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Extraction of the $D_{13}(1520)$ photon-decay couplings from pion- and η-photoproduction data

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We compare results for the $D_{13}(1520)$ photon-decay amplitudes determined in analyses of η- and pion-photoproduction data. The ratio of helicity amplitudes $(A_{3/2}/A_{1/2})$, determined from η-photoproduction data, is quite different from that determined in previous analyses of pion-photoproduction data. We consider how strongly the existing pion-photoproduction data constrain both this ratio and the individual photon-decay amplitudes.

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Recent precise measurements of η-photoproduction observables have spawned a number of analyses, focused mainly on the properties of the $S_{11}(1535)$ resonance [1]. These studies have found values for the photodecay amplitude $A_{1/2}^{p}$, which are significantly larger than those found in previous analyses of pion-photoproduction data [2]. As the $S_{11}(1535)$ resonance is masked by a strong ηN threshold cusp in pion photoproduction, η-photoproduction holds the promise of a less model-dependent analysis. Attempts to fit pion- and η-production data in coupled-channel approachs [3,4] have generally found values between those extracted from single-channel fits.

Two studies [5,6] have gone beyond the $S_{11}(1535)$ and have considered the sensitivity of η-photoproduction data to the nearby $D_{13}(1520)$ resonance. In both of these analyses, values for the *ratio* of photodecay amplitudes $A_{3/2}/A_{1/2}$, were found to be consistently far smaller than those inferred from pion-photoproduction analyses [7]. This discrepancy is certainly unexpected [8], as the D_{13} state appears to have a clean Breit-Wigner-like signal in the associated multipoles $E_{2-}^{1/2}$ and $M_{2-}^{1/2}$ extracted from pion-photoproduction data. This ratio, as determined from η-photoproduction data, has the value $-2.5\pm0.2\pm0.4$ [5] or -2.1 ± 0.2 [6], as compared to the PDG estimate [9] of -6.9 ± 2.1. η-photoproduction has the advantage of isospin selectivity but, in the case of the $D_{13}(1520)$, one must deal with a very small coupling to the ηN channel.

As this difference amounts to a shift by several standard deviations in a supposedly well-determined quantity, we have considered whether the η-photoproduction result can be accommodated, even qualitatively, by the existing pion-photoproduction database. Given that we are investigating a very large effect, and the background contribution to the $E_{2-}^{1/2}$ and $M_{2-}^{1/2}$ multipoles appears to be small near the resonance energy, this study was carried out assuming resonance dominance in both the η- and pion-photoproduction multipoles [10]. Clearly this implies our results will only be qualitative. However, as we will see, even qualitative results can be revealing.

We first note that the ratio of modified multipole amplitudes, corresponding to the ratio $A_{3/2}/A_{1/2}$ is given by

$$\frac{A_{3/2}}{A_{1/2}} = \sqrt{3}\left(\frac{\overline{E}_{2-}+\overline{M}_{2-}}{\overline{E}_{2-}-3\overline{M}_{2-}}\right) \tag{1}$$

with conversion factors as given in, for example, Ref. [11]. Since we will be dealing with ratios, the conversion factor is not relevant and we will drop the barred notation. Assuming resonance dominance, a ratio of -2.5 for $A_{3/2}/A_{1/2}$ can be converted to a ratio of about 1.4 for $E_{2-}^{1/2}/M_{2-}^{1/2}$. This can be compared to the result of a representative analysis of pion-photoproduction data [12,13], wherein the ratio of multipoles (imaginary parts) is found to be about 2.1 at the resonance energy [14].

In order to gauge the sensitivity of pion-photoproduction data to this ratio, we started with a single-energy analysis centered at a lab photon energy of 760 MeV, corresponding to a value of $\sqrt{s}$ near the $D_{13}(1520)$ resonance position. We then considered the effect of changes in the fitted multipoles. Some qualitative results were immediately noticed. If one D_{13} multipole was fixed and the other ($E_{2-}^{1/2}$ or $M_{2-}^{1/2}$) was shifted to achieve a ratio of 1.4, the cross sections for both $\pi^0 p$ and $\pi^+ n$ production were missed by large margins. However, if $E_{2-}^{1/2}$ was reduced and $M_{2-}^{1/2}$ was increased in magnitude, a qualitative description of the cross sections could be retained. A good fit to the existing polarization data was also preserved. It soon became apparent that a *small* increase in $M_{2-}^{1/2}$ and a *moderate* decrease in $E_{2-}^{1/2}$ was preferred in this exercise. From Eq. (1) this implies a small decrease in $A_{3/2}$ and a larger increase in the magnitude of

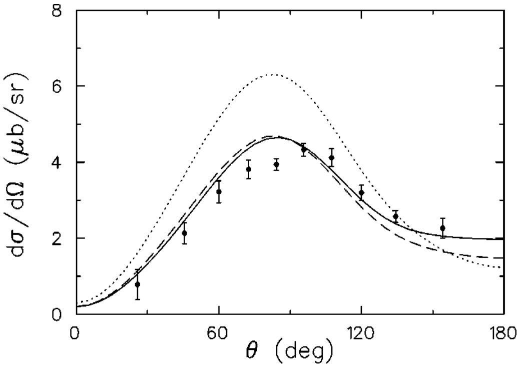

FIG. 1. Differential cross section for $\gamma p \rightarrow p\pi^0$ at 762 MeV. Data from Ref. [15]. Solid curve corresponds to the unmodified single-energy solution; dashed curve corresponds to a 15% increase in the imaginary part of $M_{2-}^{1/2}$ and the proposed $A_{3/2}/A_{1/2}$ ratio (-2.5); dotted curve corresponds to the proposed ratio assuming the largest multipole ($E_{2-}^{1/2}$) is correct.

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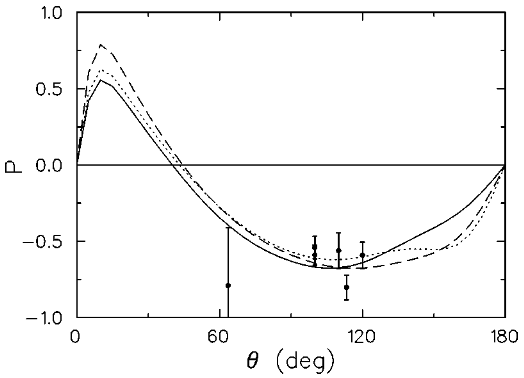

FIG. 2. Recoil polarization for $\gamma p \rightarrow p\pi^0$ at 762 MeV. Data, between 760 and 765 MeV, from Ref. [16]. Curves as given in Fig. 1.

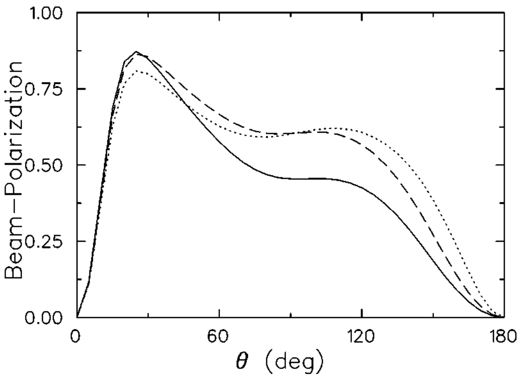

FIG. 3. Beam polarization (Σ) for $\gamma p \rightarrow n\pi^+$ at 762 MeV. Curves as given in Fig. 1.

$A_{1/2}$; results following the trend suggested in Refs. [5,6].

In Fig. 1 we show the result of increasing $M^{1/2}_{2-}$ by 15% and fixing the $E^{1/2}_{2-}/M^{1/2}_{2-}$ ratio at 1.4. For comparison purposes, we also show the result of a shift in $M^{1/2}_{2-}$ alone, leading to the required ratio. The backward-angle cross sections are particularly sensitive to these changes, as the D_{13} multipoles enter in the combination $(E^{1/2}_{2-}-3M^{1/2}_{2-})$. The larger $M^{1/2}_{2-}$ and smaller $E^{1/2}_{2-}$ both reduce the cross section at back angles. Polarization measurements, in the current data base, are not sufficiently precise to pin down $E^{1/2}_{2-}$ and $M^{1/2}_{2-}$. The relative insensitivity of recoil polarization is illustrated in Fig. 2. A somewhat greater sensitivity is seen in the beam-polarization observable (Σ) displayed in Fig. 3. It should be emphasized that this is *not* a fit to the pion-photoproduction data. As mentioned above, a fit would result in very different values for the multipoles. Here we are simply showing how the conclusions of Refs. [5,6] would effect the existing fit to pion-photoproduction data, near the D_{13} resonance position. It would be incorrect, for example, to conclude that changes in the pion-photoproduction observable Σ can be directly linked to the $E^{1/2}_{2-}/M^{1/2}_{2-}$ ratio.

In summary, properties of the D_{13} multipoles, as determined from fits to η-photoproduction data, are not entirely excluded by the existing pion-photoproduction data. It is possible to obtain a qualitative description (but not a χ^2 fit) of the pion-production data, at the resonance position, consistent with an $A_{3/2}/A_{1/2}$ ratio near -2.5. If this ratio were correct, and effects from the background were not a problem, the next step would be to determine which data, in the pion data base, were incompatible with this result. At present this would be difficult, as the data base is rather sparse, with few sets covering a wide angular range. We suggest a similar study should be interesting if performed on the η-photoproduction data base. In that test one would assume the D_{13} ratio, as extracted from pion-production data, and consider what changes in the other multipoles would be required for a qualitative fit.

A second implicit assumption in this study should also be mentioned. We have considered the effect of changes in the D_{13} multipoles *assuming* the remaining multipoles to be correct. Given the above mentioned discrepancy between η- and pion-photoproduction results for the $S_{11}(1535)$, this assumption could be questionable for the *S*-wave multipoles. As an exercise, we fixed the $E^{1/2}_{2-}/M^{1/2}_{2-}$ ratio at the resonance point and fitted the full database to 1.2 GeV. The E_{2-}/M_{2-} ratio was forced by adding amplitudes, with small errors, as pseudodata. In this fit, as might be expected, the $E^{1/2}_{0+}$ multipole showed the largest shift due to the constraint. The $E^{1/2}_{2-}/M^{1/2}_{2-}$ ratio was shifted from 2.1 to 1.6, and the imaginary part of $E^{1/2}_{0+}$ increased by 25% at 760 MeV. These results clearly depend on the (purely subjective) errors assigned to the pseudodata, and should be taken only as an indication of correlations between the S_{11} and D_{13} multipoles. More definitive tests will be possible when precise measurements of the cross section and polarization observables cover this region. Precise measurements at backward angles will be particularly useful.

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[2] In GeV$^{-1/2}$ units, typical pion-production results for the $S_{11}(1535)$ $A^p_{1/2}$ are 0.060 ± 0.015 (VPI) and 0.053 ± 0.15 (Glasgow). Results from Ref. [1] are in the range $0.120\pm0.011\pm0.015$.

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[7] Typical values, in GeV$^{-1/2}$ units, for the $D_{13}(1520)$ $A^p_{3/2}$ and $A^p_{1/2}$ are, respectively, 0.167 ± 0.005 and -0.020 ± 0.007 (VPI), 0.156 ± 0.022 and -0.028 ± 0.014 (Glasgow).

[8] Phenomenological values of the helicity 1/2 and 3/2 transition amplitudes have remained relatively stable in fits to pion-photoproduction data. Quark models, however, have predicted ratios ranging between the pion- and η-photoproduction results. See Ref. [5] for a discussion of the various quark model predictions.

[9] Particle Data Group, R.M. Barnett *et al.*, Phys. Rev. D **54**, 1 (1996); Particle Data Group, C. Caso *et al.*, Eur. Phys. J. C **3**, 1 (1998).

[10] A small background is expected in η-photoproduction based on the small ηNN coupling constant. The justification for this approximation in pion-photoproduction is more model dependent. Comparing the ratio of helicity 1/2 and 3/2 transition amplitudes, calculated in our full analysis, versus an estimate based on $E^{1/2}_{2-}$ and $M^{1/2}_{2-}$ taken at the resonance position (no background separation), we find agreement at the 10–20% level. If an improper background-resonance separation should be the problem in this case, the uncertainties associated with all other states would be questionable as well.

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[14] This study is helped by the observation that the $E^{1/2}_{2-}$ and $M^{1/2}_{2-}$ multipoles, as extracted from pion-photoproduction data, have very nearly equal phases which pass through 90° very near the resonance energy.

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