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HIGH-PRECISION MASS MEASUREMENTS OF EXOTIC NUCLEI WITH THE TRIPLE-TRAP MASS SPECTROMETER ISOLTRAP

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In the running ISOLDE period of 2003 the experiment IS413 asked for five beam times with a total number of 27 radioactive beam shifts (see Tab. 1). Due to the delayed ISOLDE startup and the failure of the HRS the beam times on ^{62}Zn and ^{62}Ga were either cancelled or stopped. Maybe another beam time can be taken in October or November. Thus, a final number of taken radioactive beam shifts can only be given by the ISOLDE Coordinator at a later time.

ISOLTRAP measured within these beam times masses of close to 50 radionuclides, almost all of them with a relative uncertainty in the order of a few times 10^{-8}. In 19 cases the accuracy was improved by more than an order of magnitude, in several cases by a factor close to 100. For ten radionuclides the masses have been measured for the first time. Table 2 gives the investigated nuclides with the half-lives, the literature and experimentally obtained mass uncertainties as well as the reached relative mass uncertainty. For some of the investigated nuclides the final data analysis is still under way. Thus, only preliminary uncertainties could be given in that cases and are marked with *.

Since the importance of the physics output of these mass measurements was already explained in detail in our proposal P160, only a few comments on the beam times and some specific highlights and problems will be addressed in the following.

Table 1: Beam times scheduled in 2003.

Beam time	Dedicated for	No. of shifts	Remark	Separator	Target/ion source
2003-04	^{62}Zn (CVC,CKM)	2	cancelled	HRS	Nb foil
2003-05	Cu (mass surface)	8		GPS	UC / SI W
2003-05	Ni, Ga (mass sur.)	5		GPS	UC / SI W
2003-05	^{62}Ga (CVC,CKM)	6	stopped	HRS	ZrO_2 / SI W
2003-06	^{74}Rb (CVC,CKM)	6		GPS	ZrO_2 / SI W

^{62}Zn, ^{62}Ga:

The beam time on ^{62}Zn was cancelled due to the delayed ISOLDE start-up in spring 2003 and the beam time on ^{62}Ga had to be stopped after a few hours because of the HRS failure. Nevertheless, ISOLTRAP was able in that short time to improve the mass uncertainty of ^{63}Ga, which was known at that time with an uncertainty of only 100 keV, by about a factor of 100 down to 1.32 keV ($\delta m/m = 2.2\cdot10^{-8}$). For both nuclides we would like to ask again for radioactive beam time next year.

^{70}Cu:

By combining selective resonant laser ionization of online produced short-lived radioactive nuclides with accurate mass measuring techniques, isomerically pure samples were produced and studied for the first time. This is a breakthrough in mass spectrometry and radioactive ion beam preparation. In combination with β decay studies, triple isomerism has been unambiguously identified in ^{70}Cu. Due to the different hyperfine structure of the ^{70}Cu isomers (see upper part of Fig. 1), the isomers could be selectively ionized depending on the laser frequency tuning. For the mass measurements of the isomers, the laser frequency was tuned to the positions *a*, *b*, and *c*, respectively, as indicated by arrows. The obtained TOF cyclotron resonances for ^{70a,b,c}Cu$^+$ are shown in Fig. 1. While for ^{70a}Cu$^+$ and ^{70b}Cu$^+$ the selectivity of the RILIS was high enough to almost separate these isomers, in the case of ^{70c}Cu$^+$ an additional cleaning of the other isomers was required to obtain a clean spectrum. These data exemplify the strength of this combined technique (RILIS+ISOLTRAP) to produce pure samples of short-lived radioactive nuclei. One should note that this is at present only possible at ISOLDE. The new mass data uncover in addition, that the literature value for the ground state is off by 226 keV due to a wrong state assignment.

Table 2: Radionuclides measured with ISOLTRAP in 2003. Some highlights discussed in the text are marked in light gray. For mass uncertainties marked by # , masses were obtained for the first time. For nuclides marked by * the analysis is under way, thus only estimated uncertainties are given.

Nuclide	Half-life $T_{1/2}$	δm_{lit} / keV	δm_{exp} / keV	$\delta m_{exp}/m$
65Cu	Stable	1.7	1.1	1.8E-8
66Cu	5.1 m	1.7	2.03	3.3E-8
67Cu	61.9 h	8	1.23	2.0E-8
68gCu	30 s	50	1.57	2.5E-8
68mCu	3.8 m	0.7	2.16	3.4E-8
69Cu	3 m	1	1.38	2.1E-8
70gCu	5 s	15	1.57	2.4E-8
70mCu	42 s	5	2.58	4.0E-8
70nCu	6 s	5	2.66	4.1E-8
71Cu	19.5 s	40	1.53	2.3E-8
72Cu	6.6 s	480#	1.44	2.1E-8
73Cu	4.2 s	330#	3.89	5.7E-8
74Cu	1.6 s	370#	6.16	8.9E-8
76Cu	0.64 s	600#	6.67	9.4E-8
63Ga	32.4 s	100	1.32	2.2E-8
64Ga	3.627 m	4	2.33	3.9E-8
65Ga	15.2 m	1.8	1.39	2.3E-8
69Ga	stable	3	1.53	2.4E-8
70Ga	21.14 m	3	2.15	3.3E-8
71Ga	stable	1.8	2.82	4.3E-8
72Ga	14.1 h	2.1	1.44	2.1E-8
73Ga	4.96 h	6	1.64	2.4E-8
74Ga	8.12 m	21	3.71	5.4E-8
75Ga	126 s	7	2.41	3.4E-8
76Ga	32.6 s	90	1.94	2.7E-8
77Ga	13.2 s	60	2.4	3.3E-8
78Ga	5.09 s	80	2.43	3.3E-8
57Ni	35.6 h	2.9	2.5	4.7E-8
60Ni	stable	1.4	1.45	2.6E-8
64Ni	stable	1.5	1.29	2.2E-8
65Ni	2.5 h	1.5	2.25	3.7E-8
66Ni	54.6 h	16	1.43	2.3E-8
67Ni	21 s	19	2.86	4.6E-8
68Ni	29 s	17	2.98	4.7E-8
69Ni	11.5 s	150#	3.68	5.7E-8
56Cr	5.94 m	10	1.9	3.6E-8
57Cr	21.1 s	100	1.86	3.5E-8
56Mn	2.6 h	1.4	1.44	2.8E-8
57Mn	85.4 s	3	2.17	4.1E-8
74Rb*	65 ms	18	<4	<5.0E-8
92Sr	2.71 h	6	4.04	4.7E-8
124Cs	30.9 s	12	14.21	1.2E-7
127Cs	6.25 h	9	7.16	6.1E-8
128Ba	2.43 d	10	19.6	1.6E-7
130Ba	stable	7	3.16	2.6E-8
229Fr*	50.2 s	360#	<10	<5.0E-8
230Fr*	19.1 s	450#	<10	<5.0E-8
230Ra*	93 ms	12	<10	<5.0E-8
231Ra*	103 s	300#	<10	<5.0E-8
232Ra*	250 s	360#	<10	<5.0E-8
233Ra*	30 s	470#	<10	<5.0E-8

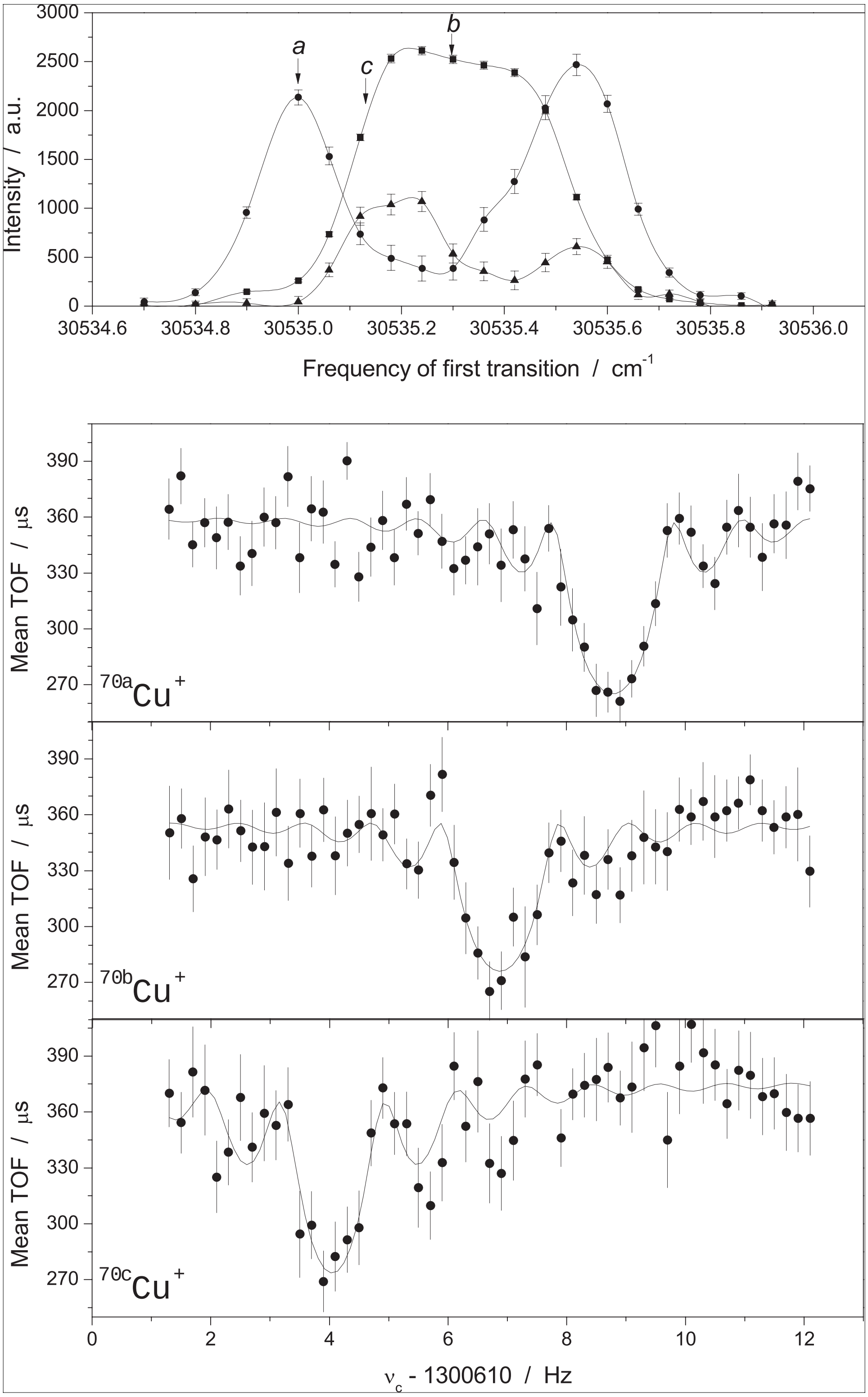

Fig.1: Top: Intensity of the 101.1 keV (circles) and 141.3 keV (triangles) isomeric transitions in coincidence with the associated β-delayed γ rays as a function of laser frequency. The γ rays associated with the decay of the (6^-) isomer are shown as squares. Bottom: Time-of-flight resonance curves of the ${}^{70a,b,c}Cu^+$ isomers at an excitation time T_{RF} = 0.9 s for the laser frequency settings *a, b,* and *c,* as marked with arrows in the upper part. The solid lines are fits by the theoretically expected line shape to the data points.

^{74}Rb:

In the case of ^{74}Rb ISOLTRAP asked for a Nb target since it is known to have the highest possible yield for that very short-lived radionuclide ($T_{1/2}$ = 65 ms). Due to a target breakdown it was decided to put an already used ZrO_2 target on the front end in order not to cancel the whole run. The yield was almost an order of magnitude lower than expected for the Nb target. Thus, the aimed mass uncertainty of 1 keV could not be reached, but at least improved by a factor of five, which is worth for an accurate test of the conserved vector current hypothesis and the unitarity of the CKM matrix. With a half-life of only 65 ms ^{74}Rb is the shortest lived nuclide ever investigated in a Penning trap.

^{229,230}Fr, $^{230-233}$Ra:

A yield test by Ulli Köster for one of the used UC target showed an extremely high Fr and Ra yield and gave thus an excellent opportunity to explore this terra incognita. It was decided to spend with this target one to two shifts on mass measurements in the very heavy mass region to extend the knowledge of masses by two more isotopes in the case of Fr and by three more isotopes in the case of Ra, allowing for tests of mass models and mass predictions far away from stability. ^{233}Ra is the heaviest mass ever investigated with a Penning trap.

Beam time request 2004:

At present we are implementing a new control and data acquisition system. In addition some technical improvements will be addressed allowing mass measurements with very high accuracy in the very light mass region. Due to these developments we plan to do in 2004 mass measurements mainly in the light mass region and ask according to the accepted proposal P160 for a total number of 26 radioactive beam shifts. The beam time request is given in Table 3.

Table 3: Beam time request for 2004.

Nuclides	Field of interest	No. of shifts	Ion Source	Target
$^{17-19, 23-26}$Ne	halo, IMME	7	Plasma CTL	MgO / UC
^{22}Mg	CVC, CKM	4	RILIS	SiC
^{26m}Al	CVC, CKM	3	Hot plasma	SiC
^{38m}K	IMME	4	W surface	Ti metal foil
^{62}Zn	CVC, CKM	2	RILIS	Nb foil
^{62}Ga	CVC, CKM	6	WSI	ZrO_2
26 radioactive beam shifts				