Neutral-Pion Photoproduction on Protons near Threshold

First experimental results[1] on neutral-pion photoproduction from protons near threshold (NPPT), of fundamental interest as rigorous tests of corrections to the low-energy theorems (LET) and current algebra, and relevant in the context of understanding electroweak structure of hadrons, are in. Mazzucato *et al.*[1] extract the E_{0^+} amplitude at threshold to be -0.5 ± 0.3, in *strong disagreement* with the value of -2.47 predicted[2] by the LET, and with the previously inferred[1] experimental value of -1.8 ± 0.6, all in units of $10^{-3}/m_{\pi^+}$. This is the first claim of experimental evidence for the large s-wave rescattering effects[2] suspected in the E_{0^+} amplitude.

We are primarily concerned here with examination of uncertainties associated with the E_{0^+} prediction of the chiral-Lagrangean theory,[3,4] incorporating the LET and current algebra. We also comment on the analysis of Mazzucato *et al.*[1]

In an effective chiral-Lagrangean theory[3,4] the pseudovector nucleon Born terms incorporate the LET. To this, we can add (Table I) contributions from t-channel vector mesons (ρ,ω), and s- and u-channel Δ and higher baryon exchanges, fitting extant mulitpoles for c.m. energies between 1100 and 1350 MeV. This theory yields real amplitudes at the tree level. Their unitarization is not unique; thus, these amplitudes can be taken as either a T- or K-matrix element, where $T=K(1-iK)^{-1}$. With $T_{33}=\sin\delta\exp(i\delta)$, we have

$$T_{31} \approx \cos\delta\exp(i\delta)\left[K_{31}+\frac{iK_{32}K_{21}}{1-iK_{22}}\right], \qquad (1)$$

where channels 1, 2, and 3 are γp, $\pi^+ n$, and $\pi^0 p$, respectively. We can use the theory to compute $|T_{31}|$ and unitarize it by giving it the Watson phase δ, or compute T_{31} via (1). The latter produces the so-called "cusp effect" in the cross section.[5]

Table I shows our theoretical predictions for the real part of the multipoles for NPPT, in the form $E_{0^+}=a/m_{\pi^+}$, $M_{1^-}=bqk/m_{\pi^+}^3$, and $M_{1^+}=cqk/m_{\pi^+}^3$, q and k being the c.m. pion and photon momenta. We find the cusp effect to be only important for E_{0^+}. $P_{11}(1450)$ and $S_{11}(1535)$ contribute less than 10% of each of these multipoles for NPPT. Other resonances may not be negligible and need further investigation. Thus, if we ignore contributions from higher resonances, the *chiral-Lagrangean–theory prediction of E_{0^+} remains in serious disagreement with the new value of E_{0^+} at threshold. However, its predictions for M_{1^+} and M_{1^-} are in excellent agreement with the recent experiment.*[1] It is also very successful in the Δ region.[4]

TABLE I. Various contributions to calculated values of multipoles for π^0 photoproduction near threshold in units of 10^{-3}. See text for definition of a, b, and c. Cusp effect is shown for "Total" only. Experimental values (Ref. 1) for a, b, and c are -0.5 ± 0.3, -2.0 ± 1.5, and 8.0 ± 0.3, respectively, in same units.

	Nucleon Born and vector meson	Δ	Total with cusp effect
a	−2.39	0.35	−2.86
b	−5.72	2.22	−3.48
c	4.13	3.83	7.97

Some comments on the results of Mazzucato *et al.*[1] are now in order. Given their fitted multipoles, we get the coefficient C to be always *negative* for E_γ between 146.5 and 169.2 MeV, consistent with zero, in contrast to values given in their Table I. Note that the coefficient C is negative, for $E_{1^+}=0$, if $c > -2b$, which is the case for multipoles extracted in Ref. 1, satisfying the relation $c \approx -4b$, b being negative. Also, fitting multipoles to their A, B, and C's, we end up with b in M_{1^-} significantly different from $(-2.0 \pm 1.5)\times 10^{-3}$, ours being close to -7×10^{-3}. This is only meant to illustrate the apparent discrepancy between the values of M_{1^-} and the coefficient C of Mazzucato *et al.*,[1] particularly close to threshold. However, such problems do not exist with their E_{0^+} and M_{1^+} values. Thus, serious disagreement between LET and experiment for E_{0^+} still persists, and calls for further experimental and theoretical work.

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[1] E. Mazzucato *et al.*, Phys. Rev. Lett. **57**, 3144 (1986).

[2] See, for example, G. Furlan *et al.*, Nuovo Cimento **62**, 519 (1969).

[3] M. G. Olsson *et al.*, Phys. Rev. D **17**, 2938 (1978), and references therein.

[4] R. Davidson, N. C. Mukhopadhyay, and R. Wittman, Phys. Rev. Lett. **56**, 804 (1986). Couplings and parameters in the calculation reported here are from a recent analysis of the photoproduction multipoles, to be published elsewhere.

[5] G. Fäldt, Nucl. Phys. **A333**, 357 (1980).