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First measurement of the helicity dependence of ^{3}He photo-reactions in the $\Delta(1232)$ resonance region

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Abstract. The first measurement of the helicity dependence for several photo-reaction channels on ^{3}He was carried out in the photon energy range between 150 and 500 MeV at the MAMI accelerator (Mainz). The experiment used the large acceptance Crystal Ball spectrometer, complemented by charged particle and vertex detectors, a circularly polarised tagged photon beam and a longitudinally polarised high-pressure ^{3}He gas target. Results of the helicity dependent total inclusive photoabsorption cross section on ^{3}He and of both the unpolarised and polarised partial cross sections for the pion photoproduction channels $\gamma\,^3He \rightarrow \pi X$ and for the $\gamma\,^3He \rightarrow ppn$ channel, measured for the first time at MAMI, will be shown. They can also be found in [1].

1 Introduction

Sum rules are of particular interest for the study of the internal structure of the nucleon, in particular its spin structure. One of this is the well-known Gerasimov-Drell-Hearn (GDH) sum rule [2, 3], which relates the nucleon anomalous magnetic moment κ, the spin S and the mass M to the integral of the helicity asymmetry 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 $\sigma_{p(a)}$ is the total absorption cross section for (anti)parallel orientation of photon and particle spins and the cross section is weighted by the inverse of the photon energy ν. The lower limit of the intregral, ν_{th}, corresponds to the inelastic pion photoproduction threshold.
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 in the photon energy range between 200 MeV and 2.9 GeV [4–6]. The combination of the experimental result with the theoretical predictions for the unmeasured energy ranges supports the validity of the GDH sum rule for the proton.
The experimental verification of the GDH sum rule for the neutron is complicated by the lack of free neutron targets, thus it necessitates the use of neutrons bounded in ^{2}H or ^{3}He. Due to ^{3}He spin structure, that strongly suppresses the polarisation-dependent proton contribution with respect to the ^{2}H case, it results that the most accurate evaluation of I^n_{GDH} is given by ^{3}He.

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2 Experimental setup

A first measurement of photoreaction cross sections on a polarised ^{3}He gas target in the $\Delta(1232)$ resonance region was carried out at the tagged photon facility of the MAMI accelerator at Mainz in July 2009.
The experiment was performed using a circularly polarised photon beam produced via bremsstrahlung of longitudinally polarised electrons with an average polarisation of 80%. The photons were then tagged using the Glasgow-Mainz magnetic spectrometer with an energy resolution of $\sim$ 2 MeV.
The polarised ^{3}He gas target, used for the first time with a photon beam line, was produced at the Physics Institute of the Mainz University via the Metastability Exchange Optical Pumping (MEOP) technique [7]. The high pressure ($\simeq$ 4 bar) gas was contained in a cylindrical cell with an outer diameter of 6 cm and a length of 20 cm; it was made from quartz glass with two 50 μm thick titanium foils as entry and exit windows for the photon beam.
The cell was placed inside the central detector system, devoted to the detection of the reaction products. It was composed by the Crystall Ball (CB) NaI spectrometer, a large solid angle, highly segmented photon and hadron spectrometer, and it was complemented by the Multi-Wire Proportional Chambers (MWPCs), used to identify and track the charged particles, and by the Particle Identification detector (PID), used to discriminate between the charged and the neutral particles detected in CB. By combining the information from these three detectors, accurate energy information is provided, as well as precise angle and particle identification in the azimuthal (ϕ) and polar (θ) angular regions from 0° to 360° and from 21° and 159°, respectively.

3 Data analysis

A description of the data analysis is given in [1]. In the following, only the results will be shown, as a function of the incoming photon energy up to 500 MeV.

3.1 Unpolarised data

3.1.1 Total inclusive cross section

Figure 1a shows the unpolarised total inclusive photoabsorption cross section (full circles) as a function of the incoming photon energy, as it results from an inclusive data analysis method (no partial channel separation). The experimental results are compared to the data published by the DAPHNE Collaboration (open circles) [8]: the good agreement gives confidence in the applied data analysis.

3.1.2 Partial reaction channels

To provide additional experimental information, the total cross sections for the semi-exclusive processes $\gamma^3 He \rightarrow \pi X$ were evaluated. None of these cross sections have been previously measured.
The experimental data, shown in Figure 1b-1d, are compared to the predictions of the Fix-Arenhövel model (FA, solid line) and of a simple plane-wave impulse approximation model (PWIA, dashed line). The first model takes into account the nuclear structure effects, whereas in the other model the cross sections are evaluated as incoherent sum of quasi-free single nucleon contributions, determined by the MAID multipole analysis and by the Fermi momentum distribution of nucleons inside ^{3}He.
Concerning the neutral channel, the FA model is in good agreement with our measurements for $E_\gamma > 250$ MeV; at lower photon energies, where the coherent $\gamma\, ^3He \rightarrow \pi^0\, ^3He$ reaction is expected to play a dominant role, it underestimates the data.

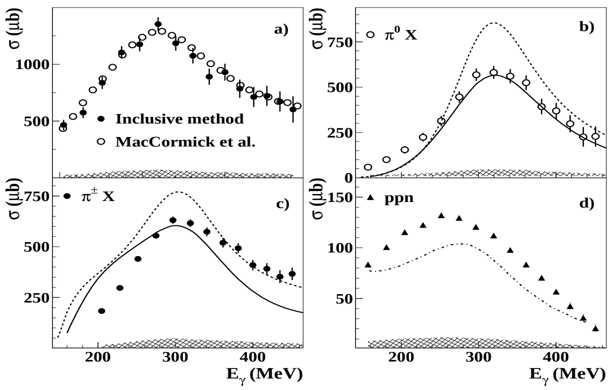

Figure 1. (a) The unpolarised total inclusive cross section on ^{3}He (full circles) is compared to previous results (open circles) [8]; the unpolarised total cross sections for $\gamma^3He \rightarrow \pi^0 X$ (b), $\gamma^3He \rightarrow \pi^\pm X$ (c) and $\gamma^3He \rightarrow ppn$ (d) are shown. The error bars are statistical and the hatched bands show the systematic uncertainties. The experimental data are compared to the FA model (solid line) and PWIA model (dashed line) in b) and c); in d) they are compared to the QD model (dashed-dotted line).

In the case of the charged channel, the FA model describes the data less well, and for $E_\gamma > 350$ MeV the agreement with the PWIA model is better.
Concerning the *ppn* channel, no specific model is available for these data: they are then compared to the predictions of the Quasi-Deuteron model (QD), as if the photon interacts only with a proton and a neutron paired in a virtual deuteron inside the ^{3}He nucleus, with a remaining spectator proton. In this approximation, $\sigma(^3He) \simeq 1.68{\cdot}\sigma(d)$, where $\sigma(d)$ is estimated with the Schwamb-Arenhövel model [9] and the factor 1.68 takes into account the number of “quasi-deuterons” contained in the ^{3}He nucleus. As expected, the QD model underestimates the data, due to the three-nucleon absorption mechanisms that are not taken into account by the model.

3.2 Polarised data

3.2.1 Total inclusive cross section

In the study of the helicity-dependent data, all previously mentioned analysis methods were applied to evaluate the cross section difference $\Delta\sigma = (\sigma_p - \sigma_a)$.
The total inclusive cross section is shown in Figure 2a and compared to the PWIA predictions: the nucleons are assumed to be free and the effect of their spin alignments are taken into account by the formula $\Delta\sigma_{PWIA} = p_n \cdot \Delta\sigma_n + 2 \cdot p_p \cdot \Delta\sigma_p$, where $p_n = 0.865$ and $p_p = -0.027$ are the effective degrees of neutron and proton polarisation inside ^{3}He and $\Delta\sigma_{p(n)}$ are the free nucleon helicity dependent $N\pi$ cross sections from MAID, smeared by the Fermi momentum distribution.

3.2.2 Partial reaction channels

The polarised cross section difference for the semi-exclusive channels (a) $\pi^0 X$, (b) $\pi^\pm X$ and (c) *ppn* is shown in Figure 2b-2d and compared to the prediction of the FA and PWIA models.
As for the unpolarised case, the FA model well reproduces the neutral data at higher photon energies but it does not show good agreement with the charged data. On the contrary, the PWIA model well

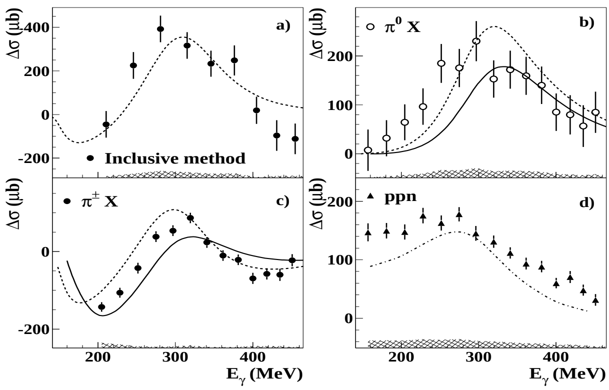

Figure 2. (a) The helicity-dependent total inclusive cross section difference on ^{3}He (full circles) is compared to the predictions of the PWIA model (dashed line). The polarised total cross section differences for $\Delta\sigma$ for $\gamma^3He \rightarrow \pi^0 X$ (b), $\gamma^3He \rightarrow \pi^{\pm} X$ (c) and $\gamma^3He \rightarrow ppn$ (d) are shown. Errors and models as in Figure 1.

reproduces the data at higher photon energies for both reactions. This is a further confirmation that the effects of the composite nuclear target are reduced in the $\Delta\sigma$ case.

3.3 Differential cross sections

In order to get a deeper insight into the mechanisms involved in these reactions and to identify the reasons of the observed discrepancies between the data and the models, the analysis of the unpolarised and helicity-dependent differential cross sections for the $\gamma^3He \rightarrow \pi^0 X$ and $\gamma^3He \rightarrow \pi^{\pm} X$ reactions has been performed. These results will be shown in detail in a future publication.

4 Conclusions

The helicity dependent total inclusive cross section on ^{3}He and both the unpolarised and polarised total and differential cross sections for the $\pi^0 X$ and $\pi^{\pm} X$ semi-exclusive channels have been measured for the first time at MAMI (Mainz) in the energy region $200 < E_\gamma < 500$ MeV.
The available state-of-the-art calculations are unable to describe in a satisfactory manner the experimental results for the πX channel; no model is at present available for the *ppn* channel.
These considerations strongly motivate further theoretical and experimental investigation in the field.

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