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The helicity E-asymmetry of $\vec{\gamma}\vec{N} \rightarrow \pi N$ reaction in the $\Delta(1232)$-resonance region

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Abstract. The helicity E-asymmetry of the reaction $\gamma(N,\pi)N$ by using polarized photon beams and polarized nucleon targets in the Δ-resonance region is investigated. This asymmetry is an adequate observable to test the weakness in the pion photoproduction model, since it is sensitive to small but important amplitudes. We present results for the E-asymmetry as a function of pion angle at different photon lab energies and compare them with available experimental data. The isobar model MAID-2007 and an Effective Lagrangian Approach (ELA) are used to analyze the recent data from CLAS experiment. A satisfactory agreement between ELA and MAID-2007 models with the CLAS data is found in the case of $\gamma(p,\pi^o)p$ reaction.

Keywords: E-asymmetry; Pion; Photoproduction

Introduction

It is important to discuss this subject of the pion photoproduction on the nucleon with using the electromagnetic interaction that give us the adequate information on the nucleon's internal structure.

As the pion photoproduction on the nucleon contains four isospin channels $\gamma(p,\pi^0)p$, $\gamma(p,\pi^+)n$, $\gamma(n,\pi^0)n$ and $\gamma(n,\pi^-)p$ still only using the proton targets to investigate the helicity E-asymmetry [1].

Actually, meson electromagnetic production from nucleons, including pion photoproducion is used since the late 1950s for studying the structure and dynamics of the different baryon resonances. In the recent time, the theoretical predictions for these reactions such as the partial-wave photo production solutions SAID [2], MAID [3], K-matrix models [4] and dynamical models as DMT [5], the model of Sato and Lee [6], Surya and Gross model [7] was brought back by the accelerators' new generation as the Thomas Jefferson National accelerator facility (Jefferson Lab) in Virginia, US, SAPHIR collaboration at electron Stretcher Accelerator (ELSA) at Bonn, Germany and MAinz MIcroton (MAMI) at Mainz, Germany and also laser backscattering facilities such as Super Photon ring-8 GeV (SPring-8) in Japan.

The isobaric model [3] from threshold to 1.6GeV photon energy acts for the method of pion photoproduction analysis which is used over the largest area. The ELA constitutes this method with the Born and vector-meson exchange terms are supreme and assessed.

In case of intermediate energies pion photoproduction can be studied in different models. For example, the authors of Ref. [4] used a K-matrix method to investigate the $\gamma(N,\pi)N$ reaction as well as various quark model calculations [7,8] achieved to describe pion photoproduction cross section data with relatively few parameters. For the low energies from threshold pion energy till 500 MeV, many theorists gave the concern for studying the electromagnetic production of pions from nucleons like Chew, Goldberger, Low and Nambu (CGLN) [8] and [3,4,9,10] pointed to the Born terms and the Δ(1232)-resonance term are the dominant at incident photon energies less than 500 MeV for $\gamma(N,\pi)N$ reaction.

Focusing on calculating the helicity E-asymmetry that we can do it by the following equation

$$E(\theta) = \frac{(\frac{d\sigma}{d\Omega})^A - (\frac{d\sigma}{d\Omega})^P}{(\frac{d\sigma}{d\Omega})^A + (\frac{d\sigma}{d\Omega})^P} = \frac{(\frac{d\sigma}{d\Omega})^A - (\frac{d\sigma}{d\Omega})^P}{2(\frac{d\sigma}{d\Omega_o})^A}, \qquad (1)$$

Where $(\frac{d\sigma}{d\Omega})^P$ and $(\frac{d\sigma}{d\Omega})^A$ stand for the parallel and antiparallel spin differential cross sections respectively, and $(\frac{d\sigma}{d\Omega_o})$ indicates the unpolarized differential cross section, we provide results of E-asymmetry for pion photoproduction channels $\gamma(N,\pi)N$ as a function of the emission pion angle in the γN c.m. frame. This E-asymmetry is a perfect appliance to verify the pion photoproduction model's frailty.

This paper is organized as follows. In the next section we present the model which used in our calculations and give a brief review of the formalism. Section III devotes to the results and discussion and conclusions are given in section IV.

I. The model

To investigate the pion photoproduction on the nucleon we use two ways for calculations, one of them is the effective Lagrangian approach (ELA) of Schmidt et al. [11] then other one is the unitary isobar MAID-2007 model [3] for comparison. The ELA model [11] was formed to investigate the reaction channels around the Δ(1232)-resonance region. It contains the usual Born terms and the Δ(1232) contribution. It was shown in [11] that this model describes well the differential and total cross sections along with the multipole amplitudes of the $\gamma(N,\pi)N$ reaction channels till a photon energy of 500 MeV.

Generally, the isobaric model which is used to describe nucleon excited states, that having masses close to nucleons but have different quantum numbers (e.g., the spin J =3/2 and isospin I = 3/2 for the Δ (1232) but J = 1/2 and I = 1/2 in case of nucleons). The isobaric models are commonly used to analyze pion production off nucleons and also are relatively easy to apply nuclei production. There are several versions for isobaric MAID model are existed. All results presented here related to MAID2007 version. The four stars resonances S31(1620), D15(1675), P31(1720), F35(1905), P31(1910) and F37(1950) were included in this version. The new available experimental data for pion photoproduction on the nucleon from CLAS [1] can be analyzed in this work.

In this section we review briefly for the derivation of the kinematics for the reaction:

$$\gamma(\mathrm{k}) + \mathrm{N}(\mathrm{p_i}) \rightarrow \pi(\mathrm{q}) + \mathrm{N}(\mathrm{p_f}), \tag{2}$$

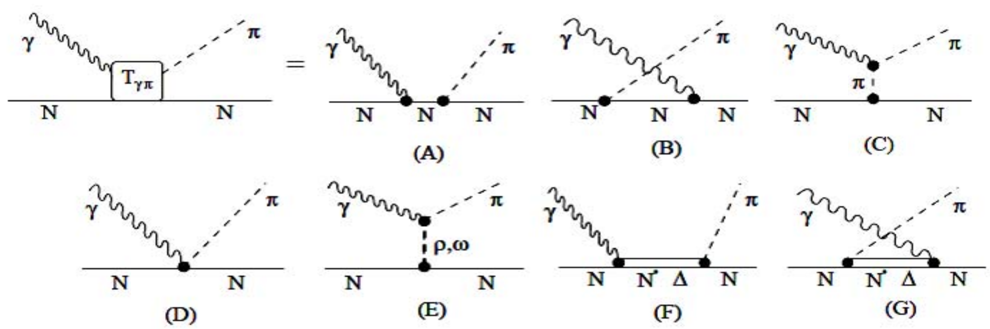

Fig. 1. Feynman diagrams for pion photoproduction on the nucleon $\gamma(N,\pi)N$. Diagrams (A) and (B) represent the nucleon pole terms; (C) represents the pion pole term; (D) displays Kroll-Rudermann term (which contributes only to the production of the charged pions); diagram (E) reveals the meson-exchange terms, while diagrams (F) and (G) stand for the resonance terms.

where the four-momentum for each particle is between in the brackets, and fulfills $\mathrm{p_i^2} = \mathrm{M_{N_i}^2}, \mathrm{p_f^2} = \mathrm{M_{N_f}^2}$ and $\mathrm{q^2} = \mathrm{m^2}$ where $\mathrm{M_{N_i}}, \mathrm{M_{N_f}}$ and m stand for the masses of the initial nucleon, final nucleon and pion, respectively; and $(\mathrm{k} = 0)$ as the photon is real in case of photoproduction, the Mandelstam variables can be expressed by the c.m . variables as: $\mathrm{s} = (\mathrm{k} + \mathrm{p_i})^2$, $\mathrm{t} = (\mathrm{k} - \mathrm{p_f})^2$ and $\mathrm{u} = (\mathrm{p_i} - \mathrm{p_f})^2$, where the energy and momentum of each particle can be expressed as: $\mathrm{k} = (\mathrm{E_\gamma}, \mathrm{k})$, $\mathrm{p_i} = (\mathrm{E_i}, \mathrm{p_i})$, $\mathrm{q} = (\omega, \mathrm{q})$ and $\mathrm{p_f} = (\mathrm{E_f}, \mathrm{p_f})$. The S-matrix elements for the pesudoscalar pion photoproduction process by using Bjorken-Drell conventions [12, 13] is:

$$S_{fi} = \frac{1}{(2\pi)^2}\sqrt{\frac{M_{N_i}M_{N_f}}{4\omega k_0 E_i E_f}}\, i\mathcal{M}_{fi}\delta^4(p_i + k - p_f - q). \tag{3}$$

where the matrix element

$$\mathcal{M}_{fi} = u(p_f)\sum_{i=1}^{4}\mathcal{A}_i M_i u(p_i), \tag{4}$$

where the $\mathcal{A}_\mathrm{i}$'s are the Lorentz invariant amplitudes. The cross section can be written by the matrices and amplitudes by the expression:

$$d\sigma = (2\pi)^4\frac{M_{N_i}M_{N_f}}{E_f\omega}\frac{1}{4[p_i.k^2 - p_i{}^2k^2]^{\frac{1}{2}}}\frac{d^3p_f}{(2\pi)^3}\frac{d^3q}{(2\pi)^3}\sum_{m_\gamma m_s m_{s'}}\left|\mathcal{M}_{fi}\right|^2\delta^4(p_i + k - p_f - q), \tag{5}$$

where $m_\gamma = \pm 1$ and m_s and m_s represent the magnetic quantum numbers of the target and the recoiling nucleons, respectively. The gauge and Lorentz invariant matrices $M_i$can be calculated by:

$$\begin{aligned} M_1 &= \frac{1}{2}\gamma_5(\gamma.k \quad \gamma.\epsilon - \gamma.\epsilon \quad \gamma.k), \\ M_2 &= 2\gamma_5\left(\epsilon.p_i \ \ k.p_f - k.p_i \quad \epsilon.p_f\right), \\ M_3 &= \gamma_5(\gamma.\epsilon \ \ k.p_i - \gamma.k \quad \epsilon.p_i), \\ M_4 &= \gamma_5\left(\gamma.\epsilon \ \ k.p_f - \gamma.k \quad \epsilon.p_f\right), \end{aligned} \tag{6}$$

the c.m. differential cross section from the initial-nucleon state to final pion-nucleon state is given by:

$$\frac{d\sigma}{d\Omega_\pi^{c.m.}} = \frac{1}{64\pi^2}\frac{qM_{N_i}M_{N_f}}{kW^2}\sum_{m_\gamma m_s m_{s'}} |\mathcal{M}_{fi}|^2, \tag{7}$$

where the invariant πN mass W is given in the γN c.m. system as:

$$W_{\pi N} = E_i + E_\gamma, \tag{8}$$

and the pion momentum q is given by:

$$q = \sqrt{(\frac{m^2 + 2E_\gamma W}{2W})^2 - m^2}. \tag{9}$$

II. Results and discussion

The results presented here are calculated by using the effective Lagrangian model of Schmidt et al. [11] for pion photoproduction from the nucleon. We used the isobar MAID-2007 model to present these results for comparison too. In our comparison with experimental data in this discussion is focus on the π^0- production from proton, because data for π^0- and π^-- production from the neutron are still unavailable as of its short lifetime ($\tau = 886.7 \pm 1.9$sec.). Figs. (2) and (3) contain the results of the E-asymmetry for the neutral pion photoproduction channels $\gamma(p, \pi^0)p$ and $\gamma(n, \pi^0)n$, respectively. It is clear that the two channels have the same qualitatively behavior, the maximum value of E equals unity at $\theta = 0^o$ and 180^o, the curves begin with unity and decrease as the pion angles increase till a minimum value of E is reached at $\theta = 90^o$, then it increases again to unity. The negative values in the helicity E-asymmetry come mainly from $(d\sigma/d\Omega)P$ which the greater than $(d\sigma/d\Omega)A$. Also, one sees that some discrepancies between the two models ELA and MAID particularly at low energies after that the two curves commence to be identical around the Δ-resonance region then discrepancies appear again at high energies but little.

Generally we can observe that the bottom of the two curves ELA and MAID for the two channels $\gamma(p,\pi^0)p$ and $\gamma(n,\pi^0)n$ decreases by increasing the energies. In case of the charged pion photoproduction from the nucleon Figs. (4) and (5), one can observe that the two curves ELA and MAID for the two channels $\gamma(n,\pi^-)p$ and $\gamma(p,\pi^+)n$ have a bottom at $\theta = 90^o$ and the maximum value of E equals unity at $\theta = 0^o$ and 180^o like neutral pion cases. At energies above the π-threshold one notes that the E-asymmetry has a smaller values and the maximum values appear close to the Δ-resonance region then decrease again by increasing the photon energy, comparing the two models ELA and MAID one can find that the two curves are very close in case of π^+-production from proton although the discrepancies will reveal strongly in the case of π^-production from neutron, especially at high energies.

In Fig. 6 the results of E-asymmetry by using both ELA and MAID models are compared to the CLAS data [1] at photon lab-energy of 625 MeV. One finds a qualitatively good agreement between the two models ELA and MAID and the data points particularly in the middle region of cos(θπ) but at forward and backward directions some discrepancies are found particularly in ELA model case. Discrepancies in the values of ELA model can be found in the backward direction because this model contains only Born and the Δ(1232)-resonance contributions. We deduce from the comparison with MAID and CLAS data that the ELA model [11] valid till 500 MeV.

III. Conclusions

The helicity E-asymmetry for the reaction $\gamma(N,\pi)N$ is evaluated by using the ELA and MAID models from threshold till 500 MeV. A qualitative behavior and a large values can be gained in the neutral pion production channels $\gamma(p,\pi^0)p$ and $\gamma(n,\pi^0)n$ but in case of charged pion channels $\gamma(p,\pi^+)n$ and $\gamma(n,\pi^-)p$ a qualitative behavior with a small values excluding the Δ-resonance region is obtained. For the reason the ELA model mainly constitutes from Born and Δ-resonance contributions we can observe the discrepancies between it and MAID in neutral pion channels although this discrepancy is not big in the charged channels but at high energies for the $\gamma(n,\pi^-)p$ channel. A satisfactory agreement with the data from CLAS at 625 MeV can be carried out.

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References

[1] Hideco Iwamoto (AIP Conf. Proc. 275) 1432 (2012).

[2] R.A. Arndt, I. Strakovsky and R.L. Workman. *Phys.Rev.* C53430 (1996) [SAIDSM97 solution at http://gwdac.phys.gwu.edu].

[3] D. Drechsel, O. Hanstein, S.S. Kamalov and L. Tiator *Nucl. Phys.* A 645 145 (1999) [http://www.kph.uni-mainz.de/MAID].

[4] M.G. Olsson and E.T. Osypowski *Nucl. Phys.* B87 399 (1974); *Phys. Rev.* D 17 174 (1978); R.M. Davidson, N.C. Mukhopadhyay and R.S. Wittman *ibid.* 43 71 (1991); O. Scholten, A.Y. Korchin, V. Pascalutsa and D. Van Neck *Phys. Lett.* B 384 13 (1996); T. Feuster and U. Mosel, *Phys. Rev.* C 59 640 (1999); G. Penner and U. Mosel *ibid.* 66 055211(2002).

[5] S.S. Kamalov and S.N. Yang *Phys. Rev. Lett.* 83 4494 (1999); S.S. Kamalov, G.Y. Chen, S.N. Yang, D. Drechsel and L. Tiator *Phys. Lett.* B 522 27 (2001).

[6] T.Sato and T.S.H. Lee *Phys. Rev.* C 54 2660 (1996); *ibid.* 63 055201 (2001).

[7] Y. Surya and F. Gross *Phys. Rev.* C 53 2422 (1996); *ibid.* 47 703 (1993).

[8] G.F. Chew, M.L. Goldberger, F.E. Low and Y.Nambu *Phys. Rev.* 106 1345 (1957).

[9] F.A. Berends, A. Donnachie and D.L. Weaver *Nucl. Phys.* B 4 54 (1967).

[10] A Donnachie in *High Energy Physics*, Vol. 5 edited by E.H.S. Burhop Academic Press, New York, 1972.

[11] R. Schmidt, H. Arenhovel and P. Wilhelm *Z Phys.* A 355 421 (1996).

[12] J.D. Bjorken and S.D. Drell *Relativistic Quantum Mechanics.* McGraw-Hill New York, 1964.

[13] J.D. Bjorken and S.D. Drell *Relativistic Quantum Fields.* McGraw-Hill New York, 1964.

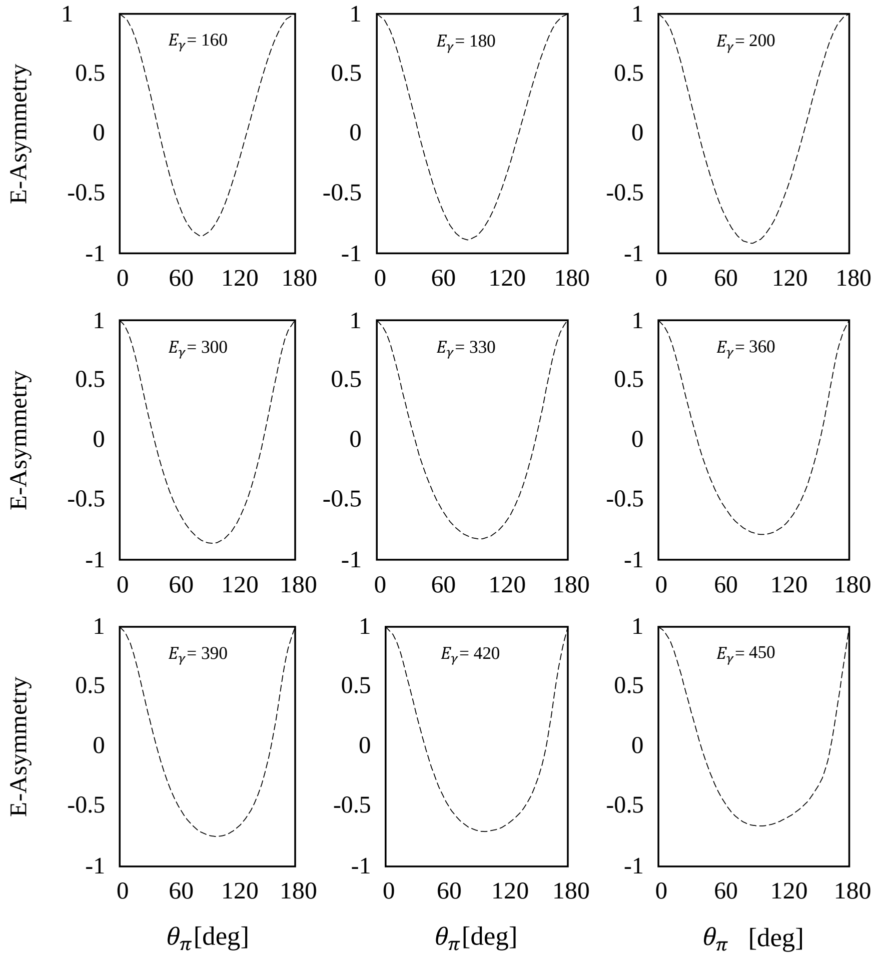

Fig. 2. The helicity asymmetry E as a function of $\theta_\pi$in the γNc.m. frame for selected photon energies E_γ for the reaction $\gamma(p,\pi^0)p$. Solid curve ELA model [11]; dashed curve MAID model [3].

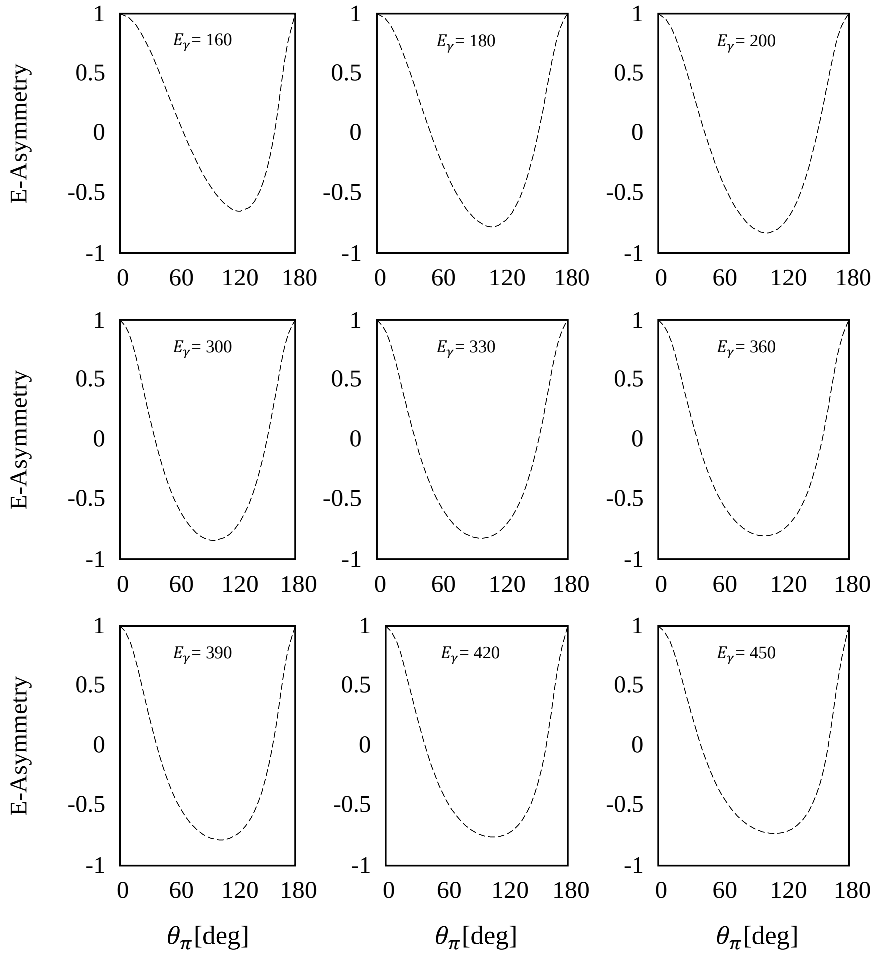

Fig. 3. Same as in Fig. 2 but for the $\gamma(n,\pi^0)n$ channel.

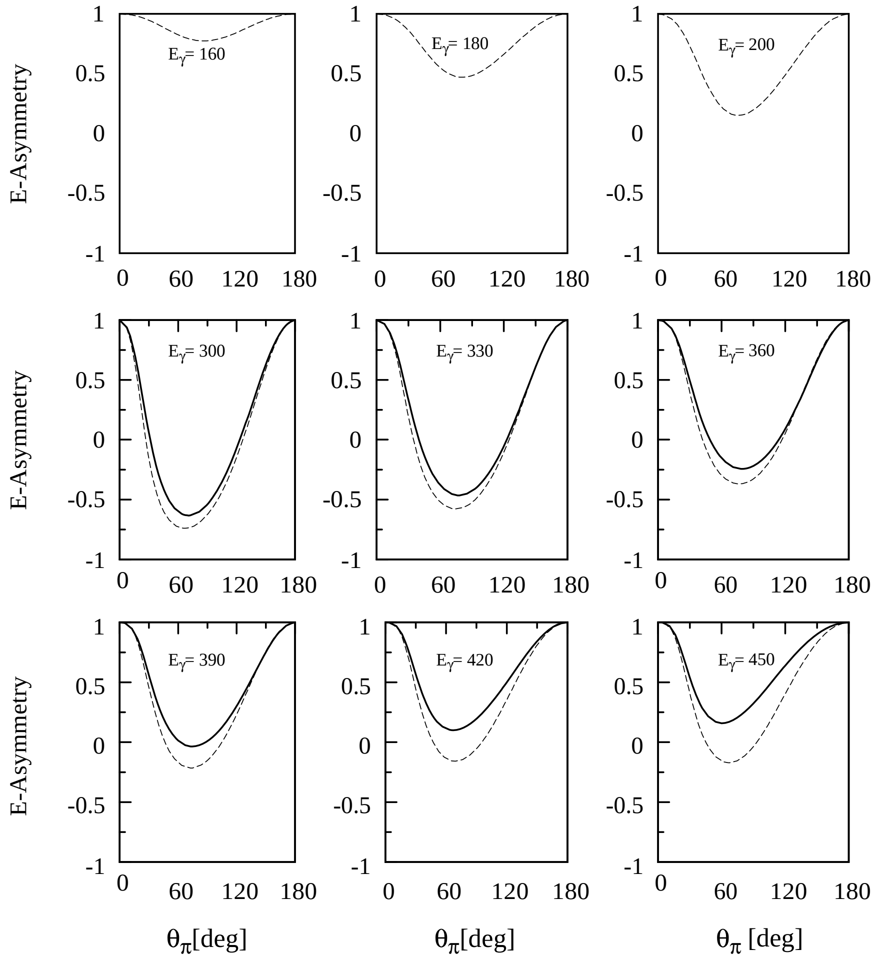

Fig. 4. Same as in Fig. 2 but for the $\gamma(n, \pi^-)p$ channel.

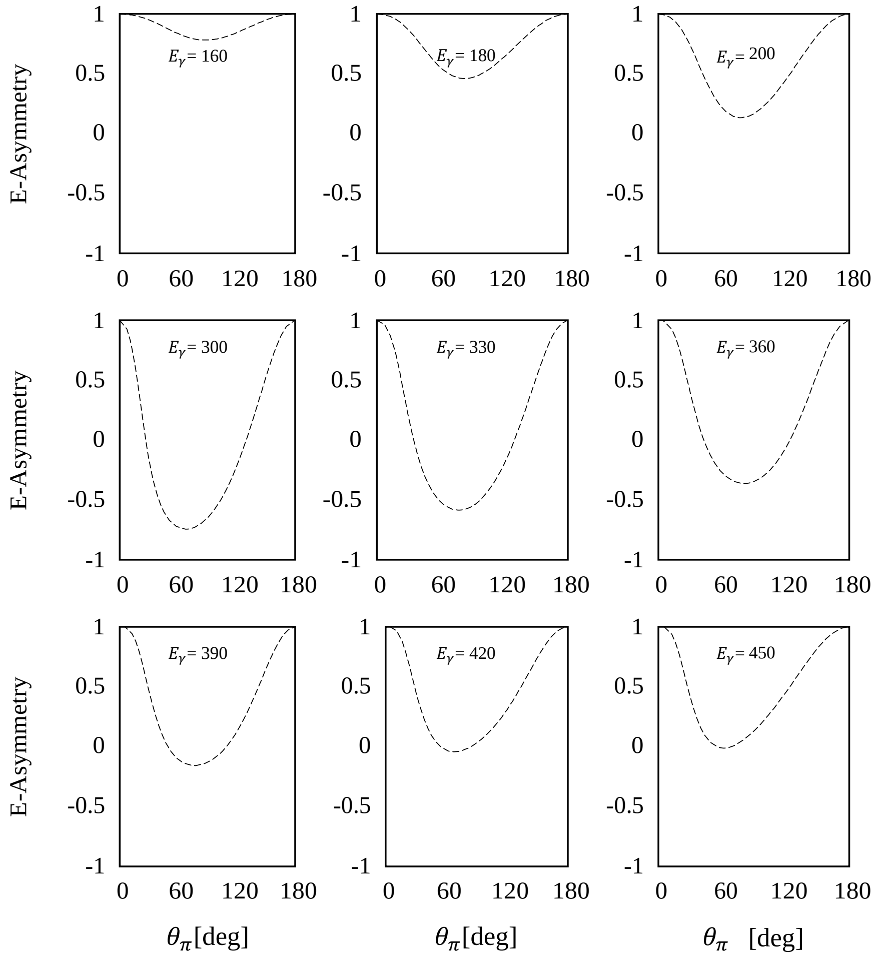

Fig. 5. Same as in Fig. 2 but for the $\gamma(p,\pi^+)n$ channel.

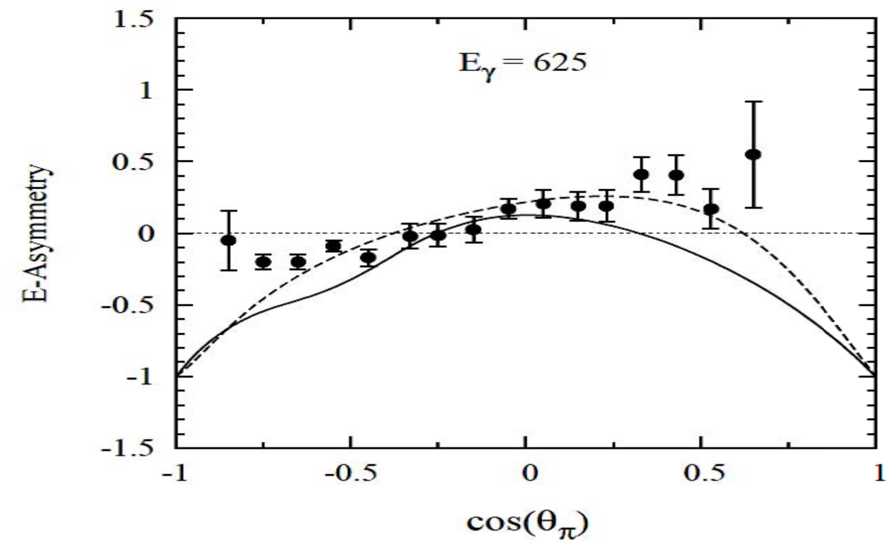

Fig. 6. The helicity asymmetry E as a function of $cos(\theta_\pi)$ in the γN c.m. frame at photon energy of 625 MeV for the reaction $\gamma(p, \pi^0)p$. Solid curve ELA model [11]; dashed curve MAID model [3]. The experimental data are from CLAS collaboration [1].