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Isoscalar giant resonance studies in a stored-beam experiment within EXL

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Abstract

In the first campaign of the exotic nuclei studied with light-ion induced reaction in storage rings (EXL) collaboration at the existing storage ring experimental heavy-ion storage ring (ESR) at Helmholtz Center for Heavy Ion Research (GSI), we performed the first experiments using a stored beam of ^{58}Ni and an internal helium gas-jet target aiming for the investigation of isoscalar giant resonances in inverse kinematics. In this experiment, inelastically scattered recoil particles (at very forward angles, $\theta_{cm} \leq 1^\circ$) were detected with a dedicated setup, including ultra-high vacuum (UHV)-compatible double-sided silicon strip detector (DSSDs). Preliminary results show evidence for the excitation of the isoscalar giant monopole resonance (ISGMR) in the ^{58}Ni nucleus. This opens the opportunity to study in the near future giant resonances also with stored radioactive beams, like ^{56}Ni , and extract important information about the nuclear matter incompressibility. In the present work the current status of the data analysis and results are shown and discussed.

Keywords: giant resonance, storage ring, inverse kinematics

(Some figures may appear in colour only in the online journal)

1. Introduction

The investigation of nuclear structure and reaction mechanisms with radioactive ion beams is a field that has attracted great interest in nuclear physics in the last years. Several facilities and programs around the world have been launched to study the nuclear properties of these nuclei. One of these programs is EXL (exotic nuclei studied with light-ion induced reaction in storage rings) at Helmholtz Center for Heavy Ion Research/Facility for Antiproton and Ion Research (GSI/FAIR) [1, 2]. The objective of the EXL collaboration is to investigate light-ion induced reactions in inverse kinematics using novel storage-ring techniques and a universal detector system providing high resolution and large solid-angle coverage, which allows for kinematically complete measurements. Many nuclear structure aspects and direct reactions at low momentum transfers can be investigated in this project.

To start up the physics program of the EXL project, the collaboration performed experiments in 2012 in the ESR (experimental heavy-ion storage ring) at GSI [3, 4]. As proof of principle, measurements were performed with a stored ^{58}Ni beam and the supersonic internal gas-jet target of ^4He [5]. One of the major advantages of carrying out this type of experiment in inverse kinematics is the option to access the scattered particles at forward angles in the center-of-mass system (c.m.s.). In measurements of light-ion inelastic scattering, at small θ_{cm} , it is possible to study the collective properties of nuclei by investigating the excitation of giant resonances, as has been extensively studied in the past in normal-kinematics experiments [6–8]. In particular, inelastic alpha scattering can be a selective probe to excite isoscalar giant resonances, like the ISGMR (isoscalar giant monopole resonance) or the ISGDR (isoscalar giant dipole resonance). This is also a direct method for deducing important properties of nuclei, such as the nuclear-matter incompressibility [9].

2. Experimental setup

In the past several years, a large amount of research and development has been performed to understand various aspects of in-ring particle detection [10–13]. Based on such experience, the detector array for the present experiment was mounted in a vacuum chamber specially designed for compatibility with the ultra-high vacuum (UHV) conditions in the storage ring. This chamber was installed in the region of the internal gas-jet target of the ESR. It was composed of two internal ‘pockets’ placed at angles of 80° and 32° with respect to the beam direction, as illustrated in figure 1. In the front part of each pocket, a DSSD (double-sided silicon strip detector) of $285\ \mu\text{m}$ thickness, $64 \times 64\ \text{mm}^2$ in area and with 128×64 channels, was installed. These DSSDs were operated as active windows between the UHV of the ring and the auxiliary vacuum inside the pockets [12, 13]. Additionally, in the first pocket (at 80°), two Si(Li) detectors were placed behind the DSSD in order to operate the whole system as a telescope for the detection of elastically scattered recoils [4]. The achievable angular resolution was kinematically limited

Figure 1. View from top of the vacuum chamber installed in the ESR. The detectors were mounted inside the two internal pockets at 80° and 32° , with respect to the beam, direction. The target flux is perpendicular to the beam, and the slit plate was placed in front of the first pocket.

Figure 2. Elastic scattering cross-section of $^{58}\text{Ni} + ^4\text{He}$ at 100 MeV/u. The differential cross-section is presented as the ratio of the Rutherford elastic scattering cross-section.

by the extension of the gas-jet target (about 5 mm full width at half maximum (FWHM)). A slit plate inside the chamber was included to reduce the acceptance and thus improve the angular resolution of this telescope.

The second pocket was set for the detection of inelastically scattered alpha recoils corresponding to small angles in the center-of-mass frame. In the angular range of this detector, the energy of the recoils was calculated from the kinematics to be only about 300 keV for excitation energies around 20 MeV. These very-low-recoil energies clearly demonstrate that the use of windowless targets and in-ring detectors is essential for this type of experiment.

The stored beam for the present investigations was fully stripped ^{58}Ni ions at an energy of 100 MeV/u with a revolution frequency of 1.2 MHz. With each beam injection, about 10^8 particles were stored in the ring. During the experiment the electron cooler was in operation. This enabled a constant beam energy and a small beam divergence. The density of the helium target was about 7×10^{12} particles/cm² and it was rather stable during the whole experiment. Thus, a luminosity of around $10^{26}\ \text{cm}^{-2}\text{s}^{-1}$ was achieved.

Figure 3. Energy spectrum of one of the strips of the DSSD at 32° (left) and a corresponding GEANT4 simulation (right).

3. Preliminary results and discussion

As previously explained, elastic events were identified using the detectors in the first pocket. In figure 2, the elastic-scattering cross-section for $\alpha(^{58}\text{Ni}, \alpha)^{58}\text{Ni}$ at 100 MeV/u is shown. Here, the experimental data are well reproduced by an optical potential that takes into account the nuclear densities of both target and projectile [14, 15]. In this analysis, the density shape of ^{58}Ni has been extracted from the fit of the experimental angular distribution [5]. A preliminary point-matter radius $r_{\text{rms}} \approx 3.7$ fm was obtained, which is in good agreement with values measured in normal kinematics [16, 17].

Inelastic scattering events from the excitation of giant resonances were detected using the second DSSD (at 32°). In order to enable an identification of the reaction channels contribution to the energy spectra in all strips of the detector, GEANT4 [18] simulations were performed with the principal reaction channels in this angular region. As an example, a measured energy spectrum of one of the strips of the DSSD is compared with the simulation in figure 3.

In all strips, an important background, most probably coming from δ -rays produced in the gas target, with energies below 200 keV, was observed. The energy position of these peaks is in agreement with simulations that assume the elastic scattering kinematics of the removed electrons from the target atoms. The most important characteristic of the energy spectra is the bump between 200 and 600 keV that, as expected from simulations, corresponds mainly to the excitation of the ISGMR.

Due to the low count rate per strip, it is convenient to add up the energy spectra of all strips from the DSSD after the transformation to the center-of-mass frame to obtain an excitation energy spectrum. The result is a well-defined peak centered around 20 MeV. Because of the intense contribution of delta rays, it was difficult to separate the excitation energies below 16 MeV from the background. In figure 4, this peak is shown after the respective background subtraction. The angular range of these events is close to one degree in c.m.s., the region where the contribution of the monopole resonance is expected to be dominant.

From a preliminary Gaussian fit, the centroid of 20.0 MeV and the FWHM of 7.8 MeV for the ISGMR were obtained. The position of the peak is affected by the parameterization of the background, which is still being studied. However, the present results are comparable with previous

Figure 4. Double-differential cross-section extracted from the sum of all strips.

experiments performed in normal kinematics [6–8]. For the moment, a more detailed analysis, using distorted wave Born approximation calculations, is being carried out in order to perform a multipole decomposition of the resonance peak. Thus, it will be possible to extract other resonance components, like the ISGDR.

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