STATIC MAGNETIC MOMENT OF THE $\Delta(1232)$*

M. Kotulla

for the TAPS and A2 Collaborations
II. Physikalisches Institut Universitaet Giessen
Heinrich-Buff-Ring 16, 35392 Giessen, Germany

(Received February 11, 2002)

The reaction $\gamma\, p \to \pi^0 \gamma'\, p$ has been measured with the TAPS calorimeter at the Mainz microtron facility. This reaction channel provides access to the static magnetic moment of the $\Delta^+(1232)$ resonance. Preliminary energy differential cross sections are presented and compared to recent calculations of the $\gamma\, p \to \pi^0 \gamma'\, p$ reaction.

PACS numbers: 13.40.Em, 14.20.Gk, 25.20.Lj

1. Introduction

The static properties of baryons like magnetic moments or polarizabilities carry valuable information about the baryonic structure. In particular, they provide an important testing ground for QCD based calculations in the confinement region. It is generally assumed that the $\Delta^+(1232)$ resonance has a similar quark structure as the proton, except that the spins couple to $J = 3/2$ instead of $J = 1/2$ as for the proton.

However, due to its short lifetime it is experimentally very difficult to investigate the internal structure of the Δ resonance. In general very little experimental information is available outside the ground state SU(3) octet. Table I shows predictions of different calculations for μ_Δ in comparison to the experimental status.

Kondratyuk and Ponomarev [7] proposed a method to investigate the static electromagnetic structure of the Δ isobar. Figure 1 shows an energy level diagram with the proton (nucleon) as the ground state and the Δ as the first excited state. The Δ structure can be probed by exciting the proton with a photon to a Δ, which subsequently emits a real photon followed by the decay into a nucleon and a pion. Spin and parity conservation requires that the lowest order electromagnetic transition is magnetic dipole (M1)

* Presented at the VI TAPS Workshop, Krzyże, Poland, September 9–13, 2001.

TABLE I

Predictions of different quark models for μ_Δ in comparison to the experimental status (PDG2000).

	$\mu_{\Delta^{++}}/\mu_N$	$\mu_{\Delta^{+}}/\mu_N$	$\mu_{\Delta^{0}}/\mu_N$	$\mu_{\Delta^{-}}/\mu_N$
PDG2000 [1]	3.7–7.5	—	—	—
SU(3): $\mu_\Delta = Q_\Delta\, \mu_p$	5.58	2.79	0	−2.79
RQM [2]	4.76	2.38	0	−2.38
lattice QCD [3]	4.9±0.6	2.5±0.3	0	−2.5±0.3
χPT [4]	4.0±0.4	2.1±0.2	−0.17±0.04	−2.25±0.25
χQSM [5]	4.73	2.19	−0.35	−2.90
LCQSR [6]	4.4±0.8	2.2±0.4	0.0	−2.2±0.4

radiation. This $\Delta \to \Delta\gamma'$ amplitude is proportional to μ_{Δ^+} and was recently investigated in [8, 9]. The next allowed multipole is the higher order electric quadrupole (E2) transition, but this contribution is generally assumed to be small [18].

Therefore, the measurement of the reaction $\gamma\, p \to \pi^0\gamma'\, p$ provides access to μ_{Δ^+}. Unfortunately, the final state $\pi^0\gamma'\, p$ can result from several reaction processes (compare figure 2). The advantage of the reaction $\gamma\, p \to \pi^0\gamma'\, p$

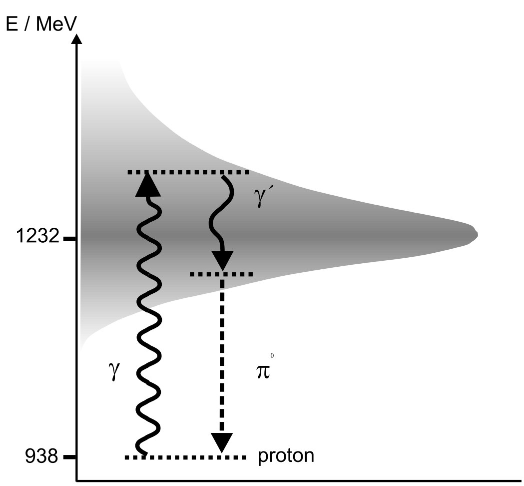

Fig. 1. Method to study the static electromagnetic properties of the $\Delta^+(1232)$ isobar. The γ' transition carries the desired information.

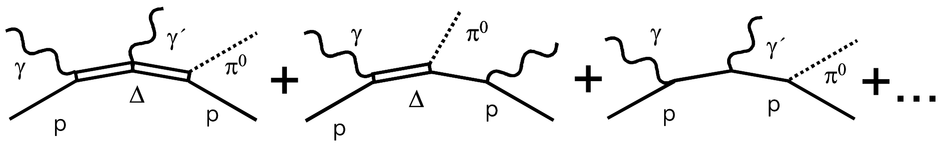

Fig. 2. Left: diagram with an amplitude sensitive to μ_{Δ^+}. Middle: a Δ-resonant bremsstrahlung diagram and (right hand side) a Born diagram as an example for other possible processes which also lead to the $\pi^0\gamma'\,p$ final state.

is that there are only heavy particles, Δ and proton, contributing to the bremsstrahlung radiation. Consequently the bremsstrahlung contributions are of the same order as the interesting $\Delta \to \Delta\gamma'$ transition. In addition the dominance of the resonant reaction process of the reaction $\gamma\, p \to \pi^0\, p$ leads to the assumption that the background Born contributions are playing a minor role which makes the extraction of μ_{Δ^+} easier. The reaction channel $\gamma\ p \to \pi^+\gamma'\, n$ is in that sense less favorable for extracting the magnetic moment of the Δ^+ isobar. In summary, a consistent theoretical description of all contributing processes is crucial for extracting μ_{Δ^+}.

The magnetic moment of the Δ^{++} isobar was extracted in a similar way from the reaction $\pi^+\ p \to \pi^+\gamma'\ p$. Two measurements at the University of California (UCLA) [11] and Schweizerisches Institut für Nuklearforschung (SIN, todays name PSI) [12] have been performed and as a result of many theoretical analyses of these data the Particle Data Group [1] quotes a range of 3.7–7.5 μ_N for $\mu_{\Delta^{++}}$.

2. Experimental setup and analysis methods

The reaction $\gamma\ p \to \pi^0\gamma'\ p$ was measured at the electron accelerator Mainz Microtron (MAMI) [13, 14] using the Glasgow tagged photon facility [15] and the photon spectrometer TAPS [16]. A quasi monochromatic photon beam was produced via bremsstrahlung tagging. The photon energy range covered was 205–820 MeV with an average energy resolution of 2 MeV. The TAPS detector consisted of six blocks each with 62 hexagonally shaped BaF_2 crystals arranged in an 8×8 matrix and a forward wall with 138 BaF_2 crystals arranged in a 11×14 rectangle. The six blocks were located in a horizontal plane around the target at angles of $\pm54°$, $\pm103°$ and $\pm153°$ with respect to the beam axis. Their distance to the target was 55 cm and the distance of the forward wall was 60 cm. This setup covered $\approx 38\%$ of the full solid angle. All BaF_2 modules were equipped with 5 mm thick plastic detectors for the identification of charged particles. The liquid hydrogen target was 10 cm long with a diameter of 3 cm.

The reaction was exclusively measured, *i.e.* the four-momenta of all particles in the final state were measured. The π^0 mesons were detected via their two photon decay channel and identified in a standard invariant mass analysis using the measured photon energies and angles as input. For the data shown in the talk, the two π^0 decay photons and the third photon in the final state were distinguished by using the π^0 invariant mass as a selection criterion. The two photons with an invariant mass closest to the π^0 mass were assigned to be the decay photons. The protons were identified using the excellent time resolution of the TAPS detector. The characteristic time of flight dependence on the energy of the proton and a pulse shape analysis were sufficient to obtain a very clean proton signal.

Exploiting the kinematic overdetermination of the reaction, further kinematic checks were performed. Special attention had to be paid to the $2\pi^0$ production as a possible background channel. This arises from the limited coverage of the full solid angle since one of the four $2\pi^0$ decay photons might have escaped undetected. In a first step, the conservation of the total momentum in the three Cartesian directions was checked, respectively. After that a missing mass analysis was performed to discriminate a possible $2\pi^0$ contamination. The following missing mass was calculated:

$$M^2_{\mathrm{miss}} = \left((E_{\pi^0} + E_p) - (E_{\mathrm{beam}} + m_p)\right)^2 - \left((\vec{p}_{\pi^0} + \vec{p}_p) - (\vec{p}_{\mathrm{beam}})\right)^2 , \qquad (1)$$

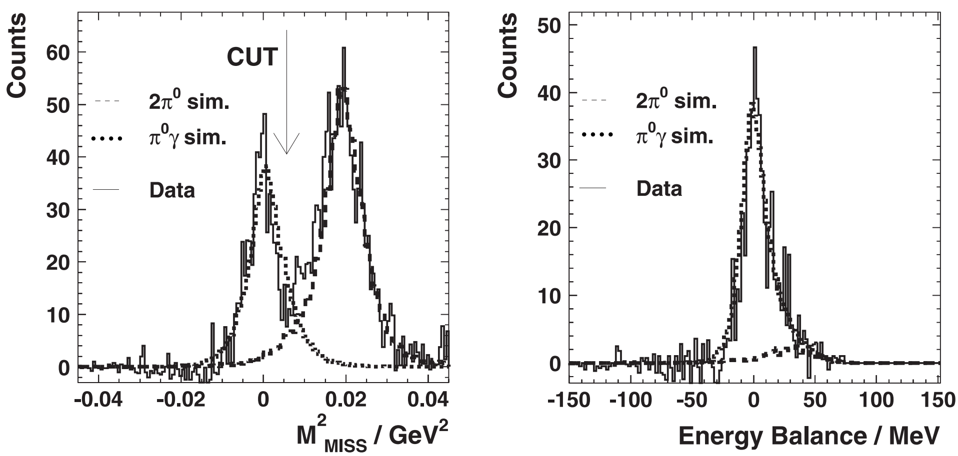

Fig. 3. Left: missing energy of the π^0 p in the final state. The peak near 0.02 GeV^2 originated from $2\pi^0$ production and was cut away. For the peak at 0 GeV^2 the energy balance of the reaction was checked (right hand side). Right: energy balance for the reaction $\gamma\, p \to \pi^0 \gamma'\, p$. The dashed and dotted lines show the corresponding simulated line-shapes using GEANT3.

where $E_{\pi^0}, \vec{p}_{\pi^0}, E_p, \vec{p}_p$ denotes the energy and momenta of the π^0 and proton in the final state and m_p the proton mass. The resulting distribution (figure 3 left hand side) allowed an efficient discrimination of the $2\pi^0$ background. A Monte Carlo simulation using GEANT3 [17] of the $2\pi^0$ and $\pi^0\gamma'$ reactions reproduced the line-shape of the measured data. As the final kinematic check the energy balance was calculated to test energy conservation

$$E_{\text{bal}} = (E_{\text{beam}} + m_p) - (E_{\pi^0} + E_p + E_{\gamma'})\,. \tag{2}$$

The notation is the same as in Eq. (1). Figure 3 right hand side shows the resulting clean identification of the $\gamma\, p \to \pi^0\gamma'\, p$ reaction channel.

The cross section can be deduced from the rate of the $\pi^0\gamma' p$ events divided by the number of hydrogen atoms per cm^2, the photon beam flux, the branching ratio of π^0 into two photons and the detector and analysis efficiency. The detector acceptance and analysis efficiency were calculated performing a Monte Carlo simulation using the GEANT3 code. For this purpose figure 4 shows the comparison between the energy distribution of the photon γ' and the π^0 meson. The phase-space assumption is in clear contradiction to the data, whereas the calculation [18] shows a nice agreement of spectral form. Therefore, the efficiency is calculated using the calculation [18] to simulate the particles in the final state.

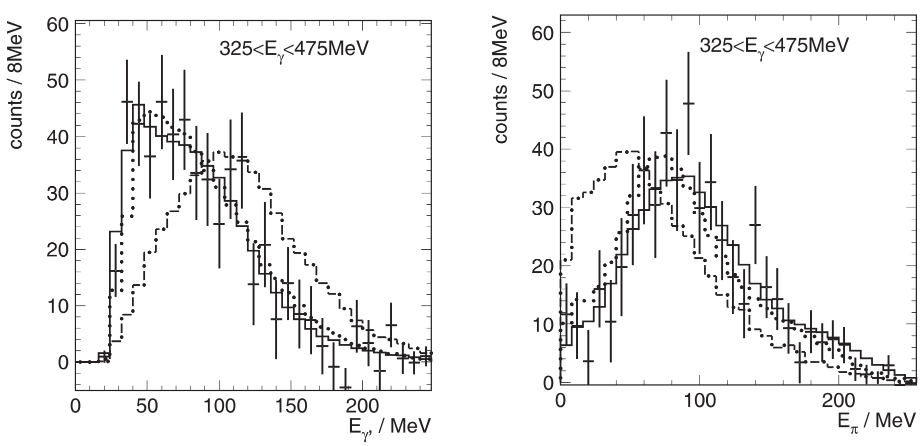

Fig. 4. Comparison of the $E_{\gamma'}$ (left-hand side) and the E_{π^0} (right-hand side). Energies between the data (points) and two GEANT3 simulations in the lab frame. The dashed dotted line shows pure phase-space and the solid line distributions according to the calculation [18].

3. Preliminary results and conclusion

The measured differential cross sections for the reaction $\gamma\ p \to \pi^0 \gamma'\ p$ are shown in figure 5 for two different incident photon beam energies. Since the data analysis is not finished yet, only preliminary cross sections are presented.

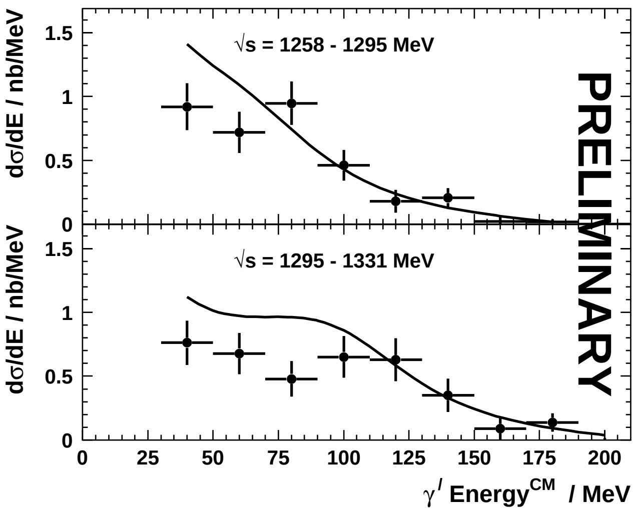

Fig. 5. Preliminary energy differential cross section for two incident photon beam energies. The solid line shows the Drechsel, Vanderhaeghen calculation [18] which includes the bremsstrahlung diagrams (Δ resonant and non-resonant Born terms). The calculation is shown for a value of $\mu_{\Delta^+} = 3\mu_N$.

The first series of calculations, only including the resonant $\Delta \to \Delta\gamma'$ process, were done by Machavariani, Faessler, Buchmann [8] and Drechsel, Vanderhaeghen *et al.* [9]. Both groups use the effective Lagrangian formalism and the latter one in addition a quark model approach to describe the reaction. Since these calculations are incomplete, they cannot reproduce the measured cross sections.

Recently Drechsel and Vanderhaeghen [18] extended their calculation and included bremsstrahlung diagrams (resonant Δ and non-resonant Born diagrams) as exemplarily indicated in figure 2. This calculation is shown in comparison to the preliminary data and a favorable agreement can be stated.

In conclusion, the possibility of measuring the reaction $\gamma\ p \to \pi^0 \gamma'\ p$ has been demonstrated. Further investigations have to be made in order to explore the accuracy of the Δ^+ magnetic moment that can be extracted from the present data set.

As an outlook, the current studies call for a dedicated experiment using a 4π detector with a high luminosity photon beam in order to measure the reaction $\gamma\ p \to \pi^0 \gamma'\ p$ with high statistical precision. Special kinematical regions for the cross section $d\sigma/(dE_\gamma\, d\Omega_\gamma\, d\Omega_\pi)$ promise a higher sensitivity to μ_{Δ^+} [18]. The same holds for measuring the photon asymmetry using a linearly polarized photon beam. Such an experiment is being prepared for the Crystal Ball detector at the Mainz Microtron accelerator facility [19].

It is a pleasure to acknowledge inspiring discussions with M. Vanderhaeghen, D. Drechsel, A. Machavariani and A. Faessler. I would like to thank the accelerator group of MAMI as well as many other scientists and technicians of the Institut für Kernphysik at the University of Mainz for the outstanding support. This work is supported by DFG Schwerpunktprogramm: Untersuchung der hadronischen Struktur von Nukleonen und Kernen mit elektromagnetischen Sonden.

REFERENCES

[1] Review of Particle Physics (Particle Data Group), *Eur. Phys. J.* **C**, 2000.

[2] F. Schlumpf, *Phys. Rev.* **D48**, 4478 (1993).

[3] D.B. Leinweber *et al.*, *Phys. Rev.* **D46**, 3067 (1992).

[4] M.N. Butler *et al.*, *Phys. Rev.* **D49**, 3459 (1994).

[5] H.C. Kim *et al.*, *Phys. Rev.* **D57**, 2859 (1998).

[6] T.M. Aliev *et al.*, *Nucl. Phys.* **A678**, 443 (2000).

[7] L.A. Kontratyuk, L.A. Ponomarev, *Yad. Fiz.* **7**, 11 (1968); [*Sov. J. Nucl. Phys.* **7**, 82 (1968)].

[8] A.I. Machavariani *et al.*, *Nucl. Phys.* **A626**, 231 (1999).

[9] D. Drechsel *et al.*, *Phys. Lett.* **B484**, 236 (2000).

[10] R. Beck, H.P.-Krahn *et al.*, *Phys. Rev. Lett.* **78**, 606 (1997).

[11] B.M.K. Nefkens *et al.*, *Phys. Rev.* **D18**, 3911 (1978).

[12] A. Bosshard *et al.*, *Phys. Rev.* **D44**, 1962 (1991).

[13] Th. Walcher, *Prog. Part. Nucl. Phys.* **24**, 189 (1990).

[14] J. Ahrens *et al.*, *Nucl. Phys. News* **4**, 5 (1994).

[15] I. Anthony *et al.*, *Nucl. Instrum. Methods* **A301**, 230 (1991).

[16] R. Novotny, *IEEE Trans. Nucl. Sci.* **A38**, 379 (1991).

[17] R. Brun *et al.*, GEANT3.21 CERN program Library, Geneva 2000.

[18] D. Drechsel, M. Vanderhaeghen, *Phys. Rev.* **C64**, 065202 (2001).

[19] R. Beck, B.M.K. Nefkens *et al.*, Letter of intent MAMI 2001.