THE SINGLE-PARTICLE AND COLLECTIVE FEATURES IN THE NUCLEI JUST ABOVE ¹³²Sn^{*}

H. MACH^{a,b}, L.M. FRAILE^c, O. ARNDT^d, A. BLAZHEV^e, N. BOELAERT^{e,f} M.J.G. BORGE^g, R. BOUTAMI^g, H. BRADLEY^{b,h},
N. BRAUN^e B.A. BROWNⁱ, P.A. BUTLER^j, A. COVELLO^k, Z. DLOUHY^l
C. FRANSEN^e, H.O.U. FYNBO^m, A. GARGANO^k, CH. HINKEⁿ P. HOFF^o,
A. JOINET^{c,p}, A. JOKINEN^q, J. JOLIE^e, U. KÖSTER^{c,r} A. KORGUL^s, K.-L. KRATZ^{t,u}, T. KRÖLLⁿ, W. KURCEWICZ^s, J. NYBERG^b
E.-M. REILLO^g, E. RUCHOWSKA^v, W. SCHWERDTFEGER^w
G.S. SIMPSON^x, M. STANOIU^y, O. TENGBLAD^g, P.G. THIROLF^w
V. UGRYUMOV^l, W.B. WALTERS^z
^aInst. for Structure and Nuclear Astrophysics, University of Notre Dame, USA
^bDept. of Nuclear and Particle Physics, Uppsala University, Uppsala, Sweden
^cISOLDE, PH Department, CERN, Geneva, Switzerland
^dInstitut für Kernchemie, Universität Mainz, Mainz, Germany
^eInstitut für Kernphysik, University of Cologne, Cologne, Germany

^gCSIC, Madrid, Spain

^hDepartment of Physics, University of Sydney, Sydney, Australia

ⁱDept. of Physics and Astronomy and NSCL, Michigan State University, USA

^jDepartment of Physics, University of Liverpool, Liverpool, UK

^kDipartimento di Scienze Fisiche, Universita di Napoli Federico II and Istituto Nazionale di Fisica Nucleare, Napoli, Italy

¹Institute of Nuclear Physics, Rez, Czech Republic

^mUniversity of Aarhus, Aarhus, Denmark

ⁿTechnical University Munich, Garching, Germany

^oDepartment of Chemistry, University of Oslo, Oslo, Norway

^PCESR, Toulouse, France

^qDepartment of Physics, University of Jyväskylä, Jyväskylä, Finland ^rInstitut Laue Langevin, Grenoble, France

^sInstitute of Experimental Physics, Warsaw University, Poland

^tMax-Planck-Institut für Chemie, Otto-Hahn-Institute, Mainz, Germany

^uHGS Virtuelles Institut für Structur der Kerne und Nucleare Astrophysik, (VISTARS)

Mainz, Germany

^vA. Sołtan Institute for Nuclear Studies, ASINS, Świerk, Poland

^wLudvig-Maximilians-University, Munich, Germany

^xLPSC, Grenoble, France

^yGSI, Darmstadt, Germany ^zDepartment of Chemistry, University of Maryland, MD, USA

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The Advanced Time Delayed method has been used to measure the lifetimes of excited states in the exotic nuclei ¹³⁴Sb, ¹³⁵Sb and ¹³⁶Te populated in the beta decay of ¹³⁴Sn, ¹³⁵Sn and ¹³⁶Sn, respectively. High purity Sn beams were extracted at the ISOLDE separator using a novel production technique utilizing the molecular SnS⁺ beams to isolate Sn from contaminating other fission products. Among the new results we have identified the $1/2^+$ state in ¹³⁵Sb and its E2 transition to the lower-lying $5/2^+$ state was found to be surprisingly collective. This measurement represents also one of the first applications of the LaBr₃ scintillator to ultra fast timing.

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1. Introduction

There is a considerable interest in the nuclei just above the exotic doubly magic ¹³²Sn that show unusual features. In particular the B(E2) value for the 0⁺ to 2⁺ excitation in ¹³⁶Te was found [1] to be very low implying special cancellation effects. On the other hand, its very close neighbor, ¹³⁵Sb, shows very low excitation energy of the first excited state at only 282 keV, much lower than expected from shell model considerations raising the possibility [2] of a local shift of the proton single particle $d_{5/2}$ and $g_{7/2}$ orbits due to the neutron excess. From the recently measured [3] lifetime of the 282 keV state one obtains very low E2 and a strongly retarded M1 strength for the 282 keV transition to the ground state. This is consistent with the low E2 collectivity of even-even nuclei of ¹³⁴Sn and ¹³⁶Te. Such picture, however, seems to be in contradiction with our new (preliminary) results presented here.

The results presented at this Conference were recently obtained by the IS441 collaboration at the ISOLDE facility at CERN. We have used the Advanced Time-Delayed method (ATD) [4] to measure level lifetimes in nuclei populated in the beta decay of 134,135,136 Sn. Critical to the success of this experiment was a strong suppression of isobaric contaminants that made it impossible to detect gamma-rays in the decay of 136 Sn in previous attempts.

The two main criteria for the "quality" of radioactive ion beams are the beam intensity, *i.e.* the number of ions per second of the desired isotopes, and the beam purity, *i.e.* the presence or absence of admixtures of other radioactive (or stable) isotopes or isobars. The present experiment profited largely from an improvement of the beam purity compared to previously available beams. This improvement is discussed next.

2. Radioactive ion beam production

Previously relatively pure beams of neutron-rich tin isotopes at ISOLDE had been produced by selective ionization of tin with the resonance ionization laser ion source (RILIS) [5, 6]. However, to assure a sufficiently rapid release the RILIS ion source cavity must be kept hot. This will unfortunately cause significant surface ionization of those isobaric elements that have low ionization potentials [7]. The isobaric Sb to Xe isotopes are practically not surface ionized, but Cs (ionization potential 3.89 eV) and to slightly less extent also Ba (ionization potential 5.21 eV) are very efficiently surface ionized in the hot Ta or W cavity of the RILIS. For decay spectroscopy experiments such background is particularly problematic at masses 135 (135m Cs and 135m Ba), 136 (136g,m Cs) and 137 (137m Ba).

Another way to produce pure ISOL beams is the separation of an abundantly populated molecular sideband. The HRIBF group at Oak Ridge observed accidentally rather pure tin beams in the molecular sideband SnS^+ which was produced by a sulfur impurity in the target material [8]. The amount of possible SbS⁺ and TeS⁺ contaminants was not detectable. Detailed studies were performed at GSI-ISOL by Reinhard Kirchner on the dependence of the SnS^+/Sn^+ ratio and the suppression of isobaric contaminants by leaking in a well-controlled way vapors of sulfur into the ion source [9].

Natural sulfur contains 95% 32 S, but also 0.75% of 33 S, 4.2% of 34 S and 0.02% of 36 S. Thus for neutron-rich tin isotopes, an unwanted mixture of different molecular sidebands would occur at the same mass. Since the production cross-sections drop from 132 Sn towards the neutron-rich side by about one order of magnitude per additional neutron, the 136 Sn³²S⁺ beam would suffer from contaminations with 134 Sn³⁴S⁺ and 132 Sn³⁶S⁺ that are stronger than the wanted beam. To avoid these ambiguities we used sulfur isotopically enriched to > 99.9% 34 S. During the run the sulfur was continuously leaked into a standard ISOLDE UC_x/graphite target (20 cm length, 45 g/cm² 238 U) connected to a MK5 ("hot plasma") ion source [10].

Throughout the entire run the molecular Sn^{34}S^+ beams were of comparable magnitude to the respective Sn^+ beams, but by far purer. Isobaric contaminations in the sulfide sideband were generally negligible, except for barium sulfide.

More details about the production and yields of ISOL beams of tin isotopes can be found in the PhD thesises of Joinet [11] and Arndt [12] and in an upcoming paper [13].

3. Experiments and results

For the study of the decay of ¹³⁶Sn the mass separated beam of A = 170was selected using the High Resolution Separator (HRS) at ISOLDE to deliver the molecular ¹³⁶Sn³⁴S⁺ beam into the experimental station. The beam was stopped on a thin Al foil in front of the beta fast timing detector. In total, the experimental setup included five detectors: three fast timing scintillators and two large volume 100% Ge detectors. The fast timing gamma scintillators included a cylindrical 2.5 by $2.5 \text{ cm LaBr}_3(\text{Ce})$ and our standard large fast timing BaF_2 crystal in the shape of a truncated cone. All scintillators were coupled to the fast response XP2020 URQ tubes. The present study represents only the third application of the $LaBr_3(Ce)$ crystal to ultra fast timing measurements. The crystal provided by Saint Gobain had the energy resolution of about 3.5% at 661 keV, which is much superior to the resolution of 9.0% for our BaF₂ crystal used in the run. The time resolutions of both gamma-ray crystals were very similar yet BaF₂ scintillator had much higher efficiency, which is an important factor for measurements on exotic nuclei.

Although the data analysis is still in progress, yet based on our preliminary results it is certain that the new production techique has provided us with a wealth of interesting results on the exotic nuclei 134 Sb and 135 Sb. In particular, we were able to identify for the first time gamma transitions and levels in ¹³⁵Sb populated from the beta-delayed neutron emission of ¹³⁶Sn. These would be mainly low spin states, which are weakly populated in the decay of the $7/2^-$ ground state of ¹³⁵Sn. Our gamma–gamma coincidences collected in the two Ge detectors have revealed strong coincidences between the 282 keV line (which is the known transition connecting the first excited state and the ground state) and the 241 and 158 keV lines, see Fig. 1. The latter two were not in coincidence with one another. Since the second one was observed in the beta decay of 135 Sn while the former was not, therefore the 241 keV line de-exciting the state at 523 keV is our prime candidate for the previously unobserved $1/2^+$ state. This state is predicted [14] at 527 keV in excitation energy (note the very close energy match) and is expected to be mainly due to the coupling of the $d_{5/2}$ state to the collective core. Consequently the 241 keV transition should be E2 in character and one expects its E2 transition strength to be somewhat similar to that of the core, thus for 134 Sn. The expected half life of the 523 keV state should then be about a few nanoseconds.

Indeed, using the fast timing triple $\beta\gamma\gamma(t)$ coincideces and the 241– 282 keV gamma cascade we have measured the half-life for this 523 keV state as $T_{1/2}=1.2(1)$ ns (preliminary result), see Fig 2. From this lifetime, we deduce a very collective B(E2; $1/2^+ \rightarrow 5/2^+$) value for this transition of



Fig. 1. Partial decay scheme for the beta delayed neutron emission of 136 Sn into 135 Sb, indicating the new excited state at 523 keV identified as $1/2^+$. Note its half-life of 1.2 ns has been also measured in this work.



Fig. 2. The time delayed spectrum based on a partial data analysis from the run. The fitted half-life for the 523 keV state in 135 Sb is 1.2(1) ns (preliminary value).

13(1) W.u., which is much more collective than the B(E2) for the 2⁺ to 0⁺ transition in the core nucleus of ¹³⁴Sn, which is 1.4(2) W.u. Correcting for the spin factor (a change by a factor of 3), it still gives a B(E2; $5/2^+ \rightarrow 1/2^+$) value of 4.3 W.u., thus well above the limits expected from the excitation of the core. It remains to be seen whether the new results will be easily interpreted within the shell model calculations particularly if combined with the properties of other states in ¹³⁵Sb.

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