Meson spectroscopy in $\pi^- p$ Interactions at 18 GeV/c –recent results from Brookhaven E852

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Brookhaven Experiment E852 is an experiment in meson spectroscopy configured to detect final states interactions of $\pi^- p$ collisions in a search for meson states incompatible with the constituent quark model. A description of the experimental apparatus and a general overview of the latest results is given.

1. INTRODUCTION

Studies of meson spectra via strong decays of hadrons provide insight regarding QCD at the confinement scale. These studies have led to phenomenological models for QCD such as the constituent quark model. However, QCD demands a much richer spectrum of meson states which includes extra states such as hybrids($q\bar{q}g$), multiquarks ($q\bar{q}q\bar{q}$), and glueballs (gg or ggg). Experiment E852 at Brookhaven National Laboratory is an experiment in meson spectroscopy configured to detect both neutral and charged final states of $\pi^- p$ collisions in a search for meson states incompatible with the constituent quark model.

The apparatus is located at the Multi-Particle Spectrometer (MPS) of Brookhaven's Alternating Gradient Synchrotron (AGS). For E852, the AGS delivered an 18 GeV/c π^- beam to a fixed liquid hydrogen target at the MPS. The MPS facility was augmented with additional detectors designed specifically for E852 and consists of 3 integral regions: target, charged tracking, and downstream regions(see Figure 1).

The target region is located in the middle of the MPS magnet and contains the following elements: a 30.5 cm long liquid hydrogen target, a four–layer cylindrical drift–proportional wire chamber, and a 198 block CsI(Ti) barrel veto detector.

The downstream half of the MPS magnet houses the main components of the charged tracking region. It consists of 3 proportional wire chambers (TPX1–3) and 6 drift chambers modules(DM1–6) each with seven–layers. In addition to the tracking chambers, there are two scintillation veto counters (CPVB and CPVC) and a window-frame lead-scintillator sandwich veto detector (DEA).

The downstream region contains a 3000 element lead–glass calorimeter (LGD) for detecting and measuring the energy of the forward going gammas and a large drift chamber (TDX4) located directly in front of the LGD for tagging charged particles entering the LGD. A more detailed description of the E852 apparatus is given in Reference [1].

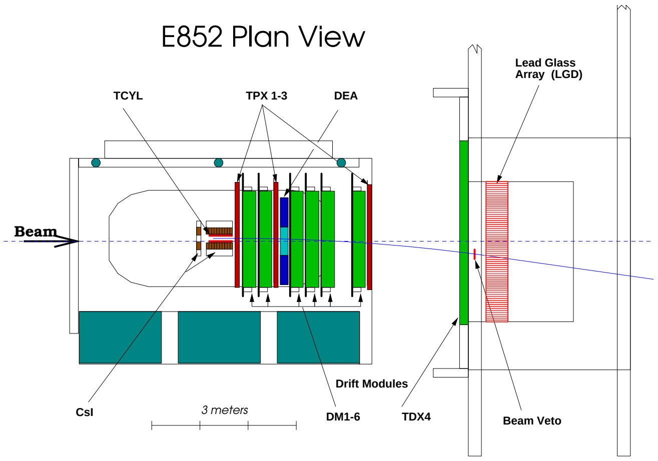

Figure 1. The plan view of E852 Apparatus at the MPS facility.

2. THE $\pi_1(1400)$ EXOTIC MESON

The $\eta\pi$ system is particularly interesting in searching for exotic (or non-$q\bar{q}$) mesons because the system has spin (J), parity (P), and charge-conjugation (C) in sequence $J^{PC} = 0^{++}, 1^{-+}, 2^{++}, 3^{-+}\ldots$ for $l = 0, 1, 2, 3, \ldots$.(Here l is the orbital angular momentum of the $\eta\pi$ system.) Hence a resonance with an $\eta\pi$ decay mode with odd l is manifestly exotic.

In previous publications[2,3], Brookhaven E852 presented evidence for an exotic meson produced in the reaction $\pi^- p \rightarrow \eta\pi^- p$ at 18 GeV/c from an analysis of the 1994 E852 data set. A large asymmetry in the angular distribution was observed indicating interference between l-even and l-odd partial waves. The $a_2(1320)$ was observed in the $J^{PC} = 2^{++}$ wave, as was a broad enhancement between 1200 and 1600 MeV/c^2 in the 1^{-+} exotic wave. The observed phase difference between these waves shows that there was phase motion in addition to that due to $a_2(1320)$ decay. An analysis of the mass dependence of the partial waves shows that the data are well described by the interference between the $a_2(1320)$ and an exotic 1^{-+} resonance with $Mass = (1370 \pm 16^{+50}_{-30})$ MeV/c^2 and $\Gamma = (385 \pm 40^{+65}_{-105})$ MeV/c^2.

During the 1995 data taking run, E852 amassed nearly 3 times the 1994 data sample. The results of a partial wave analysis (PWA) of the 1995 data compared to the 1994 results are shown in Figure 2. Here, the acceptance-corrected number of events predicted by the PWA fit for the 2^{++} and 1^{-+} waves and their phase difference are shown as a function of $Mass(\eta\pi^-)$. The intensities for the 1994 results are renormalized by a factor of 2.422. Shown are eight ambiguous solutions for each fit, each of which leads to the same angular distribution. In both data analyses, the $a_2(1320)$ is clearly observed in the 2^{++} partial wave, and a broad peak is seen in the 1^{-+} partial wave near 1400 MeV/c^2. The phase difference decreases through the $a_2(1320)$ region, and then increases above 1500 MeV/c^2. The results of the 1995 data analysis are quite consistent with the earlier E852 results. A PWA analysis of the 1995 data indicates the presence of interference between the $a_2(1320)$ and a $J^{PC} = 1^{-+}$ wave, and studies of the mass dependence show that the data are well described by the $a_2(1320)$ interfering with an exotic $J^{PC} = 1^{-+}$ resonance with $Mass = (1369 \pm 11^{+6}_{-15})$ MeV/c^2 and $\Gamma = (257 \pm 19^{+5}_{-34})$ MeV/c^2.

In addition, the $\eta\pi^\circ$ system was studied through the exclusive reaction $\pi^- p \to \eta\pi^\circ n$, $\eta \to \pi^+\pi^-\pi^\circ$, $\pi^\circ \to 2\gamma$. A partial wave analysis has been performed on 18,700 $\eta\pi^\circ$ events(compared to 60,000 $\eta\pi^-$ events). The phase motion between the 2^{++} and 1^{-+} waves is very similar to that of $\eta\pi^-$ system. A mass dependent analysis favors a hypothesis of an $a_2(1320)$ interfering with an exotic $J^{PC} = 1^{-+}$ resonance but with large systematic uncertainty for the 1^{-+} mass. Details of this analysis can be found in these proceedings[4].

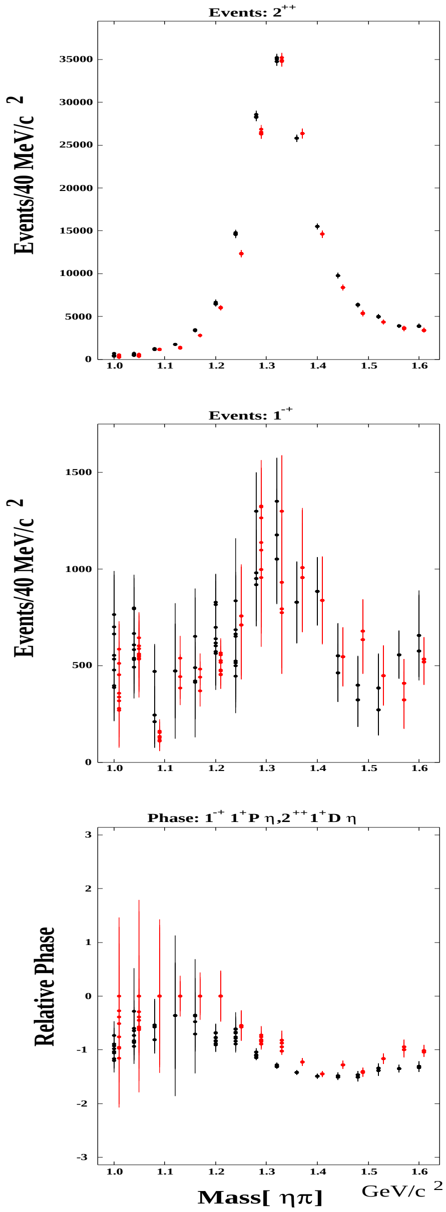

Figure 2: Results of the partial wave amplitude analysis for the E852 1994 and 1995 $\eta\pi^-$ data samples. The intensities for the 1994 results are renormalized by a factor 2.422. The data points for the 1995 results are shifted slightly to the right of the 1994 data points.

3. THE $\pi_1(1600)$ EXOTIC MESON

E852 has performed a partial wave analysis of the reaction $\pi^- p \to \pi^+\pi^-\pi^- p$[5]. In summary, all expected well-known states (a_1, a_2, and π_2) are observed. In addition, the natural parity exchange wave with manifestly exotic quantum numbers $J^{PC} = 1^{-+}$ shows structure in the intensity and phase motion which is consistent with a resonance at 1600 MeV/c^2 decaying into the $\rho\pi$ channel. A mass dependent fit results in a resonance mass of $1593 \pm 8^{+29}_{-47}$ MeV/c^2 and a width of $168 \pm 20^{+150}_{-12}$ MeV/c^2.

Another analysis currently underway studies the $\eta'\pi^-$ system produced in the reaction $\pi^- p \to \eta\pi^+\pi^-\pi^- p$. Figure 3a shows a clear signal for $\eta' \to \eta\pi^+\pi^-$ in the $\eta\pi^+\pi^-$ mass spectrum, and shown in Figure 3b is the accepted $\eta'\pi^-$ mass spectrum which exhibits a peak in the region of the $a_2(1320)$ and a broad peak near 1600 MeV/c^2. The results of a partial wave analysis find two important partial waves: the 2^{++} wave consistent with an $a_2(1320)$ signal and a broad higher mass structure; and a dominant $J^{PC} = 1^{-+}$ exotic wave which peaks at 1600 MeV/c^2.

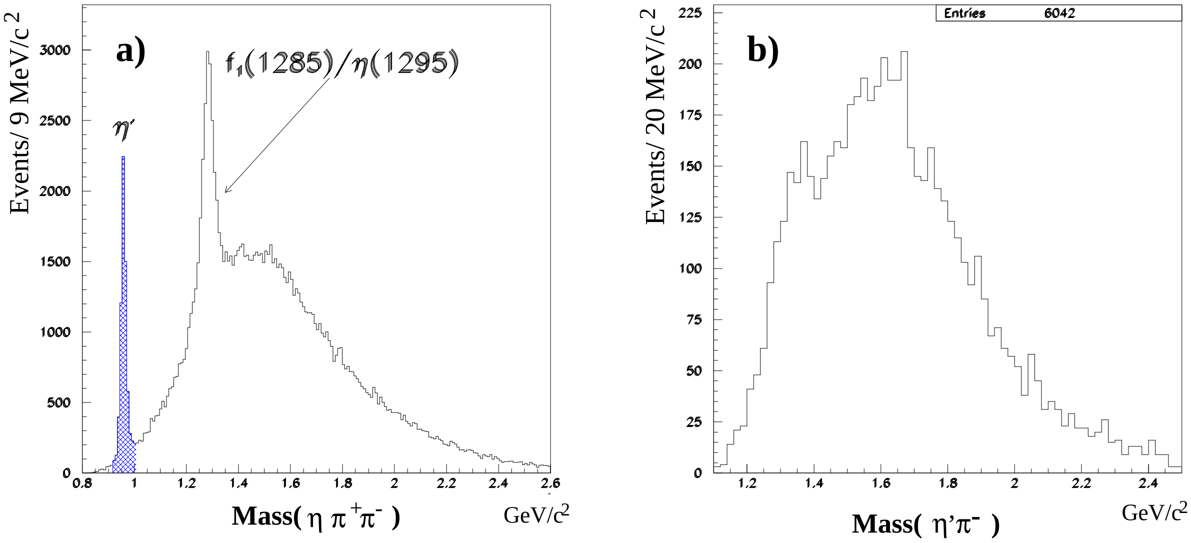

Figure 3. a) The accepted $\eta\pi^+\pi^-$ effective mass distribution. b) The accepted $\eta'\pi^-$ effective mass distribution.

A preliminary study of the mass dependence of the PWA results finds three Breit-Wigner(BW) poles in the 2^{++} wave and two BW poles in the 1^{-+} wave. Figure 4 displays the PWA results(data points with errors) with the curves showing the results of the mass dependent fit.

Since the 1^{-+} wave is dominated by a pole at 1600 MeV/c^2 with a small contribution from a pole at 1400 MeV/c^2, an alternative fit, one with a poorer χ^2/DoF of 1.22, finds that the 1^{-+} wave can be described by the pole at 1600 MeV/c^2 only. We are still investigating the low mass region of the 1^{-+} mass dependence, yet the results for the 2^{++} poles and the 1^{-+} pole at 1600 MeV/c^2 are stable and are not affected by the parameterization of the 1^{-+} low mass region.

4. OTHER ANALYSES

A partial wave analysis of the $\eta\pi^+\pi^-$ system has been performed with the focus on understanding the $\eta\pi^+\pi^-$ mass region below 1600 MeV/c^2. The data are dominated by $J^{PC} = 0^{-+}$ partial waves consistent with the observation of the $\eta(1295)$ and the $\eta(1440)$. Evidence of $J^{PC} = 1^{++}$, consistent with the $f_1(1285)$ is also seen. The analysis finds the $f_1(1285)/\eta(1295)$ region dominated by $\eta(1295)$ production. Using these results combined with results from Corden *et, al.*[6], new estimates of the $f_1(1285)$ branching fractions, which are considerably different from current PDG[7] values, were calculated and are given in Table 1. A more complete description of the analysis is given in Reference [8].

The $\eta\eta\pi^-$ and $\omega\eta\pi^-$ systems are being analyzed on a sample of 45,600 $\pi^+\pi^-\pi^-\pi^\circ\eta$ events (See these proceedings[9]). In the $\eta\eta\pi^-$ channel, a strong $a_\circ(980)$ signal decaying to $\eta\pi^-$ is present. The accepted $\eta\eta\pi^-$ mass spectrum exhibits a structure consistent with the $\pi(1800)$ that the VES Collaboration observed decaying to $\eta\eta\pi$[10]. In the $\omega\eta\pi^-$ channel, the $\omega\pi^-$ mass spectrum peaks at the mass of the $b_1(1235)$ which can indicate the presence of states decaying to $b_1(1235)\eta$.

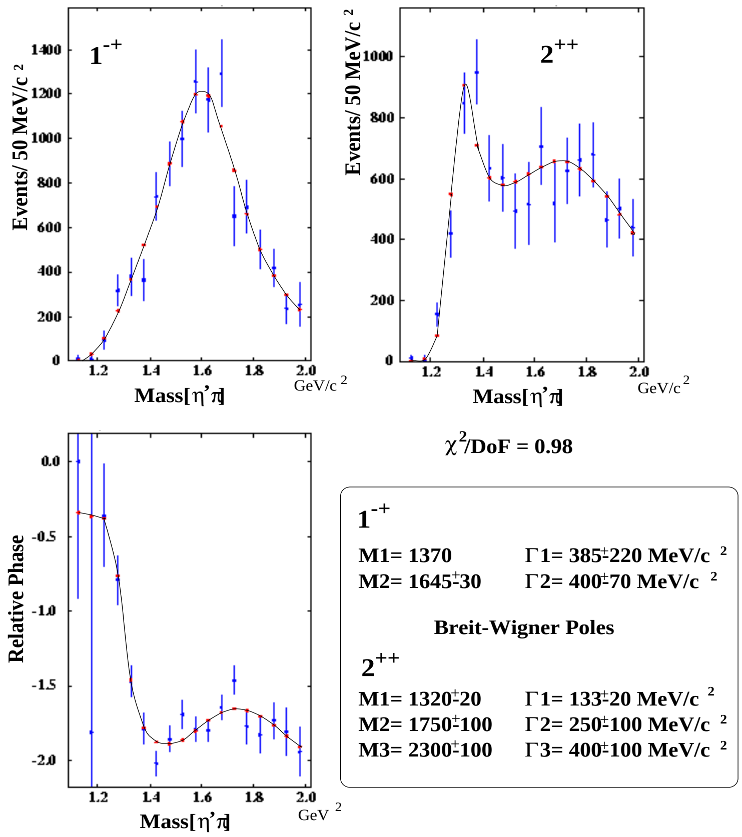

Figure 4: The mass dependency of the partial wave intensities and relative phases. Results of the PWA are given as data points with errors whereas results of a mass dependent fit assuming 2 poles in the 1^{-+} and 3 poles in the 2^{++} are shown as curves.

A study of structure in the $\omega\eta$ system produced in $\pi^-p \rightarrow \pi^+\pi^-\pi^\circ\eta n$ interactions finds both a $J^{PC} = 1^{--}$ signal consistent with the previously observed $\omega(1600)$ and a dominant $J^{PC} = 1^{+-}$ signal which exhibits phase motion relative to the $\omega(1600)$. The decay $\omega(1600) \rightarrow \omega\eta$ has not been previously reported(See these proceedings[11]).

During the 1997 and 1998-99 data taking runs, E852 required additionally a kaon multiplicity in the trigger. A total sample of nearly 1 billion triggers of this type was recorded. The analysis of these data is at an early stage. Preliminary results of an analysis of the $K\bar{K}\pi^\circ$ system shows the presence of two $J^P = 1^+$ signals consistent with the $f_1(1285)$ and the $f_1(1420)$ along with indication of an $\eta(1440)$ signal in the $J^P = 0^-$ partial wave.

Brookhaven E852 has finished data taking, and the final data processing of the 1994-95 data sample is nearing completion. The analysis of the 1997-99 accumulated sample(kaonic events) is currently in progress.

Table 1
The $f_1(1285)$ Branching Fractions

Decay Mode	*PDG %*	*E852 %*
4π	29 ± 6	59 ± 17
$\eta\pi\pi$	54 ± 15	8 ± 3
$\gamma\pi^\circ$	6.6 ± 1.3	13 ± 8
$K\bar{K}\pi$	10 ± 2	20 ± 7

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