Chiral Symmetry and $\Delta(1232)$ Deformation in the Pion Electromagnetic Production

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We will review the current status in the studies of π^0 threshold production and the lowest-energy nucleon excitation-the $\Delta(1232)$-resonance in the pion electromagnetic production. Both topics offer excellent window to gain insight on the workings of QCD, the underlying theory of strong interaction.

π^0 electromagnetic production near threshold has been very precisely measured and intensely investigated in the chiral perturbation theory (ChPT) [1]. ChPT calculation to one loop $O(p^3)(O(p^4)$ in the case of photoproduction) has been carried out. It has also been studied in the Dubna-Mainz-Taipei (DMT) dynamical model [2], a meson-exchange model which starts from an effective chiral Lagrangian as well. Both ChPT and dynamical model calculations give, in general, nice agreement with data but discrepancies exist. We will compare these two different approaches to shed light on potential problem.

The possibility that hadrons could be deformed was first suggested by Glashow in 1979 on the basis of non-central (tensor) interactions, i.e., the color spin-spin interaction, between the quarks. One case which has been under intensive study is the electromagnetic excitation of the $\Delta(1232)$ resonance. At low four-momentum transfer squared Q^2, the interest is motivated by the possibility of observing a D state in the Δ. The existence of a D state in the Δ has the consequence that the Δ is deformed and the photon can excite a nucleon through electric $E2$ and Coulomb $C2$ quadrupole transitions. In a symmetric SU(6) quark model, the electromagnetic excitation of the Δ could proceed only via $M1$ transition. In pion electroproduction, $E2$ and $C2$ excitations would give rise to nonvanishing $E_{1+}^{(3/2)}$ and $S_{1+}^{(3/2)}$ multipole amplitudes. Recent experiments give nonvanishing ratio $R_{EM} = E_{1+}^{(3/2)}/M_{1+}^{(3/2)} \sim -0.025$ at $Q^2 = 0$ which has been widely taken as an indication of the Δ deformation.

The results of the state-of-art calculations based on chiral effective field theories (EFT), lattice QCD, and QCD-inspired models on the nucleon-to-Δ transition will be compared [3] with experimental transition form factors extracted from recent precision measurements of pion electromagnetic production with the dynamical and unitary-isobar models. Future developments like the possible effects of the two-photon exchange in the electroexcitation of the Δ will be discussed.

[1] See, e.g., A.M. Bernstein, in *Chiral Dynamics 2006*, edited by M.W. Ahmed *et al.* (World Scientific, Singapore, 2007), p. 3.

[2] S.S. Kamalov *et al.*, Phys. Lett. B522 (2001) 27.

[3] V. Pascalutsa, M. Vanderhaeghen, and S.N. Yang, Physics Reports, 437 (2007) 125.

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