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Investigating the pygmy dipole resonance in ^{96}Mo using the (p,d) reaction

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Abstract. The pygmy dipole resonance (PDR) thus far has been described microscopically as a cluster of 1^- states around the neutron separation energy (S_n). This study is an attempt to probe the nature of the PDR, specifically the single-particle or collective character of these states. One-step transfer reactions represents a good probe for this study due to their selectivity in exciting single-particle states. The ^{97}Mo(p,d) ^{96}Mo and ^{95}Mo(d,p)^{96}Mo reactions, were used to populate the nucleus of interest. The experiment was conducted at the INFN-LNS facility in Catania, Italy. The ejectiles were momentum-analysed by the MAGNEX spectrometer and detected by its focal-plane detector. In this paper, preliminary results for the^{97}Mo(p,d) ^{96}Mo reaction will be presented.

1. Introduction

The pygmy dipole resonance (PDR) is a low-lying electric dipole strength and has been observed in neutron-rich nuclei. A widely used macroscopic description of the PDR is based on the hydrodynamical model which describes the PDR as an oscillation of an isospin saturated *N=Z* core against an excess of neutrons. Most microscopic models describe the PDR as 1p-1h excitations and they are able to well reproduce the strength, and isospin mixing of the response. However, the degree to which the 1p-1h excitations are collective is still under scrutiny as most models are in disagreement with each other [1]. In order to help answer the open question about the nature of the PDR, here we specifically investigate the potential single particle character of these dipole states. The probe of choice should therefore be highly selective of excited states of single particle nature. One-nucleon transfer reactions have been used in nuclear structure studies to support shell-model descriptions of nuclei, and the selectivity of these reactions in exciting states of single-particle nature has been proven [2]. In this work the (p,d) one-neutron transfer reaction as a probe to populate the PDR was investigated.

The experiment was conducted at Istituto Nazionale di Fisica Nucleare - Laboratori Nazionali del Sud (INFN-LNS) using the MAGNEX large-acceptance spectrometer where the beam was delivered by the 14 MV Tandem accelerator. The 25 MeV proton beam impinged on a ^{97}Mo self-supporting target with an areal density of 0.55 mg/cm^2 and a 98.5% enrichment to populate the nucleus of interest via the (p,d) reaction. The ejectiles were momentum-analysed by MAGNEX and its hybrid focal-plane detection system [3]. The data were collected with the spectrometer optical axis positioned at three different central angles (10^o, 17^o and 24^o) to allow for the extraction of the cross section angular distributions for the populated states. The data analysis is currently underway with the data optimization which includes the ray-reconstruction achieved by creating a 10th-order transport matrix using COSY-INFINITY [4] already completed. The inverted transport matrix allows extraction of the initial phase-space parameters from which the excitation energy (E_x) and scattering angle (θ_{scat}) in the laboratory reference frame is obtained. Owing to the large-acceptance of MAGNEX the angular range accessed was $6^o \leq \theta_{scat} \leq 30^o$ and the excitation energy range that was accessed was up to ≈7.5 MeV as seen in figure 1. The energy resolution capability of MAGNEX is $\frac{\delta E}{E} = \frac{1}{1000}$ [4] but due to the energy loss in the target and solid angle corrections, the energy resolution obtained for the low excitation energy region gated around the central angle was 46.45(1) keV FWHM.

2. Results and Discussion

The states below $E_x \approx 2.3$ MeV populated in the present measurement were observed also in a previous study which used the same reaction [5] and are labelled with diamond markers in figure 1. For the states marked with asterisks, the cross section angular distributions were extracted and are shown in figure 2(a) and 2(b). The DWBA calculations were perfomed using the reaction code TWOFNR [6]. As a first order comparison, these DWBA calculations where used to get a basic idea of the angular momentum transfer for these states and they were normalized arbitrarily to fit the data. The *l=2* angular momentum transfer signature which is similar to the results in [5] was confirmed as seen in figure 2. Since the results of this work for these states is compatible with literature, the methodology of extraction of the angular distributions will be extended to the higher excitation-energy region which includes the region of the PDR.

3. Conclusion and Outlook

The (p,d) reaction was used to investigate the PDR in ^{96}Mo in this work and the angular distributions of the states below the PDR region were found to be comparable to those in literature. This provides technical evidence on the methodolody of extracting the angular distributions. Currently underway, is the analysis of the higher-excitation energy region and due to the high level density as the particle threshold is approached, the analysis is complex.

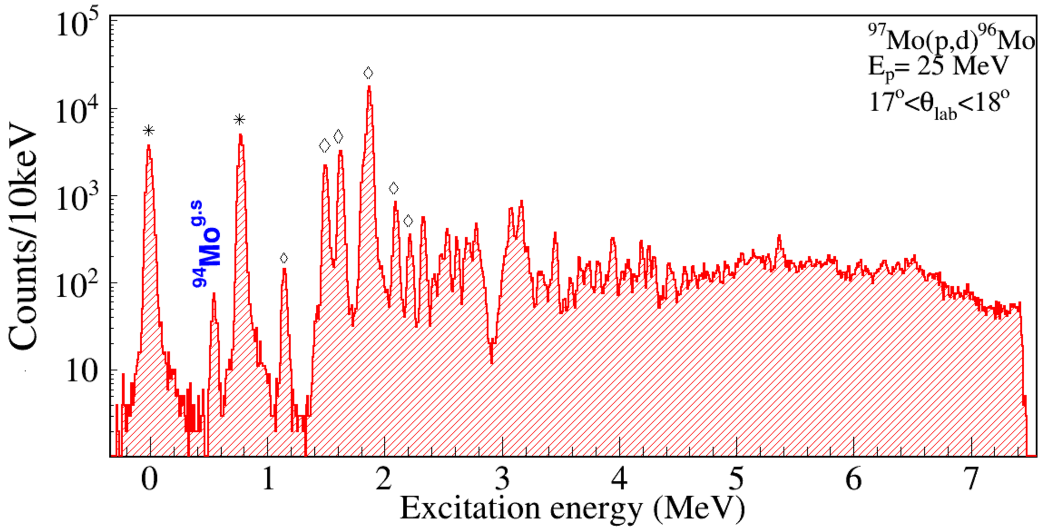

Figure 1. The excitation energy spectrum of ^{96}Mo populated via the (p,d) reaction. The asterisks indicate the states whose cross section angular distributions are presented in this paper and the diamond markers indicate the states that had been populated in previous work of Cochavi [5] using the same reaction. The peak around 0.6 MeV, as labelled, is contaminant from the Mo isotopes present in the target.

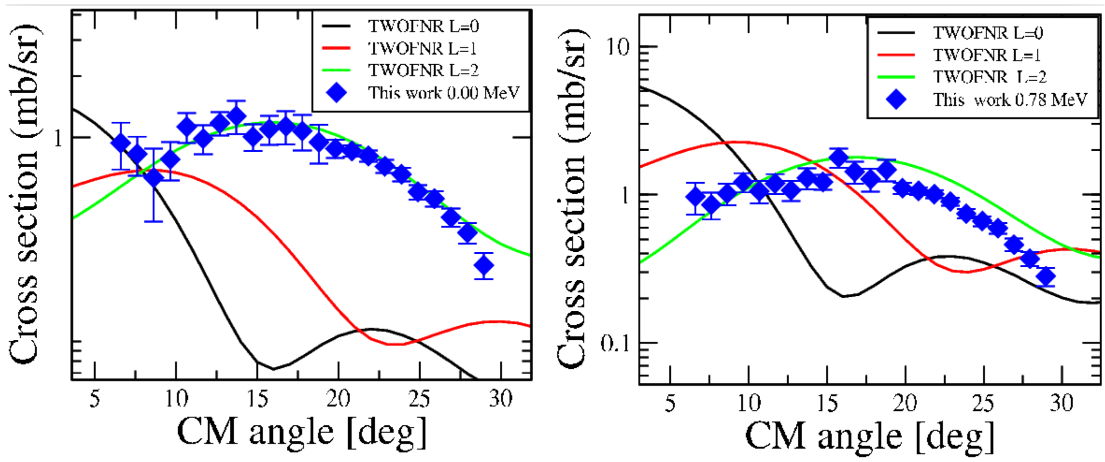

Figure 2. The cross section angular distribution of (a) the ground state and (b) first excited state of ^{96}Mo. The experimental data (blue diamonds) are compared with DWBA calculations performed with TWOFNR. The extracted angular distributions are comparable to the expected one as they exhibit $l = 2$ momentum transfer.

However, with multipole-decomposition analysis (MDA) on the data and comparison of the excitation energy spectrum to that from experiments using different types of probes, information on the PDR can be obtained. The spin and parity will be assigned to states where possible.

4. Acknowledgements

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5. References

[1] Bracco A, Lanza E G and Tamii A 2019 *Progress in Particle and Nuclear Physics* B **103** 360
[2] Glendenning N, 1983 *Direct nuclear reactions* (New York: Academic Press)
[3] Torresi D, Sgouros O, Soukeras V, Cavallaro M, Cappuzzello F, Carbone D, Agodi C, Brischetto G A, Calabrese S, Ciraldo I et al. 2021 *Nuclear Inst. and Methods in Physics Research A* **989** 164918
[4] Cappuzzello F, Agodi C, Carbone D and Cavallaro M, 2016 *The European Physical Journal A* **52** 1
[5] Cochavi S, Moalem A, Ashery D, Alster J, Bruge G and Chaumeaux A 1973 *Nuclear Physics* A **211** 21
[6] Tostevin J, Computer Program TWOFNR,University of Surrey version of Toyama M, Igarashi M and Kishida N