EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

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

Testing the mass separation capabilities of the new ISOLDE isobar separator

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Abstract: With the advent of the PUMA experiment transporting antiprotons from the antimatter factory to ISOLDE, a new isobar separator beamline at RC6 is currently being constructed to deliver purified beams with vacuum requirements of $< 10^{-10}$ mbar. The multi-reflection separator and Paul trap, integral components of the new beamline, are currently part of experiment IS671 (MIRACLS), which is under commission at LA2. With this LOI, we request dedicated development beam time to assess the separator's mass separation capabilities in its current state before its integration into the new beamline at RC6. This will benchmark the accuracy of ion optical simulations and prepare the design and exchange of a new drift region, which is necessary for the installation at RC6 to achieve the device's highest possible simulated performance.

Summary of requested shifts: 6 shifts in 1 run using a UC_x target with surface ionization

1 PUMA at ISOLDE: The new RC6 beamline

With the envisaged arrival of the PUMA experiment at ISOLDE [1], a new low-energy beamline is under construction to fulfill the different requirements posed by the antimatter experiment. As the antiprotons in the PUMA ion traps have to be stored for several weeks, the standard vacuum in the ISOLDE low-energy beamline has to transition from 10^{-6} mbar at the entrance of RC6 (near IDS) to $< 10^{-10}$ mbar at the handover point to the PUMA beamline. The second requirement is a high degree of beam purity. This will be realized by employing a multi-reflection time-of-flight mass separator (MR-ToF MS), which is currently being developed by the MIRACLS collaboration [2] for collinear laser spectroscopy. This device promises strong mass separation capabilities with ion flux dependent resolving powers between 10^4 and 10^5 for ion rates of 10^7 to 10^5 ions per second, respectively [3] (assuming a 30 keV operation, higher ion load meaning lower resolving power).
The layout of the beamline at RC6 is shown in Fig. 1. The isobar separator and the Paul trap for accumulation and bunching are situated perpendicular to the RC6 beamline to allow for DC beam operation toward the two handover points if needed. In mass separation mode, the beam will be decelerated to 3 keV beam energy using an electrostatic decelerator before being bent by 90 degrees, followed by injection into the Paul trap. After accumulation and cooling, the ion bunch will be accelerated to the initial ISOLDE beam energy and injected into the isobar separator, where the beam is stored with kinetic energies up to several tens of keV. After hundreds to thousands of revolutions inside the MR-ToF device leading to several kilometers of effective flight paths, only the ion species of interest is ejected [4] and guided back into the RC6 beamline and toward the handover points.
Large parts of this setup will be recuperated and refurbished from existing hardware: the two injector quadrupole doublets in front of the mass separator section and the final switchyard near the handover point are sourced from ISOLDE spares, and the three doublets towards the handover points are spares provided from the ELENA low-energy antiproton ring. The Paul trap and the mass separator are the devices developed by MIRACLS and presently commissioned at

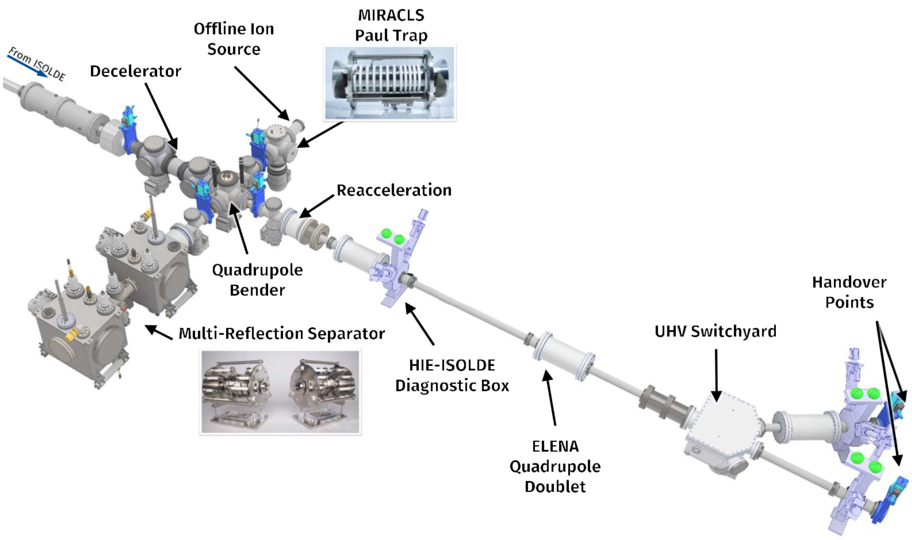

Figure 1: CAD for the planned RC6 isobar mass separator beamline which will serve beams to the PUMA experiment and a second experimental area.

LA2.
In its current configuration optimized for collinear laser spectroscopy (CLS) at LA2 for MIRACLS, the multi-reflection device consists of two electrostatic mirrors separated by a pulsed drift tube of 690 mm length to capture the ions in-flight. Ion optical simulations have shown that this length, while beneficial for CLS, results in at least one order of magnitude worse mass separation powers than those discussed in Ref. [3]. An additional manuscript discussing the influence of the drift tube length on the MR-ToF MS performance is currently in preparation. Thus, a new drift region with a shorter pulsed drift tube must be designed before it is integrated into the RC6 beamline for PUMA To benchmark the simulations for the long drift tube version, which will, in turn, inform the design for the short version needed for PUMA, we intend to measure the mass-dependent resolving power of single ion species over a large mass range and storage times, as well as the separation power for selected isobaric mass doublets delivered from a UC_x MK1 target and ion source.
While several stable magnesium isotopes are available from the MIRACLS offline source at LA2, the mass differences of one atomic mass unit are too large to properly assess the high mass resolving powers and different ion fluxes expected for the RC6 beamline operation. Different isotopes and isobaric mass doublets with a large mass range and several possible mass differences Δm are especially of interest in this LOI as the mass separation of the MR-ToF MS is, as mentioned above, not only space charge dependent but also sensitive to the absolute mass m and the mass difference Δm [3].

2 Beam request

To assess the current MR-ToF MS configuration's mass separation power, we intend to use isobars over a large mass range, as well as isobar doublets with two different masses in the MIRACLS setup at LA2. For this, we have selected suitable surface ionizable elements across the nuclear chart, as well as strontium-rubidium mass doublets previously observed using the ISOLTRAP MR-ToF MS (see Table 1 and Figure 2). These are either stable or long-lived isotopes with a large range of Q_β values, i.e. Δm mass differences, which are easily surface-ionized and require no or very little ($\leq$0.1uA) proton current on a UC_x target. Their ratio can be moderated through the amount of protons on the target, as well as scanning target and transfer line temperatures. Additionally, rubidium and/or strontium mass markers would be desired for stable beam setup but are not strictly required.

Isotopes	Q_β value (keV)	$m/\Delta m$	half-lives
^{83}Sr/^{83}Rb	-2273(6)	3.4×10^4	32.41h / 86.2d
^{86}Sr/^{86}Rb	1776.1(0.2)	4.5×10^4	stb. / 18.64d
^{88}Sr/^{88}Rb	5312.62(0.16)	1.5×10^4	stb. / 17.78m
^{23}Na	/	/	stb.
^{39}K	/	/	stb.
^{133}Cs	/	/	stb.
^{238}U	/	/	4.46Gy

Table 1: Suitable surface ionized isotopes and mass doublets with little or no proton current on the target, their half-lives, Q_β values, and mass resolving powers $m/\Delta m$ needed to resolve them.

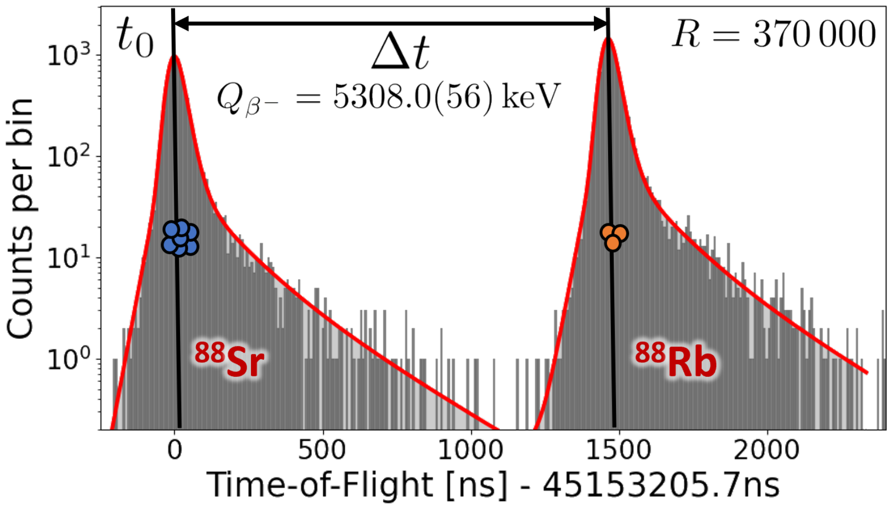

Figure 2: Time-of-flight spectrum of the ^{88}Sr/^{88}Rb mass doublet from a UC_x target measured using the ISOLTRAP MR-ToF MS. The time-of-flight difference is directly proportional to the Q_β-value.

While we do not expect the device in its current state to reach the resolving powers demonstrated by the ISOLTRAP MR-ToF MS in Fig. 2 (see discussion above), testing the apparatus in its present configuration will yield critical information to guide its integration into the RC6 beamline.

References

[1] T. Aumann et al. Puma, antiproton unstable matter annihilation. *The European Physical Journal A*, 58(5):88, May 2022.

[2] F. M. Maier et al. Simulation studies of a 30-keV MR-ToF device for highly sensitive collinear laser spectroscopy. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, 1048:167927, 2023.

[3] F. M. Maier et al. Increased beam energy as a pathway towards a highly selective and high-flux MR-ToF mass separator. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, 1056:168545, 2023.

[4] F. Wienholtz, S. Kreim, M. Rosenbusch, L. Schweikhard, and R.N. Wolf. Mass-selective ion ejection from multi-reflection time-of-flight devices via a pulsed in-trap lift. *International Journal of Mass Spectrometry*, 421:285–293, 2017.

3 Details for the Technical Advisory Committee

3.1 General information

☒ Permanent ISOLDE setup: MIRACLS

- ☒ To be used without any modification
  Safety file https://edms.cern.ch/document/2965845/1
- ☐ To be modified: *Short description of required modifications.*

3.2 Beam production

- Requested beams: see Tab. 1
- Full reference of yield information: yield database
- Target - ion source combination: UC_x MK1
- RILIS: no
- Special requirements: no
- Additional features: no
- Neutron converter: no
- Other: no
- Expected contaminants: none
- Acceptable level of contaminants: /
- Can the experiment accept molecular beams: yes
- Are there any potential synergies (same element/isotope) with other proposals and LOIs that you are aware of? no

3.3 Shift breakdown

Summary of requested shifts: 6 shifts in 1 run using a UC_x target with surface ionization source

With protons	Requested shifts: 4
Finding proper target and ion source temperature and proton beam current for optimizing mass doublet ratios Data taking, various masses and doublets	1 3
Without protons	Requested shifts: 2
Stable beam tuning	2