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SEARCH FOR PDR AND ISGQR IN $A \simeq 60$ AND $A = 120$ MASS REGIONS*

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Measurements of the γ decay from states above the neutron threshold in ^{120}Sn, ^{62}Ni, and ^{58}Ni were performed at the Cyclotron Centre Bronowice (CCB) in Kraków, Poland. The experiment on ^{120}Sn aims to study the Isoscalar Giant Quadrupole Resonance (ISGQR): data on γ decay of the ISGQR are, in fact, scarce and refer to ^{208}Pb only. To better understand this phenomenon, we chose to investigate another nucleus in a different mass region. The experiment on ^{62}Ni and ^{58}Ni, instead, is devoted to the investigation of the low-energy part of the E1 response, denoted as Pygmy Dipole Resonance (PDR), to better understand the systematic dependence on neutron excess in nickel isotopes. It is part of a campaign on PDR, including various complementary measurements carried out at different facilities. The paper will describe the performances and characteristics of the experimental setup together with the first near-line results for both experiments.

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1. Introduction

1.1. The physics case: ISGQR in ^{120}Sn

The study of giant resonances is a research field that has attracted experimental and theoretical attention since the end of the forties. This field is still very active due to interesting open problems, among them, the investigation of the microscopic structure of these states via their γ decay. The decay of giant resonances in nuclei is a prime example of how a well-ordered collective excitation dissolves into disordered motion exemplified by its spreading width. By studying this process, we can access more exclusive properties associated with their wave function through the giant-resonance γ-decay measurements.

In the experiment at the Kraków cyclotron, we address the issue of γ decay from excited IsoVector Giant Dipole Resonance (IVGDR) and IsoScalar giant quadrupole resonance (ISGQR). In particular, the measurements of the gamma-branching ratios could test in detail the microscopic structure of the giant quadrupole resonance. References [1] and [2] report on measurements for the ^{208}Pb nucleus which are the only cases in the literature. To better understand the problem, we investigated another nucleus ^{120}Sn in another mass region.

1.2. The physics case: PDR in $A \simeq 60$ mass region

One relevant feature of the electric dipole (E1) response is the strength concentration around the particle binding energy, denoted low-lying dipole response or often Pygmy Dipole Resonance (PDR). A possible interpretation of the PDR is the oscillation of the neutron excess against the $N = Z$ core.

Therefore, the PDR reflects the properties of the neutron skin in nuclei. The neutron skin plays a crucial role in nuclear polarizability, and these quantities are relevant to constrain the nuclear equation of state. In addition, the excess of the E1 strength around the neutron separation energy affects the predictions of nucleosynthesis within the r-process and neutron capture reaction rates [3, 4].

The nature of the PDR is not well understood yet, although experimental and theoretical works have been done on this subject in the past decades. To better understand the nature of the PDR states, it is necessary to develop a broad systematic study to learn about the dependence of the PDR on mass and neutron excess and the investigation of the isospin character using complementary approaches.

The nickel isotopes offer an interesting case to investigate the PDR. They offer a large variety of N/Z ratios that are experimentally accessible (see Fig. 1).

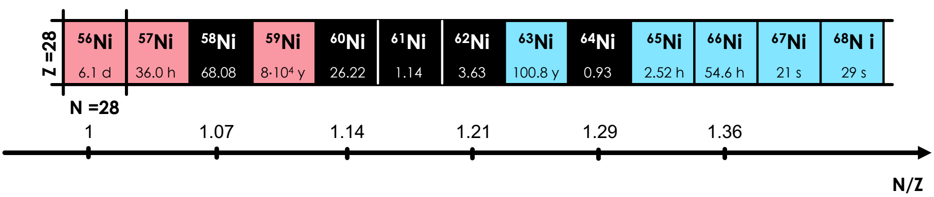

Fig. 1. Nickel isotopic chain from the $N = Z$ magic nucleus ^{56}Ni to ^{68}Ni. The ^{58,60,61,62,64}Ni isotopes are stable.

The stable isotopes ^{58,60}Ni are not so far away from the $N = Z$ line and have been studied in photon-induced reactions, together with ^{62}Ni. The more neutron-rich ^{62}Ni has been measured much less and below the neutron threshold. Exciting states in these nuclei with the $(p, p'\gamma)$ reactions is needed to understand the role of neutrons in states at the onset of the pygmy strength existence. Theory [5] predicts differences when more and more neutrons are added to Ni isotopes.

We expect a negligible PDR in ^{58}Ni and a doubling of the extra yield in ^{64}Ni compared to ^{62}Ni, as foreseen from the theoretical prediction [5] and the results of measurements with photo-absorption [6].

In a complementary campaign, we are searching for the possible survival of pygmy states at finite temperature in ^{56,62,64,66}Ni [7].

2. The experiments and the experimental setup

This paper reports on the near online results for the two distinct experiments: the γ decay of the ISGQR in ^{120}Sn and the PDR in ^{58}Ni and ^{62}Ni.

We performed both experiments at the CCB (Cyclotron Centre Bronowice), Kraków, using proton inelastic scattering. The proton beam energy chosen to maximize the cross section was 200 MeV for the ^{120}Sn experiment and 185 MeV for the ^{58}Ni and ^{62}Ni. We chose the proton beam energy to maximize the cross section. Reference [8] reports on the cross section for the ISGQR excitation already measured in ^{120}Sn.

We use the setup installed at the CCB for both experiments. Figure 2 shows the setup sketch [2], composed of a large scattering chamber with the 30 KRATTA triple telescopes (with a segmented plastic scintillator in front for a better time resolution) [9], four large volume (3.5" × 8") $LaBr_3$:Ce detectors [10] and 2 PARIS (9 single detectors) clusters [11]. In the case of the PDR experiment, the setup also included an extra 8 PARIS detectors around the two PARIS clusters.

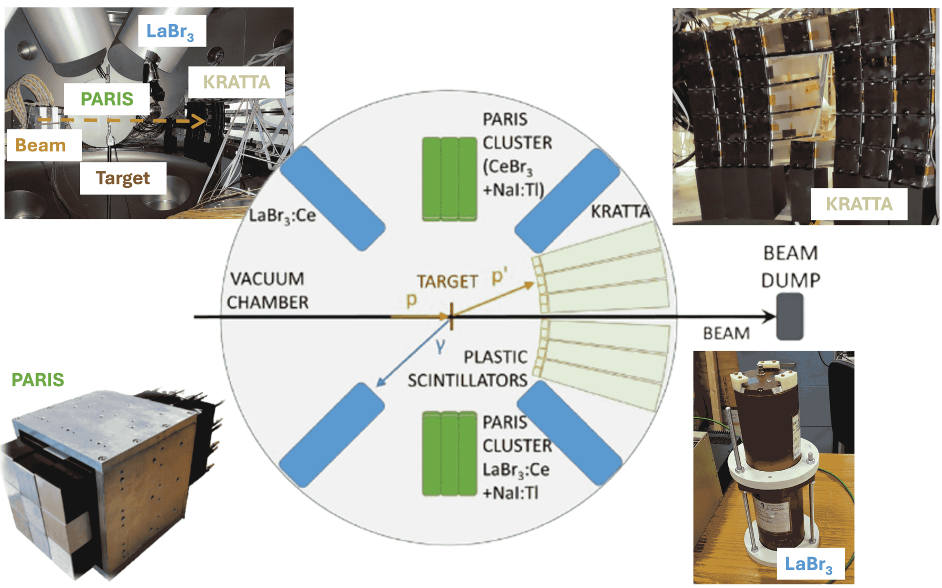

Fig. 2. A schematic view of the setup installed at CCB [2] is in the middle of the figure. Around it, some pictures show what the setup looks like.

3. The analysis technique

The data analysis technique is the same for both experiments. The protons impinge on the target and are inelastically scattered. The KRATTA telescopes measured the energy of the scattered proton. The large volume $LaBr_3$:Ce and the PARIS detectors detected the γ rays from the decay of excited-target nuclei. We calibrated the KRATTA telescopes in beam with the elastic peak at different beam energies. We calibrated the γ detectors

($LaBr_3$:Ce and the PARIS) with standard sources. Moreover, we used an AmBe(Ni) source and the proton beam impinging on a ^{12}C target to produce 9 MeV and 15 MeV γ ray, respectively. We checked the detector's stability during the whole experiment. The experiment trigger requires the coincidence between the γ rays and the scattered protons.

Once the detectors were calibrated and the time gates fixed, we selected the scattered proton using the KRATTA pd1 *versus* pd2 matrix, that is a ΔE–E matrix obtained with the two layers of the KRATTA telescopes. Afterwards, we calculated the excitation energy (E^*) as $E^* = E_p - E_{p'}$. Finally, we built the E_γ *versus* E^* matrix. Figure 3 shows the E_γ *versus* E^* matrix for the ^{62}Ni, as an example. We produced the same plots also for ^{58}Ni and ^{120}Sn.

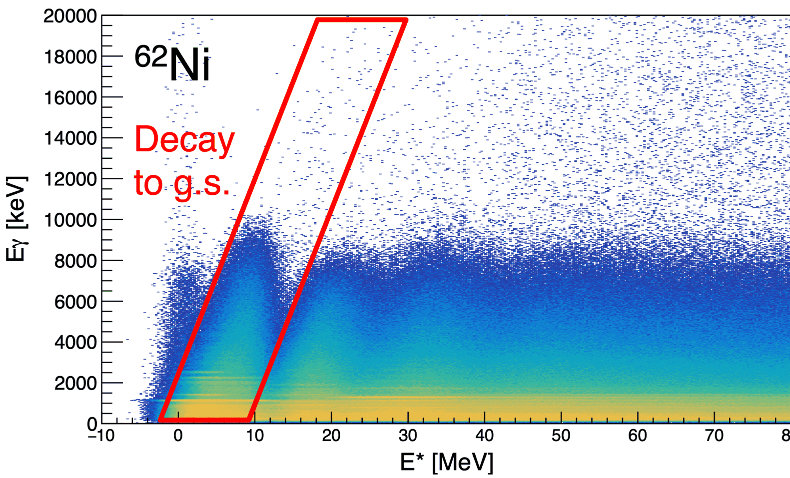

Fig. 3. (Colour on-line) The E_γ *versus* E^* matrix for ^{62}Ni. The red/black box corresponds to the gate we used to select the decay to the ground state.

The data analysis technique is the same for both experiments. However, the interpretation of the data will be different for the two experiments. We used the red/black box shown in Fig. 3 to select the decay to the ground state. As the first check, we looked at the low-energy discrete transitions. Once we are sure that there are only the low-energy transitions of the nucleus of interest, we extract the high-energy part. Figure 4 shows the preliminary high-energy γ spectra. In the case of PDR in Ni isotopes, we did a preliminary normalization and compared them. Since the PDR is probably related to the neutron excess, we expected a negligible PDR in ^{58}Ni and an appreciable PDR signal in ^{62}Ni. The left panel of Fig. 4 shows an excess of counts in the PDR region of ^{62}Ni.

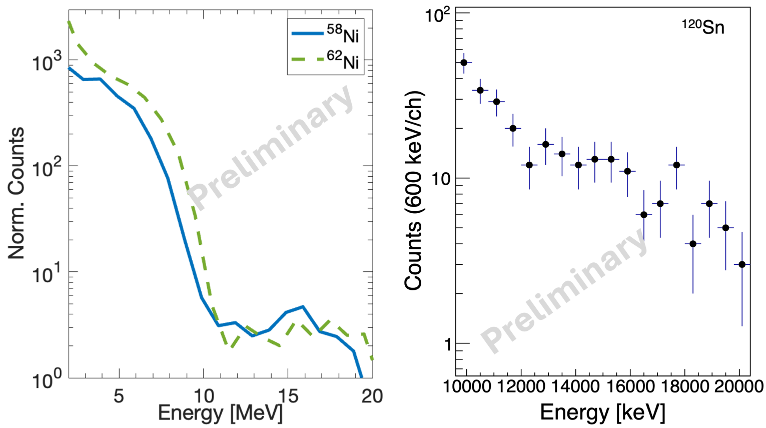

Fig. 4. (Colour on-line) Left panel: The high-energy γ spectra for ^{58}Ni (solid blue line) and ^{62}Ni (dashed green line). Right panel: the high-energy γ spectra for ^{120}Sn.

The data from both experiments are currently under analysis. For ^{120}Sn, we will have to disentangle the ISGQR signal from the IVGDR and PDR to extract the ISGQR branching ratio. In the case of the PDR Ni isotopes experiment, we will quantify the PDR signal as a function of the neutron excess.

4. Conclusions and perspectives

In this paper, we show the experimental setup and the data analysis technique of two experiments: the first one on the PDR in Ni isotopes, and the second one on the ISGQR in ^{120}Sn.

The preliminary data analysis shows an excess of counts ^{62}Ni in comparison with ^{58}Ni. The excess counts, in the PDR region, are probably connected to PDR. To have a trend of the PDR signal in Ni isotopes as a function of the neutron excess, we proposed a new experiment to study the PDR in ^{64}Ni because it is the stable Ni isotope with the largest N/Z ratio. We will perform the experiment in 2025.

For the ^{120}Sn experiment, we measured proton inelastic scattering on ^{120}Sn at CCB, Kraków. Up to now, we extracted the high-energy γ spectrum from the data. Following that, we have to interpret the data to extract the ISGQR branching ratio.

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