Observation of the $a_4(2040)$ and a radial excitation of the $a_2(1320)$ decaying into $\eta\pi^-$

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Preliminary results from the E852 experiment are given. A mass dependent partial wave analysis of the reaction $\pi^- p \to \eta\pi^- p \to \gamma\gamma\pi^- p$ has been carried out in the $\eta\pi^-$ mass range 0.7 GeV/c^2 through 2.5 GeV/c^2. This analysis is based on 60K events. The experimental data was collected with the E852 setup at the AGS accelerator during the 1995 run. A resonance with $J^P = 4^+$ and $I^G = 1^-$ is observed in the G_+-wave. The mass and width of this state are $M = 2037^{+19}_{-17}$ MeV/c^2 and $\Gamma = 401^{+70}_{-59}$ MeV/c^2 respectively. In addition, a resonant structure has been observed in the D_+-wave. This can be interpreted as a radial excitation of the $a_2(1320)$ with mass $M = 1637^{+33}_{-23}$ MeV/c^2 and width $\Gamma = 226^{+51}_{-49}$ MeV/c^2.

1. INTRODUCTION

The $a_4(2040)$ has been observed in various decay channels [1–4]. The state was predicted by a relativistic quark model which is known to work very well for conventional mesons [5]. However, the $a_4(2040)$ has not previously been observed in the $\eta\pi^-$ decay mode. Such a study is possible only with high statistics experiments such as E852.

2. DATA AND STATISTICS

The data for this work was collected at the Multi-Particle Spectrometer facility using a liquid hydrogen target with a beam of π^- at 18 GeV/c. Beam particles were delivered from the AGS accelerator located at Brookhaven National Laboratory. Separate elements of the E852 setup were described in a number of publications [6–8].

A total of 750M triggers were recorded during the 1995 run which were used for this analysis. Of these, 147M triggers correspond to the topology of the reaction under study. These events were kinematically fitted to the hypothesis $\pi^- p \to \eta\pi^- p$. Only those events with a confidence level greater than 10% were taken for the further analysis. Eventually, 60K events with the momentum transfer in the region -1 (GeV/c)^2 to -0.1 (GeV/c)^2 and $\gamma\gamma\pi^-$ mass < 2.5 GeV/c^2 constituted the final data sample.

The two gamma mass spectrum prior to the confidence level cut is shown in Fig. 1. It exhibits a strong η signal. The total mass distribution is shown in Fig. 2. One can see the well established $a_2^-(1320)$ resonance.

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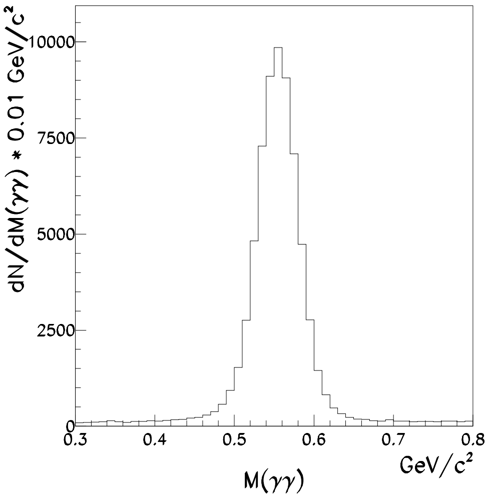

Figure 1. Two gamma mass distribution prior to the confidence level cut. The η-meson is seen.

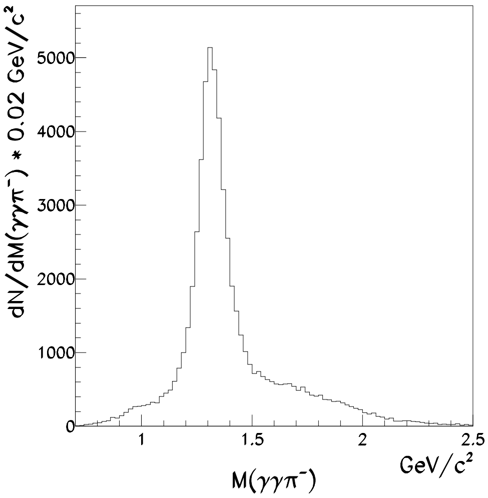

Figure 2. The total mass distribution.

3. PARTIAL WAVE ANALYSIS

Partial waves needed for the PWA can be expressed in the reflectivity basis. In this case the set of quantum numbers used to define partial waves of the $\eta\pi^-$ system is $J^P M^\epsilon$, where J is the total angular momentum of the $\eta\pi^-$, P is the intrinsic parity, M is the spin projection and ϵ is the reflectivity. Waves of different reflectivity do not interfere.

The PWA was performed for the events with the $\eta\pi^-$ mass <1.5 GeV/c^2 using the waves $S_0, P_0, P_-, D_0, D_-, P_+, D_+$ (respectively $J^P M^\epsilon = 0^+0^-, 1^-0^-, 1^-1^-, 2^+0^-, 2^+1^-, 1^-1^+, 2^+1^+$) in 40 MeV/c^2 bins. For the high mass region (above 1.5 GeV/c^2) the bin size was increased to 80 MeV/c^2 and an additional wave G_+ ($J^P M^\epsilon = 4^+1^+$) was appended.

In the resulting PWA, all the unnatural waves ($\epsilon = -1$) are relatively small and consistent with zero within error bars. The well known $a_2^-(1320)$ resonance dominates in the D_+ wave. A peak is present in the G_+ wave at 2 GeV/c^2. The phase motion $\phi_{D_+} - \phi_{G_+}$ indicates a resonant behavior of the structure in the G_+. The P_+ wave exhibits a resonance with a mass of about 1.4 GeV/c^2. The quantum numbers of the P_+ wave cannot be obtained with a conventional $q\overline{q}$ meson. The PWA result performed with this 1995 data set confirms the observation made using the 1994 run data [9].

4. MASS DEPENDENT ANALYSIS

In order to understand the observed structure in the D_+ and G_+ waves above 1.6 GeV/c^2, a mass dependent analysis was carried out. It was performed using the high spin waves D_+ and G_+ by parameterizing wave amplitudes with relativistic Breit-Wigner functions. There are eight ambiguous sets of wave amplitudes for every mass bin. However, a single representative solution per each mass bin was used in the mass dependent analysis. Further work will be done in order to determine the systematic errors which arise from these ambiguities. The intensities of the D_+ and G_+ waves and the dependence on $Re(D_+\ G_+^*)$ were used in the fit. The usage of $Re(D_+\ G_+^*)$ has an advantage over that of the phase $\phi_{D_+} - \phi_{G_+}$. The phase is defined as $arg(D_+\ G_+^*)$ and has a sign ambiguity, which can affect the physical interpretation.

The first mass dependent fit involving the $a_2^-(1320)$ and $a_4^-(2040)$ gave an unacceptable χ^2/NDF of 4.3. The fit can be improved by including of another resonance in the D_+ wave with a mass around 1.8 GeV/c^2. Such a state has been predicted by a relativistic quark model [5] to have a mass of 1.81 GeV/c^2. (The relativistic quark model is known however to give overestimates for the masses of radial excitations [10].)

The $a_2^-(1320)$, $a_2'^-$ and $a_4^-(2040)$ were used for the second fit . The fit result is shown in the Fig. 3. The χ^2/NDF for this fit is 1.9. Although this is not an excellent fit, it is significantly improved over the first fit. The resonance parameters are summarized in Table 1. As one can see, the estimated width of the $a_2^-(1320)$ is 136 MeV/c^2 compared to the accepted value of 107 MeV/c^2.

Table 1
Resonance parameters from the second mass-dependent fit.

State	M, MeV/c^2	Γ, MeV/c^2
$a_2^-(1320)$	1314^{+1}_{-1}	136^{+3}_{-3}
$a_2'^-$	1637^{+33}_{-23}	226^{+51}_{-49}
$a_4^-(2040)$	2037^{+19}_{-17}	401^{+70}_{-59}

5. CONCLUSIONS

The following summarizes the preliminary results presented in this work:

• all the unnatural-parity exchange waves are small and consistent with zero within error bars;

• the PWA result confirms the observation of the P_+ exotic state observed in the 1994 data;

• evidence for the decay of the $a_4^-(2040)$ state was found in the $\eta\pi^-$ decay channel. This is the first observation of this decay mode for the state. Its mass and width are $M = 2037^{+19}_{-17}$ MeV/c^2 and $\Gamma = 401^{+70}_{-59}$ MeV/c^2;

• evidence for a radial excitation of the $a_2^-(1320)$ was observed in the $\eta\pi^-$ decay mode for the first time. It has a mass and width of $M = 1637^{+33}_{-23}$ MeV/c^2 and $\Gamma = 226^{+51}_{-49}$ MeV/c^2 respectively.

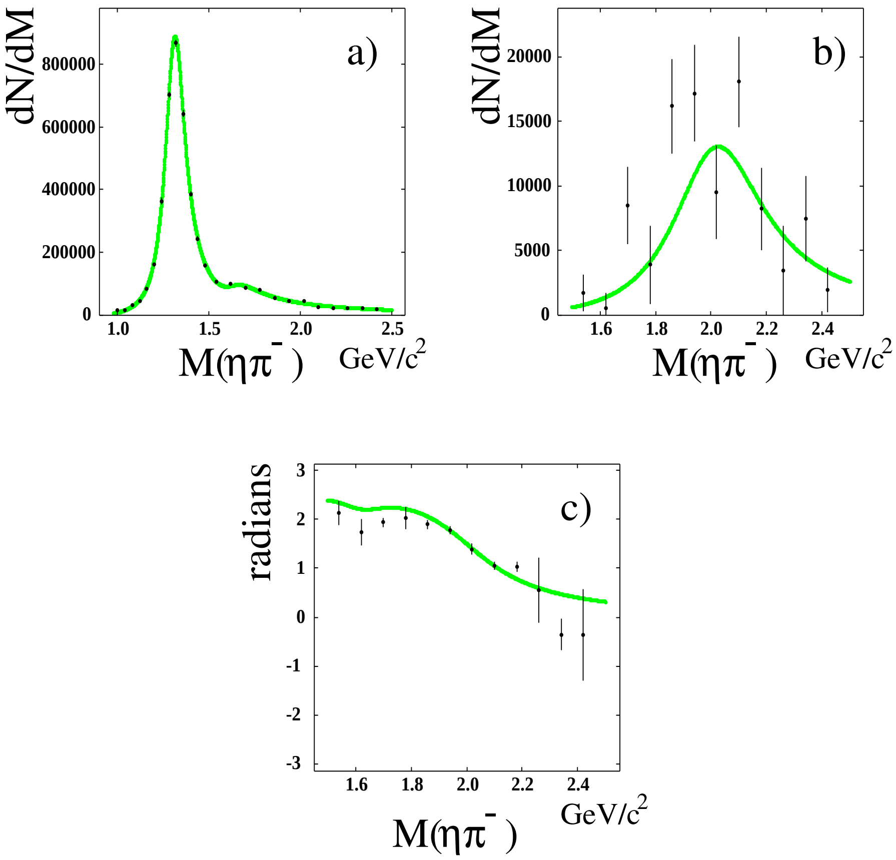

Figure 3. The result of mass dependent fit with the $a_2^-(1320)$, ${a'_2}^-$ and $a_4^-(2040)$ resonances. The plots a) and b) show the D_+ and G_+ wave intensities. The phase motion $\phi_{D_+} - \phi_{G_+}$ is shown in the plot c).

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