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# Polarized single-pion photoproduction: Test for various quark models

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The multipole analysis of resonance photocouplings of Babcock and Rosner is extended to the case of single-pion photoproduction by polarized photons. The various polarized cross sections $d\sigma_{\parallel}(n\pi^+)$, $d\sigma_{\parallel}(p\pi^0)$, $d\sigma_{\perp}(n\pi^+)$, and $d\sigma_{\perp}(p\pi^0)$ are well reproduced. The present analysis is exploited for discriminating different models which predict photocouplings of nonstrange baryon resonances. Data is found to strongly favor a negative relative sign for *P*- and *F*-wave pionic decays in accordance with the findings of Babcock and Rosner.

## I. INTRODUCTION

Baryon-resonance photocouplings have been shown to be a source of valuable information regarding quark dynamics within the context of certain explicit quark models[1–4] as well as a more general algebraic approach[5–10] (the latter emphasizing the general nature of the single-quark-transition mechanism without resorting to specific dynamic models). It is in this context and to know more about baryon-resonance spectroscopy that the interest in the process $\gamma N \to (N^*, \Delta) \to N\pi$ persists.

With the availability of better data on photocouplings, a number of analyses[11–13] during the last decade have further strengthened their utility in understanding the underlying hadron structure and dynamics. The availability of polarized photoproduction data[14] adds to the relevance of such studies, since the observation of the angular distribution of the emitted pions can throw valuable light on some of the finer aspects of photoproduction amplitudes. These aspects of photoproduction can serve as a testing ground for fine-grained quark models inspired by quantum chromodynamics,[15,16] as well as phenomenological confining models such as the MIT bag model, wherein photocoupling calculations have been performed recently.[17]

Photocouplings—their signs and magnitudes—intimately connected as they are with the dynamical content of a model, can be effectively used to compare various models. However, it should be noted that in various "experimental" analyses of photoproduction[11–13] the uncertainties associated with the models naturally creep into the derived photocoupling data. Once it is recognized that there are inherent, model-dependent uncertainties associated with the derived photocouplings, it seems desirable that the predictions of various constituent models and other approaches should be tested in a model-independent manner, preferably at the raw-data level, namely, the cross-section level.

It is with this motivation that, in this paper, we have calculated the polarized-photoproduction cross sections, adopting the technique of Berger and Feld.[18] In this technique polarized-photoproduction cross sections are basically responsive to photocouplings as the pion vertex is taken from the data. The purpose of the present analysis is twofold: (i) to extend the analysis of Babcock and Rosner,[19] carried out in the Melosh language, to the polarized-photoproduction cross sections, and (ii) to examine the performance of various constituent models of hadrons, which predict photocouplings.

Besides extending the Babcock and Rosner[19] (BR) analysis to polarized-photoproduction cross sections, we have compared their predictions with (i) "experimental" values based on photocouplings taken from Particle Data Group tables (1980),[20] and (ii) predictions of Koniuk and Isgur[21] (KI). To make the paper self-contained, we reproduce in Table I the photohelicity amplitudes used in the present analysis. It is perhaps desirable to mention that Isgur and co-workers[16] have in recent years carried out an impressive analysis of baryon spectroscopy including photocouplings,[21] wherein the one-gluon-exchange forces play an important role in generating many finer features such as configuration mixing. Another interesting feature of their calculations is the *uds* basis in which the baryon wave functions are symmetrized only in the similar (same mass) quarks. In the present study we hope to visualize the improvements due to these finer aspects on the naive quark-model[1,3] calculations of photocouplings. In this context, we also present our calculations of polarized cross sections carried out with the Feynman-Kislinger-

TABLE I. Photohelicity amplitudes $A^p_{3/2}$ and $A^p_{1/2}$ of various prominent resonances in units of GeV$^{-1/2}$, as predicted by different constituent models.

| Resonance | BR $A^p_{3/2}$ | BR $-A^p_{1/2}$ | KI $A^p_{3/2}$ | KI $A^p_{1/2}$ | FKR $A^p_{3/2}$ | FKR $A^p_{1/2}$ | "Experimental" $A^p_{3/2}$ | "Experimental" $A^p_{1/2}$ |
|---|---|---|---|---|---|---|---|---|
| $D_{13}(1.520)$ | 0.160 | −0.019 | 0.128 | −0.023 | 0.109 | −0.034 | 0.151 | −0.011 |
| $S_{11}(1.535)$ | 0.000 | 0.074 | 0.000 | 0.147 | 0.000 | 0.156 | 0.000 | 0.060 |
| $S_{31}(1.650)$ | 0.000 | 0.103 | 0.000 | 0.059 | 0.000 | 0.047 | 0.000 | 0.039 |
| $D_{33}(1.670)$ | 0.109 | 0.107 | 0.105 | 0.100 | 0.084 | 0.088 | 0.058 | 0.063 |
| $S'_{11}(1.700)$ | 0.000 | 0.049 | 0.000 | 0.088 | 0.000 | 0.000 | 0.000 | 0.045 |
| $D'_{13}(1.700)$ | 0.034 | −0.004 | 0.011 | −0.007 | 0.000 | 0.000 | 0.008 | −0.015 |
| $D_{15}(1.670)$ | 0.000 | 0.000 | 0.016 | 0.012 | 0.000 | 0.000 | 0.020 | 0.020 |
| $F_{15}(1.688)$ | 0.138 | −0.005 | 0.125 | −0.010 | 0.060 | −0.010 | 0.133 | −0.004 |
| $P_{13}(1.810)$ | −0.085 | 0.081 | 0.046 | −0.133 | −0.030 | 0.100 | −0.039 | 0.033 |
| $F_{37}(1.950)$ | −0.070 | −0.054 | −0.069 | −0.050 | −0.070 | −0.050 | −0.101 | −0.071 |
| $F_{35}(1.890)$ | −0.029 | 0.002 | −0.033 | 0.008 | −0.090 | −0.020 | −0.007 | 0.035 |
| $P_{31}(1.910)$ | 0.000 | −0.024 | 0.000 | 0.000 | 0.000 | 0.030 | 0.000 | −0.014 |
| $P_{11}(1.470)$ | 0.000 | −0.073 | 0.000 | −0.024 | 0.000 | 0.027 | 0.000 | −0.077 |
| $P_{33}(1.232)$ | −0.254 | −0.137 | −0.179 | −0.103 | 0.187 | −0.108 | −0.259 | −0.141 |

Ravndal[3] (FKR) photocouplings.

Interestingly, we find thatthe present study provides a viable approach for bringing out, in a fairly model-independent manner, the finer distinctions of various models of photocouplings besides providing an overview of their success. It will not be out of place to mention that our calculations are confined to the energy range $0.5 \leq E_r \leq 2$ GeV, which is well known to be a resonance-dominated region.

## II. RESULTS

### A. $d\sigma_\perp(\gamma_\perp + p \to n + \pi^+)$

In Fig. 1(a) we have plotted $d\sigma_\perp(n\pi^+)$, as predicted by the above-mentioned models, against the data of Alspector *et al.*[14] A cursory look at the data reveals that there is a gradual decrease in cross section as we go to higher photon energies, interspersed by two not-so-prominent bumps at 1.05 and 1.5 GeV. The BR model provides a fairly good fit to the data; however, the predictions are somewhat lower for $E_\gamma \geq 1.1$ GeV. It would not be out of place to mention that since the BR model cannot predict the photocouplings of $P_{33}$, to develop their analysis further we have used the experimental $P_{33}$ photocouplings. The "experimental" curve seems to reproduce both the structures well, besides being within the contours of the data for most of the energy range. In the KI case the overall predictions, compared to the data as well as BR, are much depressed, and strangely the cross section at 1.3 GeV goes almost to zero.

### B. $d\sigma_\parallel(\gamma_\parallel + p \to n + \pi^+)$

From the $d\sigma_\parallel(n\pi^+)$ plot [Fig. 1(b)] one can see that the "experimental" values are well within the contours of the data. The predictions of BR and KI models are somewhat higher throughout the

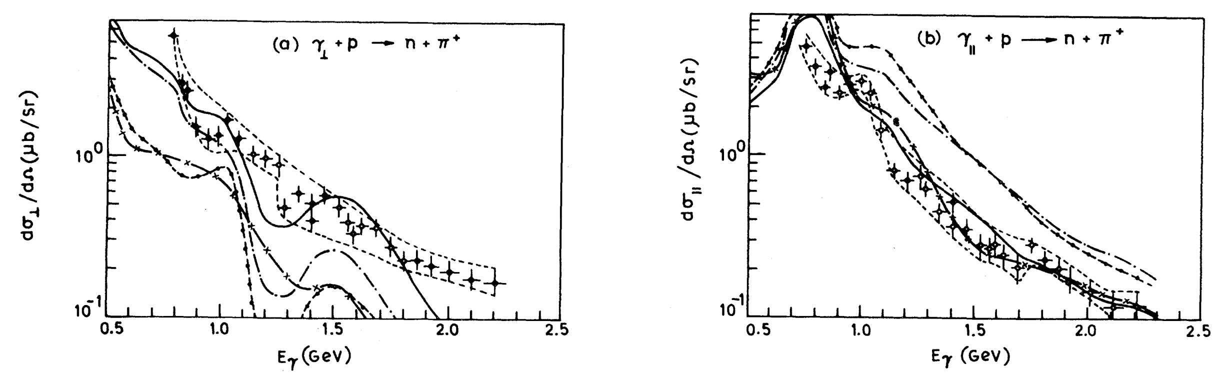


FIG. 1. $d\sigma_\perp$ and $d\sigma_\parallel$ for $\gamma_{\perp,\parallel} + p \to n + \pi^+$ plotted in Figs. (a) and (b), respectively, as function of the laboratory energy of the incident photon ($E_\gamma$). KI, dotted dashes (-·-·-); BR, dot-dashed curve; FKR, cross-dashed curve; experimental, unbroken curve.

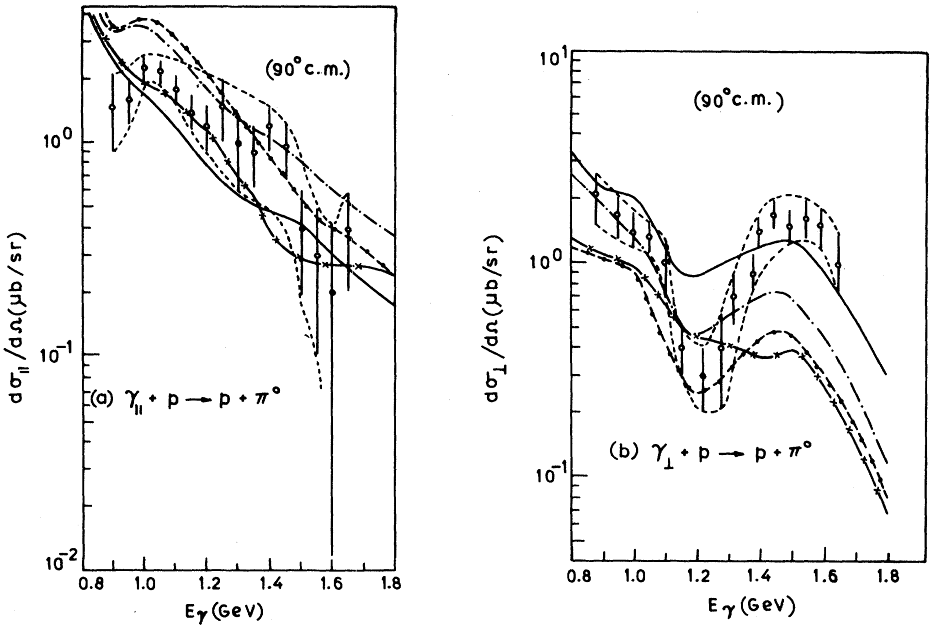


FIG. 2. $d\sigma_{\parallel}$ and $d\sigma_{\perp}$ for $\gamma_{\parallel,\perp}+p \to p+\pi^0$ plotted in Figs. (a) and (b), respectively, as function of the laboratory energy of the incident photon ($E_\gamma$). KI, dotted dashes (-·-·-); BR, dot-dashed curve; FKR, cross-dashed curve; experimental, unbroken curve.

energy range under consideration. In the smoothly decreasing cross-section data there are not many outstanding structures except a small bump around 1.0 GeV, which is reproduced fairly well by all four sets.

### C. $d\sigma_{\perp}(\gamma_{\parallel}+p \to p+\pi^0)$

For $d\sigma_{\parallel}(p\pi^0)$ [Fig. 2(a)] all four sets fall within the data. However, on closer scrutiny one can see that the "experimental" predictions do not give a very good fit around 0.9–1.0 GeV, where there is a slight increase and subsequent fall in the cross section data.

### D. $d\sigma_{\perp}(\gamma_{\perp}+p \to p+\pi^0)$

This presents an interesting feature of the data since there is a pronounced dip [Fig. 2(b)] around 1.1–1.4 GeV. Except for FKR, the rest of the curves reproduce the dip fairly well. However, beyond $E_\gamma \sim 1.3$ GeV the predicted cross sections of BR and KI are quite low compared with the data. In the "experimental" curve the minimum is somewhat raised, which smooths the latter cusp.

## III. DISCUSSION AND CONCLUSION

A general survey of the results indicates that all three fits (BR, "experimental," and KI) reproduce the data rather well. A closer examination, however, reveals somewhat better overall performance of the BR curves. This becomes more evident when one looks at the entire range of data (Figs. 1 and 2) besides the various structures present therein; e.g., the bumps around $E_\gamma \sim 1.0$ GeV in the case of $d\sigma_{\parallel}$ for $\pi^0$ as well as $\pi^+$ production. From Fig. 1(b) we also note that it will be desirable to obtain data in the region $0.5 \leq E_\gamma \leq 0.7$ GeV, which will provide a nice check on the strong peak around 0.7–0.8 GeV as predicted by all the cases under consideration. However, it is very interesting to examine more closely the behavior of various curves in the case of perpendicular cross sections $d\sigma_{\perp}(n\pi^+)$ and $d\sigma_{\perp}(p\pi^0)$.

For the $d\sigma_{\perp}(n\pi^+)$ cross sections, although BR and KI both reproduce the structures, there is an overall fall in the cross section (more in the case of KI) as compared to the "experimental" curve and the data itself. As pointed out earlier KI prediction dips to almost zero (0.0643 $\mu$b/sr) around 1.3 GeV. This can possibly be traced to the magnitude and sign of the $P_{13}$ helicity amplitudes. A look at Table I indicates that none of the models has a good overall agreement (in sign as well as magnitude) with the experimental photohelicity amplitudes. This is more pronounced in the case of KI, where the disagreement is both in sign and magnitude (rather large). In the BR case the discrepancy is limited to magnitude only.

A very prominent feature of the data in the case of $d\sigma_{\perp}(p\pi^0)$ is the sharp dip around $E_\gamma \sim 1.2$ GeV. Although all the curves, with the exception of

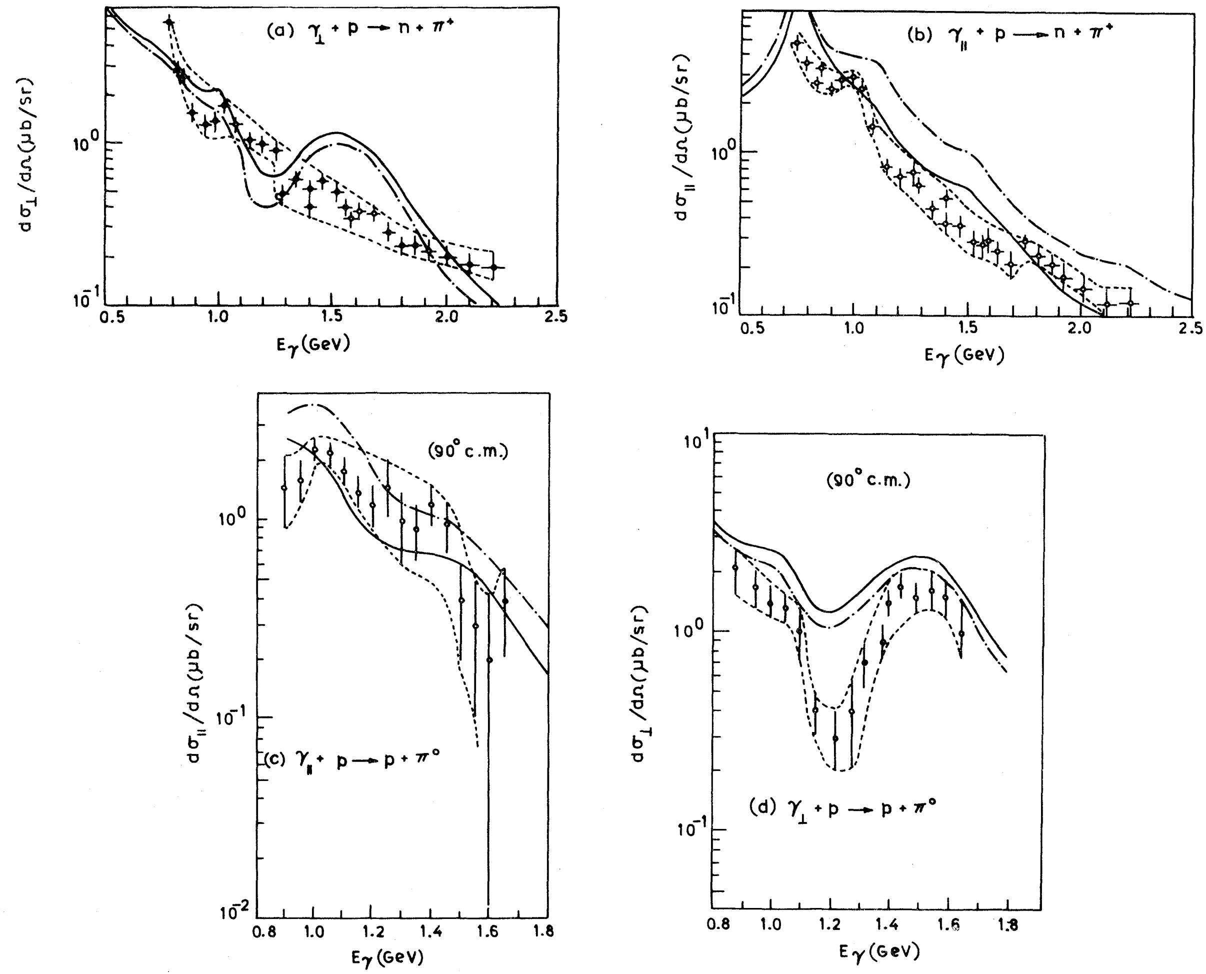


FIG. 3. $d\sigma_\perp$ and $d\sigma_\parallel$ for $\gamma_{\perp,\parallel}+p\rightarrow n\,(p)+\pi^+\,(\pi^0)$ plotted in Figs. (a), (d) and (b), (c), respectively, for the Babcock and Rosner fit with revised $F_{37}$ helicity amplitudes, and as function of the laboratory energy of the incident photon ($E_\gamma$). "Experimental", unbroken curve; BR, dot-dashed curve.

FKR, reproduce the dip to varying degrees, still it would be informative to trace the origin of the remaining discrepancy. We have found that the agreement between the fits and data improves remarkably if the increased helicity amplitudes of $F_{37}$ ($A_{3/2}=-0.180$ and $A_{1/2}=-0.080$), as deduced by Moorhouse *et al.*,[12] are used. In Fig. 3 we have plotted the results with these increased $F_{37}$ couplings for the BR fit. This indicates that $F_{37}$ amplitudes have to be larger and may be somewhat lower than quoted above as the rise in cross section is more than desired. It should be pointed out that the increased $F_{37}$ amplitudes do not significantly affect the parallel cross sections. However, the fit in case of $d\sigma_\perp(n\pi^+)$ improves considerably. The experimental curve is not much affected. This is easy to understand when one recognizes that the increase in "experimental" $F_{37}$ amplitudes is comparatively less.

In the present investigation we have also carried out the effect of increasing $P_{11}(1470)$ couplings.[22] However, we have found that the cross sections are not affected in any significant manner by this change in the photocouplings of $P_{11}(1470)$.

The BR multipole analysis[10,11] discusses the problem of relative sign of $P$- and $F$-wave pionic decays, and their fits to photoamplitudes generally do favor $\xi=\xi'=-$. But a closer look at the fits[19] indicates that out of 32 amplitudes, the cases where the analysis unambiguously favors negative sign are very few, while in most of the cases both the signs (+) and (−) fare well. However, we have seen that the photoproduction cross section data clearly rules out the possibility $\xi=\xi'=+$.

In conclusion, we emphasize that the predictions of BR analysis, which is essentially a parametrization within the algebraic framework of Melosh,[5] fit the data quite well. The present extension of their analysis can, therefore, serve as a valuable tool for checking the performance of various models which predict photocouplings. This is particularly true of the models where direct calculation of photoproduction raw data is either not easily possible or is plagued by various uncertainties. The baryon spectroscopic analysis of Isgur and co-workers as well as the present KI photoproduction cross-section curves have rather good overlap with the data. As already noted by KI (Ref. 21) the disagreement of $P_{13}$ photocouplings in their case shows its problematic role for the case of the $d\sigma_\perp(n\pi^+)$ cross section.

In view of the important role of the various structures present in the data in discriminating various models, it is highly desirable that the polarized-photoproduction data be reexamined. This is particularly true in the case of $d\sigma_\perp(p\pi^0)$ where the dip seems to have important implications for the $F_{37}$ photohelicity amplitudes. If the data retains its present form, perhaps all the models are somewhat in trouble.


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