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An Exotic Meson in $\pi\eta$ systems

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abstract

A state with $J^{PC} = 1^{-+}$ is exotic in the sense that a conventional $\bar{q}q$ meson cannot couple to it. Such an exotic meson has been studied by three groups, in the vicinity of the $a_2(1320)$ meson in the decay channel $\pi\eta$. The current status and future prospects of this exotic meson, especially on the new result coming from the data of BNL-E852 Collaboration, are given.

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1 Introduction

Although the quark model has been successful in describing and classifying hadrons, there is mounting evidence that the simple picture of a meson consisting of a quark and an anti-quark must be extended to include multi-quark states and those containing valence gluons. J^{PC}-exotic mesons, i.e. the states belonging to $J^{PC} = 0^{+-}$, 1^{-+}, 2^{+-} and 0^{--}, cannot be quarkonia. The current status and future prospects of a $\pi\eta$ state with $J^{PC} = 1^{-+}$ are given.

A short comment is in order on notations for the partial waves commonly encountered in the literature. A pure wave coupling to a system of two pseudoscalars can be completely specified by the orbital angular momentum (L), its z-component (M) and the reflectivity quantum number (ϵ). The latter is usually chosen such that it coincides with the naturality of the exchanged particles (Reggeons) in πN or $K N$ production processes (see Fig. 1). The

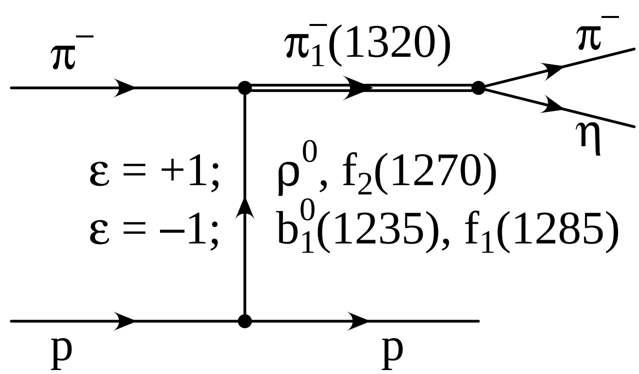

Figure 1: Resonance production via Reggeon exchange—an example.

spin J is simply L and the parity P is given by $(-)^L$. The usual notation is $|J^{PC}M^{\epsilon}\rangle$ or $|\epsilon\, LM\rangle = L_{M\epsilon}$. Here C is the charge conjugation. If $M = 0$, there is only one ϵ, i.e. $\epsilon = -1$. In addition, one makes the usual assumption that the partial waves for $M > 1$ are negligible, so that M can be dropped from the subscript above. One then merely deals with the following three partial waves, without ambiguity: L_0, L_+ and L_-, where the notations S, P, D, F are used for $L = 0$, 1, 2, 3, etc.

In this note, an J^{PC}-exotic meson is denoted following the standard convention in use, i.e. the name is determined by the combination $\{P, C\}$ of the meson. Hence, an isovector $J^{PC} = 1^{-+}$ state is denoted π_1, while its isoscalar partners are given the names η_1 and η_1'. It should be noted that the Particle Data Group[1] suggests a different convention for exotic mesons.

2 Observation of the $\pi_1(1405)$ meson

The $\pi_1(1405)$ state, called the $M(1405)$ meson, was originally reported by the GAMS group[2], seen in the reaction $\pi^- p \to \pi^0 \eta\, n$ at 100 GeV/c(see fig. 2). The forward-backward asymmetry, obtained from the cosine of the Jackson angle in the $\pi^0\eta$ system, shows a substantial non-zero swing in the $a_2(1320)$ region, as seen in Fig. 2. This can happen only if there is a strong interference effect between even-odd waves in the $a_2(1320)$ region. After a partial-wave analysis of the $\pi^0\eta$ system, the GAMS group reported that both the D_0 and the P_0 are resonant in the vicinity of the $a_2(1320)$. Because the $a_2(1320)$ and the M are seen to be produced via unnatural-parity exchange, it could be concluded that the $b_1(1235)$ exchange is the dominant one. This also indicates that the M should decay into the $b_1(1235)\pi$ final state.

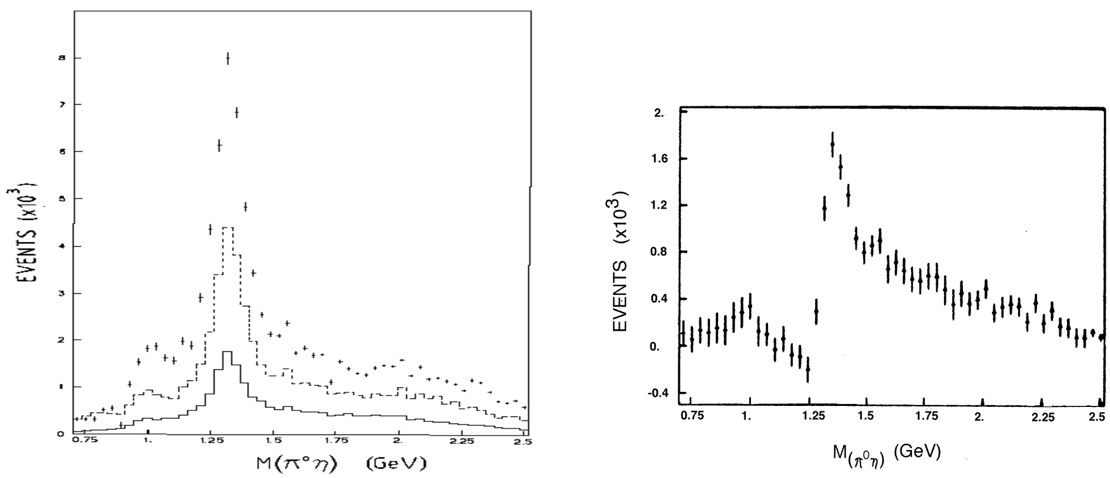

Figure 2: Spectrum of $m(\pi^0\eta)$ from the GAMS data—raw data (solid), acceptance corrected (dashed) and full fit (points with error bars); and forward-backward asymmetry as a function of $m(\pi^0\eta)$

There exist two additional pieces of evidence regarding the $M/\pi_1(1405)$ meson. The VES experiment[3] studied the reaction $\pi^- N \to \pi^- \eta\, N$ at 37 GeV/c. The $M/\pi_1(1405)$ signal is present but small with large errors in the $\pi\eta$ channel (see fig. 3). The E179 collaboration[4] at KEK studied the $\pi^-\eta$ system in the reaction $\pi^- p \to \pi^- \eta\, p$ at 6.3 GeV/c (see fig. 4). As seen in fig. 5, both D_+ and P_+ waves peak at the $a_2(1320)$ mass region; therefore, ρ- or f_2-exchange processes seem to play a central role in the production of these waves. Since the phase variation between these waves seems constant throughout the $a_2(1320)$ mass region, one must conclude that both are resonant. They have determined that $m(a_2) = 1325.1 \pm 5.1$ MeV and $\Gamma(a_2) = 126.2 \pm 14.2$ MeV for the $a_2(1320)$, and $m(\pi_1) = 1323.1 \pm 4.6$ MeV and $\Gamma(\pi_1) = 143.2 \pm 12.5$ MeV for the $M/\pi_1(1405)$.

3 New result on the $J^{PC} = 1^{-+}$ $\pi\eta$ state

The BNL-E852 Collaboration[5] is in the process of carrying out a study of the reactions

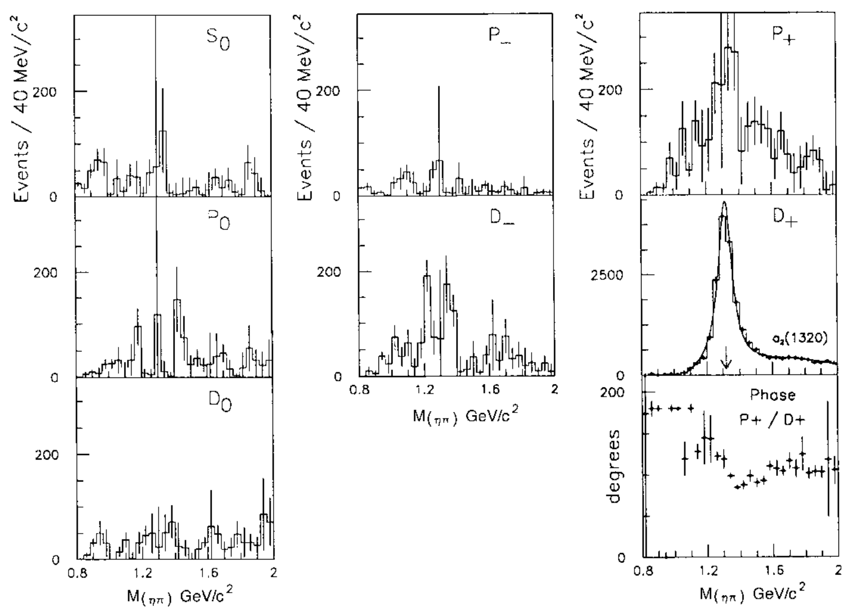

Figure 3: Partial-wave decomposition of the $\eta\pi^-$ system (VES data).

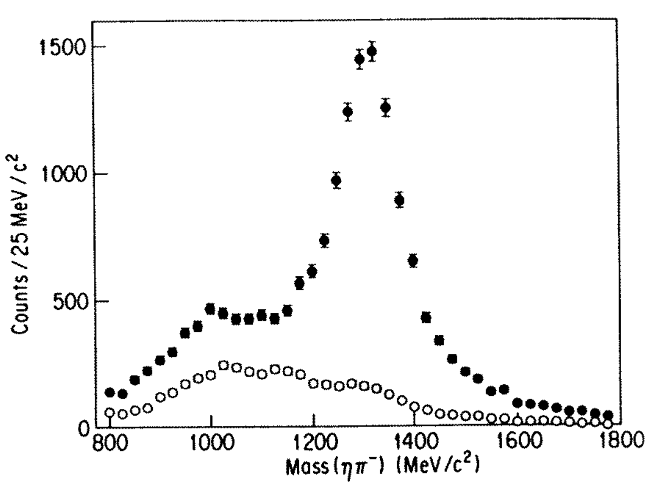

Figure 4: Spectrum of $m(\pi^-\eta)$ from the KEK data. Open circles represent their background estimate.

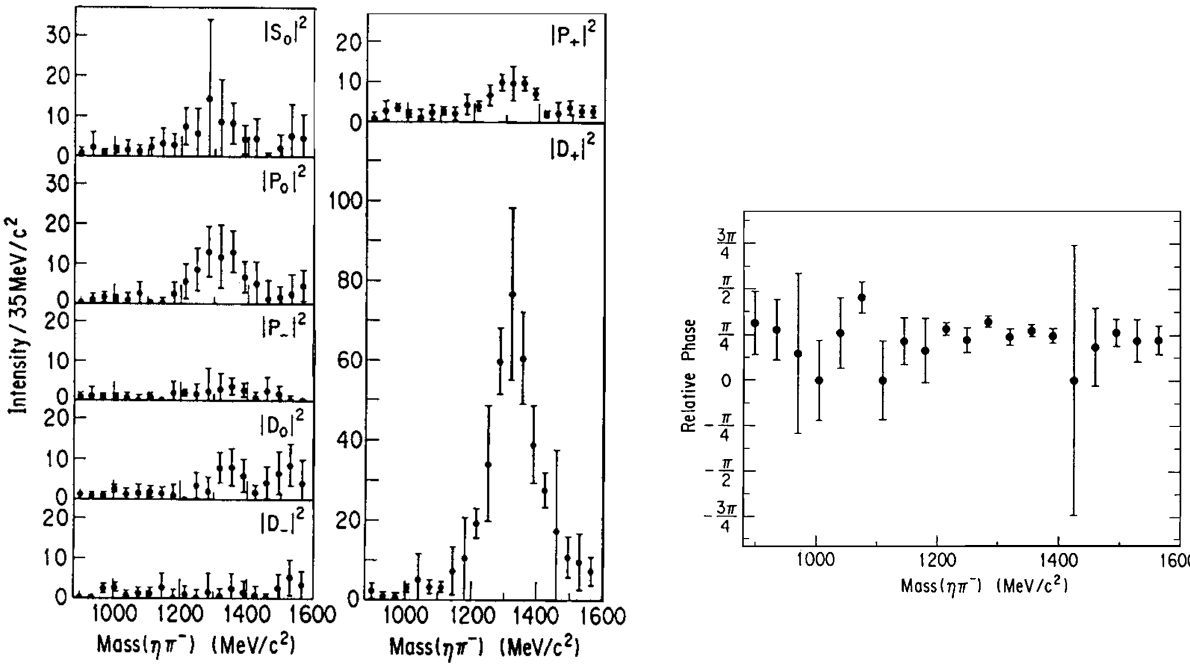

Figure 5: Partial-wave intensities for $m(\pi^-\eta)$ and the phase motion of P_+ relative to D_+ from the KEK data

$\pi^- p \to \eta\pi^- p$ and $\pi^- p \to \eta\pi^0 n$ at 18 GeV/c, where the η decay is observed in the channels $\gamma\gamma$ or $\pi^+\pi^-\pi^0$. The data presented in this note are based on 45,000 events fitting the reaction $\pi^- p \to \eta\pi^- p$ with $\eta \to \gamma\gamma$. The mass spectrum of $\eta\pi^-$ is shown in Fig. 6, and the dotted histogram corresponds to non-η background in the data. It is seen that the $a_2(1320)$ peak is most prominent, with relatively pure η events in this region.

The partial-wave analysis has been done on the data, but the results are highly preliminary and are not presented here; however, one can glean a lot from a study of the structures in the unnormalized moments,

$$H(LM) = \sum_i^n d^L_{M0}(\theta_i)\, \cos M\phi_i \tag{1}$$

where n is the number of raw experimental events in a given $m(\eta\pi^-)$ bin and (θ, ϕ) describes the orientation of the η in an $\eta\pi^-$ rest frame (the Jackson frame). One notes that $H(00)$ is merely the raw experimental mass distribution. In the limit of perfect acceptance, the

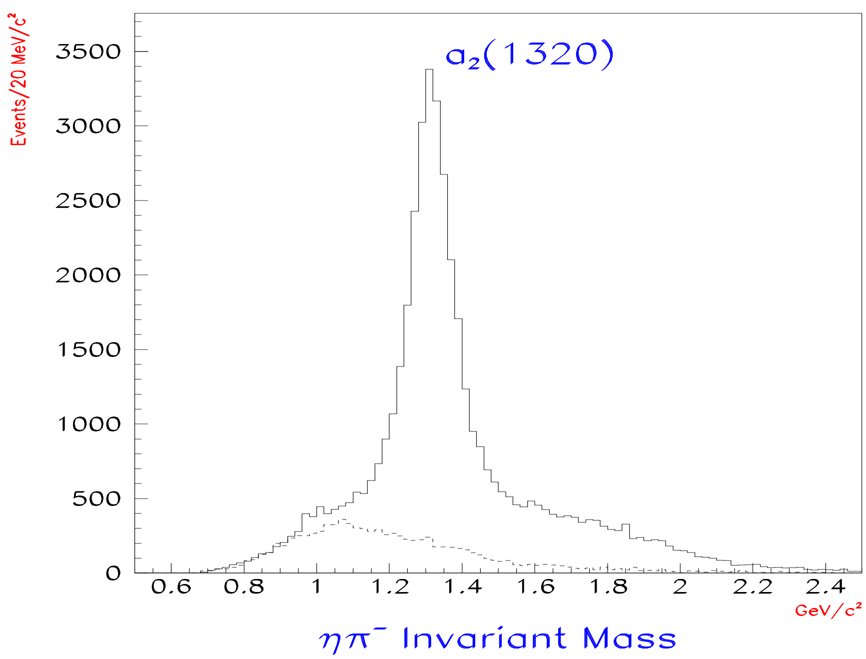

Figure 6: $m(\pi^-\eta)$ spectrum from the BNL-E852 data

experimental moments of interest are given, in terms of the partial-waves P and D,

$$\begin{aligned}
H(30) &= \frac{3}{7\sqrt{5}}(\sqrt{3}P_0D_0 - P_-D_- - P_+D_+) \\
H(32) &= \frac{1}{7}\sqrt{\frac{3}{2}}(P_-D_- - P_+D_+) \\
H(40) &= \frac{2}{7}D_0^2 - \frac{4}{21}(D_-^2 + D_+^2) \\
H(42) &= \frac{\sqrt{10}}{21}(D_-^2 - D_+^2)
\end{aligned} \tag{2}$$

with a shorthand notation in which A^2 stands for $|A|^2$ and AB for $2\,\mathrm{Re}\{AB^*\}$.

In Fig. 7 are shown the experimental moments $H(30)$, $H(32)$, $H(40)$ and $H(42)$. As expected, one sees that the $a_2(1320)$ peak is dominated by $H(40)$ and $H(42)$ moments; as they are both large and negative, one concludes that the D_+ wave must be dominant in the a_2 region. The crucial observation is that the experimental moments $H(30)$ and $H(32)$ are both large in the a_2 region as well and have the same sign (negative). From (2), one finds that the only possible solution requires presence of a substantial P_+ wave in the a_2 region. A study of the finite acceptance of the apparatus reveals that it cannot account for the structures seen in the $H(30)$ and $H(32)$ moments. The next crucial feature of the moments is that the mass and the width of the peaks in all the moments $H(30)$, $H(32)$, $H(40)$ and $H(42)$ are very much like those of the $a_2(1320)$ itself. From this one must conclude that the P_+ wave is resonant, as is the a_2 of course, and that the two phases track with each other throughout the a_2 region. A full likelihood analysis of the data—still highly preliminary—confirms these conclusions.

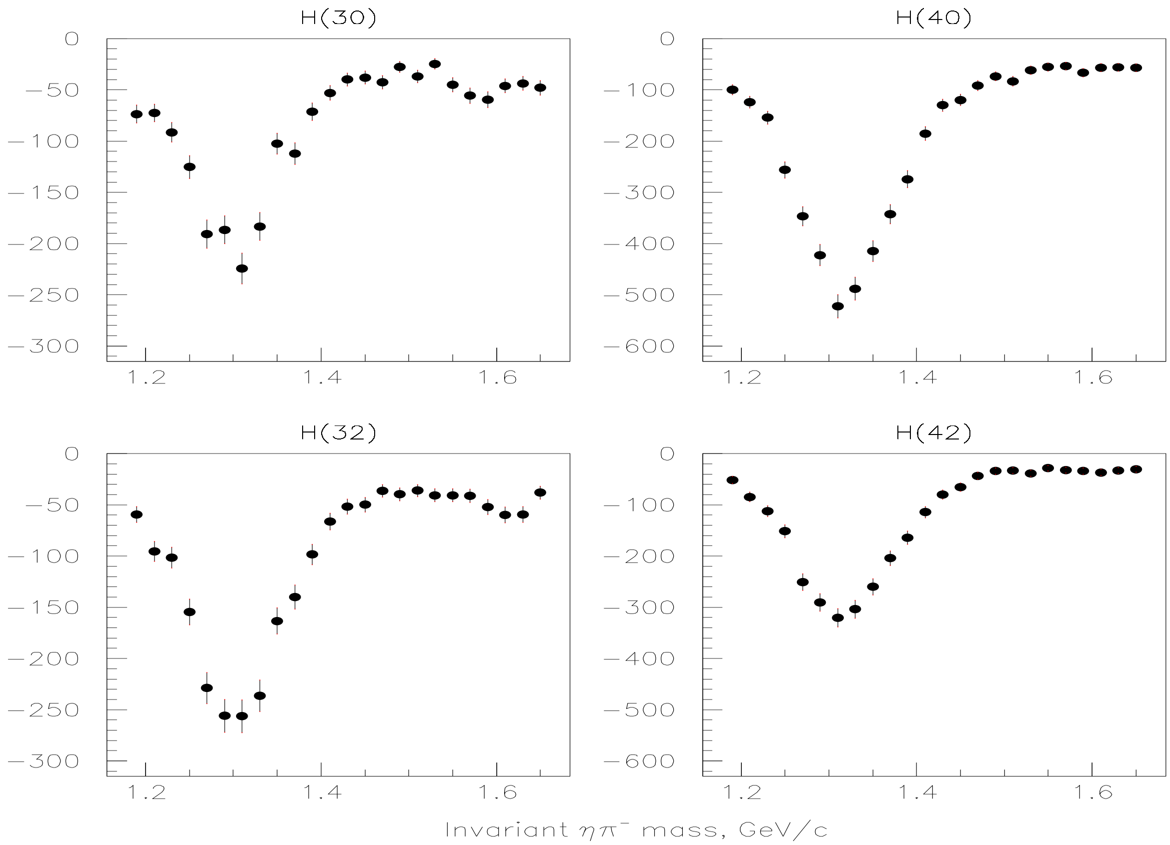

Figure 7: Experimental $H(LM)$ moments as a function $m(\pi^-\eta)$ from the BNL data

4 Discussions and Future Prospects

The KEK group sees a state at mass 1323 MeV and width 143 MeV in the $\pi\eta$ channel, produced via natural-parity exchange. This result is in conflict with an earlier GAMS result which showed a 1^{-+} state with unnatural-parity exchange. (Sadovsky[6] emphasized that the analysis technique, originally employed by the GAMS group, was unreliable.) The VES group also studied the $\pi\eta$ channel but they report no significant 1^{-+} state in the 1.3–1.4 GeV region. Now the new results from the BNL-E852 Collaboration tend to confirm those of the KEK data. It should be noted that the BNL data at 18 GeV/c is three times the KEK data (on the same reaction but at a much lower beam energy of 6.3 GeV/c). A definitive statement from the BNL Collaboration is expected soon, since their current analysis is based on 1/4 of the total data sample they have taken in 1994 and 1995.

In addition to the $\pi_1(1320)$ covered in this note, the VES group[3] claims a 1^{-+} candidate at 1620 MeV in the decay channels $\pi\rho$ and $\pi\eta'$, produced via natural-parity exchange. The BNL-E818 Collaboration[7] reported observation of a 1^{-+} $f_1(1285)\pi$ state in the 1.9–2.0 GeV mass region. All of these are in need of confirmation.

It is hoped that the situation will soon be very much clarified by the impending new results from partial-wave analyses on the BNL-E852 data, which consist of some 10^9 triggers collected over two years. In addition to $\eta\pi$, the decay channels under study include $\eta'\pi$, $\eta\eta$, $\eta\pi\pi$, $(\pi\pi\pi)^-$, $f_1(1285)\pi$, $\omega\pi$, $b_1(1235)\pi$ and $\omega\eta$. The E852 Collaboration is planning to take more data in 1997 with a segmented Cerenkov Counter for π/K separation. Because the gluons couple equally to all flavors, a comprehensive study of gluonic hadrons necessarily involves $s\bar{s}$ final states. The decay channels of interest include $K\bar{K}\pi$, $K\bar{K}\pi\pi$, $K\bar{K}\eta$, $K\bar{K}\omega$, etc.

In addition, new results are expected from the analyses being carried out on the IHEP data taken by the VES and the GAMS group. Further new information should be forthcoming from the massive statistics being accumulated by the Crystal Barrel and Obelix collaborations at LEAR, on the $\bar{p}p$ and $\bar{p}n$ annihilations at rest and in flight. The WA76 collaboration with the Omega Spectrometer at CERN, and its extension WA91, have been collecting data since 1991, to search for exotic mesons in the central production at the SPS; so far they report no 1^{-+} states in their data.

References

[1] Review of Particle Properties, Particle Data Group, Phys. Rev. **D50**, Part I (1994).

[2] D. Alde, *et al.*, Phys. Lett. **B205**, 397 (1988).

[3] G. M. Beladidze, *et al.*, Phys. Lett. **B313**, 276 (1993).

[4] H. Aoyagi, *et al.*, Phys. Lett. **B314**, 246 (1993).

[5] The collaboration consists of BNL, IHEP (Protvino), Indiana, U. Mass.(Dartmouth), Moscow State, Northwestern (Evanston), Notre Dame, RPI (Troy, NY). The group is currently carrying out a systematic study of the exotic mesons produced in $\pi^- p$ interactions at 18 GeV/c at the existing BNL Multi-Particle Spectrometer (MPS), augmented by charged-particle and photon detectors around the target and at the downstream end of the MPS magnet.

[6] S. A. Sadovsky, 'On the Choice of Minimization functional in the partial-wave analysis,' IHEP preprint 91-15, IHEP/Protvino, 1991.

[7] J. H. Lee, *et al.*, Phys. Lett. **B323**, 227 (1994).