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ADDENDUM TO PROPOSAL P160

for experiment IS413 to the ISOLDE and Neutron Time-of-Flight Committee

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

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Status report 2006:

The mass measurement program of ISOLTRAP has been very successful in the past years and a number of scientific highlights have been achieved as summarized in recent status reports [1-3] of the proposal P160 [4]. It was shown that with its high performance and the ability to address nuclides with production yields of only a few 100 ions/s and half-lives well below 100 ms, ISOLTRAP is a powerful tool for the investigation of nuclear binding energies.

An accuracy in the order of 10^{-8} is routinely achieved [5] and with a mass resolving power of 10^7 it is also possible to explore long lived isomeric states [6], i.e. to contribute to the assignment of spins to nuclear states [7] and to produce isomerically pure ensembles of nuclide ions [8] for further application in trap assisted spectroscopy.

In proposal P160 we asked for 104 shifts of radioactive beam for high-precision mass measurements of short-lived nuclides. The proposed mass measurements covered five different fields of interest. A detailed list was given in the proposal which can be summarized as follows:

- The masses of nuclides in the light mass range are of interest for the investigation of possible proton and neutron halos like ^{6,8}He, ^{11}Li, ^{11,12}Be, ^{17}Ne and $^{20-22}$N, as well as for a contribution to the analysis of laser and β-NMR experiments, e.g. in the case of ^{9}Li and $^{18-19,23-25}$Ne
- Tests of the unitarity of the Cabibbo-Kobayashi-Maskawa quark-mixing matrix require very accurate mass values of superallowed beta emitters with an uncertainty of only a few 100 eV. Possible nuclides include ^{14}O, ^{22}Mg, ^{26m}Al, ^{38m}K, and ^{62}Ga.
- Mass measurements on neutron-rich Ni, Cu, Zn, Ga, and Mn isotopes allow to explore largely unknown terrain.
- The improvement of masses of neutron-rich Sn, Cd, and Ag isotopes in the vicinity of ^{132}Sn are of astrophysical importance as well as for understanding the shell structure in this region.
- The masses of heavy nuclides for the elements Tl, Pb, and Bi are largely unmeasured and are of interest both for the understanding of nuclear structure and for the astrophysical r-process leading to the synthesis of very heavy elements.

In the last year of the four-year period, we asked for seven beam times ($^{6-8}$He, $^{17-19}$N, ^{26m}Al, $^{58-66}$Mn, $^{125-131}$Cd, $^{115-124}$Ag, and $^{213-217}$Pb) with a total number of 36 radioactive beam shifts [3]. An overview of ISOLTRAP beam times that were actually scheduled and performed in 2006 is given in Table 1.

Table 1: ISOLTRAP beam times scheduled in 2006. The actual number of taken shifts will be given by the coordinator. Only the number of requested shifts is listed in the table.

Beam time	Dedicated for	No. of shifts	Remark	Separator	Target/ion source
May 2006	$^{115-124}$Ag	7	power cut	HRS	UCx / RILIS
May 2006	*^{38}Ca*	*18*	*IS437 (proposal P196)*	*HRS*	*Ti / W CF_4*
May/June 2006	^{26}Al	3		GPS	SiC / W
June 2006	$^{58-66}$Mn	5		GPS	UCx / RILIS
July 2006	$^{125-131}$Cd	6	contaminants, power cut	HRS	UCx / RILIS
September 2006	^{6,8}He	6	test run, no protons taken, stopped (broken target)	HRS	UCx / CP
October 2006	$^{17-19}$N	6	upcoming run	HRS	MgO / CP

Table 2: Radionuclides and stable masses measured with ISOLTRAP in 2006. For nuclides marked with an asterisk the evaluation is in progress. Literature values are taken from the Atomic-Mass Evaluation AME2003 [9]

Nuclide	Half-life $T_{1/2}$	δm_{lit} / keV	δm_{exp} / keV	$\delta m_{exp}/m$
26Al*	717 ky	0.06		
38Ca*	440 ms	5		
39Ca*	860 ms	1.9		
56Mn*	2.6 h	0.7		
57Mn*	85.4 s	1.8		
58Mn*	3.0 s	30		
59Mn*	4.6 s	30		
60Mn*	51 s	90		
61Mn*	670 ms	230		
62Mn*	671 ms	220		
63Mn*	275 ms	260		
61Fe*	5.98 min	20		
62Fe*	68 s	14		
63Fe*	6.1 s	170		
124Cd	1.25 s	60	9.5	8.2×10^{-8}
126Cd	515 ms	50	4.2	3.6×10^{-8}
112Ag	3.13 h	17	2.4	2.3×10^{-8}
114Ag	4.6 s	25	4.6	4.3×10^{-8}
116Ag	2.68 min	50	3.2	3.0×10^{-8}
118mAg	2.0 s	60	2.5	2.3×10^{-8}
120Ag	1.23 s	70	4.5	4.0×10^{-8}
121Ag	790 ms	150	4.7	4.2×10^{-8}

A summary of the nuclides measured so far in 2006 is shown in Table 2. Since the importance of the physics output of these mass measurements was already explained in detail in our proposal P160, only a few further comments on the beam times and some specific highlights and problems will be addressed in the following:

$^{17-19}$N:

This beam time is scheduled for mid October. In 2005, two runs failed due to large amount of contaminants, which could not be mass separated with the HRS (even by use of the slits). However, the recorded data showed that with a clean gas inlet of the plasma ion source it should be possible to get a beam of $^{14}N^{17}N$, if the HRS is set to a resolving power of 3500 and the slits are used to cut away the $^{13}C^{18}O$ contaminant.

^{38,39}Ca:

These nuclides were not included in the P160 proposal, but the P196 proposal (experiment IS4379), where the Ca beam was shared with the group of Bertram Blank (half-life measurements of ^{38}Ca). Both mass and half-life are of high interest for the CKM unitarity test. For the first time the Ramsey measurement scheme, i.e. the use of time-separated oscillatory fields to excite the ion motion, for the determination of the cyclotron frequency was successfully performed for short-lived ions.

^{26}Al:

Instead of the superallowed beta emitter ^{26m}Al, the ground state nuclide ^{26}Al has been investigated (excitation energy is well known). Like in the case of ^{38}Ca, the Ramsey technique was applied.

^{6,8}He:

As a first test of the feasibility of cooling light ions from ISOLDE in the ISOLTRAP buncher, we asked for a ^{6}He beam. During the run, the target broke (transfer line). However, some data on the charge exchange and transfer efficiency were recorded. Note that only stable ions were investigated during the run (^{20}Ne, ^{4}He). Further studies are planned with the new ISOLTRAP ion source.

^{124,126}Cd:

It was planned to use a similar UC target with a quartz transfer line as it was employed for the successful Zn-run in 2005. Unfortunately, the performance of the target was not as good as expected and in addition, a power supply for the proton beam steering turned off during the run (still not clear why), such that the proton beam was no longer guided onto the neutron converter but almost directly on the target itself. This produced a large amount of contaminants and prevented mass measurements for very neutron-rich Cd nuclides. Finally, a power cut terminated the on-line run. However, some data were recorded for nuclides with mass 124 and 126.

$^{56-63}$Mn, $^{61-63}$Fe:

During the Mn-run the method of in-trap decay and mass measurement of the daughter nuclides [10] was performed to address for the first time Fe nuclides, which are currently not available from ISOL-type target/ion-source combinations. Data were recorded for $^{61-63}$Fe in addition to the mother nuclides $^{61-63}$Mn, such that accurate Q-values could be deduced.

^{112,114,116,118m,120,121}Ag:

With more than 4 shifts left, the on-line run was unfortunately stopped by a CERN-wide power cut. However, some data were recorded and mass values could be deduced.

Overview of results concerning the P160 proposal:

In Table 3, a summary of nuclides measured and investigated during the period 2003-2006 is given. All nuclides shown in the table were included in the P160 proposal. The green boxes indicate nuclides, for which data have been recorded and mass values have been obtained. Note that in some cases, like ^{134}Sn, more data could have been taken, but time constraints prevented more statistics and the resulting mass uncertainty is not as small as possible with the ISOLTRAP setup.

Nuclides marked with a blue box were requested but not scheduled (ISOLTRAP was the only user). Red and yellow boxes indicate unsuccessful measurements, where either contaminants or power cuts led to a failure of the respective runs.

Addendum to proposal:

Although a large number of radionuclides have been investigated, a large fraction of the initially proposed nuclide masses are not accounted for. These nuclides are still of high interest and we therefore ask for additional beam times, which will cover the so far not measured short-lived nuclides.

As already mentioned in the proposal, for some of the proposed mass measurements technical preparatory work is needed. This is especially the case for the light mass region (^{6,8}He, ^{9,11}Li, and ^{11,12}Be) where cooling in the RFQ ion beam cooler and buncher and the preparation Penning trap by H_2 gas (instead of He) has to be demonstrated. To this end, a new ion source has been tested and will replace the presently installed stable alkali ion source in the shutdown period 2006/2007. It will then be possible to produce off-line ^{4}He beams and to test the cooling of light masses with H_2 in the RFQ buncher and the preparation Penning trap, before requesting the radioactive beams of interest.

In addition, the experimental cycle has to be adopted and tested for very short-lived nuclides (half-lives of less than 50 ms). A new Channeltron detector has already been installed, which has a higher detection efficiency such that the overall efficiency of ISOLTRAP has increased by a factor 3. Therefore, nuclides with even smaller production yields or nuclides with very short half-lives and therefore larger decay losses can be addressed. In addition, a new detection scheme has been tested that employs time-separated excitation pulses, similar to the Ramsey-fringes scheme in atomic physics. This leads to a decrease of the peak width by 50% and an increase in the precision by a factor of 2-3. The application for very short-lived nuclides will also be investigated. However, the Ramsey technique is only applicable, when a clean ion beam can be provided.

Table 3: Radionuclides initially requested in the P160 proposal. The nuclides measured with ISOLTRAP within the 2003-2006 period are marked with a green box (meaning of other colors see below).

Element	***Ref.***	***Mass number***											
He		6	8										
Li		9	11										
Be		11	12										
N		17	18	19									
O		14											
Ne	[11,12]	17	18	19				23	24	25	26		
Mg	[13]	22											
Al		26m											
K	[14]	35											
Mn		58	59	60	61	62	63	64	65	66			
Ni	[15]	67	68	69	70	71							
Cu	[7,8,15]	67	68	69	70	71	72	73	74	75	76	77	78
Zn		62					74	75	76	77	78	79	
Ga	[15]	62		74	75	76	77	78	79	80	81	82	83
Rb	[16]	74											
Ag		115	116	117	118	119	120	121	122	123	124		
Cd		125	126	127	128	129	130	131					
Sn	[17]	131	132	133	134								
Tl		211	212	213	214	215	216						
Pb		213	214	215	216	217							
Bi	[18]	215	216	217	218								
		nuclide measured no successful measurement (contaminants or broken target) requested but not scheduled power cut											

For a large number of the so far not measured nuclides, on-line runs are still feasible. In some cases, new targets have been developed, which either led to an increase of the production yield or a reduction of the contaminants. An overview will be given in the following:

^{6,8}He:

A new off-line ion source will be installed at ISOLTRAP by the end of 2006. Among others, helium can be ionized by electron impact. Thus, it will be possible to perform off-line tests of the cooling of ^{4}He with hydrogen gas in the RFQ buncher in order to prepare the on-line run. In addition, a new BeO target is currently being tested, with which yields of 10^8 ions/s can be obtained in the case of ^{6}He. A new PhD student starting in November 2006 will investigate the cooling efficiency and charge exchange loses.

^{9,11}Li:

With a half-life of 8.8ms, ^{11}Li is an experimental challenge. With a maximum yield of only 7000 ions/s, ion losses during the experimental cycle need to be considered. In addition to the handling of light ions with H_2 cooling, a higher detection efficiency for the final detector and new experimental schemes will be available, in order to reduce the total cycle time and thus to address these very short-lived nuclides.

^{11,12}Be:

Similar to ^{11}Li, ^{12}Be is a challenging nuclide, since its half life with 21.5 ms is about three times less than that of ^{74}Rb, which is the radionuclide with the shortest half-life so far investigated with ISOLTRAP. Also the maximum yield of only 7000 ions/s requires the shortest experimental cycle possible, which is, however, under investigation as mentioned in the case of ^{11}Li.

$^{17-19}$N:

For the short-lived nuclide ^{17}N an on-line run is planned in mid October of 2006. The mass is important for a test of the isobaric multiplet mass equation, where another important member of this multiplet, ^{17}Ne, has already been measured within this proposal P160.. Previous runs showed, that with a very well tuned HRS (resolving power more then 3000) and operating slits, the large amount of CO molecules can be cut out of the beam.

^{14}O:

This nuclide, a superallowed beta emitter, is important for the CKM unitarity test. At the moment new targets are developed, which deliver carbon beams. Molecular beams like CO are also feasible and a successful runs seems possible.

$^{70-71}$Ni:

A new all-graphite target has been developed at ISOLDE which should give yields of $3x10^5$ and 7000 ions/s for ^{70}Ni and ^{71}Ni, respectively. With half-lives of more than one second in each case, the mass measurements should pose no problem..

$^{115-124}$Ag:

As has been observed in the latest Ag run, which was stopped due to a power cut, measurements for the neutron-rich nuclides are possible beyond the mass 121.

$^{125-131}$Cd:

So far the advantage of the newly designed quartz transfer line targets, i.e. a reduction of the alkali ion background, could not be made use of for ISOLTRAP mass measurements of neutron-rich Cd isotopes (as mentioned in the latest status reports).

$^{211-216}$Tl, $^{213-217}$Pb, $^{217-218}$Bi:

These nuclides have not been requested so far, but their masses are still of importance for the study of the nuclear structure and for tests of mass models in this mass region. Some mass measurements for heavy nuclides have already been performed, e.g. ^{215,216}Bi, and further investigations for nuclides in this mass range seem feasible.

Beam time request:

In Table 4 a list of nuclides is given, indicating which masses we would like to measure in 2007 and 2008. We have divided the list in two parts; those masses which we would like to address first, since they have high priority (**) and those masses which we would like to address second (lower priority, *). The list is not only based on the importance of the physics output by these mass measurements but also on the required preparatory studies with our setup and on the targets needed to get access to some of the proposed masses.

Table 4: Overview of radionuclides, which are requested in the addendum of the P160 proposal for 2007 and 2008. The nuclides are separated into two groups with respect to their priority.

Nuclides	Field of interest	No. of shifts	Priority	Target
2007: 22 radioactive beam shifts				
^{14}O	CVC, CKM	3	**	SiC
^{70,71}Ni	mass surface	5	**	UC / all graphite
$^{115-124}$Ag	mid masses	7	**	UC / RILIS
$^{125-131}$Cd	mid masses	7	**	UC / RILIS quartz
2008: 22 radioactive beam shifts				
^{6,8}He	Halo	5	*	ThC / UC
^{9,11}Li	Halo	5	*	Thin Ta foil
^{11,12}Be	Halo	4	*	UC or Ta foil
$^{211-216}$Tl	heavy masses	4	*	ThC / UC
$^{213-217}$Pb	heavy masses	4	*	ThC / UC

References:

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