Multichannel analyses of $\overline{K}N$ scattering

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The first multichannel analyses of $\overline{K}N$ scattering were carried out in the early 1970s at c.m. energies below about 1900 MeV where data were available from bubble-chamber experiments. In 1998, precise data on several $\overline{K}N$ reactions including $K^-p \to \pi^0\Lambda$, $K^-p \to \pi^0\Sigma^0$, and $K^-p \to \eta\Lambda$ were measured at the BNL AGS by the Crystal Ball Collaboration. It is therefore timely to consider a new multichannel partial-wave analysis incorporating these new data. Incipient work along these lines is described.

1 Introduction

Data for πN scattering and pion photoproduction have been analyzed extensively by the method of partial-wave analyses (PWAs). These analyses have provided accurate amplitudes from which the properties of many N^* resonances have been deduced. It is likewise important to obtain reliable amplitudes for $\overline{K}N$ scattering in order to identify the full spectrum of Y^* resonances, and to deduce the properties of these resonances to test quark-model predictions. Although useful information about resonances in the $\overline{K}N$ system was determined by early single-channel analyses, the focus of this article is the full coupled-channel problem.

The first multichannel analyses [1–3] were carried out in the early 1970s and mainly incorporated data obtained from bubble-chamber experiments. In 1971, Kim *et al.* [1] carried out an energy-dependent PWA using effective-range expansions to fit data over seven intervals in the center-of-mass (c.m.) energy range 1430 to 1890 MeV. The solutions obtained in this analysis suffered from unphysical cusplike behavior. In 1972, Langbein and Wagner [2] performed an energy-independent PWA of data in the c.m. energy range 1540 to 1900 MeV using a traditional K-matrix approach. Their single-energy solutions did not vary smoothly with energy. In 1973, Lea *et al.* used a traditional K-matrix approach to perform an energy-dependent PWA over the c.m. energy range 1540 to 1880 MeV. They made several simplifying assumptions, including taking the partial widths for $\overline{K}N$, $\pi\Lambda$, and $\pi\Sigma$ to be constants. Their solution was later found to be incompatible with the precise data for $K^-p \to \overline{K^0}n$ measured in 1977 by Alston-Garnjost *et al.* [4].

In 1977, Gopal *et al.* [5] obtained energy-dependent solutions for $\overline{K}N$, $\pi\Lambda$, and $\pi\Sigma$ in the c.m. range 1480 to 2170 MeV by first fitting the three channels in parallel and then considering them together to find solutions with consistent parameters (masses and widths) for the resonances in each channel. In this analysis, the pure-isospin T-matrix amplitudes were assumed to have the form $T = T_{\rm B} + T_{\rm R}$, where the first and second terms describe background and resonant contributions, respectively. Such a form generally violates unitarity. These authors also parametrized the angular momentum barriers inconsistently for different partial waves. Nevertheless, their solution was generally in reasonable agreement with the precise data for $K^-p \to \overline{K^0}n$ measured by Alston-Garnjost *et al.* [4].

Another energy-dependent PWA published in 1977 was that of Martin and Pidcock [6], who used a conventional K-matrix approach to analyze $\overline{K}N$, $\pi\Lambda$, and $\pi\Sigma$ over the c.m. energy range 1540 to 2000 MeV. Their analysis used an improved treatment of the $\eta\Lambda$ and $\eta\Sigma$ thresholds compared with prior analyses. In this analysis, all channels other than $\overline{K}N$, $\pi\Lambda$, and $\pi\Sigma$ were represented, except for S waves, by a single super channel for a given partial wave.

2 Recent measurements and analyses

In 1998, precise data on several $\overline{K}N$ reactions including $K^-p \to \pi^0\Lambda$, $K^-p \to \pi^0\Sigma^0$, and $K^-p \to \eta\Lambda$ were measured at the Brookhaven National Laboratory AGS by the Crystal Ball Collaboration.[1] A new AGS experiment to study specific Y^* resonances with higher precision has been approved [7]. To take advantage of these data, it is timely to begin a new multichannel partial-wave analysis of $\overline{K}N$ reactions. As a first step along these lines, a coupled-channel analysis of S-wave scattering was recently completed over the c.m. energy range 1500 to 1900 MeV [8]. This analysis extracted resonance parameters for the $\Lambda(1670)\frac{1}{2}^-$ using, in part, the near-threshold data for $\sigma_{\rm tot}(K^-p \to \eta\Lambda)$ recently measured by the Crystal Ball Collaboration [9]. Results were obtained using a generalization of the well-known multichannel Breit-Wigner representation for T-matrix amplitudes. Our parametrization, described briefly below, has been applied successfully to describe πN elastic and inelastic scattering, including pion photoproduction [10].

2.1 The Kent State multichannel parametrization

The partial-wave S-matrix and T-matrix are related by $S = I + 2{\rm i}T = B^{\rm T}R\,B$, where R is unitary and symmetric, and B is unitary. We can write $T = B^{\rm T}\mathcal{T}B + \mathcal{T}_B$, where $\mathcal{T}_B = (B^TB - I)/2{\rm i}$ and $\mathcal{T} = (R-I)/2{\rm i}$. We constructed $\mathcal{T}$ from a K-matrix, $\mathcal{T} = K(I - {\rm i}K)^{-1}$, where

$$K_{ij} = \sum_{\alpha=1}^{N} \tan\delta_\alpha \; f_{i\alpha}f_{j\alpha} \; . \tag{1}$$

The phases δ_α depend on the total c.m. energy W, and N is the number of resonances included in the fit. Here

$$f_{i\alpha} = \frac{g_{i\alpha}}{\sqrt{\Gamma_\alpha(W)}} \qquad ; \qquad (g_{i\alpha})^2 = \Gamma_{i\alpha} \; , \tag{2}$$

where $\Gamma_{i\alpha}$ is the ith partial width for resonance α:

$$\Gamma_\alpha(W) = \sum_i \Gamma_{i\alpha}(W) \qquad \Longrightarrow \qquad \sum_i (f_{i\alpha})^2 = 1 \; . \tag{3}$$

The corresponding resonant T-matrix has matrix elements of the form,

$$\mathcal{T}_{ij} = \sum_{\alpha=1}^{N}\sum_{\beta=1}^{N} f_{i\alpha}\,[\mathcal{D}^{-1}]_{\alpha\beta}\; f_{j\beta} \; . \tag{4}$$

The energy-dependence of the phases δ_α was constructed such that

$$[\mathcal{D}^{-1}(W)]_{\alpha\beta} \propto \prod_{\alpha=1}^{N} (M_\alpha - W - {\rm i}\Gamma_\alpha(W)/2)^{-1} \; . \tag{5}$$

[1] The Crystal Ball Collaboration consists of: D. Isenhower, M. Sadler (*Abilene Christian University*); C.E. Allgower, H. Spinka (*Argonne National Laboratory*); J.R. Comfort, K. Craig, A.F. Ramirez (*Arizona State University*); M. Clajus, A. Marušić, S. McDonald, B.M.K. Nefkens, N. Phaisangittisakul, S. Prakhov, J.W. Price, A. Starostin, W.B. Tippens (*University of California Los Angeles*); J. Peterson (*University of Colorado*); W.J. Briscoe, A. Shafi, I.I. Strakovsky (*The George Washington University*); H.M. Staudenmaier (*Universität Karlsruhe*); D.M. Manley, J. Olmsted (*Kent State University*); D.C. Peaslee (*University of Maryland*); V.V. Abaev, V. Bekrenev, A.A. Kulbardis, N.G. Kozlenko, S. Kruglov, I.V. Lopatin (*Petersburg Nuclear Physics Institute*); N. Knecht, G. Lolos, Z. Papandreou (*University of Regina*); I. Supek (Rudjer Bošković Institute); D. Grosnick, D.D. Koetke, R. Manweiler, T.D.S. Stanislaus (*Valparaiso University*).

Poles occur at complex energies $W = W_\alpha$ where $M_\alpha - W - \mathrm{i}\Gamma_\alpha(W)/2 = 0$. Here, M_α and $\Gamma_\alpha(M_\alpha)$ are conventional Breit-Wigner parameters. As a special case, if $\alpha = N = 1$, we obtain the well-known result for a single resonance:

$$\mathcal{T}_{ij} = (\mathrm{e}^{\mathrm{i}\delta_\alpha} \sin\delta_\alpha)\ f_{i\alpha} f_{j\alpha} \ . \tag{6}$$

Then

$$[\mathcal{D}^{-1}(W)]_{\alpha\alpha} = \mathrm{e}^{\mathrm{i}\delta_\alpha} \sin\delta_\alpha = \frac{1}{\cot\delta_\alpha - \mathrm{i}} \ . \tag{7}$$

One common choice is

$$\cot\delta_\alpha(W) = \frac{M_\alpha - W}{\Gamma_\alpha(W)/2} \ . \tag{8}$$

The background matrix B was constructed from a product of unitary S matrices, each of which has a form that, when squared, is similar to the multichannel Breit-Wigner representation, but with unphysical pole positions. For attractive (repulsive) backgrounds, the real and imaginary parts of the pole position were taken to be positive (negative). Our background parametrization is unitary, easily allows couplings to be introduced for each channel, maintains proper threshold behavior, and provides a smooth energy dependence (away from thresholds) for real c.m. energies.

2.2 Results for $\Lambda(1670)\frac{1}{2}^-$

As an application of our unitary parametrization, we carried out a multichannel fit over the c.m. energy range 1500 to 1900 MeV. Our fit included near-threshold data obtained with the Crystal Ball at BNL for $\sigma_{\rm tot}(K^-p \to \eta\Lambda)$. Older, less precise data for $\sigma_{\rm tot}$ were not included in the fit. We made the reasonable assumption that only the S-wave amplitude makes a significant contribution to $\sigma_{\rm tot}$ in the near-threshold region. Prior PWAs show that the $\overline{K}N \to \overline{K}N$ and $\overline{K}N \to \pi\Sigma$ S_{01} amplitudes require a large nonresonant background in the vicinity of $\Lambda(1670)$. Most analyses also require a broad $\Lambda(1800)$ to fit data up to 1900 MeV. To accommodate these structures and constrain the $\overline{K}N \to \eta\Lambda$ amplitude, the $\overline{K}N \to \overline{K}N$ and $\overline{K}N \to \pi\Sigma$ S_{01} amplitudes from the

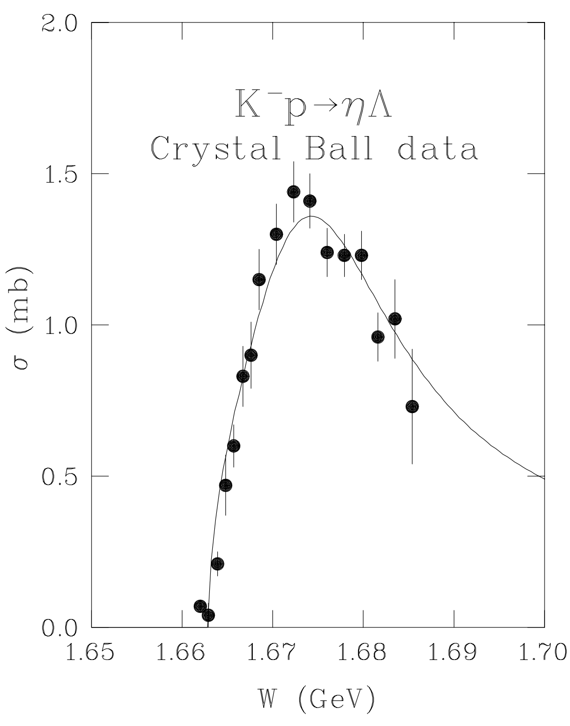

Figure 1: Total cross section for $K^-p \to \eta\Lambda$ as measured by the Crystal Ball Collaboration. The curve shows the result of our multichannel fit.

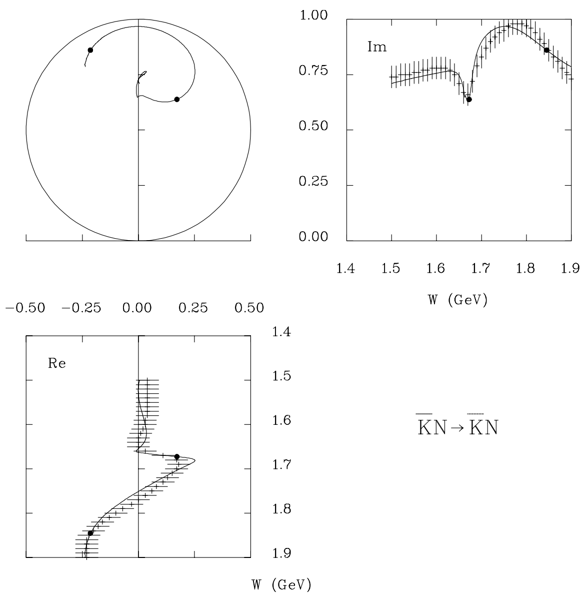

Figure 2: Argand amplitude for the $\overline{K}N \to \overline{K}N$ S_{01} partial wave. The curve shows the result of our multichannel fit. Solid dots mark the energies for the $\Lambda(1670)$ and $\Lambda(1800)$. The data are from the Gopal 77 analysis.

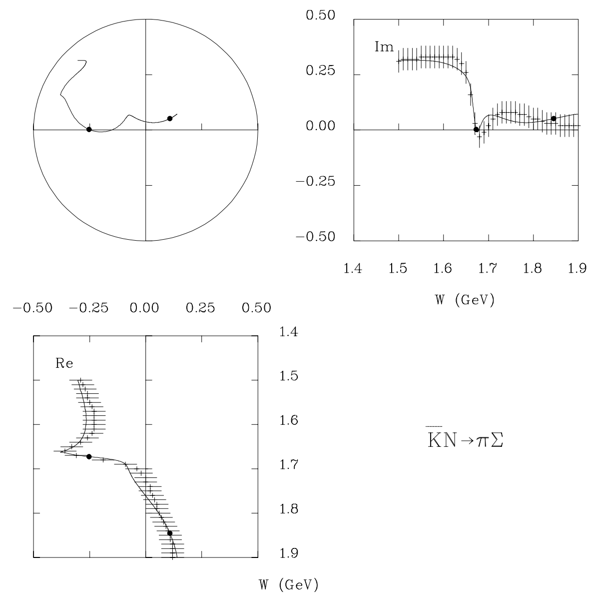

Figure 3: Argand amplitude for the $\overline{K}N \to \pi\Sigma$ S_{01} partial wave. The curve shows the result of our multichannel fit. Solid dots mark the energies for the $\Lambda(1670)$ and $\Lambda(1800)$. The data are from the Gopal 77 analysis.

Gopal 77 solution were included in our fit. We also included the $\overline{K}N \to \pi\Sigma(1385)$ $SD01$ amplitude from the Cameron 78 PWA [11]. Two additional channels were included to satisfy unitarity and account for flux into all other final states. The two added channels were a quasi-two-body $(\pi\pi)_{\mathrm{S}}\Lambda$ channel and a quasi-two-body $(\pi\pi)_{\mathrm{P}}\Sigma$ channel. An uncertainty of ± 0.05 was assigned to the real and imaginary parts of the input amplitudes. Nonresonant background was included in all six channels.

Our best fit has χ^2 per degree of freedom of 1.2 and included the broad $\Lambda(1800)$. The $\Lambda(1405)$, which has $\Gamma \approx 50$ MeV, was outside the energy range of our fit. Figures 1, 2, and 3 show some of the results of our six-channel fit. The corresponding resonance parameters for $\Lambda(1670)$ are summarized in Table 1. In the columns, Γ_i is the partial width for the i-th decay channel evaluated at the resonance energy, x_i is the corresponding branching fraction, $x = 0.37 \pm 0.07$ is the elasticity, and t is the amplitude at resonance excluding contributions from nonresonant background. The fitted Breit-Wigner mass and total width have the values $M = 1673 \pm 2$ MeV and $\Gamma = 23 \pm 6$ MeV, respectively. The corresponding pole position is $(1671 - \mathrm{i}11)$ MeV.

Channel	Γ_i (MeV)	$x_i = \Gamma_i/\Gamma$ (%)	$t = \sqrt{xx_i}$
$\overline{K}N$	8.5 ± 2.6	37.3 ± 6.8	0.37 ± 0.07
$\eta\Lambda$	3.6 ± 1.4	15.7 ± 5.5	0.24 ± 0.04
$\pi\Sigma$	8.8 ± 3.2	38.6 ± 7.9	-0.38 ± 0.03
$\pi\Sigma(1385)$	1.7 ± 1.5	7.6 ± 6.0	-0.17 ± 0.06
$\pi\pi\Lambda$	< 1	< 4	0.05 ± 0.11
$\pi\pi\Sigma$	< 1	< 1	0.00 ± 0.06

Table 1: Resonance parameters for the $\Lambda(1670)$ as determined from our multichannel fit.

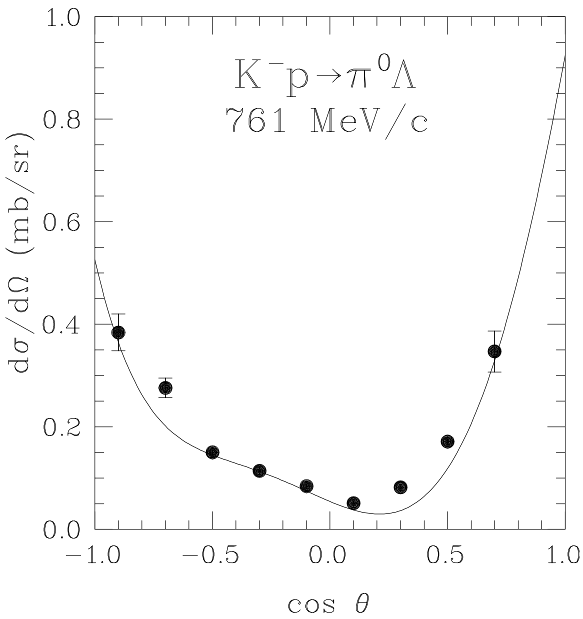

Figure 4: Preliminary results by the Crystal Ball Collaboration for the $K^-p \to \pi^0\Lambda$ differential cross section at $P_{K^-} = 761$ MeV/c, or $W = 1681$ MeV. The curve is the prediction of the Gopal 77 partial-wave analysis.

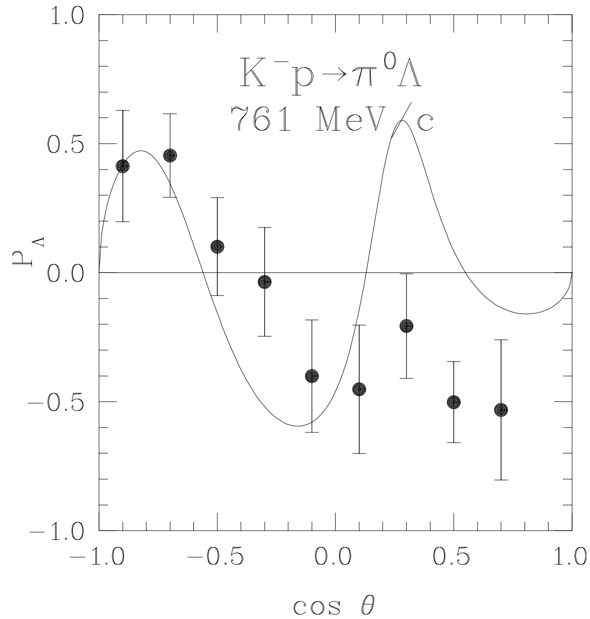

Figure 5: Preliminary results by the Crystal Ball Collaboration for the Λ polarization in $K^-p \to \pi^0\Lambda$ at $P_{K^-} = 761$ MeV/c, or $W = 1681$ MeV. The curve is the prediction of the Gopal 77 partial-wave analysis.

3 Plans for future work

Plans are underway to begin a full-scale PWA of the world data for $\overline{K}N$ reactions using the Kent State multichannel parametrization. Results of the new PWA are anticipated to improve significantly our knowledge of the light hyperon resonances. Old PWAs of the $\overline{K}N \to \pi\Lambda$ reaction in the momentum range of the new Crystal Ball data were based mainly on bubble-chamber data measured in 1970 by Armenteros *et al.* [12]. Because our differential cross section ($d\sigma/d\Omega$) data for $K^-p \to \pi^0\Lambda$ generally agree with the older, less precise data of Armenteros *et al.*, it was anticipated that the predictions of previous PWAs should also agree reasonably with our data. On the other hand, the Λ polarization (P_Λ) data of Armenteros *et al.* were of such low precision that we not *apriori* expect to find good agreement of PWA predictions with the polarization data measured by the Crystal Ball Collaboration. In order to check these expectations, we generated predictions for $d\sigma/d\Omega$ and P_Λ using the partial-wave solution of the 1977 PWA of Gopal *et al.* [5]. Figure 4 shows preliminary Crystal Ball results of $d\sigma/d\Omega$ for $K^-p \to \pi^0\Lambda$ at a lab momentum of 761 MeV/c. The solid curve in the figure is the prediction of the Gopal 77 PWA. As expected, the agreement is generally quite good. Figure 5 shows the corresponding preliminary Crystal Ball results for the Λ polarization compared with the prediction of the Gopal 77 PWA. In this case, we see fairly good agreement at backward angles, but the prediction has the wrong sign at forward angles. Based on comparisons such as these, it is clear that the new polarization data from the Crystal Ball Collaboration will make a large impact on extracting partial-wave amplitudes. In particular, in the momentum range of the Crystal Ball measurements, the polarization data should help improve the determination of the P- and D-wave amplitudes. An improved determination of the P-wave amplitudes is especially of interest because these are needed to extract the properties of the Λ and Σ analogs of the controversial Roper resonance.

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