EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Proposal for ISOLDE and Neutron Time-of-Flight Committee

Shape coexistence in the lightest Tl isotopes studied by laser spectroscopy

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Abstract

This Proposal aims at atomic spectroscopy studies of the very neutron-deficient isotopes $^{178\text{-}187}$Tl, at and far beyond the region of the neutron mid-shell at N=104, in which shape coexistence phenomena were investigated so far by particle and γ-ray spectroscopy methods only. Our motivation for this proposal is as follows:

- These studies will provide direct data on magnetic dipole moment, spin, charge radii and deformations of these isotopes. The results will form a stringent test for our current understanding of the shape coexistence phenomena in the vicinity of the neutron mid-shell at N=104, where the relevant effects are expected to be the strongest (cf. shape staggering in the isotopes ^{181,183,185}Hg, see Fig.3).
- The knowledge of the structure (configuration, spin, deformation) and whether one or two beta-decaying isomers are present in the parent isotopes ^{178,180,182}Tl isotopes are crucial for understanding of the results of our recent studies of beta-delayed fission in the lightest thallium isotopes.
- A mass measurement for ^{180}Tl with the ISOLTRAP is also requested, which will allow the experimental determination of the Q_{EC}(^{180}Tl) value. The knowledge of this value is required to interpret the results of the β-delayed fission of this isotope (e.g. to deduce the experimental fission barrier of its daughter ^{180}Hg).

The uniqueness of ISOLDE for these studies is that it provides pure Tl beams with intensities not accessible anywhere else. Importantly, isomer separation is possible in most cases using the Resonance Ionisation Laser Ion Source (RILIS) of ISOLDE.

Requested shifts: 17 shifts of ISOLDE beam time are requested for the whole project.

Introduction

The region of very neutron-deficient nuclei in the vicinity of the proton shell gap at Z=82 and neutron mid-shell at N=104 is well-known for a prolific interplay between single particle and collective nuclear structure effects [1–5]. To name a few examples specifically relevant to the present Proposal, we mention shape coexistence [1–5], shape staggering [6, 7] and related phenomena in the broad region of the Pt-Rn isotopes, and the persistence of high- and low- spin isomeric states. For a recent overview on shape coexistence, we refer to [5] where the authors state in their conclusion that ”there is much to be learned about many-nucleon systems and their separate independent-particle and correlated-particle behaviours, revealed through shape coexistence”. It is the aim of this proposal to provide experimental values for a number of observables extracted in a model independent way in order to test current theoretical descriptions.

Different complementary methods, such as transfer reactions, particle decays, in-beam and isomeric γ-ray spectroscopy, atomic spectroscopy and very recently – Coulomb excitation reactions have all been used in the lead region. Among these methods, atomic spectroscopy techniques play a crucial role, since they allow a direct characterization of the atomic nucleus ground and isomeric state properties, such as charge radius, spin, magnetic dipole and electric quadrupole moments. As two recent examples we mention the measurements of the charge radii changes in the long isotopic chains of Pb [8] and Po [9] isotopes performed by the IKS (KU Leuven)-led collaboration at ISOLDE.

The occurrence of intruder states in the Tl (Z=81) isotopes is another well-established phenomenon, see e.g. [10–13]. So far atomic spectroscopy measurements for a restricted set of isotopes $^{186\text{-}205,207,208}$Tl [14-18] have been performed, the latest measurement dating back to more than 15 years ago, due to experimental difficulties to reach even more neutron-deficient Tl isotopes. On the other hand, due to recent progress with laser-ionized Tl beams with RILIS@ISOLDE [19], more neutron-deficient Tl isotopes can be reached now [20].

1.Shape coexistence in Tl isotopes probed by atomic spectroscopy methods

The element Tl (Z=81) is a good test case for nuclear structure calculations since, with only one proton missing in the major proton shell ($\pi 3s^{-1}$ configuration), many of the nuclear properties of this element might be explained in an independent particle approach. On the other hand, by approaching the mid-shell at N=104, shape coexistence phenomena are expected to interfere at low excitation energy, which should be directly reflected in the properties of both ground and low-lying intruder states, as e.g. one can clearly see in the charge radii of the Hg isotopes in the vicinity of the mid-shell at N=104 (see Fig. 3).

a) Magnetic dipole moments of the I=1/2$^+$ spherical ground states

The spin-parity assignment of $I^\pi=1/2^+$ is expected for the ground state of all odd-A Tl isotopes, which is due to the dominant spherical $\pi 3s^{-1}$ configuration. Different atomic spectroscopy techniques have been used so far to study ground state properties of Tl isotopes, see [14-18] and refs. therein. To our knowledge, the lightest isotope so far studied by a laser spectroscopy technique and for which the spin-parity of I=1/2$^+$ was experimentally established is ^{187g}Tl [17], though no data exist for ^{189g}Tl yet. The measured magnetic moment $\mu(^{187g}\text{Tl})=1.55(6)$ n.m. was shown [17] to be very well comparable to the magnetic moments of the heavier odd-A Tl isotopes, see Fig.1a. This indicates that, at least up to ^{187g}Tl (N=106), the spherical $\pi 3s^{-1}$ configuration remains quite pure in the Tl chain.

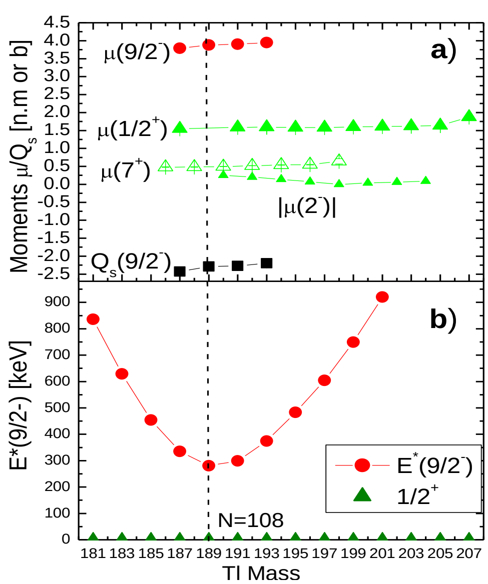

Fig. 1 a) Magnetic dipole and electric quadrupole moments (where known) for the 1/2$^+$, 9/2$^-$, 7$^+$ and 2$^-$ states in the Tl isotopes. Data are from [14-18]. b) Excitation energy of the 9/2$^-$ intruder states relative to the 1/2$^+$ gs in the Tl isotopes, data are from [21].

In the proposed measurements, we will reach ^{179g}Tl (N=98), thus going far beyond the neutron mid-shell at N=104.

b) Magnetic dipole and electric quadrupole moments for the I=9/2$^-$ deformed intruder states

An intruder $I^{\pi}=9/2^-$ configuration is known in $^{181-201}$Tl isotopes, see Fig.1b, in some cases being isomeric, which facilitates atomic spectroscopy measurements. In the spherical shell model language such intruder states are treated as the 1p-2h proton particle excitations across the Z=82 shell gap and their excitation energy is lowered due to extra pairing energy and the strong proton-neutron quadrupole-quadrupole interaction. As shown in [22], these states can equivalently be considered in the deformed mean-field approach, where they are naturally understood as based on the 9/2$^-$[514] Nilsson orbital which lies close to the Fermi surface at a moderate oblate deformation of $\beta_2\sim0.15$. Fig.1b shows that the excitation energy of these states follows a parabolic dependence as a function of neutron number, with a minimum around N=108, which is actually shifted relative to the neutron mid-shell at N=104. This is an interesting observation on its own, which is not fully understood yet. In this respect, it is important to note that, as shown in Fig.1a, the magnetic dipole and electric quadrupole moments for the 9/2$^-$ states in the $^{187m-193m}$Tl isotopes follow quite a smooth trend with decreasing mass number. This could indicate that no drastic change in their intrinsic configuration happens. Indeed the bands built on top of the 9/2$^-$ intruder states in $^{187-197}$Tl isotopes are almost identical, see Fig. 3.14 of [1]. However, the latter phenomenon was discussed in details in studies [15] as being due to an increase in neutron pairing correlations having opposite and compensation effects on the rotational moment of inertia. Finally, as can be seen from Fig. 3.14 of [1] and from Fig.5 of [23], an 13/2$^+$ intruder state and 11/2$^-$ state steeply comes down in excitation energy and might change the character and level sequence in the very neutron deficient thallium isotopes. A small kink (or deviation) of both μ and Q_s moments in ^{187m}Tl could possibly be an indication of such effects.

In the proposed measurement we will reach ^{183m,185m}Tl isotopes, which could help to shed more light on these phenomena.

c) Odd-odd $^{178-186}$Tl isotopes and expected configuration change in ^{180}Tl

The above-described features of the odd-A Tl isotopes should also be manifested in their neighbouring odd-odd Tl isotopes. In the isotopes $^{186-204}$Tl, $[\pi3s^{-1}\otimes\nu i_{13/2}]_{I=7+}$ and $[\pi3s^{-1}\otimes\nu p_{3/2}$ or $\pi3s^{-1}\otimes\nu f_{5/2}]_{I=2-}$ spherical configurations have been observed and for some of them their magnetic moments have been measured, see Fig.1a. This figure clearly demonstrates the same trend for the dipole magnetic moments for the 1/2$^+$, 7$^+$ and 2$^-$ states (see also below the discussion of the Tl charge radii and Figs. 2,3). For example, as discussed in [15], the observed magnetic dipole moment of μ=0.483(8) n.m. for the I=7$^+$ state in ^{188}Tl is well understood based on the additivity rule as being due to the $[\pi3s^{-1}\otimes\nu i_{13/2}]_{I=7}$ spherical configuration (as $\mu(^{187g}$Tl, I=1/2$^+$)= 1.55(6) n.m. and $\mu(^{187}$Hg, I=13/2$^+$)=-1.044(11) n.m.).

By moving towards the lighter Tl isotopes with N=99 and lower, a change of the neutron configuration to $[\pi3s^{-1}\otimes\nu h_{9/2}]_{I=4,5-}$ is expected to happen. This change at the neutron numbers below N=100 was already demonstrated in the neighbouring Pb, Hg and Pt nuclei, e.g. by α-decay studies of ^{179,181}Pb (N=97,99) [23,24,25], or by the observation of the low-lying 9/2$^-$ (or 7/2$^-$ of the $\nu h_{9/2}$ parentage) state in the corresponding isotones of Pt and Hg [21]. Therefore, a change of the ground state spin from presumably I=7$^+$ to I=4$^-$ or 5$^-$ should happen around ^{180,182}Tl (N=99,101). Also, the presence of the $[\pi3s^{-1}\otimes\nu p_{3/2}]_{I=2-}$ configuration cannot be excluded in e.g. ^{182}Tl, as this configuration is well-known for several heavier odd-

odd Tl isotopes. Finally, states due to the coupling of the $i_{13/2}$ and $h_{9/2}$ neutrons to the intruder $\pi h_{9/2}$ configuration could be expected at a relatively low excitation energy in the vicinity of the mid-shell at N=104. Thus, one cannot exclude the coexistence of all these isomers in these nuclei, which would be due to the spin-parity difference between the states of these two configurations.

Therefore, apart of their importance for shape-coexistence studies, the search and characterization (structure and deformation) of the possible isomers in the isotopes ^{178,180,182}Tl are of a crucial importance for our recent observation of the β-delayed fission (βDF) of ^{178,180}Tl [20]. Namely, for the precise determination of the probability for βDF we need to know whether one or two (or even more) states/isomers are present in these nuclei, and which one of them (or all of them?) decays via βDF. This can be achieved via the observation of different HFS patterns for different decay modes (α, β, γ, fission) of these nuclei, the method which was already applied in several studies [19], e.g. for isomer separation in ^{185}Pb [26]

d) Isotope shifts/charge radii variations for Tl isotopes

The charge radii for the isotopes $^{186-208}$Tl s from [14-18] are given in Fig.2 (deduced from the measured isotope shifts), while Fig. 3 compares the Tl and Hg charge radii.

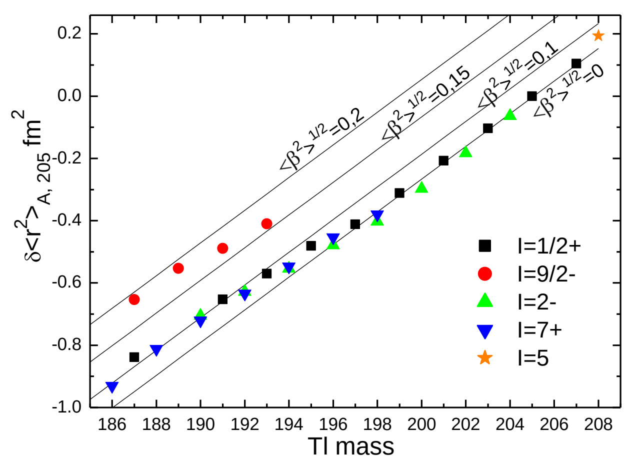

Fig.2. Tl charge radii derived from the measured isotope shifts at the 535 nm line from refs. [14-18]. Predictions of the deformed droplet model for various deformations are shown by solid lines. Note the very similar trends for the I=1/2$^+$, 2$^-$ and 7$^+$ states, and a quite large staggering between the I=1/2$^+$ gs and the 9/2$^-$ intruder states in ^{187,191,193}Tl.

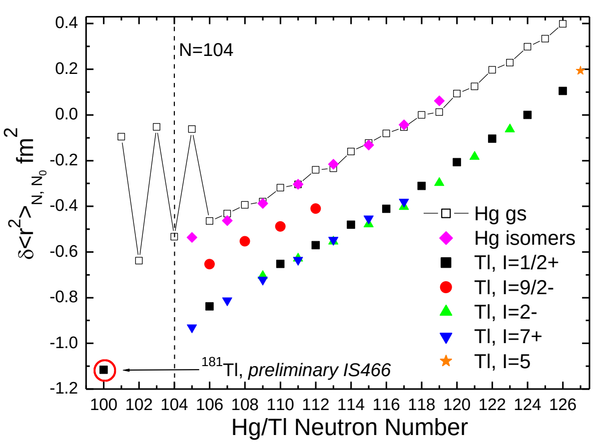

Fig.3. Comparison of the Tl and Hg charge radii. A preliminary value of charge radius for ^{181g}Tl(I=1/2$^+$) from IS466-2 run is also shown. One of the main goals of the proposal is to extend the measurements of the Tl charge radii to ^{179g}Tl (N=98), thus far beyond the neutron mid-shell at N=104, where the strong staggering was observed in the Hg chain.

For the illustration of our motivation for the HFS/IS measurements in the lightest Tl isotopes we will use the data shown in Fig.2,3. A few important points are immediately noticed:

- As seen in Fig.2, the charge radii for the I=1/2$^+$, 2$^-$ and 7$^+$ states follow the same trend and demonstrate a quite small deformation of less than |β_2|~0.1, at least up to ^{186}Tl.. As explained above, this is exactly what is expected for these states, as all of them are based on the dominant spherical $\pi 3s^{-1}$ configuration. This also confirms, that in these cases the valence $\nu p_{3/2}$ (for 2$^-$) and $\nu i_{13/2}$ (for 7$^+$) neutrons can be considered as spectators. However, the coupling of the neutron states with the $h_{9/2}$ proton intruder states should give rise to a strongly deformed isomers in ^{188}Tl and/or ^{190}Tl. The fact that they are not observed is puzzling. The better sensitivity of the in-source laser spectroscopy proposed here, should allow us to search for such isomers.
- A gradual increase in deformation in going away from stability is seen in both I=1/2$^+$ gs and the 9/2$^-$ intruder state (Fig. 2)
- A quite prominent staggering is seen between the I=1/2$^+$ gs and the 9/2$^-$ intruder state in ^{191,193}Tl (Figs. 2)
- A quite large odd-even isotope staggering is also seen in these isotopes.

Therefore, it is important to extend these data to even more neutron-deficient Tl isotopes, towards and beyond the neutron mid-shell at N=104, where all these effects might be exacerbated due to an increased number of valence neutrons and resulting increase of the configuration mixing, and also due to the possible change of the valence neutrons from e.g. $\nu i_{13/2}$ to $\nu h_{9/2}$, as well as the potential influence of the proton $i_{13/2}$ intruder state. Fig. 3 nicely shows that the strong shape staggering sets in in Hg isotopes around the mid-shell at N=104, therefore similar effects can also be expected in the lightest Tl isotopes.

2. Proposed measurements

Here, we summarize the goals of the proposed experimental program.

a) HFS measurements for $^{178-187}$Tl isotopes with the Wind-Mill system [20], by measuring α decays (8 shifts)

In our July 2010 experiment to identify the βDF of the ^{178,182}Tl isotopes, a 'proof-of-principle' measurement of the HFS for the α-decaying isotopes ^{181,182}Tl was performed, see Fig.4. Also, a measurement of the HFS for ^{205}Tl was made by directly counting RILIS-ionized ions with a Faraday Cup.

Fig.4 clearly demonstrates that with a dedicated, stability-controlled measurements, good-quality HFS scans can be obtained. We also measured the counting rates for the Tl isotopes down to ^{178}Tl, which are shown in Table 1. Based on our previous Pb and Po charge radii measurements [8,9] we are confident that reliable HFS measurements will be possible up to ^{179g}Tl (5 α/s). Even ^{178}Tl should also be possible, as its yield is comparable to that of ^{182}Pb and of ^{192}Po, both of which were measured with the yield of ~0.2 ions/s. Charge radii and moments will be deduced from these data.

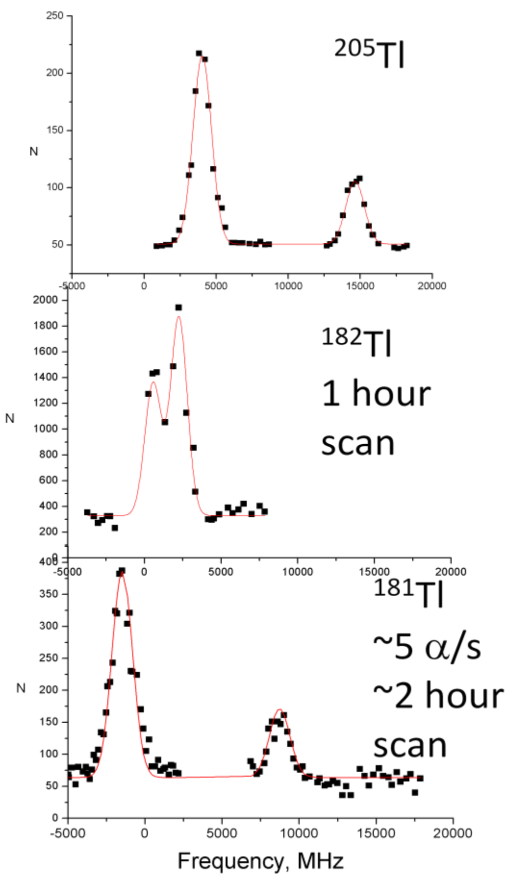

Fig.4 HFS measurements from July, 2010, for ^{205}Tl (Faraday Cup), and for ^{181,182}Tl (α-decay, Wind-Mill). The isotope shift between different isotopes is clearly seen, which allows the charge radii to be extracted. Preliminary data analysis performed by A. Barzakh (PNPI), the (preliminary) value of the charge radius of ^{181g}Tl ($I=1/2^+$) was added to Fig.3.

Since several independent scans are required to reach the necessary precision, we plan to measure at least 3-5 scans for each isotope, depending on the counting rate and complexity of the HFS pattern. The last row of Table 1 provides the shifts estimate for each nucleus, in total 8 shifts are required for this part of the program.

Table 1. Measured α-counting rates of Tl isotopes in the Si detector of the Wind-Mill system, not corrected for the alpha branching ratios or detection efficiency. For the short lived isotopes the half life is shown.

Isotope	^{178}Tl(250 ms) b_α~50%	^{179g}Tl	^{180}Tl b_α=6(4)%	^{181g}Tl b_α<10%	^{182}Tl b_α~1%	^{183m}Tl (60 ms)
Rate, α/s	~0.2	~5	~10	~5	~30(TL)	~5
Shifts	~3	~1	~1	~1	~0.5	~1

b) HFS measurements for stable ^{203,205}Tl isotopes with the Faraday Cup for absolute reference and checking the stability of the system (1 shift)

These measurements are required for a proper ***absolute reference*** of our data in respect of the previously known data for these isotopes. Both due to the large intensity of these stable isotopes, the measurements are not time-consuming (in total 1 shift for both isotopes, for several scans).

These isotopes will also be used intermittently during the measurements of more exotic species to ***routinely monitor the stability of the system*** (e.g. proton beam, laser system). These checks will be performed at 1-2 frequency points only, corresponding to the expected maxima of the respective HFS spectra.

c) HFS measurements for some of the longer-lived β/γ-decaying $^{189-199}$Tl isotopes with the Faraday Cup or by using Ge detectors of the WM system – for IS shift calibration (4 shifts)

We need these points for the ***IS calibration*** on the "old" line (535 nm) which is well suited for $\delta<r^2>$ extraction and used in the earlier studies [15-17]. To calculate reliably field constant and mass shift for the transition at 276 nm used in our work, we need at least 4-5 IS for isotopes which were earlier measured at 535 nm in [15-17]. Besides, these IS should not have linear mass dependence. Most of these isotopes have yields of 10^6-10^7 ions/μC [27], thus they should be reliably and quite quickly measurable with the Faraday Cup technique. In particular, ^{189m,g}Tl (yield ~5×10^7 ions/μC) is important, as HFS data are presently missing for the ground state of this nucleus. In some cases, a care must be taken about the presence of two isomers (for odd-odd: 2^- and 7^+; for odd-A: $1/2^+$ and $9/2^-$) in the same nucleus. However, first of all, it is well-known that the low-spin isomer is typically produced with the much lower yield (up to an order of magnitude). Secondly, the HFS parameters for most of these isomers in $^{189-206}$Tl are well-known and can be fixed in the fitting procedure, which will facilitate their separation. It should also be noted that in July 2010 we have seen $^{188-196}$Tl with the scanner, therefore, we can surely see them with the FC.

d) Mass measurement for ^{180}Tl with the ISOLTRAP (4 shifts)

Though this measurement is not directly related to the atomic spectroscopy program described above, it will provide crucial information for our program on β-delayed fission (IS466/IS466-2 experiments [20]). Namely, for the interpretation of the data extracted from the βDF measurements for ^{180}Tl [20], and in particular, for the determination of the fission barrier of ^{180}Hg, the knowledge of the experimental mass of ^{180}Tl is required with a precision of ~30-50 keV. Based on this value and a known mass of ^{180}Hg, the experimental Q_{EC}(^{180}Tl) value will be deduced. The latter quantity is one of the most important parameters required to determine the fission barrier of ^{180}Hg from the experimentally-deduced value of $P_{\beta DF}$(^{180}Tl) by using well-known approaches, see e.g. [28]. Presently, different mass models give a large range in the predicted mass for ^{180}Tl (thus in the Q_{EC} value), with a spread of predicted values of ~800 keV. Such a large spread would result in an order of magnitude uncertainty in the βDF probability (and vice versa), thus it is important to fix this input value in respective calculations.

As the ^{180}Tl beam does not present any sizeable isobar contaminant (see, [20]), its study at ISOLTRAP should be facilitated. Based on the measured rates from experiment IS466 (~200 ions/μC) and considering the required level of precision, we request 1 shift for the beam preparation through the RFQ, the MR-ToF isobar separator, and the preparation trap, followed by 3 shifts for mass measurement in the precision trap, For details on the experimental setup, experimental procedure, and safety requirements, please refer to the ISOLTRAP proposals by S.Kreim.

In this case, after finishing the Tl HFS measurements, the ^{180}Tl beam will be tuned to the ISOLTRAP for the mass measurement.

IV. Laser system

We have good understanding of the RILIS performance for the Tl isotopes, since it was used already several times in our experiments (IS387, IS463, IS466). The photoionization scheme for the in-source laser spectroscopy of Tl isotopes is presented in Fig. 5.

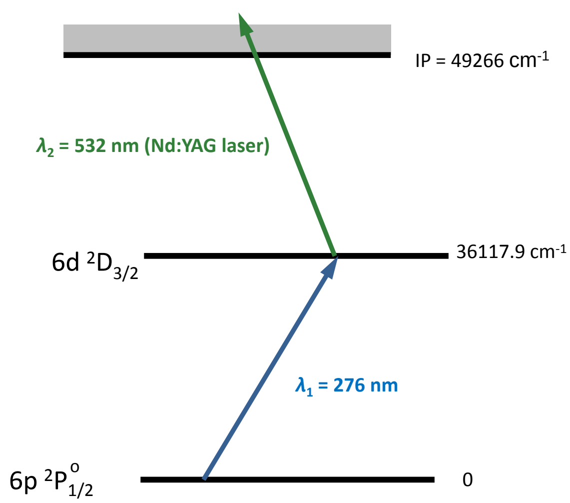

Fig. 5 The photoionization scheme for Tl atoms.

The in-source photoionization spectroscopy of Tl isotopes relies on use of the following hardware of RILIS installation:

1. Narrow band dye laser for scanning the laser wavelength across the optical resonance at λ = 276 nm (first excitation step, see Fig. 5). This laser operating with an intra-cavity Fabry-Perot interferometer provides a visible beam at 552 nm with a spectral line width of 0.03 cm^{-1} which is frequency doubled in a non-linear crystal BBO to generate the UV beam required for resonance excitation of Tl atoms. The dye laser computer control wavelength scanning over large spectral range covers hyperfine splitting and isotope shifts of the 276 nm Tl optical line .
2. High-power Nd:YAG laser *Edgewave INNOSLAB CX16III OE* (pulse repetition rate of 10kHz, output power 100W) for pumping the narrow band dye laser and for non-resonance ionization of the excited atoms of interest (see Fig. 5).
3. High-precision wavelength meters (*CLUSTER ATOS LM-007* and *Ångström HighFinesse WS/7 UV*) for wavelength reading.
4. Dye laser control system for the laser wavelength stabilization and scanning integrated into the data acquisition system.

V. Detection setup for the Present Proposal

The Wind-Mill set-up to be used in the proposed study is practically the same as used in our charge radii measurements of Po isotopes [9] and beta-delayed studies of Tl isotopes [20], see Fig. 6. The ISOLDE beam is implanted in the carbon foil, which is surrounded by 2 Si detectors for α-decay measurements. The implantation and simultaneous measurement are performed in cycles of a few seconds in duration (depends on the half-life of the nuclide). After end of the cycle, the wind-mill rotates and a "fresh" foil is introduced for the implantation. The whole setup will be surrounded by the Ge-detectors of Miniball to allow measurements of particle decays in coincidence with gammas.

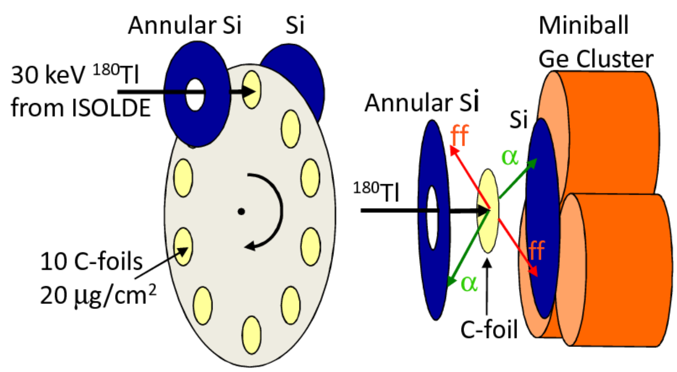

Fig. 6 The "wind-mill" system for the α-decay measurements with 10 thin (~20 µg/cm^2) carbon foils mounted (general view and a zoom of the foil-Si detectors arrangement). Taken from [20].

V. Beam time request

In total, we request 17 shifts of ISOLDE beam time:

- **8 shifts for $^{179-187}$Tl**
- **1 shift for ^{203,205}Tl (for absolute reference and stability control of the system)**
- **4 shifts for some of the isotopes $^{189-199}$Tl (for IS/field shift calibration relative to the previous measurements with the 535 nm line)**
- **4 shifts for the mass measurement of ^{180}Tl with ISOLTRAP**

We also want to notice here, that the detection system and the DAQ used in this experiment are the same as necessary for the continuation of the At RILIS development (initiated by the LoI I-086, spokespersons: A. Andreyev and V. Fedosseev). In November 2010, our collaboration successfully completed the first phase of the At RILIS development (see a separate report to the INTC). This work is planned to be continued in 2011. Therefore, if the beam were granted for the Tl studies, it would be preferable to combine it with the At RILIS development program.

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Appendix

DESCRIPTION OF THE PROPOSED EXPERIMENT

The experimental setup comprises: *a Wind-Mill system with 2-4 Si detectors inside, and 1-2 Ge detectors outside. WM system was successfully used in IS387, IS456, IS466 and I-086, therefore solid understanding of all possible hazards is available.*

For the ISOLTRAP part of the experiment – see standard documents for the ISOLTRAP setup

Part of the Choose an item.	Availability	Design and manufacturing
Windmill	☒ Existing	☒ Used in several previous experiments, e.g. IS466,IS387,IS456, I-086 ☐ To be modified
	☐ New	☐ Standard equipment supplied by a manufacturer ☐ CERN/collaboration responsible for the design and/or manufacturing

HAZARDS GENERATED BY THE EXPERIMENT:

No 'special' hazards is expected (see also the table below)

Additional hazards:

Hazards	*Wind Mill*	*[Part 2 of the experiment/equipment]*	*[Part 3 of the experiment/equipment]*
Thermodynamic and fluidic			
Pressure	-		
Vacuum	Usual vacuum of ISOLDE		
Temperature	-		
Heat transfer	-		
Thermal properties of materials	-		
Cryogenic fluid	LN2 for Ge detectors (150 l)		
Electrical and electromagnetic			
Electricity	Usual power suppliers		
Static electricity	-		
Magnetic field	-		
Batteries	☐		
Capacitors	☐		
Ionizing radiation			
Target material	The C foils where the radioactive samples are implanted are very fragile. Should they break upon opening the Windmill, the pieces are so light that they would become airborne. Great care must be taken when opening the system and removing them (slow pumping/venting protective equipment: facial mask).		
Beam particle type (e, p, ions,	-		
Beam intensity	-		
Beam energy	-		
Cooling liquids	-		
Gases	-		

Calibration sources:	☒		
• Open source	☒		
• Sealed source	☐ [ISO standard]		
• Isotope	239Pu, 241Am, 244Cm		
• Activity	1 kBq each		
Use of activated material:	-		
• Description	☐		
• Dose rate on contact and in 10 cm distance	-		
• Isotope	-		
• Activity	-		
Non-ionizing radiation			
Laser	-		
UV light	-		
Microwaves (300MHz-30 GHz)	-		
Radiofrequency (1-300MHz)	-		
Chemical			
Toxic	Pb shielding (~20 bricks)		
Harmful	-		
CMR (carcinogens, mutagens and substances toxic to reproduction)	-		
Corrosive	-		
Irritant	-		
Flammable	-		
Oxidizing	-		
Explosiveness	-		
Asphyxiant	-		
Dangerous for the environment	-		
Mechanical			
Physical impact or mechanical energy (moving parts)	The chamber is heavy and needs to be handled with care during installation/ removing.		
Mechanical properties (Sharp, rough, slippery)	-		
Vibration	-		
Vehicles and Means of Transport	-		
Noise			
Frequency	-		
Intensity	-		
Physical			
Confined spaces	-		
High workplaces	-		
Access to high workplaces	-		
Obstructions in passageways	-		
Manual handling	-		
Poor ergonomics	-		

0.1 Hazard identification

3.2 Average electrical power requirements (excluding fixed ISOLDE-installation mentioned above): Negligible