

# Photoproduction of Hybrid Mesons

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**Abstract.** In this contribution I discuss prospects for photoproducing hybrid mesons at CEBAF, based on recent model results and experimental indications of possible hybrids. One excellent opportunity appears to be a search for  $I = 1$ ,  $J^{PC} = 2^{+-}$  “ $b_2^0$ ” hybrids in  $(a_2\pi)^0$  through diffractive photoproduction. Other notable possibilities accessible through  $\pi^+$  or  $\pi^0$  exchange photoproduction are  $I = 1$   $1^{-+}$  “ $\pi_1^+$ ” in  $f_1\pi^+$ ,  $(b_1\pi)^+$  and  $(\rho\pi)^+$ ;  $\pi_1^+(1770)$  in  $f_2\pi^+$  and  $(b_1\pi)^+$ ;  $\pi^+(1800)$  in  $f_0\pi^+$ ,  $f_2\pi^+$ ,  $\rho^+\omega$  and  $(\rho\pi)^+$ ;  $a_1$  in  $f_1\pi^+$  and  $f_2\pi^+$ ; and  $\omega$  in  $(\rho\pi)^0$ ,  $\omega\eta$  and  $K_1K$ .

## Introduction: Expectations for hybrids

The search for hybrids has reached an exciting and somewhat bewildering point. Theoretical predictions for hybrid masses have historically been somewhat model dependent, with masses for the lightest hybrid meson multiplet typically lying in the range 1.5-2.0 GeV. The flux-tube model prediction of 1.9 GeV [1] has been the most widely cited hybrid mass estimate. This appears to have been confirmed by recent LGT studies [2] which find that the lightest exotic  $n\bar{n}$ -hybrid is a  $1^{-+}$ , with a mass of about 2.0 GeV. Thus, theory appears to have reached a consensus that exotic hybrids begin at around 2.0 GeV. The flux-tube model predicts that the  $I = 1$   $1^{-+}$  should not be very broad; a width of about 0.2 GeV is anticipated for a mass near 1.9 GeV, with dominant decay modes of  $b_1\pi$  and  $f_1\pi$  [3]. One surprise from LGT is that the  $0^{+-}$  exotic is found by the MILC Collaboration to have a high mass, perhaps about 2.7 GeV (from their figure). In the flux-tube model this should be approximately degenerate with the  $1^{-+}$ .

These predictions are in striking *disagreement* with recent experimental results [4]. VES and E852 are in agreement about the phase motion of the  $\eta\pi^-$  system in  $\pi^-p \rightarrow \pi^-\eta n$ , which E852 notes can be fitted with a rather broad exotic “ $\pi_1(1400)$ ” with  $M = 1.4$  GeV,  $\Gamma_{tot} = 0.4$  GeV. This mass is about 0.5 GeV below theoretical expectations, and the observed state is *much* wider than the flux-tube model would anticipate for a hybrid at this mass. This state appears to have been

confirmed by Crystal Barrel [5]. A second  $I = 1$   $1^{-+}$  exotic has been found by E852 near 1.6 GeV in  $\rho\pi$ , with a width slightly below 0.2 GeV. This relatively narrow state shows clear resonant phase motion against the  $\pi_2(1670)$ .

Thus hybrids may well have been discovered, and the disagreement with theoretical predictions, including LGT, makes their further study of the greatest interest. In this contribution we consider which hybrids might be photoproduced easily (diffractively or by pion exchange) in a future search for exotic mesons at CEBAF.

## Channels for hybrid photoproduction

Here we simply list accessible quantum numbers, since detailed model calculations at this early stage may be inappropriate. The three mechanisms believed to be the most important in light meson photoproduction [6] are diffractive vector-nucleon scattering (vector dominance followed by pomeron exchange),  $t$ -channel meson exchange (with the pion giving the leading contribution at small  $t$ ), and baryon resonance decay. The latter can be treated as a background, and the former two can be selectively enhanced through  $t$  cuts and the selection of final state quantum numbers.

Diffractive scattering is poorly understood at the QCD level, although some features are generally agreed on; it corresponds to vacuum quantum number exchange, an imaginary amplitude, and may be dominated by  $gg$  exchange. A simple  $I = 0$ ,  $0^{++}$  exchange picture gives the list of quantum numbers in Fig. 1. The accessible exotics are all  $J^{PC} = \text{even}^{+-}$ ;  $I = 1$ ,  $G = (+)$  is favored due to the larger contribution of  $\rho^0$  to vector dominance.

Assuming that the flux-tube model [1,3] is a useful guide to masses and decays

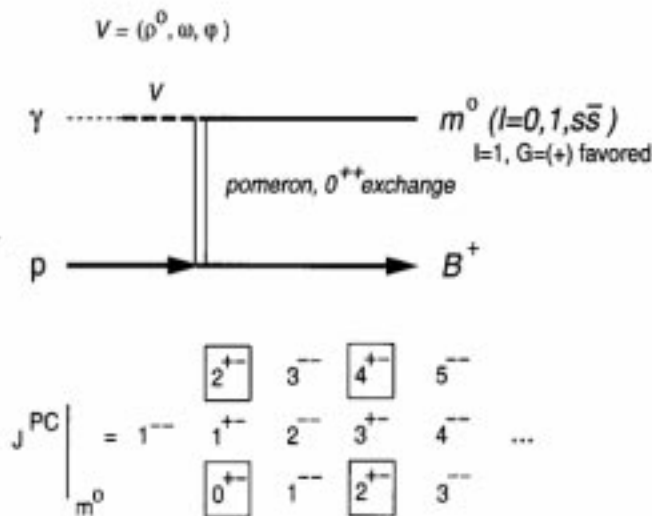


Fig.1. Quantum numbers accessible in diffractive photoproduction; exotics are boxed.

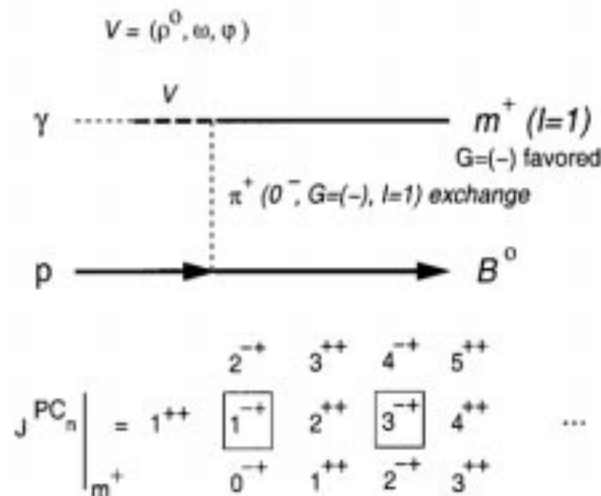
of hybrids, the  $0^{+-}$  and  $2^{+-}$  exotics  $b_0$  and  $b_2$  are the most interesting because they are in the lowest flux-tube hybrid multiplet. The  $b_0$  however is predicted to be extremely broad. The  $b_2$  is much narrower, with a predicted width of 0.4 GeV and a 50% branch to  $a_2\pi$ . Diffractive photoproduction of the neutral  $(a_2\pi)^0$  system therefore appears to offer an excellent opportunity for identifying a hybrid in photoproduction.

The  $s\bar{s}$   $2^{+-}$  exotic can also be diffractively photoproduced, and should decay mainly to  $K_2^*K$  and  $K_1K$  (both  $K_1$  states). In the flux-tube model this state has a width of 0.2 GeV and may be clearly evident because of smaller backgrounds in strange channels.

Pion exchange photoproduction offers several possibilities. There is a *caveat* that S+S couplings of hybrids in the flux-tube model are suppressed, so photoproducing a hybrid through  $\rho^0 + \pi$  might have a relatively weak amplitude. Of course the exotic candidates  $\pi_1(1400)$  and  $\pi_1(1600)$  show no S+S suppression, and violation of this selection rule in improved flux-tube calculations is found to be significant [3]. One-pion exchange photoproduction of hybrids certainly merits investigation, independent of these flux-tube predictions of possibly suppressed couplings.

First, for charged  $\pi$  exchange we find the list of quantum numbers shown in Fig.2. Here  $I = 1$  is forced, and  $G = (-)$  is preferred. This gives *odd* $^{+-}$  exotics, the most interesting of course being the  $I = 1$   $1^{-+}$ . Here one would first study  $\eta\pi$ ,  $\eta'\pi$  and  $\rho\pi$ , to see if the E852 states  $\pi_1(1400)$  and  $\pi_1(1600)$  are evident. Since the  $\pi_1(1600)$  is reported to couple strongly to  $\rho\pi$ , it should certainly appear in this reaction! Earlier work on photoproduction by Condo *et al.* [7] found another possible exotic, a  $\pi_J(1770)$  state which may be  $1^{-+}$  or  $2^{-+}$ .

Neutral pion exchange is unusual in that  $I = 0$  should dominate.  $G = (-)$  is again preferred, and the exotics are *even* $^{+-}$  and the unusual  $0^{--}$ . The  $2^{+-}$  is



$G=(-)$ ,  $C_n=(+)$  shown;  $G=(+)$ ,  $C_n=(-)$  also allowed but weaker.

Fig.2. Quantum numbers accessible in charged- $\pi$  exchange photoproduction; exotics are boxed.

expected to be lightest, and should decay mainly to  $b_1\pi$ , with  $\Gamma_{tot} = 0.3$  GeV. The  $\rho\pi$  width of this state is predicted to be very small, however, so it might be difficult to photoproduce.

Finally, although one prefers exotic channels because they are unambiguously non- $q\bar{q}$ , the flux-tube model and previous experiments suggest several non-exotic channels for photoproduction of hybrids. The highest priority is the “extra”  $\pi_J(1770)$  state reported in photoproduction by Condo *et al.* [7], which may be  $2^{-+}$  but is apparently not the  $\pi_2(1670)$ ; note that a suggestively similar doubling of  $\eta_2$  states has been reported by Crystal Barrel [8]. The  $\pi(1800)$  hybrid candidate discussed by VES [9] clearly does not decay as the  $^3P_0$  model predicts a  $3S$   $q\bar{q}$  state should [10], notably because of the S+P mode  $\pi f_0(1300)$ ; here we may be seeing a  $0^{-+}$  hybrid or a failure of the standard  $q\bar{q}$  decay model! An  $a_1$ -type hybrid with  $\Gamma_{tot} = 0.5$  GeV is expected in  $f_2\pi^+$  and  $f_1\pi^+$ . A last case, the narrowest hybrid predicted by the flux-tube model, is an  $\omega$  state with  $\Gamma_{tot} = 0.1$  GeV that should decay into  $K_1K$  (both) and notably into the final state  $\omega\eta$ , which is attractive experimentally. This dramatically narrow state could serve as a crucial test of the flux-tube picture of hybrids.

To conclude, a note of caution may be appropriate. There are no independent tests of the flux-tube model of hybrid decays, which may be inaccurate. Should hybrids be much broader than anticipated in some channels, the coupling to meson continua may give important mass shifts. In model studies one finds that these mass shifts are typically downwards and are numerically comparable to the widths, so broad hybrids might lie far from “quenched” theoretical predictions. This rather drastic scenario could explain why quenched hybrid masses in the flux-tube model and LGT differ considerably from the masses reported for the new E852 exotic candidates. In this confused situation the most important future experimental

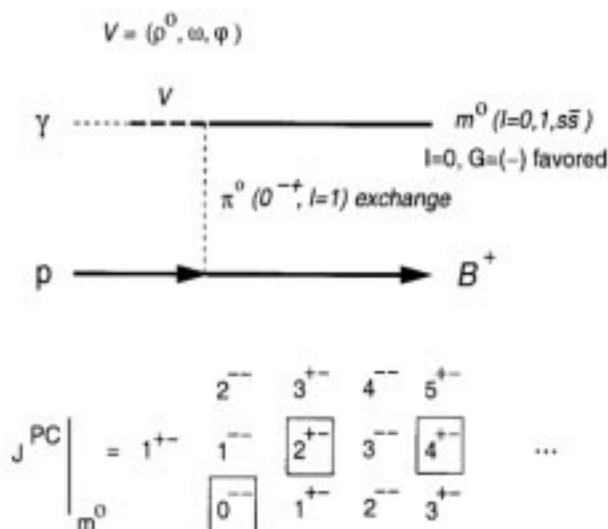


Fig.3. Quantum numbers accessible in  $\pi^0$  exchange photoproduction; exotics are boxed.

exercise will be to confirm (or refute!) the existence of the light exotics  $\pi_1(1400)$  and  $\pi_1(1600)$ .

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