Effect of exotic $S=+1$ resonances on $K_L^0 p$ scattering data

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We consider the effect of an exotic $S=+1$ Θ^+ resonance on the scattering of neutral kaons off protons. Explicit results are presented for the $K_L^0 p$ total cross sections.

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Results from a wide range of recent experiments are now consistent with the existence of an exotic $S=+1$ resonance, the $\Theta^+(1540)$, having a narrow width and a mass near 1540 MeV [1]. Width determinations have been hindered by limitations on experimental resolutions, resulting in upper bounds of order 10 MeV. The quantum numbers of this state remain unknown, though a prediction of $J^P=1/2^+$ was obtained in the work [2] that provided a motivation for the original search.

An examination of older K^+d and K^+p data has provided no confirmation for the Θ^+ or an associated Θ^{++} state [3]. In fact, these older measurements seem to require a width much smaller than 10 MeV [4–7]. Most investigations of the older data have focused on K^+d experiments from which the K^+n interaction has been extracted. The effect of Fermi motion in the deuteron is particularly important for a narrow structure, making the observation of a “bump” in any cross section more difficult. This point has been extensively demonstrated by Nussinov [4] and by Cahn and Trilling [7].

The problems of Fermi motion can be avoided if instead one considers the $K_L^0 p$ interaction. However, as the K_L^0 is a mixture of K^0 and $\bar{K}^0$, this approach requires an accounting of the $\bar{K}N$ interaction. This we have done, combining results from analyses of $\bar{K}N$ [8] and KN [9] data.

The amplitude for $K_L^0 p$ scattering is given by

$$M_{K_L^0 p} = \frac{1}{4}(Z_1 + Z_0 + 2Y_1), \qquad (1)$$

where $Z_{0,1}$ are the strangeness $S=1$, $I=0$ and 1 amplitudes, and Y_1 is the $S=-1$, $I=1$ amplitude. The Y_1 contribution dominates at low energies, the $S=1$ component growing in relative importance with increasing energy. Our result for the $K_L^0 p$ total cross section, calculated from the imaginary part of the forward scattering amplitude, is given in Fig. 1. Note that this is not a fit but rather a prediction based on analyses of other reactions.

Starting from this description of the data, we have added a narrow Breit-Wigner resonance in order to demonstrate the magnitude of its effect. In doing so, we have taken into account the fact that the incident K_L^0 beam has a momentum spread, which also tends to smear out a narrow structure. In Fig. 2, we have added an $S=+1$ resonance, having a 5 MeV width, to the P_{01} partial wave. Here we compare the result for beam momentum distributions (assumed Gaussian) having widths of 10 and 20 MeV/c at 440 MeV/c, the latter being an estimate of the momentum spread associated with the beam used in Ref. [10]. A resonance in the D_{03} partial wave is also included for comparison.

The measurement of Ref. [10] was reported with total cross sections calculated over 20 MeV/c bins. We have accordingly averaged over this interval, finding a further minimal reduction in the peak. Results for resonances with a range of widths are compared in Fig. 3. From Fig. 1, the most pronounced deviations from our predicted smooth behavior occur near 280 and 460 MeV/c (corresponding to c.m. energies of 1480 and 1550 MeV). The apparent “bump” at 1480 MeV could be more than a statistical fluctuation. The Particle Data Group (PDG) [12] reports a 1-star $\Sigma(1480)$ based on an analysis of $K^- p \to \bar{K}^0 p \pi^-$, with a 3.5 standard deviation signal being seen in $\bar{K}^0 p$. (The data of Ref. [11] do not show this structure.) Given the large experimental uncertainties, a fluctuation near 1550 MeV is only interesting in that it occurs near the expected $\Theta^+(1540)$ signal. (The overall momentum scale has a quoted uncertainty of 2%.) Here too the PDG reports a weak evidence for a nearby bump, the $\Sigma(1560)$.

In conclusion, present $K_L^0 p$ scattering data are insuffi-

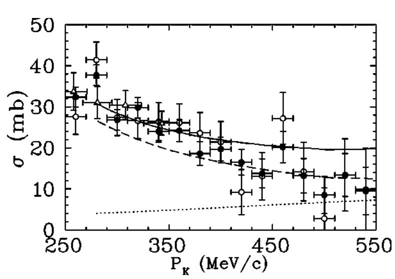

FIG. 1. Total cross section for $K_L^0 p$ (solid line) and contributions (dashed line) from $S=-1$ [8] and (dotted line) $S=+1$ [9]. Data sets from Ref. [10] (open and closed circles) and Ref. [11] (open triangles).

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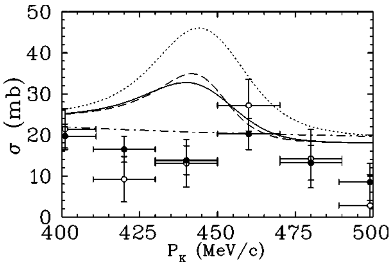

FIG. 2. Effect of 1540 MeV P_{01} resonance of width 5 MeV for a 10 MeV/c (dashed line) and 20 MeV/c (solid line) momentum spread. Effect of a D_{03} resonance of same mass and width (20 MeV/c spread) displayed for comparison (dotted line). Dash-dotted curve gives the unmodified total cross section for $K_L^0 p$. Data as in Fig. 1.

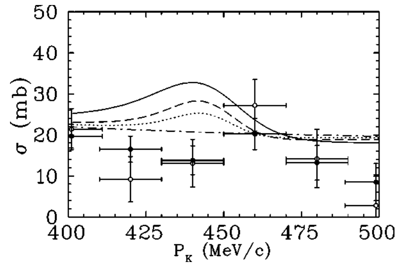

FIG. 3. Resonance signal for a 1540 MeV P_{01} resonance of width 1 MeV (dotted line), 2 MeV (dashed line), and 5 MeV (solid line), for a 20 MeV/c momentum spread. Dash-dotted curve gives the unmodified total cross section for $K_L^0 p$. Data as in Fig. 1.

ciently precise to confirm the $\Theta(1540)$. However, if more precise data were to become available, with improved momentum resolution, this method would have the advantage of producing a resonance structure, unlike most previous K^+n cross sections extracted from deuteron target experiments which were fundamentally limited by Fermi momentum. In this case, the main limiting factor for a determination of Θ^+ properties would be our knowledge of weak Σ resonances [13].

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