Experimental Evidence for Hadroproduction of Exotic Mesons

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New measurements of peripheral meson production are presented. The data confirm the existence of exotic mesons at 1.4 and 1.6 GeV/c^2. The latter state dominates the $\eta'\pi^-$ decay spectrum. The data on $\eta\pi^+\pi^-\pi^-$ decay show large strength in several exotic ($J^{pc}=1^{-+}$) waves as well.

1. INTRODUCTION

Although the form of the QCD Lagrangian is well established, the structure of the low lying hadrons is still an open question. The existence of gluonic states has emerged as one of the most promising avenues for further study. Lattice gauge calculations of hybrid meson masses lead one to believe that there should be numerous states below 2.5 GeV/c^2 in mass.[1] Flux-tube model predictions suggest that many of these states should have decay widths comparable to those of other mesons.[2] The predictions for exotic hybrids, for example those with $J^{pc}= 1^{-+}$, are particularly noteworthy since those states are excluded in the conventional quark-model picture for mesons. Previous attempts to locate these exotic states met with rather limited success. The present experiment, E852 at Brookhaven National Laboratory, has carried out a high-statistics search for exotic mesons by measuring multi-meson final-state decays.

2. EXPERIMENT

Theoretical predictions in the flux-tube model provide some guidance when designing an experiment to search for these new states. Exotic hybrids are predicted to decay preferentially to states with a spin-one meson.[2] As all of these are rather high in mass, one is obliged to detect multi-meson final states. The measurements are further complicated by the fact that such decays often yield either a π^0 or an η. Thus one must detect the two-photon decays of these particles as well.

In the present experiment 18 GeV/c negative pions from the Brookhaven National Laboratory Alternating Gradient Synchrotron facility were incident on a liquid hydrogen target. The Multi-Particle Spectrometer was used to detect charged and neutral final state particles. It was augmented with a 3000 element photon detector in the downstream region. This apparatus provided high detection efficiency for multi-particle final states, as well as soft-photon rejection. Further details of the apparatus can be found in reference [3]. Data were acquired during four running periods in 1994, 1995, 1997 and 1998.

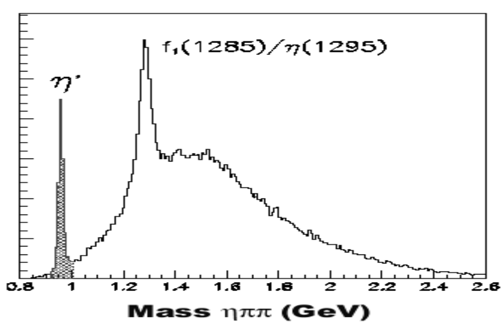
3. ANALYSIS

The data from the present experiment were analyzed by selecting exclusive events of a particular topology and fitting the meson distributions to extract the relevant partial-wave amplitudes. A separate fit was made for each bin of total meson mass. These were done in the isobar model, with secondary decays parametrized as Breit-Wigner resonances.[4]

Two reaction channels have been analyzed from the 1994 data sample, $\pi^- p \rightarrow \eta\pi^- p$ and $\pi^- p \rightarrow \pi^+\pi^-\pi^- p$. The former yielded a 1^{-+} exotic signature at M=1370±16 (+50-30) MeV/$c^2$with a width Γ=385±40 (+65-105).[5] The $\eta\pi^-$ resonance is consistent with earlier claims of P-wave strength,[6] and was later confirmed by the Crystal Barrel collaboration.[7] Subsequent analysis of a new data sample from our 1995 run yielded results which are consistent with the earlier fits, M=1369±11 (+6-15) MeV/c^2, Γ=257±19 (+5-34) MeV/c^2.

The fits to $\pi^+\pi^-\pi^-$ decay revealed another 1^{-+} exotic with M=1593±8 (+29-47) MeV/c^2 and Γ=168±20 (+150-12) MeV/c^2.[8] Previous work by the VES collaboration indicated strength in exotic waves near this mass also.[9]

The remainder of this report will be devoted to a preliminary analysis of $\eta\pi^+\pi^-\pi^-$ decays from the 1995 data sample. As one can see in Fig. 1, the data show peaks at the masses of the η' and $f_1(1285)$. Two separate PWA analyses were carried out to study each of these channels.



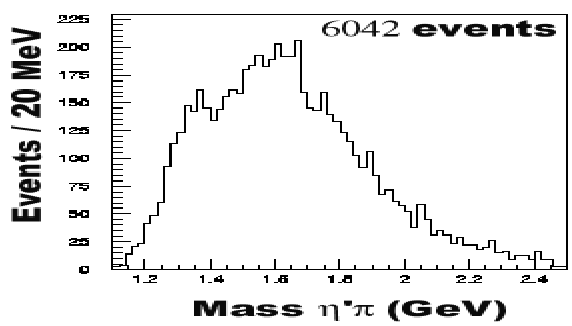


Figure 1. Effective mass of $\eta\pi^+\pi^-$. Figure 2. Effective mass of $\eta'\pi^-$ after event selection.

In the first analysis 6042 events having an $\eta\pi^+\pi^-$ mass near the η' value (Fig. 2) were extracted. Those data show a clear $a_2(1320)$ peak, as well as a broad enhancement at 1600 MeV/c^2, also shown in Fig. 2. This sample was fitted to extract the $\eta'\pi^-$ decay amplitudes. The preliminary results of this analysis (Fig. 3) show clear confirmation of an exotic $J^{pc}= 1^{-+}$ resonance at 1600 MeV/c^2. This P-wave decay amplitude dominates the spectrum in that mass region. Excitation of the a_2 is evident in the D wave.

Fig. 3 also shows the result of a mass-dependent fit to the PWA amplitudes. Relativistic Breit-Wigner peak shapes with standard Blatt-Weisskopf factors were assumed. A good description of the data was obtained with only four resonances, two each in the P and D waves.

The mass of one exotic was fixed at the value previously determined, 1370 MeV/c^2, and the mass of the a_2 was fixed at 1318 MeV/c^2. The quality of the fit was only slightly worse when the 1370 MeV/c^2 state was removed from the fit. Therefore the data yield accurate results only for the mass (M=1643±20 MeV/c^2) and width (Γ=392±35 GeV/c^2) of the second exotic $J^{pc}= 1^{-+}$ state. The precise nature of the high mass part of the spectrum is still under investigation so the results for all states are likely to change as the analysis progresses.

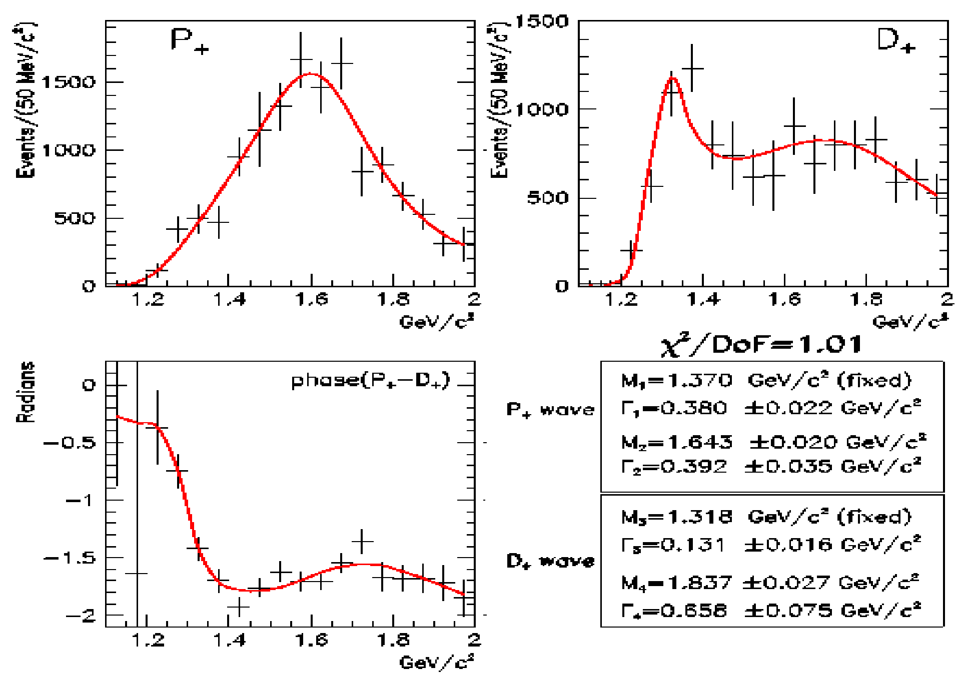


Figure 3. P-wave and D-wave amplitude for $\eta'\pi^-$, and their relative phase. The solid curve shows the result of a four-resonance fit to the data.

A second analysis was made on $\eta\pi^+\pi^-\pi^-$ after rejecting those events having an $\eta\pi^+\pi^-$ mass near the η' value (see Fig. 1). Only natural parity exchange has been included in the fits to date. A total of 68,900 events was included in this rank-2 fit. The list of primary decays that were included is shown in Table 1. Fifty-one waves were included in the fit including an isotropic, non-interfering background wave. This background wave was included in order to account for the background under the η mass peak as well as contributions from small waves that were omitted from the fit.

Table 1: Primary decays included in the $\eta\pi^+\pi^-\pi^-$ PWA fit.

$J^{pc}m^{\varepsilon}$	$1^{-+}1^{+}$	$1^{++}0^{+}$	$2^{++}1+$	$2^{-+}0^{+}$	$3^{++}0^{+}$	$3^{++}1^{+}$
$f_1(1285)\pi$	S, D	P	P	D	F	
$a_1(1260)\eta$	S	P	P	D	F	F
$a_0(980)\rho$	S	P		D		
$\eta(1295)\pi$	P					
$a_2(1320)\rho$	D		P, F	S, D	P	P
$a_2(1320)\eta$		P	P	S	P	

Figs. 4 and 5 show our preliminary results for the largest $\eta\pi^+\pi^-\pi^-$ waves. Prominent peaks were observed for 1^{++} $f_1\pi$, $a_o\rho$ and $a_1\eta$ waves, as well as the 2^{-+} $a_2\eta$ and 1^{-+} $f_1\pi$ waves. The 1^{++} $f_1\pi$ peak appears rather broad on top and may in fact be two states. The 1^{-+} $f_1\pi$ amplitude peaks at about 1.7 GeV/c^2, consistent with the mass previously reported for an exotic isovector state seen in $\pi^+\pi^+\pi^-$ decay, [8] and with the $\eta'\pi$ results shown in Fig. 3.

In addition to these structures one can observe smaller peaks in the 1^{-+} ρa_0 and $a_1\eta$ waves at about 1.9 GeV/c^2. Since the PWA analysis for this channel is in a very early stage of development it would be premature to speculate about the origin of these peaks. However it is clear that the $\eta\pi^+\pi^-\pi^-$ final state is a promising avenue for research. Further refinements are now being made to the pwa fits, including the addition of un-natural parity exchange and higher spin states. This work was supported in part by the U.S. Department of Energy, the National Science Foundation, and the Russian Ministry of Science and Technology.

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Mass $\eta\pi^+\pi^-\pi^-$ (GeV/c^2) **Mass $\eta\pi^+\pi^-\pi^-$ (GeV/c^2)**

Figure 4. Preliminary results for some of the largest $\eta\pi^+\pi^-\pi^-$ waves.

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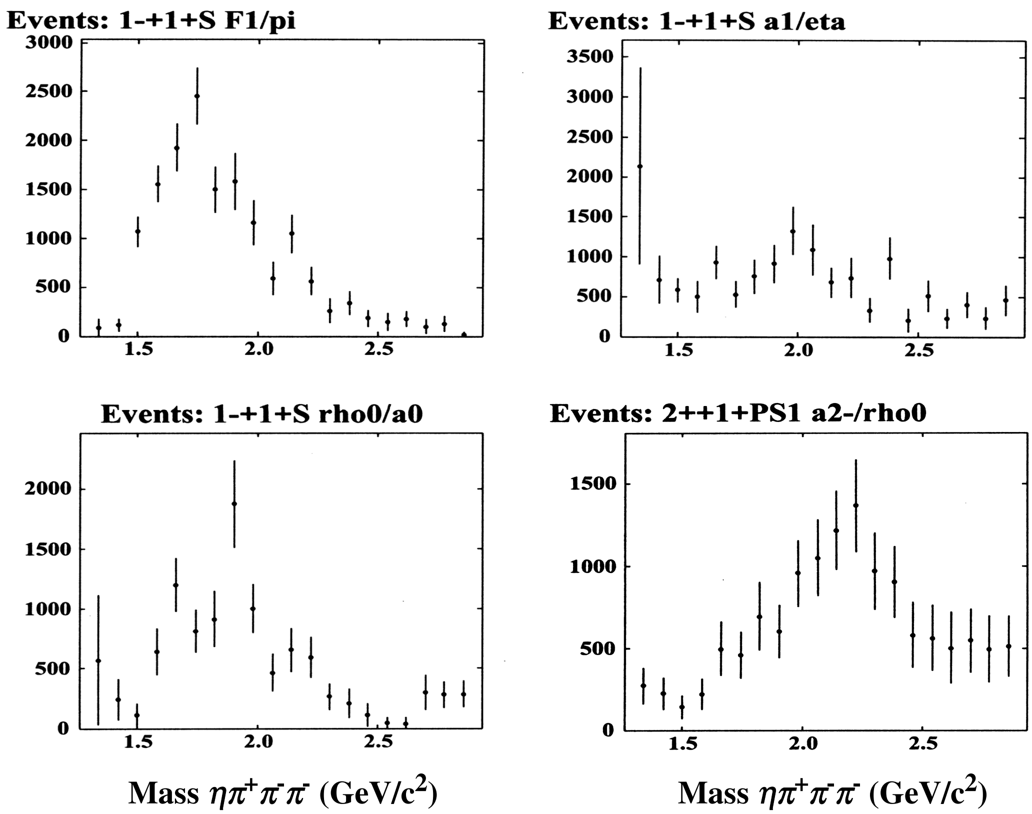

Figure 5. Preliminary results for some of the largest $\eta\pi^+\pi^-\pi^-$ waves.