

New analysis of threshold photoproduction data from MAMI

César Fernández-Ramírez^a

Grupo de Física Nuclear, Departamento de Física Atómica, Molecular y Nuclear, Facultad de Ciencias Físicas, Universidad Complutense de Madrid, Avda. Complutense s/n, 28040 Madrid, Spain

Abstract. In this talk I will review the recently published results by the A2 and CB-TAPS Collaborations at MAMI on neutral pion photoproduction in the near-threshold region. The combined measurement of the differential cross section and the photon beam asymmetry with low statistical errors allowed for a precise determination of the energy dependence of the real parts of the S- and P-wave amplitudes for the first time, providing the most stringent test to date of the predictions of Chiral Perturbation Theory and its energy region of agreement with experiment.

1. Introduction

The dynamical consequences of the spontaneous breaking of chiral symmetry in Quantum Chromodynamics (QCD) and the appearance of the π meson as a pseudoscalar Nambu–Goldstone boson are well known and many predictions are available in the literature [1]. One of the most important is the softness of the S-wave amplitude for the $\gamma N \rightarrow \pi^0 N$ reaction in the near threshold region which vanishes in the chiral limit [2]. On top of the softness of the S-wave, the P waves are expected to provide a large contribution due to the early appearance of the Δ resonance [3] and also, because of the softness of the S wave, even D waves have an important impact due to their interference with P waves [4, 5]. Hence, the accurate extraction of the S and P waves from pion photoproduction data becomes an important issue in the study of chiral symmetry breaking and hadron dynamics.

In order to test hadron dynamics in the low-energy regime and Chiral Perturbation Theory (CHPT) predictions, A2 and CB-TAPS Collaborations have run several experiments at MAMI (Mainz) collecting accurate differential cross sections and photon beam asymmetries for the $\gamma p \rightarrow \pi^0 p$ reaction in the near-threshold region [6, 7]. The high quality of these data allows to extract the S-wave and P-waves energy dependence and to use the data to test current CHPT and assess the energy range where the theory is accurate for this particular process [8, 9].

^a *Current address:* JLab Physics Analysis Center, Center for Theoretical and Computational Physics, Thomas Jefferson National Accelerator Facility, 12000 Jefferson Avenue, Newport News, VA 23606, USA, e-mail: cesar@jlab.org

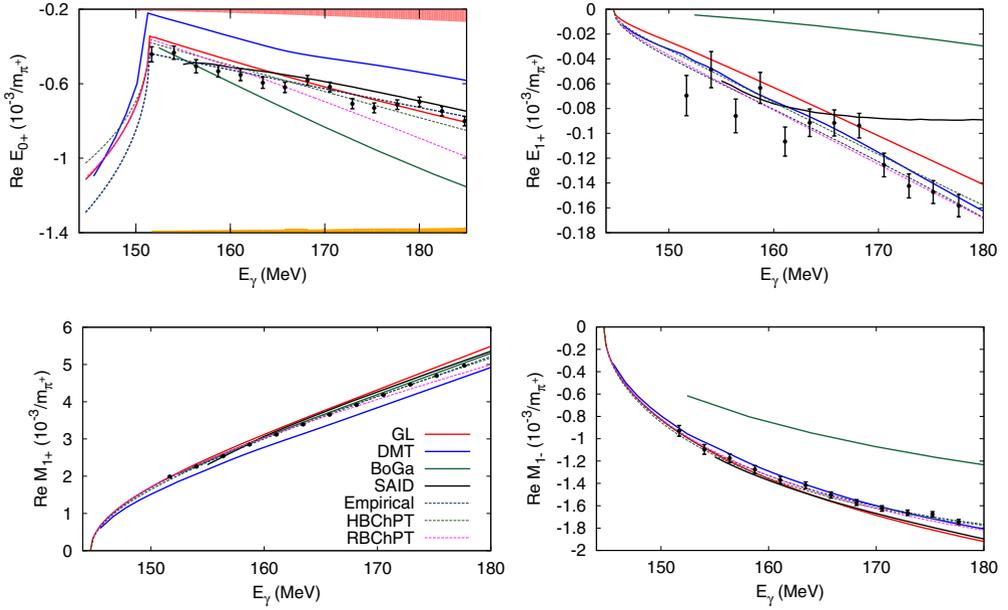


Figure 1. Extracted single-energy S and P partial waves (E_{0+} , E_{1+} , M_{1+} and M_{1-} : black dots) compared to fits to the experimental data (Empirical [6] HBChPT [8] and RBChPT [9]: dashed lines) and to predictions: dispersive Effective Field Theory by Gasparyan and Lutz (GL) [11], Dubna-Mainz-Taipei (DMT) [12], Bonn-Gatchina (BoGa) [13], and SAID (SN11 solution) [14]: solid lines). The red area at the top of the E_{0+} figure represents the uncertainty in the single-energy multipoles due to D waves.

2. Partial wave analysis

2.1 Single-energy multipoles

Data starting at $E_\gamma = 146$ MeV of photon energy in the laboratory frame were collected approximately every 2.4 MeV, obtaining simultaneously for each energy bin the differential cross section and the photon beam asymmetry. To extract the single-energy multipoles, each observable was fitted with the real part of E_{0+} , E_{1+} , M_{1+} , and M_{1-} as free parameters employing the algorithm described in [10]. The imaginary part of E_{0+} was set to the unitary value [6, 8] although the experiment is not sensitive to $\text{Im}E_{0+}$, and the imaginary parts of E_{1+} , M_{1+} , and M_{1-} were set to zero, which is an excellent approximation if we stay below 185 MeV where the Δ contribution to the imaginary part of M_{1+} starts to play a role. D waves were fixed to Born terms. The results are presented in Fig. 1 together with several fits and predictions which will be discussed in the next section. The uncertainty due to our choice of D waves is presented with a red band on the top of the $\text{Re}E_{0+}$ multipole plot. D waves uncertainty makes no impact in the extraction of the P waves [5]. In this way, we have been able to extract single-energy S and P waves experimentally in a model independent way except for the uncertainty in the D waves, which is believed to be under control.

2.2 Energy dependent multipoles

To parametrize the multipoles we have employed three different approaches which we have fitted to the data: (i) Empirical fit [5–7] which depends on eight parameters and serves as a consistency test to single-energy multipole extraction; (ii) Heavy Baryon Chiral Perturbation Theory (HBChPT) [8] which depends on five parameters; and (iii) Relativistic Baryon Chiral Perturbation Theory (RBChPT)

[9] which depends on five parameters. In Fig. 1 we compare the obtained multipoles from these fits (dashed curves) to the extracted single-energy multipoles. The empirical fit provides a good description of both data and multipoles up to $E_\gamma = 185$ MeV where the imaginary part of M_{1+} (Δ) starts to provide a sizeable contribution. Both HBChPT and RBChPT provide a good description of data and multipoles up to $E_\gamma \approx 170$ MeV. Above that energy they fail to reproduce the differential cross section although still provide very good results for the photon beam asymmetry.

Once the multipoles have been extracted, one can compare to predictions from the available literature. In Fig. 1 we compare to four calculations designed to work best in the resonance region: (i) Dispersive Effective Field Theory by Gasparyan and Lutz (GL) [11]; (ii) Dubna-Mainz-Taipei (DMT) [12]; (iii) Bonn-Gatchina (BoGa) [13]; (iv) and SN11 solution of SAID [14]. On the overall they provide a good description of the multipoles (solid lines in Fig. 1), however, the deviations shown can translate into large discrepancies with the actual data. The inclusion of the recent MAMI data in their analyses should improve the agreement in this energy region together with a stringent constrain in the background contribution to the resonance amplitudes [15].

3. Conclusions

1. A2 and CB-TAPS Collaborations at MAMI have measured the differential cross section and the photon beam asymmetry in the near threshold region for the process of neutral pion photoproduction from the proton. The energy dependence of the photon beam asymmetry was obtained for the first time for this energy region.
2. The measurement of these observables has allowed to obtain the single energy S and P waves experimentally in a model independent way except for the uncertainty in the D waves, which is believed to be under control and impacts only the extraction of the S wave.
3. Several energy-dependent extractions of the multipoles have been performed: (i) Empirical [6] – that serves as a consistency test to single-energy multipole extraction, provides a baseline to ponder on the quality of the other multipole extractions and serves to predict other observables for future experiments; (ii) HBChPT [8]; (iii) RBChPT [9]. This last can be accessed through the MAID webpage [16].
4. Current Chiral perturbation theory calculations only work up to 170 MeV of photon energy in the laboratory frame [6, 8, 9]. Above this energy the theory calls for further improvement, such as the inclusion of the Δ [17].
5. Lack of unitarity in the HBChPT amplitudes [5] is not responsible for the disagreement between theory and data [8].
6. Current theoretical calculations designed to work in the resonance region [11–14] provide a good description of the multipoles in the near threshold region. We expect that once these data are incorporated in the fits the agreement will improve and will help on achieving a better understanding of the background in such calculation [15].
7. Data on the F and T asymmetries in the same energy region are currently under analysis [18].

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