The Photoproduction of the \( b_1(1235)\pi \) System

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We report on a study of the reaction, \( \gamma p \to p\pi^+\pi^-\pi^-\pi^0 \), at an incident photon energy of 19.3 GeV. The most significant feature of this reaction is \( \Delta^{++} \) production which occurs with a cross section of \( 0.6\pm0.1\mu\text{b} \). An upper limit is set for the cross section for the reaction, \( \gamma p \to \Delta^{++}b_1^- (1235) \), and a search is made for resonances decaying to \( b_1^+\pi^- \).

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Although the non-relativistic quark model has had great success in describing the well-established light quark mesons as \( q\bar{q} \) combinations, it is not clear why states with gluonic degrees of freedom remain unobserved. Close [1] has suggested that the preponderance of experimental data for \( q\bar{q} \) states may merely be reflective of the preponderance of studies executed with hadronic beams. In a similar vein, Isgur [2] has remarked that the identification of non-\( q\bar{q} \) states may require the equivalent of a \( J^{PC} \) filter. Thus some advantage in a search for non-\( q\bar{q} \) states may accrue to photoproduction reactions which are dominated by diffractive processes (Pomeron exchange) and by one-pion exchange (OPE) processes.

Currently a popular model for describing some non-\( q\bar{q} \) mesonic states is the flux tube model, originally developed by Isgur, Kokoski and Paton [3], and later by Close and Page [4] and Barnes, Close and Swanson [5]. This model can be used to predict masses, widths and decay modes for several possible hybrid states with exotic \( J^{PC} \) quantum numbers. Most of the flux tube hybrid states, predicted in reference [3] are experimentally inaccessible either because they decay to very broad states (\( \Gamma \approx 500 \text{ MeV} \)) or to poorly understood final states, such as \( a_1(1260) \) and \( h_1(1170) \), which have themselves been difficult to isolate and quantify. There are two exceptions in reference [3] which have decay widths \( \lesssim 300 \text{ MeV} \), both of which decay to \( b_1(1235)\pi \) over \( 70\% \) of the time. These states have the patently exotic quantum numbers \( J^{PC} = 2^{-+} \) and \( 1^{-+} \). In the more recent flux tube model calculations by Close and Page [4], these states acquire additional decay modes and, concomitantly, decay widths exceeding 425 MeV. However, there do exist two states in these calculations with widths \( \lesssim 300 \text{ MeV} \) and predominant \( b_1(1235)\pi \) decay modes. These states have \( J^{PC} = 2^{-+} \) and \( 2^{+-} \). The latter would appear to be a particularly attractive object to search for in photoproduction since it has exotic quantum numbers, can be photoproduced diffractively by a \( P \) wave Pomeron, and is predicted to decay to \( b_1(1235)\pi \) nearly \( 90\% \) of the time.

The purpose of this note is to study the photoproduction of the \( b_1(1235)\pi \) system in the reaction, \( \gamma p \to p\pi^+\pi^-\omega \to p\pi^+\pi^-\pi^-\pi^0 \), at an incident photon momentum of 19.3 GeV/c. As far as we are aware, there is but a single investigation into the photoproduction of the \( b_1\pi \) final state. In that study [6], it was concluded that there was evidence for the production of a \( b_1\pi \) final state at \( \approx 1880 \text{ MeV} \) which could be consistent with flux tube model predictions. However that experiment did not identify final state protons, in general, so that any resulting \( 5\pi \) spectrum could contain unknown amounts of \( \Delta^{++} \) contamination. Strong photoproduction of the \( \Delta^{++} \) via one-pion exchange has been shown to be a feature of the experiment we are reporting here [6].

Our data come from a large triggered hydrogen-bubble-chamber experiment which was performed at the Stanford Linear Accelerator Center, utilizing incident photons of average energy 19.3 GeV with a full width at half maximum of 1.7 GeV. The photon beam was generated by backscattering laser photons from the SLAC 30 GeV electron beam. The experimental details have been presented in prior publications [8].

In the present experiment we will study events of the type, \( \gamma p \to p\pi^+\pi^+\pi^-\pi^-\pi^0 \). The events comprising our sample are those five-prong events which did not have an acceptable kinematic fit to the three-constraint reaction, \( \gamma p \to p\pi^+\pi^+\pi^-\pi^- \). An acceptable fit required a derived photon energy between 16.5 and 21.0 GeV and had a probability in excess of \( 10^{-2}\% \). After these events were excluded, we determined those five-prong events with a single \( \pi^0 \) by the following procedure. The beam momentum was set to 19.3 GeV/c, and the square of the missing mass was calculated. If this quantity exceeded 0.1 GeV\(^2\), the event was rejected. If the event survived this cut, the missing mass

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was treated as a “track” with its mass set equal to that of the \( \pi^0 \). Lastly a zero-constraint calculation of the five-prong final state was made to determine the incident photon energy. If this reconstructed energy fell between 16.0 and 21.5 GeV, the event was accepted. With this procedure our overall sample of events of the type, \( \gamma p \rightarrow p \pi^+ \pi^+ \pi^- \pi^- \pi^0 \), consists of 2553 events.

Since our goal is to study \( b_1(1235)^\pm \) photoproduction in the reaction, \( \gamma p \rightarrow p \pi^+ \pi^+ \pi^- \pi^- \pi^0 \), and since the dominant decay of the \( b_1(1235)^\pm \) is to \( \omega \pi^\pm \), we begin by plotting the neutral three pion mass combination (Fig. 1). The fit on the histogram gives an\( \omega \) mass and width of 790 \( \pm 3 \) MeV and 66 \( \pm 8 \) MeV respectively. For the \( \eta \), we find a mass of 552 \( \pm 2 \) MeV and an associated width of 17 \( \pm 6 \) MeV. These results seem reasonable considering the nature of the zero-constraint fitting process that was adopted.

Before proceeding to the \( b_1 \pi \) spectrum, we wish to point out that we have used the present experiment to present evidence for the one-pion exchange photoproduction reaction [9], \( \gamma p \rightarrow a_2(1320)^- \Delta^{++} \), with a cross section of 0.45 \( \pm 0.05 \) \( \mu b \). We have also observed the reaction, \( \gamma p \rightarrow a_2(1320)^+ n \), with a cross section of 0.29 \( \pm 0.06 \) \( \mu b \) in this experiment [9]. These latter data were found to be consistent with one-pion exchange expectations when compared with early low energy \( (E_\gamma = 3.5 - 5.0 \) GeV) data [10] as well as with charged \( a_2(1320) \) photoproduction observed at much higher energies [11] \( (< E_\gamma >= 110 \) GeV). These data suggest the presence of a \( \gamma \pi a_2(1320) \) vertex which had been previously quantified by measurements, based on the Primakoff effect, of the \( (\pi \gamma) \) radiative width of the \( a_2(1320) \). This latter experiment [12] gave the result, \( \Gamma(a_2(1320)^\pm \rightarrow \pi^\pm \gamma) = 295 \pm 60 \) KeV. In the same experiment [13], the \( (\pi \gamma) \) radiative width of the \( b_1(1235) \) was found to be \( \Gamma(b_1(1235) \rightarrow \pi^\pm \gamma) = 230 \pm 60 \) KeV. With the near equalities of their masses and radiative widths, it is reasonable to expect comparable one-pion exchange cross sections for \( \gamma p \rightarrow \Delta^{++} b_1(1235)^- \) and \( \gamma p \rightarrow \Delta^{++} a_2(1320)^- \). Therefore in Fig. 2 we present the \( \pi^\pm \) mass spectrum, where a large enhancement is observed in the \( \Delta^{++} \) mass region. The fit shown corresponds to a \( \Delta^{++} \) cross section of 0.6 \( \pm 0.1 \) \( \mu b \). Fig. 3 shows the \( \omega \pi^- \) mass spectrum for those events where a \( \Delta^{++} \) exists. (We define the \( \Delta^{++} \) as \( M(\pi^\pm \pi^-) \leq 1.4 \) GeV and the \( \omega \) as \( 0.73 \leq M(\omega) \leq 0.84 \) GeV.) It is clear that there is, at best, marginal \( b_1(1235)^- \) production. In order to set an upper limit for \( \Delta^{++} b_1(1235)^- \) production, we assume that all \( \omega \pi^- \) events in Fig. 3 with mass less than 1.5 GeV comprise \( b_1(1235)^- \Delta^{++} \) signal. With corrections for our overall detection efficiency \( (0.7 \pm 0.1) \) and for unseen \( b_1(1235)^- \pi \) decays, the upper limit of the cross section for the reaction, \( \gamma p \rightarrow \Delta^{++} b_1(1235)^- \), is 0.04 \( \pm 0.02 \) \( \mu b \). Insofar as the relative photoproduction cross sections for these particles, of nearly equal mass, can be taken as a measure of their relative \( (\pi \gamma) \) decay widths, these data imply that \( \Gamma(b_1(1235)^\pm \rightarrow \pi^\pm \gamma) \leq 0.1 \Gamma(a_2(1320)^\pm \rightarrow \pi^\pm \gamma) \).

This result is clearly inconsistent with the previous measurements of the \( (\pi \gamma) \) radiative widths for the \( a_2(1320) \) and \( b_1(1235) \). However Ishida et. al. [14] have reported a theoretical value as small as 65 KeV for \( \Gamma(b_1(1235)^\pm \rightarrow \pi^\pm \gamma) \). We should also point out that in the experiment we are reporting on, no signal representing \( a_1(1260)^- \Delta^{++} \) photoproduction [9] could be isolated even though the \( (\pi \gamma) \) radiative width of the \( a_1(1260) \) very likely exceeds that of the \( a_2(1320) \) [12,13,14]. We are unable to explain the absence of this \( J^P = 1^- \) state in charge-exchange photoproduction. Another example of this result occurs in the \( f_1(1285)^\pi \) spectrum where partial waves representing amplitudes with \( J^{PC} = 1^{-+} \) and \( 1^- \) were present in \( \pi^\pm \) interactions [17]. This is in contrast to the \( f_1(1285)^\pi \) spectrum observed from \( \gamma \pi \) interactions where the decay angular distributions suggested the existence of a \( J^{PC} = 1^- + \) state only [18].

Because of the large \( \Delta^{++} \) signal in Fig. 3 the remainder of this paper will pertain only to the sample of events for which the \( \Delta^{++} \) has been removed \( (i.e. \), we accept events only if \( M(\pi^\pm \pi^-) \geq 1.4 \) GeV for both final state pions). In Figs. 4 and 5 we present the \( \omega \pi^\pm \) and \( \omega \pi^- \) mass spectra for this sample. The only significant enhancement in either spectrum occurs in the mass region of the \( b_1(1235) \) meson. The fits shown on these plots correspond to the following parameters:

\[
M(b_1^{+}) = 1.226 \pm 0.015 \text{ GeV} \quad \Gamma(b_1^{+}) = 0.151 \pm 0.032 \text{ GeV}
\]

\[
M(b_1^{-}) = 1.219 \pm 0.018 \text{ GeV} \quad \Gamma(b_1^{-}) = 0.165 \pm 0.054 \text{ GeV}
\]

These values are in tolerable agreement with each other as well as with the average values determined by the Particle Data Group [19]. If we define the \( b_1(1235) \) by the mass cut, 1.135 \( \leq M(\omega \pi^-) \leq 1.335 \) GeV, Fig. 3 shows the combined \( b_1(1235)^\pm \pi^\pm \) mass spectrum. While we can identify no significant resonance in this spectrum, it should be noted that the largest intensities occur in the mass region of the \( \omega(1670) \) and at \( \approx 1900 \) MeV. This result is somewhat similar to that obtained by the Omega Spectrometer Group [3] in the only previous \( b_1(1235)^\pi \) photoproduction study. The failure to observe any \( b_1(1235)^\pi \) states via photoproduction may not be too surprising since the quantum numbers of the most likely theoretical hybrid candidates are \( J^{PC} = 1^- +, 0^{++} \) and \( J^{PC} = 2^- +, 2^+ - \). If we assume that the photoproduction of any of these states proceeds via either Pomeron exchange or one-pion exchange, only states with negative charge parity and \( J \geq 1 \) will be present. This eliminates all but the \( (\text{isoscalar}) \) state with \( J^{PC} = 2^- + \). We are aware of no prior reports of experimental evidence for the existence of any state with these quantum numbers. If, on the other hand, the spectrum in Fig. 3 is interpreted as confirming the \( b_1(1235)^\pi \) enhancement near 1900 MeV, reported by Atkinson et. al. [9], the most likely hybrid assignment for that state would appear to be \( J^{PC} = 2^- + \).

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![FIG. 1. $\pi^+\pi^-\pi^0$ mass spectrum.](image-url)
FIG. 2. $p\pi^+$ mass spectrum.

FIG. 3. $\omega\pi^-$ mass spectrum opposite the $\Delta^{++}$. 
FIG. 4. (a) $\omega\pi^+$ mass spectrum and (b) $\omega\pi^-$ mass spectrum with $\Delta^{++}$ events removed.

FIG. 5. $b_1(1235)^{\pm}\pi^{\mp}$ mass spectrum with $\Delta^{++}$ events removed.