EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Status Report to the ISOLDE and Neutron Time-of-Flight Committee

Probing Shape Coexistence in neutron-deficient ^{72}Se via Low-Energy Coulomb Excitation

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Abstract: This status report presents the status of HIE-ISOLDE experiment IS597 including a summary of the 2017 running period and an update to the scientific motivation to include relevant new experimental and theoretical work.

Remaining Shifts - 9

Updates to Scientific Motivation and Recent Work

A detailed description of the the physics case can be found in Ref [1], the motivation remains broadly the same and is still pertinent. Consequently, the scientific motivation is only summarized briefly here, in order to include relevant new work and to aid the discussion that follows.

Nuclei in the mass region A ~ 70 close to the *N* = *Z* line are known to exhibit a variety of nuclear shapes, which may be attributed to large shell gaps at both prolate and oblate deformation. These gaps are most pronounced for proton and neutron numbers 34 and 36 and the resulting coexistence of prolate and oblate shapes was predicted over three decades ago [2]. The nuclear shape is a very sensitive probe of the underlying nuclear structure and the effective interaction between the nucleons. Observables related to the nuclear shape, for example the electric quadrupole moment (QM), and the reduced electric quadrupole transition probability (B(*E2*)), are thus important benchmarks for testing nuclear structure theory.

Studies in this important mass region initially focused on the neutron-deficient krypton isotopes, e.g. Refs [2-5], however the situation in the neighboring selenium isotopes is equally intriguing and much less well established. The situation for ^{72}Se, as predicted by Adiabatic Self-Consistent Coordinate (ASCC) calculations is shown in Figure 1 (a), here the ground state wave function is expected to be widely spread over the triaxial region; a maximum is expected at oblate deformation, but with the wave function extending to the prolate region [6]. The prolate character of this ground state band is then expected to develop with increasing angular momentum, as shown for both the GCM(GOA) and ASCC calculations in Figure 2(b). However, it is clear that the results of the two theoretical approaches disagree for the structure of the states in the band built on top of the 0^+_2 level as the ASCC calculations predict a weakly deformed, oblate excited band. Whereas, the more recent GCM(GOA) calculations predict that mixing is present for the low-lying 0^+ and 2^+ states before giving way to purer configurations at larger excitation energy.

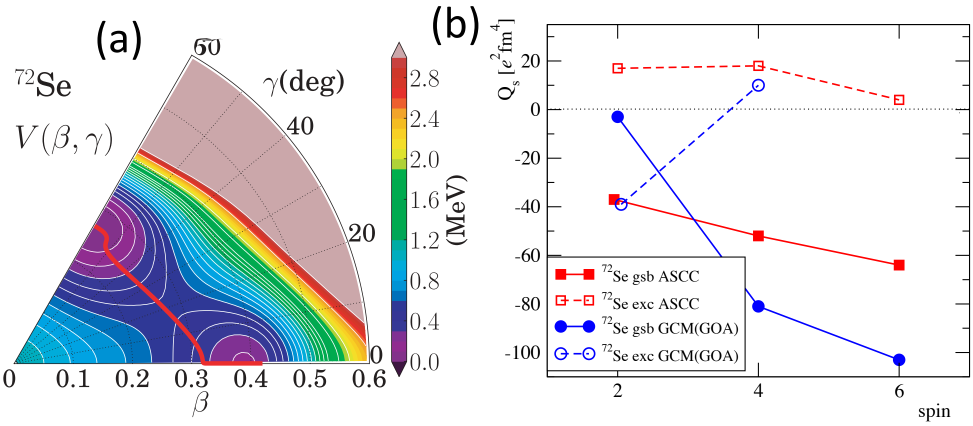

Figure 1. (a) Potential energy V(β,γ) map for ^{72}Se, plot is taken from Ref [6]. It is clear that two distinct local minima are predicted by the ASCC calculations, with the oblate minimum at γ = 60° having a slightly lower energy, of the order if a few hundred keV, than the prolate minimum (γ = 0°). ***(b)*** *Theoretical quadrupole moments of the ground-state and excited bands in ^{72}Se. The GCM(GOA) calculations [7] are represented by blue circles, while ASCC calculations, represented by red squares, are from the work of Hinohara et al. [8].*

Testing the predictions, of both theoretical approaches, by measurement of E2 matrix elements connecting the states and of the QM of the key levels was, therefore, a key goal of the proposed Coulomb excitation study.

In the years since the proposal was prepared there has been one major experimental work of relevance aimed at investigating nuclear shapes and configuration coexistence in ^{72}Se. In this work, see Ref [9], a dedicated Coulomb-excitation study of ^{72}Se was performed at the ReA3 facility [10] at the National Superconducting Cyclotron Laboratory (NSCL) [11]. In this study, the ^{72}Se beam was produced following the fragmentation of a 150 MeV/u ^{78}Kr beam before being transferred to a linear gas stopper, thermalized and charge bred. The charge-bred ^{72}Se ions were then injected into the ReA3 accelerator chain, accelerated to 4 MeV/u and delivered to the Janus setup for Coulomb-excitation studies. In the data analysis, a negative quadrupole moment (QM), corresponding to prolate deformation, was determined for the 2^+_1 level which suggests that the transition to oblate deformation does not occur until the more neutron-deficient Se isotopes. However, due to the losses associated with stopping and reaccelerating the secondary beam the ^{72}Se intensity in this work was ~ 4000 pps, which is approximately two orders of magnitude less than what can be achieved at HIE-ISOLDE, as discussed below. This intensity limits the physics that can be extracted with a Coulomb-excitation study utilizing a ^{72}Se beam at ReA3 to the structure of the 1st excited state until FRIB is fully operational. The scientific goals of the present proposal require the QMs of the critical 2^+_1, 2^+_2 and 4^+_1 states to be determined and, for J = 0 states, the shape to be determined by employing the "quadrupole sum rules" method [12,13], which requires a complete set of E2 matrix elements. Clearly, therefore, HIE-ISOLDE is the only facility where a low-energy Coulomb-excitation study of ^{72}Se can be performed with the goal of accessing further excited states and obtaining a set of nuclear matrix elements rich enough to be used to determine shape deformation parameters. These are the key quantities that are required to discriminate between, and benchmark, the results from various state-of-the-art theoretical studies performed for nuclei in this region. It is also important to point out that in this study the precision of the 2^+_1 QM determined in Ref [9] will be substantially improved.

Finally, we note that a ^{72}Se beam can be produced at TRIUMF. There has been one yield measurement, performed in 2010 [14], in which an intensity of 1.3 x 10^6 ions/s is quoted. However, after post-acceleration the intensities, and purity, of this beam would not be sufficient for a detailed Coulomb-excitation study, such as that proposed here, to be performed.

Summary of 2017 Beam Time

The shifts for experiment IS597 were scheduled to be performed during the summer of 2017 and were the first HIE-ISOLDE shifts of the year. Of the 12 shifts awarded by the INTC 1.5 were delivered over the first night and into the following morning, where a 4.2 MeV/u ^{72}Se beam was directed onto ^{208}Pb and ^{196}Pt targets positioned at the centre of the Miniball/ CD detector setup. An example spectrum obtained with ^{72}Se ions incident on a ^{196}Pt target is shown in Figure 2 below.

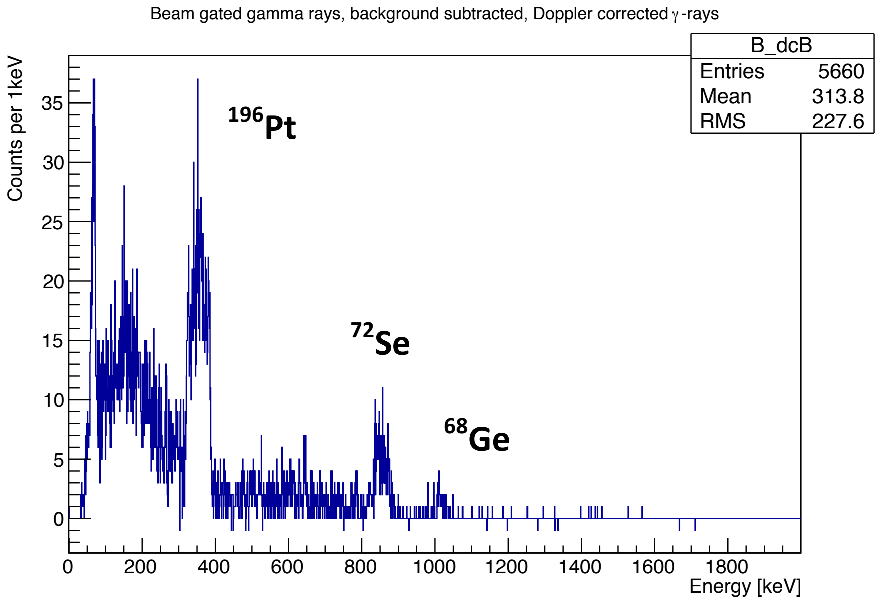

Figure 2. Coincident, random-subtracted gamma-ray spectrum obtained for ^{72}Se incident on a 1.5 mg/cm^2-thick ^{196}Pt target. The likely origin of the ^{68}Ge contaminant is that it is extracted as a ^{68}GeS molecule, which has the same mass as the ^{72}SeCO ones of interest.

An initial beam intensity of 3 x 10^5 pps was estimated from the collected data (both Coulomb excitation and using a beam-dump detector), which was in agreement with expectations from the ISOLDE yield database. Unfortunately, however, this intensity rapidly decreased over the course of the running period until it reached a point, approximately 12 hours after the start of the experiment, where no radioactive beam was being delivered to Miniball.

In this experiment, in order to avoid the problems associated with A~70 contaminants in the beam, ^{72}Se was extracted fro the ZrO_2 target as a selenium-carbonyl (^{72}SeCO) molecule and the molecules were then subsequently broken apart in the EBIS. It is important to point out that this innovative approach was previously successfully employed at ISOLDE in the past, for the study of, for example, ^{70}Se [15]. However, during the IS597 running period this approach proved to be problematic and extremely unreliable. The likely reason for this, based on discussions during and since the experiment, is that a VADIS ion source (containing molybdenum) was used instead of a FEBIAD (carbon) one. This would strongly suggest that the dominant mechanism responsible for forming SeCo molecules is collisions between Se ions and carbon surfaces. The potential use of RILIS laser ionisation was also discussed however at the time of the experiment the Se scheme was still extremely preliminary and consequently this was not used. Therefore, moving forward, we would request to utilize a FEBIAD ion source to produce the ^{72}Se beam following a period of offline yield testing.

Outlook and Summary

The physics case described in Ref [1] and summarized here is still pertinent. A dedicated Coulomb-excitation study remains the only way of obtaining the key information necessary to test the conflicting configuration coexistence phenomena predicted by theory and of benchmarking the results of these state-of-the-art calculations. Consequently, we request that the remaining 9 shifts be used to perform the proposed Coulomb-excitation measurement following a period of offline testing. The shifts will be split between ^{196}Pt and ^{208}Pb targets.

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