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EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

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

for ISOLDE Proposal CERN-INTC-2016-008 / INTC-P-458

Study of neutron-rich ^{52,53}K isotopes by the measurement of spins, moments and charge radii.

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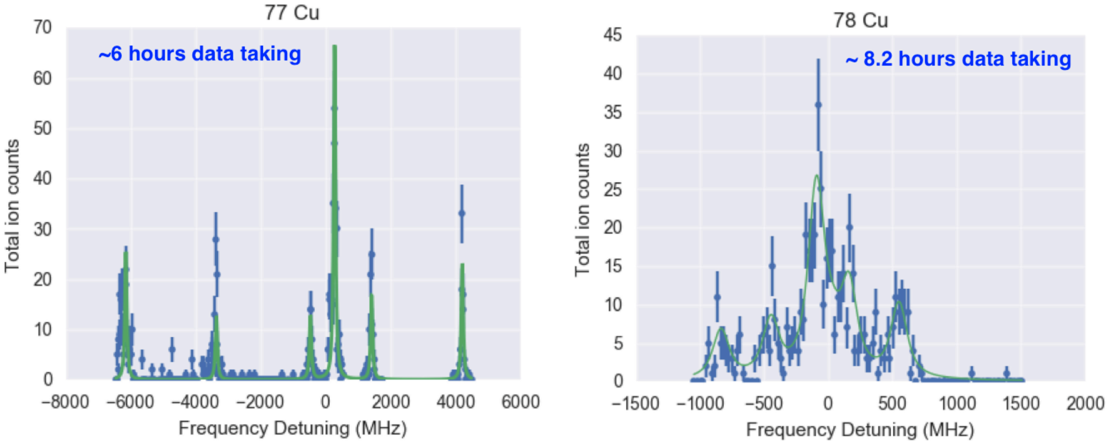
Abstract

This Letter of clarification is to demonstrate the experimental feasibility for laser spectroscopy of neutron-rich ^{52,53}K proposed at CRIS-ISOLDE (CERN-INTC-2016-008. INTC-P-458). Detailed information related to the estimated beam time is provided based on the recent development on our laser system and the demonstrated efficiency from a recent experiment on Cu isotopes at CRIS .

Requested shifts: 14 shifts of radioactive beam and 2 shifts of stable beam



(a) (b)

Figure 1: Achieved hyperfine spectra for ^{77,78}Cu using CRIS setup, with a FWHM of 70 MHz for the resonance peaks, similar as in previous COLLAPS experiments on Cu. The HFS are taken by using a two step (249 nm and 314 nm) ionization scheme, for the production yields of ∼200 ions/s (^{77}Cu) and ∼20 ions/s (^{78}Cu) [3]. In the case of ^{78}Cu, the background rate is measured to be ∼0.01 ion/s

1 Introduction

This proposal [1] was defended at the 55th meeting of the INTC held on February 03, 2016, to study the neutron-rich ^{52,53}K using Collinear Resonance Ionization Spectroscopy (CRIS). In the original proposal, we demonstrated the feasibility of the proposed K experiment based on the previous studies of ^{202}Fr (∼100 ions/s) with a broad-band laser (1.5 GHz line width) and a K production yield confirmed from other experiments and by the target group. The physics cases are endorsed by the INTC. However, there were some concern from the INTC, as outlined in the minutes from the meeting [2]:

There are some issues of concern in this proposal in terms of experimental details. Before beam time is granted, the proposers should demonstrate that after the presented case of broad-band excitation with ^{202}Fr, narrow-band excitation yields the results expected. This would also allow them to give a more detailed beam-time request based on experimental numbers.

The INTC asks therefore for a clarification letter which demonstrates technically that the experiment as proposed can be carried out.

2 The feasibility of the proposed experiment

The efficiency of each aspect of the CRIS experiment has been established during a recent experiment studying the neutron-rich Cu isotopes, as summarized in **Table 1**. Using stable ^{63,65}Cu ion beams from HRS, the transmission (∼40% from ISCOOL to ion detection) and ion detection efficiency (∼80%) of the CRIS setup have been measured.

Table 1: Overall efficiency of the CRIS setup established during the Cu experiment IS531 in May 2016. See text for a detailed explanation of each part.

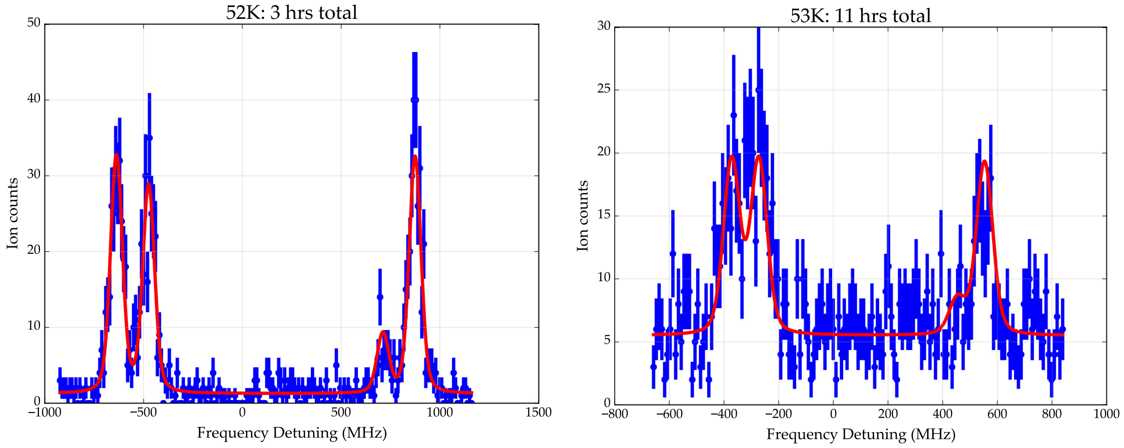
Transmission	Detection	Neutralization	Population on one atomic GS levels	Laser ionization	**Total**
40% Measured	80% Measured	90% Measured	50% Estimated	5-10% Estimated	**0.5- 1%** Measured

This was achieved by measuring the beam intensity at different Faraday cups placed between the exit of the ISCOOL to the end of the CRIS beam line. Using K vapor in the charge exchange cell (CEC), the neutralization of Cu ions populating one of the ground-state (GS) hyperfine levels is ∼45%. This results from a 90% neutralization factor after the charge exchange cell and 50% population into one of the atomic GS levels. By checking the recorded resonantly ionized ^{65}Cu ions with our MCP ion detector, we could confirm a total efficiency of 0.5-1% (ions detected at the end of our beam line compared to ions released from ISCOOL). In combination with the above efficiencies for transmission, neutralization, detection and population into the atomic GS, this yields a 5-10% laser ionization efficiency for the two step ionization scheme (using the new narrow-band injection-seeded pulsed TiSa laser for the first step). The 0.5-1% total efficiency has been consistently measured for all the radioactive isotopes with yields measured by the target group (up to ^{75}Cu with a production rate of 2000 ions/μC, ISOLDE-HRS elog at Thu 21-04-16 DAY) . The hyperfine spectra of neutron-rich ^{77,78}Cu isotopes are achieved with high-resolution laser excitation, as shown in **Figure 1**. The production yields for ^{77,78}Cu are estimated as ∼200 ions/s and ∼20 ions/s based on our calibrated efficiency. These yields are consistent with the previous ISOLTRAP experiment. The high-efficiency and high-resolution laser spectroscopy measurement on Cu isotopes benefited from the recent upgrade of the CRIS setup and laser system: an injection-seeded pulsed Ti:Sa laser system developed at Jyvaskyla [4] has been installed and frequency-tripling of this laser light allowed production of high-resolution (40-50 MHz) laser light at 249 nm. The ionization into an autoionizing state of Cu was achieved by frequency-doubled pulsed dye laser light.

For the K isotopes, a three-steps scheme is favored, as presented in Ref. [1], which will also benefit from the injection-seeded pulsed Ti:Sa laser (first resonant step: 769.9 nm, $4s\ ^2S_{1/2}-\ 4p\ ^2P_{1/2}$). This transition has been studied during previous COLLAPS experiments, and thus will be used to calibrate systematic uncertainties by remeasuring the hyperfine structure of all the isotopes using the CRIS system. The pulsed dye laser will be used for the second resonant step at 691.1 nm ($4p\ ^2P_{1/2}-6s\ ^2S_{1/2}$) and a Nd:YAG laser (100 Hz) for the final non-resonant step at 1064 nm ($6s\ ^2\mathrm{S}_{1/2}-\mathrm{IP}$) for ionization into the continuum. All three-steps are fundamental frequencies, thus providing higher laser power, with each laser system having been demonstrated previously [3, 5], and no potential instability associated with degradation of the non-linear frequency doubling crystal. The production yield for ^{52,53}K has been measured to be 500 ions/s and 50 ions/s,

Table 2: Production yields of ^{52}K and ^{53}K, taken from the ISOLDE yield database and Ref. [6, 7]

Isotopes	Half life	Yield (ions/s)	Target/ion source
$^{38-51}$K		>1000	UC$_x$ /WSI
^{52}K	105 ms	560	UC$_x$ /WSI
^{53}K	30 ms	$\sim$ 50	UC$_x$ /WSI



(a) (b)

Figure 2: Simulated hyperfine spectra of ^{52,53}K for the transition of 769.9 nm, $4s\ ^2S_{1/2}-\ 4p\ ^2P_{1/2}$, based on the estimated overall efficiency of 0.1-0.2% for K and a line width of 60 MHz [3, 5], which is comparable to the linewidth achieved at COLLAPS[8]. The splitting of the hyperfine structure is calculated based on the shell-model predicated magnetic moments. The background was calculated using the suppression factor of $1:10^5$ [9], which is mainly from the surface ionized Cr isotopes (2000-3000 ions/s) as measured at ISOLTRAP [10].

during the ISOLTRAP and IDS experiment, and confirmed during the technical meeting before the last INTC (see **Table 2**). The yields for ^{52,53}K are comparable with the case of the ^{77,78}Cu. For beam time estimates, we assume a similar overall transmission and detection efficiency ($\sim$32%). The neutralization efficiency of K isotopes was measured during an offline test last November to be 40%. Based on previous experiences at CRIS, we conservatively estimate a laser-ionization efficiency of 1-2% for the high-resolution K measurement. Therefore, a total efficiency is estimated to be 0.1-0.2% .

3 Beam time request

Based on this expected total efficiency and the production yield listed in **Table 2**, the hyperfine spectra of ^{52,53}K are simulated for the transition of 769.9 nm ($4s\ ^2S_{1/2}-\ 4p\ ^2P_{1/2}$), as shown in **Figure 2**. The time has been adjusted to reproduce spectra of a similar quality as the data obtained for ^{77,78}Cu. The beam time estimated for each part of the experiment, based on this simulation, is summarized in **Table 3**.

Beam time estimated for ^{52}K

Table 3: Estimated beam time for ^{52}K and ^{53}K, based on the production yield, contamination and the estimated efficiency for K. See text for detailed information.

A	Steps /scan	T(s) /step	T(h) /scan	T(h) for 5 scans	T(h) for others [1]	T(h) Total	**Shifts** Total
52	208	50	3	15	3	18	**2**
53	150	250	11	55	3	58	**8**
38-51					3 isotopes	per shift [2]	**4**
Total							**14**
Stable	beam						2

1. Searching resonance, reference scan on ^{39}K.
2. Estimated based on the past experiment: 3 isotopes per shift, including reference scan.

For the scanning region of about 2000 MHz (**Figure 2a**), 208 steps (10 MHz/step) is used for the simulation. In order to obtain the spectrum as shown in **Figure 2a**, about 20-30 counts on resonance, in total 3 h is necessary, using 50 s measurement time for each step (typically a full supercycle). For a typical laser spectroscopy measurement, dedicated beam time is needed for the preparation of separate measurements as well as multiple calibration measurements. For each isotope, 3 to 5 independent measurements are needed. In-between each scan reference measurements on stable ^{39}K are required for isotope shift calibration (about 2 hour). In addition, we count about 1 hour time for resonance search. Therefore, we estimate 2 shifts for high-resolution hyperfine spectra of ^{52}K.

Beam time estimated for ^{53}K

The scanning region for the hyperfine structure of ^{53}K is $\sim$1.5 GHz, and therefore 150 steps for a whole scan. Based on the production yield of ^{53}K isotopes (50 ions/s), the spectrum (simulated in **Figure 2b**) with at least 15 ions on resonance, requires 11 hours in total, using 250 s measurement time for each step. As 5 independent measurement are required, 8 shifts are needed to study this isotope. This measurement includes the reference scan time and time needed for searching hyperfine resonances.

Beam time estimated for $^{38-51}$K

Although the hyperfine structures of $^{38-51}$K have been measured at COLLAPS, it is still necessary to perform measurements of the whole isotopic chain. This will provide important calibration of systematic uncertainties, especially for isotope shifts. Based on our experience in the past experiment, for isotopes with a production yield $>$ 1000 ions per second, we can measure 3 isotopes per shift, including reference measurements in between. Therefore, 4 shifts are required for this systematic calibration. These calibration measurements are repeated several times during the experiment, to check the voltage stability and calibration.

Additionally, 2 shifts with stable beam before the run are requested for optimizing the experimental set-up and laser scheme (transmission, ion-laser spatial and time overlap, etc.).

Summary of requested shifts: 14 shifts of radioactive beam are being requested for the study of very neutron-rich $^{52-53}$K (as summarized in **Table 3**).

References

[1] X. F. Yang *et al. NTC-P-458*, Jan 2016.

[2] *Minutes of the 52nd meeting of the INTC*, 2016.

[3] R. P. de Groote *et al. in preparation*, 2016.

[4] V. Sonnenschein. PhD thesis, UNIVERSITY OF JYVSKYL, 2014.

[5] R. P. de Groote *et al. Phys. Rev. Lett.*, vol. 115, p. 132501, 2015.

[6] M. Rosenbusch *et al. Phys. Rev. Lett.*, vol. 114, p. 202501, 2015.

[7] A. Gottardo *et al.*, "Study of neutron-rich $^{51-53}$Ca isotopes via β-decay," Tech. Rep. CERN-INTC-2014-061. INTC-P-425, CERN, Geneva, Oct 2014.

[8] J. Papuga *et al. Phys. Rev. C*, vol. 90, p. 034321, 2014.

[9] K. T. Flanagan *et al. Phys. Rev. Lett.*, vol. 111, p. 212501, 2013.

[10] F. Wienholtz *et al. Nature*, vol. 498, p. 346, 2013.

Appendix

DESCRIPTION OF THE PROPOSED EXPERIMENT

The experimental setup comprises: CRIS

Part of the	Availability	Design and manufacturing
(CRIS)	☒ Existing	☒ To be used without any modification

HAZARDS GENERATED BY THE EXPERIMENT
Hazards named in the document relevant for the fixed CRIS installation.

Additional hazards: None