EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

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

Development of neutron-rich Cu ion beams

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On behalf of the CRIS-, IDS- and ISOLTRAP-collaborations and the ISOLDE TISD-team

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Abstract: This Letter Of Intent aims to investigate the best way of delivering ion beams of neutron-rich copper. Low production yields of these highly-exotic nuclei and strong contamination through surface ionized Rb and Ga have prevented previous laser spectroscopy studies beyond ^{78}Cu. We propose to test the feasibility of using a LIST for surface ion suppression to produce an isobar-free ion beam, which would be delivered for detection to IDS and ISOLTRAP.

Summary of requested shifts: [6] shifts, (split into [1] runs over [1] years)

1 Introduction

With a single valence proton outside of a nickel core, copper isotopes are an ideal laboratory to study the robustness of the $Z = 28, N = 50$ shell closures. From these studies so far, evidence has been found for the erosion of $Z = 28$ [1], the inversion of the $\pi p_{3/2}$ and $\pi f_{5/2}$ shell model orbits [1, 2], possible subtle sub-shell effects at $N = 40$. These combined datasets have been used to provide key tests of large-scale shell-model calculations [3] as well as nuclear DFT and valence-space in-medium calculations [3]. Extending these measurements to the key isotope ^{79}Cu represents the next crucial step - as this isotope has 50 neutrons, its magnetic moment will provide a clean probe of the magicity of ^{78}Ni and an important benchmark for future theoretical developments. Establishing the nuclear spin of this isotope is furthermore key in verifying if the shell inversion observed for lighter isotopes persists to ^{79}Cu, as is currently predicted. Currently, little to nothing is known about the next isotope in the chain, ^{80}Cu. Developing the ability to produce this beam in clean conditions, even if the production yields are low, would open the door to such studies.

The Cu isotopic chain has also been investigated through laser spectroscopy using in-source laser spectroscopy (RILIS) [1, 2] up to ^{78}Cu. These same isotopes were later re-studied in high-resolution at CRIS [3]. For the results presented in [3], the yield and purity of the beam at ISOLDE was insufficient to measure ^{79}Cu, which lies just one neutron further at the $N = 50$ shell-closure. In the case of the in-source spectroscopy, the achievable Doppler-limited resolution only allowed for extraction of magnetic dipole moments, but not the electric quadrupole moments. Due to the high neutron rate from the decay of ^{79}Ga, ^{79}Cu could not be measured in the setup described in [2].

So far, the heaviest studied Cu isotope at ISOLDE is $A = 79$, whose mass was measured by ISOLTRAP [4]. For this experiment, the ion beam was produced from a UC_x target with protons incident on a neutron-converter, which was used to minimise the production of isobaric contamination of surface ionised Rb and Ga. The same target and ion source approach was used in IS622 [5] in to study the decays of $^{74-79}$Cu at IDS – however, no appreciable intensity of ^{79}Cu was observed.

2 Proposed beam development

We propose to investigate the best way to produce neutron-rich isotopes of Cu, tailored to the requirements of the different possible experiments at ISOLDE (in-source laser spectroscopy, CRIS, ISOLTRAP or IDS). In comparison to the previous attempt to measure these isotopes through neutron detection with in-source laser spectroscopy [2], we propose to use IDS which has higher detection efficiencies than the previously used neutron-detection setup. Activity will be implanted into the movable tape of IDS, which will be used to remove long-lived daughter and isobaric contamination from the measurement position. The short half-life of ^{79}Cu ($T_{1/2} = 241$ ms) relative to the main

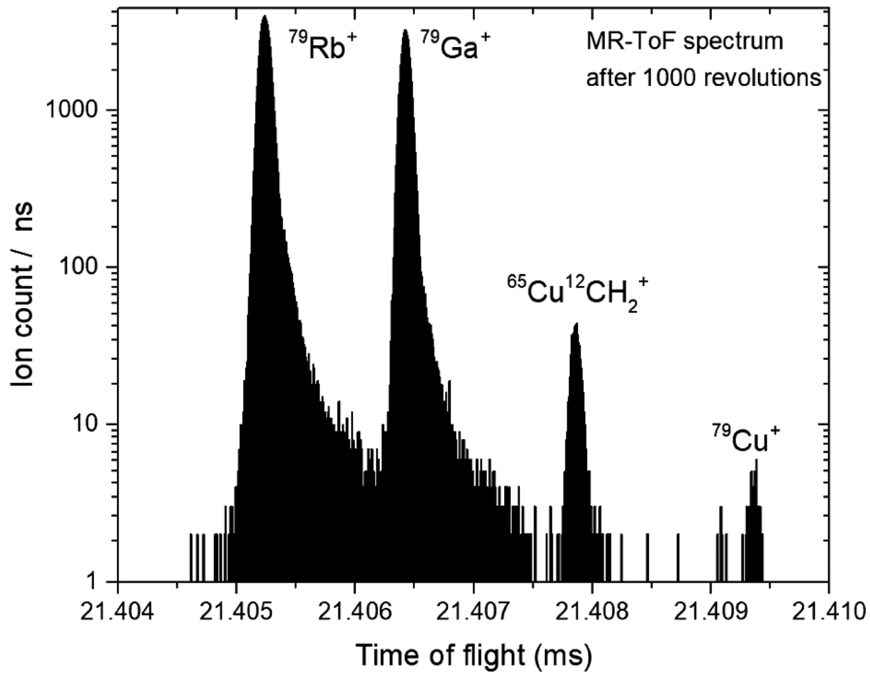

Figure 1: Mass spectrum for Cu recorded by ISOLTRAP with protons on n-converter[4]

beam contaminants ^{79}Rb ($T_{1/2} \approx 23$ mins) and ^{79}Ga ($T_{1/2} \approx 3$ s) means that it should be possible to make relatively pure samples by combining narrow beamgate settings and moving the tape after each proton pulse. Measurements of $\beta - \gamma$ coincidences in the β- and βn-decay daughter nuclei ^{78,79}Zn will be performed using arrays of plastic scintillator detectors ($> 30\%$ efficiency) and germanium clover detectors (up to 6.4% efficiency at 1 MeV).

In addition to working together with IDS for data collection, we also propose to send beam to ISOLTRAP. Previously, the mass of ^{79}Cu was measured using ISOLTRAP's MR-ToF MS [4], showing that this could be an ideal technique to identify the few ions expected to be produced through the in-source resonance laser ionization. A refined measurement of ^{79}Cu and a first measurement of ^{80}Cu using the MR-ToF MS would allow the trend in two-neutron separation energies in copper isotopes to be extended beyond $N = 50$ for the first time, which was not possible in the the previous study [4].

In the mass region of neutron-rich copper isotopes, the main contamination in the extracted ion beams stems from surface ionized Rb and Ga (see Figure 1). Both of these elements are produced with up to 5 orders of magnitude higher yield when irradiating the target directly with protons. Even through the use of a neutron converter the yield of these elements can still be up to 3 orders of magnitude higher. Nevertheless, ^{79}Cu has been measured by ISOLTRAP with yields of 2 ions/µC. These production yields could make a classical in-source laser spectroscopy run feasible. However, routes to suppress the surface-ionized isobars should be investigated for ensuring safe operating conditions.

The most obvious solution to the problem of surface ionized isobaric contamination is the application of the LIST, described in [6, 7]. Here, the surface ions are suppressed while the laser ions created just behind the repeller can be delivered as clean ion beams to the experimental setups. An additional advantage is the reduction in Doppler-broadening, which stems from the heating of the ion source: Since only atoms moving towards the exit of the ion source make it to the region behind the repeller, the ensemble-width is reduced by almost a factor 2.

During the beam development, several production and ion beam delivery pathways will be investigated. We will attempt measurements with and without surface ion suppression and protons on target or n-converter. A detailed list of the envisaged operational modes is given below:

- Proton beam incident on n-converter with ion-guide (IG) mode (no surface ion suppression): With this method, the expected yield for ^{79}Cu will be in the order of 2 ions/µC (see [4]). If the contaminants can be handled by the ion detection setup, a “standard” in-source laser spectroscopy run is feasible. A loss of another factor of 10 when attempting to go to ^{80}Cu would still result in a sufficient yield for attempting to measure this isotope. Yields as low as 0.1 ions/s have been used in the past [8].
- Proton beam incident on target with LIST (surface ion suppression): Typical loss factors when moving from ion-guide mode into LIST mode can be in the order of 100. With protons incident on target, the expected yield for ^{79}Cu is 20 ions/µC. This would then reduce to 0.2 ions/µC, which makes an in-source spectroscopy run feasible. Due to the isobar-free beam, detection could be achieved without risk of contaminating either IDS or ISOLTRAP. Measuring beyond ^{79}Cu might not be achievable.

If time at the GPS mass separator can be granted, tests with 1.7 GeV proton energy could be added to the yield measurements. According to the in-target production simulations performed with ABRABLA [9] for 1.4 and 2 GeV protons on target an increase in yield of factor 2 can be expected, meaning a factor of $\sim$1.5 improvement of the yield at the currently available max. energy of 1.7 GeV.

Based on the relative production yields which we measure with the different operational modes, we expect several proposals could be submitted to study these beams. Among these would be a proposal to study the magnetic moments of these isotopes using in-source laser spectroscopy, and potentially using the PI-LIST technique to gain access the changes in mean-squared charge radii and quadrupole moments.

3 Summary of requested shifts

We would like to request 6 shifts with protons and 5 shifts for ion beam tuning and target/ion-source optimization for the beam development outlined above. From past experimental campaigns with the LIST ion-source we have learned that beam tuning parameters need to be optimized when going from ion-guide to LIST-mode due to a change of ion beam emittance. The shifts will be structured as follows:

# of shifts	Isotope(s)	Proposed measurements
1	^{63}Cu (stable)	ion-source and target optimization
2	^{63}Cu (stable)	beam tuning to IDS with IG- and LIST-mode
2	^{63}Cu (stable)	beam tuning to ISOLTRAP with IG- and LIST-mode
3	^{79,80}Cu	n-converter: IG-mode yields and contamination limit investigations
3	^{79,80}Cu	p+ on target: LIST-loss factors & yields, suppression factor tests for isobars

References

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[9] Aleksandra Kelic, M. Valentina Ricciardi, and Karl-Heinz Schmidt. *ABLA07 - towards a complete description of the decay channels of a nuclear system from spontaneous fission to multifragmentation.* 2009.

4 Details for the Technical Advisory Committee

4.1 General information

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

☒ Permanent ISOLDE setup: IDS, ISOLTRAP

  ☒ To be used without any modification

  ☐ To be modified: *Short description of required modifications.*

☐ Travelling setup (*Contact the ISOLDE physics coordinator with details.*)

  ☐ Existing setup, used previously at ISOLDE: *Specify name and IS-number(s)*

  ☐ Existing setup, not yet used at ISOLDE: *Short description*

  ☐ New setup: *Short description*

4.2 Beam production

For any inquiries related to this matter, reach out to the target team and/or RILIS (please do not wait until the last minute!). For Letters of Intent focusing on element (or isotope) specific beam development, this section can be filled in more loosely.

- Requested beams:

Isotope	Production yield in focal point of the separator (/μC)	Minimum required rate at experiment (pps)	$t_{1/2}$
78Cu	200/20 (with n-converter)		330.1 ms
79Cu	20/2 (with n-converter)		241 ms
80Cu	2/0.2 (with n-converter)		113.3 ms

- Full reference of yield information: ISOLDE yield database, publications by CRIS [3] and ISOLTRAP [4].
- Target - ion source combination: LIST with UCx target material and n-converter
- RILIS? (*YES*)

  ☒ Special requirements: All of them (*isomer selectivity, LIST, PI-LIST, laser scanning, laser shutter access, etc.*)

- Additional features?

  ☒ Neutron converter: Yes, probably for all isotopes to be tested

  ☐ Other: (*quartz transfer line, gas leak for molecular beams, prototype target, etc.*)

- Expected contaminants: $^{78-80}$Rb with yields up to 10^7/µC if we go directly on target and do not use LIST, otherwise (with n-converter) yields below 10^4/µC; $^{78-80}$Ga with yields up to 10^6/µC (according to Yield DB entries)

- Acceptable level of contaminants: (*Not sensitive to stable contaminants, limited by ISCOOL overfilling, etc.*)

- 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? YES: we can use the same traget and ion-source unit which will be used for yield measurements of Np and Pu (accepted LOI INTC-I-264) with the addition of a n-converter