EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

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

Development of a fast-timing array for reactions studies at HIE-ISOLDE

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Abstract: HISTARS is an array aimed at measuring lifetimes of excited states populated in reactions at HIE-ISOLDE, presently under development. It makes use of fast scintillators for charged particle reaction products and fast scintillator detectors for de-excitation γ-rays in order to measure time differences between particles and γ-rays. This letter of intent presents the new device and its potential for reactions in preparation for a future proposal to the INTC. Test beam time is also requested.

Summary of requested shifts: 6 shifts

1 HISTARS

The HISTARS (HIE-ISOLDE Timing Array for Reaction Studies) is a highly sensitive detector under development. It is intended for the measurement of lifetimes of nuclear-excited states populated in reactions at the HIE-ISOLDE facility. Excited-state lifetimes are essential to gain direct access to electromagnetic transition rates, which are sensitive to the details of nuclear wave functions.

The idea of HISTARS is combining a charged particle inner detector system with enhanced capabilities for reaction tagging and with excellent timing response and an external gamma fast-timing array based on $LaBr_3$(Ce) (or similar) detectors. The system aims to benefit from recent advancements in instrumentation and electronics, utilizing improvements in digital signal processing and innovative analysis techniques based on genetic algorithms. This project has received nearly 1 M€ in funding from the Spanish government to support new initiatives developed by Spanish research groups at CERN. The proposal is to integrate HISTARS with existing instrumentation to create a hybrid array, enhancing the capabilities of current experimental setups and hopefully expanding research opportunities for the large community of accelerated beam users at ISOLDE.

At present the instrument is in the design phase. Test of scintillator crystals including Ce:GaGG, fast LGSO, Pr:LuAG, and YSO have been performed. The performance of plastic scintillators coupled to fast SiPM has been also assessed. Several fast photomultiplier assemblies to match $LaBr_3$(Ce) crystals have been tested. A proposal to characterize a small part of the equipment has been submitted to the local tandem accelerator facility at CMAM in Madrid [1].

2 Tests and benchmark experiments

The purpose of this letter of intent is to present the instrument concept and to request endorsement of the project before the submission of a full commissioning proposal. It is expected that readiness of the equipment will improve within a short time, after tests at our laboratory and at the CMAM facility.

2.1 Structure of odd-odd Rb isotopes

Multinucleon transfer reactions between heavy ions are considered an effective mechanism for producing heavy neutron-rich nuclei. Recent models predict that reactions near the Coulomb barrier yield large primary cross sections [2, 3]. At these low energies, the reactions are primarily influenced by optimal Q-values and nuclear form factors. The Q-value balance is mainly dictated by the lighter reaction partner, leading to dominant processes such as neutron pick-up and proton stripping from the lighter nucleus. Simultaneously, the heavier partner gains protons while losing neutrons.

One of the available examples in literature, Ref. [3], where lead isotopes were populated in binary reactions using a ^{94}Rb radioactive beam, shows Coulomb excitation of the lighter beam. In the context of HISTARS this type of reactions can be used below the Coulomb barrier to populate excited states. Coulomb excitation of (odd-A) Rb isotopes is discussed in detail in [4]. A possibility is illustrated in Fig. 1, where the low-energy excited states

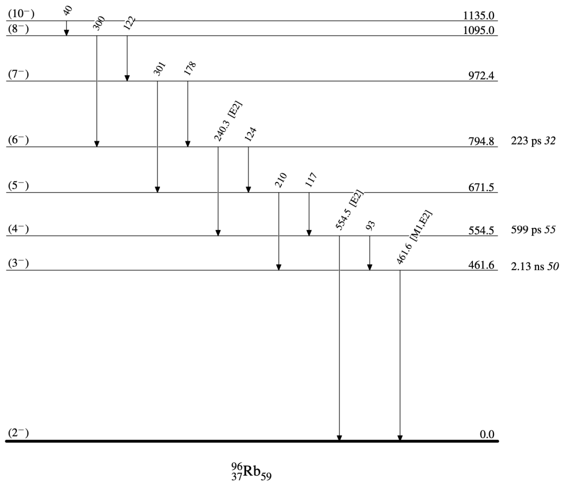

Figure 1: Level scheme of ^{96}Rb

in the odd-odd nucleus ^{96}Rb are shown [5]. They can be populated in Coulomb excitation on a stable ^{208}Pb target. The level lifetimes are well suited for timing measurements since they can be selected in the $LaBr_3$(Ce) detectors because they range from 200 ps to 2 ns. The uncertainty of some previous lifetime measurements could be improved with the use of fast scintillators. From the point of view of production, Rb isotopes are easily ionized and produced at ISOLDE. Other population mechanisms, such as incomplete fusion reactions, could also be explored.

2.2 Investigation of neutron-deficient Hg isotopes

Shape coexistence in neutron-deficient even-even mercury isotopes around the neutron mid-shell (N=104) is well-established, with evidence for weakly-deformed oblate ground states and more deformed, likely prolate, excited 0^+ states. Large changes in mean-square charge radii of odd-even Hg isotopes around N = 104 also indicate a change of deformation between ground and isomeric states [6, 7]. Coulomb excitation studies have provided valuable information on the electromagnetic properties of these states, but the interpretation of the data is hindered by the limited spectroscopic information, such as lifetimes, branching ratios, and internal conversion coefficients [8]. Lifetime measurements, when available, show large E2 transition probabilities for yrast band members up to the 8^+ state in even-mass $^{180-188}$Hg isotopes [9, 10] (Fig. 2), while the strength drops for the 2_1^+ state, pointing to the mixing of configurations.
Coulomb excitation and β-decay studies using γ-ray and internal conversion electron spectroscopy, provide information about energy levels, transition probabilities, and mixing ratios [11, 12, 13, 14], ultimately revealing details about deformation and shape coexistence. Further investigation into the nature of shape coexistence and mixing of configurations at higher excitation energies requires comprehensive experimental data. A promising approach to obtain this information is to measure lifetimes of the excited states using HISTARS.
Selected transition rates and lifetimes, taken from [9, 10], are shown in Table 1. The pop-

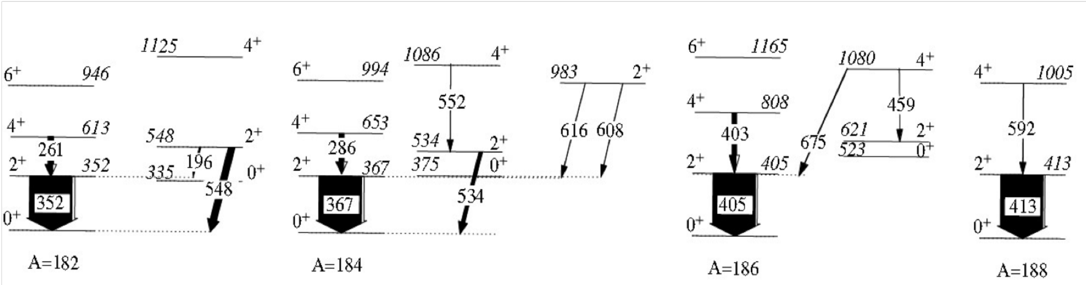

Figure 2: Level schemes of excited states in $^{182-188}$Hg taken from [11]

ulation in Coulomb excitation offers a good opportunity to cross-check the simultaneous measurement of excitation probabilities and lifetimes with HISTARS. Odd-A Hg isotopes and the population of high-spin isomers in *non-safe* Coulomb excitation will be explored in future studies.

Isotope	**Energy (keV)**	J_i^π	J_f^π	**B(E2↓)** (W.u.)	τ (ps)
^{182}**Hg**	351.8	2^+	0^+	55(3)	42.1(23)
	261.4	4^+	2^+	253.1(75)	37.1(11)
	333.1	6^+	4^+	331(33)	9.1(9)
	413.7	8^+	6^+	375(40)	2.8(3)
	487.4	10^+	8^+	327(73)	1.44(32)
^{184}**Hg**	366.8	2^+	0^+	52(2)	35.7(15)
	287.0	4^+	2^+	191(6)	30.2(10)
	340.1	6^+	4^+	308(15)	8.7(4)
	418.3	8^+	6^+	309(13)	3.19(14)
	329.1	9	7	169(40)	12.1(8)
^{186}**Hg**	405.3	2^+	0^+	47(6)	24(3)
	402.7	4^+	2^+	200(70)	5.6(20)
	356.8	6^+	4^+	231(10)	9.1(4)
	424.2	8^+	6^+	202(14)	4.5(3)
	488.9	10^+	8^+	238(25)	1.9(2)

Table 1: Selected lifetime and transition rates for ^{182,184,186}Hg

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2.3 Commissioning with stable beams

To advance in the commissioning of the equipment under more realistic conditions, it will be important to test HISTARS detectors and electronics together with the MINIBALL data acquisiton and the specific HIE-ISOLDE bunching structure. This is particularly relevant to test the inner particle detector array.
We would like to explore the possibility of using stable beams accelerated at HIE-ISOLDE of heavy noble gases such as Xe, that could be injected if required and post accelerated.

Table below shows the B(E2; $2^+ \rightarrow 0^+$) transition rates and 2^+ state lifetimes for some of the potential candidates. Lifetimes are in the tens of ps range.
In this case, we would like to employ post-accelerated stable gases to commission the equipment. The most favourable (longer) lifetimes occur for lighter isotopes with lower abundances, but they will still provide useful information on the detector performance, time correlations between particle and γ detectors and integration with other instruments. It is expected that 6 shifts (2 days) of beam time will be enough for this purpose. Part of the intended equipment could be also installed in the XT03 beam if availability is better.

Isotope	**Natural abundance**	**Energy** (keV)	**B(E2↓)** (W.u.)	τ (ps)
^{124}Xe	0.095%	354.14(4)	52.3(33)	75(5)
^{126}Xe	0.089%	388.634(10)	41.0(13)	58.8(19)
^{128}Xe	1.91%	442.910(9)	39.2(21)	31.6(17)
^{130}Xe	4.07%	536.085(22)	33.2(26)	14.2(11)

Table 2: Data for xenon isotopes, taken from [15]

Summary of requested shifts: We request 6 shifts in total for tests with stable isotopes.

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Appendix

DESCRIPTION OF THE PROPOSED EXPERIMENT
Please describe here below the main parts of your experimental set-up:

Part of the experiment	Design and manufacturing
HIE-ISOLDE, XT03 (SEC) beam line and XT01 (Miniball) beam line	☒ To be used without any modification ☒ To be modified

HAZARDS GENERATED BY THE EXPERIMENT
Additional hazard from flexible or transported equipment to the CERN site:

Domain	Hazards/Hazardous Activities		Description
Mechanical Safety	Pressure	☐	[pressure] [bar], [volume][l]
	Vacuum	☒	
	Machine tools	☐	
	Mechanical energy (moving parts)	☐	
	Hot/Cold surfaces	☐	
Cryogenic Safety	Cryogenic fluid	☐	[fluid] [m3]
Electrical Safety	Electrical equipment and installations	☐	[voltage] [V], [current] [A]
	High Voltage equipment	☒	1250 V
Chemical Safety	CMR (carcinogens, mutagens and toxic to reproduction)	☐	[fluid], [quantity]
	Toxic/Irritant	☐	[fluid], [quantity]
	Corrosive	☐	[fluid], [quantity]
	Oxidizing	☐	[fluid], [quantity]
	Flammable/Potentially explosive atmospheres	☐	[fluid], [quantity]
	Dangerous for the environment	☐	[fluid], [quantity]
Non-ionizing radiation Safety	Laser	☐	[laser], [class]
	UV light	☐	
	Magnetic field	☐	[magnetic field] [T]
Workplace	Excessive noise	☐	
	Working outside normal working hours	☐	
	Working at height (climbing platforms, etc.)	☐	
	Outdoor activities	☐	
Fire Safety	Ignition sources	☐	
	Combustible Materials	☐	
	Hot Work (e.g. welding, grinding)	☐	
Other hazards			