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How well do we know the $E2/M1$ ratio for the $\Delta(1232)$?

Ron L. Workman, Richard A. Arndt, and Zhujun Li
Department of Physics, Virginia Polytechnic Institute and State University,
Blacksburg, Virginia 24061

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The ratio of electric quadrupole ($E2$) and magnetic dipole ($M1$) photodecay amplitudes for the $\Delta(1232)$ is determined. This extraction is based on direct multipole analyses of the existing database for the pion photoproduction reaction. Our values are in qualitative agreement with the results of Davidson, Mukhopadhyay, and Wittman. We compare and contrast our results with other recent determinations of this ratio.

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The desire for precise values of the Δ photodecay amplitudes has spawned numerous theoretical and experimental investigations in recent years. Much of this effort has been directed toward the $E2/M1$ ratio of Δ photodecay amplitudes. There is general agreement that the ratio is "small" for real photon ($Q^2=0$) transitions. Davidson and coworkers [1] have examined this ratio from several points of view, generally finding values for $E2/M1$ between -1% and -2%.

Model-based predictions have spanned a much wider range. For example, very similar models [2,3] have predicted the $E2/M1$ ratio to be near 3% in magnitude but with different signs. The effect of πN rescattering on this ratio has been discussed by several groups [4,5]. In particular, Christillin and Dillon [4] have noted that some of the spread in model predictions may be due to the difference between bare and renormalized couplings. The separation of these couplings requires knowledge of the off-shell πN interaction and is intrinsically model dependent.

In the following, we will confine ourselves to a study of the ratio $\mathrm{Im}E_{1+}^{3/2}/\mathrm{Im}M_{1+}^{3/2}$ evaluated at the energy where $\mathrm{Re}M_{1+}^{3/2}=0$. This corresponds to the K-matrix pole value of $E2/M1$. Other definitions of this ratio have been used and will be briefly discussed at the end. Before proceeding, however, we should indicate how our study differs from other recent work. Most previous studies have employed rather old (pre 1980) energy-independent multipole analyses as representations of the pion-photoproduction process. A scan of our database [6] from 250 to 400 MeV indicates that about 400 measurements have been added since 1980—much of this being polarization data. We have studied the $E2/M1$ ratio by analyzing the present database directly. Several multipole solutions have been generated over a variety of energy ranges. Our method of analysis involves both energy-dependent and single-energy methods, and has been described previously [7]. In some cases we have found rather large deviations [7] from the older solutions.

A primary motivation for this work was the recent Brookhaven beam-asymmetry ($d\sigma_{\parallel}/d\sigma_{\perp}$) measurement for the reaction $\gamma p \rightarrow p\pi^0$. This measurement was expected to be particularly sensitive to the $E2/M1$ ratio. Preliminary data from this experiment were not well described [8] by the calculations of Davidson and Nozawa. The predictions of our multipole analyses were similarly unsatisfactory. A comparison of $E2/M1$ values for several solutions derived prior to the Brookhaven (LEGS) measurement is given in Table I. The quality of fit to the recent LEGS data [9] is also displayed. While not reflected in Table I, these fits do predict the qualitative behavior of the LEGS data. The rather large χ^2/datum is due mainly [9] to small statistical errors. The errors are smallest in the 105° measurements, which are most sensitive [10] to the $E2/M1$ ratio.

The LEGS beam-asymmetry data were subsequently included and our most recent fit (SM92) to 1.8 GeV was repeated. In the revised fit, the LEGS data were not weighted more heavily than any of the other 12 000 data in this energy range. This fit was a check to see how easily the new data could be accommodated. The test was then repeated over an energy range extending from threshold to 500 MeV. This result is labeled B500 in Table II. If one removes the 291 MeV points, the resulting χ^2/datum is near 4 in both cases.

Since the χ^2/datum for our global fit to 1.8 GeV is near 3.5, we could possibly have stopped at this point. However, we feel the rather high χ^2 in our global fit is due mainly to inconsistencies within a very "noisy" database. Given that the LEGS measurement was expected [8] to be free of problems existing in previous measurements, we obtained a "forced" fit [11] to this data. This fit is labeled F500 in Table II. Unfortunately, F500 does a very poor job of reproducing the existing differential cross section data. The overall χ^2/datum for F500 is near 3.5 compared to 2.5 for B500. Given that the overall fit has been degraded in F500, the resulting value of $E2/M1$

TABLE I. Comparison of VPI solution (pre-LEGS data).

Solution	$E2/M1$	χ^2/data (LEGS)
V400 (400 MeV)	-1.5%	168/20
SP89 (1 GeV)	-1.4%	412/20
SP92 (1.8 GeV)	-1.3%	405/20

TABLE II. Comparison of fits including the LEGS data.

Solution	$E2/M1$	χ^2/data (LEGS)
SM92 (1.8 GeV)	-1.5%	124/20
B500 (500 MeV)	-1.5%	132/20
F500 (500 MeV)	-2.9%	29/20

TABLE III. Estimates of the $E2/M1$ ratio.

$E2/M1$	Reference	Year
$(-1.4\pm0.6)\%$	[1a,13]	1984
$(-1.5\pm0.2)\%$	[1a]	1986
$(-1.07\pm0.37)\%$	[1c]	1990
$(-1.57\pm0.72)\%$	[1b]	1991
$(-1.5\pm0.4)\%$	Our result	1992

should be taken only as an indication of sensitivity to beam-asymmetry data.

In order to estimate the error on $E2/M1$ from our "unforced" fits, we looked at both energy-dependent and single-energy solutions. The error matrix from an energy-dependent fit to 400 MeV resulted in an error of only 6% for the $E2/M1$ ratio. Generally, these errors are quite small, coming from a 25 parameter fit to 2800 data. We also centered several single-energy fits at the resonance position, varying the energy bin width from 10 to 25 MeV. In this case, fewer parameters were being searched [12] against a much smaller dataset. The resulting error varied with the bin width. For a bin width of 15 MeV the single-energy result for $E2/M1$ matched the energy-dependent value, with an error of about 25% cited in Table III.

A summary of recent determinations is given in Table III. In general, we find the above value of the $E2/M1$ ratio to be in excellent agreement with previous determination. As we have intimated, the estimation of errors is not trivial. However, the results of Table III do support a ratio between approximately -1% and -2%, given the present database. Unfortunately, the results of our forced fit appear to imply the existence of data conflicts. This problem remains to be solved. Clearly, these extractions of the $E2/M1$ ratio are only as reliable as the underlying data.

In closing, we should mention that a different definition of the $E2/M1$ ratio has been discussed recently [14]. Using a variant of the model described in Ref. [2] for our background, a second fit has been attempted. With this model-based background, a fit to our $M_{1+}^{3/2}$ and $E_{1+}^{3/2}$ has been made up to 450 MeV. The "resonance" part was then identified from this fit. The resulting "bare" resonance amplitudes, $M_{1+}^{3/2}$ and $E_{1+}^{3/2}$, obtained at the resonance energy, had the values 38.8 am and -1.5 am respectively. The resulting $E2/M1$ ratio was then approximately -3.9%. The work of Ref. [14] has raised interesting questions regarding comparisons with the nonrelativistic quark model. It would be useful if the results described above could be explained in conjunction with the findings of Ref. [5].

Note added in proff. We have recently been informed (LEGS Data Release L2-5.3) that previous data releases contained some transposing errors. The revised data set, and further tests regarding the resonance enegy, suggest our error estimate in Table III be increased to 0.5%.

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[8] A. Sandorfi, private communications.

[9] Of the 20 LEGS data listed in Table I, only 17 are independent. The remaining 3 points have much smaller errors (generating approximately half of the quoted χ^2) and have been obtained from the 17 independent data shifted to 291 MeV. The "true" χ^2/datum is about half that given in Table I.

[10] A. Sandorfi, invited talk, Baryons '92, Yale, 1992 (unpublished).

[11] A forced fit was achieved by reducing the errors on the LEGS data to a level that resulted in a χ^2/datum near unity. In all of the low-energy fits (to 400 or 500 MeV), those multipoles coupled to *s*- and *p*-wave πN final states were searched. The *d*-wave and higher multipoles were fixed at values determined in our 1.8 GeV analysis.

[12] The number of data varied from about 100 to 300, depending on the energy range. If too few data were included, the $E2$ multipole was essentially undetermined in the search. Only the dominant multipoles were searched. A variation of the number of searched multipoles did not significantly alter the magnitude of errors found for the $E2$ multipole. The error on $M1$ was much smaller, having little effect on the $E2/M1$ ratio.

[13] Particle Data Group, Rev. Mod. Phys. **56**, S1 (1984).

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