son would tend to be emitted from the exchanged intermediate vector boson line. Aside from numerical phase-space factors, the probability of producing the Higgs boson would be of order $G_F E^2$.

I am grateful for valuable conversations with S. Coleman and E. Gildener.

Note added.—After this paper was submitted for publication, I received a Lebedev Physics Institute report by A. D. Linde (to be published) in which similar conclusions are presented. Linde calculated the lower bound only for Abelian gauge theories, but his estimate for the more realistic SU(2)⊗U(1) theory agrees with the results given here.

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Search for Charmed Mesons and Baryons*

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Data from a 15-GeV/c π^+d experiment have been used to search for both short- and long-lived narrow resonances. No statistically significant high-mass narrow resonance has been observed up to a mass of 5 GeV. There is a single long-lived V that remains unexplained. Cross-section limits (95% confidence level) of 0.7 μb for the long-lived possibility and 2 to 4 μb for the short-lived possibilities have been obtained.

Since the discovery of the $J(\psi)$ and ψ' narrow resonances,[1] there has been a lot of speculation whether these resonances are the manifestation of a new quantum number called charm.[2] If charm exists then it should be possible to form meson and baryon resonances which contain the charm quantum number. The least massive of the charmed mesons and baryons should decay weakly, implying long lifetimes and narrow widths.

There are many predicted decay modes for these resonances[3] but to date only a few experimental searches have been reported. There has been one experiment looking for long-lived charmed mesons[4] with a sensitivity several orders of magnitude lower than ours. There are a few other experiments which search for short-lived high-mass narrow resonances with negative results.[5-7] Only one experiment has reported one possible event which could be a charmed baryon.[8] In our experiment, in addition to searching for long-lived charmed particles, we also searched for narrow high-mass resonances among such final states as $K^\pm\pi^\mp$, $K^0\pi^+\pi^-$, $K^\pm\pi^+\pi^\mp$, K^-p, K^+n, etc.

The data of this experiment[9] come from an exposure of a 15-GeV/c rf-separated π^+ beam to the Stanford Linear Accelerator Center 82-in. bubble chamber filled with liquid deuterium. The strange-particle events were measured at Florida State University and the nonstrange events were measured at the University of Pennsylvania Hough-Powell device. The geometric reconstruction program was TVGP; the kinematic fitting program used was SQUAW. The mass resolution of a system of particles is, of course, dependent on the reaction and mass of the particles considered, but generally it was less than 25 MeV.

The search for long-lived candidates assumed that the neutral particles or resonances would travel a measurable distance in the bubble chamber before decaying into two or more charged particles. Approximately 10 000 V's were measured—occurring in events with single V's or double V's corresponding to 9.5 V's/μb. All events which failed in fitting but did not have some obvious measurement difficulty (such as a scatter near the decay vertex) were remeasured. Of this total sample there remained about 40 V's which did not fit a K^0, Λ, or $\bar{\Lambda}$ with a χ^2 probability larger than 0.1%. These events were minutely examined on the scanning table, and those that had any measurement problems were rejected. In addition, in the kinematic fitting program, the mass of the neutral particle was left free and required to make a fit with χ^2 probability better than 2%. This last requirement effectively ensures that the sum of the momenta of the two charged particles points to the main vertex of the event.

After all these tests, fourteen events were still left as good V's pointing to the main vertex of the interaction but not consistent with the hypotheses $K^0 \to \pi^+ + \pi^-$, $\Lambda \to p + \pi^-$, or $\bar{\Lambda} \to \bar{p} + \pi^+$. In view of the known decay rates, not all of these events could be explained in terms of rare decay modes of K^0, Λ, or $\bar{\Lambda}$. In addition, the probability is very small that the neutral particle among the decay products, such as the ν in $\Lambda \to pe\nu$, has traveled in approximately the same direction as the parent neutral particle such that the transverse momentum of the visible particles was still balanced within measurement uncertainties.

Of the sample of fourteen events, thirteen could still be associated with K^0, Λ, or $\bar{\Lambda}$: Eight had $\pi\pi$ masses within 50 MeV of K^0 mass; two had $\pi^- p$ mass within 35 MeV of Λ mass; two had $\pi^+\bar{p}$ mass within 35 MeV of $\bar{\Lambda}$ mass. The thirteenth event was identified by ionization as $p\pi^-$ with a mass of 1205 ± 15 MeV. Being conservative, we accepted these events as K^0, Λ, or $\bar{\Lambda}$'s but ones which for some reason, such as a very small-angle scatter near the secondary vertex or a three-body decay that came very close to balancing the transverse momentum, failed in the normal fitting criteria. The last remaining V, which was measured twice, could not be explained away. Based on δ rays on the charged tracks it is definitely not a scatter or a decay of a charged particle that came from the walls of the chamber. The V has an opening angle of 44.6°; therefore it is not an electron pair. The positive track has a momentum of 3131 MeV/c and the negative track has 1853 MeV/c. If both tracks are interpreted as pions the mass is 1832 ± 35 MeV. If charmed mesons exist, it is expected that they could decay into $K^+\pi^-$ or $K^-\pi^+$. Such a fit was performed with the resulting masses $M(K^+\pi^-) = 1926 \pm 37$ MeV and $M(K^-\pi^+) = 1988 \pm 36$ MeV. Particle identification is not possible because the charged tracks have high momentum, and no δ rays useful for particle identification occurred. The proper lifetime of this event corresponds to 2×10^{-10} sec. The high mass excludes rare decay modes of K^0 or Λ.

This high-mass V event is from a two-prong, two-V event where the other V is a K^0. The visible outgoing momentum excluding the high-mass V is 8.5 GeV/c leaving 6.5 GeV/c for the high-mass V and neutrals, if any. The main vertex has, in addition, a spectator neutron. Several possible likely reactions were considered for this anomalous V. Since the V has momentum of 4.6 GeV/c, any interacting particle that can produce it has to have momentum between 4.6 and 6.5 GeV/c. If a neutron or K^0 is produced at the main vertex, the possible interactions are the following:

(1) $n + n \to n + n + \pi^+ + \pi^-$ where the $\pi^+\pi^-$ looks like a V. This reaction is kinematically impossible as the incoming n needs a minimum momentum of 7.1 GeV.

(2) $n + n \to p + \pi^- + n$. This is kinematically possible, since the minimum neutron momentum needed is 5.5 GeV/c. To calculate the number of such events the following assumptions were made: (a) Nonspectator neutron momentum distribution at high momenta corresponds to $\exp(1.8t)$; (b) 50% of all events have a nonspectator neutron; (c) 60% of all events have nonvisible proton spectator; (d) the cross section for $n + n \to p + \pi^- + n$ is 1.5 mb; (e) the probability of the final n being in the same direction as the incoming n is 0.1. Using the above values, 0.001 such event is expected.

(3) $\bar{K}^0 + n \to K^- + p$. This is kinematically impos-

sible.

(4) $K^0+n\to K^\pm+\pi^\mp+n$. This is kinematically possible for K^0 momenta greater than 4.9 GeV/c. To compute the number of such events the following assumptions were made: (a) $K_L{}^0$ production is same as $K_s{}^0$ production; (b) using data from Ref. 9, the number of two-prong events with a K^0 is computed to be 4100; (c) cross section for $K^0+n\to K^\pm+\pi^\mp+n$ is 2 mb for each final state; (d) there is 60% probability for spectator being non-visible; (e) this reaction is diffractive and the probability of the $K\pi$ mass to be greater than 1.9 GeV/c is less than 1%; (f) probability of final n in same direction of K^0 is 10% (a very conservative estimate). With the above values 0.002 event of each charged state is expected.

There are other less likely possibilities with π^0 or unseen K^0 in the final state. We estimate that the number of events which could explain this V as a secondary interaction is less than 0.01 event in the total exposure. Still, even though the probability of such a secondary interaction is very small, it is not zero. To be believable, another such event has to be found with a $K\pi$ mass similar to this event. To calculate an upper limit on the cross section, it was assumed that two such events are needed to be believable; using Poisson distribution this corresponds to 0.3 μb (95% confidence level) if no such events are found. If this event is considered as a possible charm candidate, then for $K\pi$ masses between 1.9 and 2.0 GeV, the 95% confidence level upper limit becomes 0.7 μb. The other thirteen events, if interpreted as $K\pi$, have all masses less than 920 MeV. This search places a limit of 0.3 μb on production and decay of $D^0\to K^\pm\pi^\mp$ for a lifetime $>1\times10^{-11}$ sec and a mass between 1 and 5 GeV with the exception of 1.9 to 2.0 GeV. If it is assumed that the charmed resonances are created in pairs, the upper mass limit becomes 2.5 GeV.

The search for short-lived narrow resonances entailed looking at the effective-mass combinations of many final states such as $K^\pm\pi^\mp$, $K^0\pi^\pm$, $K\pi\pi$, K^-p, $\Lambda\pi$, etc., produced at the primary vertex. The K^0 and Λ^0 particles used were those identified by fitting in events with V's in the final state. The $K^\pm$ mesons were merely assumed as mass possibilities in forming combinations among the charged tracks of the event. Table I lists the reactions considered and the visible sensitivity. In Reactions (1)–(6), each π meson in turn was replaced by a charged K meson and all possible mass combinations excluding the spectator proton (p_s) were computed. For example the first π^+ was replaced and Reaction (1) became $\pi^+d\to p_sK^+\pi^+\pi^-X^0$. The K^+ had the same momentum as the π^+ it replaced and the new energy for X^0 was computed. In this new reaction, the $K^+\pi^-$, $K^+\pi^+\pi^-$, π^+X^0, π^-X^0, X^0 masses were computed. Figure 1 shows the mass plots of $K^+\pi^-$ and $K^+\pi^+\pi^-$ from this reaction.

TABLE I. Reactions used in short-lived charm search. X^0 is two or more neutral particles. A charged K was substituted for each π in Reactions (1) to (6) and all two-, three-, and four-particle final states including one charged K were computed. The 95% confidence levels are for two- and three-body final states at 2.5-GeV mass.

Reaction $\pi^++d\to$	Sensitivity (events/μb)	95% C.L. upper limit Two-body	95% C.L. upper limit Three-body
(1) $p_s\pi^+\pi^+\pi^-X^0$	3.7	2 μb	4 μb
(2) $p_sp\pi^+\pi^-X^0$	3.7	2	4
(3) $p_s\pi^+\pi^+\pi^+\pi^-\pi^-X^0$	2.9	3	4
(4) $p_sp\pi^+\pi^+\pi^-\pi^-X^0$	2.9	3	4
(5) $p_s\pi^+\pi^+\pi^+\pi^+\pi^-\pi^-\pi^-X^0$	2.9	3	4
(6) $p_sp\pi^+\pi^+\pi^+\pi^-\pi^-\pi^-X^0$	2.9	3	4
(7) $p_s\pi^+K^0X^0$	0.9	4	...
(8) $p_spK^0X^0$	0.9	4	...
(9) $p_s\pi^+\pi^+\pi^-K^0X^0$	0.9	4	6
(10) $p_sp\pi^+\pi^-K^0X^0$	0.9	4	6
(11) $p_s\pi^+\Lambda X^0$	1.9	2	...
(12) $p_sp\Lambda X^0$	1.9	2	...
(13) $p_s\pi^+\pi^+\pi^-\Lambda X^0$	1.9	2	3
(14) $p_sp\pi^+\pi^-\Lambda X^0$	1.9	2	3

Since the search was for high-mass resonances, i.e., greater than 1.5 GeV for mesons and 2.0 GeV for baryons, a special cut was used to enhance high-mass resonances selectively. High-mass combinations of two- or three-particle final states can happen if one particle belongs to the beam fragmentation and another one comes from target fragmentation. These particles will be traveling in opposite directions in the center-of-mass system and the combined mass will be high. But if a true resonance exists, e.g., $X\to a+b$, then a and b need not be in the beam direction nor along the X direction, and the transverse momentum, $P_\perp$, of either a or b with respect to either X or the beam should often be large; i.e., in the c.m. system of X the particles decay predominantly near 90°, where the largest solid angle exists. Such a high-$P_\perp$ cut was performed on the data. The slashed plots in Fig. 1 show the

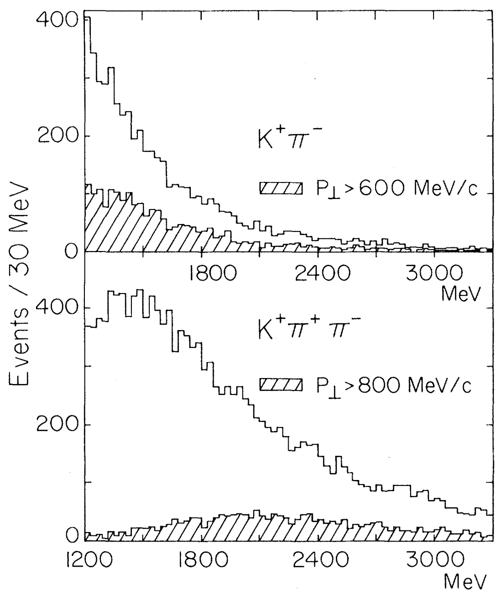

FIG. 1. Mass histograms for possible $K^+\pi^-$ and $K^+\pi^+\pi^-$ from reaction $\pi^+d \to p_s\pi^+\pi^+\pi^-X^0$ where each π^+ was replaced by a K^+ of the same momentum.

$K^+\pi^-$ and $K^+\pi^+\pi^-$ histograms with this $P_\perp$ cut with respect to the beam direction.

Every possible mass combination was plotted both in one- and two-dimensional histograms, the latter to look specially for pair production. The $P_\perp$ cuts tried on each plot were from 400 to 1000 MeV/c in 100-MeV/c steps. The number of plots studied was very large. In Reaction (1) over eighty histograms and ten scatter plots were studied. For Reactions (3) to (6), the histograms studied exceeded 100 each. Figure 1 is presented just as an example. All possible two- and three-body final states were also examined for Reactions (8) to (14). In addition, other reactions including two-V events were searched, but the number of events in these samples was too small for any effective conclusions.

The sensitivity of each final state has folded in it the observational probabilities of K^0 and Λ^0 and also the various subsamples measured. For example, some three-prong events (i.e., no visible spectator) were measured while five- and seven-prong events were not. In order for a narrow resonance of width 25 MeV or so to be believable, a 4-times-standard deviation was required for masses above 1.5 and 2.0 GeV for meson and baryon final states. No statistically significant narrow, high-mass resonance was observed. Some of the known low-mass K^* and Y^* were observed even in Reactions (1) to (6) where the $K^\pm$ was not identifiable, but with masses below our low-mass limits. The 95% confidence upper limits for the search of the high-mass resonances are listed in Table I for two- and three-body decay modes. Each upper limit quoted in the table is an average of all possibilities for that final state. The individual values rarely varied by more than 50%. These cross sections were computed using events that survived the various $P_\perp$ cuts, corrected for the loss of events by the assumption that the decay of the K or Λ in the high-mass particle center-of-mass system, with respect to the original high-mass particle direction, is uniform. Because the target is deuterium, masses up to 5 GeV have been observed. The maximum mass limit will, of course, be reduced, if it is assumed that charmed resonances are formed in pairs, in which case the mass limit will drop to 2.5 to 3.0 GeV, depending on whether two charmed mesons are produced or a charmed meson and charmed baryon pair is produced.

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Heavy-Ion $L = 1$ Transfer: A Sensitive Test of Reaction Theory*

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Angular distributions presented for reactions ^{40,42,44}Ca(^{13}C, ^{14}N)^{39,41,43}K (transferred $L=1$) at 68-MeV bombarding energy are observed to oscillate out of phase with exact, finite-range, distorted-wave-Born-approximation (DWBA) calculations. It is shown that differential cross sections for $L=1$ transfer reactions are particularly sensitive tests of the DWBA. Simple arguments follow which indicate that the difficulty in fitting present data lies with our understanding of the reaction mechanism.

The angular distributions of many heavy-ion-induced, one-nucleon transfer reactions, measured at sufficiently high incident energy, display pronounced oscillations. In most cases the phase and period of the oscillations are accounted for by the distorted-wave Born approximation (DWBA), using optical-model parameters determined by elastic scattering. The reactions ^{40,42,44}Ca(^{13}C, ^{12}C)^{41,43,45}Ca (g.s., $J^\pi = \frac{7}{2}^-$) reported here (Fig. 1) and elsewhere[1] provide examples of such agreement. In contrast, we also present data for ^{40,42,44}Ca(^{13}C, ^{14}N)^{39,41,43}K (g.s., $J^\pi = \frac{3}{2}^+$) and ^{40}Ca(^{13}C, ^{14}N)^{39}K (2.53 MeV, $J^\pi = \frac{1}{2}^+$) transitions at incident energies of 60 and 68 MeV (Figs. 1 and 2). Although DWBA calculations reproduce the magnitude, period, and overall shape of each (^{13}C, ^{14}N) angular distribution, the calculated oscillations are consistently out of phase with those of the data. The failure of the DWBA to reproduce the first few oscillations for these strong transitions is particularly serious, since the calculated pattern for the most forward angle is

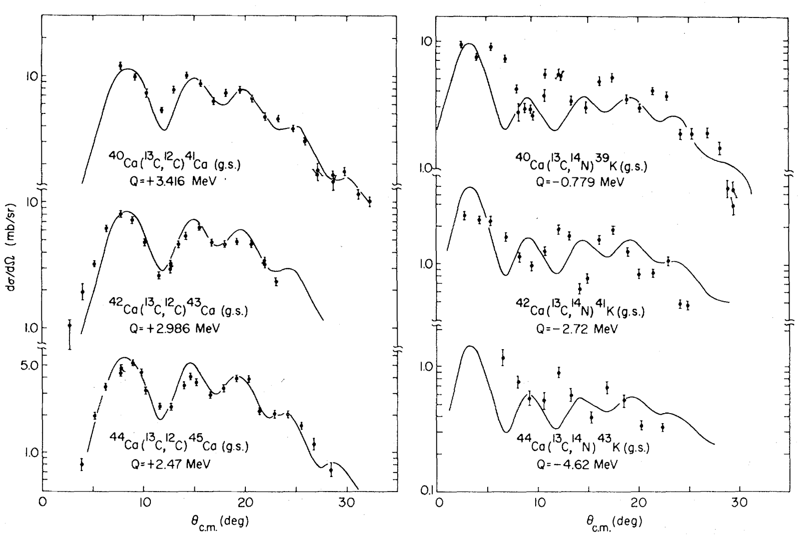

FIG. 1. The reactions ^{40,42,44}Ca(^{13}C, ^{12}C)^{41,43,44}Ca (g.s.) (left) and ^{40,42,44}Ca(^{13}C, ^{14}N)^{39,41,43}K (g.s.) (right) measured at 68 MeV. The solid curves are results of exact, finite-range, DWBA calculations with the code LOLA (Ref. 2) using parameters which fit elastic scattering (Ref. 3). The agreement for the (^{13}C, ^{12}C) reactions is satisfactory but all the (^{13}C, ^{14}N) calculations are out of phase with the data.