

Pion photoproduction in the Δ resonance region

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We have updated our multipole analyses to incorporate new data from the low-energy and Δ resonance regions. We note a slight decrease in our estimate of the Δ photodecay amplitudes. This agrees with results found in Compton scattering. Our values are also in good agreement with another previous determination. We have reexamined our determinations of the $E2/M1$ ratio at the resonance energy and at the pole. We find an $E2/M1$ ratio (at the pole) which is in good agreement with the recent Mainz value. [S0556-2813(97)06107-4]

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Recent interest in the pion photoproduction reaction has been focused on the threshold and Δ resonance regions. Most studies have been motivated by a desire to check the predictions of chiral perturbation theory and to pin down the photodecay amplitudes of the $\Delta(1232)$. With the flood of new and precise data in this region, we have reexamined the $\Delta(1232)$ photodecay amplitudes coming from our analyses of the pion photoproduction data base. Given the recent interest in a more precise determination of the $E2/M1$ ratio, we have extracted this quantity as well.

Our method of analysis is the same as was used to generate the results of Ref. [1], with one modification. The πN interaction is currently being determined by the pion c.m. momentum rather than the c.m. energy. This gives a proper threshold behavior for all charge-channel multipoles but shifts the on-shell resonance points (in $W_{c.m.}$) slightly according to the specific charge channel being considered. The pole position is not altered.

Most important to the present analysis were the recent total cross section measurements of Ref. [2]. Our previous analysis [1] predicted total $\pi^0 p$ and $\pi^+ n$ total cross sections systematically above these new data. This was also suggested in an analysis of Compton scattering data [3]. In that work, a $2.8 \pm 0.93\%$ reduction in our $M_{1+}^{3/2}$ amplitude was found to be necessary.

Our present findings complement, and now agree with, the value found in Ref. [3]. For the helicity 1/2 and 3/2 photodecay amplitudes, we find values about 4% lower than our previous determinations. These are compared to values from the Glasgow [4] and RPI [5] groups in Table I. Though the RPI values have larger errors, the central values from the VPI and RPI [5] determinations are in good agreement. The ranges for $A_{1/2}$ and $A_{3/2}$ were chosen to cover results found in fits to our global solution to 2 GeV (SP97), a more restricted analysis to 500 MeV (W500), and fits to our single-energy solutions (SES) [6].

There are a number of ways to define the $E2/M1$ ratio. In the following, we will restrict ourselves to determinations which can be made directly from the multipole amplitudes. The resonance value which we quote is determined by evaluating the ratio $\text{Im}E_{1+}^{3/2}/\text{Im}M_{1+}^{3/2}$ at the resonance energy. Both the RPI [5] and VPI [7] groups have found ratios near -1.5% in the past. However, while the PDG [8] quotes these values, a number of recent determinations have found larger negative values.

TABLE I. Comparison of recent determinations of the $\Delta(1232)$ decay amplitudes. Values have the units $10^{-3} \text{ GeV}^{-1/2}$. See the text for a discussion of the range of values quoted for the VPI analyses.

Source	$A_{1/2}$	$A_{3/2}$
VPI (old) [1]	-141 ± 5	-261 ± 5
Glasgow [4]	-145 ± 15	-263 ± 26
RPI [5]	-135 ± 16	-251 ± 33
VPI	-135 ± 5	-250 ± 8

Khandaker and Sandorfi [9] have suggested that a higher value is required to fit the new LEGS beam-asymmetry (Σ) data [10]. This claim is supported in a recent paper from the Mainz group [11]. A value consistent with the finding of Ref. [9] was found in an analysis of the new Mainz [11] cross section and Σ data. A second Mainz analysis [12] used dispersion relations in analyzing data over the Δ resonance region. In this work, the speed-plot method was used to determine an $E2/M1$ ratio at the pole.

In Table II, we compare our updated values for the $E2/M1$ ratio at the resonance and the pole with both recent and older determinations. We find good agreement with the Mainz pole value, supporting the view that this quantity is relatively model-independent. Adding the new Mainz data did not increase the $E2/M1$ ratio [13] as much as was found in Ref. [11]. We attribute this to differing assumptions and data bases used in the analyses.

TABLE II. Comparison of recent values for the $E2/M1$ ratio evaluated at the pole (P) and resonance (R) positions. See the text for a discussion of the range of values quoted for the VPI analyses.

Source	Location	Value
RPI [5]	R	$-1.57 \pm 0.72\%$
VPI (old) [7]	R	$-1.5 \pm 0.5\%$
BNL [9]	R	-2.7%
Mainz [11]	R	$-2.5 \pm 0.2 \pm 0.2\%$
VPI	R	$-1.5 \pm 0.5\%$
Mainz [12]	P	$-0.035 - i 0.046$
VPI	P	$-0.034 \pm 5 - i 0.055 \pm 5$

The SES results favor a slightly larger $E2/M1$ ratio than was found in our energy-dependent fits. Depending on how the data are binned (we compared results using 10 MeV and 25 MeV bins), the SES value ranges between approximately -1.5% and -1.9% . This value is closer to the one found in Ref. [11]. However, the low-energy analysis (W500), which results in a very different $E2/M1$ ratio (-1.2%), fits the Mainz cross section and Σ data [11] quite well. (The overall χ^2/data is 193/182.) This variability in the $E2/M1$ ratio is greatly reduced in the ratio of pole residues.

While we found good agreement for the pole positions and moduli of the residues using the speed plot method, we also determined the pole value for $E2/M1$ using a different method. Writing our amplitudes in the form

$$M = A_B(1 + iT_{\pi N}) + A_R T_{\pi N}, \quad (1)$$

where $T_{\pi N}$ is the associated πN T matrix, we fit $T_{\pi N}$ using analytic forms and extrapolated to the pole. (A_B and A_R are analytic functions determined in the energy-dependent analysis.) The agreement between these different methods gives further confidence in the pole value [14]. A comparison with the Mainz value [12] is given in Table II. The modulus of this ratio varied by only about 10% in our fits to SP97, W500, and the SES.

We also found, in our fits, a pole position ($1210 \pm 2 - i50 \pm 2$ MeV) consistent with the result in Ref. [12]. This should not be considered an independent determination, however, as the Δ mass (1230 ± 2 MeV), width (115 ± 5 MeV), and pole position are built into the pion-nucleon amplitudes used in Eq. (1).

Our updated $\Delta(1232)$ photodecay amplitudes now agree with both the results from Compton scattering and an earlier RPI determination. We also agree with the pole value for the $E2/M1$ ratio found by the Mainz group. Our determinations confirm the view that this ratio is relatively model-independent. Given our agreement with the Mainz pole value, the discrepancy between the resonance values remains to be explained.

There are two tests which might help to clarify the discrepancy. First, the pole value found in Ref. [12] could be extrapolated to the resonance point. Second, the multipoles which will come from a Mainz fit to $\gamma p \rightarrow p \pi^0$ and $\gamma p \rightarrow n \pi^+$ data (used to determine $E2/M1$ at the resonance point [11]) could be ‘‘speed plotted’’ to determine a pole value for this ratio. This would give three independent sets of both pole and resonance values.

If the extrapolation to the pole is indeed model-independent (as it appears to be), it is interesting to consider whether amplitudes giving an $E2/M1$ ratio near -2.5% (at the resonance point) extrapolate to a pole value close to that found here and in Ref. [12]. A resonance value for the $E2/M1$ ratio has, in fact, already been extracted from the amplitudes of Ref. [12]. The result [15] being that the two Mainz groups [11,12] agree upon the $E2/M1$ ratio at the resonance point.

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 [13] A number of our earlier solutions predict the Mainz data [11] with a χ^2/data near unity. The solution SM95 [6] actually gives a χ^2/data of 168/182 for this data set. This explains why our result for the $E2/M1$ ratio was not greatly influenced by the Mainz experiment.
 [14] We expect the ratio of pole residues to be less model dependent than the individual residues for $E2$ and $M1$. If one assumes a factorizable pole [see, for example, R.A. Arndt *et al.*, Phys. Rev. C **42**, 1864 (1990)], the pion-nucleon residue cancels in the ratio. In a representative fit with the ratio (modulus, phase) of $(0.065, -126^\circ)$, we found $(1.33, -152^\circ)$ and $(20.5, -26^\circ)$ for the $E2$ and $M1$ residues, in the units $(10^{-3}/m_\pi)$ of Ref. [12].
 [15] L. Tiator has claimed a value of -2.4% for the $E2/M1$ ratio at the resonance energy, using the amplitudes of Ref. [12]. A comparison of the resonant and pole values from several sources was given during the N^* meeting at INT, Seattle, 1996, edited by T.-S.H. Lee and W. Roberts (World Scientific, Singapore, in press).