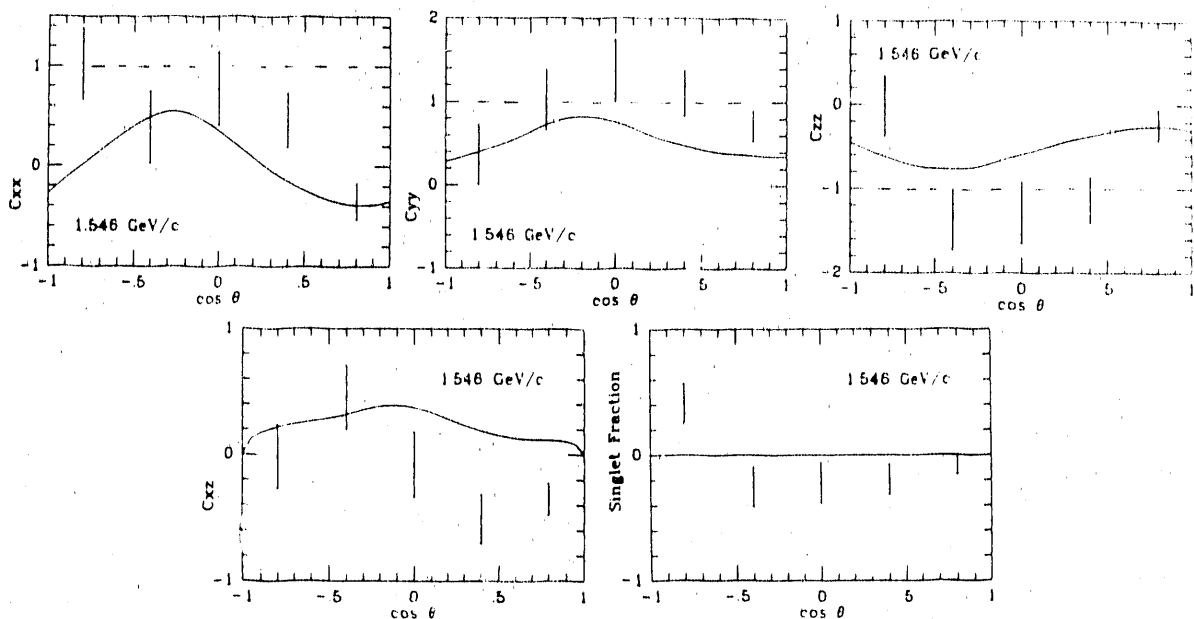
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Figure 4

Spin correlation coefficients and singlet fraction for the best fit at $\bar{p}$ lab momentum of 1.546 GeV/c. The dashed lines represent limits on the physical values of the measurements.
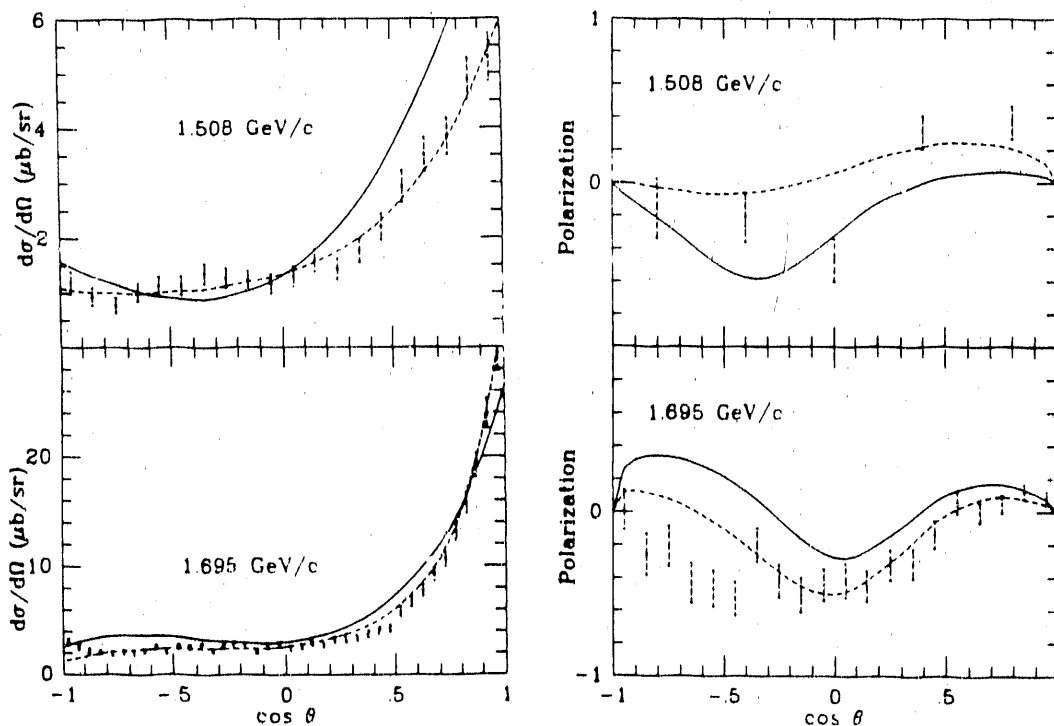

Figure 5

Differential cross sections and polarizations for $\bar{p}$ lab momenta of 1.508 GeV/c and 1.695 GeV/c. The solid curves are found by using the best fit parameters of 1.546 GeV/c; the dashed curves are best fits at each respective momentum.

5. Conclusion

We have shown that the best fits to $\bar{p}p \to \bar{\Lambda}\Lambda$ occur for an interference between scalar and vector mechanisms, rather than for either term alone. The sensitivity of our results to the parameters of the $\bar{\Lambda}\Lambda$ potential indicates that the $\bar{p}p \to \bar{\Lambda}\Lambda$ reaction may be a source of information on the $\bar{\Lambda}\Lambda$ interaction.

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