Analysis of Pion Photoproduction over the Delta Resonance Region

R.A. Arndt, I.I. Strakovsky, and R.L. Workman
Department of Physics, Virginia Tech, Blacksburg, VA 24061

Abstract

A number of recent multipole analyses from Mainz, RPI, BNL and Virginia Tech (VPI) have focused on the first resonance region. One goal common to these studies was an improved set of $\Delta(1232)$ photo-decay amplitudes. There has been considerable debate over the differing results found for $A_{1/2}$, $A_{3/2}$ and the $E2/M1$ ratio. We show that a much more consistent set of values is possible if differences in the database are considered.

RECENT MULTIPOLE ANALYSES

The importance of the $\Delta(1232)$ photo-decay amplitudes in constraining quark models is well known. While those constructing models have struggled to reproduce the ‘observed’ scale and ratio of the photo-decay amplitudes, a similarly vigorous program has been launched by both the experimentalists and the phenomenologists. Very recently, the Mainz\cite{1} and BNL\cite{2} groups have released differential cross section and beam-asymmetry ($\Sigma$) data, along with their own multipole analyses. These new data have also been analyzed by the VPI\cite{3}, RPI\cite{4}, and Mainz theory\cite{5} groups. Having so many groups working on essentially the same problem brings to mind a quote (attributed to Lovelace) which can be found in Höhler’s book\cite{6} on $\pi N$ scattering.

“To have five groups trying to cut each other’s throats is more efficient than random searching”

While there may be some truth to this, the intended purpose of the present paper is to search for unity rather than diversity in the various approaches. This is actually possible if the database is critically examined. However, before doing so, we should outline how the various analyses differ.

The VPI analyses\cite{3} are either energy-dependent (based on a K-matrix approach) or energy-independent. In the energy-independent analyses, data in a narrow window of energy are analyzed together. Here multipoles take
their phases from the energy-dependent fit; the moduli are allowed to vary. Results for the photo-decay amplitudes ($A_{1/2}$ and $A_{3/2}$) agree with the Mainz and RPI results, within uncertainties, but are below the BNL value for $A_{3/2}$. The E2/M1 ratio has generally been lower (in magnitude) than those found in more recent analyses. The reason for this is given below.

The analysis made by the Mainz theory group[5] employs fixed-t dispersion relations for the multipoles (as opposed to fixed-t relations for the invariant amplitudes). Details are given in Tiator’s contribution to this symposium.

The BNL analysis[2] fits both pion photoproduction and Compton scattering data (linked by common systematic errors). The form used in describing the photoproduction multipoles is similar to that used in the VPI analysis. The multipoles are further constrained via dispersion relations for Compton scattering. As mentioned above, the BNL value for $A_{3/2}$ is somewhat larger (in magnitude) than those reported in other recent analyses.

The RPI analysis[4] differs from those already described in that an effective Lagrangian is used and only five parameters[7] are fitted to the data. The value found for the E2/M1 ratio is slightly larger (in magnitude) than that found in the Mainz fits over a similar database.

The Mainz experimental group[1] has determined the E2/M1 ratio from a polynomial fit (in cos(θ)) to the beam-polarized cross sections. One particular ratio of the polynomial coefficients corresponds to the E2/M1 ratio, if other terms and the interference of other multipoles can be shown to be small. No values for $A_{1/2}$ and $A_{3/2}$ are extracted.

**EFFECT OF CHANGES IN THE FITTED DATABASE**

Much of the confusion surrounding the E2/M1 ratio can be traced back to the use of different databases in the various fits. Not surprisingly, the Mainz[5] and BNL[2] fits were based largely on data produced at their own facilities. The RPI fit[4] was similarly restricted to include mainly the Mainz data[1] over the resonance. The initial VPI fits[3] were unique in that they included the entire database. Changes between the previous and most recent VPI amplitudes were due mainly to the addition of Mainz differential cross section, $\Sigma$, and total cross section data[1, 8].

More restrictive fits have now been made in order to track down the source of the differing results. Our first and most severe test was a fit which rejected
all pre-1980 cross section data. By considering how the fit to individual data had changed, we managed to narrow the cut down to just two sources of $\pi^0 p$ differential cross sections. These are two Bonn sets\[9\] which are essentially consistent with the more recent Mainz measurements. Our analysis of this modified data set (F500) resulted in $\Delta(1232)$ parameters which are in close agreement with the Mainz values\[5\]. These are displayed in Table I. This observation is also supported by a remark made by the BNL group\[2\]. In that work, as a test, the BNL cross sections were removed and replaced by the Bonn cross sections. The result was an E2/M1 ratio of $-1.3\%$. Preliminary fits by Davidson\[7\] appear to show a qualitatively similar behavior. The addition of more cross section data tends to lower the E2/M1 ratio.

The above result seems to contradict the often repeated remark that: “the Mainz and Bonn cross sections agree”. A more appropriate statement would be that: “the Mainz and Bonn cross sections agree over the angular range where they can be compared”. At the resonance energy, the Bonn cross sections\[9\] range from 10° to 160° while the Mainz cross sections\[1\] go from 75° to 125°. The Bonn data (for neutral pion photoproduction) are not well described by analyses which have excluded them.

Finally, we note that the BNL E2/M1 ratio\[2\] is slightly larger in magnitude than the Mainz value. Understanding this difference is complicated by the fact that BNL carried out a joint analysis of their pion photoproduction and Compton scattering data. We can, however, ask whether the new BNL $\Sigma$ data for $\pi^0 p$ and $\pi^+ n$ are mainly responsible for the difference. In order to address this question, we included the new BNL $\Sigma$ data in a low-energy fit. The result was a solution (B500) with essentially the same E2/M1 ratio. We should also note that the Mainz analysis\[5\] appears to fit this $\pi^0 p \Sigma$ data\[2\] quite well (though it was not included). Thus, it would seem that differences in the cross section and/or the influence of the Compton scattering data are mainly responsible for the slightly higher BNL ratio.

The status of the photo-decay amplitudes is much clearer. The results for $A_{1/2}$ and $A_{3/2}$ from VPI/RPI/Mainz agree within uncertainties. The only significant problem is posed by the BNL result which is probably a reflection of their larger cross sections.

**CONCLUSIONS AND SUGGESTIONS**

We have seen that the VPI analysis is able to reproduce the Mainz\[5\] val-
Table 1: Results for photo-decay parameters from our most recent publication (W500) (using the full SAID database), from a fit (F500) using a restricted SAID database (see text), a similar fit (B500) which includes recent BNL Σ data, and the Mainz analysis.

| Fit  | A\(_1/2\) (10\(^{-3}\))GeV\(^{-1/2}\) | A\(_3/2\) (10\(^{-3}\))GeV\(^{-1/2}\) | E2/M1 | E2/M1(pole) |
|------|--------------------------------|--------------------------------|-------|-------------|
| W500 | -135(5)                        | -250(8)                        | -1.5(5)% | -0.034(5) - 0.055(5)i |
| F500 | -130(4)                        | -250(6)                        | -2.6%  | -0.033 - 0.043i |
| B500 | -129(2)                        | -248(3)                        | -2.5%  | -0.032 - 0.049i |
| Mainz | -129(2)                      | -247(4)                        | -2.4%  | -0.035 - 0.046i |

Values for A\(_1/2\), A\(_3/2\), and the E2/M1 ratio (both at the resonance energy and at the pole) by either (a) removing all pre-1980 differential cross sections or (b) removing two sets\(^{[4]}\) of \(\pi^0 p\) differential cross sections measured at Bonn in the 1970’s. Statements made by the authors of the BNL analysis\(^{[2]}\) imply the converse. By using the older Bonn cross sections in their data set, they were able to obtain an E2/M1 ratio of -1.3%, a value consistent with the VPI result. There are also preliminary indications\(^{[7]}\) that a qualitatively similar effect can be seen in the RPI analysis\(^{[4]}\), which is based on an effective Lagrangian approach. It is therefore vitally important to verify the forward and backward Bonn cross sections for neutral pion photoproduction. [The scale and shape of the recent BNL differential cross sections\(^{[2]}\) present yet another problem when compared with previous Bonn and Mainz cross section measurements.] According to Beck\(^{[10]}\), there have been wider angle measurements of the differential cross section for \(\pi^0 p\) photoproduction at Mainz. Given the above comments, these could be crucial to a more definitive resolution of the E2/M1 problem.

The discrepancy between the BNL and VPI/RPI/Mainz values for A\(_3/2\) is likely related to the larger BNL differential cross sections. Until these larger cross sections are understood, every determination of the \(\Delta(1232)\) photo-decay amplitudes will require some comment on this issue. It is amusing to compare lattice predictions\(^{[11]}\) with the most recent determinations of this amplitude. The lattice value for A\(_3/2\), \(-195(34) \times 10^{-3}\) GeV\(^{-1/2}\), lies just
outside the VPI range, $-250(8) \times 10^{-3} \text{ GeV}^{-1/2}$, with nearly overlapping errors. The BNL value, $(−268.9 \pm 2.8 \pm 4.9) \times 10^{-3} \text{ GeV}^{-1/2}$, lies somewhat further from the lattice result. We may see lattice results with errors reduced by a factor of 2 or 3 in the not-too-distant future. This would certainly make the above comparison much more interesting.

R.W. thanks R. Beck, R.M. Davidson, N.C. Mukhopadhyay, A. Sandorfi, and L. Tiator for numerous helpful communications and for sharing their data and multipole analyses. This work was supported in part by a U.S. Department of Energy Grant No. DE-FG02-97ER41038.

References

[1] R. Beck et al., Phys. Rev. Lett. 78, 606 (1997).

[2] G. Blanpied et al., BNL-64382, submitted to Phys. Rev. Lett.

[3] R.A. Arndt et al., Phys. Rev. C56, 577 (1997).

[4] N.C. Mukhopadhyay and R.M. Davidson, invited talk, MAX-lab Workshop on the Nuclear Physics Programme with Real Photons below 200 MeV, Lund, 1997.

[5] O. Hanstein, D. Drechsel, and L. Tiator, Phys. Lett. B385, 45 (1996); contribution to this conference.

[6] G. Höhler et al., Handbook of Pion-Nucleon Scattering, Physik Daten, Fachinformationszentrum, Karlsruhe, 1979.

[7] R.M. Davidson, private communications, 1997; to be submitted.

[8] M. MacCormick et al., Phys. Rev. C53, 41 (1996).

[9] H. Genzel et al., Z. Physik 268, 43 (1974); G. Fischer et al., Z. Physik 245, 225 (1971).

[10] R. Beck, private communication, 1997.

[11] D. Leinweber et al., Phys. Rev. D 48, 2230 (1993).

[12] D. Leinweber, private communication, 1997.