EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Proposal to the ISOLDE and Neutron Time-of-Flight Committee

Spectroscopy of particle-phonon coupled states in ^{133}Sb by the cluster transfer reaction ^{132}Sn on ^{7}Li: an advanced test of nuclear interactions

[8th October 2014]

S. Leoni[1,2], G. Benzoni[2], G. Bocchi[2], S. Bottoni[1], A. Bracco[1,2], F. Camera[1,2],F.C.L. Crespi[2],
A. I. Morales[2]
B. Fornal[3], B. Szpak[3], P. Bednarczyk[3], N. Cieplicka[3], W. Królas[3], A. Maj[3]
K. Rusek[4]
D. Bazzacco[5], S. Lunardi[5], D. Mengoni[5], F. Recchia[5], C.A.Ur[5]
J. Valiente-Dobon[6], F. Gramegna[6], T. Marchi[6]
M. Huyse[7], R. Raabe[7], P. Van Duppen[7]
M. Sferrazza[8]
G. Georgiev[9]
A. Blazhev[10], D. Rosiak[10], B. Siebeck[10], M. Seidlitz[10], P. Reiter[10], N. Warr[10]
A.L. Hartig[11], C. Henrich[11], S. Ilieva[11], T. Kroell[11], M. Thürauf[11]
R. Gernhaeuser[12], D. Mücher[12], …
R. Janssens [13], M.P. Carpenter[13], S. Zhu[13]
M. Kowalska[14]

[1] Università degli Studi di Milano, Via Celoria 16, 20133, Italy
[2] INFN, sezione di Milano, Italy
[3] The Niewodniczanski Institute of Nuclear Physics, Polish Academy of Sciences, Krakow, Poland
[4] Heavy Ion Laboratory, University of Warsaw, Poland
[5] University of Padova and INFN sez. Padova, Italy
[6] Legnaro National Laboratory, Italy
[7] Instituut voor Kern-en Stralingsfysisca, K.U.Leuven, Belgium
[8] Université libre de Bruxelles, Belgium
[9] CSNSM, Orsay, France
[10] Institut fur Kernphysik der Universitat zu Koln, Germany
[11] TU Darmstadt, Germany
[12] TU Munchen, Germany
[13] Argonne National Laboratory, USA
[14] ISOLDE, CERN, Switzerland

CERN-INTC-2014-053 / INTC-P-419
08/10/2014

Spokespersons: S. Leoni, B. Fornal
(Silvia.Leoni@mi.infn.it, Bogdan.Fornal@ifj.edu.pl)
Local contact: Magdalena Kowalska (Kowalska@cern.ch)

Abstract

We propose to investigate, with MINIBALL coupled to T-REX, the one-valence-proton ^{133}Sb nucleus by the cluster transfer reaction of ^{132}Sn on ^{7}Li. The excited ^{133}Sb will be populated by transfer of a triton into ^{132}Sn, followed by the emission of an alpha particle (detected in T-REX) and 2 neutrons. The aim of the experiment is to locate states arising from the coupling of the valence proton of ^{133}Sb to the collective low-lying phonon excitations of ^{132}Sn (in particular the 3^-). According to calculations in the weak-coupling approach, these states lie in the 4 – 5 MeV excitation energy region and in the spin interval 1/2 - 19/2, i.e., in the region populated by the cluster transfer reaction. The results will be used to perform advanced tests of different types of nuclear interactions, usually employed in the description of particle-phonon coupled excitations. States arising from couplings of the proton with simpler core excitations, involving few nucleons only, will also be accessible, providing a very specific test of effective shell model interactions across the shell gap.

Predictions for the reaction mechanism, the expected statistics and the observed γ transitions are based, in part, on the experience gained in a test experiment performed by this collaboration at REX-ISOLDE in November 2012, in preparation of the present research program.

Requested shifts: 21 shifts (split into 1 run over 1 year)

1. Introduction

In doubly-magic nuclei, in general, the lowest excited states exhibit a high degree of collectivity. For example, in ^{208}Pb, the lowest excitation (at 2615 keV) is the 3^- octupole vibration with a large transition strength of 34 W.u. In ^{132}Sn, the first three excitations, 2^+ at 4041 keV, 3^- at 4352 keV and 4^+ at 4416 keV show a sizable collectivity with a transition probability of about 7 W.u. for the 2^+ and 4^+ and > 7 W.u. for the 3^- phonons, respectively. This characteristics of doubly-magic nuclei is related to the fact that, due to the large energy gaps for both neutrons and protons, simple particle-hole core-excited states are located at rather high energies, while the energy of excitations arising from very complex configurations (phonons) is lowered significantly.

In view of the property of doubly-magic nuclei discussed above, in nuclei with one particle outside of a doubly-closed core the lowest structure should be dominated by the couplings between phonon excitations and this valence particle, giving rise to a series of multiplets. The identification of these multiplets can provide precise, quantitative information on the phonon-particle couplings. In fact, the energy and transition probability for states belonging to phonon-particle multiplets can be calculated within mean-field based models and comparisons with experiment can provide a unique test of various effective interactions like Skyrme, Gogny, etc.

From a broader perspective, understanding the coupling of a single particle to vibrational motion in nuclei is of primary importance, as this coupling is responsible for the quenching of spectroscopic factors [Tsa09]; it is also the key process at the origin of the damping of giant resonances [Bor98].

Only in one case the complete set of states arising from phonon–particle coupling is known – it is the $3^- \otimes \pi h_{9/2}$ multiplet in ^{209}Bi (one-proton nucleus with respect to the ^{208}Pb core) consisting of states with spins ranging from $J^{\pi}=3/2^+$ to $15/2^+$. In other nuclei around ^{208}Pb, states originating from couplings of the 3^- phonon with single particles/holes have been located as well, although these are mostly only the highest spin members of the multiplets. The examples include $^{206-209}$Pb, ^{206,207}Tl and ^{206}Hg [Rej00, For01]. Several indications of states of particle-phonon nature have also been found around other doubly-magic nuclei lying near the stability valley [Pie09, Kle82, Lun84, Gal88, Lis80]. Present techniques allow for searches for particle-phonon coupled states away from the stability valley, as, for example, in neutron-rich nuclei - they should provide information on the robustness or softness of nuclear collectivity which can be measured with the purity of single-nucleon excitations on top of core vibrations.

From the theory point of view, phonon-particle couplings can be treated within mean-field based models. In this approach, one can start from a description where single-particle and vibrational states are treated independently, and then introduce their mutual coupling by applying appropriate effective interactions. It is worth noting that effective interactions like Skyrme, Gogny, etc have been used, although not extensively, to study the effect of vibrational coupling on the single-particle states. On the other hand, multiplets are an even better testing ground for particle-vibration coupling, and no microscopic calculations have been performed so far. We can, thus, aim at understanding whether presently available effective forces are able to describe particle-vibration coupling, in particular in nuclei lying far from the valley of stability.

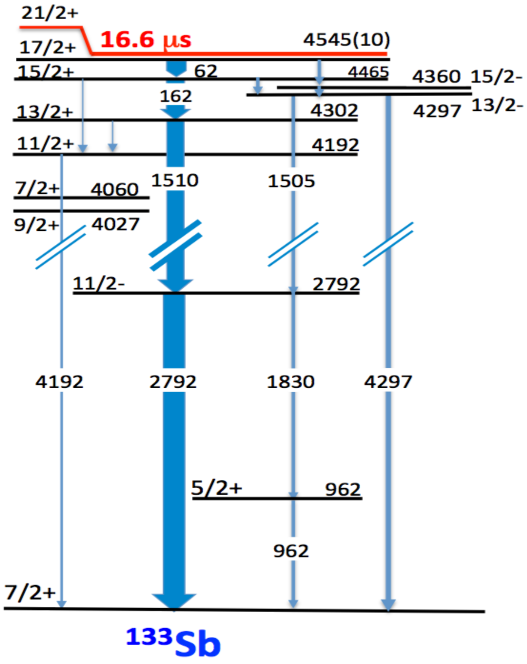

Figure 1. *Experimental level scheme of ^{133}Sb, as obtained from the decay of the long-lived 16.6 μs isomer at spin $21/2^+$ [Urb09] and from beta-decay study [Nud2]. While the positive parity states 7/2+, $9/2^+$, $11/2^+$, $13/2^+$, $15/2^+$, $17/2^+$ and $21/2^+$ are members of the $\pi g_{7/2}\otimes\nu(f_{7/2}h^{-1}{}_{11/2})$ multiplet, the $13/2^-$ state is expected to arise from the coupling of the $g_{7/2}$ proton and the 3^- octupole phonon of ^{132}Sn.*

^{133}Sb, with one proton outside the doubly-magic ^{132}Sn core, is an ideal neutron-rich nucleus in which particle-phonon coupled states can be investigated. In this nucleus, all single-particle proton excitations, $d_{5/2}$, $h_{11/2}$, $d_{3/2}$ and $s_{1/2}$, have been located as well as most of the members of the $\pi g_{7/2}\otimes\nu(f_{7/2}h^{-1}{}_{11/2})$ multiplet with $J^\pi = 7/2^+$, $9/2^+$, $11/2^+$, $13/2^+$, $15/2^+$, $17/2^+$ and $21/2^+$ of which the $21/2^+$ state is isomeric with 16.6 μs half-life. However, knowledge about the phonon-particle couplings is limited to only a single state, $13/2^-$ at 4297 keV, which is a candidate for the highest spin member of the $\pi g_{7/2}\otimes 3^-$ multiplet (see Fig. 1).

In the present proposal, we would like to study the low-lying structure of ^{133}Sb nucleus, with particular emphasis on non-yrast excitations which should include most of the unknown members of the multiplets arising from the phonon-proton particle couplings. In addition, excited states above the long-lived $21/2^+$, 16 μs isomer will be studied, including the highest spin members of the $\pi g_{7/2}\otimes\nu(f_{7/2}h^{-1}{}_{11/2})$ multiplet with $J^\pi=23/2^+$ and $25/2^+$ that have not been located so far, as well as other multiplets of states arising from excitations of the ^{132}Sn core involving few nucleons only. We plan to employ the cluster-transfer reactions induced by a radioactive beam of ^{132}Sn on a ^{7}Li target. The ^{133}Sb nucleus will be populated in a ^{7}Li(^{132}Sn,α2n) process. The gamma-ray spectroscopic data will be collected and used to identify and locate new states. These new structures will serve as unique tests of various effective interactions of mean field-based models, like Skyrme, Gogny. They will also be employed to test the validity of realistic, effective shell model interactions to describe particle-hole configurations involving few nucleons in the neutron-rich, one-proton-particle nucleus ^{133}Sb.

2. The Physics Case of ^{133}Sb

As was mentioned in the introduction, in ^{133}Sb only the highest-spin member of the $\pi g_{7/2}\otimes 3^-$ multiplet, with $J^\pi=13/2^-$, has been located at 4297 keV, quite close in energy to the location of the 3^- phonon at 4352 keV. Around this energy, one can expect 6 other states from this coupling with spin in the range of $1/2^-$ – $11/2^-$. Since in ^{132}Sn the excitations 2^+ and 4^+ at 4041 keV at 4416 keV, respectively, exhibit sizeable collectivity, also members of the $\pi g_{7/2}\otimes 2^+$ and $\pi g_{7/2}\otimes 4^+$ multiplets should be present around those respective energies. To make those expectations more quantitative, calculations based on a semi-microscopic model have been performed. The single-particle states obtained with the Skyrme interaction SkX, and the experimental 2^+, 3^- and 4^+ phonons, have been used as a basis. The Hamiltonian including the particle-phonon interaction, treated as in the Bohr-Mottelson model, has been diagonalized in the sub-spaces corresponding to states of ^{133}Sb having different spin and parity [Col14]. The calculations predict that the coupled states lie in the 4 – 5 MeV excitation energy range and in the spin interval 1/2-19/2, i.e., in the region populated by the proposed cluster transfer reaction.

From the shell model point of view, high-spin states arising from the coupling of the $g_{7/2}$ or $h_{11/2}$ proton to excitations of the ^{132}Sn core involving few nucleons only, are expected above the long-lived 16.6 μs isomer located at 4545(10) keV. To this class of states belong, for example, the highest spin members of the $\pi g_{7/2} \otimes \nu(f_{7/2} h^{-1}_{11/2})$ multiplet, $23/2^+$ and $25/2^+$, [Urb00]. When searching for these excitations, we plan to take advantage of a large gamma-gamma data collected for products of neutron-induced fission on ^{235}U and ^{241}Pu targets, in a recent campaign of EXOGAM at ILL (Grenoble). The data have already allowed us to identify, for the first time, transitions feeding the 16.6 μs isomer [Leo14], and can now serve as starting points to extend the ^{133}Sb level scheme further up in excitation energy. The knowledge on the energy of the new states will offer quite specific test of modern realistic effective shell-model interactions, including, in particular, single particle orbitals across the shell gap.

We would like to identify the predicted excited states in ^{133}Sb by employing the triton-transfer reaction induced by a radioactive beam of ^{132}Sn at 3.9 MeV/A, delivered by HIE-ISOLDE, on a ^{7}Li target: $^{132}\mathrm{Sn} + {}^{7}\mathrm{Li} \rightarrow {}^{135}\mathrm{Sb} + \alpha$, Q=+5.6 MeV. This will lead to production of the excited ^{135}Sb, compound nucleus, and the subsequent evaporation of two neutrons will populate excited states in ^{133}Sb nucleus. We would like to measure discrete gamma rays in coincidence with emitted alpha particles.

The proposed reaction has two distinct features that greatly facilitate detection of the discrete gamma rays and their identification:

• Firstly, the **very inverse kinematics** guarantees that the product nuclei all travel downstream in a very small recoil cone, thus Doppler reconstruction of the gamma-ray data does not require recoil detection.

• Secondly, the reaction channel of interest will be uniquely associated with the **emission of an alpha particle**. By detecting this alpha particle, we will be able to produce a very clean trigger for the ^{7}Li(^{132}Sn,α2n) processes.

The reaction proposed here will populate both yrast and non-yrast states, and should provide information on the excited structures in ^{133}Sb, which will be complementary to the results obtained in ^{248}Cm spontaneous fission [Urb00,Urb09] and ^{133}Sn beta-decay measurements [Nud2]. Our confidence in using the triton-transfer reaction ^{7}Li(^{132}Sn,α2n) for accessing unknown excited structures in ^{133}Sb relies also on the experience that was gained by the present collaboration in a short, preparatory experiment performed at REX-ISOLDE in November 2012, in which the triton-transfer reactions induced by ^{98}Rb and ^{98}Sr beams on a ^{7}Li target were used to populate Sr and Y neutron-rich nuclei. The results of this test experiment are briefly summarized in the next section.

3. The ^{98}Rb+^{7}Li Test Case at ISOLDE

A first test of the cluster-transfer reaction mechanism with a radioactive beam on a ^{7}Li target has been carried out by the present collaboration at the REX-ISOLDE facility, in November 2012. In a three-day experiment, a ^{98}Rb beam at 2.85 MeV/A impinged on a ^{7}LiF target, 1.5 mg/cm^2 thick, with an average intensity of 2.4×10^4 pps. Due to the short half-life of ^{98}Rb (~100 ms), a strong isobaric component of ^{98}Sr was present in the beam, of the order of 40%. The experimental setup consisted of the MINIBALL Ge array (with ~5% efficiency at 1.3 MeV), coupled to the double sided E-ΔE Si detectors from the T-REX setup, which was used for the detection of charged particles in the angular range 24°- 65°.

Figure 2 displays the ΔE-E spectrum measured with the Si detectors. The reaction channels of interest correspond to the detection of α's and tritons (*t*), which are associated with *t* and α transfer, respectively. Figure 3 provides the γ spectra obtained in coincidence with the α– detection events: they are very selective, with contributions from *t*-transfer reactions only, followed by 2- and 3-n evaporation. Neutron evaporation is a consequence of the high excitation energy of the systems formed in *t*--transfer processes (~20 MeV in the ^{98}Rb reaction), while the neutron separation energy is only ~3 MeV for this neutron-rich reaction product. The constructed level schemes (see Fig. 3b), indicate the population of states up to spin 6*ħ*.

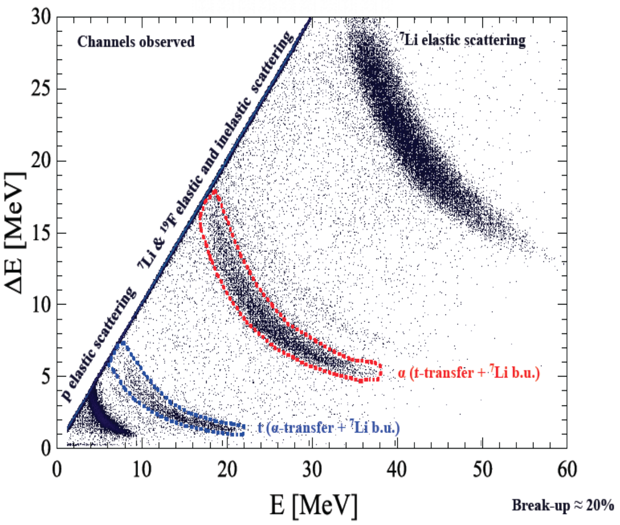

Figure 2. *E-ΔE spectrum measured in the ISOLDE experiment by the Si telescopes of the T-REX setup. The regions delineated by red and blue dotted lines are associated to α and t particles, respectively.*

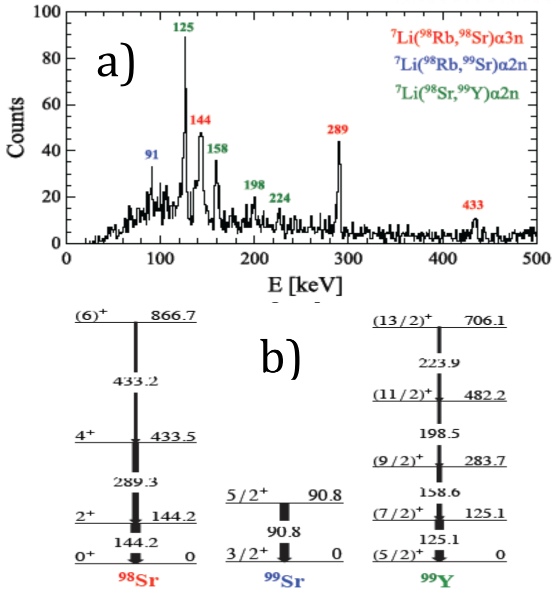

Figure 3. *γ spectra measured in coincidence with α particles detected in T-REX (panel a)). The corresponding level schemes of the final nuclei, as deduced from the present data, is given in b).*

The ISOLDE results have been interpreted with the code FRESCO [Fre88] using a DWBA approach and a weakly bound approximation to describe states in the continuum (due to the high excitation energy of the systems obtained by cluster transfer). The predicted cross sections for *t* and α transfer are of the order of 200 mb and 50 mb, respectively, and reproduce rather well the experimental ratio between the two reaction channels, as a function of the detection angle. Based on the measured excitation energy of the system after the cluster transfer, the amount of evaporated neutrons was estimated with the code CASCADE [Cas77]. For the stronger *t*-transfer channel at the most probable excitation energy, relative yields of ~75% and 25% for the 3n and 2n channels were calculated, respectively, in good agreement with the experimental results We are, therefore, rather confident in the estimates of final product cross sections for another cluster-transfer reactions with ^{7}Li, in a mass region close to the one of the test case.

4. Proposed reaction and Experimental Setup

The neutron-rich ^{133}Sb nucleus will be populated by the cluster-transfer reaction with a ^{7}LiF target, 1.5 mg/cm^2-thick, bombarded by the HIE-ISOLDE radioactive beam of ^{132}Sn at 510 MeV (about 3.9

MeV/A, corresponding to 3.5 MeV/A at mid-target). We stress that the reaction channels of interest are uniquely associated with emission of an α particle. By detecting this α particle, we will be able to produce a very clean trigger of the ^{7}Li(^{132}Sn,αxnγ) processes. Moreover, the very inverse kinematics guarantees that the product nuclei all travel downstream in a very small recoil cone, thus Doppler reconstruction of the γ-ray data does not require, to first approximation, recoil detection. These two distinct features will greatly facilitate the detection of the discrete γ rays and their identification, as demonstrated by the REX-ISOLDE test case with the ^{98}Rb beam, discussed in Section 3.
Quantitative predictions for the proposed ^{132}Sn+^{7}Li cluster-transfer reaction have been obtained again with the code FRESCO, while the amount of neutron evaporation was estimated with the help of the CASCADE code. In the calculation of the t-transfer process, leading to ^{135}Sb, the residual nucleus will be produced mainly in high excited states, above 8 MeV, because the Q-value of the reaction is high and positive and t–cluster states in nuclei are typically placed at high excitation energies. As is seen in Fig. 4(left), α emission (associated with triton transfer) is expected to be much favored with respect to the emission of tritons (following α transfer).

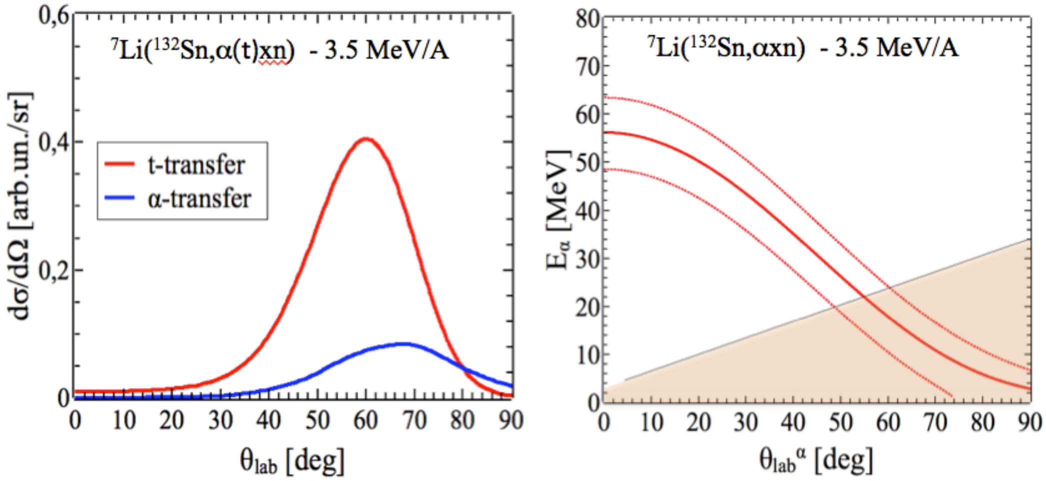

Figure 4. *Left: DWBA calculations for the emission of α (i.e., t-transfer) and t (i.e., α-transfer) particles for the reaction* ^{132}*Sn +* ^{7}*Li at 3.5 MeV/A, as a function of scattering angle in the laboratory frame. The transfer to one state only, around 9 MeV, is considered. Right: Energy of the emitted α's, in the laboratory frame, after the t-transfer process. The calculations assume for* ^{135}*Sb an excitation energy distribution centered at 13 MeV with a width of ±4 MeV, which corresponds to the width of the emitted α's energy distribution. The shadowed area indicates the energy region where α particles are absorbed by the ΔE detectors, with a thickness of 140 μm .*

It is also found that the angular distribution of the differential cross section for α emission varies rather rapidly with beam energy: going from 3.5 to 4.5 MeV/A the maximum of the expected distribution moves from ~55° to 85° in the laboratory frame. The shape of the distribution is found to exhibit little dependence on the amount of angular momentum transferred and the total integrated cross section is almost constant at the level of 6 mb, if *t*-transfer to only one state (around 9 MeV) is assumed. By integrating over all possible excited states which should be populated in ^{135}Sb, an increase of a factor 10-20 is expected for the total ^{7}Li(^{132}Sn,αxn) reaction cross section. **In the case of the reaction at E_{lab} = 3.5 MeV/A, this means a total cross section of ~100 mb for the population of the ^{132,133,134}Sb isotopes, which are expected as the final products of 1-3 neutron evaporation, after the emission of the α particle**.

The amount of neutron evaporation for the present reaction has been estimated with the CASCADE code, assuming for ^{135}Sb an excitation energy of 13 MeV, which is consistent with a semi-classical estimate based on optimum Q-value argumentation, and a spin distribution centered around 20 ℏ (similar to the approach that best reproduced the previous ^{98}Rb test case). The CASCADE calculations predict the evaporation of 1 and 2 neutrons only, resulting in approx. 80% population of

^{133}Sb (the 2n channel and our nucleus of interest) and 20% population of the 1n channel, leading to ^{134}Sb. No 3n channel is foreseen. These predictions are different from the ^{98}Rb ISOLDE test case where 2n and 3n as the main evaporation channels were observed. This is a consequence of the different balance between excitation energy and neutron separation energy in ^{135}Sb, ^{134}Sb and ^{133}Sb: E_{ex} = 13 MeV and S_n= 3.6, 3.2 and 7.3 MeV, respectively, as compared to the situation for ^{101}Sr, ^{100}Sr and ^{99}Sr: E_{ex} = 19 MeV and S_n = 3.2, 6.1 and 4.1 MeV, respectively.

Figure 4(right) shows kinematics calculations for the energy of the emitted α's, assuming, for ^{135}Sb, an excitation energy distribution centered around 13 MeV, as given by the FRESCO calculations (corresponding to the maximum of the distribution according to semi-classical estimates). It is found that in the angular range of interest (i.e., between 40° to 80°, see Fig. 4(left)) α particles energy will be between a few MeV and 40 MeV.

One should also keep in mind that the main channel of the studied reaction, ^{132}Sn+^{7}Li, will be the fusion-evaporation channel. According to the PACE calculations, it will lead to the ^{139}I compound nucleus, which will decay mostly by emission of 3 and 4 neutrons into ^{136}I and ^{135}I nuclei, with cross-section of the order of 450 and 100 mb, respectively. Evaporation of alpha particles from the ^{139}I compound is negligible.

In the experiment considered, one will observe also α particles arising from the elastic break-up of the weakly-bound ^{7}Li target (binding energy $S_\alpha \sim 2.5$ MeV): $^{7}\mathrm{Li} \rightarrow \alpha + t$. Break-up will occur with a cross section of the order of few tens of mb. In this case, emission of light particles at forward angles is expected, but not in coincidence with γ rays. In the ^{98}Rb test case, this contribution was of the order of less than 20% of the total detected alpha's.

To summarize, the main features of the proposed cluster-transfer reaction are as follows:

- Integrated cross section for triton transfer leading to ^{133,134}Sb: ~ 100 mb;
- Angular distribution of emitted α's (for triton transfer): peaked at 55° (see Fig. 4(left));
- Energies of the emitted α particles: between ~2 and 40 MeV (see Fig. 4(right));
- Population after 1n evaporation (^{134}Sb): ~20%;
- Population after 2n evaporation (^{133}Sb): ~80%

Experimental Setup

The experimental setup requires the MINIBALL array coupled to the T-REX apparatus, for the detection of α particles in coincidence with γ transitions. T-REX should be in the Coulex barrel configuration, consisting of CD and Barrel telescopes in forward direction, thus allowing to optimize the detection of the emitted α particles. Coincidence between α particles and γ transitions will largely reduce the background from break-up contributions allowing to select the Sb nuclei of interest.

A thickness of 140 μm is requested for the ΔE detectors, to limit the absorption of the low-energy α particles, while the E detectors can have the standard thickness of 1000 μm. A mylar foil of 25 μm should also be used in front of the Si detectors of the Barrel to stop elastically-scattered ^{7}Li and avoid damages of the ΔE Si detectors. As a consequence of this, in the E-ΔE spectrum the diagonal events will contain α events which are stopped in the ΔE detectors, with no significant contributions from other particles.

The ^{132}Sn beam requested for this proposal is reported to be produced at ISOLDE via a SnS+ molecular ion with a yield of 3 x 10^{7} ions/μC. The accelerator efficiency for the complete HIE-ISOLDE chain from REX-trap to the MININBALL target was estimated to be only 2%. Therefore, a beam intensity of 8.5 x 10^{5} pps of ^{132}Sn can be expected at the secondary target inside MINIBALL with a PSB proton beam current of 1.4 μA.

Considering a detection efficiency of T-REX for α particles at forward angles of the order of 90% (as confirmed by experiments and simulations), and assuming: i) a ^{132}Sn beam of 510 MeV with an intensity of ~8.5×10^{5} pps, ii) a 1.5 mg/cm^{2} thick ^{7}LiF target (leading to a beam energy of approx. 3.5 MeV/A at mid-target) and iii) a total cross section of ~100 mb, we expect to be able to collect in T-REX ~0.7 α particles/second from the triton transfer process.

Further, assuming a population probability of 80% for the 2n channel, a 2-6% efficiency of MINIBALL for γ rays in the 1-4 MeV energy range (where we expect most of the transitions of interest) and a population of a particular state arising from the phonon coupling between 1 and 10%, we can observe for a specific line in the α–γ coincidence spectrum 100 to 3000 counts in a 7-days experiment. Several thousands counts are instead expected for γ lines (with energies of the order of few hundreds keV and relative population of the order of more than a few percent) depopulating multiplets of states arising from couplings which involve a few particle-hole excitations, as in the case of the $\pi g_{7/2}\otimes\nu(f_{7/2}h^{-1}_{11/2})$ multiplet. With this statistics, α–γ–γ coincidences will be used to locate new states and analysis of angular distributions will provide information on transitions mutipolarity.

This will allow us to perform a rather detailed γ-spectroscopic study of excited structures in the nucleus of interest,^{133}Sb. There will also be a possibility to obtain information on the structure of high-spin states of ^{134}Sb for which the production yield should be of the order of 20%.

The high granularity of the MINIBALL detectors will also help considerably in reducing the Doppler broadening of the γ rays emitted by the Sb nuclei (in flight with a velocity of ~7.5% of the speed of light), leading to an energy resolution of 12 keV at 1.3 MeV, at most.

Since we are going to use a LiF target, one may expect gamma rays from the products of fusion-evaporation reaction of ^{132}Sn on ^{19}F. However, at the beam energy of 3.5 MeV/A expected in the middle of the target, the total cross section for this process is about 150 mb and is concentrated in ^{146}Pr, the product of 5n evaporation. No significant charged particle emission from ^{132}Sn+^{19}F fusion-evaporation processes is expected.

Summary of requested shifts:

We ask for a total of 7 days of beam time of ^{132}Sn at 510 MeV (3.9 MeV/A) with the maximum available beam intensity, which is reported to be at least 8.5 10^{5} pps on target in MINIBALL. This corresponds to 21 shifts in one run.

References:

[Bor98] P.F. Bortignon, A. Bracco, and R. A. Broglia, Giant Resonances: Nuclear Structure at Finite Temperature (Harwood Academic, New York, 1998).
[Col14] G. Colò and P.F. Bortignon, private communications.
[Cas77] F. Pulhofer, Nucl. Phys. A 280, 267 (1977).
[Fre88] I. J. Thompson, Comp. Phys. Rep. 7, 167 (1988).
[For01] B. Fornal et al. Phys. Rev. Lett. 87, 212501 (2001).
[Gal88] S. Gales, Ch. Stoyanov, and A. I. Vdovin, Phys. Rep. 166, 125 (1988).
[Kle82] P. Kleinheinz et al., Phys. Rev. Lett. 48, 1457 (1982).
[Jon10] K. L. Jones et al., Nature (London) 465, 454 (2010).
[Jud07] D.S. Judson et al., Phys.Rev. C 76, 054306 (2007).
[Leo14] S. Leoni at al., in preparation.
[Lun84] S. Lunardi et al., Phys. Rev. Lett. 53, 1531 (1984).
[Lis80] C. J. Lister et al., J. Phys. G: Nucl. Part. Phys. 6, 619 (1980).
[Nud2] NuDat - National Nuclear Data Center – Brookhaven, http://www.nndc.bnl.gov/nudat2/
[Pie09] N. Pietralla et al., Phys. Lett. B 681, 134 (2009).
[Rej00] M. Rejmund et al., Eur. Phys. J. A 8, 161 (2000).
[Tsa09] M. B. Tsang et al., Phys. Rev. Lett. 102, 062501 (2009).
[Urb00] W. Urban et al., Phys. Rev. C 62, 027301 (2000).
[Urb09] W. Urban et al., Phys. Rev. C 79, 037304 (2009).

Appendix

DESCRIPTION OF THE PROPOSED EXPERIMENT

The experimental setup comprises: *(name the fixed-ISOLDE installations, as well as flexible elements of the experiment)*

Part of the Choose an item.	**Availability**	**Design and manufacturing**
HIE-ISOLDE	☒ Existing	☒ To be used without any modification
MINIBALL + T-REX	☒ Existing	☒ To be used without any modification ☐ To be modified
	☐ New	☐ Standard equipment supplied by a manufacturer ☐ CERN/collaboration responsible for the design and/or manufacturing

HAZARDS GENERATED BY THE EXPERIMENT

(if using fixed installation) Hazards named in the document relevant for the fixed [MINIBALL + only CD, MINIBALL + T-REX] installation.

Additional hazards:

Hazards			
	HIE-ISOLDE	*MINIBALL + T-REX*	*[Part 3 of the experiment/equipment]*
Thermodynamic and fluidic			
Pressure	[pressure][Bar], [volume][l]		
Vacuum			
Temperature	[temperature] [K]		
Heat transfer			
Thermal properties of materials			
Cryogenic fluid	[fluid], [pressure][Bar], [volume][l]		
Electrical and electromagnetic			
Electricity	[voltage] [V], [current][A]		
Static electricity			
Magnetic field	[magnetic field] [T]		
Batteries	☐		
Capacitors	☐		
Ionizing radiation			
Target material	[material]	Secondary target: LiF$_4$ foil 1.5 mg/cm^2	
Beam particle type (e, p, ions, etc)	Heavy ions: tuning and calibrations : stable Sn, ^{22}Ne Measurement : ^{132}Sn	Heavy ions: tuning and calibrations : stable Sn, ^{22}Ne Measurement : ^{132}Sn	
Beam intensity	max 1 nA (injection plate REXTRAP)	max 10 pA (after EBIS)	
Beam energy		3.9 MeV/nucleon	
Cooling liquids	[liquid]		

Gases	[gas]		
Calibration sources:	☐	☒ Standard alpha- and gamma-calibration sources from ISOLDE	
- Open source	☐		
- Sealed source	☐ [ISO standard]		
- Isotope			
- Activity			
Use of activated material:			
- Description	☐		
- Dose rate on contact and in 10 cm distance	[dose][mSV]		
- Isotope			
- Activity			
Non-ionizing radiation			
Laser			
UV light			
Microwaves (300MHz-30 GHz)			
Radiofrequency (1-300MHz)			
Chemical			
Toxic	[chemical agent], [quantity]		
Harmful	[chemical agent], [quantity]		
CMR (carcinogens, mutagens and substances toxic to reproduction)	[chemical agent], [quantity]		
Corrosive	[chemical agent], [quantity]		
Irritant	[chemical agent], [quantity]		
Flammable	[chemical agent], [quantity]		
Oxidizing	[chemical agent], [quantity]		
Explosiveness	[chemical agent], [quantity]		
Asphyxiant	[chemical agent], [quantity]		
Dangerous for the environment	[chemical agent], [quantity]		
Mechanical			
Physical impact or mechanical energy (moving parts)	[location]		
Mechanical properties (Sharp, rough, slippery)	[location]		
Vibration	[location]		
Vehicles and Means of Transport	[location]		
Noise			
Frequency	[frequency],[Hz]		
Intensity			
Physical			
Confined spaces	[location]		
High workplaces	[location]		
Access to high workplaces	[location]		
Obstructions in passageways	[location]		
Manual handling	[location]		
Poor ergonomics	[location]		

3.2 Average electrical power requirements (excluding fixed ISOLDE-installation mentioned above): *(make a rough estimate of the total power consumption of the additional equipment used in the experiment)*

… kW