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Mainz Microtron MAMI

Collaboration A2: "Real Photons"
Spokesperson: A. Thomas

Proposal for an Experiment

" Photon asymmetry measurements of the ^{16}O($\vec{\gamma}$,pp) reaction for photon energies up to 400 MeV"

Collaborators :

CrystalBall@MAMI collaboration

Spokespersons for the Experiment :

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Abstract of Physics :

Photonuclear cross section measurements average the parallel and perpendicular response of nuclei. In contrast measurements of the photon asymmetry, using polarised photons, allow the difference between the parallel and perpendicular responses to be measured. The asymmetry of two-nucleon knockout reactions is predicted to be sensitive to details of the photonuclear reaction mechanisms. In particular it is expected to be sensitive to interference between contributions from one- and two-body currents. Previous measurements of the ($\vec{\gamma}$,pn) and ($\vec{\gamma}$,pp) reactions in light nuclei have shown strong asymmetries and distinct differences between the two charge channels. The measured asymmetries do not, however, agree with the best available theoretical calculations. Regrettably the previous data have very poor statistical accuracy, particularly in the ($\vec{\gamma}$,pp) channel, which severely limits the comparison with theory and prevents a more detailed interpretation.

This proposal is to make a comprehensive survey of the photon asymmetry for ^{16}O($\vec{\gamma}$,pp) from 200 to 400 MeV with high statistical accuracy and covering a much wider range of emitted proton angles than the previous work. This will provide a high quality data set against which models of two-nucleon knockout mechanisms can be judged and should lead to much better understanding of currents in nuclei, and the basic interaction between nucleons. The experiment will also provide some exploratory data at higher photon energies.

Abstract of Equipment :

The experiment will make use of the full energy of MAMI-C together with the upgraded Glasgow tagged photon spectrometer. A thin diamond radiator will be used to provide coherent bremsstrahlung photons for the experiment. The higher energy electron beam available from MAMI-C will significantly increase the photon polarisation which can be achieved and will allow the photon energy range 200–400 MeV to be covered in just two goniometer settings. Protons will be detected in the Crystal Ball making full use of the PID and wire chambers for particle identification and tracking.

MAMI–Specifications :

beam energy	1500 MeV
beam current	< 100nA
time structure	cw
polarization	linearly polarized photons

Experiment–Specifications :

experimental hall/beam	A2
detector	Crystal Ball, MWPC, PID
target material	^{16}O (Water target), or ^{12}C (solid target)

Beam Time Request :

set–up without beam	2 days
set–up/tests with beam	20 hours
data taking	185 hours

Title: Photon asymmetry measurements of the $^{16}O(\vec{\gamma},pp)$ reaction for photon energies up to 400 MeV

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Introduction

Measurements of two-nucleon knockout reactions provide a means to study the interaction between nucleons in the nucleus. In general there are several contributions to reaction cross sections including Meson Exchange Currents (MEC) (Seagull, pion-in-flight), Delta-currents, and two-nucleon correlations (Short range central correlations and tensor correlations) [1-5]. These individual processes contribute in different measures to each of the reactions (e,e'pp), (e,e'pn), (γ,pp) and (γ,pn). For instance MEC are suppressed in two proton emission reactions for isospin reasons and tensor correlations only contribute strongly to the (e,e'pn) reaction. In addition each process has a different dependence on kinematic variables such as energy transfer or particle emission angles. Therefore to obtain the maximum information about the interaction between nucleons it is important to measure all four reaction channels over a wide range of kinematic variables.

Considering photon induced reactions, measurements of unpolarised cross sections are sensitive only to the transverse structure function $W_T = W_{xx} + W_{yy}$ which gives an average of the parallel and perpendicular nuclear response[1-5]. On the other hand polarised photons allow access to the difference between the parallel and perpendicular responses through the structure function $W_{TT} = W_{xx} - W_{yy}$. Specifically using linearly polarised photons allows the photon asymmetry $\Sigma = - W_{TT} / W_T$ to be measured. W_{TT} is sensitive both to the angular momentum contributions to nuclear currents and to interference between contributing processes. This provides a more sensitive observable against which models of nuclear currents contributing to two-nucleon emission can be compared.

In (γ,pp) reactions MEC are suppressed leaving Δ-currents and central Short Range Correlations (SRC) (1-body currents) as the main contributors, whereas in (γ,pn) reactions MEC and tensor correlations also contribute.

Previous measurements

Only a small number of measurements have previously been made of the photon asymmetry of two-nucleon emission reactions in light nuclei. In ^{3}He measurements made by the LEGS collaboration [6] were averaged over the wide photon energy range 235-305 MeV. In this energy range the asymmetry Σ for the ($\vec{\gamma}$,pn) reaction is $\sim$–0.2 whereas that for ($\vec{\gamma}$,pp) is smaller at $\sim$–0.05. The data are compared to theoretical calculations by Laget which include one-, two- and three- body currents. The agreement is reasonably good with the ($\vec{\gamma}$,pn) channel being well described by one- and two- body currents, but three-body currents are seen to have a large effect in the ($\vec{\gamma}$,pp) channel.

Measurements of the ^{6}Li(γ,pn) and ^{4}He(γ,pn) reactions have been made at the Yerevan 3.5 GeV electron synchrotron over the photon energy ranges 300-900 MeV and 450-550 MeV, respectively [7]. These were averaged over a wide range of missing energies E_m and had limited kinematic acceptance. The asymmetry for ^{6}Li was systematically smaller in magnitude than that for deuterium.

Unpublished measurements of $\Sigma_{(\gamma,pp)}$ and $\Sigma_{(\gamma,pn)}$ on ^{16}O have been carried out at LEGS in coplanar kinematics with symmetric detection angles for E_γ= 245-315 MeV [8]. For E_m <50 MeV, where direct photon absorption on proton pairs is expected, a result of $\Sigma_{(\gamma,pp)}$ $\sim$–0.3 was obtained. This is far smaller than the -1.0 expected for a pure $^1S_0$ interaction in coplanar kinematics and is interpreted as evidence for the knockout of nucleon pairs from higher relative angular momentum states. For E_m <50 MeV, $\Sigma_{(\gamma,pp)}$ is a factor of $\sim$2 greater than $\Sigma_{(\gamma,pn)}$, indicating fundamental differences in the two reaction channels at low E_m. However for E_m >70 MeV $\Sigma_{(\gamma,pp)}$ and $\Sigma_{(\gamma,pn)}$ are similar at $\sim$–0.1. Little strength from direct processes persists at these high E_m and reactions involving intermediate pion production become the largest contributor to both charge channels. See Figure 3 below.

Further ^{16}O data for the ($\vec{\gamma}$,pn) channel, obtained for $(1p)^{-2}$ emission in quasideuteron kinematics over the wider photon energy range E_γ=210-330 MeV, is reported in the PhD thesis of Gladyschev [9], from the University of Virginia. Regrettably this work has not yet been followed up by a peer reviewed publication in the literature. Gladyschev's kinematics are directly comparable with the ^{12}C($\vec{\gamma}$,pn) work of Franczuk *et al.* [10] discussed below and the ^{16}O data have similar Σ magnitudes to the ^{12}C data of Franczuk *et al.*

Measurements of the ^{12}C($\vec{\gamma}$,pn) and ^{12}C($\vec{\gamma}$,pp) reactions have been carried out at Mainz for E_γ=160-350 MeV [10,11]. These measurements used the PiP/ToF detector system. The angular acceptance of PiP was $\Delta\Theta = 50° – 130°$, $\Delta\Phi$= -23° – 23°. Σ was extracted from separate measurements of $Y_\perp$ and $Y_\parallel$ using the equation $\Sigma = (1/P)(Y_\parallel - Y_\perp)/(Y_\parallel + Y_\perp)$ where P is the photon polarisation and Y is the experimental yield. The photon polarisation was rotated every 5 minutes to ensure that the parallel and perpendicular yields were sampled under the same beam conditions. Three separate goniometer settings were used to cover the E_γ range from 160 to 350 MeV.

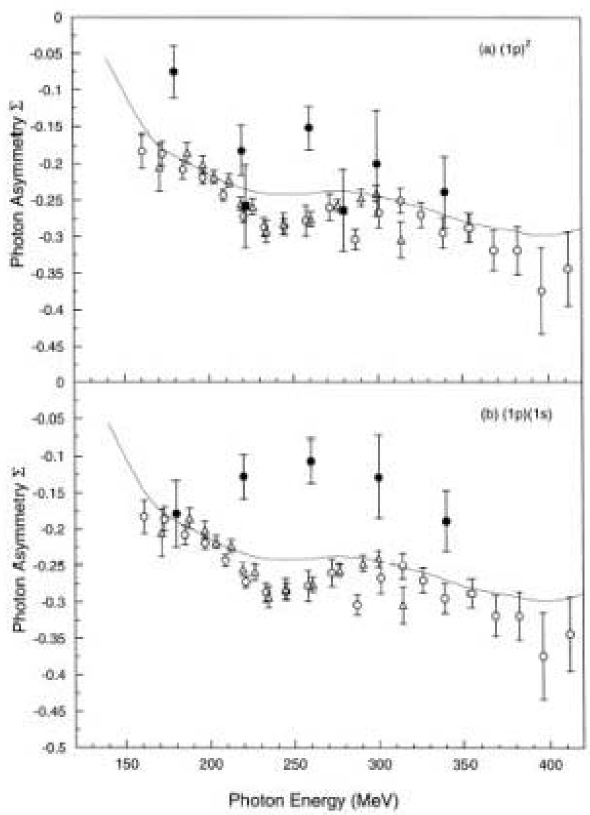

Figure 1: Photon asymmetry for ^{12}C(γ,pn) reaction a function of photon energy. (a) solid circles (1p)$^{-2}$ emission [10]. (b) (1p)$^{-1}$(1s)$^{-1}$ emission. The data are compared to ^{2}H(γ,pn) data: the solid squares are from [10], the open circles are from Daphne measurements at Mainz [12] and the open triangles are from LEGS [13,14]. The solid line is a quasi-deuteron Monte Carlo calculation which simulates the effects Fermi motion would have on the deuterium data.

The experiment was designed to give a sufficiently good E$_m$ resolution to allow the selection of events in which nucleon pairs are emitted from (1p)$^{-2}$ and (1p)$^{-1}$(1s)$^{-1}$ orbitals. The ^{12}C($\overrightarrow{\gamma}$,pn) reaction at E$_m$ <40 MeV, corresponding to the emission of nucleon pairs from 1p-shell orbits has a simliar energy dependence to the ^{2}H($\overrightarrow{\gamma}$,pn) reaction, but a significantly lower magnitude [10]. Reactions at missing energies $40 < E_m < 70$MeV, corresponding to emission of (1s)$^{-1}$(1p)$^{-1}$ nucleon pairs, have asymmetries slightly lower in magnitude than the (1p)$^{-2}$ reactions, but have a different photon energy dependence.

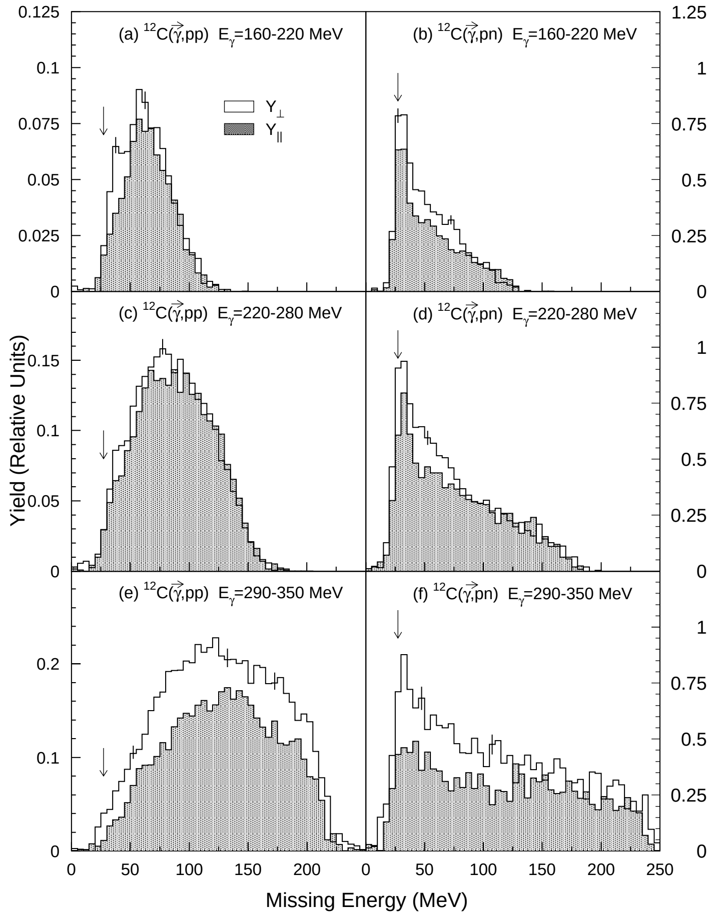

Figure 2: ^{12}C(γ,pp) and (γ,pn) E$_m$ spectra for photons polarised perpendicular (open) or parallel (shaded) to the detector plane [11].

Looking in more detail at the E$_m$ spectra for both ^{12}C($\overrightarrow{\gamma}$,pp) and ^{12}C($\overrightarrow{\gamma}$,pn) reactions the perpendicular yield $Y_\perp$ generally exceeds the parallel yield $Y_\parallel$, indicating a negative asymmetry Σ. The ^{12}C($\overrightarrow{\gamma}$,pn) reaction is characterised by peak in both $Y_\perp$ and $Y_\parallel$ at low E$_m$, whereas the ^{12}C($\overrightarrow{\gamma}$,pp) yields are smoother as a function of E$_m$ but show a distinct shoulder in perpendicular yield at low E$_m$.

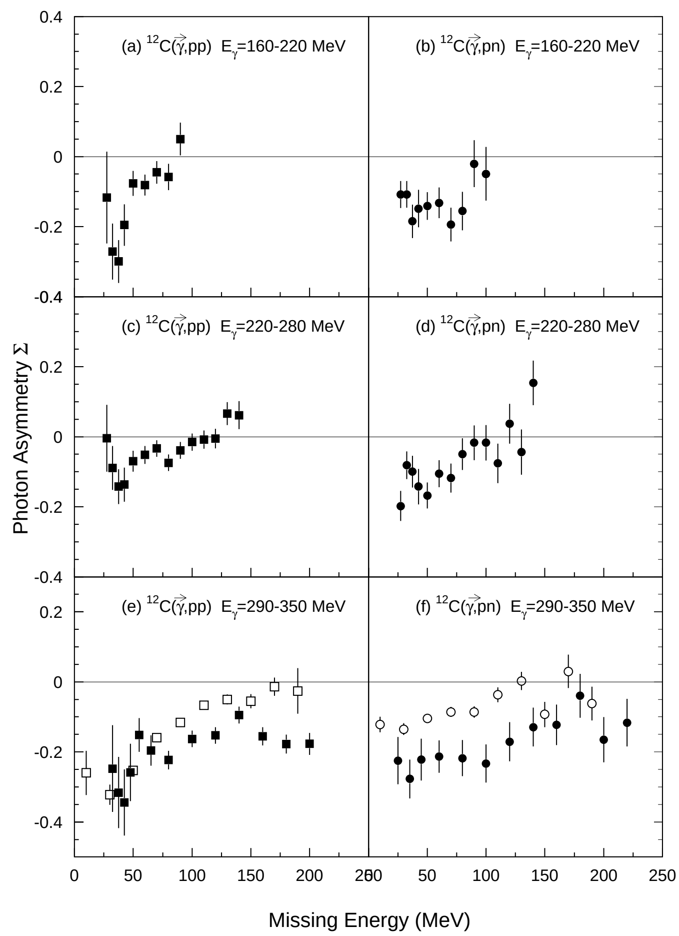

Figure 3: Photon asymmetry for ^{12}C(γ,pp) and (γ,pn) plotted as a function of E$_m$ [11]. The open squares and circles are ^{16}O data from LEGS [8].

This produces a strong negative peak in the asymmetry for ^{12}C($\overrightarrow{\gamma}$,pp) at low E$_m$. The asymmetry at higher E$_m$ remains negative over most of the range of the data but is much lower in magnitude. This indicates differences between reactions in which only two protons particpate (direct emission) at low E$_m$ and reactions in which more nucleons take part (2N +FSI, 3N etc) at higher missing energies. A similar behaviour is seen in the ^{16}O($\overrightarrow{\gamma}$,pp) data from LEGS [8] in the highest photon energy bin. The peak is slightly broader due to poorer energy resolution, but it has a similar magnitude to the ^{12}C peak. However at higher E$_m$ the asymmetry is lower in magnitude compared to ^{12}C.

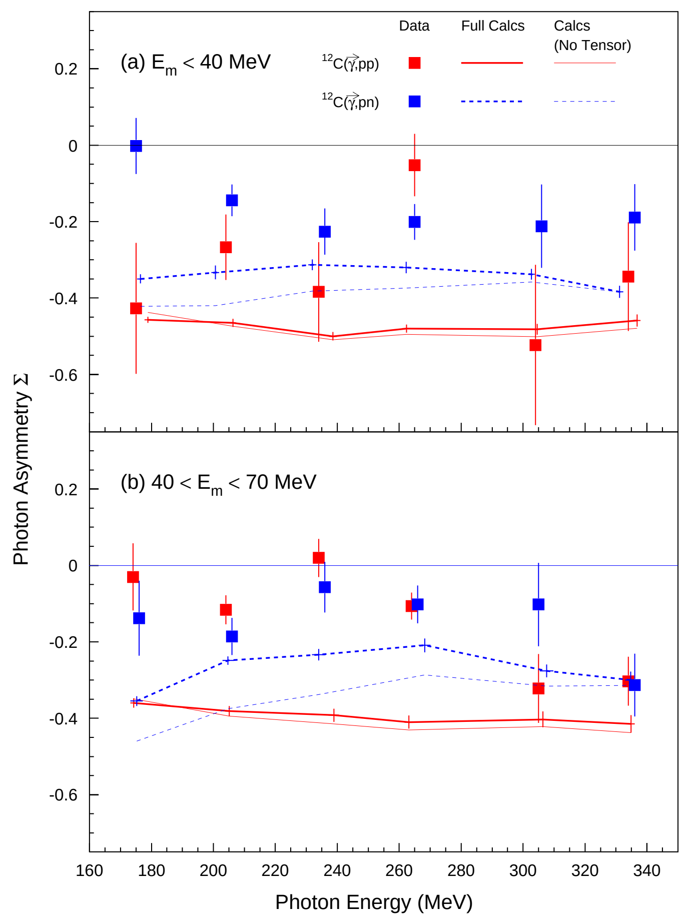

Figure 4: Photon asymmetry for ^{12}C(γ,pp) and (γ,pn) plotted as a function of E_γ for missing energy regions corresponding to $(1p)^{-2}$ and $(1p)^{-1}(1s)^{-1}$ emission [11]. The data are compared with theoretical calculations using the Gent unfactorised model.[3-5]

Figure 4 shows the photon energy dependence of Σ for the missing energy regions E_M <40 MeV and 40<E_M <70 MeV. The statistical accuracy of the data is poor, particularly for the ($\vec{\gamma}$,pp) channel, once these cuts have been applied and the data have been split into ∼30 MeV wide photon energy bins. Nevertheless, significant differences are seen in Σ between ^{12}C($\vec{\gamma}$,pp) and ^{12}C($\vec{\gamma}$,pn) reactions, and between the two different missing energy regions. These differences reflect differences in the asymmetry of the mechanisms which contribute to each data set.

The Σ data are also compared with theoretical calculations of direct 2N knockout processes carried out using the Gent unfactorised two-nucleon knockout model [3-5]. The overall agreement is rather poor, although the ^{12}C($\vec{\gamma}$,pp) channel is described considerably better by the theory than the ($\vec{\gamma}$,pn) channel, in the low E_m region.

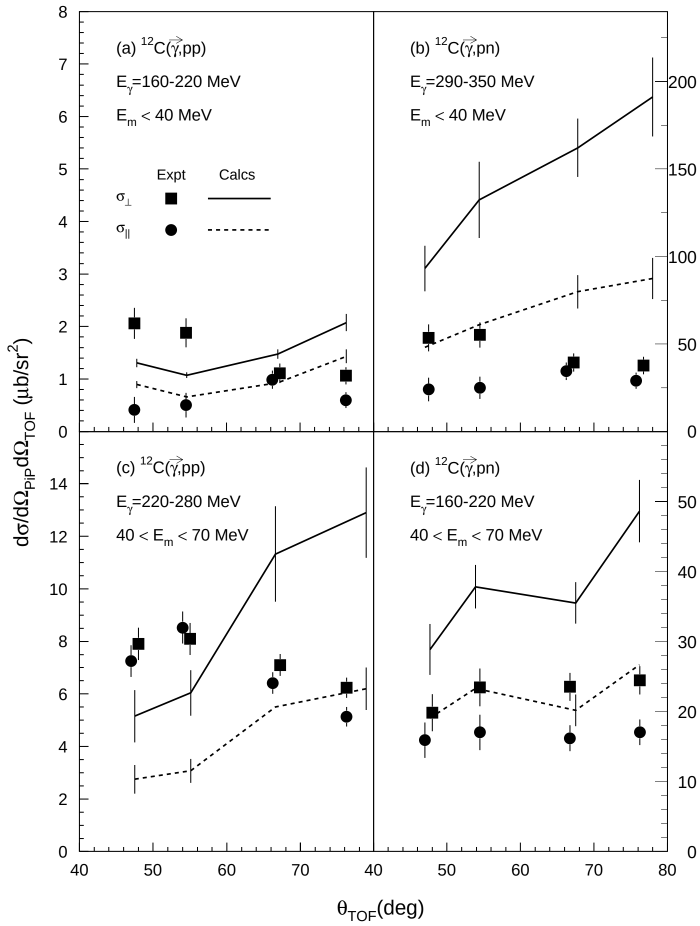

Figure 5: Parallel and perpendicular differential cross sections for ^{12}C(γ,pp) and (γ,pn) reactions plotted as a function of Θ_{TOF} for missing energy regions corresponding to $(1p)^{-2}$ and $(1p)^{-1}(1s)^{-1}$ emission [11]. The data are compared with theoretical calculations using the Gent unfactorised model [3-5].

A limited investigation was made of the angular dependence of parallel and perpendicular differential cross sections for both charge channels. It was only possible to measure over a very limited range of polar angles. There parallel and perpendicular differential cross sections show large differences in their angular dependence. The theoretical calculations also show strong angular dependences, but do not agree with the experimental data.

The results of the previous work on ($\overrightarrow{\gamma}$,pp) and ($\overrightarrow{\gamma}$,pn) reactions in light nuclei show strong sensitivity in both the angular dependence, and in the photon energy dependence of the asymmetry, to the shells of the emitted nucleons and to the charge state of the emitted nucleons. However, the available data have rather poor statistical accuracy and restricted angular ranges. The ^{12}C data are restricted in the photon energy range covered. Improved data with better statistical accuracy and more extensive angular and energy ranges will provide sensitive tests of the mechanisms contributing to two-nucleon knockout reactions.

The best theories currently available do not agree in detail with the data currently available, but the quality of this data is not sufficient to warrant further theoretical developments at the present time. However, the prospect of accurate new data mapping out in detail the response of the nucleus to linearly polarised photons is likely to provide the stimulus for improved theoretical treatments.

Proposal

We wish to take advantage of the improvements which the Crystal Ball and upgraded Glasgow tagged photon spectrometer can provide to make a comprehensive survey of the photon asymmetry of the ($\vec{\gamma}$,pp) reaction in ^{16}O in the photon energy range E_γ=200-400 MeV. Using this apparatus we can make very substantial improvements in the statistical accuracy, angular range covered and the photon energy coverage compared to the previous ^{12}C measurements of Franczuk *et al.* [10] and Powrie *et al.* [11].

The Crystal Ball (CB), together with the PID particle identification scintillator barrel and the MWPCs multi-wire proportional counters, has a proton Θ acceptance of 23° – 150°. The initial Fermi motion of the nucleon pair smears out the angular correlation between the two emitted protons. The half-angle of the resulting Fermi cone varies with kinematics but has a maximum of ∼25° for accepted forward-backward proton pairs at E_γ=200 MeV. The cone becomes narrower at larger emission angles and higher photon energies. Taking the Fermi cone into account, the CB acceptance should allow almost complete acceptance of the (backward) correlated protons for all (forward) protons emitted at an angle greater than 35°.

In terms of Φ acceptance the CB allows complete 2π coverage. This will allow the expected cos(2Φ) to be observed easily and will make extraction of Σ from the equation $\sigma(\Theta, \Phi) = \sigma(\Theta)[1 + P\Sigma cos(2\Phi)]$ more accurate than in the previous work where the photon polarisation was flipped repeatedly by 90° and the asymmetry extracted from $\Sigma = (1/P)(Y_{\parallel} - Y_{\perp})/(Y_{\parallel} + Y_{\perp})$.

The increased electron energy of 1.5 GeV which will be available from MAMI-C will, in conjunction with the upgrade to the Glasgow tagged photon spectrometer, provide improvements to the degree of linear photon polarisation and to the tagging efficiency.

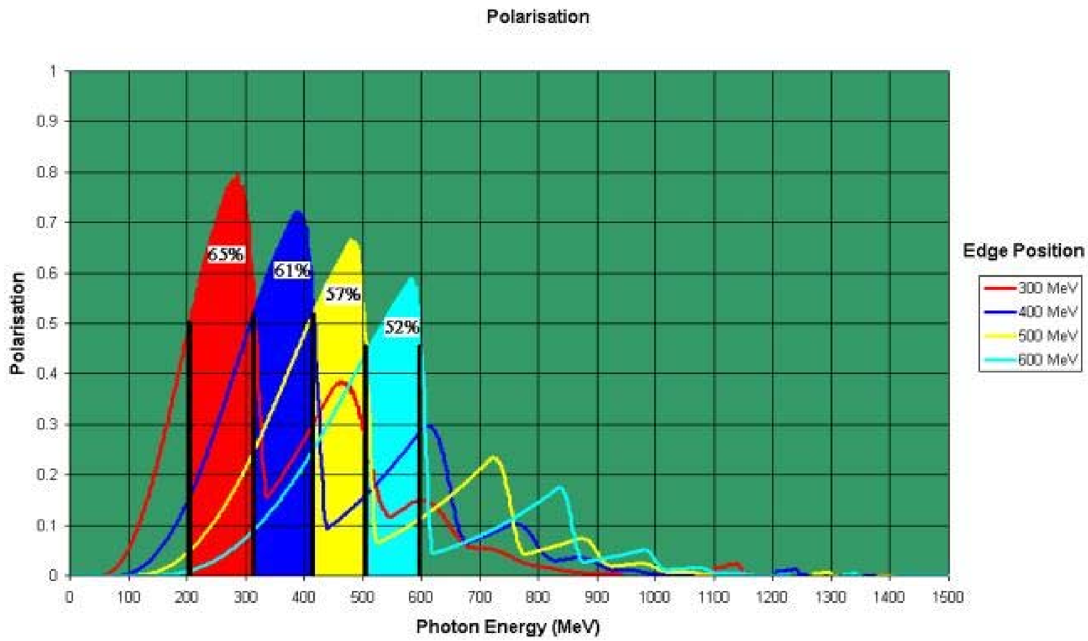

Figure 6: Calculated photon polarisations for 4 different goniometer settings, using an electron beam energy of 1.5 GeV.

Calculations using the photon polarisation code ANB developed at Tuebingen show that average photon polarisations of 65% and 61% can be obtained in the photon energy ranges 200-300 MeV and 300-400 MeV using two settings of the goniometer. In the previous work of Powrie *et al*. three settings were required to cover the narrower photon energy range 180-340 MeV and the average polarisation obtained in the lowest photon energy range was lower at $\sim$55%.

In the previous work the average tagging efficiency achieved was $\sim$50% in the lowest photon energy setting of the goniometer. The higher energy electron beam will result in a narrower cone of polarised photons and with a 3mm diameter collimator the tagging efficiency is calculated to be of the order of 80%.

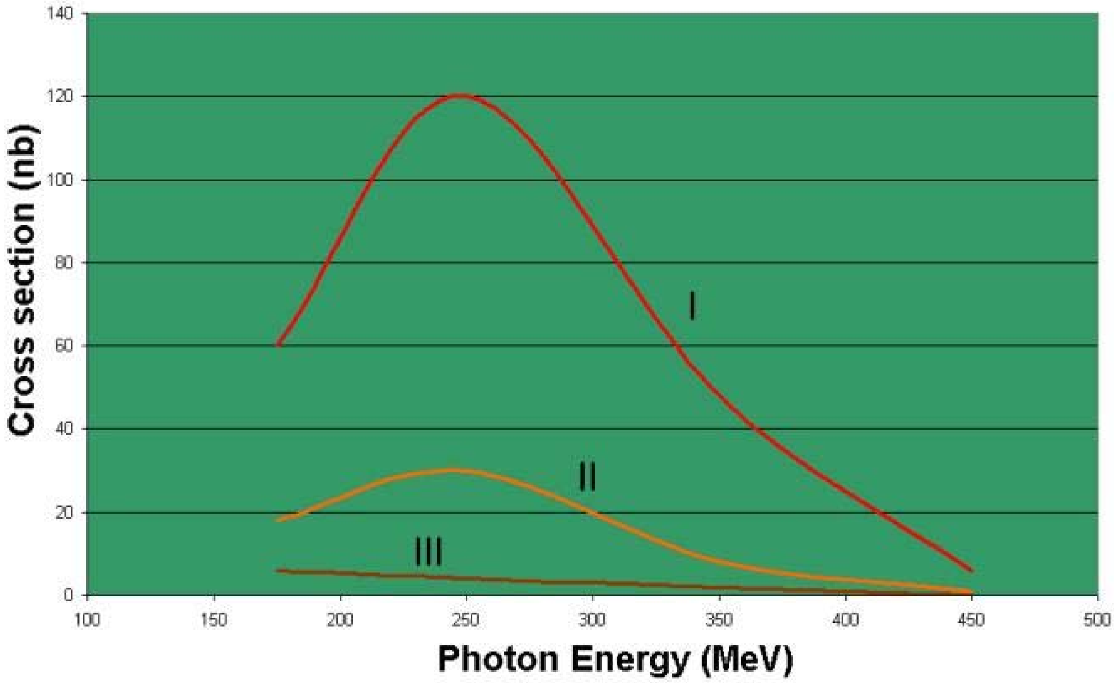

Figure 7: "Visible" integrated cross sections extracted from data measured by Watts *et al.* [15] for two proton emission from $(1p)^{-2}$ orbitals in ^{12}C in three different kinematic regions. Region I corresponds to back-to-back quasi-deuteron kinematics similar to the present proposal. Regions II and III have larger proton pair opening angles used to sample high values of the initial pair momentum.

There are several physical limits to how high in photon, or proton energy, it is possible or sensible to measure the asymmetry of the ($\overrightarrow{\gamma}$,pp) reaction. The cross section for two-proton emission falls rapidly with photon energy. Figure 7 shows the cross section measured by Watts *et al*. [15] in three different kinematics. Kinematics I corresponds to back-to-back emission in the centre of mass frame, at central proton angles. Kinematics II and III are more extreme kinematics away from the back-to-back geometry and were disigned to sample very high momentum components in the pair momentum distribution. It is clear that the cross section for region I follows the Δ resonance and falls away rapidly at higher photon energies.

There is more than sufficient strength in this channel to make detailed measurements up to 400 MeV. From 200 to 300 MeV Δ currents are expected to make the strongest contribution. However above this energy, particularly at forward proton angles, it is expected that the influence of SRC and other higher order processes will be important [3-5].

The maximum energy of protons which can be stopped in the CB is 425 MeV but from our experience with the present detector system a lower limit is imposed by the maximum proton energy which can be distinguished in the CB/PID which is estimated to be ~300 MeV. At E_γ=400 MeV the maximum expected proton energy from a two-nucleon emission reaction, at an angle of 35° is 274 MeV which is less than this limit. However at 500 MeV, protons of 300 MeV are emitted at ~52° which will limit the angular range available at higher photon energies.

Another consideration is that we require an E_m resolution better than 20 MeV to identify direct emission of proton pairs form 1p shell orbitals. Previous work on large NaI detectors shows proton energy resolution 10 MeV FWHM at $E_p \sim$150 MeV [16]. Combining the resolution of two protons together gives estimates of the total E_m resolution of $\sim$12 MeV at E_γ=200 MeV, rising to $\sim$16 MeV at 400 MeV and $\sim$18 MeV at 500 MeV. The total resolution does not vary significantly with proton angle at a given photon energy and on the basis of this criterion the experiment is viable up to E_γ=500 MeV.

Inelastic interactions of proton with scintillator material generally result in the scintillator not recording the whole of the deposited energy. This produces a long tail in the proton energy response of the scintillator. Events with inelastic scintillator interactions will be rejected using restrictions on the correlation between PID and CB energy deposits and restrictions on the number of crystals in the proton cluster. Inelastic events remaining in the data sample will have a deficit between their measured and actual proton energies and are therefore not expected to contribute significantly in the low missing energy region that we wish to study. As the inelastic events will be removed proportionally the lost inelastic events will not affect the measurement of photon asymmetry other than by reducing the statistical accuracy of its determination.

Previous work has shown that the peak-to-tail ratio produced by proton interactions a single large NaI crystal increases rapidly with proton energy and reaches $\sim$30% at $E_p \sim$ 200 MeV [16]. For two such protons, corresponding to photon energies $\sim$400 MeV, this would represent a loss of 50% of the yield from the low missing energy region. For two 100 MeV protons the total loss is less at $\sim$22%. The losses in the CB detector array may be smaller than these values as some of the energy lost from interactions in one crystal may be recovered in neighbouring crystals. However, the reponse of the CB to high energy protons is not fully known, and we must expect substantial losses to the yield from inelastic interactions. We are prepared to accept losses up to $\sim$50% due to such processes given that there will not be any effect on the asymmetry of the events remaining at low E_m, but increasing losses at higher energies provide an additional reason why measurements at energies above E_γ=400 MeV may prove difficult.

There are two possible candidates targets for this experiment: ^{16}O and ^{12}C. The most extensive previous measurements have been carried out on ^{12}C and so measurements on ^{12}C would provide a direct comparison with previous work. On the other hand ^{16}O is a closed shell nucleus and this makes future theoretical calculations more straightforward. On balance we favour using ^{16}O for this study.

We will use a cylindrical water target 2cm thick and 3cm in diameter. The variation in the total energy loss of the two emitted protons across the volume of the target is expected to contribute $\sim$4 MeV to the missing energy resolution at E_γ=200 MeV, falling to $\sim$ 2.5 at 400 MeV. It may be possible reduce this contribution somewhat by using vertex reconstruction from the wire chamber tracks.

As a trigger we will select two or more clusters in the CB, together with two signals on opposite sides of the PID detector. The proposal is to measure at two goniometer settings covering the photon energy ranges E_γ=200–300 MeV and 300–400 MeV. The experiment will provide an accurate and detailed study of the angular distribution of Σ for the ^{16}O($\overrightarrow{\gamma}$,pp) reaction in range E_γ=200–400 MeV. We plan to measure angular distributions in 10° bins in the centre-of-mass frame, corresponding roughly with the forward going proton in the range from 35° to 75° in the lab. In terms of photon energy we plan to plot the energy dependence in 25 MeV bins from 200 MeV to 400 MeV.

While the main focus of this experiment is on photon energies in the range 200-400 MeV, we will also obtain some exploratory data up to E_γ ∼600 MeV from higher polarisation peaks in the diamond spectrum (see figure 6). For instance the second polarisation peak in the lowest energy gonoimeter setting (red) provides polarisations of ∼35% in the photon energy range 400–500 MeV. We will analyse the data from these higher polarisation peaks and this should allow us to determine whether further more detailed studies at higher energies are worthwhile.

Figure of Merit

In this section we make a direct comparison of the experimental parameters with the previous $^{12}C(\vec{\gamma}$,pp) measurement of Powrie *et al.* [11].

Solid angle for first proton: The solid angle for PiP detector: 1sr. Solid angle of CB (35°-150°): 10.6 sr. Both the Θ angular range and the solid angle are much larger using the CB. Factor of improvement: 10.6

Acceptance for the second proton. This is the detector coverage for the second emitted proton, taking into account the correlation in angle with the first proton and the smearing of this correlation by the initial Fermi motion of the two protons. ToF detector (Powrie *et al.*): ∼0.6. CB: ∼1.0. Factor of improvement: 1.7

Extraction of asymmetry: Powrie *et al.*: two separate measurements at $\Phi=0\pm23°$ and $\Phi=90\pm23°$. CB: one measurement covering all azimuthal angles. Factor of improvement: There is an immediate factor of 2.0 improvement in the use of beam time as the CB measures both the $\Phi=0\pm23°$ and $\Phi=90\pm23°$ angles at the same time. However, the real improvement is considerably greater as all Φ angles will be used to improve the accuracy of the measured photon asymmetry.

Degree of Photon Linear Polarisation: Powrie *et al.* (220–320 MeV): 0.49. CB (200-300 MeV): 0.65. Factor of improvement: 1.3

Tagging Efficiency: Powrie *et al.*: 0.55. CB: 0.8. Factor of improvement: 1.7

Photon energy range: Powrie *et al.*: 180-340 MeV. CB: 200-400 MeV (plus some test data at photon energies up to 600 MeV). Factor of improvement: 1.25+

Tagger counting rate (per 100 MeV bin). This is reduced using MAMI-C because the photon energy acceptance of each tagger detector is approximately a factor of two greater than for MAMI-B. However this loss is offset by increases in tagging efficiency, photon polarisation and most importantly the fact that two goniometer settings are sufficient to cover the photon energy range 200-400 MeV, compared to four settings for MAMI-B. Powrie *et al.*: $\sim4.2\times10^7$. CB: $\sim2.4\times10^7$. Factor of improvement: 0.6

Livetime: Powrie *et al.*: ∼0.7. CB: ∼0.75. Factor of improvement: 1.07

Inelastic losses: Powrie *et al.*: ∼0.3 at E_γ=400 MeV. CB: ∼0.5. Factor of improvement: 0.8

Overall Factor of improvement: ∼50

This improvement in the figure of merit will allow more accurate determination of the energy and angular distributions of the photon asymmetry. The ranges of both these quantities will also be extended compared to the previous measurments.

Count Rate Estimate and Beam Time Request

Assuming that the Crystal Ball, Tagger, Wire Chambers and PiD are operational and calibrated we request 2 days without beam to install and test the diamond radiator in the goniometer and to install and align the water target in the Crystal Ball.

We request 20 hours of beamtime to align the diamond radiator and to set up and test the specific trigger we require for this experiment.

The statistical accuracy in the measured asymmetry will depend on the final binning chosen for the data. A sample calculation is given here assuming that the data will be divided into 25 MeV photon energy bins and 10° angular bins.

A 2cm thick water target contains 6.7×10^{22} ^{16}O nuclei cm^{-2}.

In a 25 MeV photon energy bin there are 6 counters on the tagger focal plane detector, each of which can count at a rate of 1×10^6. This gives a total electron rate of 6×10^6 s^{-1}.

The tagging efficiency is estimated at 80% in the polarisation peak for a 3mm diameter collimator. (A narrower collimator will reduce the tagging efficiency slightly, but would increase the photon polarisation.)

We use an average differential cross section for of 0.35μb/sr for reactions in which two protons are emitted from 1p orbits, estimated from previous ^{12}C(γpp) experiments carried out at E$_\gamma$=200–300 MeV [15,17], and taking into account the increased number of 1p-shell proton-proton pairs in ^{16}O compared to ^{12}C.

At Θ=90° a 10° angular bin subtends a solid angle of 1.1sr.

The livetime is taken to be 75% from previous rates measured with the CB+TAPS detectors. Improvements to the readout electronics may improve this figure slightly.

Using the above cross section, the count rate into a Θ_p=10° bin will be:

$N = N_{tar} \times N_e \times \epsilon_{tag} \times d\sigma/d\Omega \times \Delta\Omega \times Livetime$

$= 6.7 \times 10^{22} \times 6 \times 10^6 \times 0.8 \times 0.35 \times 10^{-30} \times 1.1 \times 0.75$

$= 0.09 s^{-1}$.

This gives a count rate of ~330 hr^{-1} for each bin.

To this figure we have to apply a factor of ~0.7 to allow for losses due to inelastic proton interactions in the NaI scintillator, which brings this figure down to ~230 hr^{-1}.

In 50 hours this gives a total number of real events of ~11500 distributed over all azimuthal angles for each bin. This number of counts is sufficient to extract photon asymmetries with a statistical accuracy $\Delta\Sigma$ of about ±0.02. However previous experience indicates that the final accuracy is likely to be a factor of 2-3 poorer than this once the effects of subtracting random tagger-CB coincidences and empty target background measurements have been taken into account.

For the E_γ=300–400 MeV bin ~100 hours will be required for the same accuracy, because the cross sections are lower by a factor of ~2, losses of events due to inelastic interactions in the scintillator will be larger, and the photon polarisation will be slightly lower.

Previous experience suggests that background from the empty target cell could be of the order of 5%. To obtain the optimum statistical accuracy from subtractions warrants spending about 20% of the target-full beamtime measuring background. For background measurements we therefore require 30 hours. We also require around 5 hours to make measurements of tagging efficiency for each of the two goniometer settings.

This brings the total request for data taking to 185 hours.

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