Measurement of the photoabsorption cross section of ^{24}Mg.

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Abstract. Accurate nuclear data is a key factor in determining the suitability and reliability of many theoretical nuclear models and large-scale calculations. One of the main ingredients of these calculations is how nuclei respond to an electromagnetic field. The excitation of the isovector giant dipole resonance (GDR) is of particular importance in both nuclear structure studies as well as being the main mode of interaction of ultra-high-energy cosmic rays with the extra-galactic medium en route to Earth. This study investigates the photoabsorption cross section in the region of the GDR in ^{24}Mg through the use of proton inelastic scattering and the equivalent virtual photon method. The K600 spectrometer at the iThemba LABS facility was used to obtain high resolution, low background ^{24}Mg(p,p')^{24}Mg* inelastic scattering data. The virtual photon absorption method is described and the (p,p') spectrum that will be converted from a double-differential cross section to a photoabsorption cross section is presented.

1. Introduction

The field of nuclear astrophysics is littered with examples of calculations that require accurate experimental inputs to replicate and describe physical systems [1]. One of the pertinent examples of these calculations is a simulation of the propagation of ultra-high-energy cosmic rays (UHECR) that break up through absorption of the Lorentz-boosted cosmic microwave background, which requires input from hundreds of nuclei below mass 56 [2]. Obtaining all of the necessary quantities for all of these nuclei is unfeasible; however, some of the nuclei are of much greater importance and dominate these processes and model validations. This project aims at extracting the total photoabsorption cross section in the energy region of the isovector giant dipole resonance (IVGDR) for one of the keystone nuclei in this calculation: ^{24}Mg. This is done through relativistic Coulomb excitation of the IVGDR in ^{24}Mg, which falls in the energy region from 16-23 MeV, along with the use of the virtual photon absorption technique [3]. An exhaustive amount of E1 gamma transitions occur through this channel and it is a strong indicator of the reaction mechanism through which the energy and mass composition of the UHECR will be modified during the propagation path.

2. Experimental Methods

The K600 magnetic spectrometer at iThemba LABS is one of the few facilities in the world that can deliver high-resolution, low-background spectra for 0° measurements[4] and is shown in

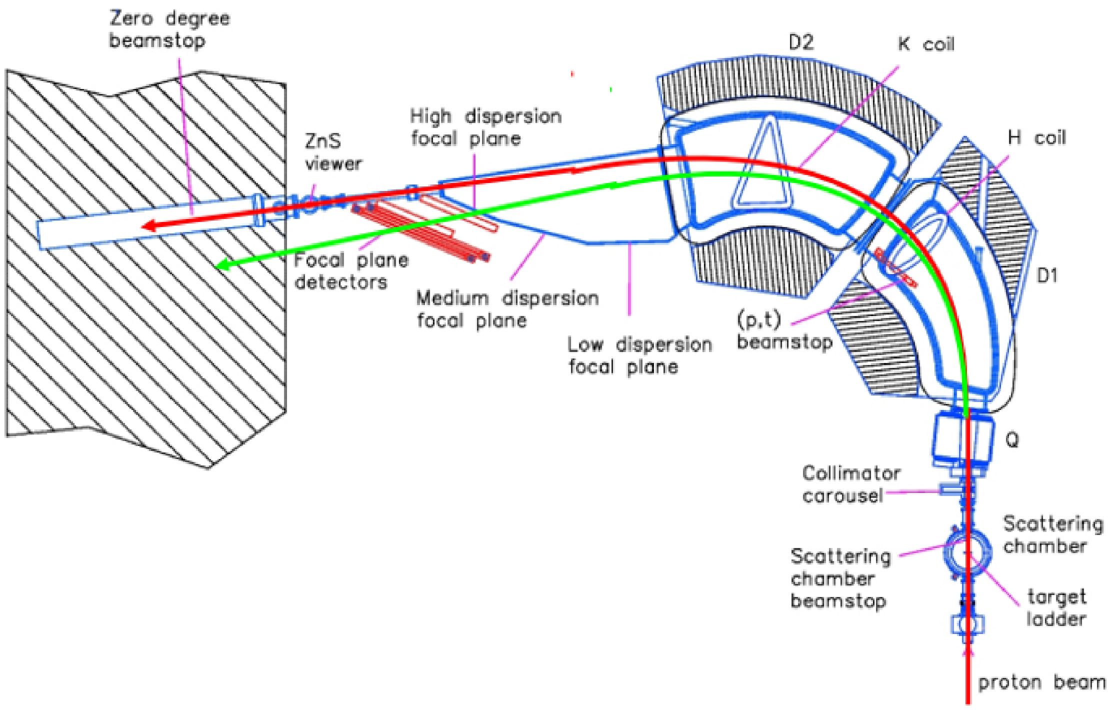

Figure 1. Schematic diagram of the K600 magnetic spectrometer at zero degrees mode.[4]

Fig. 1. The separated sector cyclotron (SCC) accelerates protons to 200 MeV and they are then transported to the target chamber using a series of magnets and beamlines. The unreacted beam is separated from the reacted beam using a magnetic spectrometer consisting of two dipoles, a quadrupole and two trim coils. The focal-plane detectors consists of two paddle scintillator detectors and two multi-wire drift chambers. The spectrometer is used in high-dispersion mode, where the focal plane angle of the detectors corresponds to a scattering angle between 0° and 2°. The ^{24}Mg target was hot rolled in argon atmosphere to a thickness of 2mm and an areal density of 2.1mg/cm^2.

3. Theoretical Considerations

The use of 200 MeV protons at 0° scattering angle allows one to access a reaction system that greatly favours the IVGDR E1 excitation via Coulomb interaction. This is convenient because it limits the interference between the nuclear and Coulomb interactions, thus eliminating the arduous process of disentangling different contributions to the spectrum. One of the methods used to characterise and calculate the Coulomb excitation of the nucleus is virtual-photon production method, which recasts the electromagnetic interaction between the projectile and the target as a spectrum of virtual photons that are absorbed by the target [6]. The calculation of virtual photon production in this work was done using a code provided by Carlos Bertulani based on the methods described in reference [3]. This approach allows the equivalent photoabsorption cross section to be extracted from the double-differential cross section obtained in the experiment

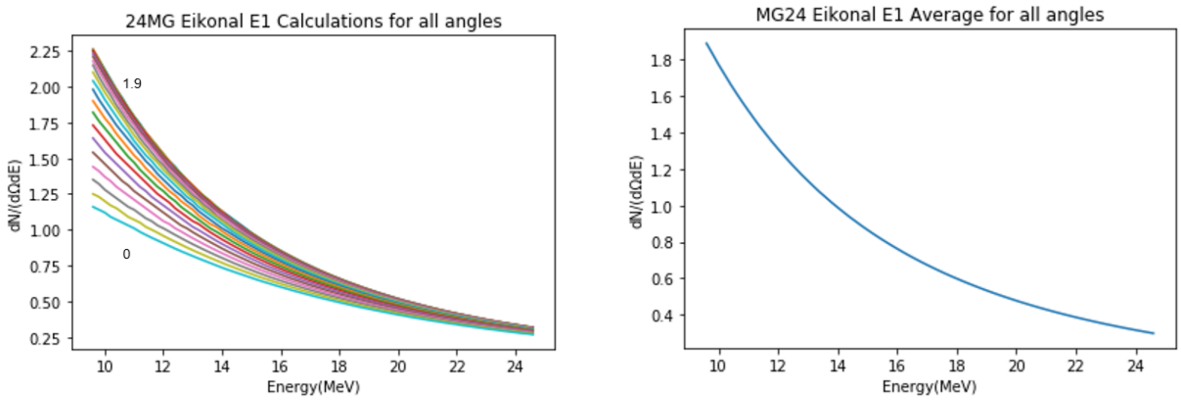

Figure 2. The Calculated number of virtual photons produced in the angular range of the K600 spectrometer. This is used in conjunction with the double differential cross section calculation to calculate the total E1 photoabsorption.

in the following way:

$$\frac{d^2\sigma}{d\Omega dE_\gamma} = \frac{1}{E_\gamma}\frac{dN_{E1}\sigma_\gamma^{\pi\lambda}}{d\Omega}(E_\gamma). \tag{1}$$

Here $\frac{dN_{E1}}{d\Omega}$ represents the amount of E1 virtual photons that are produced per solid angle, $\frac{d^2\sigma}{d\Omega dE_\gamma}$ is the double differential cross-section and E_γ is the energy of the γ. The model used to calculate the virtual-photon production is the Eikonal model and its main advantage over the semi-classical model is that it does not exhibit asymptotic behaviour at small angles, which is crucial to the implementation of the method at 0°. The number of virtual photons produced is calculated at regular intervals between 0° and 2° as can be seen in the left panel of Fig. 2. The right panel of Fig. 2 shows the weighted average of all of these calculations[3]. The photoabsorbtion cross section is calculated by dividing the double differential cross section by the right panel of Fig.2 and multiplying the result by the energy at each energy, thus solving for $\sigma_\gamma^{\pi\lambda}$ in Eqn. 1.

4. Results

The double differential cross section is calculated using the following formula:

$$\frac{d^2\sigma}{d\Omega d\sigma} = \frac{10^{27}\cdot N_c}{N_0\cdot\rho\cdot D\cdot\Delta\Omega\cdot\Delta E\cdot\epsilon_{tot}} \tag{2}$$

Where:

- N_0 is the amount of protons incident on the target.
- N_c is the number of counts in a bin.
- rho is the areal density of the target nucleus.
- $\Delta\Omega$ is the solid angle of the detector used in the K600 and has a value of 3.41 msr.
- ΔE is the energy bin of the histogram.
- ϵ_{tot} is the efficiency of the VDC's used in the K600.
- D is the alive time of the electronics used.

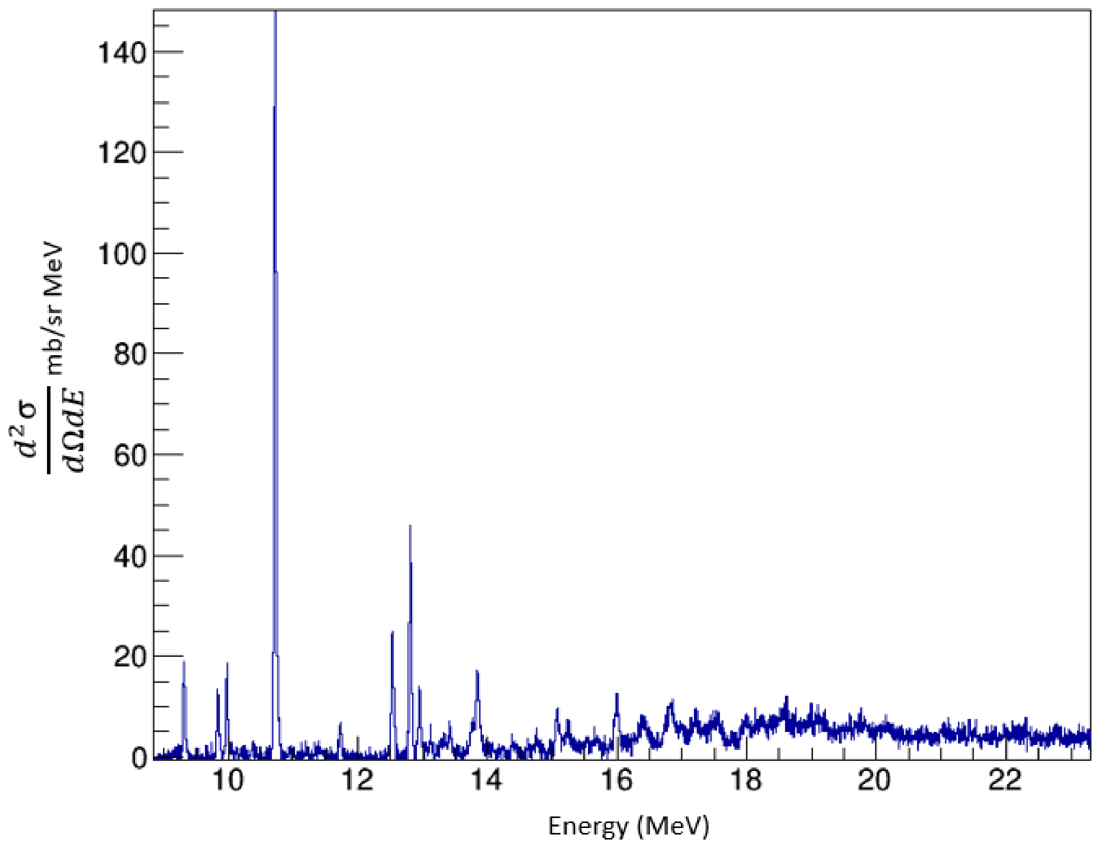

Figure 3. The Extracted double-differential cross section using the procedures described in sections 2 and 3.

The final result of the processes describe above are in the process of being calculated from the double-differential cross-section shown in Fig. 3. Still present in this spectrum is the background from higher multipolarities and quasi-free particle scattering. The quantification of these backgrounds requires a rigorous DWBA calculation to estimate the relative strength of the isoscalar giant quadrupole resonance in the area of interest $16 < E_{\mathrm{x}} < 23$ MeV and to account for other higher energy, higher mulitpolarity contributions. After the calculation has been finalised a meaningful comparison can be made to a previous (γ,abs) spectrum obtained by Dolbilkin *et al*[6] and systematic calculations made using the RIPL database[7].

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