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Comments and Addenda

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Reaction $K_L^0 p \to K_S^0 p$ and the possible existence of a Z_0^* resonance[†]

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We show that the reaction $K_L^0 p \to K_S^0 p$ is very sensitive to the ambiguous $I=0$ KN phase-shift solutions because of the interference with the $I=1$ $\bar{K}N$ amplitudes. The cross sections and differential cross sections measured by different experiments in the 1800-MeV c.m. energy region favor one of the exotic $I=0$ p_1-resonance solutions and tend to reject the p_1-nonresonant solution. The χ^2/DF for nine cross-section points is 0.7 for the favored p_1-resonance solution and 3.1 for the p_1-nonresonant solution, while the respective χ^2/DF for the 25 independent normalized differential cross-section points are 1.2 and 2.4.

The important but vexing problem of whether or not there are Z^* resonances (with $I=0$ or $I=1$) has been with us since the discovery by Cool *et al.*[1] of peaks in the $I=0$ and $I=1$ total cross sections in K^+p and K^+d measurements. Since that time, a large peak (about 20 mb) has been observed in the $I=0$ elastic cross section at about 1800 MeV c.m. energy.[2] In addition, an extensive study has been made of K^+p elastic scattering (differential cross sections[3] and polarization[4]), K^+n charge exchange, and K^+n elastic scattering.[5] A polarization measurement in the charge-exchange channel has been made at 600 MeV/c.[6]

The $I=1$ K^+p elastic scattering is characterized by the rapid increase in inelasticity in the p_3 wave near threshold for $K\Delta$ production. There is no preference for a resonance solution among the four preferred solutions.[7]

The $I=0$ wave as studied in K^+n charge exchange and elastic scattering (which include both $I=0$ and $I=1$ waves) in the 0.6 - 1.5 GeV/c region gives more tantalizing evidence of resonance structure in the p_1 wave. Starting with each of the four fixed $I=1$ solutions, searches have been made for $I=0$ solutions. Three $I=0,1$ families of solutions have been found, called A, C, and D. Solutions C and D exhibit classical resonance behavior in the p_1 wave (near an energy ~1800 MeV), with solution D almost purely elastic, while solution A does not appear to have a p_1-resonance interpretation.[8] Naturally, more scattering experiments would help us understand the situation, but qualitatively new data are needed.

We would like to note that there are data of a qualitatively different character which do bear on this problem but which have apparently been overlooked. The reaction

$$K_L^0 p \to K_S^0 p \tag{1}$$

has been measured[9a-9f] at various points in the interesting region. Using the CP-conserving definition of K_L and K_S and isospin and strangeness conservation, one can easily show that the amplitude for this reaction is

$$T = \tfrac{1}{4}(Z_0 + Z_1 - 2Y_1), \tag{2}$$

where

Z_0 = the $I=0$ KN amplitude ,

Z_1 = the $I=1$ KN amplitude ,

Y_1 = the $I=1$ $\bar{K}N$ amplitude .

Since Y_1 is well known in the 600–1200-MeV/c region,[10] one can see which of the Z_0, Z_1 solutions best fit the data. Due to the fact that there is a highly elastic and relatively narrow resonance in this region, the $Y_1^*(1765)$, the reaction is in fact very sensitive to the different Z_0 solutions through

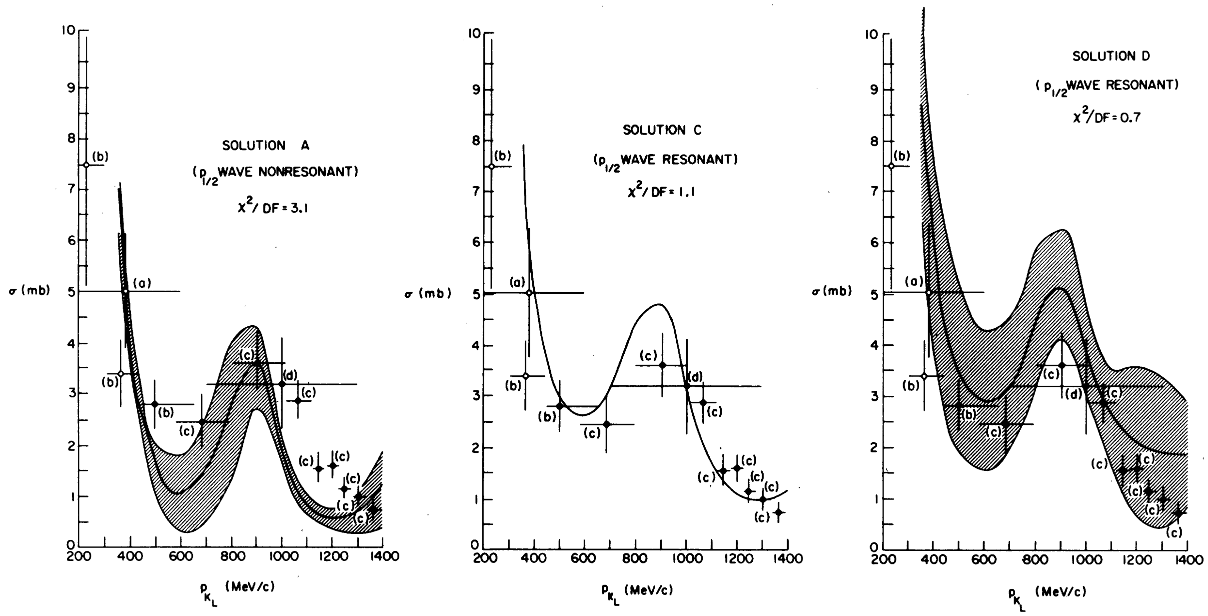

FIG. 1. The predicted excitation function for $K_Lp \rightarrow K_Sp$ for the three Z_0 solutions; see text for definition. The shaded regions indicate the theoretical variance. The same experimental points are indicated on each figure and are labeled (a)–(d) corresponding to Refs. 9a–9d. Only the open circle points are included in the statistical analysis.

interference with the rapidly varying Y_1 amplitude. The cross-section predictions as well as the differential cross-section predictions are quite different.

Using the appropriate energy-dependent Z_1 solutions,[3] Z_0 solutions,[8] and Y_1 solutions,[10] we have calculated the cross section and the differential cross section for reaction (1) for the three Z_0, Z_1 combinations as a function of K_L momentum. The parametrization was checked by recalculating the published amplitudes, differential cross sections, and cross sections. The errors on the predictions come only from the full error matrix for the Z_0 parameters. We note that the Z_1 parameters are left fixed in this calculation, as in the K^+n analysis which gave solutions we are testing, at the values given by the K^+p analysis. Probably these parameters should be introduced with their full error matrix in both analyses or an over-all fit should be made. The Y_1 parameters were held fixed since these are much better known than the Z parameters.

We have used nine cross-section measurements.[9b-9d] We have only used the highest point, 450–650 MeV/c, measured by Luers *et al.*, since only this point overlaps the region in which the ambiguous solutions were determined. Both the Luers *et al.* point and the Leipuner *et al.* point were corrected for the new K_L lifetime,[11] 5.18×10^{-8} sec, and a ±25% normalization error specified by the authors has been added to the latter point.[12] The Brandenburg *et al.* points have an additional correlated ±15% normalization error included. We have checked each experiment by comparing its measurement of the $K_Lp \rightarrow \Lambda\pi^+$ cross section with the well-known $K^-p \rightarrow \Lambda\pi^0$ cross section.[13] All agree well except the Hawkins point,[9f] which differs by a factor of 2.7; therefore we have omitted this point. The experimental points with their uncorrelated errors are displayed in Figs. 1(a)–1(c), in which we have included the predicted cross sections with their variances as a function of momentum. Note that the predicted errors are correlated in energy. The very small errors for the C solution are due to the highly correlated nature of its error matrix. We have performed a χ^2 test and obtained for 9 degrees of freedom 28.0, 9.5, and 6.2 for solutions A, C, and D, respectively, corresponding to probabilities of 0.1%, 39%, and 72%. These results support the p_1-resonance solutions, C and D, and tend to reject the p_1-nonresonant solution, A. We note, however, that the predictions have the same shape, and that therefore these results greatly depend on the normalization, which is quite difficult to determine in a broad-momentum neutral beam.

In an independent test of the three solutions, we have avoided this experimental problem by using *normalized* differential cross sections[9c] (i.e., the frequency distribution). The highest four-momentum bins have been combined into two differential cross-section distributions because of statistics. In Figs. 2(a)–2(c) we display one of these experimental distributions with the three predicted normalized differential cross sections and their variances. Note that the predicted errors are strongly correlated in energy and scattering angle. We have performed a χ^2 test and obtain for 25 degrees of freedom 60.2, 75.7, and 31.1 for Solutions A, C, and D, respectively, corresponding to probabilities of 0.01%, 0.00005%, and 19%.[14] These results support the p_1-resonance solution D and tend to reject the p_1-resonance solution C and the p_1-nonresonance solution A.

These results strongly suggest that a highly elastic $I = 0$ Z^* resonance exists, which of course has important theoretical implications. Before we accept this result, three notes of caution seem appropriate. First, it is important to realize that only one particular solution of each class of solutions has been used, the one with the best χ^2. The error matrix for that particular solution was evaluated in a 25-parameter space[8] and may not represent a proper error for propagation in a χ^2 analysis. Second, we have combined experimental results for reaction (1) from different experiments, with possibly different systematic errors. Third, an over-all partial-wave analysis including all the K^+p, K^+n, and K_Lp data could give a new p_1-nonresonant solution with an acceptable χ^2/DF. It is clear that a single experiment (perhaps with knowledge of the K_L momentum for better flux evaluations) is needed to measure reaction (1) with high statistics as a function of momentum. Likewise an over-all partial-wave analysis is needed.

In conclusion, the measured cross sections and normalized differential cross sections for the $K^0_L p \to K^0_S p$ reaction have been used separately to distinguish among the three $I = 0$ KN phase-shift solutions. The results strongly suggest but do not compel the existence of an $I = 0$ Z^* resonance in the p_1 partial wave.

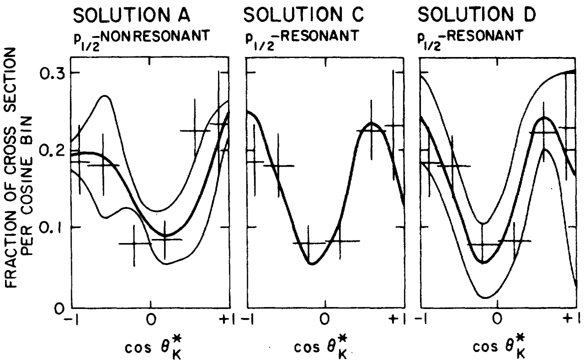

FIG. 2. The predicted normalized differential cross section for the momentum interval 796–1009 MeV/c for $K_Lp \to K_Sp$ for the three Z_0 solutions; see text for definition. The upper and lower curves indicate the +/– theoretical variance. Note that the theoretical errors are highly correlated. The same experimental histograms with errors are indicated on each figure.

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[9b] D. Luers *et al.*, in *Proceedings of the Aix-en-Provence Conference on Elementary Particles, 1961* (Centre d'Etudes Nucléaires de Saclay, Gif-sur-Yvette, Seine et Oise, Saclay, France, 1961), p. 235.

[9c] G. W. Brandenburg *et al.*, Phys. Rev. D (to be published); J. Matthews (private communication).

[9d] L. Leipuner *et al.*, Phys. Rev. 132, 2285 (1963).

[9e] T. Bacon, private communication referring to an experiment in the Yale-BNL 14-in. bubble chamber.

[9f] C. Hawkins, Phys. Rev. 156, 1444 (1967).

[10] R. Armenteros *et al.*, Nucl. Phys. B8, 195 (1968).

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[12] In the subsequent statistical test, we have only used the cross section of Ref. 9d in the limited angular region in which it was measured. The point plotted in Figs. 1(a)–1(c) is an extrapolation, with no extrapolation error.

[13] E. Bracci *et al.*, CERN Report No. CERN/HERA 72-2, 1972 (unpublished).

[14] If we include the data of Refs. 9d and 9e, for which errors are unavailable but for which we have assigned crude statistical errors, the χ^2/DF for 54 degrees of freedom for solutions A, C, and D become 2.5, 2.3, and 1.35, respectively.