EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

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

In-source laser spectroscopy of neutron-deficient lutetium isotopes

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Abstract: This proposal seeks to perform in-source laser spectroscopy on the neutron-deficient lutetium isotopes using the Perpendicularly-Illuminated Laser Ion Source and Trap (PI-LIST) setup. This will provide nuclear spins, magnetic dipole moments, electric quadrupole moments and charge radii measurements allowing investigation into the evolution of nuclear deformation toward the proton emitter ^{151}Lu, with the future aim of measuring its charge radius. Additional insight will be gained into how the nuclear structure changes as the $N = 82$ shell closure is approached across a region rich in triaxiality.

Summary of requested shifts: 15 shifts

1 Introduction

This proposal seeks to measure the nuclear structure of the neutron-deficient lutetium isotopes by performing in-source laser spectroscopy utilizing the Perpendicularly-Illuminated Laser Ion Source and Trap (PI-LIST) setup. This will provide nuclear spins, magnetic moments, quadrupole moments and charge radii measurements, investigating the evolution of nuclear deformation towards the proton emitter ^{151}Lu. With the ultimate aim of measuring the charge radius of ^{151}Lu after the Long Shutdown 3, this proposal will lay the groundwork by studying the neutron-deficient lutetium isotopes from ^{161}Lu. We will gain insight into how the nuclear structure changes as the $N = 82$ shell closure and proton drip line are approached, comparing our measurements to the theoretical nuclear BSkG models that predict triaxiality in this region. This proposal follows our Letter of Intent (LoI278) [1] which, motivated by the study of ^{151}Lu and already endorsed by the INTC, tested the sensitivity of a new atomic transition to the charge radii of these isotopes.

2 Physics Motivation

At the edge of the neutron-deficient nuclear landscape, the proton drip line marks the region where proton emission from the nucleus becomes energetically allowed. As the neutron number decreases, so does the proton separation energy, resulting in nuclei whose protons are no longer bound by the nuclear force. However, these unstable nuclei have a certain lifetime as the protons can only pass through the Coulomb and centrifugal potential energy barrier by quantum tunneling. With the proton existing outside the nuclear potential, the proton-unbound nucleus is expected to display an enhanced charge radius due to the larger spatial extent of the proton distribution. This has yet to be measured experimentally and has become an exciting area of interest in recent years [2, 3, 4, 5].

Since its discovery [6], the study of proton radioactivity by means of emitted proton energies, Q-values and half-lives has been a thriving field in nuclear physics [7]. As the potential energy barrier is strongly influenced by the centrifugal potential experienced by the proton, the rate of proton decay is extremely sensitive to the orbital angular momentum of the proton in the nucleus, so the correct nuclear spin assignment is essential for reproducing the experimental decay rate in nuclear models [8]. For many proton emitters, the rate of proton decay can only be explained by the inclusion of nuclear deformation. While the proton-emitting ^{150,151}Lu lie very close to the $N = 82$ shell closure, where one expects nearly spherical shapes, the lighter proton-emitters lie much further from the shell closure. As such, for ^{150,151}Lu, the proton decay rates (for the ground and isomeric states) can only be described by the assignment of oblate deformations [9, 10, 11]. In contrast, the original observation of the proton emission in ^{141}Tm was first interpreted based on prolate deformation [12], in line with the predictions of the time based on axially-symmetric models [13]. More recently, the inclusion of triaxiality in the ground state has been considered in the interpretation of the proton emission in ^{140,141}Ho [14, 15], ^{144,145}Tm [16, 17] and ^{149}Lu [18].

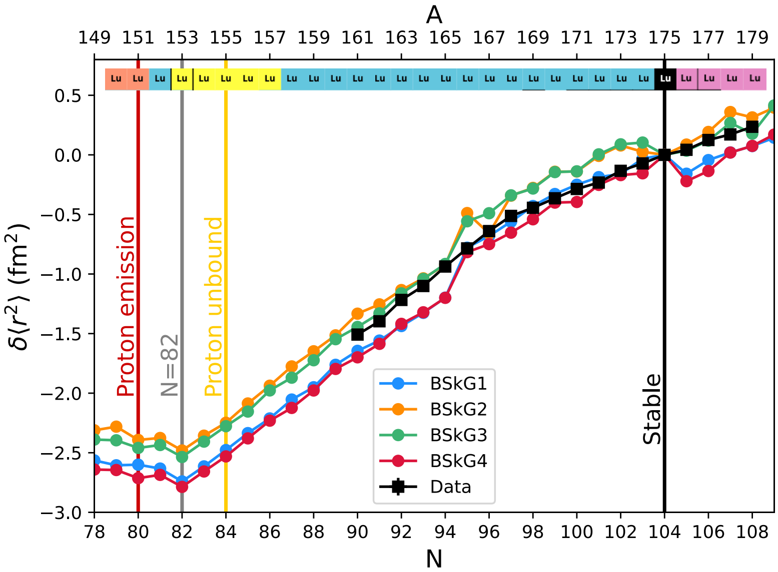

Figure 1: Previous charge-radii measurements (black squares) of the lutetium isotopes, $^{161-178}$Lu [19], compared with theoretical predictions (circles) from the BSkG model series 1-4 [20, 21, 22, 23].

In such cases, it is only by comparison between experimental values (e.g., proton decay rates) and theoretical calculations that assignments of nuclear spin and deformation can be deduced. In order to provide definitive answers to these questions, a direct and nuclear-model independent measurement of the deformation of proton-emitting nuclei is required. Laser spectroscopy allows us to measure the nuclear spin, the static deformation (by means of the quadrupole moment), and how the dynamic deformation changes (charge radii) as the proton drip line is crossed. Furthermore, measurement of the magnetic moment provides information on the configuration of the valence particles in the nucleus, and thus the proton orbital from which the proton is likely emitted. With the proton-emitting ^{151}Lu needing a deformed framework to explain the observed properties, direct measurement of the deformation of the lutetium isotopes will provide insights into how the deformation changes as the proton drip line is crossed.

While our ultimate aim is to measure the charge radius of the proton emitter ^{151}Lu, this proposal seeks to lay the groundwork for such a measurement after the Long Shutdown 3, when we hope to benefit from the higher yields expected with the increase in proton energy to 2 GeV. Those measurements will require a thorough understanding of the isotopic chain reaching out towards the isotopes of interest. Here, we seek to investigate how the nuclear structure changes as the proton drip line (at ^{155}Lu) and $N = 82$ shell closure (at ^{153}Lu) are approached. Previous measurements of the charge radii of the lutetium isotopes down to ^{161}Lu are shown in Figure 1. By measuring the charge radii across the proton drip line at ^{155}Lu ($N = 84$), and towards the proton emitter ^{151}Lu ($N = 80$), the evolution of nuclear deformation can be investigated. Additional insight into the stability of the nuclear structure and shell-effects will be gained as we approach the $N = 82$ shell closure. For example, the presence and magnitude of the odd-even staggering of the charge radii, the adherence (or deviation) of the magnetic moments to the single-particle picture, and the trend of the static (quadrupole) deformation as we approach $N = 82$.

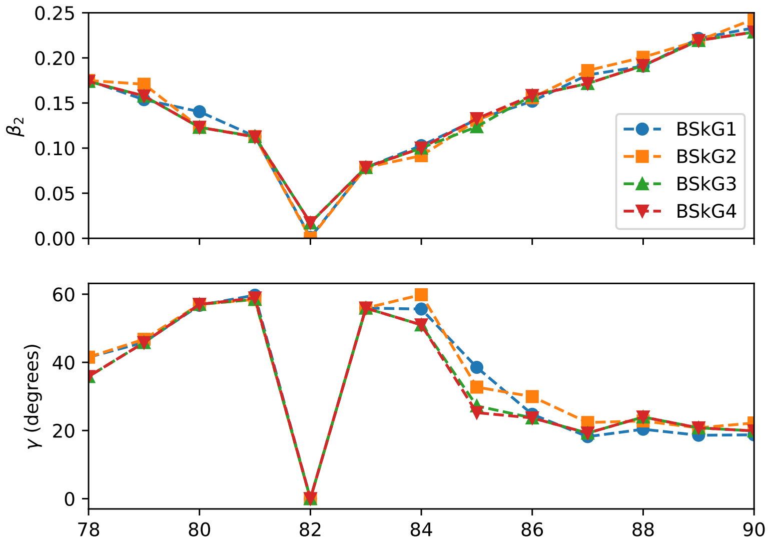

Figure 2: Theoretical predictions from the BSkG model series 1-4 [20, 21, 22, 23] predicting the nuclear deformation, (above) total quadrupole deformation β_2 and (below) triaxiality angle γ, for the neutron-deficient lutetium isotopes.

In addition to investigating the axially-symmetric quadrupole deformation, the impact of triaxiality on the shape of nuclei in the rare-earth region has also long been inferred [24, 25, 26] and will be explored. Figure 1 also presents theoretical predictions for the charge radii from the Brussels-Skyrme-on-a-Grid (BSkG) model series. The BSkG models, BSkG1 [20], BSkG2 [21], BSkG3 [22] and BSkG4 [23], employ mean-field calculations with a Skyrme energy density functional. The BSkG models are fitted to all known nuclear masses and charge radii, offering a very good description of absolute radii, and allow for triaxial and octupole deformation. Those models support the suggestion of the rapidly varying deformation from the proton emitters ^{150,151}Lu to the lighter cases mentioned earlier. Figure 2 presents the predictions of nuclear deformation of the four BSkG models for the neutron-deficient lutetium isotopes. Figure 2 shows how the quadrupole deformation is expected to decrease with decreasing neutron number, reaching zero as expected at the $N = 82$ shell closure. By contrast, the triaxiality angle γ is expected to increase from 20° (triaxial) at $N = 90$ (^{161}Lu) to 60° (oblate) at $N = 84$ (^{155}Lu). With measurement of the charge radii and quadrupole moments of the lutetium isotopes from ^{161}Lu towards ^{155}Lu, we can challenge these theoretical predictions.

Furthermore, the neutron-deficient lutetium isotopes have a rich structure of ground and isomeric states. For example, the level structure of the ground and isomeric states of lutetium isotopes ^{154,160}Lu remain an open question [27, 28]. Future experiments after the Long Shutdown 3 will also aim to exploit the selectivity of the PI-LIST setup to perform laser-assisted decay spectroscopy with the ISOLDE Decay Station (IDS) on the ground or isomeric states of these nuclei. IDS will provide the means of answering questions that remain about the level scheme, alpha-emission energies and lifetimes of these isotopes.

3 Experimental Method

This proposal seeks to use a Ta-foil LIST target to perform in-source laser spectroscopy in the PI-LIST geometry in order to measure the hyperfine structure of neutron-deficient lutetium isotopes. Based on the Laser Ion Source and Trap (LIST) device, in the 'Perpendicularly-Illuminated' geometry the laser beam is perpendicularly aligned with the atom beam. This leads to a significant reduction of thermal Doppler broadening, thus improving the resolution of the hyperfine structure [29]. Resolution improvements of around a factor 10 compared to classic in-source laser spectroscopy can be achieved, with linewidths as low as 100 MHz demonstrated previously [30]. Recent online tests performed on the Ac ($Z = 89$) isotopes at ISOLDE have produced linewidths around 200 MHz [29].

Using the PI-LIST setup will allow us to benefit from both the suppression of the large surface-ionized contamination (created from other lanthanides) and the higher resolution of the perpendicular laser geometry to measure the neutron-deficient lutetium isotopes. Measurement of the hyperfine structure of the lutetium isotopes will allow extraction of the nuclear spin, magnetic dipole moment, electric quadrupole moment, and change in mean-square charge radii. This will provide insight into how the nuclear structure changes as the proton-drip line at $N = 84$ and the neutron-shell closure at $N = 82$ are approached, paving the way for measuring the nuclear properties of the proton emitter ^{151}Lu.

Results from LoI278

One aim of our Letter of Intent was to measure the yields of the lutetium isotopes. However, the Ta-foil LIST target used for our LoI had already suffered from significant target degradation, which meant that yields of the lutetium isotopes were significantly reduced. The target then suffered from a vacuum leak, which prematurely ended our tests. With the time available, we focused our efforts on determining the best resonance ionization scheme to use in future studies. The hyperfine structures of ^{175}Lu, ^{173}Lu, ^{171}Lu, ^{169}Lu, ^{167}Lu, ^{165}Lu, ^{163}Lu and ^{162}Lu isotopes were measured, probing a new 299-nm transition to test its sensitivity to the charge radii.

Using a King-plot analysis, we have compared the sensitivity of the 299-nm transition to the well-known 451-nm transition [19], see Figure 3. From the atomic field-shift factor (F) of a particular transition, the sensitivity of the isotope shift (more specifically, the field-shift component of the isotope shift) to the changes in the charge radius can be determined. Extraction of F_{299} for the 299-nm transition concluded that this new transition was not significantly more sensitive to the isotope shift. While the resonant ionization scheme of 299-nm + 888-nm has an efficiency of 53%, compared to 37% for the 451-nm + 460-nm scheme [31], given the relatively small efficiency increase, it was decided to use the well-known 451-nm transition for this proposal. This allows us to benefit from well-known reference measurements with which to benchmark our results.

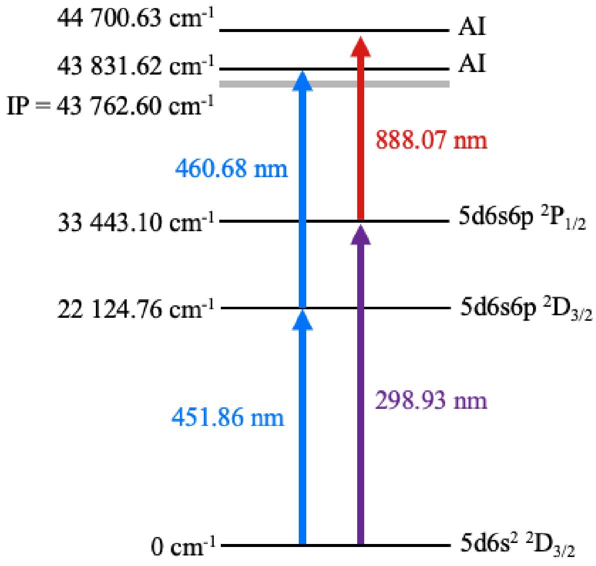

Figure 3: Resonance ionization schemes for lutetium. The 451-nm resonant excitation step was used in previous laser-spectroscopy measurements [19] and will be used again in this work.

Therefore, the hyperfine structure studies of the lutetium isotopes will be measured with in-source laser spectroscopy using the 451-nm + 460-nm two-step resonance ionization scheme. In addition to the standard 'narrow-band' laser operation of RILIS, high-resolution laser light will be produced via collaboration with RILIS and CRIS, whereby continuous-wave laser light from the CRIS laser laboratory is used to seed an injection-locked TiSa system at RILIS. Such a setup has already been successfully demonstrated [32, 33] and will allow the hyperfine structure to be resolved. The resonant ions will be measured by an ISOLDE Faraday cup (providing total beam current) and a magnetof detector located in the central beam line CB0 (providing time-resolved single-ion detection). Simultaneous measurements of the laser frequency and the ion count rate will be performed, as demonstrated in our Letter of Intent.

4 Beam Time Request

There are no known production yields for the lutetium isotopes using 1.4 GeV protons from the PSB. As presented in our Letter of Intent [1], Figure 4 shows historic production yields (full markers) from the SC with 0.6 GeV protons, alongside simulations (dashed lines) for in-target production rates (ABRABLA simulations for Ta foil and 1.4 GeV beam energy) and out-of-target production estimates (empty markers) using two different approaches. Estimate 1 [34] and 2 [35] both use the in-target production ABRABLA simulations with 1.4 GeV protons on a Ta-foil target. Estimate 1 assumes a lutetium release behaviour similar to promethium and applies this to the in-target production to estimate the

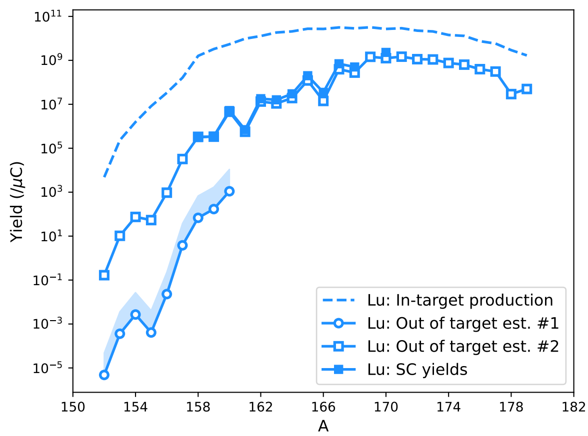

Figure 4: In-target production yield ABRABLA simulations (lines) with 1.4 GeV protons and from-target production yield estimates (empty markers) for lutetium isotopes, using a Ta-foil target. Production yield estimates are given for two approaches (circles and squares). Historic yields (full markers) from the SC with 0.6 GeV protons are also shown.

Isotope	Spin	Half-life	Estimated yield (ions/s)	Requested shifts	New results
^{175}Lu	$7/2^+$	Stable	>1,100	2	Setup, no protons
$^{175-161}$Lu	$7/2^+$ - $1/2^+$	Stable - 77 s	>1,100	3	Reference and benchmarking
^{160g}Lu	?	36.1 s	2,200	2	I, μ, Q, $\delta\langle r^2\rangle$
^{160m}Lu	?	40.0 s			I, μ, Q, $\delta\langle r^2\rangle$
^{159}Lu	?	12.1 s	340	1	I, μ, Q, $\delta\langle r^2\rangle$
^{158}Lu	$(2)^-$	10.6 s	140	1	I, μ, Q, $\delta\langle r^2\rangle$
^{157g}Lu	$(1/2^+, 3/2^+)$	7.6 s	8	3	I, μ, Q, $\delta\langle r^2\rangle$
^{157m}Lu	$(11/2^-)$	4.8 s			I, μ, Q, $\delta\langle r^2\rangle$
^{156g}Lu	$(2)^-$	494 ms	0.04	5	$\delta\langle r^2\rangle$
^{156m}Lu	$(9^+, 10^+)$	198 ms			I, μ, Q, $\delta\langle r^2\rangle$

Table 1: Isotopes of interest, half-lives, estimated yields, requested shifts and potential new results. We note that the I, μ and Q values for ^{156g}Lu are also unknown but are not expected to be measured in this work due to employing the lower-resolution collinear LIST mode for these measurements.

out-of-target production yields. Estimate 2 extrapolates the release fraction parameters from the SC yields with 0.6 GeV protons to the in-target production simulations with 1.4 GeV protons, in order to calculate the out-of-target production estimates for lutetium.

While our Letter of Intent intended to measure the yields of the lutetium isotopes, the degraded target did not allow accurate measurements to be taken. However, before the Ta-foil target degraded, the thulium yields were investigated. These yields, measured in collinear LIST mode, were shown to follow the predictions of estimate 1, as shown in Figure 2 of Ref. [4]. Thus, given the success in predicting the thulium yields with the same Ta-foil LIST target, we use these yield estimates for the lutetium isotopes for our shift request, as presented in Table 1.

We request a total of 15 shifts to perform hyperfine structure measurements of the neutron-deficient lutetium isotopes, as outlined in Table 1. The shift allocation is based on simulated spectra with yields assuming $2\,\mu$A of proton current, and realistic measurement background conditions that have been achieved in previous runs. Figure 5 shows these simulations for the most exotic cases and the respective total measurement time requested to achieve sufficient statistics to meet the experiment goal in the best-suited LIST operation mode.

We note that this proposal nicely complements other laser spectroscopy investigations using a Ta-foil LIST target that are planned for 2025 studying the promethium [36] and thulium [4] isotopes. We hope that such complementary measurements will allow for ease of scheduling due to the demand for the LIST targets.

Summary of requested shifts: 15 shifts of radioactive beam

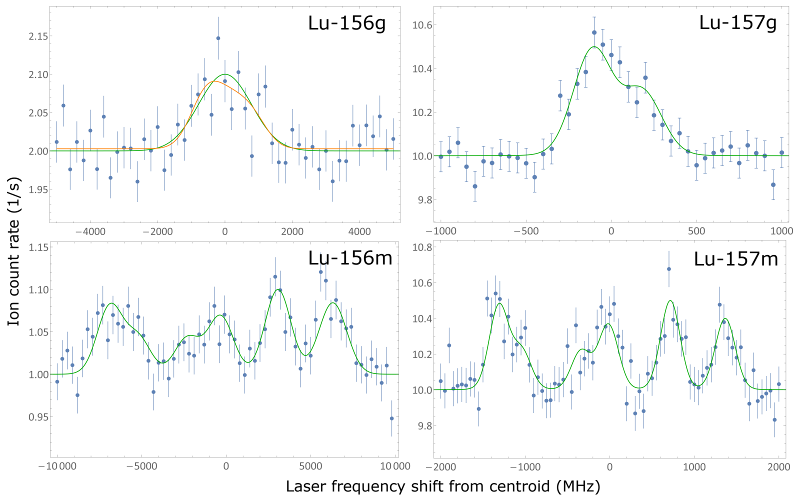

Figure 5: Simulated spectra of the most exotic cases for a measurement time as requested: 3 shifts for ^{157}Lu and 5 shifts for ^{156}Lu. ^{156g}Lu can be measured with lower resolution in standard collinear LIST mode to preserve the efficiency. For isotopes with higher yields (and even less-favorable background conditions), PI-LIST can be employed with an additional factor of 20 loss in yield [29] to sufficiently resolve the hyperfine structure. ^{157g}Lu assumes a spin $1/2^+$. Green lines denote the assumed hyperfine structure, the yellow line in the ^{156g}Lu graph shows a fit to the data, sufficient to extract an isotope shift.

References

[1] K.M. Lynch, T.E. Cocolios et al., Tech. rep., CERN-INTC-2024-038, INTC-I-278, CERN, Geneva (2024), https://cds.cern.ch/record/2894970

[2] K.M. Lynch et al., Tech. rep., CERN-INTC-2023-016, INTC-P-657, CERN, Geneva (2023), https://cds.cern.ch/record/2845948

[3] B. Cheal, L. Rodriguez, S. Bai, K. Blaum, P. Campbell, R. Garcia Ruiz, P. Imgram, K. Koenig, T. Lellinger, P. Muller et al., Tech. rep., CERN-INTC-2022-041, INTC-I-245, CERN, Geneva (2022), https://cds.cern.ch/record/2834596

[4] B. Cheal, L. Vazquez Rodrigues, R. Heinke et al., Tech. rep., CERN-INTC-2024-065, INTC-P-673-ADD-1, CERN, Geneva (2024), https://cds.cern.ch/record/2912229

[5] L.G. Sarmiento, T. Roger, J. Giovinazzo, B.A. Brown, B. Blank, D. Rudolph, A. Kankainen, H. Alvarez-Pol, A.A. Raj, P. Ascher et al., Nature Communications **14**, 5961 (2023)

[6] J. Cerny, J.E. Esterl, R.A. Gough, R.G. Sextro, Physics Letters B **33**, 284 (1970)

[7] B. Blank, M.J.G. Borge, Progress in Particle and Nuclear Physics **60**, 403 (2008)

[8] P. Woods, Nature **381**, 25 (1996)

[9] L.S. Ferreira, E. Maglione, Phys. Rev. Lett. **86**, 1721 (2001)

[10] A.P. Robinson, C.N. Davids, G. Mukherjee, D. Seweryniak, S. Sinha, P. Wilt, P.J. Woods, Phys. Rev. C **68**, 054301 (2003)

[11] L.S. Ferreira, E. Maglione, Phys. Rev. C **61**, 021304 (2000)

[12] C.N. Davids, P.J. Woods, D. Seweryniak, A.A. Sonzogni, J.C. Batchelder, C.R. Bingham, T. Davinson, D.J. Henderson, R.J. Irvine, G.L. Poli et al., Phys. Rev. Lett. **80**, 1849 (1998)

[13] P. Möller, J.R. Nix, W.D. Myers, W.J. Swiatecki, Atomic Data and Nuclear Data Tables **59**, 185 (1995)

[14] P. Siwach, P. Arumugam, S. Modi, L.S. Ferreira, E. Maglione, Phys. Rev. C **106**, 044322 (2022)

[15] P. Arumugam, L. Ferreira, E. Maglione, Physics Letters B **680**, 443 (2009)

[16] P. Siwach, P. Arumugam, S. Modi, L.S. Ferreira, E. Maglione, Phys. Rev. C **105**, L031302 (2022)

[17] P. Arumugam, L.S. Ferreira, E. Maglione, Phys. Rev. C **78**, 041305 (2008)

[18] Q. Lu, K.Y. Zhang, S.S. Zhang, Physics Letters B **856**, 138922 (2024)

[19] U. Georg, W. Borchers, M. Keim, A. Klein, P. Lievens, R. Neugart, M. Neuroth, P.M. Rao, C. Schulz, et al., The European Physical Journal A - Hadrons and Nuclei **3**, 225 (1998)

[20] G. Scamps, S. Goriely, E. Olsen, M. Bender, W. Ryssens, The European Physical Journal A - Hadrons and Nuclei **57**, 333 (2021)

[21] W. Ryssens, G. Scamps, S. Goriely, M. Bender, The European Physical Journal A - Hadrons and Nuclei **58**, 246 (2022)

[22] G. Grams, W. Ryssens, G. Scamps, S. Goriely, N. Chamel, The European Physical Journal A - Hadrons and Nuclei **59**, 270 (2023)

[23] G. Grams, N.N. Shchechilin, A. Sanchez-Fernandez, W. Ryssens, N. Chamel, S. Goriely (2024), `https://doi.org/10.48550/arXiv.2411.08007`

[24] G.A. Lalazissis, M.M. Sharma, P. Ring, Nuclear Physics A **597**, 35 (1996)

[25] L. Geng, H. Toki, J. Meng, Progress of Theoretical Physics **113**, 785 (2005)

[26] D. Bonatsos, A. Martinou, S.K. Peroulis, D. Petrellis, P. Vasileiou, T.J. Mertzimekis, N. Minkov, J. Phys. G: Nuclear and Particle Physics **52**, 015102 (2024)

[27] C.W. Reich, Nuclear Data Sheets **110**, 2257 (2009)

[28] N. Nica, Nuclear Data Sheets **176**, 1 (2021)

[29] R. Heinke, M. Au, C. Bernerd, K. Chrysalidis, T.E. Cocolios, V.N. Fedosseev, I. Hendriks, A.A.H. Jaradat, M. Kaja, T. Kieck et al., Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms **541**, 8 (2023)

[30] T. Kron, R. Beerwerth, S. Raeder, S. Fritzsche, R. Heinke, P. Schönberg, M. Trümper, K. Wendt, Phys. Rev. C **102**, 034307 (2020)

[31] V.M. Gadelshin, R. Heinke, T. Kieck, T. Kron, P. Naubereit, F. Rösch, T. Stora, D. Studer, K. Wendt, Radiochimica Acta **107**, 653 (2019)

[32] K. Chrysalidis, S.G. Wilkins, R. Heinke, A. Koszorus, R. De Groote, V.N. Fedosseev, B. Marsh, S. Rothe, R. Garcia Ruiz, D. Studer et al., Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms **463**, 476 (2020)

[33] R. Heinke et al., Tech. rep., CERN-INTC-2020-029, INTC-P-556, CERN, Geneva (2020), `https://cds.cern.ch/record/2717945`

[34] J. Wessolek, *Private communication* (2024)

[35] T.E. Cocolios, *Private communication* (2024)

[36] K. Chrysalidis, J. Cubiss, J. Wessolek, A. Andreyev, D. Lange et al., Tech. rep., CERN-INTC-2024-070, INTC-P-722, CERN, Geneva (2024), `https://cds.cern.ch/record/2912235`

[37] *The ISOLDE Yield Database, Version 0.2*, https://cern.ch/isolde-yields (2021), [Online; accessed 09.04.2024]

[38] J. Ballof, J. Ramos, A. Molander, K. Johnston, S. Rothe, T. Stora, C. Düllman, Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms **463**, 211 (2020)

[39] K. Chrysalidis, R. Heinke, M. Au, C. Bernerd, A.A.H. Jaradat, U. Köster, R. Mancheva, B. Marsh, E. Reis, M. Schütt et al., Tech. rep., CERN-INTC-2022-042, INTC-I-246, CERN, Geneva (2022), `https://cds.cern.ch/record/2834598`

[40] K. Chrysalidis, R. Heinke, M. Au, C. Bernerd, A.A. Jaradat, U. Köster, R. Mancheva, B. Marsh, E. Reis, M. Schütt et al., Tech. rep., CERN-INTC-2023-065, INTC-I-263, CERN, Geneva (2023), `https://cds.cern.ch/record/2872420`

5 Details for the Technical Advisory Committee

5.1 General information

Describe the setup which will be used for the measurement. If necessary, copy the list for each setup used.

☒ Permanent ISOLDE setup: *RILIS, CRIS high-resolution laser*

☒ To be used without any modification

5.2 Beam production

- Requested beams:
  - Neutron-deficient Lu isotopes, between ^{161}Lu and ^{156}Lu
- Full reference of yield information: *ISOLDE Yield Database [37, 38], J. Wessolek (CERN/Uni. of Manchester) for the ISOLDE yields team and T. E. Cocolios (KU Leuven)*
- Target - ion source combination: *Ta-foil target with LIST*
- RILIS? *Yes + CRIS high-resolution laser light, as required*

  ☒ Special requirements: *LIST, laser scanning, laser shutter access, CRIS high-resolution laser light*
- Additional features? *Fast beam-gating required*
- Expected contaminants: *TBD*
- Acceptable level of contaminants: *TBD*
- Can the experiment accept molecular beams? *No*
- Are there any potential synergies (same element/isotope) with other proposals and LOIs that you are aware of? *Very good synergy with lanthanide yield measurements [39, 40] and laser spectroscopy of neutron-deficient Tm isotopes [4] and Pm isotopes [36], both using a Ta-foil target with the LIST.*

5.3 Shift breakdown

Summary of requested shifts:

With protons	Requested shifts
$^{175-161}$Lu	3
^{160}Lu	2
^{159}Lu	1
^{158}Lu	1
^{157}Lu	3
^{156}Lu	5
Without protons	Requested shifts
^{175}Lu	2

5.4 Health, Safety and Environmental aspects

5.4.1 Radiation Protection

- Radioactive sources required? *No*
- Collections? *No*