Abstract

Using the Mainz 48cm Ø x 64cm NaI(Tl) detector and the segmented Göttingen recoil detector SENECA in coincidence, Compton scattering by the proton at $\theta_{\text{lab}} = 136^\circ$ has been measured at MAMI (Mainz) in the energy range from 200 to 470 MeV. The new data confirm the previous observation that there is a systematic discrepancy between MAMI and LEGS (Brookhaven) data leading to different spin polarizabilities $\gamma_{\pi} = -38.7 \pm 1.8$ and $-27.2 \pm 3.1 \times 10^{-4}\text{fm}^4$, respectively.

11.55.Fv, 13.60.Fz, 14.20.Dh, 25.20.Dc
The electromagnetic structure of the nucleon has been a fascinating field of research for a long time. Great progress has been made recently by determining basic electromagnetic structure constants with increasing precision – the electric and magnetic dipole polarizabilities $\alpha$ and $\beta$, the forward and backward spin polarizabilities $\gamma_0$ and $\gamma_\pi$, and the multipole ratio $E_2/M_1$ of the radiative $\gamma N \to \Delta$ transition. While there is now a consistent set of data for the electromagnetic polarizabilities of the proton, a controversy remains for its backward spin polarizability $\gamma_\pi$. The sum of the electromagnetic polarizabilities has been determined via the Baldin sum rule. A recent redetermination of this quantity \cite{1} gave the value

$$\alpha_p + \beta_p = 14.0 \pm 0.3,$$

(in units of $10^{-4}\text{fm}^3$ used for the dipole polarizabilities in the following), which seems to be the most reliable result replacing previous determinations as discussed in \cite{1}. This value is in agreement with another recent determination \cite{2} giving $\alpha_p + \beta_p = 13.8 \pm 0.4$. A new value for the difference of the electric and magnetic polarizabilities has been obtained by Olmos et al. \cite{2} at MAMI, which, combined with previous results, gives a global average of

$$\alpha_p - \beta_p = 10.5 \pm 0.9_{\text{stat+syst}} \pm 0.7_{\text{model}}.$$  

A detailed comparison of this number with the previous results may be found in \cite{2}.

A remarkable result obtained by the LEGS group \cite{3,4} was the value of the backward spin polarizability of the proton $\gamma_\pi = -27.23 \pm 2.27_{\text{stat+syst}} +2.24_{\text{stat+syst}} -2.10_{\text{model}}$ (in units of $10^{-4}\text{fm}^4$ used for $\gamma_\pi$ throughout this paper). This value is in contradiction with the predictions of standard dispersion theory \cite{5-7} and also with chiral perturbation theory \cite{8-10} ranging from $-34$ to $-41$ and, therefore, led to the speculation that some hitherto unknown effect related to the spin structure of the nucleon might exist. However, a Compton scattering experiment carried out at MAMI using the $48\text{cm} \times 64\text{cm}$ NaI(Tl) detector \cite{11} confirmed the standard value of $\gamma_\pi = -37.6$ \cite{12}. This latter result has recently been confirmed in further experiments carried out at MAMI using the large acceptance arrangement LARA \cite{13,14} and TAPS \cite{2}. The result obtained with LARA through fits to the experimental differential cross section \cite{13,14} is

$$\gamma_\pi = -37.1 \pm 0.6_{\text{stat+syst}} \pm 3.0_{\text{model}},$$

when using the SAID-SM99K parameterization \cite{15} as a basis in the unsubtracted dispersion theory \cite{12} and

$$\gamma_\pi = -40.9 \pm 0.6_{\text{stat+syst}} \pm 2.2_{\text{model}},$$

when using the MAID2000 parameterization \cite{16}. The result obtained from low energy Compton scattering using the TAPS detector \cite{2} is

$$\gamma_\pi = -35.9 \pm 2.3_{\text{stat+syst}}.$$  

Although there is a slight dependence of the results obtained on the type of parameterization of photomeson amplitudes the accuracy is good enough to clearly not agree with the corresponding values obtained by the LEGS group.
It has been shown [11,13,14] that these discrepancies between MAM I and LEGS can be traced back to a discrepancy in the experimental differential cross sections for Compton scattering by the proton obtained in the $\Delta$ resonance region. In the present work we use new data on Compton scattering by the proton, which were obtained in the course of a series of systematic studies of free and quasi-free Compton scattering by the nucleon, carried out to determine the electromagnetic polarizabilities of the neutron, where the present experiments served as a test.

The apparatus used is shown in Fig. 1. Tagged photons produced in the tagging facility at MAMI entered a scattering chamber, containing a 4.6cmØ×16.3cm liquid hydrogen target in a Kapton target cell. The 48cmØ×64cm NaI(Tl) detector was positioned at a distance of 60 cm from the target center under a scattering angle of $\theta_{\text{lab}} = 136^\circ$. As a recoil detector the Göttingen SENECA detector was used, positioned at a distance of 250 cm. SENECA was built as a neutron detector capable of pulse-shape discrimination. It is a honeycomb structure of 30 hexagon-shaped detector cells of 15.0 cm minimum diameter and 20.0 cm length filled with NE213 liquid scintillator. The entrance face is covered by four plastic scintillators to discriminate between charged and neutral particles. For Compton scattering by the free proton carried out in the $\Delta$ range the energy resolution of the NaI(Tl) detector is already sufficient to discriminate between photons from Compton scattering and $\pi^0$ photoproduction. However, as shown previously [17], there is an advantage in also detecting the recoil proton for photon energies above the peak of the $\Delta$ resonance.

The result of the experiment is shown in Fig. 2, together with theoretical predictions and compared with the recently published results from the LEGS experiment [4,18], and the Mainz-LARA [13,14] and Saskatoon [19] data. For the comparison of the different sets of data a scattering angle of $\theta_{\text{c.m.}} = 135^\circ$ was chosen. This scattering angle is close enough to the ones of the four experiments, so that only small corrections were needed to compensate for the shifts in scattering angle. These small corrections were calculated from the nonsubtracted dispersion theory [12] used throughout this analysis. As an input of this theory the MAID2000 and SAID-SM99K parameterizations of photomeson amplitudes have been used to determine the imaginary parts of invariant amplitudes. As obtained previously [13,14] a mass parameter of $m_\sigma = 600$ MeV was applied for the pole term used to model the asymptotic part of the invariant amplitude $A_1(\nu,t)$. As a further parameter of this amplitude the difference $\alpha - \beta = 10.5 \pm 1.1$ (see Eq. (2)) was used. Then the only remaining parameter is $\gamma_\pi$. The backward spin polarizability extracted from the present data is

\begin{align}
g_\pi &= -36.5 \pm 1.6_{\text{stat}} \pm 0.6_{\text{syst}} \pm 1.8_{\text{model}} \, (\text{SAID-SM99K}), \\
g_\pi &= -39.1 \pm 1.2_{\text{stat}} \pm 0.8_{\text{syst}} \pm 1.5_{\text{model}} \, (\text{MAID2000}).
\end{align}

From the Mainz values of Eqs. (3) – (7) given above we obtain a weighted average of $g_\pi = -38.7 \pm 1.8$. As in previous investigations [13,14] our present values are consistent with the standard $\pi^0$ pole to describe the asymptotic part of the amplitude $A_2(\nu,t)$ and are also in agreement with model predictions.

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FIG. 1. Experimental arrangement used for the present experiment on Compton scattering by the proton. Compton scattering events were identified through coincidences between the Mainz 48 cm Ø × 64 cm NaI(Tl) photon detector positioned under 136° and the Göttingen segmented recoil counter SENECA positioned under 18°. The insert shows a perspective view of this arrangement.

FIG. 2. Experimental differential cross sections for Compton scattering by the proton at $\theta_{c.m.} = 135^\circ$. Full squares: present data. Open circles: LEGS data. Open triangles: Mainz-LARA data. Open squares: Saskatoon data. The solid curve was calculated using the nonsubtracted dispersion theory based on the MAID2000-parameterization and adopting the Mainz weighted average of $\gamma_\pi = -38.7$. The dashed (dotted) curve was obtained in the same way, but replacing the value of the spin polarizability by $\gamma_\pi = -27.2$ ($-23.3$), where $\gamma_\pi = -23.3$ corresponds to an optimal fit to the LEGS data at $\theta_{c.m.} = 135^\circ$ in the framework of the MAID2000-parameterization.
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