New Results on Baryon Spectroscopy with the Crystal Ball Spectrometer

D. Mark Manley
for the Crystal Ball Collaboration[1]

Department of Physics, Kent State University, Kent, OH 44242 U.S.A.

Abstract. Data on $\pi^- p$ and $K^- p$ interactions to various neutral final states were measured in 1998 with the Crystal Ball multiphoton spectrometer. The measurements were carried out for beam momenta up to about 760 MeV/c at the C6 beam line of the Alternating Gradient Synchrotron at Brookhaven National Laboratory. This article focuses primarily on the new results from the $K^- p$ measurements. Our data for $K^- p \to \eta\Lambda$ and $K^- p \to \pi^0\Sigma^0$ provide new constraints on the properties of light Λ^* resonances, while our data for $K^- p \to \pi^0\Lambda$ provide new constraints on the properties of light Σ^* resonances. Our preliminary results, for example, on the Λ polarization in $K^- p \to \pi^0\Lambda$ tend to rule out the two-star $\Sigma(1580)3/2^-$. This state, if confirmed, cannot be an ordinary three-quark state because of its very low mass.

INTRODUCTION

Our principal knowledge of the properties of light hyperon (Λ, Σ) resonances is based almost entirely on bubble-chamber experiments that were carried out in the 1970s. Bubble chambers are best suited for studying reactions involving at most a single neutral particle in the final state; consequently, little is known about some $K^- p$ reactions involving all-neutral final states. During the late 1970s, the Crystal Ball multiphoton spectrometer was constructed at the Stanford Linear Accelerator Center (SLAC). This detector contains 672 optically isolated NaI crystals and provides good energy resolution and a solid-angle coverage of 93% of 4π steradians. Between 1978 and 1986, the Crystal Ball was used for meson spectroscopy experiments, initially at SPEAR and later at DESY. Then from 1987 to 1995, the Crystal Ball lay dormant in storage at SLAC. In late 1995, the Crystal Ball was transported to Brookhaven National Laboratory (BNL) where it was installed in the C6 beamline at the Alternating Gradient Synchrotron

[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*).

(AGS). There it began its "new life" as a detector for baryon spectroscopy experiments. Experiment E913 used the Crystal Ball detector to study N and Δ resonances formed in $\pi^- p$ experiments and experiment E914 used the detector to study Λ and Σ resonances formed in $K^- p$ experiments. This article summarizes some of the results obtained in the $K^- p$ experiments.

SUMMARY OF PRELIMINARY RESULTS

The C6 beamline at the BNL AGS has a maximum laboratory momentum of about 760 MeV/c. Experiment E914 used the Crystal Ball to make simultaneous measurements for $K^- p$ reactions involving all-neutral final states at eight nominal momenta ranging from about 500 to 750 MeV/c. No results were obtained at momenta below 500 MeV/c because beam flux on target was too low for these momenta. For results with adequate statistics, we were able to rebin our data into smaller momentum intervals. We obtained data on several reactions including $K^- p \to \gamma\Lambda$, $K^- p \to \pi^0\Lambda$, $K^- p \to \overline{K^0}n$, $K^- p \to \eta\Lambda$, $K^- p \to \pi^0\pi^0\Lambda$, $K^- p \to \pi^0\overline{K^0}n$, and $K^- p \to \pi^0\pi^0\pi^0\Lambda$. We also obtained data, with one exception,[2] for the corresponding reactions in which the Λ is replaced by Σ^0. Neutral pions were detected by their decays, $\pi^0 \to 2\gamma$, while η mesons were detected by both $\eta \to 2\gamma$ and $\eta \to 3\pi^0 \to 6\gamma$. Short-lived neutral kaons were detected by their decays, $K^0_S \to 2\pi^0 \to 4\gamma$. We detected the Λ and Σ^0 by their decays, $\Lambda \to \pi^0 n$ and $\Sigma^0 \to \gamma\Lambda$, respectively. In all cases, the final states were reconstructed by detecting the final-state photons. In some cases, final-state neutrons were also detected. Our data span the center-of-mass energy range 1560 to 1680 MeV. Here we present preliminary results for a few selected cases.

We have obtained the world's most precise data [1] in the near-threshold region for the pure isospin ($I = 0$) reaction $K^- p \to \eta\Lambda$. In 1965, Berley *et al.* [2] discovered that the cross section for this reaction has a strong peak just above threshold. It is now recognized that this peak is associated with S-wave formation of the $\Lambda(1670)1/2^-$ resonance. This feature is analogous to the strong S-wave formation of the $N(1535)1/2^-$ state just above threshold in $\pi^- p \to \eta n$. The $\Lambda(1670)$ and $N(1535)$ are of special interest because they are among the three known baryon resonances with decays having a large η branch.[3] Recently the author carried out a unitary, multichannel fit [3] of S-wave $I = 0$ $\overline{K}N$ amplitudes using the Crystal Ball total cross-section data for $K^- p \to \eta n$ near threshold, which was assumed to be dominantly S-wave. The results of this fit yielded the most reliable resonance parameters to date for $\Lambda(1670)$.

Our data for the pure $I = 1$ reaction $K^- p \to \pi^0\Lambda$ and the pure $I = 0$ reaction $K^- p \to \pi^0\Sigma^0$ are much more precise than older data. These reactions are of interest in part because they selectively excite intermediate Σ^* and Λ^* resonances, respectively. In our momentum range, the most important prior measurements are the 1970 bubble-chamber results of Armenteros *et al.* [4]. Because the Λ and Σ^0 are self-analyzing, polarizations

[2] We were below threshold for the pure $I = 1$ reaction $K^- p \to \eta\Sigma^0$.
[3] The only other known baryon resonance with a large η branch is the $\Sigma(1750)1/2^-$.

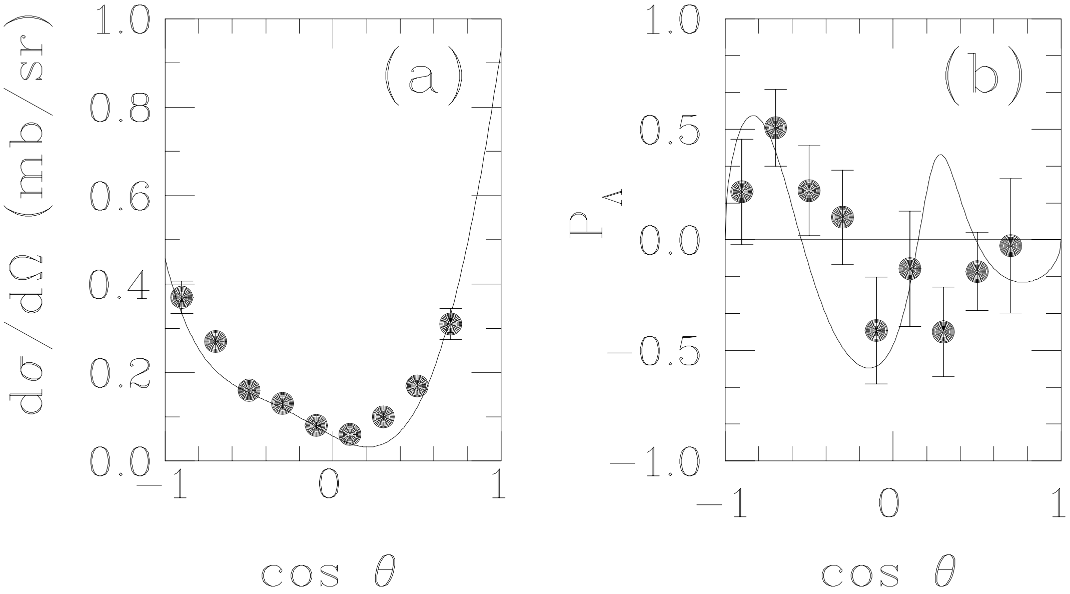

FIGURE 1. (a) Differential cross section and (b) Λ polarization for the reaction $K^- p \to \pi^0 \Lambda$ at 750 MeV/c. The data are preliminary results by the Crystal Ball Collaboration. The curves are predictions based on the 1977 PWA of Gopal *et al.* [5].

as well as differential cross sections can be extracted. Figure 1 shows preliminary Crystal Ball results for the differential cross section and Λ polarization for $K^- p \to \pi^0 \Lambda$ at 750 MeV/c. For comparison, we also show curves predicted by the partial-wave analysis (PWA) of Gopal *et al.* [5]. The curve predicted for the Λ polarization does not agree well with our data. The reason for this is simple: *The older polarization data for these reactions are of such low precision that they made little constraint on PWAs*. The polarization data for $K^- p \to \pi^0 \Lambda$ and $K^- p \to \pi^0 \Sigma^0$ are sensitive only to P- and D-wave contributions in our momentum range. The P-waves are especially interesting because they will tell us about the $\Lambda(1600)1/2^+$ and $\Sigma(1660)1/2^+$, which are the most likely candidates for SU(3) analogs of the controversial Roper resonance, or $N(1440)1/2^+$. Very little is known about these analog states. For example, the *Review of Particle Physics* [6] lists the totals widths for the $\Lambda(1600)$ and $\Sigma(1660)$ to be 50–250 MeV and 40–200 MeV, respectively.

Another state of great interest is the $\Sigma(1580)3/2^-$. The mass of this state is too low for it to be accommodated as an ordinary 3-quark state. The first evidence for this two-star state was a narrow bump observed in the total $\overline{K}N$ cross section. (See Ref. [7] and references therein.) Later, P. J. Litchfield [8] carried out a PWA of the $K^- p \to \pi^0 \Lambda$ data measured by Armenteros *et al.* [4], which he rebinned into 10-MeV/c intervals. Litchfield concluded including a D_{13} resonance with a mass 1582 ± 4 MeV and width 11 ± 4 MeV made a significant decrease in χ^2. We have made a comparison of our preliminary results for the $K^- p \to \pi^0 \Lambda$ Legendre fitting coefficients with Litchfield's predictions. Our results agree much better with his predictions that do *not* include the narrow D_{13} resonance. We conclude that the $\Sigma(1580)$ is not required to describe our data.

We have obtained preliminary Dalitz plots for both $K^- p \to \pi^0\pi^0\Lambda$ and $K^- p \to \pi^0\pi^0\Sigma^0$ at all eight nominal momenta. We expect our data for the former reaction and $K^- p \to \pi^0\Sigma^0$ to provide new information about the Roper analog state, $\Lambda(1600)1/2^+$, through the process $K^- p \to \Lambda(1600)1/2^+ \to \pi^0\Sigma^0(1385) \to \pi^0\pi^0\Lambda$. Indeed, plots of the $\pi^0\Lambda$ invariant mass clearly reveal a strong peak due to the $\Sigma(1385)3/2^+$. Our Dalitz plots for $K^- p \to \pi^0\pi^0\Sigma^0$ reveal the presence of the intermediate state $\pi^0\Lambda(1405)$ although there is a fairly large background from other processes.

CONCLUDING REMARKS

In 1998, we used the Crystal Ball spectrometer to measure new data for several $\overline{K}N$ reactions, including $K^- p \to \pi^0\Lambda$, $K^- p \to \pi^0\Sigma^0$, and $K^- p \to \eta\Lambda$, at the BNL AGS. A multichannel analysis incorporating our $K^- p \to \eta\Lambda$ total cross-section data was carried out and yielded improved resonance parameters for the $\Lambda(1670)1/2^-$. Our preliminary differential cross sections and polarizations for $K^- p \to \pi^0\Lambda$ strongly refute the existence of the $\Sigma(1580)3/2^-$, a state too light to be accommodated as an ordinary 3-quark state if its spin-parity determination is correct. Plans are underway to begin a new PWA of the world data for $\overline{K}N$ reactions, including the new Crystal Ball data. It is anticipated that our new polarization data will effectively add a new constraint to PWAs. A new AGS experiment (E953) to study specific hyperon resonances has been approved. This experiment will provide better statistics for several reactions, including $K^- p \to \pi^0\Sigma^0$ and $K^- p \to \pi^0\Sigma^0(1385) \to \pi^0\pi^0\Lambda$, which should help elucidate the properties of the Roper resonance analog, $\Lambda(1600)1/2^+$.

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