

STUDY OF THE UNBOUND ^{13}Be RESONANCE IN A $(p, 2p)$ REACTION AT GSI*

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The neutron-rich unbound resonance ^{13}Be is a key to understand the Borromean nucleus ^{14}Be that is situated on the edge of the neutron dripline. This contribution reports on a kinematically-complete measurement at relativistic energies, performed by the R3B Collaboration using the $^{14}\text{B}(p, 2p)^{13}\text{Be}$ reaction in inverse kinematics.

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1. Introduction

There is a growing interest in studying the more extreme cases of the nuclei chart; isotopes such as $^{5,6,7,8}\text{He}$, $^{10,11}\text{Li}$ that are close, or beyond, the neutron dripline are now under investigation. These systems show bound halo structures for even neutron numbers, while the odd ones are unbound. In the case of the Be isotopes, ^{14}Be shows a double neutron halo whereas ^{13}Be is an unbound resonance. From the nuclear structure point of view, a deeper knowledge of the shell-structure of ^{13}Be is required.

Since the 80s, the nucleus ^{13}Be has been the focus of several investigations [1–5]. Over the last years this interest has increased with experiments at RIKEN [6], GSI [7, 8] and more recently at GANIL [9]. The majority of cases have used ^{14}Be as the incoming secondary beam for production of ^{13}Be , and not feature gamma-ray detection. This contribution reports on an experiment of the R3B Collaboration performed at GSI in 2010, in which an array of gamma-ray detectors surrounded the target and produced the isotope of interest via the reaction $^{14}\text{B}(p, 2p)^{13}\text{Be}$.

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2. Experimental method

The GSI accelerator complex starts with a linear accelerator (UNILAC). In this experiment, a primary beam of ^{40}Ar was injected into the synchrotron (SIS18) in order to reach an energy of 490 MeV/ u . After the acceleration stage, the beam impinged on a beryllium target producing a cocktail beam that continued through the FRagment Separator (FRS) before reaching the experimental hall (Cave C).

The setup inside the experimental hall has a wide variety of detectors in order to obtain a complete kinematic measurement (see figure 1).

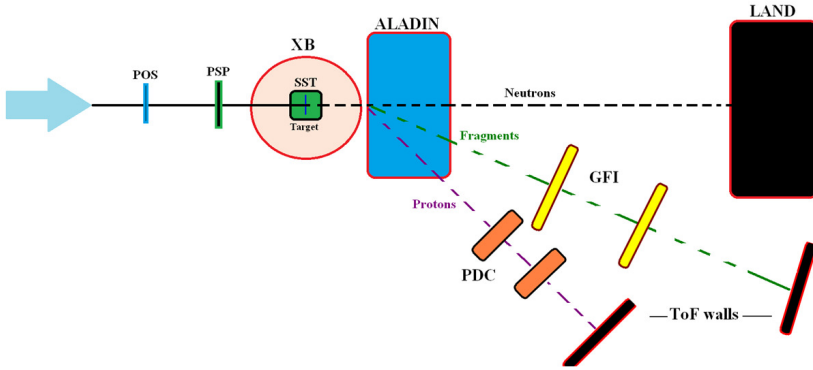


Fig. 1. The R3B Collaboration setup during the s393 experiment, featuring time-of-flight and energy loss measurement of the incoming beam using a plastic scintillator (POS) and a square plate silicon detector (PSP). Surrounding the CH_2 (9.81 mm) target, micro-strip silicons detectors (SST) for position and energy loss measurements and a gamma detector (XB) comprising of 162 NaI scintillators. After the target, there are two relevant branches for heavy fragments and neutrons, which give position, time-of-flight and energy loss measurement using fiber detectors (GFI) and plastic scintillators (ToF Walls and LAND). The third branch for proton detection was not used for this reaction channel. The dipole magnet ALADIN situated just after the target bends the reaction products in the direction of the corresponding branches.

The $(p, 2p)$ reaction produces ^{13}Be via knockout, thus in a direct reaction, which can be simplified as an interaction between two protons, one from the target and the other from the ^{14}B nucleus. This is known as quasi-free scattering [10]. The isotope ^{13}Be has a half-life of the order of 10^{-21}s that does not allow to measure the isotope itself but instead the $^{12}\text{Be}+n$ system.

3. Analysis method

In order to extract information on the structure of ^{13}Be , we have followed the invariant mass method. The idea behind is the reconstruction of the energy of the nuclei from the detection of the fragment ^{12}Be and the neutron. However, if the ground state mass of the residual nucleus is subtracted the energy left can be understood as the excitation energy of the isotope (see the equation below). This energy produces a relative energy spectrum that gives information about the resonances fed in the unbound ^{13}Be

$$E_{\text{rel}} = \sqrt{M_{^{12}\text{Be}}^2 + m_n^2 + 2m_n M_{^{12}\text{Be}} \gamma_n \gamma_{^{12}\text{Be}} [1 - \beta_n \beta_{^{12}\text{Be}} \cos(\theta_{^{12}\text{Be}-n})]} - M_{^{12}\text{Be}} - m_n.$$

The equation shows that only three parameters are relevant; the angle between the outgoing fragment (^{12}Be) and the neutron ($\theta_{^{12}\text{Be}-n}$), and the velocity of each. The procedure to extract the parameters is the following; from the cocktail beam of the FRS the ^{14}B must be selected avoiding contamination from other isotopes and the reaction products have to be energy-wise selected in order to constrain the outgoing fragments to beryllium isotopes. Using the complete kinematics detection system, it is possible to track the products through the fragment branch and to separate via the different masses, thus selecting $A = 12$. After finding the fragment, selecting one (and only one) neutron in LAND, the channel of interest is cleaned up and the angle and the velocities can be extracted (see figure 2).

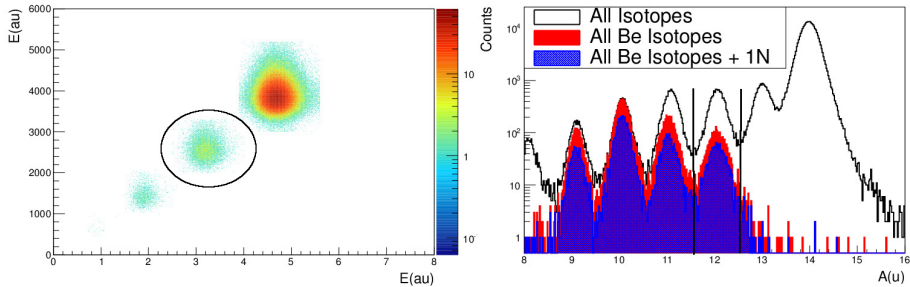


Fig. 2. Left: Energy loss in one SST after the reaction *vs* energy loss in the ToF Wall (see figure 1). The beryllium isotopes are selected ($Z = 4$). Right: Tracked masses through the fragment branch. All the isotopes produced in the reaction are in white. The selected beryllium is in grey (red), and in black (blue) if it fulfils the condition of one neutron in LAND. The mass $A = 12$ is selected.

When the ^{13}Be is produced, several resonant energies can be fed, therefore the neutron decay can populate different states in ^{12}Be . In order to clarify the ^{13}Be structure, the invariant mass method is not enough as the spectrum will only unfold the energy between the neutron and the fragment,

but it cannot distinguish between different excitations of the ^{12}Be . Unless the only fed state of the fragment is the ground state, the measurement has to be complemented by gamma detection, otherwise different ^{13}Be resonances decaying to different ^{12}Be states with the same energy will interfere and contribute to the same relative energy peak of the spectrum.

However, ^{12}Be has three possible excited states in the energy range of this analysis, thus two possible gammas at 2.1 and 2.7 MeV can be measured. The third state at 2.4 MeV [11] is an isomeric state with a long lifetime ($\tau = 357(22)$ ns [12], $\tau = 331(12)$ ns [13]) and will escape the gamma-ball before decaying and so avoid detection.

4. Summary and conclusion

The analysis of these data is still ongoing. The incoming ^{14}B and the outgoing ^{12}Be have been identified including the events with one neutron multiplicity. The relative energy spectrum is being folded with the detector resolution and fitted to different Breit–Wigner distributions to get preliminary positions for the resonant energies. This result is going to be compared with the gamma spectra in order to yield physics interpretation. The low cross section for the production of this exotic nucleus has resulted in a very low statistics introducing complications in the analysis procedure.

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