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Proposal to the INTC Committee

Laser Spectroscopy Studies in the Neutron-Rich Sn Region

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Summary
In this addendum to the experiment IS383, we propose to carry on the study of the neutron rich tin isotopes and isomers using laser spectroscopy to determine the magnetic moment μ and the variation of the mean square charge radius ($\delta\langle r_c^2\rangle$). After having measured the $\delta\langle r_c^2\rangle$ of the even isotopes up to A=132 with the COMPLIS experimental set-up and thus proved that this set-up is perfectly adapted for this kind of studies, we want to complete our data by measuring $\delta\langle r_c^2\rangle$ of the heavier isotopes as far from stability as possible and μ of the odd isotopes and isomers.
The COMPLIS set-up will be used with the UC_2 target associated to the hot plasma source for the study up to mass 134. To perform laser spectroscopy on the heavier isotopes, the RILIS set-up has to be upgraded *i)* by injecting our narrow bandwidth cw laser inside the cavity of the RILIS laser to improve the frequency resolution and *ii)* by modifying the geometry of the source to reduce the Doppler width. Some tests have already been performed recently and the resolution of the laser itself has been improved by a factor of 7.

1. Physics case

The aim of a laser spectroscopy experiment is to measure the variation of the mean square charge radius ($\delta<r_c^2>$) over an isotope series and the static moments (magnetic, quadrupole) of the nucleus using the isotope shift and the hyperfine structure. This kind of experiment can also be applied to unambiguously determine the nuclear spin by counting the number of hyperfine transitions. The COMPLIS experimental set-up, which is a typical laser spectroscopy experiment, has proved over the last years to be perfectly adapted to study such properties of the nucleus very far from stability ([Le 97], [Le 99], [Ve 00], [Le 00], [Sa 00]). We are now studying the effect of the shell closure in a magic number region far from stability which is that of the tin isotopes around ^{132}Sn (N=82). The physics motivations have already been presented in detail in the original proposal. In this addendum, we are going to show the first results we got on tin with COMPLIS and what is our plan to continue our study of this element.

Out of the 36 shifts asked for this complete experiment, 12 shifts were allocated to show the feasibility of the experiment with different experimental set-up.

2. Experimental methods

The measurement of the isotope shift and hyperfine structure requires high resolution laser spectroscopy. At ISOLDE, such studies can be performed using either the COLLAPS, the COMPLIS or even the RILIS experimental set-up. COLLAPS gives a very good frequency resolution but needs a rather pure ion beam, COMPLIS has a medium resolution but can work with a large ion beam background and RILIS has a low resolution but an excellent efficiency. This last system was designed mainly to obtain highly efficient ion source. So the spectral resolution was not the main priority.

Half of the allocated shift were used with COMPLIS which was outlined for tin. We used the UC_2 target with the hot plasma source instead of the laser ion source since this latter gives a relatively pure tin ion beam but with 50 times more Cs at mass 132 which can be ionised by our lasers giving much background. Using the UC_2 target with the hot plasma source, the beam background did not prevent us to perform the experiment. Indeed, at mass number 132, tin represents 0,24 % only of the nuclei produced. But only the Cs contamination is perturbing. The experimental conditions were already described in the original proposal so we will only present the results we obtained. The transition we have used is the $5s^25p^2\ ^3P_0 \rightarrow 5s^25p6s\ ^3P_1$ laser excitation step at 286 nm for which the hyperfine splitting is about 7 GHz for ^{117}Sn. We measured for the first time the isotope shift of the even $^{126-132}$Sn nuclei giving access to the $\delta<r_c^2>$ between these isotopes with relatively small error bars. The experimental spectra are presented on the Fig. 1.

The efficiency we measured is 10^{-5}, which means that we can hope to reach atoms produced as 10^6/s (like ^{134}Sn for example). For this, we have to be in best conditions that is using a new target at the beginning of a series of runs. This was not the case during our test run where the production of ^{132}Sn was 100 times lower at the end of the run compared to that obtained with the target test made in April 1999.

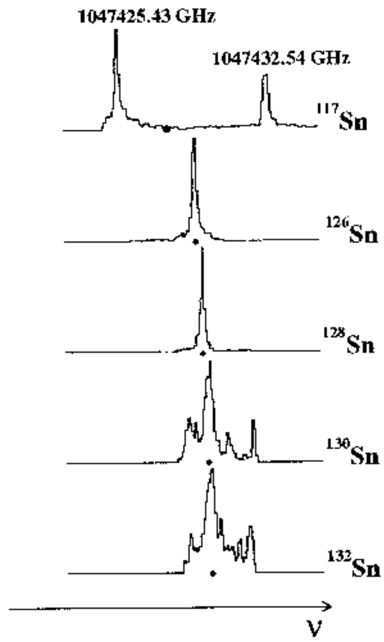

Figure 1 : Measured isotope shift in the heavy tin isotopes with COMPLIS.

The experimental isotope shift consists of a mass shift $\delta\nu_{MS}$ and a field shift $\delta\nu_{FS}$; it is from this last contribution that $\delta<r_c^2>$ can be extracted : $\delta\nu_{FS}^{AA'} = K.F_\lambda.\delta<r_c^2>^{AA'}$ [To 85], where K=0.975 [To 85] and F_λ=3.35(20) GHz/fm^2 [Pi 90]. Using formula (2) in [An 86] but with the correct values of F_λ and $\delta<r_c^2>^{124,116}$=0.442(5) [Pi 90], one can avoid to introduce the specific mass shift which is very difficult to estimate. The updated $\delta<r_c^2>$ curve is presented in Fig 2.

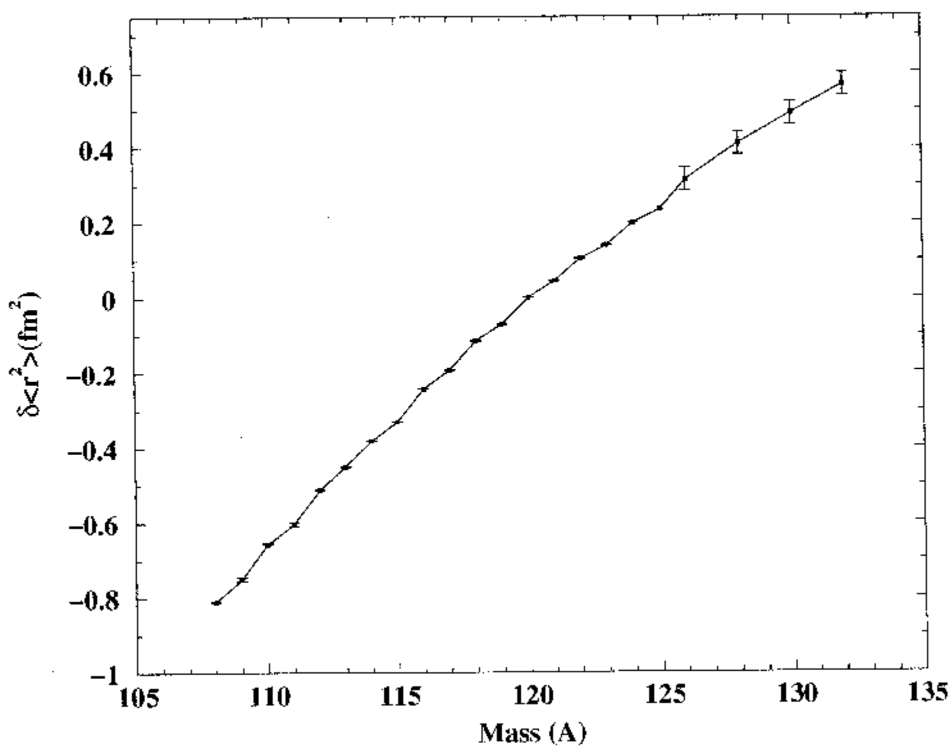

Figure 2 : Updated mean square charge radius variation in the tin isotopes from A=108 to A=132 (from [An 86], [Eb 87] and our measurements for A=126, 128, 130, 132)

At the first order, the mean square deformation variation $\delta<\beta^2>$ can be extracted via:

$$\delta < r_c^2 >^{A,A'} = \delta < r^2 >_{sph}^{A,A'} + \frac{5}{4\pi} < r^2 >_{sph} \delta < \beta_2^2 >^{A,A'},$$

where $\delta<r^2>_{sph}$ and $<r^2>$ are calculated according to the prescription of Myers and Schmidt [My 83]. Knowing $|\beta_2|^{120}$ from B(E2) [Ra 89], one can deduce $<\beta_2{}^2>^{1/2}$ for each nucleus. The evolution of the deformation is shown in Fig. 3. Of course the deformation obtained for ^{132}Sn is almost zero which confirms that this doubly magic nucleus located far from stability is still spherical.

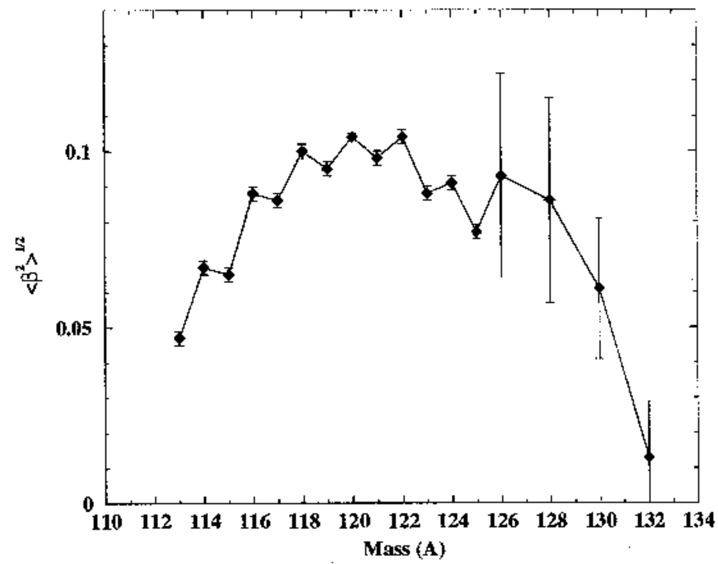

Figure 3 : Deformation parameters extracted from the isotope shift.

To conclude on our new data, the question asked in the original proposal, is there a kink or not in the $\delta<r_c^2>$ at A=132, remains open. The comparison is made with some other elements of this region in Fig. 4.

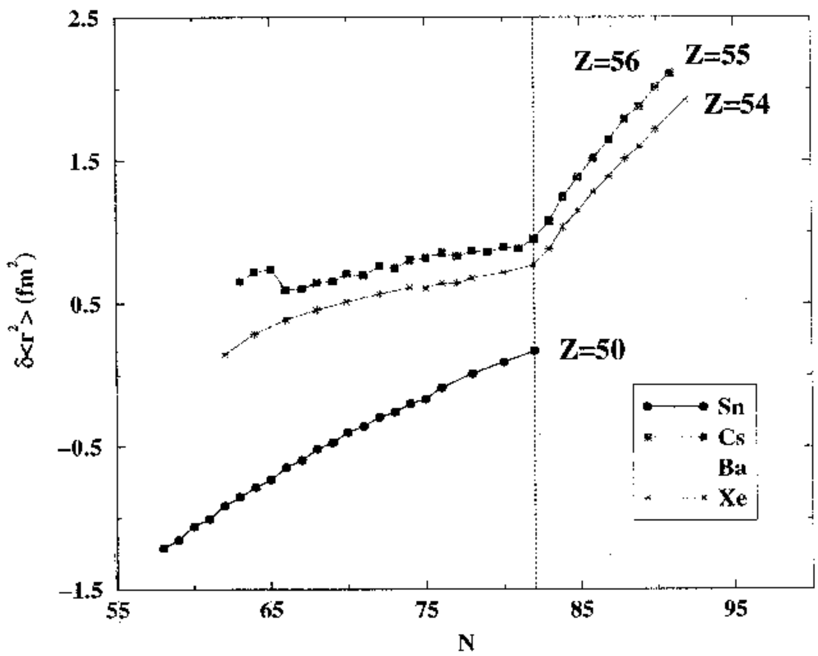

Figure 4 : Change in the mean square charge radius of some elements in the tin region.

Moreover, one can now compare our measurements with theoretical predictions [Re 97, Gi 98] (see Fig. 5). A poor agreement is found for the Skyrme I force, but more precise measurements up to 132 and data beyond are needed to settle between the different remaining models.

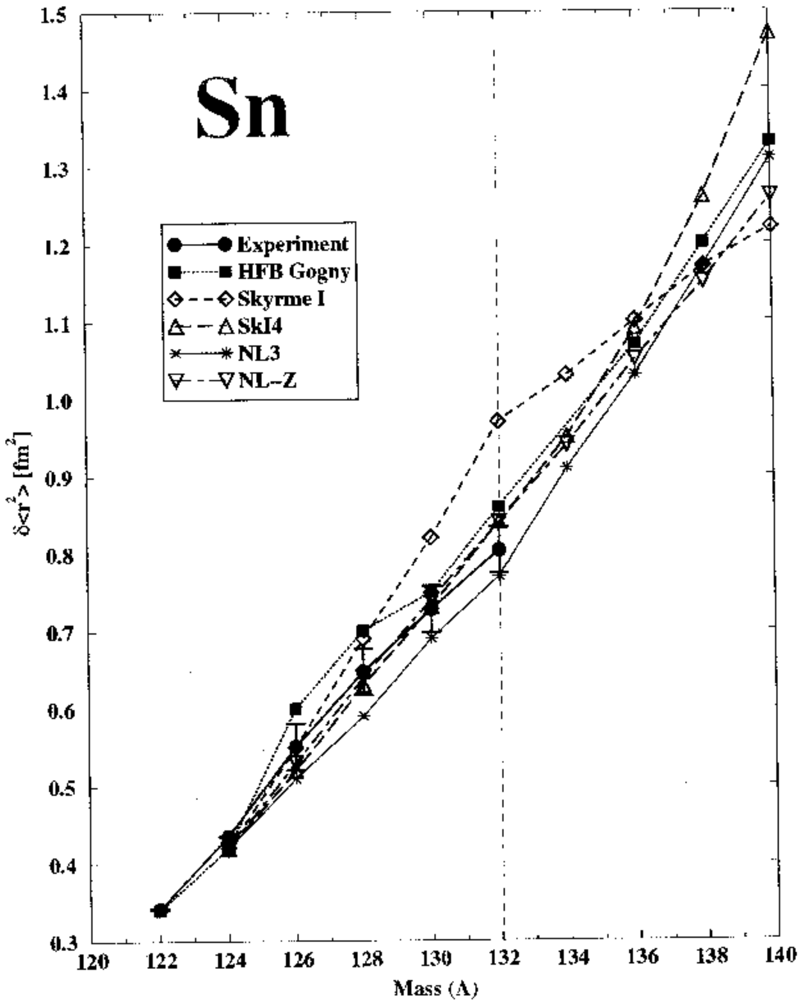

Figure 5 : $\delta < r_c^2 >$ calculated for mean field theory (HFB Gogny, SkyrmeI and SkI4 forces) and relativistic mean field model (NL3 and NL-2 forces)[Re 97, Gi 98]. The curves have been normalized at A=122.

3. Beam time request

Out of the 12 allocated shifts for testing the experiment, 6 remains to be used with the COLLAPS experimental set-up. They will be used for testing the following :

The resolution we typically obtain with COMPLIS is about 200 MHz which is rather sufficient to extract a measurable isotope shift. With COLLAPS, the expected resolution is about 3 times better that is about 60 MHz. In the original proposal, we wanted to perform the experiment with COLLAPS using the $5s^25p^2\ ^1S_0 \rightarrow 5s^25p6s\ ^3P_1$ transition at 563 nm or the $5s^25p^2\ ^3P_0 \rightarrow 5s^25p6s\ ^1P_1$ transition at 452 nm both decaying in the UV. The first transition has a quite large hyperfine splitting (9 GHz for ^{119}Sn) but decays with a 286 nm transition that cannot be transmitted to the detector by our light guide (it cuts at about 300 nm). The 563 nm transition decay can be transmitted by the light guide (326 nm) but has a very small hyperfine splitting (100 MHz for ^{109}Sn which has a 7/2 spin). So the precision we gain in resolution would be annihilated by this small hyperfine splitting : so the relative resolution which is the ratio 'hyperfine splitting/resolution' will be worse with this transition with COLLAPS that with the transition we use with COMPLIS. It is thus very difficult to measure a magnetic moment of an odd nucleus with the 563 nm transition. We can only gain in the precision on the centre of gravity of the hyperfine spectra which allows to increase the precision on the $\delta<r_c^2>$.

However, we can use another transition which is the $5s^25p^2\ ^1D_2 \rightarrow 5s^25p6s\ ^1P_1$ at 326 nm (decaying at 452 nm) which has the advantage to give a different number of hyperfine line following the odd nuclei spin (this not the case for the precedent transitions which have 3 lines for all the odd nuclear spins). So even if the hyperfine splitting is small, we will be able to confirm or not the spins of the odd ground states and isomers which are all in parenthesis from mass number 127. This can only be done with COLLAPS.

However, we already know that COMPLIS is operational to continue our study of the heavy tin isotopes until mass 134. The Figure 6 represents all the series of the isotopes and the isomers we can measure with the half-life of each one. Beyond mass number 134, using RILIS could be a good solution to increase the efficiency. But in this case, such experiments near the target need a modified configuration of the system in order to improve the resolution that is now insufficient.

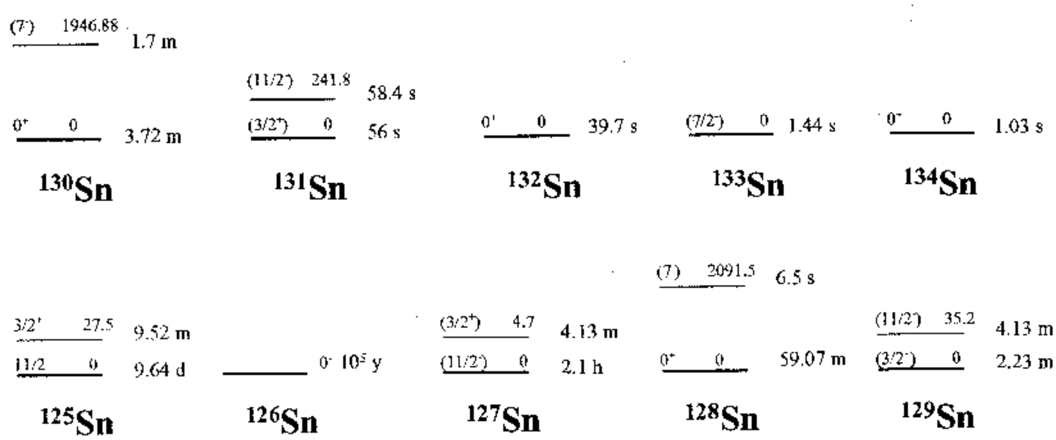

Figure 6 : Series of tin isotopes and isomers we can measure with COMPLIS

We first plan to measure these 9 isotopes ($^{126-134}$Sn) and 6 isomers ($^{125m,127m-131m}$Sn). For the even isotopes, only one line is expected and for the odd isotopes and isomers, 3 lines are expected. So the recording time for an even isotope is shorter that for the odd ones. On average, one can estimate it at 1.5 shift for one even isotope (for example 1 shift for ^{126}Sn and 3 shifts for ^{134}Sn) and at 3 shifts for an odd one. This makes a total of **19.5 shifts** to which we have to add **9 shifts** for the study of the 6 isomers (the isomers are obtained in the same time than the ground state, but we need more statistics for them since the signal is generally weaker). So the total demand for COMPLIS represents **29 shifts**.

Direct measurements on the RILIS

For Sn isotopes heavier than A=134, the Sn yield is not high enough to perform laser spectroscopy measurements using either the COLLAPS or the COMPLIS set-up. Therefore, such measurements should be done directly at the ion source. To get accurate results, the frequency resolution of the RILIS laser set-up has to be improved. There are two contributions to this resolution : one coming from the laser itself, and the other coming from the large velocity dispersion of the atoms in the ionisation tube giving rise to a strong Doppler effect which enlarges the line to some GHz. The best first laser excitation step bandwidth ever obtained is about 4 GHz which is too large to measure any tin isotope shift. So we improved this resolution by injecting, with an optical fibre, the cw beam of our laser at the same wavelength (which has some few MHz FWHM at the output of the optic fibre) inside the cavity of the RILIS laser. In this case, the linewidth of the seeded laser will be strongly reduced. An example of a spectrum is showed in Fig. 7. In the best conditions, the resolution is improved by a factor of 7 to reach 600 MHz FWHM.

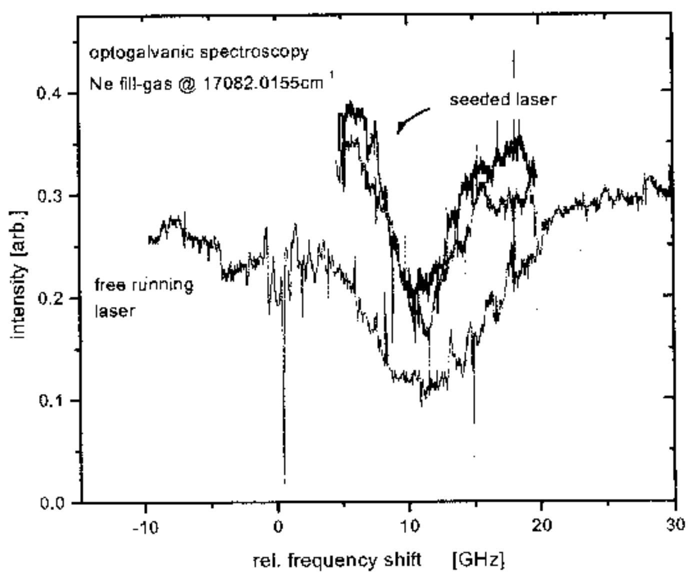

Figure 7 : Spectra obtained from an optogalvanic signal by scanning a Ne resonance at 17082 cm^{-1} with and without seeding the RILIS oscillator.

The second contribution has also to be reduced and for this, we propose to modify the geometry of the tube where the ionisation takes place. An ideal solution would be to cross the first excitation laser beam perpendicularly to the ionisation laser beam. In this case, the velocity dispersion seen by the 2 lasers is considerably reduced. But for geometry reasons, it is impossible to send a laser at 90 degrees of the ion source (see Fig. 7A). So, to avoid as much as possible Doppler broadening, we can however send the 2 laser beams perpendicular to the direction of the outcoming atoms. We can thus bend the ionisation tube at the end to send the atoms vertically. The principle of the modification is presented Fig. 8. This modification will of course reduce the efficiency but improve the frequency resolution. Moreover, if we apply a negative voltage before the atoms enter in the tube, a lot of the parasitic ions (which are essentially Cs) come back to the target.

This new laser spectroscopy set-up needs to be tested and we require **6 shifts** for this. If these modifications allow us to perform measurements on tin, this method will open a wide range for the study of a lot of isotopes very far from stability.

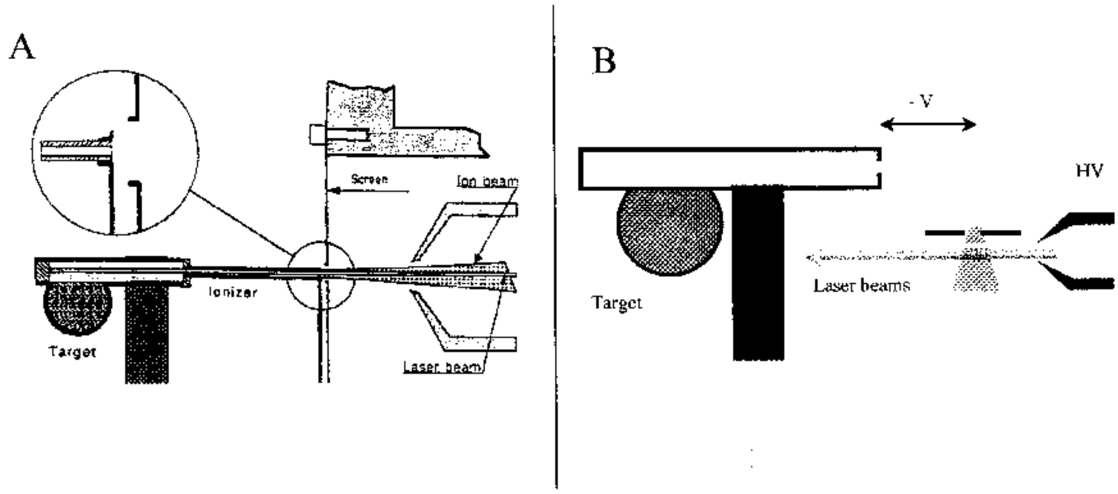

Figure 8 : Present ion source (A) and proposed modification for laser spectroscopy (B).

4. Summary of the beam time request

• Study of the even $^{126-134}$Sn	**8 shifts**
• Study of the odd $^{127-133}$Sn	**12 shifts**
• Study of $^{125m,127m-131m}$Sn	**9 shifts**
• Testing high resolution laser spectroscopy at RILIS	**6 shifts**
Total requested shift	**35 shifts**

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