August 1975

SEARCH FOR EXOTIC MESONS AT SLAC*

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ABSTRACT

We review the theoretical justification and results from recent experimental searches for backwards-produced exotic mesons including two experiments carried out by our collaboration at SLAC. Our first experiment put upper limits of about 1-2μb for $X^{++} \to (2\pi, 4\pi, \omega\pi)^{++}$ and $\bar{p}p\pi^+\pi^+$ in the reaction $\pi^+ + p \to X^{++} + n_{forward}$ at 8.4 GeV/c studied with the SLAC 14 inch rapid cycling bubble chamber triggered by a downstream neutron detector. We also discuss the important features of the recently completed second experiment with the SLAC streamer chamber to study the reaction $\pi^- + p \to X^{--} + p_{forward}$ at 14 GeV/c.

* Invited talk presented by R. Panvini at Argonne Symposium on New directions in Hadron Spectroscopy, July 7-10, 1975.

** Work supported by Energy Research and Development Administration.
***Work supported by National Science Foundation.

1. INTRODUCTION

A significant feature of hadron spectroscopy is the fact that all meson states (excluding higher symmetries inferred from the existence of the ψ-J particles) can be assigned to SU(3) families of 1 or 8 members and all baryons can be fit into 1, 8 or 10 member families. Likewise, in the conventional quark model, all known mesons can be composed of a single $q\bar{q}$ pair and all known baryons can be formed from qqq combinations. There is no convincing evidence for particles that would require classification outside of the conventional scheme but further experimentation to find such "exotic" states or put upper limits on their cross section for production is clearly important.

We discuss below two experiments carried out by our collaboration to search for exotic mesons having two units of charge which would require no less than two quark-antiquark pairs, i.e., $\bar{q}\bar{q}qq$. The first of these experiments is completed with published results on the upper limits of the cross-sections for backwards-production of exotic X^{++} states in the reaction

$$\pi^+ + p \to X^{++} + n_{forward} \tag{1}$$

at 8.4 GeV/c. The only final states that could be analyzed in this experiment were those where the X^{++} consisted of $\pi^+\pi^+$, $\pi^+\pi^+\pi^+\pi^-$, $\pi^+\pi^+\pi^+\pi^-\pi^+\pi^-$, or $\bar{p}p\pi^+\pi^+$. This experiment involved the SLAC 15-inch Rapid Cycling Bubble Chamber which was triggered to take pictures by a downstream neutron detector. The statistical level of this experiment was about 10 events/μb and the upper limit of the cross-section for X^{++} resonances of mass < 3 GeV and width < 100 MeV is .1-2 μb for the final states analyzed. Currently we are carrying out the analysis of data from the SLAC streamer chamber to search for backwards-produced exotic mesons with much higher statistics. The reaction being studied is

$$\pi^- + n \to X^{--} + p_{forward} \qquad (2)$$

at 14 GeV/c, where the π^-n interactions occur in a liquid deuterium target inside the streamer chamber. In this experiment we will be able to reach close to the 1000 event/μb level and we will analyze more final states.

Before discussing these two experiments, we give some motivation for searching for backwards-produced exotic mesons in baryon-exchange reactions and other experiments of the same type are discussed as well.

II. SURVEY OF EXOTIC MESON SEARCHES AND THE IMPORTANCE OF BACKWARDS PRODUCTION PROCESSES

A. The Experimental Situation

Since there is no practical method for performing scattering experiments with pairs of particles such as $\pi^+\pi^+$, $\pi^-\pi^-$, $K^+\pi^+$, $\overline{\Lambda}n$ etc. to search for exotic mesons, it is necessary to study these systems in production experiments where states with three or more particles are also accessible. The manifestly exotic strangeness = +1 baryonic system can be investigated in formation experiments, and the status of these Z^* states is reviewed by Steinberg at this conference.

There are three categories of production experiments by which one might choose to search for exotic mesons. The three possibilities are illustrated by the following specific examples:

i) Two-body forward-production as in the meson exchange reaction

$$\pi^+ + p \to n + X^{++}_{forward}.$$

ii) The inclusive production of exotic mesons as in the reaction

$$\pi^+ + p \to X^{++} + \text{anything}.$$

iii) Two-body backwards-production in the baryon-exchange reaction

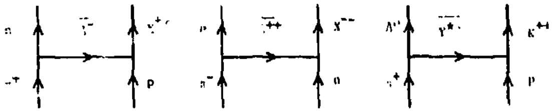
$$\pi^+ + p \to X^{++} + n_{forward}.$$

Most of the negative or controversial evidence for exotic meson production comes from studies of reactions of types i) and ii) involving pion, kaon, and anti-proton beams in bubble chamber experiments. These data are summarized in recent reviews by Cohen[1] and Bratson[2] where typical upper limits of 2-10 μb were reported. Also, high statistics counter data designed to study virtual $\pi^+\pi^+$ scattering from reaction type i) with $X^{++} \to \pi^+\pi^+$ reveal no s-channel resonant behavior.[3]

To push downwards the upper limits on exotic meson production it will be necessary to perform more counter or hybrid experiments that can investigate the charge = ±2 systems with much larger numbers of events per μb of cross-section. Reactions types i) and ii) above are generally hard to trigger, except for the three-body final states to study $\pi\pi$ scattering where no evidence for exotics were found. The third possibility, reaction type iii), is relatively easy to trigger and is therefore a very interesting possibility from a purely experimental point of view. Furthermore, there are theoretical arguments based on two-component duality that suggest that backward-production is where exotic mesons are to be found. Estimates can be made of the cross-sections at which these exotic states should be produced if the theory is meaningful as described in the following section.

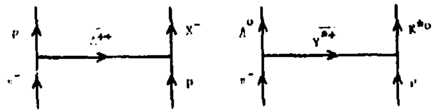
B. Theoretical Motivation for Experiments on Backwards-Production of Exotic Mesons

Three examples of backwards-production reactions are discussed as pictured below.



The first two of these are reactions (1) and (2) respectively, that our collaboration has been investigating. These two reactions are dynamically identical since they are 180° reflections of each other in isospin space. The third picture is that of a Y^* exchange reaction, i.e. $\pi^+ + p \to K^{++} + \Lambda^0_{forward}$, to search for backwards-produced strangeness = + 1 exotic mesons, for which recent data also exists.

The interest in these reactions from a theoretical viewpoint is based on the fact that a virtual baryon-antibaryon interaction occurs giving rise to doubly charged states. Clearly, no real beam of the required antibaryons is experimentally possible; therefore, these baryon-exchange processes provide a means for producing virtual baryon-antibaryon interactions in manifestly exotic, charge = ± 2 final states. According to arguments by Rosner, Jacob and Weyers, and by Lipkin[4], two-component duality constraints suggest that exotic mesons should couple to these baryon-antibaryon vertices. An important prediction from these theoretical ideas is that the cross-sections for backwards-produced exotic mesons should be of the same order as the cross sections for backwards-produced non-exotic mesons. More specifically, consider the non-exotic production reactions pictured below:



Comparing these with the exotic production diagrams shown above, the prediction is that

$$\sigma_{exotic}(X^{++} \text{ or } X^{--}) \sim \sigma_{non\text{-}exotic}(X^-)$$

and

$$\sigma_{exotic}(K^{++}) \gtrsim \sigma_{non\text{-}exotic}(K^*)$$

III. EXOTIC MESON SEARCHES IN BACKWARDS-PRODUCTION EXPERIMENTS

A. Study of the Reaction $\pi^+ + p \to K^{++} + \Lambda^0_{forward}$

Two experiments have been completed recently to search for backwards-produced strangeness = +1 exotic mesons. A Columbia-Binghamton collaboration[5] analyzed 866,000 photographs from the SLAC 82-inch bubble chamber with 15 GeV/c incident π^+. This exposure had a statistical level of about 10 events/μb when corrections for unseen forward Λ^0's are taken into account. The K^{++} mass is computed as a missing mass off of the forward Λ^0. Upper limits on K^{++} production with 95% confidence level are given as follows:

for K^{++} mass < 2.8 GeV, σ_{exotic} < 1.7 μb

and for K^{++} mass between 2.8 and 4.5 GeV, σ_{exotic} < [illegible] μb.

These values are to be compared with a value of about 0.03 μb for backward non-exotic K^0 production at the same incident momentum in the reaction $\pi^- + p \to K^0 + \Lambda^0_{forward}$. In this experiment the upper limits on the exotic meson production are not low enough to violate the duality requirement.

The second recent experiment to search for backwards K^{++} production was carried out by a CERN-Frieburg-Saclay collaboration with the CERN Omega Spectrometer.[6] The beam momentum was 12 GeV/c. This was also carried out as a missing mass experiment although plots were given showing the K^{++} for various charged particle multiplicities. Upper limits on backward K^{++} exotic production ranged between 0.060 and 0.150 μb from the low mass to the high mass part of the K^{++} mass spectrum for K^{++} mass squared less than $\sim$15 GeV^2. This upper limit range is to be compared with the backward non-exotic K* production at $\sim$12 GeV/c of approximately 0.07 μb. Since the non-exotic and exotic cross section values are essentially the same, this is a result which, based on the absence of exotics, is barely significant for weakening the two-component duality arguments.

B. SLAC Experiments to Search for Backwards-Produced Exotic Mesons

1) Study of the reaction $\pi^+ + p \to X^{++} + n_{forward}$ at 8.4 GeV/c

This was the first experiment carried out by our collaboration (Indiana-Purdue-SLAC-Vanderbilt) and was also the first experiment involving the SLAC 15 inch Rapid Cycling Bubble Chamber. Results from this experiment have already been published and we summarize the main results here.[7] The experimental setup is shown in Figure 1. Forward neutrons within $\sim 9^0$ of the beam direction were detected with a downstream neutron detector consisting of iron-plated spark chambers interspersed with scintillation counters. A gamma veto package was also placed downstream of the bubble chamber and upstream of the neutron detector. The location of the neutron interaction in the spark chambers was determined by photographing the spark locations. Since the forward neutron momentum cannot be measured, the only channels that can be analyzed in this experiment are those in which $X^{++} \to \pi^+\pi^+$, $\pi^+\pi^+\pi^+\pi^-$, $\pi^+\pi^+\pi^+\pi^-\pi^+\pi^-$, and $pp\pi^+\pi^+$. The average statistical level for these channels in our experiment was $\sim$30 events per μb. Upper limits for an exotic X^{++} state in each of these channels for a resonance width $<$100 MeV was $\sim$1-2 μb for masses $<$ 3 GeV.

To compare these with the non-exotic X^- production in the reaction $\pi^- + p \to X^- + p_{forward}$ at 8 GeV/c from a BNL-Carnegie-Mellon experiment[8] where $\sigma(\rho^-) = 1.86 \pm 0.2$ μb and $\sigma(A_2^-) = 0.5 {}^{+0.5}_{-0.3}$ μb. Our upper limits for the channels studied are comparable with the non-exotic meson cross sections and the absence of exotic mesons in this experiment, like those from the Omega Spectrometer, are barely significant for questioning the validity of the two-component duality hypothesis.

Clearly, the analysis of the entire X^{++} spectrum including the investigation of additional final states at a higher statistical level is desirable.

2) The reaction $\pi^+ + d \to X^{++} + p_{spec} + p_{forward}$ at [illegible] GeV/c

The second experiment performed by our collaboration made use of the SLAC streamer chamber. The experimental setup shown in Figure 2 illustrates the salient features of the system with a downstream magnetic spectrometer including counter hodoscopes, wire spark chambers, and a Čerenkov counter for triggering on forward protons. An internal liquid deuterium target 60 cm long and 2.5 cm wide extends into the streamer chamber with the deuterium entirely within the visible region of the chamber. Data taking was completed on July 14, 1975 and the analysis of the data is now under way. We project what we expect to obtain in this experiment.

This experiment was designed to measure the X^{--} spectrum as a missing mass off of the forward proton as well as to analyze specific channels by measuring the X^{--} decays in the streamer chamber. The estimated missing mass error versus the missing mass is shown in Figure 3. This is from a Monte Carlo calculation incorporating all expected measuring errors including the beam momentum error $\frac{\Delta p}{p} \sim 1/2\%$, and angular divergence $\Delta\theta \sim 1$ mrad, the ± 1 mm error in the location of sparks in the wire spark chambers, and multiple scattering effects. We also show in Figure 3 what would be expected if the target were hydrogen rather then deuterium revealing the spread in the missing mass error due to the Fermi momentum.

While the missing mass resolution with a deuterium target is not ideal, it is seen that over the missing mass range expected to be most interesting, i.e., from about 1.5 to 2.5 GeV/c, the missing mass error is about ± 80 MeV which is comparable with the half width for typical hadronic decays. Kinematic fits to events in the streamer chamber have been shown to be of about the same quality as fits to similar final states with a large bubble chamber such as the SLAC 82-inch bubble chamber. The $\pi^+\pi^-\pi^o$ mass spectrum from the 14 GeV/c $\pi^+p \to \mu^+p\pi^+\pi^-\pi^o$ of the Santa Cruz-SLAC collaboration is shown in Figure 4. A sharp ω^o peak is seen with a full width at half maximum of about 35 MeV which is consistent with the resolution obtained from 1C fits in the 82-inch bubble chamber.

The SLAC streamer chamber equipped with a narrow internal target serves well for nearly 4π detection of slow charged tracks. This is seen from past experience with the SLAC streamer chamber data together with preliminary results from scanning of our own data. Averaged over all interactions, we expect that not more than $\sim$10% of the events will have one or more tracks that cannot be reconstructed for any of a variety of reasons. Two typical pictures are shown in Figure 5 revealing the similarity in the quality of these photographs with bubble chamber photographs. Low momentum ($\lesssim$100 MeV/c) large angle tracks are easily measured and high multiplicities pose no particular problem. However, since the SLAC duty cycle is such that an average beam burst is spread over only $\sim$1.5 μsec, the interaction that triggers the streamer chamber will often be accompanied by one or more interactions by other beam particles entering within the 1.5 μsec time slot. We averaged about five particles per beam burst and 120 bursts per second. The fact that the interaction vertex is not seen is a source of possible confusion since accompanying interactions, interactions of secondaries tracks, and knock-on electrons can all emerge from nearby locations within the target. To simplify the analysis, we electronically tag all the pictures where more than one beam track interacts. Furthermore, by extrapolating tracks to a common vertex in the target, tracks not associated with the primary interaction can be eliminated. Referring again to Figure 5, the closely spaced parallel tracks with high momentum curving toward the left at the top of the picture are the negative beam particles. The highest momentum positive particle is likely to be the one that triggered the event.

The completed experiment consists of about 130,000 pictures of backwards-produced X^- and X^{--} considering both proton and neutron interactions in deuterium. From these pictures there will not be more than ~50,000 events of single interactions as described above. This sample amounts to ~800 events per μb-nucleon for forward protons with momentum $\gtrsim 9$ GeV/c or, equivalently, for X^- or X^{--} masses ranging from threshold to about 3.2 GeV.

A valuable feature of having a deuterium target is that in the same data we have both the non-exotic backwards-produced X^- from π^-p interactions along with the desired exotic X^{--} system resulting from the needed π^-n interactions. The various exclusive channels to be most cleanly analyzed include the following:

X^{--}	X^-
$(2\pi)^{--}$, $(4\pi)^{--}$, . . . even G-parity	$(3\pi)^-$, $(5\pi)^-$, . . . odd G-parity
$K^0K^-\pi^-$, $K^0K^-\pi^-\pi^-\pi^+$, . . .	K^0K^-, $K^0K^-\pi^-\pi^+$, . . .
$\bar{p}\pi^-n$, $\bar{p}p\pi^-\pi^-$, . . .	$\bar{p}p\pi^-$, $\bar{p}n$, . . .

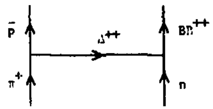
The baryon-antibaryon decays will be of special interest since it has been argued that exotics should be coupled to baryon-antibaryon channels to preserve two-component duality. We can cross-check our 1C fits to final states involving a single π^0 since the singly charged X^- system complements the manifestly exotic X^{--} system by providing clean fits to multiplicities not accessible to the latter. Structure not seen in fitted channels may appear in the missing mass off of the forward proton.

C. A Complementary Reaction to Understand the Role of Δ-Exchange

In addition to the π^-d data mentioned above, a smaller sample of data from the reaction

$$\pi^+ + d \to B\bar{B}^{++} + p_{spec} + \bar{p}_{forward}$$

was taken at 14 GeV/c. As suggested by Lipkin,[5] this provides a means for comparing virtual $\overline{\Delta^{++}}$-nucleon interactions with Δ^{++}-nucleon interactions. This is easily seen by comparing the diagram below (neglecting the spectator proton) with the previous diagrams involving forward protons and backward mesons.



The process $\overline{\Delta^{++}}n \to X^{--}$ can be made up of

i) A diffractive component,

ii) Direct channel exotic resonances,

iii) A third non-resonant component specifically associated with the annihilation mechanism.

However, the process $\Delta^{++}n \to BB^{++}$ is presumed to consist only of a diffractive component.

It is hoped that even if obvious X^{--} resonances do not appear, by comparing the π^+d with the π^-d data, dramatic differences in the virtual $\overline{\Delta^{++}}n$ and $\Delta^{++}n$ cross sections may give important clues for further understanding of the problem of exotics.

We gratefully acknowledge the assistance given us by K. Bunnell, S. Flatté and T. Schalk in providing information from previous streamer chamber experiments.

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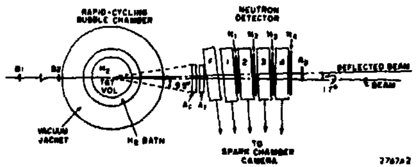

Figure 1 - Experimental setup of SLAC 15-inch rapid cycling bubble chamber with downstream neutron detector.

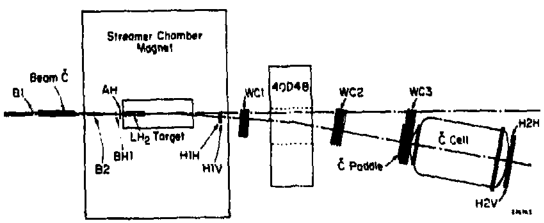

Figure 2 - Experimental setup of SLAC 2-meter streamer chamber and downstream spectrometer.

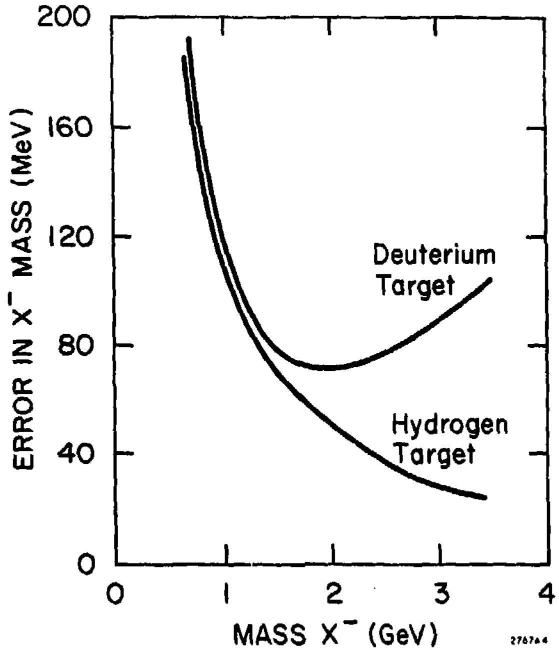

Figure 3 - Error on missing mass off of forward proton versus missing mass for the deuterium target reaction $\pi^- + d \rightarrow (n_{spec}) + X^- + p_{forward}$ and for the hydrogen target reaction $\pi^- + p \rightarrow X^- + p_{forward}$ at 14 GeV/c.

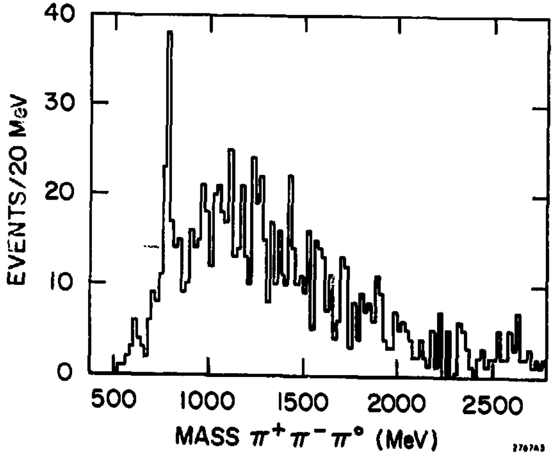

Figure 4 - Mass spectrum of $\pi^+\pi^-\pi^0$ from the reaction $\mu^+ + p \to \mu^+ + p + \pi^+ + \pi^- + \pi^0$ at 14 GeV/c from an analysis by the Santa Cruz-SLAC collaboration.

Figure 5 - Two streamer chamber photographs from exotic meson search experiment.