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EVIDENCE FOR A $T=2$ $\Sigma\pi$ RESONANCE

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Since the discovery of the $Y_1^*(1385)$, there has been continuous speculation concerning the existence of a pion-hyperon resonance with isospin $T=2$, but experiments to date have failed to find any evidence for its existence.[1,2] To further this investigation, we studied the reaction

$$K^- + n(\mathrm{C}) \to \Sigma^- + \pi^- + \pi^+ + \text{recoils} \qquad (1)$$

in a 1.15-BeV/c K^- interaction on neutrons in carbon in the Berkeley 30-in. propane chamber. The reaction

$$K^- + n(\mathrm{C}) \to \Sigma^+ + \pi^- + \pi^- + \text{recoils} \qquad (2)$$

does not give any information concerning any $T=2$ resonance, but has been studied for completeness. We also studied the reaction

$$K^- + p(\mathrm{C}) \to \Lambda + \pi^- + \pi^+ + \text{recoils} \qquad (3)$$

to see how a well-known resonance is produced in carbon.

For the charged pionic decays, the scan-table identification of sigmas depended completely on the ionization change at the decay point. This criterion did not bias against higher momentum sigmas,[3] but did give a bias against events where the pion track from the sigma decay was steep in the chamber. A total of 330 events of the type (1) was found in our scanning. The lifetime measured for Σ^- from the events $[(1.12 \pm 0.20) \times 10^{-10}$ sec$]$ agrees with the accepted value.

The pion tracks involved in this experiment were generally long, and the momenta were determined by curvature measurements to approximately 12% on the average. However, the average sigma track length was 1.1 cm, and only a minimum value of the momentum could be obtained from range measurements. The angle of decay and the pion momentum were used to calculate the momentum of the sigma at the decay point. About half of the time, this resulted in solutions that were double-valued corresponding to forward or backward decay of the sigma in the center-of-mass (c.m.) system. For most of these events, ionization of the sigma was used to resolve this ambiguity. For the few cases where the ambiguity was not resolved by sigma ionization, the two solutions were equal within the errors, and the average value was used. The range-momentum relationship was then used to find the sigma momentum at the production vertex, but no constraints were applied at this point.

To observe resonances in the invariant-mass plot, we needed to know the phase space involved. Since, in our case, we had a variable c.m. energy available due to the Fermi momentum of the nucleons in the carbon nucleus, we adopted the following procedure to calculate the phase space:

(a) First the invariant mass of the total three-body system was calculated for each event. This was the available energy in the center of mass for this system.

(b) The ordinary three-body phase space was calculated for each event corresponding to the available c.m. energy.

(c) All phase-space distributions calculated for each event were then added. Each distribution was given the same weight in the summation.

As a first step in our search for sigma-pion resonances, we looked for the well-known $Y_1^*(1385)$ in Reaction (3). To get a reasonable sample of events, we chose for further analysis only events with a $\Lambda\pi^-\pi^+$ invariant mass between 1600 and 1865 MeV. The lower cut was determined by the phase space available for the production of the $Y_1^*(1385)$, and the upper cut was the available energy in the center of mass in the absence of the nuclear Fermi momentum. Figure 1 shows the $\Lambda\pi^-$ and $\Lambda\pi^+$ invariant-mass distributions. The phase-space distributions are normalized to the number of events. The existence of $Y_1^{*-}(1385)$ is clear, indicating that a resonance produced in carbon can be observed. The $Y_1^{*+}(1385)$ production is known to be suppressed by a factor of 1.5 relative to Y_1^{*-} in this energy region.[4]

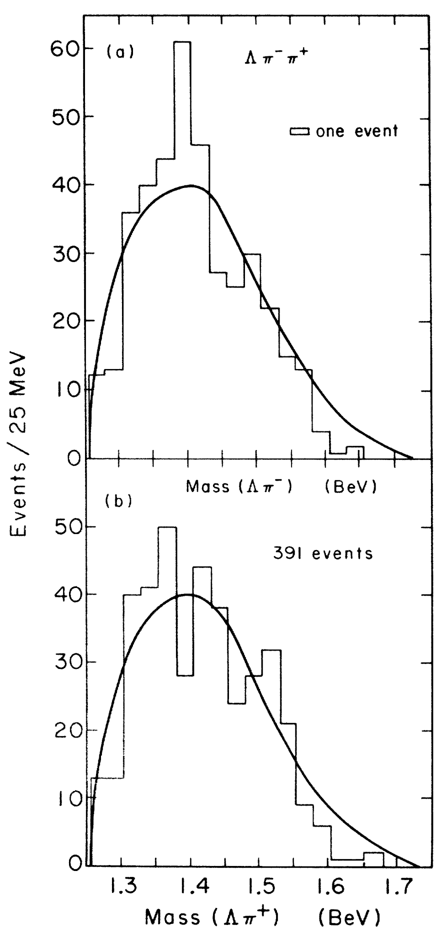

FIG. 1. Lambda-pion invariant-mass distributions.

The sigma events were analyzed in the same fashion. The same three-body invariant-mass cuts were used. A total of 185 $\Sigma^-\pi^-\pi^+$ events and 94 $\Sigma^+\pi^-\pi^-$ events was left for the final analysis. The Dalitz plot for the $\Sigma^-\pi^-\pi^+$ events is shown in Fig. 2. The different ellipses are the kinematical limits for several available energies.

Figure 3 shows the sigma-pion invariant-mass distributions. The phase-space distributions are normalized to the total number of events. The resolution of the sigma-pion invariant mass was 16 MeV. In the $\Sigma^-\pi^+$ invariant-mass plot, Fig. 3(b), we see the familiar $Y_0^*(1405)$ and, to a lesser extent, indications of the $Y_0^*(1520)$.

In the $\Sigma^-\pi^-$ plot, Fig. 3(c), we see a sharp enhancement at 1415 MeV. As can be seen from Fig. 2, this is not due to reflections of other resonances. A comparison with the $\Sigma^+\pi^-$ invariant-mass plot, Fig. 3(a), indicates that this peaking is not due to effects attributable to carbon production.

A Y^* with a mass of 1415 MeV and a width of 50 MeV would travel about 2 fermis in one mean life. Thus, approximately half of the Y^*'s would get out of the carbon nucleus before it decays. Some of the Y^*'s that decayed in the carbon nucleus were moving slowly. Therefore, we would

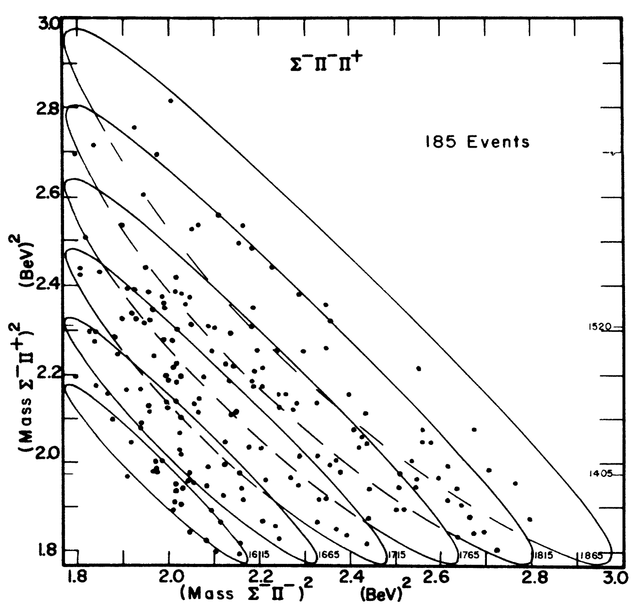

FIG. 2. Dalitz plot for the $\Sigma^-\pi^-\pi^+$ events.

expect a peak in the laboratory kinetic-energy distribution of the pion from the Y^* decay. This peak would exist even if the pion undergoes an elastic scattering in the carbon nucleus. For a 1415-MeV Y^* decay, the peak would be at a pion laboratory kinetic energy of 79 MeV. We observed a peak in this region.

As mentioned before, our detection of sigmas depended completely on the ionization change at the decay point; therefore, we biased against events where the pion track from the sigma decay was steep in the chamber. When we removed this bias, the peaking persisted.

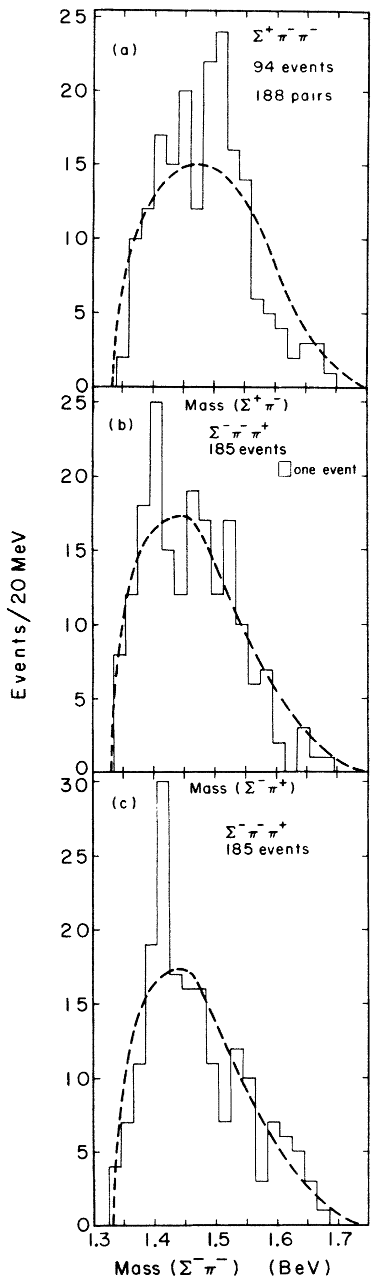

FIG. 3. Sigma-pion invariant-mass distributions.

We conclude that the biases and contaminations did not give rise to this enhancement. Since no simple interference effects are known to produce the sharp enhancement observed, and the excess is more than three standard deviations from the phase space, we conclude that it is a resonance. The mass is 1415 ± 16 MeV. The width cannot be determined because of large backgrounds.[5]

In general, all the previous experiments were either limited by statistics or by suppression of the production of this resonance by other stronger resonances, for example, K^*, ρ, and other Y^*'s. In particular, in the data at $P_{K^-} = 1.51$ BeV/c,[2] there exists an enhancement at 1415 MeV in the $T_z = 1$ system. This was attributed to possible interferences by the ρ meson, but could be interpreted in terms of the $T_z = 1$ component of a $T = 2$ resonance.

The relation of this Y_2^* with the existing "$T = 0$" 1405-MeV resonance has not been determined.

An experiment in deuterium is in progress. We hope to verify our present result.

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FURTHER SEARCH FOR FRACTIONALLY CHARGED PARTICLES*†

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Recent theoretical works by Gell-Mann[1] and Zweig[2] have suggested the possible existence of fractionally charged particles, with magnitudes $\frac{1}{3}$ and $\frac{2}{3}$ in units of the electron charge, as an esthetically appealing representation of SU(3) triplets. Several unsuccessful searches for these fractionally charged particles have been reported both for strongly interacting particles of charges $-\frac{1}{3}$ and $-\frac{2}{3}$, and for weakly interacting particles of charges $\pm\frac{1}{3}$, for masses up to 2.2 BeV[3] or somewhat higher.[4] Here we report a further unsuccessful search for positive fractionally charged particles, of charge $\frac{1}{3}$ or $\frac{2}{3}$, lifetime greater than 10^{-7} sec, and masses as high as about 2.5 BeV (for charge $\frac{1}{3}$) or 3.0 BeV (for charge $\frac{2}{3}$).

We used the 80-in. BNL liquid-hydrogen bubble chamber, and an unseparated beam of positive secondaries, at the AGS. The momentum of the internal circulating proton beam of the AGS before striking a tungsten target was 31 BeV/c. The secondary beam had a direction of 120 mrad with respect to the circulating proton beam and was tuned to 8.5 BeV/c for particles of unit electric charge. About one third of the secondary particles were π^+ mesons and the rest mostly protons. 10 000 pictures were taken with an average of 30 tracks per picture, corresponding to 100 000 π^+ at 8.5 BeV/c. No particles of charges between $\frac{1}{4}$ and $\frac{3}{4}$ were found. From available data on secondary beams at the AGS,[5] the sensitivity of this experiment was calculated to be better than one particle of charge $\frac{1}{3}$ in 6×10^5 π^+ at 2.83 BeV/c and one particle of charge $\frac{2}{3}$ in 3×10^5 π^+ at 5.67 BeV/c.

For comparison with these figures it may be noted that the antiproton intensity under the beam conditions used is about 1%, relative to π's of the same momenta.

If the production mechanism for making the fractionally charged particles is pair production of a particle-antiparticle pair, then the highest masses that could be formed in this experiment would be about 2.5 BeV for charge $\frac{1}{3}$ and about 3 BeV for charge $\frac{2}{3}$. These mass values include a rough estimate of the effect of the "Fermi" motion of the nucleons in the target. Our conclusion is that if particles of charge ze with z in the range of $+\frac{1}{4}$ to $+\frac{3}{4}$ exist, and if they are produced in pairs with production matrix element similar in magnitude to that for nucleon pairs, then either the lifetime is shorter than about 10^{-7} sec or the mass is greater than 2.5 to 3.0 BeV, depending on the magnitude of z.

Since this experiment, sensitive to positive particles, and other similar ones, sensitive to negative particles,[3,4] had similar mass and lifetime sensitivities, and since, if fractionally charged particles exist, at least one of them must be absolutely stable, we conclude from the combined results of the experiment that, with no lifetime limitation, no strongly interacting fractionally charged particles of charge $\frac{1}{3}$ or $\frac{2}{3}$, with mass up to about 2.5 BeV, are produced in proton-nucleus collisions at about 30 BeV.

The remainder of this note gives some further reasons for the choice of the experimental conditions and some further experimental details.

In this experiment, the most favorable way of making massive fractionally charged particles is by particle-antiparticle pair production. If the mass of these fractionally charged particles were about that of a nucleon or less, then breaking a nucleon into three of these particles would be en-