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EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Letter of Clarification to the ISOLDE and Neutron Time-of-Flight Committee

IS702: Probing the doubly magic shell closure at ^{132}Sn by Coulomb excitation of neutron-rich ^{130,134}Sn isotopes

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Abstract: By this Letter of Clarification we follow the recommendation made by the INTC during its 72nd meeting on February 8–9, 2023 concerning our addendum to experiment IS702: The proponents were asked to "demonstrate the impact of the ^{130}Sn results

on the physics case in a new proposal for ^{134}Sn." Although the present addendum includes experimental data from the November 2022 campaign, suggesting that a precise value for the B(E2) will probably be inferred, the INTC regrets that no preliminary value has been provided by the proponents. Accordingly, it is requested that the proponents submit a clarification letter, in which the physics gain from their experiment is clearly explained, in order to convince the INTC of the interest of this additional measurement. The INTC recommended the submission of a letter of clarification.
The proposed study of the isotope ^{134}Sn by γ-ray spectroscopy following "safe" Coulomb excitation will be feasible after evaluation and data analysis of the first part of IS702 which is concerned with ^{130}Sn. An improved experiment has been performed in October 2023 with the upgraded Miniball spectrometer. It yielded high statistics and high quality results which will allow a precise determination of the $B(E2; 0^+_{\rm g.s.} \rightarrow 2^+_1)$ value in ^{130}Sn. Based on this achievement we ask for approval of the requested beam time to study reduced transition strengths in ^{134}Sn.

Requested shifts: [15+3] shifts
Installation: [MINIBALL + CD (C-REX)]

1 Status of IS702

The first part of experiment IS702 [1], the Coulomb excitation of ^{130}Sn, was subject of two beam times. A first attempt was made in November 2022 and preliminary results of this beam time were reported last year to the INTC. The INTC expressed 'regrets that no preliminary value has been provided by the proponents'. The addendum was prepared only few weeks after the experiment was performed. Meanwhile, the analysis of this run advanced with a preliminary GOSIA analysis with a value of $B(E2; 0^+_{\rm g.s.} \rightarrow 2^+_1) = 0.056^{(+10)}_{(-14)}$ e^{2}b^2 for ^{130}Sn. This is an intriguing result as it compares quite well to the theoretical prediction of $B(E2; 0^+_{\rm g.s.} \rightarrow 2^+_1) = 0.055$ e^{2}b^2 by [2]. The result is well above the previous $B(E2)$ value of 0.023(5) e^{2}b^2 given in a conference proceedings article by [3].
However, the beam time in 2022 was the first experiment after long shut down 2 at CERN with the Miniball spectrometer and its new data acquisition system. Data taking was hampered by major difficulties with the new electronics and a reduced period of beam time. Therefore, a new experiment was performed in October 2023. Meanwhile the new digital electronics, data acquisition system and read-out software were revised for all Miniball experiments.
The Coulomb excitation (Coulex) of ^{130}Sn employed the upgraded Miniball array which is identical to the configuration proposed in the addendum for Coulex of ^{134}Sn. The obtained ^{130}Sn beam intensity from HIE-ISOLDE was about $5 \cdot 10^5$ 1/s at an energy of 4.4 MeV/u using ≈ 0.5 μA protons.^{130}Sn was extracted from the production target as ^{130}Sn^{32}S$^+$ molecular ion which was cracked in the EBIS. The beam was impinging on a 4 mg/cm^2 thick ^{206}Pb target.
The beam purity was determined from γ spectroscopy after beta decay of beam contribu-

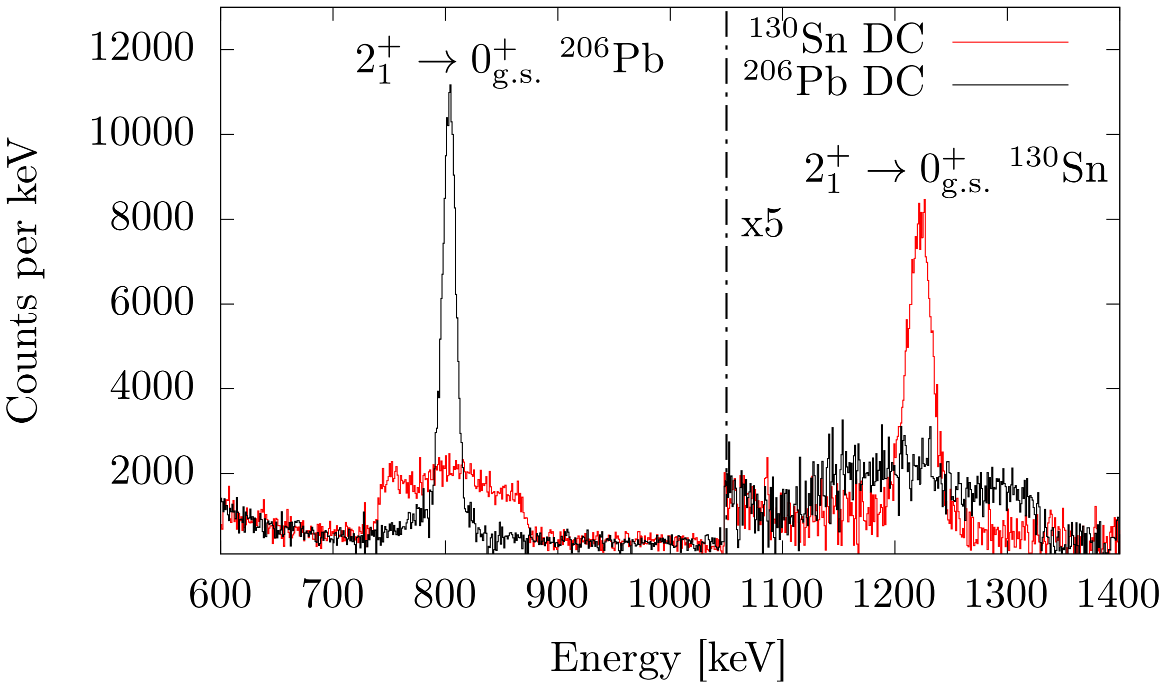

Figure 1: Preliminary γ-ray spectrum detected in coincidence with scattered $A = 130$ and $A = 206$ nuclei. The left part of the spectrum shows the $2^+_1 \rightarrow 0^+_{g.s.}$ transition in ^{206}Pb after Doppler correction for nuclei with $A = 206$ (black colour) and $A = 130$ (red colour)). The right part of the spectrum shows the $2^+_1 \rightarrow 0^+_{g.s.}$ transition in ^{130}Sn (red colour) after Doppler correction for nuclei with $A = 130$ and background subtraction. Y-axis is enlarged by a factor of 5 on the right side for energies above 1050 keV.

tions. A nearly pure beam of ^{130}Sn was delivered by the HIE-ISOLDE accelerator. Only a small beam contribution of $\leq 5\%$ has to be attributed to ^{130}Sb as possible isobaric impurity. The ^{130}Sn beam itself consisted of a major fraction of the 0^+ ground state. A second part of about 25% is caused by a known 7^- isomer ($T_{1/2} = 1.7$ min) in ^{130}Sn.

A preliminary Doppler-corrected γ-ray spectrum is shown in Fig. 1 yielding a high statistics of 40.000 counts in the $2^+_1 \rightarrow 0^+_{g.s.}$ transition of ^{130}Sn. Data was taken for 105 hours of beam time. A count rate of 380 counts/hour was recorded, which is in excellent agreement with the estimated value in the proposal for experiment IS702 (we estimated 370 counts/hour for the ^{130}Sn experiment).

It should be noted that the beam current of ^{130}Sn was high and was finally limited by the count rate of the HPGe detectors of Miniball. For this purpose the proton beam current coming from the PS booster was reduced by a factor of four from 2 to $\approx 0.5\mu A$. In case of the much reduced ^{134}Sn beam intensity we will not apply this reduction.

ISOLDE yield measurements for Sn isotopes ^{130,132}Sn in September and October 2023 obtained remarkable high ion beam intensities comparable to highest yields from past experiments. In October 2023, we obtained for ^{130}Sn a beam secondary beam intensity of $\approx 5 \cdot 10^5$ 1/s at the Miniball target using ≈ 0.5 μA of protons, which is double the value we used in the original proposal and addendum. With a proton current of ≈ 2 μA and the

HIE-ISOLDE efficiency which was achieved for the ^{130}Sn beam time, the following beam current is expected at the Miniball spectrometer: $\approx 2 \cdot 10^4$ 1/s for ^{134}Sn. Slow extraction from the EBIS with pulse lengths of at least 1 ms is still desirable for this experiment to reduce the instantaneous particle rate.

Taking into account the integrated cross sections for Coulex of ^{134}Sn (see the addendum for details) the given values for future spectroscopy are well justified for our proposed measurement. The calculated particle-γ-ray yields for Coulomb excitation of ^{134}Sn are as follows: $I(2_1^+ \rightarrow 0_{\text{g.s.}}^+) = 30$ counts/hour and $I(4_1^+ \rightarrow 2_1^+) = 0.6$ counts/hour. These rates will result in 3600 counts for the crucial $2_1^+ \rightarrow 0_{\text{g.s.}}^+$ transition in ^{134}Sn. The estimate for the $4_1^+ \rightarrow 2_1^+$ transition will yield 68 counts. The numbers are based on 15 shifts of ^{134}Sn beam on target.

In summary, the latest results from Coulex of ^{130}Sn with Miniball at HIE-ISOLDE demonstrate unambiguously the feasibility of the addendum to experiment IS702. Based on identical set-up, experimental method and analysis procedure as used by us for ^{130,132}Sn we are confident that Coulomb excitation of the first excited 2^+ and possibly 4^+ state in ^{134}Sn can be performed successfully as proposed in our Addendum for IS702. The requested 15 shifts will allow to determine the $B(E2; 0_{\text{gs}}^+ \rightarrow 2_1^+)$ value also in this case with much reduced statistical errors with respect to results from [4]. The impact of the diagonal matrix elements (not discussed in [4]) will be included in our analysis. The measurement of the $B(E2, 0_{gs}^+ \rightarrow 2_1^+)$ values in both neighbours of the doubly-magic ^{132}Sn will be crucial for understanding the nuclear structure of Sn isotopes around the $N = 82$ shell closure and an experimental benchmark for theory.

In total we ask 18 (15+3) shifts for ^{134}Sn.

References

[1] P. Reiter, Th. Kröll et al., CERN-INTC-2021-039 / INTC-P-608.

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[4] R. L. Varner *et al.*, Eur. Phys. J. A 25, s01, 391 (2005).

Appendix

DESCRIPTION OF THE PROPOSED EXPERIMENT

The experimental setup comprises:

Part of the	Availability	Design and manufacturing
(fixed ISOLDE installation: MINIBALL + only CD, or MINIBALL + C-REX)	☒ Existing	☒ To be used without any modification
[^{134}Sn experiment/ equipment]	☒ 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	[Part 1 of experiment/ equipment]	[Part 2 of experiment/ equipment]	[Part 3 of 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]			

Beam particle type (e, p, ions, etc)	^{134}Sn		
Beam intensity at MINIBALL	10^4 ions/s		
Beam energy	4.4 MeV/u		
Cooling liquids	[liquid]		
Gases	[gas]		
Calibration sources:	☐		
• Open source	☐		
• Sealed source	☒ [ISO standard]		
• Isotope standard sources	^{60}Co, ^{152}Eu		
• Activity (sources are available)			
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 (1-300 MHz)			
Chemical			
Toxic	[chemical agent], [quantity]		
Harmful	[chem. agent], [quant.]		
CMR (carcinogens, mutagens and substances toxic to reproduction)	[chem. agent], [quant.]		
Corrosive	[chem. agent], [quant.]		
Irritant	[chem. agent], [quant.]		
Flammable	[chem. agent], [quant.]		
Oxidizing	[chem. agent], [quant.]		
Explosiveness	[chem. agent], [quant.]		
Asphyxiant	[chem. agent], [quant.]		
Dangerous for the environment	[chem. agent], [quant.]		
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]		

Hazard identification:

none