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Study of the Pygmy Dipole Resonance in (p,p'γ) and (d,pγ) experiments with SONIC@HORUS

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Abstract. Last year, the new silicon-detector array SONIC with up to 8 silicon-detector positions was installed inside the existing γ-ray spectrometer HORUS consisting of 14 HPGe detectors. The combined setup SONIC@HORUS allows for a coincident detection of γ-rays and light charged particles in the exit channel of inelastic scattering and transfer reactions. As a first physics case, the Pygmy Dipole Resonance (PDR) in ^{92}Mo has been investigated in a (p,p'γ) experiment at E_p = 10.5 MeV. Since a specific excitation energy can be chosen offline in the coincidence data, the sensitivity to weak decay branchings of PDR states is increased. Additionally, a second reaction mechanism for the excitation of PDR states has been tested with the new setup. In a ^{119}Sn(d,pγ) transfer reaction at E_d = 8.5 MeV, PDR states in ^{120}Sn could be excited. Since this one-neutron transfer reaction is sensitive to the neutron single-particle structure, it could reveal new information on the microscopic structure of the PDR.

1 Introduction

Low-lying electric dipole strength in neutron-rich nuclei, commonly denoted by Pygmy Dipole Resonance (PDR), has recently attracted a lot of experimental and theoretical interest due to its implications for the neutron skin [1], the symmetry energy in the equation of state [2], and isotopic abundances from astrophysical network calculations [3]. To complement to previous experimental approaches, presented in a recent review [4], a new experimental setup was commissioned at the 10 MV Tandem accelerator at the Institute for Nuclear Physics in Cologne. This setup consists of the HPGe-detector array HORUS for high-resolution γ-ray spectroscopy and the silicon-detector array SONIC for light charged-particle identification and spectroscopy and will be described in more detail in section 2. By applying the particle-γ coincidence technique, this setup enables the investigation of the PDR in inelastic particle-scattering and light-ion transfer reactions to learn more about its underlying structure.

2 Experimental setup

2.1 γ-ray detection: HORUS

The HORUS array is an HPGe-detector array consisting of 14 HPGe detectors, 6 of which are equipped with BGO shields for active Compton suppression. Under typical experimental conditions, it has a photo-peak efficiency of the order of 2% at 1.3 MeV and a resolution of 2 keV at 1.3 MeV. Due to the granularity of the setup, it has already been used very successfully for γ-γ coincidence experiments and to extract multipolarities from angular correlations of the emitted γ-rays.

2.2 Particle detection: SONIC

The new particle-detector array SONIC consists of passivated implanted planar silicon (PIPS) detectors inside the target chamber on up to 8 positions. To allow for particle identification, each position can be equipped by a ΔE-E telescope of two detectors of 300 μm and 1500 μm thickness. The active area of one detector is 150 mm^2, leading to a maximum solid angle coverage of the whole array of 4%. The energy resolution of the PIPS detectors is 15 keV using a ^{241}Am standard source, but is worsened in beam to around 70 keV due to straggling effects in the target and the solid angle coverage of the detectors.

2.3 Particle-γ coincidences: SONIC@HORUS

The great improvement for nuclear physics experiments comes from the combination of the two devices (SONIC@HORUS). Since the excitation energy E_X can be determined from the ejectile energy, a two-dimensional matrix can be constructed with the excitation energy and the γ-ray energy as axes, see Fig. 1. In this matrix, certain structures appear, which can be studied selectively: Horizontal columns and vertical bars correspond to a certain E_X and E_γ, respectively. Most importantly, transitions *to* any level at E_{level} are appear as diagonals and can be selected by requiring the condition $E_X = E_{\mathrm{level}} + E_\gamma$. To take advantage of the excellent energy resolution of the HPGe-detectors, the events fulfilling this condition (gate) are then

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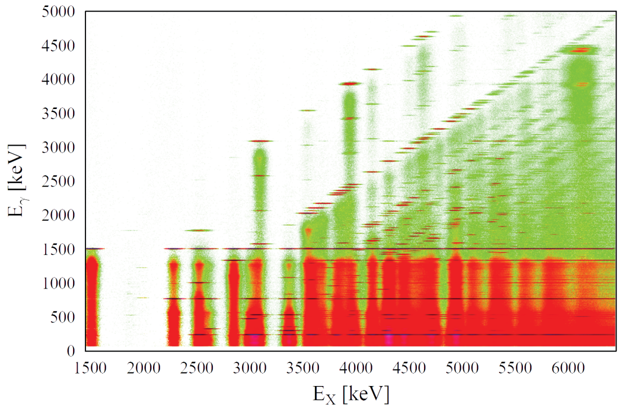

Figure 1. p-γ coincidence matrix of the ^{92}Mo(p,p'γ) experiment. Due to the good excitation energy resolution and the very good γ-ray energy resolution, all transitions to low-lying states can be completely resolved.

Table 1. Observed decay pattern of $J = 1$ states of ^{92}Mo in the PDR energy region (up to E_X=7 MeV).

J_i	J_f^π	# of transitions
1	0_1^+	23
1	2_1^+	11
1	2_2^+	8
1	0_2^+	4

projected onto the γ-ray axis for further analysis. Due to this procedure, several advantages can be achieved: First of all, the peak-to-background ratio is greatly improved compared to the ungated spectra. Most importantly, the level scheme and branching ratios can be extracted rather easily with the additional information on E_X. However, the calculation of branching ratios also relies on the correct determination of detector efficiency and angular correlations, which will not be covered in this article.

3 Inelastic proton scattering: ^{92}Mo(p,p'γ)

Last year, a proton scattering experiment on ^{92}Mo was performed at the 10 MV Tandem accelerator in Cologne to investigate the PDR in this nucleus. A 10.5 MeV proton beam impinged on a 0.6 mg/cm^2 self-supporting target of 94% enriched ^{92}Mo. The average beam current was 20 nA and the experiment lasted 5 days. The goal of the experiment was to investigate the decay branching of previously observed $J = 1$ states [5] below the particle threshold by taking advantage of the p-γ-coincidence technique as explained above. For many states, a sizeable decay branching to excited states was observed. A summary of the decay pattern up to 7 MeV is given in Table 1. For all these transitions, branching ratios will be determined. However, the analysis is still ongoing and some aspects of the setup (*e.g.* efficiency and angular correlations) still have to be accounted for before branching ratios can be determined. Afterwards, they will be compared with theoretical calculations within the Quasiparticle Phonon Model [6].

4 Transfer experiment: ^{119}Sn(d,pγ)^{120}Sn

Recently, a transfer experiment has been performed with the new setup to investigate the PDR in a pioneering (d,pγ) experiment. By using this reaction on ^{119}Sn, the single-particle structure of the PDR in ^{120}Sn was investigated, since this reaction represents a neutron stripping. After applying a gate on the outgoing proton channel in the ΔE-E plot and on ground state decays, the preliminary spectrum as seen in Fig. 2 was obtained. A clear excitation of states in the PDR region was observed as well as peaks from the individual states previously assigned to the PDR in an NRF experiment [7]. The analysis of this experiment is still ongoing and the excitation and de-excitation of states in the PDR region will be investigated.

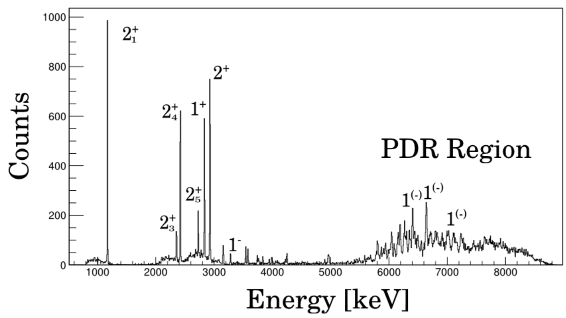

Figure 2. γ-ray spectrum of the ^{119}Sn(d,pγ)^{120}Sn experiment obtained by requiring protons as ejectiles and gating on $E_X \approx E_\gamma$, *i.e.* ground-state transitions, as explained in 2.3. Low-lying transitions and strong dipole transitions are marked with spin and parity of the initial state.

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