

Measurement of the Gerasimov-Drell-Hearn integrand for the proton and deuteron from 200 to 1400 MeV

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New data for the total inclusive helicity-dependent cross section for the proton and deuteron were obtained in the photon energy interval 200–1400 MeV. The experiment was performed at the A2 tagged-photon facility of the Mainz Microtron (MAMI) using a circularly polarized photon beam and longitudinally polarized proton and deuteron targets. The reaction products were detected using the large-acceptance Crystal Ball/TAPS calorimeter, which covers 97% of the full solid angle. These new results, obtained with fine energy binning, significantly expand both the quantity and the quality of the available data for these observables and enable a detailed comparison with state-of-the-art theoretical calculations. From the combination of the results for the deuteron and the proton, important information could also be extracted for the neutron. Based on these data, and using existing models to evaluate the missing contributions from unmeasured photon energy regions, the validity of the Gerasimov-Drell-Hearn (GDH) sum rule has been verified for the proton, the neutron, and the deuteron. These new data provide a precise experimental benchmark for theoretical models used to study nucleons, both in their free state and when embedded in the nuclear medium.

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I. INTRODUCTION

The Gerasimov-Drell-Hearn (GDH) sum rule establishes a fundamental link between the total absorption cross section of circularly polarized photons on longitudinally polarized nucleons and nuclei and their static properties [1,2]. The two relative spin configurations, parallel or antiparallel, determine the two absorption cross sections σ_P and σ_A . In the target rest frame, the integral over the photon energy E_γ of the difference of these two cross sections, weighted by the inverse of E_γ , is related to the mass M , spin S , and anomalous magnetic moment κ of the nucleon (nucleus) as follows:

$$I = \int_{\nu_0}^{\infty} \Delta\sigma \frac{dE_\gamma}{E_\gamma} = \frac{4\pi^2\alpha}{M^2} S\kappa^2, \quad (1)$$

where $\Delta\sigma = (\sigma_P - \sigma_A)$, ν_0 is the minimal photon energy that can be absorbed by the target, and α is the fine-structure constant.

This key sum rule, formulated in the 1960s, rests upon basic physics principles (Lorentz-invariance, gauge invariance, unitarity) and an unsubtracted dispersion relation applied to the forward Compton amplitude (for comprehensive reviews of the GDH sum rule and related integrals, see [3–5]). It implies that a nonzero anomalous magnetic moment κ is directly connected to the excitation spectrum of the nucleon (nucleus) and, therefore, to its composite nature.

Experiments performed by the GDH Collaboration at both Bonn (ELSA) and Mainz (MAMI) have measured for the first time the GDH integrand for a proton (deuteron) target through the range of incident photon energies $E_\gamma = 0.2$ – 0.8 GeV (MAMI) and 0.7 – 2.9 (1.8) GeV (ELSA) [6–12]. The combination of these experimental results with model-dependent estimates of the contributions of the unmeasured photon energy intervals yields an estimate that is consistent with the GDH sum rule values of the proton ($205 \mu\text{b}$) within the experimental uncertainties.

Recently, additional interest in the GDH sum rule has been stimulated by its connection to understanding and describing the properties of nucleons bound in the nuclear medium [13,14].

In this context, both sides of Eq. (1) are expected to be modified. This is because the nucleon magnetic moment is predicted to be enhanced (see, for instance, [15,16]), and the contribution of the $\Delta(1232)$ resonance excitation, which constitutes the main contribution to the left-hand side integral, will occur at slightly lower incident photon energies compared to the free-nucleon case, due to nuclear binding energy effects. Thus, measuring the GDH sum rule integral for different nuclear targets constitutes an extremely sensitive tool for the quantitative experimental study of possible medium modifications, a fundamental problem in nuclear physics.

For these studies, it is crucial to have highly precise data for both the free nucleon and the deuteron (the simplest nucleon bound state), particularly in the first and second resonance regions, where nuclear effects are most significant (see, for instance, [17] and references therein). In both cases, microscopic theoretical models can be used to perform a precise isospin decomposition of the free reaction amplitudes. In line with these objectives, ongoing plans to study the con-

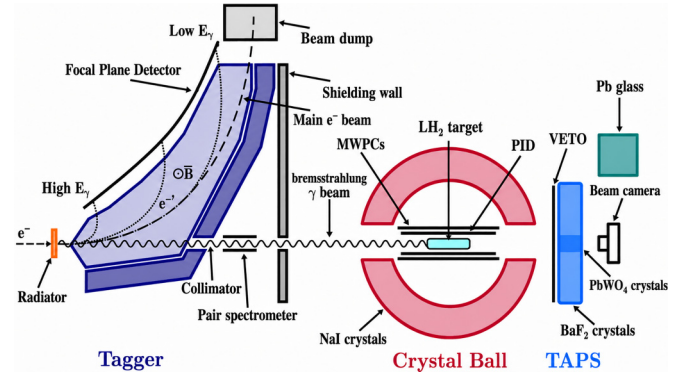


FIG. 1. Sketch of the experimental setup of the A2 Collaboration tagged photon facility, including photon tagging apparatus and detectors [22]. The figure is not to scale.

vergence of the GDH integral for the nucleon [18] and the helicity dependence of the total inclusive photoabsorption cross section on light and medium nuclei are currently under development at the JLab facility (see, for instance, [19,20]).

In this paper, we present a precise measurement of the GDH integrand for both the proton and the deuteron at incident photon energies from 200 MeV up to approximately 1.4 GeV. This experiment was performed at the tagged-photon facility of the MAMI electron accelerator in Mainz, Germany [21], using the experimental setup of the A2 Collaboration. From the combination of the results obtained for the deuteron and the proton, important information has also been deduced for the neutron.

II. EXPERIMENTAL SETUP

The helicity-dependent data used for this analysis were collected in different beamtime periods at the A2 tagged photon facility of the MAMI electron accelerator in Mainz, Germany [21].

Figure 1 shows a sketch of the A2 experimental setup used for the measurement. Since this setup has already been described in detail (see, for instance, Refs. [17,23–27] and references therein), we will limit the discussion to those features relevant to the present experiment.

A. The photon beam

The circularly polarized photons used for this measurement were produced using bremsstrahlung of the longitudinally polarized electrons on an amorphous radiator from a longitudinally polarized electron beam. Electron energies of both 450 and 1557 MeV were used to collect the data presented here.

To avoid polarization dependent photon flux values, the helicity of the electron beam was flipped at a rate of 1 Hz. The electron polarization degree, P_e , was regularly determined by Mott scattering close to the electron source [28] and was found to be more than 80% with a systematic uncertainty of $\pm 3\%$. In addition, Moeller scattering at the bremsstrahlung radiator was used as a secondary polarization monitor.

The recoil electrons from the bremsstrahlung process were momentum analyzed using the Glasgow-Mainz spectrometer with an energy resolution, depending on the electron beam energy, of $\approx 1\text{--}4$ MeV, which corresponds to the width of the detector channels [29]. The resulting photon beam passed through a 2-mm-diameter lead collimator, before reaching the target and detection apparatus.

The degree of the energy-dependent circular photon polarization, $P_{\odot}^{\gamma}$, was determined using the Olsen and Maximon equation [30]:

$$\frac{P_{\odot}^{\gamma}}{P_e} = \frac{4x - x^2}{4 - 4x + 3x^2},$$

where $x = E_e/E_{\gamma}$, with E_e and E_{γ} being the energies of the electron and the bremsstrahlung photon, respectively.

The photon tagging efficiency was measured once a day using a Pb-glass Cherenkov detector in dedicated low flux runs. During the standard data taking operation, fluctuations in the photon flux were monitored using a low-efficiency pair spectrometer located in the photon beamline after the collimator. An absolute systematic uncertainty in the photon flux of 4% was estimated by comparing the data from these detectors, obtained under a range of different experimental conditions.

B. The target system

The longitudinally polarized proton (deuteron) target used in this experiment was the Mainz-Dubna Frozen Spin Target [31,32]. The filling factor for the ≈ 2 -mm-diameter butanol spheres contained in the 2-cm-long, 2-cm-diameter target container was estimated to be 60%, with a systematic uncertainty of 2% [31].

The target material (butanol or deuterated butanol) was polarized using the dynamic nuclear polarization effect [33], which requires a high magnetic field (about 2.5 T) and a temperature of about 25 mK. A small holding magnetic field of 0.6 T, which replaced the polarizing magnet during the data taking phase, allowed regular relaxation times of about 1000 h to be achieved.

The target polarization was measured with an NMR system before and after each data taking period and then exponentially interpolated at intermediate times. Corrections to the calculated polarization values of the proton (butanol) target were necessary due to ice formation on the NMR coils. These corrected values were taken from Refs. [34–36], which independently analyzed the same proton data sets used in the present work.

Corrections were also applied to a portion of the deuteron (deuterated butanol) data due to small inhomogeneities in the field of the polarizing magnets. In this case, the correction values were taken from Refs. [17], which independently analyzed the same deuteron data sets.

As in all previous references, a conservative systematic uncertainty of 10% was assigned to all evaluated target polarization values to account for the effects of these corrections.

Some dedicated data runs with a carbon target were also performed to determine the background contributions from the unpolarized carbon and oxygen nuclei present in the target material. The carbon target was made from a foam of the

same density as the heavy nuclei in the butanol target. It was fitted into the butanol's Teflon container to ensure identical geometry and surrounding materials.

C. The hadron detector

The photon-induced reaction products were detected by using the Crystal Ball (CB) [37] as the central calorimeter and TAPS¹ [38,39] as the forward calorimeter, which was installed approximately 1.5 m downstream of the CB center. The CB detector was placed around the target cell and covered the full azimuthal (ϕ) angle and a polar (θ) angle range from 21° to 159° . It consisted of 672 NaI(Tl) crystals and had a $\approx 100\%$ detection efficiency for photons coming from π^0 decay. Inside the CB, starting from the center, there were a particle identification detector (PID), consisting of a barrel of 24 plastic scintillators, followed by two multi-wire proportional chambers (MWPCs). The combination of these detectors provided precise tracking and identification of charged particles. TAPS was a hexagonal wall covering the polar angle forward region outside the CB acceptance, $5^\circ < \theta < 20^\circ$, and was made of 366 hexagonal BaF₂ and 72PbWO₄ crystals. In front of each TAPS crystal there was a 5-mm-thick plastic scintillator (VETO) that was used for charged particle identification. The combination of the large acceptance CB and TAPS calorimeters covered $\approx 97\%$ of the full solid angle.

Two different triggers were used to collect the data presented here:

- (1) For the 450 MeV beam energy setting, the total sum of pulse amplitudes from CB crystals was required to exceed a hardware threshold corresponding to approximately 40 MeV. This trigger setting was used for a subset of the polarized proton target runs analysed in the present work.
- (2) For the 1557 MeV beam energy setting, the total sum of pulse amplitudes from CB or TAPS crystals was required to be above a hardware threshold, which varied between approximately 40 and 90 MeV, depending on the specific data set. This threshold energy setting was used for another subset of the proton runs and for all the runs with a polarized deuteron target. For this setting, an additional Cherenkov detector was placed in front of TAPS to online veto unwanted triggers in TAPS from e^+e^- pairs produced by the photon beam.

Independent analyses of all previous beam time periods have been presented in Refs. [17,34–36,40].

III. DATA ANALYSIS AND UNPOLARIZED RESULTS

A. Experimental method

Within the considered photon energy range, the photoabsorption process leads to many different multiparticle final

¹TAPS is an acronym for Two-/Three-Arm Photon Spectrometer, since it was previously used as a stand-alone detector.

states that are very difficult to detect individually with full acceptance and efficiency.

To avoid the large systematic uncertainties associated with unobserved final states, the total photoabsorption cross section must be measured inclusively, as was done previously by the GDH Collaboration [7–12]. The identification of individual processes is not necessary; what is required is to detect at least one reaction product from all possible hadronic final states with nearly complete acceptance in terms of solid angle and efficiency. This approach minimizes the corrections for detector inefficiencies and the loss of events emitted into angular and momentum regions outside the detector's coverage, thereby reducing model-dependent uncertainties.

Meeting these requirements necessitates both the reliable detection of charged particles and high efficiency for detecting the neutral decay modes of hadrons. The CB-TAPS detector, which covers 97% of 4π solid angle and has a detection efficiency of $\gtrsim 99\%$ for both charged hadrons and photons from neutral meson decays, fulfills all of these criteria.

A GEANT4 based simulation [41] was used to determine the model-dependent corrections required to account for the fraction of the total photoabsorption cross section where all of the final-state particles are emitted outside the detector acceptance. This simulation accurately modeled the detector's geometry, composition, and electronic thresholds.

For this evaluation, differential cross sections for the $\gamma p \rightarrow N\pi$ channels were taken from the SAID-SM22 [42] partial-wave analysis, while the total cross sections for the $\gamma p \rightarrow N\pi\pi$ channels were taken from the Fix-Arenhövel model [43], under the assumption that they proceed through the $\gamma p \rightarrow \Delta\pi$ intermediate state. For these last channels, the helicity asymmetry $\Delta\sigma/(\sigma_P + \sigma_A)$ for all these processes was also assumed to be the same inside and outside the detector acceptance.

The simulation confirmed that the efficiency for partial reaction channels with at least three pions in the final state is practically 100% across the entire measured photon energy range. Consequently, no acceptance corrections were applied to these channels.

The simulated reconstruction efficiency for all $\gamma p \rightarrow N\pi$ and $\gamma p \rightarrow N\pi\pi$ channels contributing to the unpolarized cross section $\sigma_{\text{unp}} = (\sigma_P + \sigma_A)/2$ is shown in the upper plot of Fig. 2 as a function of the incident photon energy. In the middle (lower) plot of the same figure the evaluated corrections σ_{corr} ($\Delta\sigma_{\text{corr}}$) to the unpolarized (polarized) cross section are shown for each of the previous channels. The different line styles represent the values for the CB (dashed lines) and the CB-TAPS (solid lines) trigger settings with the 40 MeV threshold.

The overall correction is mostly due to the $n\pi^+$ channel and rapidly decreases (in absolute values) from $E_\gamma = 200$ MeV to about $E_\gamma = 330$ MeV and remains very low throughout the rest of the measured energy interval.

In the deuteron case, total cross sections for the $\gamma d \rightarrow pn$ and $\gamma d \rightarrow d\pi^0$ reactions were taken from the theoretical approach of Arenhövel, Fix, Schwamb (AFS) [44], assuming a pure phase-space distribution for both. Furthermore, for all $\gamma d \rightarrow NN\pi(\pi)$ processes, the dominance of quasifree processes on single nucleons was assumed.

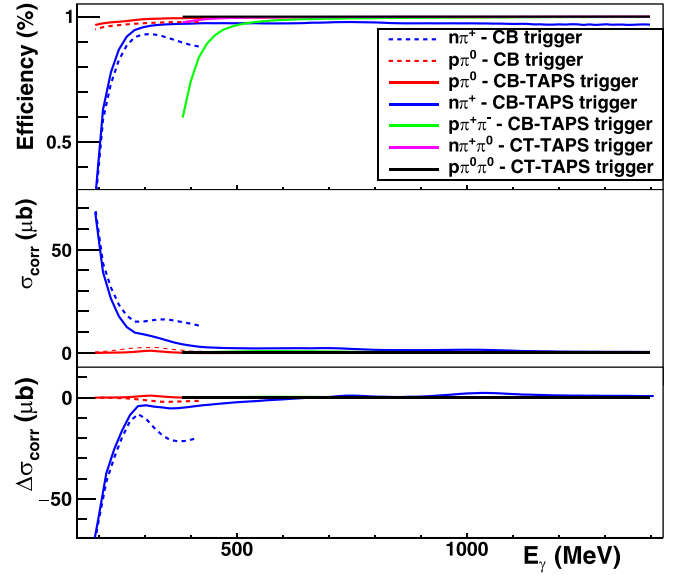


FIG. 2. Upper plot: simulated reconstruction efficiency for all $\gamma p \rightarrow N\pi$ and $\gamma p \rightarrow N\pi\pi$ channels as a function of the incident photon energy. Middle plot: the evaluated corrections to the unpolarized cross section σ_{unp} are shown separately for each of the previous channels. Lower plot: as before but for the $\Delta\sigma$ cross section. In all plots: red line: $\gamma p \rightarrow p\pi^0$; blue line: $\gamma p \rightarrow n\pi^+$; green line: $\gamma p \rightarrow p\pi^+\pi^-$; magenta line: $\gamma p \rightarrow n\pi^+\pi^0$; black line: $\gamma p \rightarrow p\pi^0\pi^0$. The different line styles represent the efficiency and correction values for the CB (solid lines) and CB-TAPS (dashed lines) trigger settings, using a 40 MeV threshold. Above approximately 400 MeV, most of the lines become difficult to distinguish because they converge to values of either one or zero, depending on the plot.

The systematic uncertainty associated with the efficiency correction was evaluated by examining the different experimental thresholds and trigger conditions applied to both the experimental and simulated data. Simulations were also performed using $N\pi$ distributions from the BnGa-2019 partial wave analysis [45] and a pure phase-space distribution for the $N\pi\pi$ channels.

For the $N\pi$ channels, a maximal efficiency difference of about 10% was found for the $n\pi^+$ reaction compared to the previous case. The relative uncertainty on the extrapolated values for these channels was then conservatively estimated to be 10% of the applied correction.

Due to the inadequate theoretical description of the experimental data for the proton in the range $500 \lesssim E_\gamma \lesssim 1100$ MeV (see Sec. IV A), a conservative systematic uncertainty of $\pm 50\%$ was assumed for the evaluation of the missing contribution from the $N\pi\pi$ reactions, which provide the dominant contribution to the total inclusive cross section in this energy region.

The maximum absolute correction from these channels is about $0.5 \mu\text{b}$ at $E_\gamma \approx 650$ MeV, corresponding to about 15% of the total applied correction. The linear combination of this uncertainty and that of the $N\pi$ channels yields a maximal overall systematic uncertainty of 15% of the applied correction. We then conservatively assumed this uncertainty to remain constant for $E_\gamma > 500$ MeV.

TABLE I. Relative systematic uncertainties given as total widths of uniformly-distributed values.

Source	Error
Tagging efficiency	$\pm 4\%$
Beam polarization	$\pm 3\%$
Target polarization	$\pm 10\%$
Target density	$\pm 2\%$
Extrapolation correction $E_\gamma \leq 500$ MeV	$\pm 10\%$ of the extrapolated value
Extrapolation correction $E_\gamma > 500$ MeV	$\pm 15\%$ of the extrapolated value

This inclusive method was applied to evaluate the helicity-dependent cross-section difference $\Delta\sigma$ for both the proton and the deuteron. For this evaluation, unpolarized background subtraction was not required due to the vanishing contributions from the spinless carbon and oxygen nuclei.

B. Systematic uncertainties

The various sources of systematic uncertainties discussed previously are summarized in Table I.

Sources of common constant systematic uncertainties come from the photon flux normalization, the beam and target polarization, and the target surface density. In contrast, the systematic uncertainty related to the extrapolation correction depends on the extrapolated value and, therefore, on E_γ . For the proton case, its absolute value (in rms units) starts from $\approx 6 \mu\text{b}$ at $E_\gamma = 200$ MeV and quadratically decreases to less than $1 \mu\text{b}$ for $E_\gamma \gtrsim 300$ MeV. The systematic uncertainty associated with the extrapolation correction for the deuteron turned out to be about twice that estimated for the proton.

The overall systematic uncertainty is calculated as the sum in quadrature of all individual uncertainties.

C. Unpolarized total inclusive cross section

As a cross-check to validate the overall analysis procedure, the unpolarized cross section was evaluated for both the proton and the deuteron and compared to previously published results.

To obtain this cross section, the substantial background from the carbon and oxygen nuclei in the target, which constitutes $\gtrsim 75\%$ of the measured raw butanol yields, was evaluated using data from carbon runs. The normalized butanol and carbon yields were subtracted by applying a scaling factor determined from the ratio of the live-time corrected tagger scalars for the respective data sets.

In Fig. 3 the values of σ_{unp} obtained for the deuteron are shown and compared to previous results [46,47].

Taking into account both the statistical and systematic uncertainties, the good agreement observed confirms the reliability of both the entire experimental setup and of the complete analysis procedure.

IV. RESULTS

Figure 4 shows the helicity-dependent total inclusive cross section $\Delta\sigma$ for the proton, measured using both the CB trigger

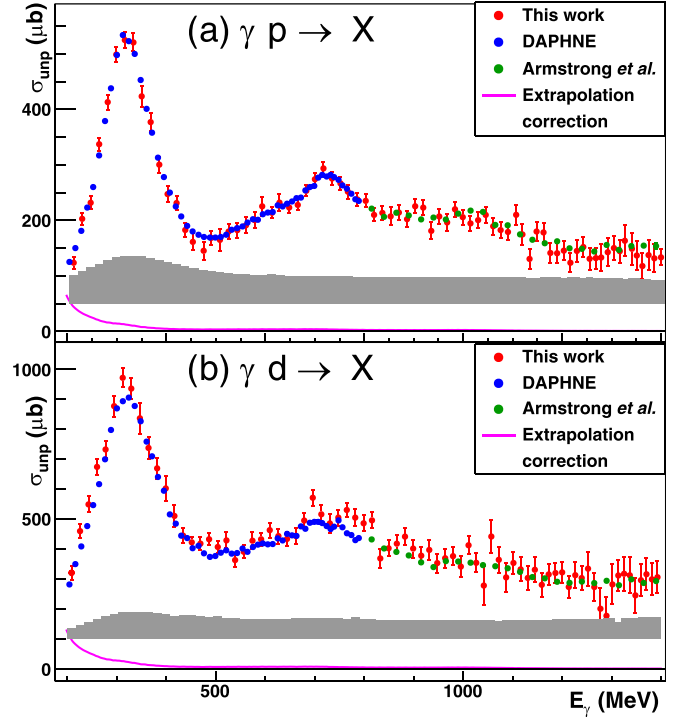


FIG. 3. The unpolarized total inclusive cross section for the proton (upper plot) and deuteron (lower plot) is compared with previous results published by the DAPHNE Collaboration ([46]), red circles, and by Armstrong *et al.* [47], green circles. The solid line represents the model-dependent correction applied to account for detector inefficiency. The systematic uncertainties are shown as a gray bands.

setting (for $E_\gamma < 400$ MeV) and the CB-TAPS trigger setting, in the region $E_\gamma < 500$ MeV. The excellent agreement between these two different configurations further validates the overall analysis procedure.

For the final results, the CB trigger setting is used for photon energies below 400 MeV, while the CB-TAPS setting is employed above this value. Owing to the very high

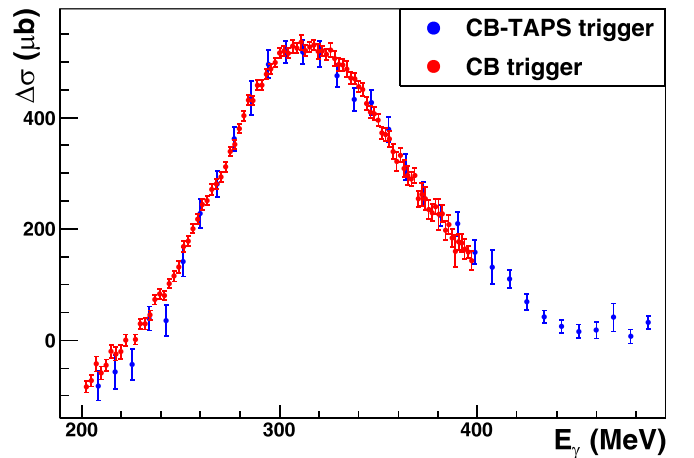


FIG. 4. The helicity dependent total inclusive cross section $\Delta\sigma$ for the proton evaluated with the CB (for $E_\gamma < 400$ MeV) and CB-TAPS trigger settings is shown for $E_\gamma < 500$ MeV.

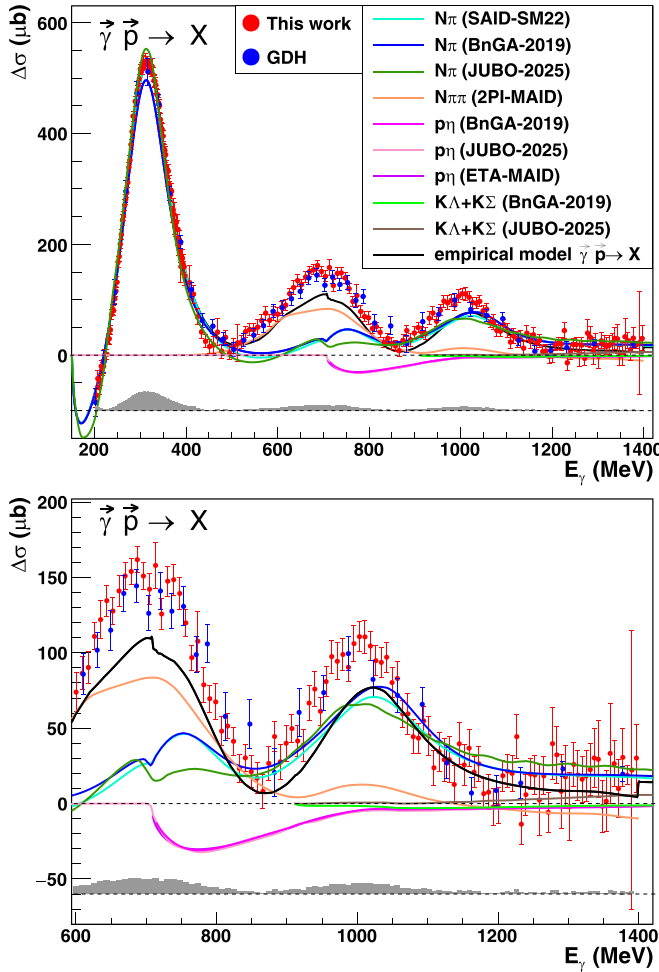


FIG. 5. Upper plot: the measured inclusive helicity dependent cross section $\Delta\sigma$ for proton (red circles) from $E_\gamma = 200$ to 1400 MeV compared with the published results by the GDH Collaboration [9] (blue circles). The different solid lines show the predictions of the relevant partial reaction channels given by different approaches: azure line: $\gamma\bar{p} \rightarrow N\pi$ (SAID-SM22 [42]); blue line: $\gamma\bar{p} \rightarrow N\pi$ (BnGA-2019 [48,49]); dark green line: $\gamma\bar{p} \rightarrow N\pi$ (Jülich-Bonn (JuBo-2025) [50]); orange line: $\gamma\bar{p} \rightarrow N\pi\pi$ (2-PION-MAID [43]); magenta line: $\gamma\bar{p} \rightarrow N\eta$ (BnGA-2019); pink line: $\gamma\bar{p} \rightarrow N\eta$ (JuBo-2025); violet line: $\gamma\bar{p} \rightarrow N\eta$ (ETA-MAID [51]); green line: $\gamma\bar{p} \rightarrow K\Lambda + K\Sigma$ (BnGA-2019 [48,49]); brown line: $\gamma\bar{p} \rightarrow K\Lambda + K\Sigma$ (JuBo-2025 [50]). The black line represents an empirical $\gamma\bar{p} \rightarrow X$ prediction obtained by adding the $N\pi$ values given by SAID-SM22, the $N\pi\pi$ values from MAID-2PI, the $N\eta$ values from ETA-MAID, and the $K\Lambda + K\Sigma$ values from BnGA-2019. The overall contribution of the systematic uncertainties is depicted as a gray band. Lower plot: as before, but from $E_\gamma = 600$ to 1400 MeV. See text for further details.

statistics collected, $\Delta\sigma$ for the proton was calculated in fine photon energy bins, with a width of approximately 2 MeV for $E_\gamma < 400$ MeV and 7–9 MeV for $E_\gamma > 400$ MeV.

A. $\gamma\bar{p} \rightarrow X$

The obtained total inclusive helicity dependent cross section $\Delta\sigma$ for the proton is shown in the upper plot of Fig. 5

(red points) in the region from $E_\gamma = 200$ to 1400 MeV and compared to the data previously published by the GDH Collaboration [9] (blue points). All numerical values of are reported in Table III of the Appendix. The lower plot of the same figure shows the subset of the obtained data between 600 and 1400 MeV. With respect to the previous results, this work provides a huge improvement in statistical precision with a much finer energy binning, especially in the Δ -resonance region.

In the same figure, the different solid lines show the predictions for all the more relevant partial reaction channels given by different approaches. Azure line: $\gamma\bar{p} \rightarrow N\pi$ (SAID-SM22 [42]); blue line: $\gamma\bar{p} \rightarrow N\pi$ (BnGA-2019 [48,49]); dark green line: $\gamma\bar{p} \rightarrow N\pi$ (Jülich-Bonn (JuBo-2025) [50]); orange line: $\gamma\bar{p} \rightarrow N\pi\pi$ (2-PION-MAID [43]); magenta line: $\gamma\bar{p} \rightarrow N\eta$ (BnGA-2019); pink line: $\gamma\bar{p} \rightarrow N\eta$ (JuBo-2025); violet line: $\gamma\bar{p} \rightarrow N\eta$ (ETA-MAID [51]); green line: $\gamma\bar{p} \rightarrow K\Lambda + K\Sigma$ (BnGA-2019 [48,49]); brown line: $\gamma\bar{p} \rightarrow K\Lambda + K\Sigma$ (JuBo-2025 [50]).

Below $E_\gamma \approx 500$ MeV, the predictions of the SAID-SM22 model are nearly indistinguishable from the experimental points, as they overlap almost completely. The predictions for the $K\Lambda + K\Sigma$ final states are also nearly indistinguishable in this plot, as both lie very close to the zero y-axis value. Likewise, the various predictions for the $\gamma\bar{p} \rightarrow N\eta$ channel are very similar and almost completely overlap.

The black line represents an empirical $\gamma\bar{p} \rightarrow X$ overall prediction obtained by simply adding the $N\pi$ values given by SAID-SM22, the $N\pi\pi$ values from 2-PION-MAID, the $N\eta$ values from ETA-MAID, and the $K\Lambda + K\Sigma$ values from BnGA-2019.

The $N\pi\pi$ prediction shown in this plot was evaluated with an updated version of the 2PION-MAID framework presented in Ref. [43]. In this new version, resonance parameters (masses, hadronic and radiative widths) were not fixed (as in the previous version) to the central values given by the Particle Data Group (PDG) compilation. Instead, they were treated as free parameters and adjusted within narrow intervals around the PDG values [52] in order to achieve better agreement with the existing data.

A further modification of the $\gamma N \rightarrow \pi\pi N$ amplitudes involved the introduction of additional phenomenological (and smoothly varying) background terms in the $\pi\Delta$ channel for partial waves with spin-parity $J^\pi = 3/2^\pm$ and isospin $I = 1/2$. These terms were specifically designed to resolve the significant discrepancies previously observed with respect to the experimental $\pi^0\pi^0$ data at energies below the $N(1520)$ resonance peak, and were evaluated using the data from Refs. [53–56]. Further details can be found in Ref. [57].

In the $\Delta(1232)$ -resonance region the high quality of our data allows the small discrepancies existing among the three different $N\pi$ approaches shown in the previous figure to be resolved, with the SAID-SM22 prediction reproducing our data better. Above $E_\gamma = 500$ MeV a significant discrepancy emerges between our data and the empirical prediction obtained by summing the contribution of all the main partial photoreaction channels. In the so-called third resonance region ($900 \lesssim E_\gamma \lesssim 1250$ MeV), our data peaks at a lower energy than the empirical model.

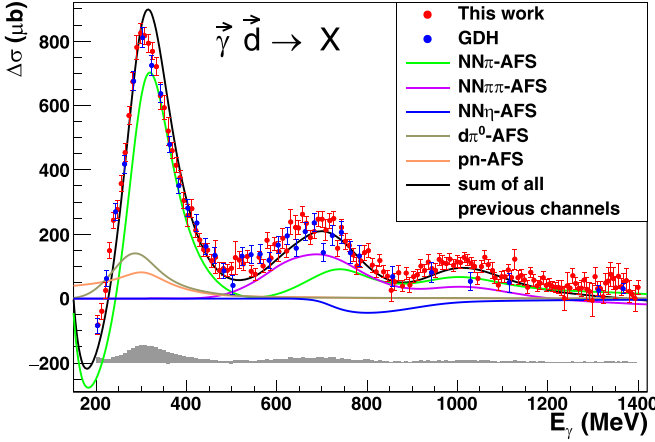


FIG. 6. The new total inclusive helicity dependent cross section $\Delta\sigma$ for the deuteron (red circles) compared with the published results by the GDH Collaboration [10–12] (blue circles). The different solid lines show the predictions of the main partial reaction channels given by the AFS theoretical analysis [44]. Green line: $\vec{\gamma}\vec{d} \rightarrow NN\pi$; violet line: $\vec{\gamma}\vec{d} \rightarrow NN\pi\pi$; blue line: $\vec{\gamma}\vec{d} \rightarrow NN\eta$; brownish line: $\vec{\gamma}\vec{d} \rightarrow d\pi^0$; orange line: $\vec{\gamma}\vec{d} \rightarrow pn$; black line: sum of all previous contributions. The overall contribution of the systematic uncertainties is depicted as a gray band.

As mentioned before, this difference is mainly due to an inadequate description of the $N\pi\pi$ channels, which provide the major contribution in this part of the measured photon energy range.

A comprehensive, coupled multichannel approach is therefore required to accurately evaluate the contributions from all relevant electromagnetic multipoles using the available experimental database, and to improve our understanding of the properties of the higher baryon resonances.

B. $\vec{\gamma}\vec{d} \rightarrow X$

The total inclusive helicity dependent cross section $\Delta\sigma$ for the deuteron is shown in Fig. 6 (red circles) in the region from $E_\gamma = 200$ MeV up to 1400 MeV and compared to the results published by the GDH Collaboration [10–12] (blue circles). All numerical values of are reported in Table V of the Appendix. In this case, the present work provides a significant improvement in statistical precision with respect to the previous data, with a finer energy binning especially for $E_\gamma > 800$ MeV.

The different solid lines in the previous figure show the predictions for the main partial reaction channels given by the theoretical AFS approach [44]: green line: $\vec{\gamma}\vec{d} \rightarrow NN\pi$; violet line: $\vec{\gamma}\vec{d} \rightarrow NN\pi\pi$; blue line: $\vec{\gamma}\vec{d} \rightarrow NN\eta$; brownish line: $\vec{\gamma}\vec{d} \rightarrow d\pi^0$; orange line: $\vec{\gamma}\vec{d} \rightarrow pn$; black line: sum of all previous contributions.

A limitation of the calculations, which may introduce some uncertainty, stems from the use of different theoretical frameworks for different channels. In particular, the coherent process $\gamma d \rightarrow \pi^0 d$ is treated within a coupled-channel approach for the ΔN - NN - πNN system, whereas $\gamma d \rightarrow \pi NN$ and $\gamma d \rightarrow \pi\pi NN$ are calculated within the impulse approx-

imation with final-state rescattering included perturbatively. Furthermore, for single π and η meson production, the elementary operator from MAID is employed, whereas the $\pi\pi$ photoproduction operator is derived using effective Lagrangians.

This lack of a uniform approach may be one of the reasons for the discrepancies with the data. A more rigorous methodology is therefore required, based on a unified and consistent theoretical framework capable of describing all relevant channels.

Even considering these limitations, it is nevertheless interesting to note that the present data confirm the apparent shift, noted in [14], in the $\Delta(1232)$ excitation contribution to $\Delta\sigma$ deuteron compared to the AFS model predictions, which employ free-space masses for the nucleon and the Δ . As shown in [14], this downwards excitation shift, ≈ -20 MeV, is observed in the spin-parallel but not in the spin-antiparallel or spin averaged cross sections and cannot be explained merely by accounting for the Fermi motion of the target nucleons. This evidence points to the modification of the Δ excitation in nuclei.

The properties and the role of the Δ resonance in nuclear matter are still open puzzles requiring further theoretical and experimental investigations. Previous early studies suggested an attractive Δ potential in nuclei [58]. Chiral model studies of pion-nucleus elastic scattering gave a Δ mass shift in medium of $-33 \times \rho/\rho_0$ MeV, where ρ is the nuclear density and ρ_0 is the density of nuclear matter. Similar values, $-23 \pm 5 \times \rho/\rho_0$ MeV, were found from studies of the Δ self-energy in nuclei using the same theoretical framework [59,60].

Different interpretations have been given of coherent π^0 photoproduction from carbon nuclei (see [61] for measurements performed by the TAPS Collaboration at the A2-MAMI tagged photon facility). These data have been interpreted in [62] as evidence for a Δ mass reduction of 30 MeV. On the other hand, [63] obtained a positive Δ mass shift of +20 MeV using the same data, which they attributed to the Landau-Migdal effect.

In the different experimental conditions of heavy-ion collisions, data from the SIS18 Collaboration at GSI [64] showed that about 30% of the “nucleons” behave as excited Δ resonances (so-called resonance matter) at 2–3 times nuclear matter density (the typical density of neutron star interiors), suggesting an important role for the Δ at these high densities. Detailed studies of the Δ in nuclear matter will be an important part of future experimental investigations at the GSI FAIR facility.

C. $\vec{\gamma}n \rightarrow X$

Extracting information on the neutron GDH integrand requires some theoretical input. Free neutron targets are not available in nature, necessitating measurements on neutrons bound in nuclei. Theory and phenomenology are then used to extract a “free” neutron cross section.

In the most naive model, the rather loosely bound deuteron can be thought of as a combination of one free neutron and one free proton, allowing us in principle to extract information on the neutron GDH integrand after subtracting the contribution from the proton. In reality, the situation is complicated by the

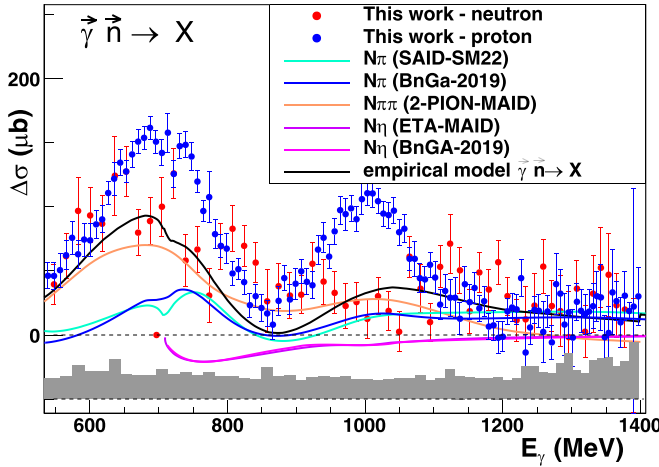


FIG. 7. The total inclusive helicity-dependent cross section $\Delta\sigma$ for the neutron (red circles), evaluated using Eq. (2), compared with $\Delta\sigma$ for the proton (blue circles) and with the predictions for the relevant $\bar{\gamma}n \rightarrow X$ partial reaction channels given by different approaches. Azure line: $\bar{\gamma}n \rightarrow N\pi$ (SAID-SM22 [42]); blue line: $\bar{\gamma}n \rightarrow N\pi$ (BnGa-2019 [48,49]); orange line: $\bar{\gamma}n \rightarrow N\pi\pi$ (2-PION-MAID [43]) (with the modifications described later); violet line: $\bar{\gamma}n \rightarrow N\eta$ (ETA-MAID [43]); magenta line: $\bar{\gamma}n \rightarrow N\eta$ (BnGa-2019). The black line represents an empirical $\bar{\gamma}n \rightarrow X$ overall prediction obtained by simply adding the $N\pi$ values given by SAID-SM22, the $N\pi\pi$ values from MAID-2PI, and the $N\eta$ values from ETA-MAID. The overall contribution of the systematic uncertainties is depicted as a gray band. See text for further details.

presence of various nuclear effects (Fermi motion, off-shell corrections, etc.). In addition, the measured cross-section differences also contain contributions not present for single free nucleons, such as coherent π^0 production and the two-body breakup of the deuteron.

Here we use the Plane Wave Impulse Approximation (PWIA) to extract the helicity-dependent cross section for the neutron from the deuteron and proton data for the higher-energy region of the measured photon energy interval ($E_\gamma \gtrsim 500$ MeV). In this region, as demonstrated for the $\bar{\gamma}d \rightarrow \pi^0 X$ channel in Ref. [17], nuclear effects can be neglected to first approximation. This allows the photoproduction reaction on the deuteron to be treated as an incoherent sum of reactions on quasifree protons and neutrons.

Within this framework, the primary correction to be applied accounts for the effective nucleon polarization P_E arising from the deuteron D -state contribution. This correction can be evaluated as (see, for instance, [65])

$$P_E = 1 - 1.5P_D,$$

where $P_D = 0.05$ is the D -state probability of the deuteron.

The total inclusive helicity-dependent cross section for the “free” neutron, $\Delta\sigma_{\text{neut}}$, is thus obtained as

$$\Delta\sigma_{\text{neut}} = \Delta\sigma_{\text{deut}}/P_E - \Delta\sigma_{\text{prot}}. \quad (2)$$

This is shown in Fig. 7 and compared to predictions for the most relevant partial reaction channels calculated using different approaches: azure line: $\bar{\gamma}n \rightarrow N\pi$ (SAID-SM22 [42]);

blue line: $\gamma p \rightarrow N\pi$ (BnGa-2019 [48,49]); orange line: $\bar{\gamma}n \rightarrow N\pi\pi$ (2-PION-MAID [43]) (with the modifications described earlier); violet line: $\bar{\gamma}n \rightarrow n\eta$ (ETA-MAID [43]); magenta line: $\gamma n \rightarrow n\eta$ (BnGa-2019).

The predictions for the $n\eta$ final state given by the ETA-MAID and BnGa-2019 analyses are very similar and overlap almost completely in this plot. The black line represents an empirical $\bar{\gamma}n \rightarrow X$ overall prediction obtained by simply adding the $N\pi$ values given by SAID-SM22, the $N\pi\pi$ values from MAID-2PI, and the $N\eta$ values from ETA-MAID.

The overall contribution of the systematic uncertainties is calculated as the sum in quadrature of the deuteron and proton uncertainties, weighted according to Eq. (2).

Even though the error bars are larger than those for the proton, some important conclusions can still be drawn from these data. In both the so-called second ($500 \lesssim E_\gamma \lesssim 900$ MeV) and third ($900 \lesssim E_\gamma \lesssim 1250$ MeV) resonance regions, $\Delta\sigma_{\text{neut}}$ is smaller than $\Delta\sigma_{\text{prot}}$, with the difference being more significant in the latter region. This behavior is expected, as the $F_{15}(1680)$ resonance, which dominates this region, couples more strongly to the proton than to the neutron (see, for instance, [66]).

In this case, the empirical $\bar{\gamma}n \rightarrow X$ model, represented by the black line in Fig. 7, seems to describe $\Delta\sigma$ more accurately for the neutron than for the proton. However, improved theory and more precise data would be needed to go further and to draw more definitive conclusions.

V. EVALUATION OF THE GDH INTEGRAL

Due to the wide energy range covered by the present, precise experimental data, a reasonable estimate of the GDH integral [left-hand side of Eq. (1)] for the proton and deuteron can be obtained by using existing models to evaluate the missing contributions from the unmeasured energy regions. From these estimates, the GDH integral can also be calculated for the neutron using appropriate approximations.

A. Proton

The diagram of Fig. 8 shows the so-called “running” GDH integral:

$$I_{\text{running}} = \int_{\nu_{0,\text{exp}}}^{E_\gamma} \frac{\Delta\sigma}{E_\gamma} dE_\gamma, \quad (3)$$

where the infinite integral on the left-hand side of Eq. (1) is replaced by an integration starting from $\nu_{0,\text{exp}} = 200$ MeV, the lowest measured photon energy value, to an upper limit that constitutes the running variable.

This integral has been obtained from the present data, ranging from 200 to 1.4 GeV in photon energy, in combination with the higher energy data up to 2.9 GeV of Ref. [9]. The measured values of $I_{\text{GDH}}^{\text{prot}}$ between 200 and 2900 MeV then amounts to $255 \pm 2(\text{stat}) \pm 18(\text{sys}) \mu\text{b}$.

On the low-energy side ($E_\gamma < 200$ MeV), the first contribution to photoabsorption arises from the pion production threshold (m_π), which occurs at about 145 MeV. In the photon energy range between 145 and 200 MeV, the only open channels are the single-pion production channels $p\pi^0$ and

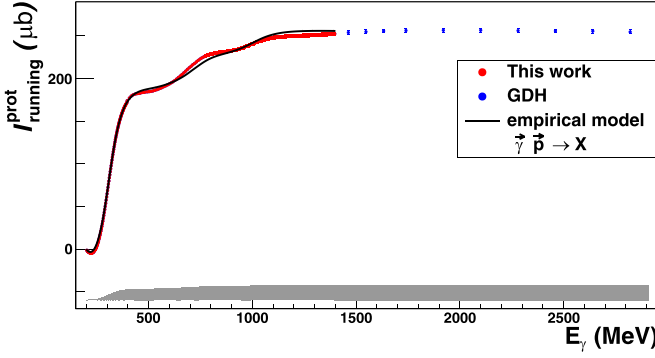


FIG. 8. The running GDH integral for the proton $I_{\text{running}}^{\text{prot}}$ obtained with the present data (red circles) and with the data from [9] (blue circles) compared to the predictions of the empirical $\vec{\gamma} \vec{p} \rightarrow X$ model defined in Sec. IV A (black solid line). The gray band shows the systematic uncertainties, obtained by linearly adding the errors of each individual bin.

$n\pi^+$. The dominant contribution in this region comes from the latter reaction, $n\pi^+$, driven primarily by the nonresonant E_0^+ multipole. The integration of all amplitudes across this energy range yields a contribution of $-30 \pm 2 \mu\text{b}$, calculated as the mean of the values obtained from the SAID-SM22 [42] and BnGa-2019 [45] partial wave analyses. The quoted systematic uncertainty corresponds to the difference between these two estimates.

For energies above 2.9 GeV, a Regge parametrization indicates that the contribution to the GDH integral becomes negative. In Ref. [67], this high-energy term was estimated to be $-15 \pm 2 \mu\text{b}$ based on a fit of experimental data for the proton's spin structure function at low Q^2 .

Presented in the third column of Table II, the combination of experimental and model-dependent contributions produces a result that, within the experimental uncertainties, is consistent with the GDH sum rule value of $205 \mu\text{b}$. This finding confirms the results of the GDH collaboration [9].

B. Deuteron

The GDH sum rule on the deuteron predicts a very small value ($0.65 \mu\text{b}$) for the integral of Eq. (1) because the anomalous magnetic moment of the deuteron is much smaller than that of the proton or neutron ($0.14\mu_N$ versus $1.8\mu_N$ and $1.9\mu_N$, respectively).

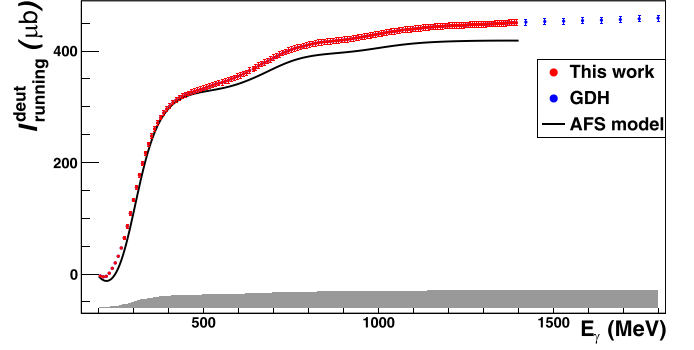


FIG. 9. The running GDH integral for the deuteron $I_{\text{running}}^{\text{deut}}$ obtained with the present data (red circles) and with the data from [10] (blue circles) is compared to the predictions of the AFS model [44] (black solid line). The gray band shows the systematic uncertainties, obtained by linearly adding the errors of each individual bin.

From the experimental point of view, this result arises from a strong cancellation between the two-body deuteron breakup channel ($\gamma d \rightarrow pn$), which has a very large cross section at photon energies of a few MeV, and the incoherent sum of inelastic channels on the individual nucleons [e.g., $\gamma N \rightarrow N\pi(\pi)$ production at photon energies above $\approx 145 \text{ MeV}$].

In Fig. 9, the experimental running GDH integral for the deuteron, obtained by combining the present data (red circles) with the higher energy data (up to 1.8 GeV) from Ref. [10] (blue circles), is compared to the predictions of the AFS model [44]. The experimental running integral between 200 and 1400 MeV amounts to $459 \pm 5 \pm 32 \mu\text{b}$.

The missing contribution to the GDH integral below 200 MeV has been evaluated using the AFS model [44], which predicts a value of $-502 \mu\text{b}$. This very large contribution is mostly concentrated in the energy region below $E_\gamma = 10 \text{ MeV}$, where this model predicts a value of $-634 \mu\text{b}$. This behavior arises because, in this energy range, the $\gamma d \rightarrow pn$ transition from the bound 3S_1 state to the continuum 1S_0 state can occur only for antiparallel photon and deuteron spins, due to the dominance of the $M1$ electromagnetic transition.

An indirect experimental determination of the GDH integrand for the deuteron between the photodisintegration threshold and 6 MeV yielded a value of $-603 \pm 43 \mu\text{b}$ [68]. This result is in good agreement with the theoretical AFS

TABLE II. Estimated values of the GDH integral for proton, deuteron, and neutron and GDH sum rule predictions for the unmeasured energy intervals (units: μb). $I_{\text{GDH}}^{\text{neut}}$ has been evaluated from deuteron and proton data using the approach outlined in Sec. V C. The quoted errors of both the low and high-energy contributions represent the estimated systematic uncertainties. See the article text for further explanations.

		$I_{\text{GDH}}^{\text{prot}}$	$I_{\text{GDH}}^{\text{deut}}$	$I_{\text{GDH}}^{\text{neut}}$
low-energy contribution	$E_\gamma < 0.2 \text{ GeV}$	-30 ± 2	-502 ± 25	-35 ± 5
measured	$0.2 \leq E_\gamma \leq 2.9 \text{ GeV}$	$255 \pm 2 \pm 18$		
interval	$0.2 \leq E_\gamma \leq 1.8 \text{ GeV}$		$459 \pm 5 \pm 31$	$234 \pm 6 \pm 37$
high-energy	$E_\gamma > 2.9 \text{ GeV}$	-15 ± 2		
contribution	$E_\gamma > 1.8 \text{ GeV}$		8 ± 11	23 ± 10
total		$210 \pm 2 \pm 18$	$-35 \pm 5 \pm 41$	$222 \pm 6 \pm 38$
GDH sum rule value		205	0.65	232

value of $-627 \mu\text{b}$ for the GDH sum rule integrated over the same energy range. From the comparison between the experimental and theoretical results, we estimate a relative systematic uncertainty of $\pm 5\%$ of the AFS prediction below 200 MeV.

The contribution above 1.8 GeV can be evaluated from Regge-theory-inspired analyses of low- Q^2 photoabsorption data by combining predictions from the proton and neutron according to Eq. (2). For the neutron, our evaluation is based on the estimate of $25 \pm 10 \mu\text{b}$ for $E_\gamma > 1.7$ GeV given by [3], which combines the predictions given by [69] and [70] (see also Ref. [71]). This value has been corrected to account for the experimental deuteron GDH integral value between $1.7 \leq E_\gamma \leq 1.8$ GeV. The resulting contribution from the neutron is $23 \pm 10 \mu\text{b}$.

The contribution for the proton above $E_\gamma = 1.7$ GeV ($-17 \pm 10 \mu\text{b}$) was evaluated in a similar way by summing up the Regge correction term used in the previous section with the experimental proton GDH integral value in the range $1.7 \leq E_\gamma \leq 2.9$ GeV. Finally, applying Eq. (2), we obtained a high-energy contribution to $I_{\text{GDH}}^{\text{deut}}$ of $8 \pm 11 \mu\text{b}$.

Summing up all previously mentioned contributions (see fourth column of Table II), we obtain a total estimate of $I_{\text{GDH}}^{\text{deut}} = -35 \pm 5 \pm 41 \mu\text{b}$, which is compatible (within the present systematic and statistical uncertainties) with the deuteron GDH sum rule value.

C. Neutron

The challenge of extracting a “free” neutron cross section from the deuteron and proton data was discussed in Sec. IV C. For the virtual photon case, it has been shown (see, for instance, [72,73]) that the simple assumptions leading to Eq. (2) reproduce the experimental data well down to very low values of Q^2 ($Q^2 \approx 0.01 \text{ GeV}^2$), provided that the effects due to the D -state component of the deuteron wave function, which reduces the effective nucleon polarization, are taken into account. In the present work, this approach was assumed to be valid also for the real photon case. The value of the GDH integral for the neutron ($I_{\text{GDH}}^{\text{neut}}$) was then calculated within the photon energy interval $0.2 < E_\gamma < 1.8$ GeV as

$$[I_{\text{GDH}}^{\text{neut}}]_{\text{exp}} \approx \frac{[I_{\text{GDH}}^{\text{deut}}]_{\text{exp}}}{P_E} - [I_{\text{GDH}}^{\text{prot}}]_{\text{exp}},$$

where, as before, P_E accounts for the nucleon depolarization caused by the deuteron D state. This then gives a value of $234 \pm 6 \pm 37 \mu\text{b}$. By summing up the low-energy contribution—obtained, as in the proton case, from the SAID-SM22 [42] and BnGa-2019 [45] partial wave analyses—and the high-energy contribution evaluated previously (see Sec. V B), the final estimated $I_{\text{GDH}}^{\text{neut}}$ value is also compatible with the GDH sum rule prediction (see the fourth column of Table II).

VI. SUMMARY AND CONCLUSIONS

New precise data on the helicity-dependent total inclusive photoabsorption cross section for both the proton and the

deuteron have been obtained for incident photon energies from 200 MeV up to 1.4 GeV.

Compared to previous results, this work provides a significant improvement in statistical precision and a much finer energy binning.

Using these data, an estimate of the GDH integral was obtained by employing existing models to evaluate the missing contributions from the unmeasured energy regions. Based on these estimates, the validity of the GDH sum rule has been verified for both the proton and the deuteron.

From the combination of the results for the deuteron and the proton, important information has been extracted for the free neutron. In particular, a significant difference between the reactions $\bar{\gamma}p \rightarrow X$ and $\bar{\gamma}n \rightarrow X$ was found in the third resonance region, arising from the different strengths of the intermediate excitation of the $F_{15}(1680)$ resonance. The value of the GDH integral for the neutron, calculated using appropriate approximations, was also found to be compatible with the GDH sum rule prediction.

These new data provide additional insight into nucleon properties and establish a precise experimental benchmark for the theoretical models used to study nucleons, both in their free state and when embedded in the nuclear medium.

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DATA AVAILABILITY

There are no publicly available research data or software supporting this manuscript. Requests for further information or data should be sent to the authors.

APPENDIX

See Tables III–V for the numerical values of the total inclusive helicity-dependent cross section for the proton, deuteron, and neutron.

TABLE III. Numerical values of the total inclusive helicity dependent cross section $\Delta\sigma$ for the proton as a function of the photon energy E_γ in the target rest frame. The quoted errors represent the 68% confidence level of the statistical and systematic uncertainties of the experimental data, respectively.

E_γ	Value
202.3	$-83.5 \pm 10.5 \pm 7.9$
204.8	$-72.4 \pm 10.6 \pm 7.4$
207.3	$-42.2 \pm 13.9 \pm 5.7$
209.8	$-58.6 \pm 11.6 \pm 5.7$
212.3	$-44.7 \pm 10.4 \pm 5.1$
214.8	$-19.9 \pm 11.0 \pm 3.8$
217.3	$-24.7 \pm 12.0 \pm 4.0$
219.8	$-20.2 \pm 12.7 \pm 3.4$
222.2	$0.3 \pm 10.6 \pm 3.2$
227.1	$1.5 \pm 8.8 \pm 2.5$
229.6	$29.7 \pm 8.8 \pm 3.2$
232.1	$29.7 \pm 10.1 \pm 3.0$
234.5	$45.6 \pm 8.6 \pm 3.7$
236.9	$73.3 \pm 8.4 \pm 5.2$
239.4	$83.2 \pm 9.1 \pm 5.8$
241.8	$80.4 \pm 8.9 \pm 5.6$
244.2	$101.7 \pm 8.5 \pm 6.9$
246.6	$115.5 \pm 9.1 \pm 7.8$
249.0	$131.6 \pm 9.9 \pm 8.8$
251.4	$168.3 \pm 9.4 \pm 11.1$
253.8	$178.1 \pm 9.2 \pm 11.8$
256.2	$200.3 \pm 8.5 \pm 13.2$
258.6	$217.4 \pm 9.3 \pm 14.3$
261.0	$243.8 \pm 9.7 \pm 16.0$
263.4	$250.8 \pm 8.1 \pm 16.5$
265.7	$270.8 \pm 9.4 \pm 17.8$
268.1	$280.7 \pm 9.2 \pm 18.4$
270.4	$293.3 \pm 9.3 \pm 19.2$
272.7	$311.6 \pm 8.8 \pm 20.5$
275.0	$339.0 \pm 8.7 \pm 22.2$
277.4	$351.7 \pm 8.4 \pm 23.1$
279.7	$380.0 \pm 8.5 \pm 24.9$
282.0	$403.3 \pm 9.2 \pm 26.5$
284.3	$431.2 \pm 9.3 \pm 28.3$
286.5	$430.4 \pm 8.7 \pm 28.2$
288.8	$457.9 \pm 8.9 \pm 30.0$
291.1	$458.2 \pm 8.9 \pm 30.0$
293.3	$477.8 \pm 9.3 \pm 31.3$
295.6	$487.2 \pm 8.4 \pm 32.0$
297.8	$498.7 \pm 8.5 \pm 32.7$
300.0	$515.8 \pm 8.5 \pm 33.8$
302.2	$519.4 \pm 9.3 \pm 34.1$
304.4	$515.3 \pm 9.2 \pm 33.8$
306.6	$528.2 \pm 11.7 \pm 34.6$
308.8	$524.5 \pm 8.8 \pm 34.4$
311.0	$530.4 \pm 13.3 \pm 35.1$
313.1	$530.0 \pm 9.7 \pm 34.1$
315.2	$530.6 \pm 8.7 \pm 34.5$
317.4	$525.3 \pm 8.6 \pm 34.8$
319.5	$518.9 \pm 13.1 \pm 34.0$
321.6	$519.7 \pm 9.5 \pm 34.1$
323.7	$513.4 \pm 10.2 \pm 33.7$

TABLE III. (*Continued.*)

E_γ	Value
325.8	$521.1 \pm 13.3 \pm 34.2$
327.9	$506.0 \pm 13.1 \pm 33.2$
329.9	$495.3 \pm 11.5 \pm 32.5$
332.0	$494.3 \pm 10.4 \pm 32.4$
334.0	$486.9 \pm 14.0 \pm 31.9$
336.0	$470.9 \pm 10.7 \pm 30.9$
338.0	$469.5 \pm 9.7 \pm 30.8$
340.0	$455.4 \pm 10.2 \pm 29.9$
342.0	$450.2 \pm 11.9 \pm 29.5$
344.0	$425.2 \pm 10.8 \pm 27.9$
345.9	$409.6 \pm 10.2 \pm 26.9$
347.9	$406.6 \pm 11.7 \pm 26.7$
349.8	$395.3 \pm 10.3 \pm 25.9$
351.7	$372.4 \pm 10.1 \pm 24.4$
353.6	$369.3 \pm 11.6 \pm 24.2$
355.5	$361.6 \pm 14.4 \pm 23.7$
357.4	$338.8 \pm 13.2 \pm 22.2$
359.3	$321.1 \pm 16.3 \pm 21.1$
361.1	$332.1 \pm 12.6 \pm 21.8$
363.0	$308.5 \pm 15.3 \pm 20.2$
364.8	$296.0 \pm 17.1 \pm 19.4$
366.6	$289.6 \pm 11.7 \pm 19.0$
368.4	$295.9 \pm 13.5 \pm 19.4$
370.2	$254.2 \pm 14.4 \pm 16.7$
371.9	$261.9 \pm 20.6 \pm 17.2$
373.7	$254.1 \pm 20.9 \pm 16.7$
375.4	$234.9 \pm 17.5 \pm 15.4$
377.2	$228.8 \pm 15.4 \pm 15.0$
378.9	$239.9 \pm 13.2 \pm 15.7$
380.6	$226.3 \pm 27.9 \pm 14.8$
382.3	$227.1 \pm 15.1 \pm 14.9$
383.9	$197.5 \pm 17.1 \pm 13.0$
385.6	$207.8 \pm 17.8 \pm 13.6$
387.2	$183.8 \pm 16.0 \pm 12.1$
388.9	$159.8 \pm 28.6 \pm 10.5$
390.5	$176.9 \pm 14.3 \pm 11.6$
392.1	$174.7 \pm 15.6 \pm 11.5$
393.7	$163.8 \pm 18.0 \pm 10.7$
395.4	$158.5 \pm 10.2 \pm 10.4$
397.1	$142.9 \pm 16.7 \pm 9.4$
407.5	$131.2 \pm 30.5 \pm 8.6$
416.3	$110.1 \pm 16.1 \pm 7.2$
425.0	$69.2 \pm 14.6 \pm 4.5$
433.8	$42.0 \pm 11.0 \pm 2.8$
442.5	$25.0 \pm 11.6 \pm 1.7$
451.3	$15.6 \pm 12.0 \pm 1.0$
460.1	$18.4 \pm 15.0 \pm 1.2$
468.8	$41.6 \pm 25.0 \pm 2.7$
477.6	$7.2 \pm 12.6 \pm 0.5$
486.4	$32.2 \pm 11.6 \pm 2.1$
495.1	$3.9 \pm 11.8 \pm 0.3$
503.9	$16.4 \pm 13.1 \pm 1.1$
512.7	$22.1 \pm 33.1 \pm 1.5$
521.4	$24.1 \pm 11.6 \pm 1.6$
530.2	$42.4 \pm 10.1 \pm 2.8$
539.0	$46.3 \pm 10.1 \pm 3.0$

TABLE III. (*Continued.*)

E_γ	Value
547.7	$46.1 \pm 10.4 \pm 3.0$
556.5	$50.7 \pm 13.2 \pm 3.3$
565.3	$62.3 \pm 11.4 \pm 4.1$
574.0	$75.9 \pm 12.8 \pm 5.0$
582.7	$63.1 \pm 11.1 \pm 4.1$
591.5	$74.6 \pm 12.9 \pm 4.9$
600.3	$73.9 \pm 12.9 \pm 4.8$
609.0	$86.4 \pm 11.0 \pm 5.7$
617.7	$90.3 \pm 10.5 \pm 5.9$
626.5	$110.9 \pm 9.0 \pm 7.3$
635.2	$122.0 \pm 12.8 \pm 8.0$
643.9	$134.6 \pm 10.2 \pm 8.8$
652.6	$127.7 \pm 8.9 \pm 8.4$
661.3	$141.1 \pm 10.0 \pm 9.3$
670.0	$151.0 \pm 9.2 \pm 9.9$
678.7	$154.0 \pm 8.8 \pm 10.1$
687.3	$161.8 \pm 8.8 \pm 10.6$
696.0	$151.0 \pm 8.9 \pm 9.9$
704.6	$142.2 \pm 10.1 \pm 9.3$
713.2	$158.0 \pm 15.1 \pm 10.4$
721.9	$125.8 \pm 10.4 \pm 8.2$
730.5	$147.5 \pm 10.0 \pm 9.7$
739.0	$148.5 \pm 10.2 \pm 9.7$
747.6	$139.4 \pm 10.7 \pm 9.1$
756.2	$119.8 \pm 8.9 \pm 7.9$
764.8	$96.8 \pm 8.3 \pm 6.4$
773.3	$107.7 \pm 19.9 \pm 7.1$
781.8	$78.8 \pm 11.4 \pm 5.2$
790.3	$69.6 \pm 9.1 \pm 4.6$
798.8	$67.5 \pm 12.0 \pm 4.4$
807.2	$48.1 \pm 9.5 \pm 3.2$
815.7	$51.4 \pm 8.0 \pm 3.4$
824.1	$41.3 \pm 9.4 \pm 2.7$
832.5	$23.3 \pm 9.3 \pm 1.5$
840.8	$30.3 \pm 8.8 \pm 2.0$
849.2	$21.1 \pm 10.5 \pm 1.4$
857.6	$16.8 \pm 10.4 \pm 1.1$
865.9	$8.1 \pm 11.2 \pm 0.5$
874.2	$26.7 \pm 11.5 \pm 1.7$
882.4	$44.5 \pm 10.0 \pm 2.9$
890.7	$27.7 \pm 11.8 \pm 1.8$
898.9	$40.0 \pm 12.0 \pm 2.6$
907.1	$49.7 \pm 9.2 \pm 3.3$
915.2	$41.5 \pm 10.0 \pm 2.7$
923.4	$38.8 \pm 10.6 \pm 2.5$
931.5	$66.7 \pm 11.3 \pm 4.4$
939.6	$76.0 \pm 11.6 \pm 5.0$
947.6	$61.2 \pm 9.4 \pm 4.0$
955.6	$80.9 \pm 10.2 \pm 5.3$
963.6	$97.5 \pm 10.9 \pm 6.4$
971.6	$94.4 \pm 12.4 \pm 6.2$
979.5	$98.9 \pm 10.3 \pm 6.5$
987.4	$90.4 \pm 9.7 \pm 5.9$
995.3	$106.1 \pm 11.9 \pm 7.0$
1003.1	$110.7 \pm 9.8 \pm 7.3$
1010.9	$110.6 \pm 11.2 \pm 7.3$
1018.6	$104.5 \pm 9.7 \pm 6.9$

TABLE III. (*Continued.*)

E_γ	Value
1026.4	$94.8 \pm 9.8 \pm 6.2$
1034.1	$93.6 \pm 10.1 \pm 6.1$
1041.8	$97.1 \pm 9.9 \pm 6.4$
1049.4	$80.3 \pm 10.0 \pm 5.3$
1056.9	$83.0 \pm 11.0 \pm 5.4$
1064.5	$59.5 \pm 9.1 \pm 3.9$
1072.0	$59.5 \pm 13.6 \pm 3.9$
1079.5	$44.4 \pm 11.1 \pm 2.9$
1086.9	$43.4 \pm 9.9 \pm 2.9$
1094.3	$54.9 \pm 9.7 \pm 3.6$
1101.6	$44.9 \pm 12.8 \pm 2.9$
1109.0	$23.7 \pm 11.5 \pm 1.6$
1116.2	$34.4 \pm 13.1 \pm 2.3$
1123.5	$29.1 \pm 14.4 \pm 1.9$
1130.6	$29.1 \pm 15.4 \pm 1.9$
1137.8	$12.7 \pm 12.6 \pm 0.8$
1144.9	$39.7 \pm 13.8 \pm 2.6$
1152.0	$25.7 \pm 13.8 \pm 1.7$
1159.0	$36.8 \pm 12.4 \pm 2.4$
1165.9	$20.8 \pm 10.4 \pm 1.4$
1172.9	$26.4 \pm 11.6 \pm 1.7$
1179.8	$6.6 \pm 10.1 \pm 0.4$
1186.6	$7.6 \pm 11.8 \pm 0.5$
1193.4	$-2.2 \pm 12.4 \pm 0.2$
1200.1	$-1.4 \pm 11.9 \pm 0.1$
1206.8	$18.5 \pm 10.3 \pm 1.2$
1213.5	$21.5 \pm 10.7 \pm 1.4$
1220.1	$20.0 \pm 11.9 \pm 1.3$
1226.7	$44.4 \pm 14.3 \pm 2.9$
1233.2	$-13.7 \pm 13.8 \pm 0.9$
1239.6	$5.9 \pm 13.5 \pm 0.4$
1246.1	$19.6 \pm 10.5 \pm 1.3$
1252.4	$18.9 \pm 12.8 \pm 1.2$
1258.8	$2.4 \pm 23.5 \pm 0.2$
1265.1	$18.4 \pm 12.7 \pm 1.2$
1271.3	$-5.8 \pm 13.4 \pm 0.4$
1277.5	$39.8 \pm 24.1 \pm 2.6$
1283.6	$32.3 \pm 18.7 \pm 2.1$
1289.7	$8.1 \pm 24.5 \pm 0.5$
1295.8	$17.7 \pm 20.8 \pm 1.2$
1301.8	$-2.0 \pm 22.3 \pm 0.2$
1307.7	$25.9 \pm 14.5 \pm 1.7$
1313.7	$18.9 \pm 16.6 \pm 1.2$
1319.6	$16.1 \pm 15.3 \pm 1.1$
1325.4	$18.3 \pm 17.1 \pm 1.2$
1331.2	$22.5 \pm 17.5 \pm 1.5$
1336.9	$30.3 \pm 19.3 \pm 2.0$
1342.6	$29.4 \pm 25.5 \pm 1.9$
1348.2	$-1.7 \pm 17.2 \pm 0.1$
1353.8	$1.6 \pm 20.4 \pm 0.1$
1359.4	$33.3 \pm 33.3 \pm 2.2$
1365.2	$26.5 \pm 15.2 \pm 1.7$
1371.2	$9.9 \pm 19.3 \pm 0.7$
1377.4	$30.7 \pm 19.0 \pm 2.0$
1383.8	$18.7 \pm 6.3 \pm 1.2$
1390.2	$22.2 \pm 92.5 \pm 1.5$
1397.0	$30.2 \pm 22.6 \pm 2.0$

TABLE IV. Numerical values of the total inclusive helicity dependent cross section $\Delta\sigma$ for the deuteron as a function of the photon energy E_γ in the target rest frame. The quoted errors represent the 68% confidence level of the statistical and systematic uncertainties of the experimental data, respectively.

E_γ	Value
204.1	$-81.9 \pm 29.7 \pm 12.7$
212.6	$-39.2 \pm 24.6 \pm 8.8$
221.2	$25.3 \pm 23.7 \pm 6.5$
229.7	$149.0 \pm 24.4 \pm 11$
238.3	$243.6 \pm 25.2 \pm 16.5$
246.9	$276.8 \pm 26.8 \pm 18.5$
255.5	$357.2 \pm 25.8 \pm 23.6$
264.1	$453.8 \pm 26.7 \pm 29.9$
272.7	$568.9 \pm 26.8 \pm 37.4$
281.4	$673.9 \pm 28.6 \pm 44.3$
290.1	$780.6 \pm 36.4 \pm 51.3$
298.7	$824.9 \pm 30.8 \pm 54.2$
307.4	$817.0 \pm 26.3 \pm 53.6$
316.0	$793.4 \pm 27.3 \pm 52.1$
324.7	$768.2 \pm 26.2 \pm 50.4$
333.4	$720.7 \pm 28.1 \pm 47.3$
342.1	$630.5 \pm 41.7 \pm 41.4$
350.8	$593.0 \pm 36.6 \pm 38.9$
359.5	$520.5 \pm 43.6 \pm 34.2$
368.2	$459.6 \pm 24.9 \pm 30.2$
376.9	$414.3 \pm 23.4 \pm 27.2$
385.7	$375.6 \pm 21.2 \pm 24.7$
394.4	$304.6 \pm 25.7 \pm 20.0$
403.2	$258.5 \pm 33.5 \pm 17.0$
411.9	$279.5 \pm 28.8 \pm 18.4$
420.7	$211.8 \pm 22.1 \pm 13.9$
429.4	$182.0 \pm 21.3 \pm 12.0$
438.2	$152.2 \pm 20.4 \pm 10.0$
446.9	$150.9 \pm 20.7 \pm 9.9$
455.7	$117.6 \pm 20.1 \pm 7.7$
464.4	$129.0 \pm 50.6 \pm 8.5$
473.2	$87.4 \pm 23.4 \pm 5.7$
482.0	$93.3 \pm 20.4 \pm 6.1$
490.8	$87.9 \pm 19.2 \pm 5.8$
499.5	$94.4 \pm 17.9 \pm 6.2$
508.3	$127.4 \pm 51.0 \pm 8.4$
517.1	$119.9 \pm 27.5 \pm 7.9$
525.8	$107.9 \pm 20.4 \pm 7.1$
534.6	$131.1 \pm 18.6 \pm 8.6$
543.4	$85.0 \pm 17.5 \pm 5.6$
552.1	$75.7 \pm 18.3 \pm 5.0$
560.9	$128.6 \pm 18.8 \pm 8.4$
569.6	$101.5 \pm 20.9 \pm 6.7$
578.4	$181.3 \pm 24.7 \pm 11.9$
587.1	$125.9 \pm 38.0 \pm 8.3$
595.9	$169.5 \pm 20.1 \pm 11.1$
604.6	$146.1 \pm 30.2 \pm 9.6$
613.4	$187.5 \pm 31.2 \pm 12.3$
622.1	$148.0 \pm 21.5 \pm 9.7$
630.8	$238.1 \pm 39.8 \pm 15.6$
641.7	$221.4 \pm 38.4 \pm 14.5$
648.2	$219.5 \pm 21.8 \pm 14.4$
656.9	$262.1 \pm 25.7 \pm 17.2$

TABLE IV. (*Continued.*)

E_γ	Value
665.6	$234.2 \pm 21.8 \pm 15.4$
674.3	$189.9 \pm 22.2 \pm 12.5$
683.0	$208.5 \pm 21.8 \pm 13.7$
691.6	$246.8 \pm 22.6 \pm 16.2$
700.3	$246.8 \pm 25.4 \pm 16.2$
708.9	$213.0 \pm 31.4 \pm 14.0$
717.6	$242.3 \pm 23.3 \pm 15.9$
726.2	$248.8 \pm 22.9 \pm 16.3$
734.8	$156.5 \pm 25.6 \pm 10.3$
743.3	$221.3 \pm 24.2 \pm 14.5$
751.9	$178.3 \pm 24.2 \pm 11.7$
760.5	$165.3 \pm 19.6 \pm 10.9$
769.0	$136.1 \pm 20.4 \pm 8.9$
777.5	$101.8 \pm 26.4 \pm 6.7$
786.0	$117.2 \pm 19.8 \pm 7.7$
794.5	$143.0 \pm 23.0 \pm 9.4$
803.0	$148.9 \pm 21.3 \pm 9.8$
811.5	$104.0 \pm 21.7 \pm 6.8$
819.9	$83.2 \pm 18.3 \pm 5.5$
828.3	$118.4 \pm 19.9 \pm 7.8$
836.7	$83.4 \pm 19.1 \pm 5.5$
845.1	$69.7 \pm 17.9 \pm 4.6$
853.4	$25.8 \pm 35.0 \pm 1.7$
861.7	$51.9 \pm 25.3 \pm 3.4$
870.0	$80.4 \pm 23.1 \pm 5.3$
878.3	$39.1 \pm 18.3 \pm 2.6$
886.5	$79.3 \pm 18.5 \pm 5.2$
894.8	$42.4 \pm 23.5 \pm 2.8$
903.0	$68.0 \pm 16.9 \pm 4.5$
911.2	$73.9 \pm 17.0 \pm 4.9$
919.3	$101.2 \pm 19.4 \pm 6.6$
927.4	$87.6 \pm 19.3 \pm 5.8$
935.5	$113.4 \pm 22.7 \pm 7.4$
943.6	$93.2 \pm 18.3 \pm 6.1$
951.6	$87.4 \pm 20.9 \pm 5.7$
959.6	$121.7 \pm 17.7 \pm 8.0$
967.6	$111.4 \pm 21.4 \pm 4.7$
975.5	$108.8 \pm 18.2 \pm 7.1$
983.5	$122.7 \pm 16.8 \pm 6.1$
991.3	$103.4 \pm 19.0 \pm 5.5$
999.2	$114.2 \pm 18.3 \pm 7.5$
1007.0	$111.8 \pm 16.7 \pm 6.7$
1014.8	$128 \pm 16.3 \pm 8.4$
1022.5	$119.7 \pm 16.5 \pm 7.9$
1030.2	$110.1 \pm 17.2 \pm 7.2$
1037.9	$100.1 \pm 18.0 \pm 6.6$
1045.6	$62.6 \pm 17.3 \pm 4.1$
1053.1	$99.5 \pm 19.3 \pm 6.5$
1060.7	$128.5 \pm 20.8 \pm 8.4$
1068.3	$105.6 \pm 15.8 \pm 6.9$
1077.6	$87.4 \pm 25.8 \pm 5.7$
1083.2	$64.7 \pm 17.2 \pm 4.3$
1090.6	$42.2 \pm 16.7 \pm 2.8$
1098.0	$68.0 \pm 16.6 \pm 4.5$
1105.3	$68.1 \pm 19.0 \pm 4.5$
1112.6	$89.0 \pm 17.4 \pm 5.9$
1119.9	$65.6 \pm 22.7 \pm 4.3$

TABLE IV. (*Continued.*)

E_γ	Value
1127.0	$122.6 \pm 30.9 \pm 8.1$
1134.2	$65.2 \pm 20.9 \pm 4.3$
1141.4	$71.8 \pm 18.8 \pm 4.7$
1148.4	$58.0 \pm 17.1 \pm 3.8$
1155.5	$35.5 \pm 19.7 \pm 2.3$
1162.4	$81.7 \pm 16.0 \pm 5.4$
1169.4	$57.2 \pm 19.2 \pm 3.8$
1176.3	$39.3 \pm 17.5 \pm 2.6$
1183.2	$48.1 \pm 19.2 \pm 3.2$
1190.0	$64.9 \pm 20.6 \pm 4.3$
1196.8	$41.1 \pm 18.3 \pm 2.7$
1203.5	$45.2 \pm 16.8 \pm 3.0$
1210.2	$37.4 \pm 16.2 \pm 2.5$
1216.8	$35.2 \pm 16.1 \pm 2.3$
1223.4	$35.1 \pm 19.8 \pm 2.3$
1229.9	$32.5 \pm 23.4 \pm 2.1$
1236.4	$0.7 \pm 36.3 \pm 0.2$
1242.9	$39.4 \pm 41.8 \pm 2.6$
1249.3	$32.7 \pm 13.4 \pm 2.2$
1255.6	$71.2 \pm 23.6 \pm 4.7$
1261.9	$47.0 \pm 19.5 \pm 3.1$
1268.2	$31.0 \pm 17.8 \pm 2.0$
1274.4	$32.4 \pm 24.6 \pm 2.1$
1280.6	$57.6 \pm 22.8 \pm 3.8$
1286.7	$29.0 \pm 35.9 \pm 1.9$
1292.8	$21.6 \pm 29.9 \pm 1.4$
1298.8	$-5.5 \pm 51.0 \pm 0.4$
1304.8	$68.3 \pm 27.6 \pm 4.5$
1310.7	$30.6 \pm 21.2 \pm 2.0$
1316.6	$31.1 \pm 23.1 \pm 2.0$
1322.5	$5.8 \pm 20.8 \pm 0.4$
1328.3	$48.5 \pm 29.5 \pm 3.2$
1334.0	$54.5 \pm 41.0 \pm 3.6$
1339.7	$75.5 \pm 37.6 \pm 5.0$
1345.4	$61.9 \pm 33.4 \pm 4.1$
1351.0	$33.6 \pm 34.2 \pm 2.2$
1356.6	$69.4 \pm 39.3 \pm 4.6$
1362.3	$36.3 \pm 26.5 \pm 2.4$
1368.2	$51.2 \pm 26.6 \pm 3.4$
1374.3	$55.9 \pm 37.4 \pm 3.7$
1380.6	$22.4 \pm 33.5 \pm 1.5$
1387.0	$13.2 \pm 13.0 \pm 0.9$
1393.5	$0.32 \pm 40.2 \pm 0.04$

TABLE V. Numerical values of the total inclusive helicity dependent cross section $\Delta\sigma$ for the neutron [evaluated using Eq. (2)] as a function of the photon energy E_γ in the target rest frame. The quoted errors represent the 68% confidence level of the statistical and systematic uncertainties of the experimental data, respectively.

E_γ	Value
508.3	$118.5 \pm 59.7 \pm 9.1$
517.1	$106.5 \pm 37.2 \pm 8.7$
525.8	$83.4 \pm 24.5 \pm 8.0$
534.6	$97.4 \pm 22.5 \pm 9.8$
543.4	$45.7 \pm 21.5 \pm 6.8$

TABLE V. (*Continued.*)

E_γ	Value
552.1	$33.5 \pm 23.1 \pm 6.3$
560.9	$82.5 \pm 23.7 \pm 9.9$
569.6	$40.6 \pm 25.6 \pm 8.5$
578.4	$126.5 \pm 29.2 \pm 13.7$
587.1	$67.3 \pm 42.8 \pm 10.0$
595.9	$109.0 \pm 25.2 \pm 13.0$
604.6	$77.8 \pm 34.7 \pm 11.6$
613.4	$114.3 \pm 35.4 \pm 14.5$
622.1	$59.4 \pm 25.3 \pm 12.4$
630.8	$140.9 \pm 44.4 \pm 18.5$
641.7	$107.9 \pm 43.1 \pm 17.8$
648.2	$106.2 \pm 25.4 \pm 17.8$
656.9	$149.0 \pm 29.3 \pm 20.6$
665.6	$107.1 \pm 25.4 \pm 19.2$
674.3	$52.8 \pm 25.6 \pm 16.8$
683.0	$67.5 \pm 25.1 \pm 18.1$
691.6	$110.4 \pm 26.0 \pm 20.3$
700.3	$120.2 \pm 29.1 \pm 20.0$
708.9	$80.2 \pm 36.2 \pm 18.0$
717.6	$120.1 \pm 28.3 \pm 19.6$
726.2	$132.3 \pm 26.8 \pm 19.8$
734.8	$21.1 \pm 29.5 \pm 14.7$
743.3	$95.2 \pm 28.1 \pm 18.3$
751.9	$63.2 \pm 27.9 \pm 15.2$
760.5	$70.4 \pm 22.9 \pm 13.7$
769.0	$44.8 \pm 26.2 \pm 11.8$
777.5	$16.8 \pm 32.6 \pm 9.5$
786.0	$52.6 \pm 23.7 \pm 9.6$
794.5	$86.1 \pm 27.0 \pm 11.1$
803.0	$103.2 \pm 25.4 \pm 11.2$
811.5	$62.7 \pm 25.0 \pm 8.1$
819.9	$43.6 \pm 21.6 \pm 6.6$
828.3	$95.7 \pm 23.4 \pm 8.7$
836.7	$63.4 \pm 22.5 \pm 6.2$
845.1	$49.7 \pm 21.6 \pm 5.2$
853.4	$8.9 \pm 39.2 \pm 2.2$
861.7	$43.7 \pm 29.4 \pm 3.8$
870.0	$69.6 \pm 27.4 \pm 5.8$
878.3	$6.7 \pm 22.5 \pm 3.6$
886.5	$49.7 \pm 22.7 \pm 6.1$
894.8	$12.0 \pm 28.0 \pm 3.7$
903.0	$28.6 \pm 21.1 \pm 5.7$
911.2	$34.3 \pm 20.7 \pm 6.0$
919.3	$69.2 \pm 23.4 \pm 7.7$
927.4	$42.0 \pm 23.6 \pm 7.1$
935.5	$51.2 \pm 27.1 \pm 9.3$
943.6	$32.1 \pm 22.4 \pm 8.0$
951.6	$23.4 \pm 24.6 \pm 7.8$
959.6	$42.4 \pm 21.8 \pm 10.4$
967.6	$24.4 \pm 25.9 \pm 8.1$
975.5	$20.9 \pm 22.7 \pm 10.0$
983.5	$38.0 \pm 20.7 \pm 9.1$
991.3	$13.5 \pm 23.2 \pm 8.8$
999.2	$15.0 \pm 22.5 \pm 10.8$
1007.0	$10.2 \pm 20.9 \pm 10.2$
1014.8	$30.8 \pm 20.4 \pm 11.5$
1022.5	$29.8 \pm 20.4 \pm 10.7$
1030.2	$24.8 \pm 21.1 \pm 10.0$

TABLE V. (*Continued.*)

E_γ	Value
1037.9	$12.8 \pm 21.9 \pm 9.5$
1045.6	$-20.9 \pm 21.2 \pm 7.3$
1053.1	$26.0 \pm 23.4 \pm 8.9$
1060.7	$67.7 \pm 24.6 \pm 10.3$
1068.3	$54.6 \pm 20.5 \pm 8.5$
1077.6	$46.3 \pm 30.5 \pm 7.1$
1083.2	$26.0 \pm 21.4 \pm 5.4$
1090.6	$-3.5 \pm 20.6 \pm 4.4$
1098.0	$23.6 \pm 21.2 \pm 5.8$
1105.3	$39.3 \pm 23.8 \pm 5.3$
1112.6	$67.1 \pm 22.4 \pm 6.6$
1119.9	$39.2 \pm 28.2 \pm 5.1$
1127.0	$103.4 \pm 36.5 \pm 8.9$
1134.2	$49.6 \pm 26.6 \pm 4.8$
1141.4	$51.4 \pm 24.2 \pm 5.4$
1148.4	$30.0 \pm 23.1 \pm 4.6$
1155.5	$7.1 \pm 25.0 \pm 3.3$
1162.4	$59.5 \pm 20.7 \pm 6.1$
1169.4	$38.2 \pm 23.5 \pm 4.4$
1176.3	$26.0 \pm 21.8 \pm 3.0$
1183.2	$45.0 \pm 23.5 \pm 3.5$
1190.0	$67.5 \pm 25.3 \pm 4.6$
1196.8	$46.2 \pm 23.3 \pm 2.9$
1203.5	$40.3 \pm 21.3 \pm 3.3$
1210.2	$20.5 \pm 20.4 \pm 3.0$
1216.8	$17.3 \pm 20.8 \pm 2.9$
1223.4	$5.7 \pm 25.1 \pm 3.3$
1229.9	$19.9 \pm 29.0 \pm 3.0$

TABLE V. (*Continued.*)

E_γ	Value
1236.4	$4.6 \pm 41.5 \pm 0.7$
1242.9	$29.8 \pm 46.8 \pm 2.9$
1249.3	$16.1 \pm 18.6 \pm 2.7$
1255.6	$66.4 \pm 31.3 \pm 5.1$
1261.9	$40.4 \pm 27.7 \pm 3.4$
1268.2	$27.2 \pm 23.3 \pm 2.3$
1274.4	$18.1 \pm 32.6 \pm 2.8$
1280.6	$26.3 \pm 32.6 \pm 4.7$
1286.7	$11.1 \pm 44.4 \pm 2.5$
1292.8	$10.4 \pm 39.5 \pm 1.8$
1298.8	$-13.7 \pm 59.2 \pm 0.8$
1304.8	$61.8 \pm 35.0 \pm 4.9$
1310.7	$10.7 \pm 27.7 \pm 2.6$
1316.6	$16.1 \pm 29.6 \pm 2.5$
1322.5	$-11.0 \pm 27.7 \pm 1.2$
1328.3	$32.1 \pm 36.3 \pm 3.7$
1334.0	$32.5 \pm 48.0 \pm 4.2$
1339.7	$51.8 \pm 46.5 \pm 5.7$
1345.4	$53.2 \pm 41.9 \pm 4.5$
1351.0	$36.4 \pm 41.5 \pm 2.4$
1356.6	$57.7 \pm 50.3 \pm 5.1$
1362.3	$9.3 \pm 37.6 \pm 3.2$
1368.2	$37.1 \pm 33.5 \pm 3.8$
1374.3	$40.2 \pm 44.7 \pm 4.2$
1380.6	$-0.5 \pm 38.4 \pm 2.3$
1387.0	$-6.2 \pm 51.4 \pm 1.6$
1393.0	$-25.9 \pm 72.1 \pm 1.7$

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