EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

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

Spectroscopy of the low lying states of neutron rich ^{134}I

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Abstract

We propose to carry out the off-beam decay spectroscopy of ^{134}Te ($\tau_{1/2}$ = 42 mins) to measure the lifetime and transition moments for the low lying states of the decay product (^{134}I) using the ^{134}Te beam from ISOLDE facility. The measurements will be performed with three different setups.

a. The gamma spectroscopic measurements, viz., γ-singles and the γ–γ coincidence will be carried out by using three HPGe detectors. Angular correlation measurements will be helpful to resolve the ambiguities in spin assignments.
b. The lifetimes of the excited states of ^{134}I will be measured by using the Mirror Symmetric Centroid Difference (MSCD) technique using two $LaBr_3$(Ce) detectors.

The above two measurements will be performed after collecting the ^{134}Te nuclei in an ice chamber and then placing the activity in the corresponding offline measurement setup.

c. One of the important aims of the experiment is to measure the quadrupole moments of the excited states of ^{134}I by Time Differential Perturbed Angular Correlation (TDPAC) technique. For this purpose, the ^{134}Te will be implanted in the ^{nat}Te metal to provide the required Electric Field Gradient (EFG) by the hexagonal structure of Te metal and the subsequent TDPAC measurement will be carried out with the DIGIPAC setup.

The present study will address the important aspects of nuclear structure around the doubly closed ^{132}Sn. The experimental results will provide information about the low lying structure for the N=81 isotope of Iodine. This will enrich our knowledge on the single particle energy and two body interaction in this mass region. This work may also provide us some new insight into the origin of the anomalous behaviour of $\pi d_{5/2}$ orbital observed for nuclei with N>82 above ^{132}Sn core.

Requested shifts: Twelve (12) shifts

Introduction and Motivation

Experimental study of the nuclei around any doubly closed nucleus is of special importance as it provides a testing ground for effective interactions used in interacting shell model calculations. The region around the doubly closed ^{132}Sn nucleus carries an extra importance as this lies away from the line of β-stability and difficult to access experimentally [1,2]. This region hence has remained almost unexplored and limited to some decay studies. The energy and transition probabilities of the low lying states of the nuclei in this region have striking similarity with the nuclei around ^{208}Pb shell closure[3,4]. The investigation of structural features of nuclei having few valence nucleons/holes near ^{132}Sn has been of current interest both experimentally and theoretically. The odd-odd isotopes of these nuclei are of specific importance as they provide the information on the nature of the p-n interaction giving rise to the p-n matrix elements used for the shell model calculations [5,6]. One of the striking feature in this mass region is the sudden drop of the excitation energy of the lowest $5/2^+$ state in odd-A ^{135}Sb (N=84) compared to ^{133}Sb (N=82) [7]. Several authors have suggested the lowering of the single particle energy for the $\pi d_{5/2}$ orbital by 300-400 keV in order to reproduce the experimental data in ^{135}Sb, which in turn also reproduces many of the associated structure properties [7-11]. On the other hand, Coraggio et al. [12] has claimed that the shell model calculation with a realistic effective interaction derived from CD-Bonn N-N potential can explain the anomalously low position of this state. It is important to distinctly attribute either the n-p interaction or the monopole shift to the anomalous behaviour of the states involving the $\pi d_{5/2}$ orbital. To resolve this issue, the lifetime of the $5/2^+$ state of ^{135}Sb has been measured by the Advanced Time-Delayed βγγ (t) method at the OSIRIS fission product mass separator at Studsvik [13]. The measured half-life yields an exceptionally low B(M1; $5/2^+_1 \rightarrow 7/2^+_1$) value, indicating a strong $\pi d_{5/2}$ single particle component of the state. The amount of lowering of the single particle energy of $\pi d_{5/2}$, which seems to be a delicate matter depending on the number of protons and neutrons in the valence space, must be explored. Hence, the studies on the complete spectroscopy of the nuclei around ^{132}Sn nucleus are required spanning both the particle and hole space for protons and neutrons. The measurements of transition probabilities, hence lifetimes and transition moments, are of extreme importance.

The experimental and theoretical information have been very few [14] in the neighbouring iodine nuclei although the signature of the $\pi d_{5/2}$ anomaly has been observed long back in the systematics of the quadrupole moments of the odd-A iodine nuclei [15]. In that work, the authors have shown that, at N=82 shell closure, the quadrupole moment of the $5/2^+$ state is larger than that of $7/2^+$ state, as obtained by the extrapolation of the existing experimental data. However, the theoretical predictions could not explain this observation and suggested for a configuration mixing. The systematic measurement of the quadrupole moments for both odd-A and odd-odd iodine nuclei along with the same for excitation energy and level lifetimes are necessary in order to address the discussed physics issues.

The comparison of the low lying levels of the odd-odd N=81 Iodine nucleus to that of the neighbouring Sb nucleus shows the population of similar proton particle neutron hole multiplets. The recent shell model calculation, although could predict the energy of the observed states, could not reproduce the experimentally assigned spin parities for these states [16]. The information for the low lying levels of ^{134}I is not adequate for understanding the underlying structure. Also, the population of the multiplets involving neutron $h_{11/2}$ orbitals has not yet been observed for this nucleus. Hence the existing information on this nucleus, as briefed in the next two paragraphs, is not complete. There is a substantial scope to improve the experimental information of the low lying states of this nucleus which is the aim of the present proposal. This proposal describes the experimental study for the low lying structure of neutron rich odd-odd iodine nucleus with N = 81. The γ spectroscopy for low lying states of ^{134}I will be performed from the decay of ^{134}Te along with the measurement of lifetime and transition moments for these states. The study will add meaningful information on the structure around the double shell closure of ^{132}Sn and will also add data to the systematics of low lying states of Iodine nuclei.

<u>Literature Survey on ^{134}I and Scope:</u>

The low lying states of ^{134}I have been studied mainly from the decay of ^{134}Te, produced from the fission of Uranium and show a complicated structure with a higher level density compared to the neighbouring ^{132}Sb. A three proton particle and one neutron hole structure has been proposed for these low lying states with a large configuration mixing [17]. One 3.8 min, 8^- isomer has been identified in the nucleus from the decay measurements [18]. Recently, the high spin members of the nucleus have been observed from the fission of ^{252}Cf source [19]. The study shows the levels excited beyond the 8^- isomeric state and the findings matches well with the shell model calculation on ^{134}I [16], considering the particle hole configuration with respect to the ^{132}Sn core. The 79 keV level of ^{134}Te is known to have a lifetime of 1.62 ns as measured by the electron–gamma coincidence by V. Berg and A. Hogglund [20] and from the same work the limits are given for the lifetimes of 180.8 and 210.5 keV levels. The decay scheme of ^{134}Te as obtained from the earlier works [21] is given below in figure 1.

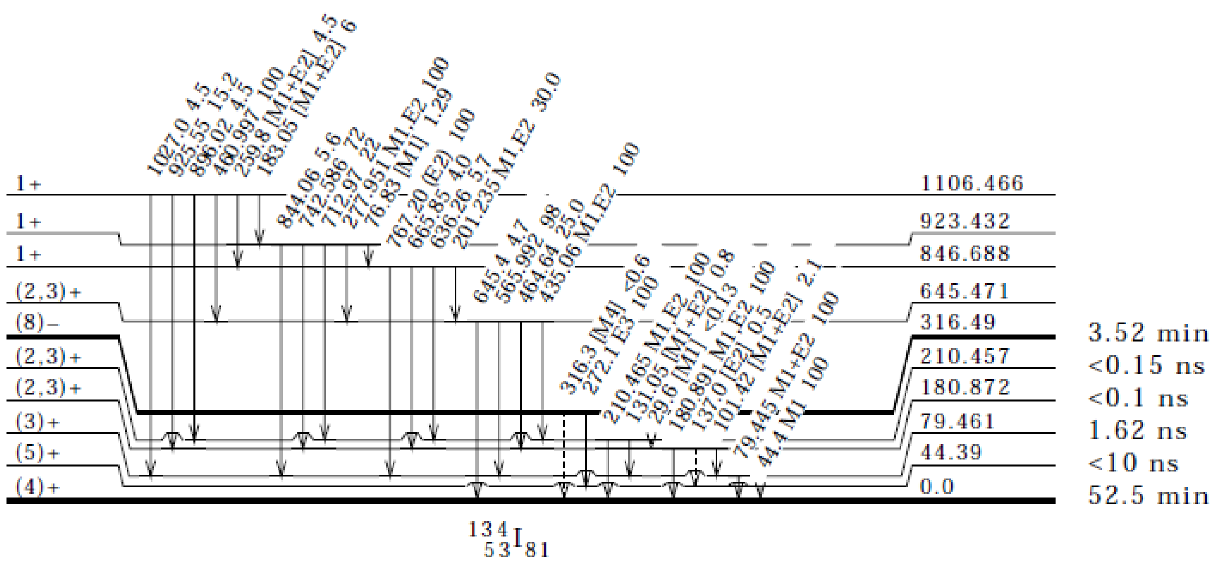

Figure 1: The level scheme of ^{134}I populated from the decay of ^{134}Te [21].

The existing experimental data [21] on ^{134}I describes the 79 keV state to have $J^{\pi}=(3^{+})$ while the recent shell model calculation has described this (3^{+}) state as 5^{+} [16]. It is thus important to confirm the spin-parity of the 79 keV level along with its lifetime and quadrupole moment. It is also important to confirm the spin-parities of several low lying levels in ^{134}I because of the existing discrepancies between experimental values and theoretical predictions. The life times and transition moments will give more direct evidences on the underlying configurations for these states of ^{134}I nucleus, as observed in case of neighbouring ^{132}I [22,23]. Hence, the experimental study on complete spectroscopy of ^{134}I involving the measurements of γ-singles, γ–γ coincidences, γ-ray angular distribution, level lifetime and quadrupole moment is of extreme importance to provide significant information on the nuclear structure of ^{134}I.

Shell Model Calculation of ^{134}I and Related Experimental Scope:

We have performed the shell model calculation on this nucleus using OXBASH code. The calculations have been performed with SN100 interactions and ^{100}Sn as core. A comparison between the experimental results and the theoretical calculations is shown in figure 2.

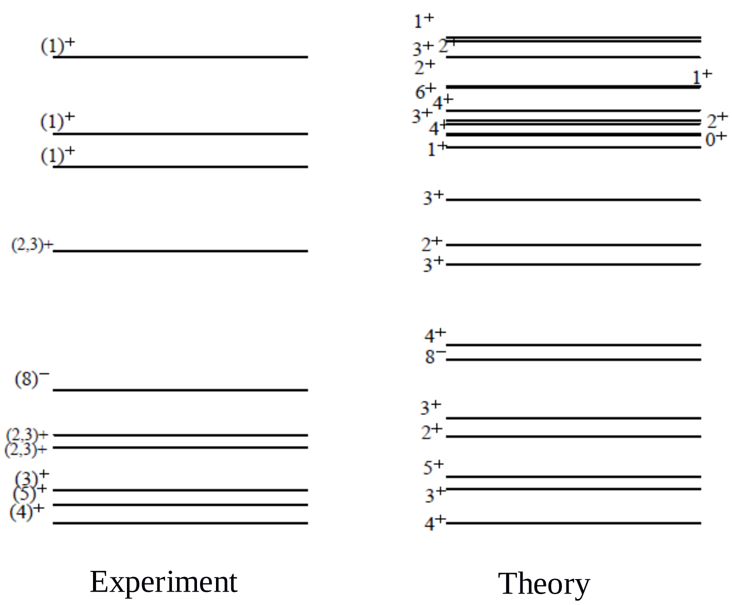

Figure 2: The results of Shell Model calculation for ^{134}I.

It has been observed that the results from our calculation match with that of Corragio et al. [16], done with ^{132}Sn as the closed core. One of the important aspects of these calculations is the interchanging of the first 3^{+} and 5^{+} levels with respect to the existing experimental data [21]. It is important to confirm experimentally by the angular correlation and lifetime measurements. According to this calculation, the 44 keV, 79 keV, 180 keV and 846 keV states have the J^{π} values of 3^{+}, 5^{+}, 2^{+} and 1^{+} respectively, developed from a pure configuration of $\pi g_{7/2}\nu d_{3/2}$. The 210 keV level is predicted to have a J^{π} value of 3^{+} with a major configuration of $\pi g_{7/2}\nu s_{1/2}$ (56%) but a mixing from $\pi g_{7/2}\nu d_{3/2}$ (25%). The 1106 keV (1^{+}) level has the similar configuration mixing as per the calculation. The candidates of $\pi d_{5/2}\nu d_{3/2}$ multiplets are predicted to lie above the 8^{-} isomeric state. The 645 keV and 923 keV states are the possible candidates from this multiplet with J^{π} value of 3^{+} and 1^{+} respectively. This experimental data on the 79 keV and 180 keV states will address uniquely the properties of the $\pi g_{7/2}$ orbital. The lifetime measurement of the 210 keV level can determine the involved configuration mixing. The information on the energy and spin-parity of the levels having configuration involving $\pi d_{5/2}$ orbital is important to understand its role in the structure of ^{134}I. Hence the experimental data on the low lying levels of ^{134}I will provide important information regarding the single particle level energies and the effective interactions used in shell model calculation.

Details of the measurements to be done:

In the present proposal, the authors would like to study the N=81 ^{134}I nucleus from the decay of ^{134}Te nucleus to be provided by the ISOLDE facility. The details of the measurements that are proposed to be carried out are as follows.

1. **Measurement of γ-singles, γ–γ coincidence and angular correlation:** The data from the γ-singes measurement will provide the information on intensity of the de-exciting transitions. The data from γ–γ coincidence measurement will provide the information on the level structure and the data on angular correlation will allow the authors to assign the spins of the excited states of the nucleus.
   For this part of the measurement, the ^{134}Te activity will be collected in ice sample and will be counted with three HPGe detectors available at ISOLDE, CERN with electronics and DAQ.

2. **Measurement of the life-time and quadrupole moment of the 79 keV, (3^+) level of ^{134}I:** It is required to be confirmed from the more precise technique as the earlier measurement used electron-gamma coincidences. The 767-79 keV or the 565-79 keV cascade can be used for the lifetime measurement of the 79 keV level. The quadrupole moment of this state will be measured by doping the ^{134}Te nuclei in the ^{nat}Te metal matrix and measuring the quadrupole frequency with the TDPAC technique. This can be accomplished by directly implanting ^{134}Te activity on Te metal target (kept at 300^{o}C during implantation) and then carrying out the off-beam TDPAC measurement. The quadrupole moment will be calculated from the EFG (V_{zz}) value for ^{134}Te in ^{nat}Te metal matrix. The EFG value can either be taken from the literature value for ^{132}Te or be calculated using Wien2K code based on Density Functional Theory. This data will help to assign the right single particle configuration and spin to the 79 keV level. Also the data is expected to give some light on the n-p interaction as well as configuration mixing.
   This part of the measurement will be carried out with the DIGIPAC facility available at ISOLDE, CERN. The facility consists of six $LaBr_3$(Ce) detector coupled to a digital data acquisition system.

3. **Measurement of lifetimes for the 181keV, (3^+) and 210 keV, (2^+) levels:** This will be carried out by the MSCD technique [24] using the $LaBr_3$(Ce) detectors, which have proved to be an efficient tool to measure lifetimes down to few ps [25]. The calibration of prompt time curve will be made using the ^{60}Co and ^{152}Eu sources. The existing assignments of the spin parity of these states are not unambiguous and also the transition probabilities will be important to assign the appropriate configuration to these levels.
   For this part of the measurement, two separate $LaBr_3$(Ce) detectors [25] will be required. The data is required to be taken with a time per channel(TPC) of 6ps or less. As the DIGIPAC system might not be modified accordingly, we will carry our $LaBr_3$(Ce) detectors assembled with PMT and the local group will arrange the required electronics, DAQ and the offline sources like ^{152}Eu and ^{60}Co.

Proposal Summary

We propose to carry out the decay spectroscopy of ^{134}Te ($\tau_{1/2}$ = 42 mins) and to measure the lifetime and quadrupole moments for the low lying states of ^{134}I using the ^{134}Te beam from ISOLDE facility. The study will address the important aspects of nuclear structure around the doubly closed ^{132}Sn. The experimental results are expected to enrich the information of the low lying structure for the N=81 isotope of Iodine. This will add up to the existing understanding on the behaviour of single particle orbitals in this mass region in a model space with proton particle and neutron hole compared to the ^{132}Sn core.

Three HPGe detectors for the measurement of γ–singles and γ–γ coincidence will be required. For the measurement of lifetimes and quadrupole moment of the 79 keV state, the TDPAC technique will be used and the measurement will be done using the DIGIPAC system. For the measurements of the lifetimes for the other excited levels, MSCD technique will be used with a setup of two $LaBr_3$ detectors. For the calibration of prompt time we will take data with ^{60}Co and ^{152}Eu source before starting the real run.

Summary of requested shifts:

We intend to take twelve shifts of beam time in total. Each irradiation will be of one hour duration with a suitable gap between the consecutive irradiations.

A source calibration time will be required before the experiment depending on the strength of the used sources like ^{152}Eu and ^{60}Co.

Target, Ion Source and Instruments:

Target Unit: UCx

Ion source : VADIS plasma ion source

Note : The expected isobaric contamination(A~ 132) and possible oxides and/or flourides from a plasma ion source will not be a problem for the experiment.

Instruments :

1. Three HPGe detectors with electronics and DAQ for γ singles and γ–γ coincidence measurements. A XIA make digital DAQ will be used for the experiment.
2. DIGIPAC system.
3. HVPS units for biasing PMT (upto 2500 V), CFDs, spectroscopy amplifiers, ns delay units, NIM Bin, TAC, CAMAC Crate and Computer with Scientific Linux. The XIA make digital DAQ can be used in this case also. We propose to carry two $LaBr_3$(Ce) detectors with PMT assembly.

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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	Availability	Design and manufacturing
SSP-GLM chamber	☐ Existing	☐ To be used without any modification
Existing equipment on the solid state labs in building 115 - 6 detector PAC standard setups - annealing furnaces - glove boxes	☐ 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 SSP-GLM chamberand building 115 installations.

Additional hazards:

Hazards	*SSP-GLM*	*Building 115*	*[Part 3 of the experiment/equipment]*
Thermodynamic and fluidic			
Pressure	[pressure][Bar], [volume][l]		
Vacuum	10-6 mbar at SSP chamber 10 during collections		
Temperature	295 K room temperature collections		
Heat transfer	-		
Thermal properties of materials	-		
Cryogenic fluid		Liquid nitrogen, 1 Bar, few litres used during the PAC measurements on	

		appropriate dewar	
Electrical and electromagnetic			
Electricity	[voltage] [V], [current][A]		
Static electricity			
Magnetic field	[magnetic field] [T]		
Batteries	☐		
Capacitors	☐		
Ionizing radiation			
Target material	[material]		
Beamparticle type (e, p, ions, etc)			
Beam intensity			
Beam energy			
Cooling liquids	[liquid]		
Gases	[gas]		
Calibration sources:	☐		
• Open source	☐ Produced at ISOLDE: ^{134}Te	Sources to be measured at 115	
• Sealed source	☐	^{60}Co and ^{152}Eu are needed as the calibration sources for the centroid shift measurement	
• Isotope	^{134}Te		
• Activity	^{134}Te		
Use of activated material:	none		
• Description	☐		
• Dose rate on contact and in 10 cm distance	[dose][mSV]		
• Isotope			
• Activity			
Non-ionizing radiation			
Laser	none		
UV light	none		
Microwaves (300MHz-30 GHz)	none		
Radiofrequency (1-300MHz)	none		
Chemical			
Toxic	[chemical agent], [quantity]		
Harmful		Hydrochloric acid (ICSC: 0163) , in quantities less than few centilitres per	

		chemical. From this acid solution Te will be precipitated as Te metal by sodium sulphite.	
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)	[none]		
Mechanical properties (Sharp, rough, slippery)	[none]		
Vibration	[none]		
Vehicles and Means of Transport	[none]		
Noise			
Frequency	[frequency],[Hz] Ambient noise at the ISOLDE Hall, building 170		
Intensity	Ambient noise at the ISOLDE Hall, building 170		
Physical			
Confined spaces	[none]		
High workplaces	[none]		
Access to high workplaces	[none]		
Obstructions in	[none]		

passageways			
Manual handling	All samples and sample holders are manually handled either by long tweezers to insert and extract the sample holder into and out of the SSP implantation chamber at GLM, or when manipulating the samples and sample holders inside glove boxes or fume houses on building 115 r-007	All samples and sample holders are manually handled either by long tweezers to insert and extract the sample holder into and out of the SSP implantation chamber at GLM, or when manipulating the samples and sample holders inside glove boxes or fume houses on building 115 r-007	
Poor ergonomics	[none]		

0. Hazard identification

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)*

There is no additional equipment with relevant power consumption on these small-scale experiments.