Measurement of helicity dependent total inclusive $\gamma-^3\text{He}$ cross section and the GDH sum rule on the neutron

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Abstract. A first experiment using a polarised $^3\text{He}$ target has been carried out in Mainz at the MAMI accelerator, with the aim of investigate the Gerasimov-Drell-Hearn sum rule on the neutron. In fact, due to the spin structure of $^3\text{He}$, the data obtained with the polarised $^3\text{He}$ target gives a complementary and more direct access to the neutron compared to the existing data on the deuteron. Results of the unpolarised and helicity dependent total photoabsorption cross section $\gamma^3\text{He} \rightarrow X$, of the pion photoproduction channels $\gamma^3\text{He} \rightarrow \pi X$ and of the $\gamma^3\text{He} \rightarrow ppn$ channel, obtained in a photon energy range between 200 MeV and 500 MeV, will be presented.

1. The GDH sum rule
Since the beginning of the 1960s, a central issue of nuclear and particle physics has been the study of the internal structure of the nucleon, in particular of its spin structure, which is not so well understood as other nucleon properties.
For this study, of particular interest are sum rules, which connect information from all energies to fundamental parameters of the present interaction models.
The Gerasimov-Drell-Hearn sum rule [1, 2] is a good example of these rules: it relates the nucleon anomalous magnetic moment (AMM) $\kappa$, the spin $S$ and the mass $M$ of a nucleon to the integral over the weighted helicity difference of the total absorption cross section for circularly polarised photons on a longitudinally polarised nucleon target.

$$I_{GDH} = \int_{\nu_{th}}^{\infty} \frac{\sigma_{p} - \sigma_{a}}{\nu} d\nu = 4\pi^2 \kappa^2 \frac{e^2}{M^2} S, \tag{1}$$

where $\nu$ is the photon energy, and $\sigma_{p}$ and $\sigma_{a}$ denote the total absorption cross section for parallel and antiparallel orientation of photon and particle spins, respectively. The lower limit of the integral, $\nu_{th}$, corresponds to pion production and photodisintegration threshold for a nucleonic and nuclear target, respectively.
Table 1 reports the magnetic moment $\mu$ and the AMM $\kappa$ values for protons, neutrons, deuterons

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Table 1. Magnetic moment $\mu$ and AMM $\kappa$ (units: $\mu_N$, nuclear magneton) for protons, neutrons, deuterons and $^3$He nuclei.

|     | p   | n   | d   | $^3$He |
|-----|-----|-----|-----|--------|
| $\mu$ | 2.79 | -1.91 | 0.86 | -2.13 |
| $\kappa$ | 1.79 | -1.92 | 0.65 | 498    |

and $^3$He nuclei.

The GDH sum rule is derived from very general fundamental physical principles, in particular from the forward Compton scattering, the optical theorem and the low energy one.

In the past, there have been several attempts to find causes for a failure of the GDH sum rule. The only “weak” hypothesis is the assumption that the Compton scattering becomes spin-independent as the energy tends to infinity.

Possible explanations for this violation could be the exchange of a $a_1$-like meson between the photon and the nucleon or the non-pointlike quark structure.

The test of this relation provides a fundamental check of our knowledge of the $\gamma$-nucleon interaction, as well as of the physics of strongly interacting systems; it is also a check of the existing photo-reaction models. In addition, through the helicity dependent partial channels, it will be possible to access new observables and to study the baryonic resonances.

2. Theoretical predictions for the GDH on the nucleon

It is possible to estimate the GDH sum rule value for the nucleon by using a combination of multipole analyses of the available single pion photoproduction data (mostly from unpolarised experiments) [3, 4] and phenomenological models of multipion and heavy meson photoproduction reactions [5, 6, 7] up to $E_\gamma \simeq 2$ GeV. Above this energy, the contribution can be estimated from Regge-type approaches [8].

Table 2 reports the current theoretical estimates of the GDH sum rule values both for the proton and the neutron. Predictions for the $N\pi$ channel are from the SAID [3] and MAID [4] (within brackets) multipole analyses; the contribution for the $N\pi\pi$ channel are from [5]; the estimates for $N\eta$ are from [4], the kaon contributions are from [6] and the vector meson ones are from [7]; finally, the Regge estimates are from [8].

There is a disagreement between these theoretical predictions and the GDH sum rule value for the proton, while the neutron GDH value is roughly reproduced.

In addition, it is worth noting that according to the models, $I_{GDH}$ for the proton and the neutron are roughly the same, while this is not the case for the GDH sum rule values.

In order to find out the reasons for this discrepancy, a precise measurement of the GDH integral for both the proton and the neutron is needed, as well as a systematic study of the partial channels, in particular of the $N\pi(\pi)$ ones, which give the dominant contribution to the GDH integral.

3. The GDH sum rule on the proton

The first experimental check of the GDH sum rule for the proton was performed by the GDH collaboration jointly at the Mainz and Bonn tagged photon facilities, where the $I_{GDH}^p$ was experimentally evaluated in the photon energy range between 200 MeV and 2.9 GeV [9, 12].

The estimated value of the GDH integral is $211 \pm 5 (stat) \pm 12 (sys) \mu$b. This value comes out from the combination of the experimental results, shown in figure 1, with the theoretical...
predictions for the unmeasured energy ranges, as reported in table 3. The obtained result supports the validity of the GDH sum rule for the proton, contrarily to the estimates given in table 2. The discrepancy is mainly due to the oscillating photon energy dependence of the GDH integrand, because of the alternating sign of the multipole contributions. In order to have a reliable prediction of the GDH integral, it is then needed a very high accurate model that has not been reached yet.

![Figure 1. Helicity dependent cross section on the proton.](image)

4. The GDH sum rule for the neutron
In the neutron case, the experimental verification of the GDH sum rule is complicated by the lack of free neutron targets. In order to compensate for this lack, deuteron and $^3$He targets can be used. In both cases, nuclear structure effects and final state interactions will prevent the direct access to the cross section of the “free nucleon” and the evaluation of the free neutron contribution will be model

| $\gamma N \to N\pi$ | $I_{GDH}$ proton | $I_{GDH}$ neutron |
|----------------------|------------------|------------------|
| $\gamma N \to N\pi\pi$ | 172 [164] | 147 [131] |
| $\gamma N \to N\rho$ | -8 | -6 |
| $\gamma N \to K\Lambda(\Sigma)$ | -4 | 2 |
| $\gamma N \to N\rho(\omega)$ | 0 | 2 |
| Regge contribution ($E_\gamma > 2$ GeV) | -14 | 20 |
| TOTAL | $\sim 239$ [231] | $\sim 247$ [231] |
| GDH sum rule | 204 | 233 |
dependent. On the other hand, the comparison between the two different free neutron values extracted from both targets and the usage of different nuclear models will play a crucial role in constraining the theoretical analyses and will give a fundamental cross check of the reliability of the extraction procedures.

4.1. Deuteron targets as free neutron substitutes

Deuterons are systems consisting of one proton and one neutron with paired spins, with the 96% of probability to be in relative $S$ state. Hence the magnetic moment of the deuteron is the sum of the magnetic moment of the proton and of the neutron:

$$\mu_d \approx \mu_p + \mu_n.$$

The results of the helicity dependent total inclusive photoabsorption cross section obtained by the GDH collaboration at Bonn [15] and at Mainz [14] are shown in figure 2 and compared to a nuclear model proposed by Arenhövel, Fix and Schwamb (AFS) [16]. Above 700 MeV the AFS model overestimated the data: this could be due to a poor treatment of the double pion photoproduction channels, whose contribution becomes relevant at high energies. The experimental value of $I_{GDH}^d$ between $E_\gamma = 200$ MeV up to $E_\gamma = 1.8$ GeV is $452 \pm 9$ (stat) $\pm 24$ (sys) $\mu$b.

In a partial wave analysis approach, assuming that the incoherent, quasi-free meson production processes dominate in the measured energy region, the GDH integral above the pion production threshold can be approximated by the sum of the proton and neutron contribution, weighted on effective degrees of proton and neutron polarisation $p^d_p$ and $p^d_n$, respectively:

$$I_{GDH}^d|_{\nu>m_\pi} \sim p^d_p \cdot I_{GDH}^p + p^d_n \cdot I_{GDH}^n$$

where $p^d_p = p^d_n = 0.93$ as evaluated by [13] when taking into account all nuclear wave function components.

This formula was used to extract a rough value of the GDH integral for the free neutron from the measured values of the GDH integral for the deuteron and for the proton in the energy region between 0.2 and 1.8 GeV. In this way, a value $I_{GDH}^n[0.2-1.8$ GeV] comparable with the GDH sum rule prediction for the neutron ($\sim 233 \mu$b) was found.

This estimation is quite crude, since the low ($E_\gamma < 200$ MeV) and very high ($E_\gamma > 1.8$ GeV) are missing in the available data. In addition, there are also other channels ($\gamma d \rightarrow \pi^0 d$ and $\gamma d \rightarrow pn$) which contribute to $I_{GDH}^d$. Unfortunately, these channels cannot be treated in the quasi-free approximation; on the other hand, their contribution is quite small compared to the

| $E_\gamma$ (MeV)               | $I_{GDH}^p$ (µb) | $I_{GDH}^n$ (µb) |
|-------------------------------|-----------------|-----------------|
| $\leq 0.2$ (theoretical)      | $-28.5 \pm 2$   |                 |
| $0.2 - 0.8$ (measured)        | $226 \pm 5 \pm 12$ | $27.5 \pm 2 \pm 1.2$ |
| $0.8 - 2.9$ (measured)        |                 |                 |
| $\geq 2.9$ (theoretical)      | $-14 \pm 2$     |                 |
| **Total**                     | $211 \pm 5 \pm 12$ |                 |
| **GDH sum rule**              |                 | $204$           |
incoherent pion production.
Furthermore, the reactions on the deuteron are affected by its internal structure, so these experimental results represent a good test of our knowledge and understanding of nuclear dynamics.

4.2. $^3\text{He}$ targets as free neutron substitutes

$^3\text{He}$ is a system consisting of two protons with spins paired off and an "active" unpaired neutron, in relative $s$ state with 90% probability. As a result, the contribution of the two protons to the magnetic moment of $^3\text{He}$ cancels off and it can be approximated with the magnetic moment of the neutron:

$$\mu_{^3\text{He}} \approx \mu_n.$$ 

So it is clear that the spin structure function of $^3\text{He}$ is much closer to the free neutron than the deuteron one. Therefore, it is expected that the measured GDH integral function for $^3\text{He}$ above the pion production threshold will be a good approximation of the GDH integral value for the neutron. In a PWA approach, the following formula can be used:

$$I_{^3\text{He}}^{\text{GDH}}|_{\nu>m_{\pi}} \approx -2 \cdot p_{^3\text{He}}^p \cdot I_{p}^{\text{GDH}} + p_{^3\text{He}}^n \cdot I_{n}^{\text{GDH}},$$

(3)

where $p_{^3\text{He}}^p = -0.026$ and $p_{^3\text{He}}^n = 0.87$ are the effective degrees of proton and neutron polarisation, respectively.

Since the proton contribution to the measured helicity dependent yields is much smaller for $^3\text{He}$ than for the deuteron, it can be clearly seen that the most accurate evaluation of $I_{n}^{\text{GDH}}$ will come from $^3\text{He}$, which has been used at MAMI as the substitute for polarised neutron target.

While the GDH integral for $^3\text{He}$ is expected to have approximately the same value of the GDH integral for the neutron above the pion production threshold, this is not true if the photodisintegration energy region is taken into account in the integral, as comes out from the generalized formula of the GDH sum rule for nuclei:

$$I_{GDH}(^3\text{He}) = 4\pi^2 S \left( \frac{1}{S} \mu - Q \frac{M}{M} \right)^2 = \int_{\nu_{th}}^{\infty} \frac{\sigma_{3/2}(\nu) - \sigma_{1/2}(\nu)}{\nu} d\nu,$$

(4)

Figure 2. The helicity dependent total inclusive photoabsorption cross section obtained in [14] (full circles) and in [15] (open circles), compared to the theoretical predictions of AFS (Arenhövel, Fix and Schwamb) [16].
which is expected to be of the order of 498 $\mu$b, $\gg I_{GDH}$. This means that the contribution from the two-body break up to the pion production threshold is quite large, in order to satisfy the predicted value of 498 $\mu$b. Precise experimental data are clearly required from the photodisintegration threshold upwards.

The Mainz tagged facility cannot access such low energies: MAMI can perform investigations beyond the $\pi$ production threshold. The direct measurement of $I_{GDH}(d)$ and $I_{GDH}(^3He)$ from the break-up threshold region up to about 60 MeV is planned at the new upgraded HILγS facility, of the TUNL laboratory (Durham NC, USA) [17].

The results obtained from both measurements will provide useful information to better understand the GDH sum rule integrand for $^3$He and to extract from this the neutron information.

5. Helicity dependent results on $^3$He

A first experiment for the measurement of the double polarised photoabsorption cross section on $^3$He in the $\Delta(1232)$ baryon resonance region has been performed at the tagged photon facility of the MAMI accelerator in Mainz, during July 2009.

This experiment was carried out with a circularly polarised photon beam produced via bremsstrahlung process of a longitudinally polarised electron beam. In the following, some preliminary results from runs limited to 525 MeV will be shown, as a function of the incoming photon energy up to 500 MeV.

5.1. The MAMI experimental setup at Mainz

The experiment was carried out at the tagged photon facility of the MAMI accelerator in Mainz. Circularly polarized photons were obtained by bremsstrahlung of longitudinally polarized electrons with an average polarization of 75% [18]. The bremsstrahlung photons were tagged using the Glasgow-Mainz magnetic spectrometer with an energy resolution of about 2 MeV [19, 20]. The relative tagging efficiency was monitored throughout the experiment by a CCD photon camera and absolute measurements were made regularly using a lead-glass detector.

The reaction products were detected by the central detector system, consisting of the Crystal Ball (CB) NaI spectrometer, complemented by the Multi-Wire Proportional Chambers (MWPCs), used to identify and track the charged particles, and the cylindrical Particle Identification Detector (PID), used to distinguish the charged from the neutral particles detected by the CB. The combined information provided by these three detectors provides accurate energy, angle and particle identification in the azimuthal ($\phi$) and polar ($\theta$) angular regions from 0$^\circ$ to 360$^\circ$ and from 21$^\circ$ to 159$^\circ$, respectively.

In addition, the TAPS spectrometer provides information about the particles flying in the forward direction, outside the acceptance region of CB, but it has not been included in the data analysis that will be presented in the following.

The polarised $^3$He gas target has been produced at the Physics Institute of the Mainz University as a substitute for a polarised neutron target. The gas has been polarised via the Metastability Exchange Optical Pumping (MEOP) method [21].

The polarisation process starts by applying a weak gas discharge to the gas sample maintained at a pressure of 0.8-1 mbar: this induces a small fraction of the atoms ($\sim 10^{-6}$%) to reach the metastable state $^3S_1$.

In the presence of a non-null magnetic field, the metastable state is split by the fine and hyperfine interactions in two sublevels with quantum numbers $m_F = \pm 1/2$.

The absorption of right-handed circularly polarised laser light with $\lambda = 1083$ nm causes then the transition to the $^3P_{0,1,2}$ states. According to the angular momentum conservation laws, only transitions with $\Delta m_F = 1$ are allowed.

Then, after excitation, a spontaneous remission to both sublevels of the metastable occurs.
Figure 3. Side view of the MAMI experimental setup used for the $^3$He measurements (left); sketch of the detectors (right): the Crystal Ball (CB), MultiWire Proportional Chambers (MWPCs), Particle Identification Detector (PID) and TAPS subdetectors are shown.

However, the continue depopulation of the $^2\,^3S_1$($m_F = -1/2$) state results in a higher population of the $^2\,^3S_1$($m_F = 1/2$) sublevel. Finally, the nuclear polarisation of the metastable state is transferred to the unpolarised ground state atoms via atomic collisions, during which they exchange the excitation of their atomic electrons without altering the nuclear spins of the atoms involved:

$$ ^\uparrow \, ^3\text{He}(^2\,^3S_1) + ^3\text{He}(^1\,^1S_0) \rightarrow ^\uparrow \, ^3\text{He}(^2\,^3S_1) + ^\downarrow \, ^3\text{He}(^1\,^1S_0). $$

As a result, one obtains a ground state with polarised nucleus and a new metastable atom can be further optically pumped by the laser.

After the polarisation process, the gas is compressed with minimal polarisation losses to the desired pressure by a non-magnetic piston.

The target cell (figure 4) is cylindrical, with an outer diameter of 6 cm and a total length of 20 cm; it is made from quartz glass with two 50 $\mu$m thick titanium foils as entry and exit windows for the photon beam. This material was chosen since it provides the necessary gas tightness and give an acceptably long relaxation time of the gas polarisation.

The target cell is then inserted inside the CB detector, where the polarisation alignment is maintained by a solenoid inside a region with a very low magnetic field gradient. The measurement of the polarisation was carried out via a NMR technique, with an external magnetic field produced in the z-direction by Helmholtz coils, providing a quantization axis along which the $^3$He spins are oriented. The setup used is the one shown in figure 3.

Under these conditions, with a gas pressure of 5 bar, the $^3$He gas target density is relatively low ($N_T \sim 2.5 \cdot 10^{21}$ cm$^{-2}$) compared to that of a solid or liquid target (about 100 times less). Despite this, the $^3$He gas target is pure, so it has a greater fraction of polarised neutron with respect to the deuterated butanol case.

The plot shown in figure 5a) shows the $z$-vertices of the emitted charged hadrons, as reconstructed by using the MWPCs information. Around -100 and +100 mm the effect of the target cell windows is clearly visible and much bigger than the $^3$He contribution. The influence of the windows cancels exactly when taking into account the $(N_P - N_A)$ difference, where $N_P(A)$ is the number of experimental events with parallel and antiparallel $\gamma$-$^3$He spin configuration. As shown in figure 5b), in this case the only contribution from the polarised $^3$He gas gives rise to a non-zero count rate in the target region.
6. Data Analysis
In the following, the obtained unpolarised and helicity dependent photoabsorption cross sections on $^3$He will be showed. In particular, the total inclusive cross sections will be presented, as well as the results for the partial channels $\gamma^3He \rightarrow \pi^\pm X$, $\gamma^3He \rightarrow \pi^0 X$ and $\gamma^3He \rightarrow ppm$. In addition, a comparison between the total inclusive and the sum of partial channels will be shown.
Concerning the total inclusive cross section, the analysis has been performed without partial channels separation; concerning the semi-inclusive channels, the $\pi/p$ separation has been performed through the dE/dx vs E technique, using PID and MWPCs information, while the $\pi^0$ have been identified by the $\gamma\gamma$ invariant mass plot, using only CB information.
Finally, concerning the $ppm$ partial channel, these events have been separated by the $ppm\pi^0$ events using missing mass and missing energy plots.
6.1. Unpolarised cross section

Figure 6 shows the preliminary results obtained for the unpolarised total inclusive photoabsorption cross section (blue circles) as a function of the incoming photon energy. These results are compared to the experimental data previously published by the DAPHNE Collaboration. The good agreement between the two different data sets gives confidence in the applied data analysis procedure.

![Preliminary data](image)

**Figure 6.** The unpolarised total inclusive photoabsorption cross section on $^3$He (blue circles) is compared to the unpolarised results obtained by the DAPHNE collaboration (red circles) [22].

Concerning the unpolarised cross sections for the partial channels, the preliminary results for the $\pi^\pm X$ and $\pi^0 X$ channels are shown in figure 7, where the data are compared to the predictions from the Fix model (full line) and from the MAID multipole analysis (dotted line) [23].

In the MAID-based empirical model, the $^3$He prediction is evaluated simply assuming that the protons and the neutron inside $^3$He behave as free nucleons.

On the contrary, the Fix semi-empirical model [24] accounts also for the Fermi motion of the interacting nucleons inside the nuclei and the nuclear effects, like the Final State Interactions (FSI). These effects result in a damp and broadening of the peak corresponding to the $\Delta$-resonance, with respect to the free nucleons MAID estimation.

The data are in a good agreement with the Fix model in the case of the charged partial channels, whereas there is a sizeable discrepancy for the neutral channel, where a bigger contribution is due to nuclear structure effects, which are more difficult to be reproduced.

The first preliminary results for the $\gamma^3He \rightarrow ppm$ partial channel are shown in figure 8.

In this case, the model predictions come from the so-called “quasi-deuteron” approximation, as if the photon interacts only with a proton and a neutron paired in a virtual deuteron inside the $^3$He nucleus, with the remaining spectator proton.

In this approximation, the cross section for $^3$He can be obtained by multiplying the cross section for the deuteron, estimated with the Schwamb model [25], by the factor 1.68 [26], that takes into account the number of “quasi-deuterons” contained in the $^3$He nucleus.

From the plot, there is a clear discrepancy between the experimental data and the “quasi-deuteron” model; this is mainly due to the fact that this model does not take into account the...
three body effects, which are to contribute to this channel for about 30% [27].

Finally, if we compare the total inclusive cross section to the sum of the partial channels (figure 9), a good agreement is obtained, demonstrating that all different analyses have been performed in a proper and consistent way.

6.2. Helicity dependent cross section on $^3$He

In the polarised cross section case, the same channels as before (both the total inclusive and the partial ones) will be presented in the following.
Figure 9. Comparison between the unpolarised $\gamma ^3\text{He}$ total cross sections obtained with the inclusive analysis (blue circles) and as sum of the partial/semi-inclusive channels (red circles).

The plot in figure 10 shows the preliminary results for the helicity dependent cross section difference $\Delta \sigma$ on $^3\text{He}$ as a function of the incoming photon energy. The data are compared to the prediction of two models: the red one is a combination of the Fix and Schwamb contributions, in order to take into account both the nuclear effects and the FSI and the “quasi-deuteron” description of the $\text{ppn}$ partial channel, respectively. The other prediction in the plot (green line) is that of the MAID-based model, where the nucleons inside the nucleus are assumed to be free and only the effect of the spin alignments are taken into account. In this framework, the prediction is evaluated as:

$$\Delta \sigma _{^3\text{He}} = 0.87 \cdot \Delta \sigma _n - 2 \cdot 0.026 \cdot \Delta \sigma _p,$$

where the numbers are the effective nucleon polarisations and $\Delta \sigma _{n(p)}$ are the free neutron and proton helicity dependent $N\pi$ cross sections obtained from the MAID model.

The agreement between the experimental data and these empirical models is reasonable, taking into account the non-negligible statistical experimental errors.

In figure 11, the total helicity dependent cross section difference $\Delta \sigma _\pi = \sigma _{\pi,a} - \sigma _{\pi,p}$ for the $\gamma ^3\text{He} \rightarrow \pi^0 X$ (upper plot) and $\gamma ^3\text{He} \rightarrow \pi^\pm X$ channels (lower plot) are shown and compared to the corresponding model predictions from Fix and MAID.

It seems that in these cases the nuclear effects are not so important as for the unpolarised case. Both models fail to predict the measured shape of the $\pi^0 X$ channel, while they better reproduce the $\pi^\pm X$ channels, especially in the lower measured energy range.

As for the unpolarised case, the $\text{ppn}$ partial channel described in the “quasi-deuteron” approach is shown in figure 12. For this channel, the same considerations as for the corresponding unpolarised channel hold.

6.3. Estimation of the GDH integral for the neutron

From the results presented in the previous sections, it is clear that the present models cannot be used for a reliable extraction of the free neutron information. Nevertheless they can provide
a very rough neutron extraction method, as shown in figure 13.
The plot in the upper part is the helicity dependent total cross section difference as a function of the photon energy obtained with the $^3$He measurement, compared to the results obtained by the GDH collaboration for the proton and the deuteron.

From these results, the “free neutron” contribution can be extracted in a very simple way, both from the $^3$He and from the deuteron data, disregarding nuclear effects and taking into account only the effects of the different spin alignment of the nucleons.

According to equations (2) and (3), the “free neutron” contribution can be obtained with the following approximations for the deuteron:

$$\Delta\sigma_{\text{neutron}} = \frac{\Delta\sigma_{\text{deuteron}}}{0.92} - \Delta\sigma_{\text{proton}}$$

and for $^3$He:

$$\Delta\sigma_{\text{neutron}} = \frac{\Delta\sigma_{^3\text{He}} + 2 \cdot 0.026 \cdot \Delta\sigma_{\text{proton}}}{0.87},$$

where the numerical factors in the previous equations are the effective nucleon polarisation coefficients, as explained in section 4.

The comparison of the “free neutron” extracted contributions is shown in the lower plot of figure 13. The results obtained with this simple model are then compared to the MAID model for the sum of all the single pion photoproduction channels on the neutron ($\gamma n \rightarrow N\pi$).

Given the very rough nature of the extraction method, we can say that there is a good agreement between the two “free neutron” extracted data.

Comparing the upper and lower plots, it is easy to see that the difference between the helicity dependent total photoabsorption cross section difference for the deuteron and the “free neutron” contribution extracted from this cross section is bigger than the corresponding difference for $^3$He. This is due to the fact that the proton contribution to the helicity dependent cross section

![Figure 10](image_url)

**Figure 10.** Preliminary results of the helicity dependent total inclusive cross section $\Delta\sigma_{\text{tot}}$ on $^3$He, compared to the theoretical predictions of the Fix and Schwamb combined model (red line) and of the MAID model (green line).
difference is much smaller for $^3$He than for the deuteron, because of the spin structure of $^3$He. This means that photoabsorption on polarised $^3$He targets is a very promising alternative method to investigate the GDH integral for the neutron.

7. Conclusions
Preliminary results on the unpolarised and helicity dependent total photoabsorption cross section on $^3$He have been obtained from the analysis of the data collected at MAMI (Mainz) in the energy region $200 < E_\gamma < 500$ MeV.
Figure 13. The upper plot shows the helicity dependent total cross section difference on $^3$He as a function of the energy of the incoming photon (blue circles); the data are compared to the experimental results obtained by the GDH collaboration on the proton (green circles) and the deuteron (red circles). The lower plot is a comparison between the “free neutron” contribution extracted from $^3$He (blue circles) and from the deuteron (red circles).

This first experimental test has provided unprecedented data of this kind and preliminary results proving the feasibility of the use of polarised $^3$He gas target to check the GDH sum rule on the neutron.

The unpolarised total inclusive photoabsorption cross section on $^3$He ($\gamma^3He \rightarrow X$) has been compared to previous data obtained with the DAPHNE detector. The good agreement found demonstrates the good quality of the data and of the analysis method.

The unpolarised and polarised cross sections for the partial channels $\gamma^3He \rightarrow \pi^\pm X$, $\gamma^3He \rightarrow \pi^0X$ and $\gamma^3He \rightarrow ppm$ in the $\Delta$ resonance region have also been measured for the first time. The present theoretical models are not able to describe in a satisfactory manner the experimental results. They provide additional constraints for nuclear and subnuclear models, as well as for improved theoretical calculations, which are needed for a better description of the considered processes.

Further measurements to improve statistics and investigate a wider energy range are needed.

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