EVIDENCE FOR A MASS ENHANCEMENT IN THE $\bar{\Lambda}N$ SYSTEM*

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In the present note we report our results on the study of $\bar{\Lambda}$ and $\bar{\Sigma}^0$ production in the K^+p reaction at 9 BeV/c.[1] We observe a strong enhancement for low mass value in the $\bar{Y}^0N$ mass distribution. Such a system can have the quantum numbers of a positive-strangeness boson. If we interpret our result as a resonance it would correspond to an $I=\frac{1}{2}$ K^* with $M=2240\pm20$ MeV and $\Gamma=70\pm20$ MeV.

Recently evidence has been presented for the existence of several high-mass nonstrange boson resonances; R, S, T, and U, seen in multiparticle missing-mass distributions, as well as in the structure of the $\bar{p}N$ total cross section.[2] In the framework of the SU(3) particle classification, these high-mass bosons may belong to octets with K^* resonances as members. In particular, if the observed peaks[2] in the $\bar{p}N$ cross section indeed represent boson resonances, corresponding $\bar{\Lambda}N$ decay modes would be expected for K^*'s of mass above 2.06 BeV. The search for, and the study of, high-mass K^* resonances through their $\bar{\Lambda}N$ or $\bar{\Sigma}N$ decay modes offers several attractive features. In particular, background in the low-mass $\bar{Y}N$ system from reactions other than K^* decay is likely to be smaller than for the $K\pi$ and $K\pi\pi$ final states to which more reaction channels can contribute. The polarization of the $\bar{\Lambda}$, readily measured through its weak decay, may offer support for the existence of resonances as well as yield information on their spin-parity assignments. The $\bar{Y}N$ decay mode of a K^* is allowed for either "normal" ($J^P=0^+, 1^-, 2^+, 3^-, \cdots$) or "abnormal" ($J^P=0^-, 1^+, 2^-, 3^+, \cdots$) spin-parity values. For normal J^P values the $\bar{Y}N$ decay mode may be favored over the corresponding abnormal-parity case with equal J because of the allowed reduction of the orbital angular momentum from $l=J$ to $l=J-1$.

The present study was carried out on 90 000 pictures taken with the 80-in. hydrogen bubble chamber at the Brookhaven National Laboratory alternating-gradient synchrotron, exposed to an rf-separated 9-BeV/c K^+ beam.[3] Events having a visible V^0 decay were measured with the Lawrence Radiation Laboratory flying spot digitizer, and the remeasurements were carried out with a conventional digitizing machine. The events were spatially reconstructed and kinematically fitted in the program TVGP-SQUAW.[4] Those events with a visible neutral decay, kinematically consistent with interpretation as $\bar{\Lambda}$, were examined on the scanning table by a physicist to check ionization consistency and to resolve kinematic ambiguities. For the $\bar{Y}^0$ final states the cross sections were found to be the following: (1) $\bar{\Lambda}pp+\bar{\Sigma}^0pp$, 11.4 ± 2.3 μb (25 events); (2) $\bar{\Lambda}pp\pi^0$, 9.0 ± 2.0 μb (21 events); (3) $\bar{\Lambda}pn\pi^+$, 35.2 ± 4.0 μb (76 events); and (4) $\Lambda pp\pi^+\pi^-$, 2.7 ± 1.1 μb (6 events). The quoted errors are purely statistical. Of the 25 events listed as $\bar{Y}^0pp$, 13 were kinematically ambiguous between the seven-constraint multivertex interpretation $\bar{\Lambda}pp$ and the five-constraint multivertex interpretation $\bar{\Sigma}^0pp$. Eight events were identified unambiguously as $\bar{\Lambda}pp$ and four events as $\bar{\Sigma}^0pp$. In the following analysis the events ambiguous between $\bar{\Lambda}pp$ and $\bar{\Sigma}^0pp$ were classed as $\bar{\Lambda}pp$. The $\bar{\Lambda}$ or $\bar{\Sigma}^0$ assignment has very little effect on the resulting $\bar{Y}N$ mass distribution. The four-body final states $\bar{\Sigma}^0pp\pi^0$ and $\bar{\Sigma}^0pn\pi^+$ are underconstrained and therefore could not be indentified in this experiment. We cannot, however, rule out the possibility that a fraction of the events which fit $\bar{\Lambda}pp\pi^0$ or $\bar{\Lambda}pn\pi^+$ are in fact $\bar{\Sigma}^0pp\pi^0$ or $\bar{\Sigma}^0pn\pi^+$.[5]

In Fig. 1 we show the two-body baryon-pion masses for the four-body final states $\bar{\Lambda}pp\pi^0$ and $\bar{\Lambda}pn\pi^+$. There is no evidence for the $\bar{\Lambda}\pi$ decay of the $\bar{Y}^*(1385)$. Furthermore, there is no evidence for $\Delta(1238)$ decay in the $p\pi^0$ and

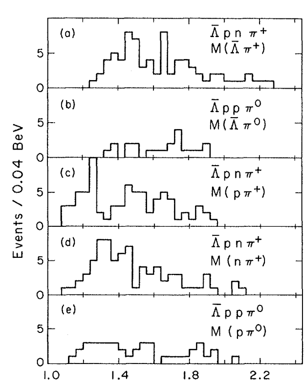

FIG. 1. The two-body baryon-pion masses for the four-body final states $\bar{\Lambda}pp\pi^0$ and $\bar{\Lambda}pn\pi^+$.

$n\pi^+$ mass distributions, and only a weak Δ^{++} signal in the $p\pi^+$ distribution. In the combined $p\pi^0$ and $n\pi^+$ mass distributions an $N_{1/2}^*$ signal for masses <1500 MeV cannot be excluded. The $\bar{Y}^0N\pi$ mass distributions do not show significant structure in any of the three charge combinations.

In order to study the $\bar{Y}^0N$ invariant-mass distributions, we first examine the production mechanism of the three final states $\bar{Y}^0pp$, $\bar{\Lambda}pp\pi^0$, and $\bar{\Lambda}pn\pi^+$. Figure 2 shows the angular distributions of the nucleons and antihyperons in these three final states. The $\bar{Y}^0pp$ events are highly peripheral in the production center of mass, with one proton emitted forward and the other emitted backward. The $\bar{\Lambda}pp\pi^0$ events also exhibit a similar peripheral structure. The $\bar{\Lambda}pn\pi^+$ events show a strong peripheral signal, but in this case there is also nonperipheral background. The $\bar{Y}^0$ production center-of-mass angular distributions are shown in Fig. 2(d). In both the $\bar{\Lambda}pp\pi^0$ and $\bar{\Lambda}pn\pi^+$ final states, the pion center-of-mass angular distributions are consistent with isotropy.

In view of the highly peripheral nature of the majority of events, it is reasonable to assume that a nucleon-antihyperon pair is produced at the K^+ vertex and that the production mechanism is dominated by Pomeranchuk or nonstrange meson exchange while the backward nucleon is produced at the target proton vertex. For the events with pion production it is not clear, from the present data, at which location the pion is to be assigned in such an exchange diagram. To exploit the peripheral feature we impose a peripheral cut on the events, i.e., we select only those events in which one nucleon is forward in the production center of mass ($\cos\theta_{\text{c.m.}} > 0$) and the other backward ($\cos\theta_{\text{c.m.}} < 0$). This peripheral cut selects a total of 95 events in the three final states $\bar{Y}^0pp$ (23 events), $\bar{\Lambda}pp\pi^0$ (18 events), and $\bar{\Lambda}pn\pi^+$ (54 events).

The invariant-mass distributions of the $\bar{Y}^0N$ system are shown in Fig. 3. In Fig. 3(a) is plotted the $\bar{Y}^0N$ mass distribution for all 122 events in the three final states $\bar{Y}^0pp$, $\bar{\Lambda}pp\pi^0$, and $\bar{\Lambda}pn\pi^+$, with two mass combinations plotted for each event. The shaded area refers to the three-body events. In Fig. 3(b) is plotted the $\bar{Y}^0N$ mass for the 95 peripheral events where now only the forward nucleon mass combination $\bar{Y}^0N_f$ is plotted. Figure 3(c) shows the same data as Fig. 3(b) with the events weighted for decay probability inside a predetermined fiducial volume. The weighted sum of the 95 events becomes 106.9. As may be noted from Fig. 3(b) and 3(c) we observe a very marked enhancement at low $\bar{Y}^0N$ mass values, in particular in the mass region 2.2 to 2.3 BeV. The smooth curve in Fig. 3(c) shows the combined three-body and four-body phase-space distribution.

From the present sample we cannot ascertain with certainty the nature of the $\bar{Y}N$ enhancement we have observed. If we interpret it as a K^*

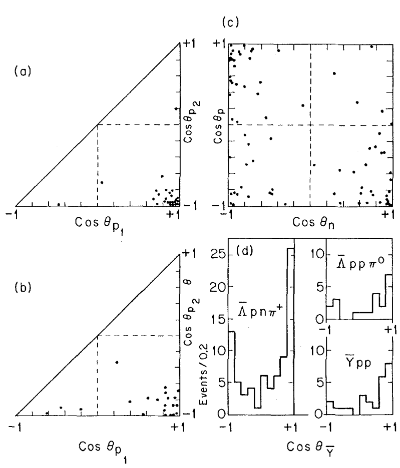

FIG. 2. Production center-of-mass angular distributions of the nucleons and antihyperons for the final states $\bar{Y}^0pp$, $\bar{\Lambda}pp\pi^0$, and $\bar{\Lambda}pn\pi^+$. (a) $\cos\theta_{p_1}$ vs $\cos\theta_{p_2}$ for the $\bar{Y}pp$ events, (b) $\cos\theta_{p_1}$ vs $\cos\theta_{p_2}$ for the $\bar{\Lambda}pp\pi^0$ events, (c) $\cos\theta_p$ vs $\cos\theta_n$ for the $\bar{\Lambda}pn\pi^+$ events, and (d) the $\cos\theta_{\bar{Y}}$ distributions for the three final states.

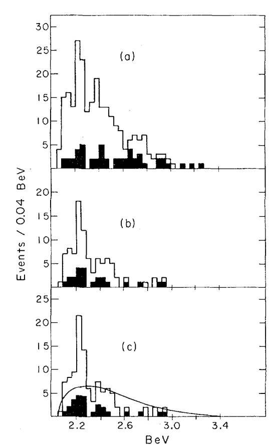

FIG. 3. Invariant-mass distributions of the $\bar{Y}^0N$ system: (a) all three-body and four-body events, each plotted twice; (b) the peripheral events only, each plotted once; and (c) the same as (b) with the events weighted for decay probability. The shaded regions refer to the three-body events. The smooth curve in (c) corresponds to phase space normalized to the total number of (weighted) events.

resonance, the best-fit parameters corresponding to a Breit-Wigner shape are found to be $M = 2240 \pm 20$ MeV and $\Gamma = 70 \pm 20$ MeV, with $40 \pm 10\%$ of resonance production.

To explore the $\bar{Y}N_f$ mass "enhancement region" 2.2 to 2.3 BeV further, we have studied the decay angular distributions of this system as well as the $\bar{\Lambda}$ polarization. The decay angles are $\theta_{K\bar{Y}}$ and φ in the $\bar{Y}N_f$ center-of-mass system.[6] Here $\cos\theta_{K\bar{Y}}$ is strongly backward peaked outside the enhancement region while it is consistent with a symmetric distribution (after allowance for background) inside that region. The distributions in φ show no strong distinguishing features. The polarization of the $\bar{\Lambda}$ along the normal to the $\bar{\Lambda}N_f$ production plane, $\hat{n} = \hat{p}_{K^+} \times \hat{p}_{\bar{Y}N}$, was calculated from the decay $\bar{p}$ direction using the value -0.64 for the decay parameter $\alpha_{\bar{\Lambda}}$. We find the polarization to be 0.70 ± 0.49 inside the "enhancement region" and 0.07 ± 0.28 outside this region. The distribution in the square of the four-momentum transfer, Δ^2, from the K^+ to the $\bar{Y}^0N_f$ system rises slowly to a maximum at ~1 $(\mathrm{BeV}/c)^2$ and falls off rather gently beyond this value. No significant variation in Δ^2 with $M(\bar{Y}^0N_f)$ is observed.

If the enhancement in the $\bar{Y}^0N_f$ mass spectrum is interpreted as a $\bar{K}^* \to \bar{\Lambda}N$, its isospin would be $\frac{1}{2}$. An isospin value of $\frac{3}{2}$ is possible only if the $\bar{\Lambda}$ hyperons in the enhancement region are in fact the decay products of $\bar{\Sigma}^0$ hyperons. This hypothesis is unlikely because (a) the 13 ambiguous $\bar{\Lambda}pp$-$\bar{\Sigma}^0pp$ events, if interpreted as $\bar{\Sigma}^0pp$, have a strongly backward peaked angular distribution for the γ in the $\bar{\Sigma}^0$ center of mass; (b) four of the eight unique $\bar{\Lambda}pp$ events lie in the enhancement region; (c) all four of the unique $\bar{\Sigma}pp$ events lie outside the enhancement region; and (d) the $\bar{\Lambda}$ polarization observed in the enhancement region, if taken at face value, is large compared with the maximum polarization allowed if the $\bar{\Lambda}$'s were decay products of $\bar{\Sigma}^0$'s.

We have looked for evidence of K^* production in the mass region 2.2 to 2.3 BeV in the reactions

$$K^+p \to K^0\pi^+p, \quad K^0 \to \pi^+\pi^-,$$

$$K^+p \to K^+\pi^+\pi^-p,$$

$$K^+p \to K^+p\omega, \quad \omega \to \pi^+\pi^-\pi^0,$$

and

$$K^+p \to K^+p\varphi, \quad \varphi \to K^+K^-,$$

and find no statistically significant enhancements in the mass region 2.2 to 2.3 BeV in the $K\pi$, $K^*\pi$, $K^+\omega$, or $K^+\varphi$ mass distributions in this experiment.[7]

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[1]Studies of $\bar{Y}^0$ production in K^+p interactions have been previously reported at incident momenta 5, 7.3, and 12.7 GeV/c. G. Bassompierre et al., Nuovo Cimento 48A, 589 (1967); C.-Y. Chien et al., Phys. Letters 25B, 426 (1967); J. C. Berlinghieri et al., University of Rochester Report No. 875-218, 1967 (unpublished).

[2]M. N. Focacci, W. Kienzle, B. Levrat, B. C. Maglić, and M. Martin, Phys. Rev. Letters 17, 890 (1966); R. J. Abrams, R. L. Cool, G. Giacomelli, T. F. Kycia, B. A. Leontić, K. K. Li, and D. N. Michael, Phys. Rev. Letters 18, 1209 (1967); I. Butterworth, Rapporteur talk, in Proceedings of the International Conference on Elementary Particles, Heidelberg, Germany, 1967 (to be published).

[3]H. Foelsche, J. Lach, J. Sandweiss, and M. Gundzik, Brookhaven Alternating-Gradient Synchrotron Report No. HF/JL/JS/MG-1, 1964 (unpublished).

[4]F. T. Solmitz, A. D. Johnson, and T. B. Day, Three-View Geometry Program, Alvarez Group Programming Note No. P-117 (unpublished); O. I. Dahl, T. B. Day, and F. T. Solmitz, SQUAW, Alvarez Programming Note No. P-126 (unpublished), Lawrence Radiation Laboratory, Berkeley, Calif.

[5]We have performed a Monte Carlo calculation generating four-body $\bar{\Sigma}^0$ events and have found that the majority of these can indeed fit the four-body $\bar{\Lambda}$ hypotheses. More important, however, this study showed that such erroneous fits do not generate a low mass enhancement in the $\bar{\Lambda}N$ system above phase space.

[6]We have used the definition of the decay angles θ and φ as given by J. D. Jackson, Nuovo Cimento 34, 1644 (1964). θ is defined as the angle between the incident K^+ and the $\bar{Y}$ in the $\bar{Y}N_f$ rest system. φ is defined as the azimuth angle of $\bar{Y}$ around the incident K^+ meson in the $\bar{Y}N_f$ rest frame.

[7]G. Goldhaber, A. Firestone, and B. C. Shen, Phys. Rev. Letters 19, 972 (1967).