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Status report to the ISOLDE and Neutron Time-of-Flight Committee

Penning-trap mass measurements with ISOLTRAP during the period 2014-2018

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Abstract: The high-precision mass spectrometer ISOLTRAP is dedicated to the determination of atomic masses using state-of-the-art ion-trap techniques. The experiments concerned by this status report were directed towards the study of physics topics that include nuclear structure, nuclear astrophysics and the weak interaction. Key to the successful operation of the spectrometer is its flexibility under a wide range of online experimental conditions of low-production yields and high-levels of contamination. To allow for more efficient use of online beam a series of technical developments have been undertaken within the period covered by this reports, in particular the implementation of the Phase-Imaging Ion-Cyclotron Resonance technique.

Experiments and remaining shifts: At present, the ISOLTRAP experiment has 9 experiments for which a status report was required by the INTC. A summary of the current and proposed status for these experiments is listed in the table bellow:

Exp.	Total shifts	Used shifts/Remaining shifts in 2018	Accepted isotopes	Last scheduled in	Remaining shifts in 2019	Proposed status after LS2
IS490	28	0/0	$^{46-48}$Ar, $^{96-98}$Kr	2017	0	Close
IS532	27	11/11	$^{52-55}$Sc	2018	0	Close
IS542	9	0/9	^{32}Ar	2014	9	Open
IS565	8	0/0	^{23}Mg/Na, ^{21}Na/Ne	2016	0	Close
IS567	17	0/0	^{34}Mg/Al	2015	0	Close
IS574	19	0/0	$^{127-132}$Cd	2017	0	Close
IS592	12	0/10	^{131}Cs/Xe	2017	10	Open
IS625	12	0/12	^{56}Cu, ^{58}Zn		12	Open
IS642	12	6/12	^{70}Br/Se	2018	6	Open
Total Shifts in 2018 : 54			**Total Shifts in 2019 : 37**			

Together with the already closed IS473, IS498, IS513, IS518, IS535 experiments and the IS534 and IS598 experiments related to an in-source laser spectroscopy program, the experiments above have produced since 2014 21 scientific publications including 1 Nature Physics Letter and 3 Physical Review Letters. In addition, the wealth of data collected allowed for 8 PhD and 2 Master's theses to be successfully completed.

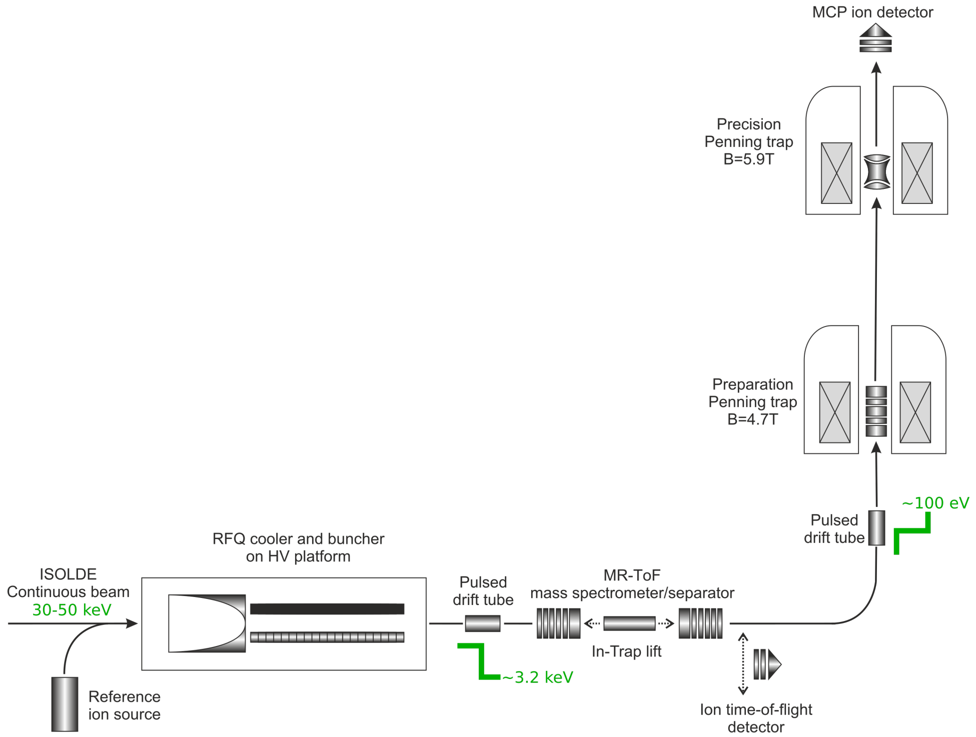

Figure 1: Schematic representation of the ISOLTRAP on-line mass spectrometer. The typical kinetic energy of the ions at various stages of the ISOLTRAP apparatus is presented in green. See text for details.

1 Experimental Setup

Figure 1 shows the current layout of the ISOLTRAP experimental setup [1, 2]. The spectrometer presently consists of four ion traps. The first such devices is a linear segmented radio-frequency quadrupole (RFQ) trap [3] where the quasi-continuous beam delivered by the ISOLDE facility is accumulated and helium buffer cooling is applied for a typical time ranging between 5-20 ms. The typical transport efficient between a Faraday-cup placed after the ISOLTRAP ion beam cooler and the main ISOLDE switchyard is typically between 1-3%. Maintenance work, including re-alignement work, is currently ongoing in order to address this issue. In order to make a more efficient use of on-line beam time a complete automation of the ISOLTRAP beamline has been undertaken over the past years. This not only now allows a fully remote operation of the apparatus but also offers the possibility to script the whole measurement procedures, including switching between online and offline beam.

The beam exits ISOLTRAP's RFQ trap as a short ion bunch which is then decelerated from the initial ISOLDE beam energy ($\sim$ 30-50 keV) to an energy of $\sim$ 3.2 keV using a pulsed drift cavity before being injected into ISOLTRAP's Multi-Reflection Time-of-Flight mass spectrometer/separator (MRToF-MS) [4, 5]. This device is composed of a set of two electrostatic mirrors between which the beam travels back and forth for a typical time a few tens of ms correspondingly extending the flight path of the ions. As a result, the various species constituting the ISOLDE beam naturally separate in time-of-flight and the beam composition can be studied on a time-of-flight detector placed after the device. Since its implementation within the ISOLTRAP setup in 2010, this device has been routinely used to separate the species of interest from the rest of the isobaric contaminants and has very consistently been reaching mass resolving powers in excess of 10^5. Originally intended to be used in combination with a Bradbury-Nielsen beam gate, a new mass-selective ejection technique has recently been developed for the ISOLTRAP MRToF-MS [6]. Based on the careful adjustment of the ejection timings out of the device, this technique was not only found to be straightforward to setup, but was also shown to allow for the separation of species as close as 200 ns apart. After separation, a clean ion bunch can then be delivered to the subsequent tandem Penning-trap system. Since 2013, the ISOLTRAP MRToF-MS device is also routinely used as a mass spectrometer in its own right [7] reaching typical relative mass uncertainties of a few 10^{-7}. However, the accuracy and precision of this mass measurement technique heavily relies on the stability of the voltages applied on the set of electrodes constituting the mirrors. Through active and passive voltage stabilization of the electrode closer to the ion's turning point, we recently showed that these effects can be greatly mitigated [8]. The simultaneous stabilization of the other mirror electrodes is already under way and offers promising preliminary results. During this study, the influence of the cooling process on the systematic of the MRToF-MS measurement method was also investigated [9]. Combining the single ion counting capabilities and separation power of the MRToF-MS device with in-trap decay inside the ISOLTRAP beam cooler it was also recently shown that nuclear ground-state half-life measurements can be performed at ISOLTRAP thus extending further the capabilities of the spectrometer [10]. During the period concerned by this status report, the ISOLTRAP MRToF-MS has solidified its status as a high performance beam diagnostics tool and has demonstrated its usefulness for the ISOLDE facility as a whole. Indeed, this device has been used in many occasions to assist the ISOLDE user community. Performed studies include identifying and quantifying stable or long-lived contaminants (inaccessible to the ISOLDE tape station), optimizing the targets and ion sources working parameters for the production of rare isotopes and even assisting in online-tests of new RILIS laser-ionisation schemes [11]. ISOLTRAP has notably been providing assistance in all of these aspects for the collections of ^{149,152}Tb at ISOLDE. These isotopes are of societal relevance for their potential medical applications. In fine, the collected activity was successfully used to perform *in-vivo* tests and spawn several publication in medical journals[12, 13, 14, 15]. Furthermore, the yields of neutron-rich laser-ionized chromium and scandium isotopes, two elements the availability of which is scarce at ISOL facilities, were measured using the ISOLTRAP MRToF-MS and were used to bring to the INTC proposals dedicated to the measurement of their ground-state electromagnetic properties [16, 17].

Before entering the first of two Penning traps located at ISOLTRAP, the kinetic energy of the ion is brought down to below 100 eV by a second pulsed drift cavity. Inside the preparation Penning trap the so-called mass selective buffer gas-centering technique is applied [18]. Using Helium buffer-gas this technique not only allows the cooling of the axial and radial motions of the ions but also offers the possibility to provide additional purification of the ion beam if necessary. A mass resolving power similar to that of the MRToF-MS is achieved but the typical trapping time there is of a few 100 ms, i.e one order of magnitude more than the MRToF-MS.

The selected ions are then transferred to ISOLTRAP's fourth and final ion trap where the mass measurement is typically performed. For the past three decades, the Time-of-Flight Ion Cyclotron Resonance technique [19] has been employed to measure the free-cyclotron frequency of an ion confined inside the trap. In conjunction with two reference measurements using ions of well known mass, the cyclotron frequency of an ion of interest is easily related to its mass. This method offers a typical relative mass uncertainties in the 10^{-8} level in about a 1 s of measurement time. The Phase-Imaging Ion-Cyclotron Resonance (PI-ICR) technique has been recently proposed and successfully implemented at the SHIPTRAP mass spectrometer [20]. It relies on position information instead of time-of-flight detection to study the evolution of the ion's phase inside the Penning trap. From the phase information, the cyclotron frequency can be determined with increased precision compared to the traditional ToF-ICR technique. The PI-ICR technique offers the additional advantage of being a non scanning and as a result required far less ions for a successful measurement to be performed. Implementing this technique was one of ISOLTRAP top priority over the past years. Modification of the ISOLTRAP apparatus were found to be necessary in order to preserve the symmetry of the electric fields guiding the ions from the Penning-trap to the position sensitive detector [21]. After these modifications, the PI-ICR technique was successfully commissioned in 2017 and is now fully available for online operation. Nonetheless, a thorough re-evaluation of the systematics of the ToF-ICR measurement as well as a first thorough assessment of the measurement systematics of the PI-ICR technique is planned during LS2.

2 Status report of IS490

- Title: Masses of Noble gases

- Spokesperson : D. Lunney

- Accepted isotopes : $^{46-48}$Ar, $^{96-98}$Kr

2.1 Performed studies

The IS490 experiment was originally accepted in 2009 [22] (INTC-P-263) for mass measurements of the isotopes of noble gases. This experiment included measurements of $^{46-48}$Ar to study the persistence of the $N = 28$ shell closure in neutron-rich systems, mass measurements $^{70-72}$Kr of interest for the modeling of the rp-process and finally $^{96-98}$Kr to study the development of mid-shell collectivity around $A \sim 100$. $^{70-72}$Kr were originally part of the scientific program but the corresponding shifts were re-allocated to the measurement of neutron-rich argon and krypton isotopes following the previous

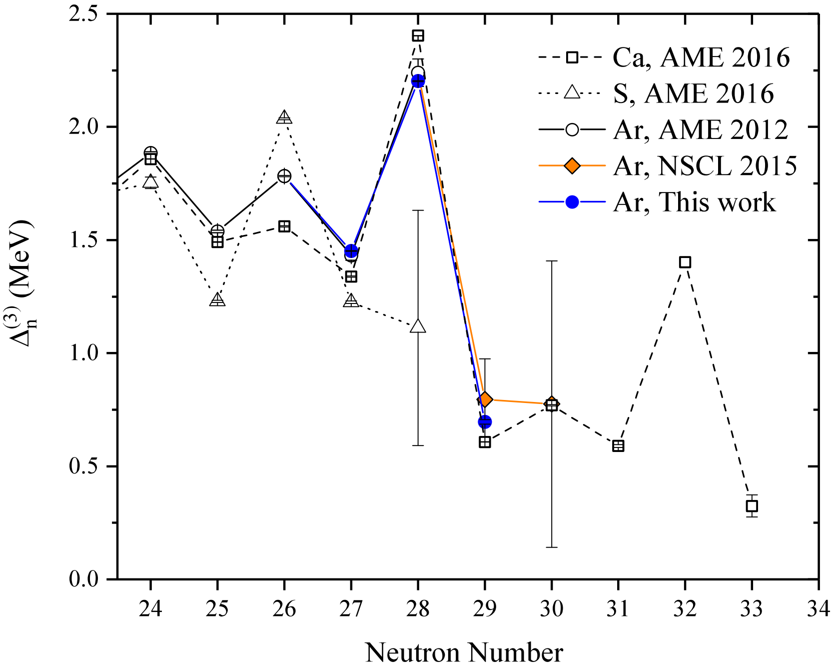

Figure 2: Three points estimator of the odd-staggering for the calcium, argon and sulfur isotopic chains.

status report submitted to the INTC in January 2014 [23]. This experiment was already successful to measure the neutron-rich $^{96-97}$Kr which showed that the shape transition taking place at $A \sim 100$ and $N = 60$ for the Rb and Sr chains is not visible in Kr before $N = 61$ [24].

An experiment was scheduled in July 2015. A ToF-ICR measurement of ^{97}Kr was successfully performed confirming the measurement of [24] which could only be achieved at the time with the preparation Penning trap. In addition, ion counts compatible with ^{98}Kr were observed using ISOLTRAP's MRToF-MS. Step wise increasing the storage time of the $A = 98$ beam inside the ion beam cooler we could confirm that the count rate within the time window of interest was decreasing at the same rate than that observed for stable Kr. The loss of stable noble gases inside the ion beam cooler was attributed to the charge exchange phenomenon. To mitigate this effect, makeshift cold traps were installed to purify the helium injection lines. Hence, a mass measurement was performed but the low ion rate, the high level of ^{186}Hg^{2+} contamination and the limited time remaining for the experiment were such that the obtained precision did not allow constraining the trend of the two-neutron separation energy beyond $N = 61$. This experiment also aimed at the measurement of the $^{46-48}$Ar isotopes. The contamination level was too extreme on mass $A = 48$ for ^{48}Ar to be observed. Nonetheless, Penning-trap measurements of $^{46-47}$Ar were successfully performed. The measurement conditions were difficult with for example the presence of the ^{12}C^{34}S molecular ion significantly hindering the measurement of ^{46}Ar. An addendum was submitted to the INTC in 2016 to complete the obtained dataset. The corresponding beam time was scheduled in August 2017. During this beam time both argon and krypton datasets grew with the addition of MRToF-MS measurements of ^{48}Ar and ^{98}Kr respectively.

The complete analysis of the krypton dataset is currently pending. The analysis of the argon dataset is completed and is part of one PhD thesis [25]. If all the measured argon masses were found to be more bound than previous measurements they all amount to a net reduction of $\sim$ 70 keV of the one-neutron empirical shell gap at $N = 28$. However, compared to ^{48}Ca, ^{46}Ar exhibits a N = 28 shell gap which is only $\sim$ 400 keV smaller suggesting the persistence of the $N = 28$ gap (see Figure 2) down to the argon chain. However, a study of the ground-state wavefunction of these isotopes in light of shell model calculations performed using a traditional phenomenological interaction and an *ab-initio* approach (VS-IMSRG) shows significant contributions from intruder states in the ground state, indicating a more fragile shell closure than what is inferred from the mass systematics alone.

A summary of the scientific publications related to the IS490 experiment is provided in the following table :

IS Exp.	Type	Bibliographic information
IS490	Article	M. Mougeot *et al.*, "Study of the $N = 28$ shell closure in neutron-rich with high-precision mass measurement of $^{46-48}$Ar", Article in preparation (2019)
	Thesis	M.Mougeot, "Nuclear collectivity studied through high-precision mass measurements of neutron-rich argon and chromium isotopes", PhD Thesis, Université Paris-Saclay, France (2019) [CERN-THESIS-2019-002]
		I. Kulikov, *In preparation*, PhD Thesis, Heidelberg Universität, Germany, (2021)

2.2 Future plans with available shifts

There are no shifts remaining and we consider the scientific program of this experiment completed. We therefore request this experiment to be closed.

3 Status report of IS532

• Title: Seeking the purported magic number $N = 32$ with high-precision mass spectrometry

• Spokesperson : S. Kreim, V. Manea

- Accepted isotopes : $^{52-55}$Sc, $^{58-64}$Cr

3.1 Performed studies

The IS532 experiment was accepted in 2011 [26] (INTC-P-317) for mass measurements of calcium of scandium isotopes. The underlying physics question is that of the study of the evolution of the $N = 32$ subshell closure far from stability. If the most important outcome of this mass measurement campaign is the Nature Letter published in 2013 [7] which firmly established the strong shell effect at $N = 32$ in the calcium chain it is far from being its only significant outcome. During the very same run, the neutron-rich ^{52,53}K isotopes were determined for the first time. The results published as a Physical Review Letter suggested the presence of a reduced but sizable shell gap at $N = 32$ in the potassium chain [27] .

Following the addendum submitted to the INTC in 2014 [28] (INTC-P-317-ADD-1) an experiment was dedicated to the other isotopes included in the original proposal, namely the neutron-rich $^{52-55}$Sc. Unfortunately, the transfer line of the target unit broke early during the run. Eager to make the most of the available beam time, the experiment continued nonetheless and provided an ideal testing ground for a new RILIS laser ionisation scheme dedicated to chromium atoms. This test provided various successful penning-trap measurements of neutron-rich chromium isotopes up to $A = 58$ as well as an MRToF-MS measurement of ^{59}Cr. The wealth of data collected during this run also includes the Penning trap mass measurement $^{100-102}$Sr and the MRToF-MS measurement of $^{100-102}$Rb, among which ^{102}Sr and ^{101,102}Rb were measured for the first time. The rubidium and strontium results were published in [29] and this publication was selected for *Editor's Suggestion*. They confirmed the continuation of the region of deformation with the increase of neutron number, at least as far as $N = 65$. A new technique consisting in performing ground-state half-life measurement by varying the storage time of the ion bunch inside ISOLTRAP's ion beam cooler while monitoring the ion rate of the peak of interest after the MRToF-MS was also tested and results are reported in [10].

Two addenda followed [30, 31] before an experiment could fully be dedicated to the measurement of neutron-rich chromium isotopes. During the corresponding experiment, which took place in 2016, Penning-trap measurement of $^{59-62}$Cr were performed. ^{63}Cr could only be measured with the MRToF-MS (see Figure 3). This run was particularly interesting as MRToF-MS measurement of $^{59-62}$Cr could also be performed and compared to the ToF-ICR data revealing no significant deviations between the two methods. The mass systematics extracted from the new high-precision data, point to a much more gradual onset of nuclear collectivity approaching $N = 40$ than what could have been inferred from previous measurements. This dataset was combined with the chromium data measured in 2014 and stemmed a Physical Review Letter publication [32].

After several tests with the RILIS and target and ion-source development teams, laser-ionised radioactive ^{51}Sc beam was proven to be present in the ISOLDE beam

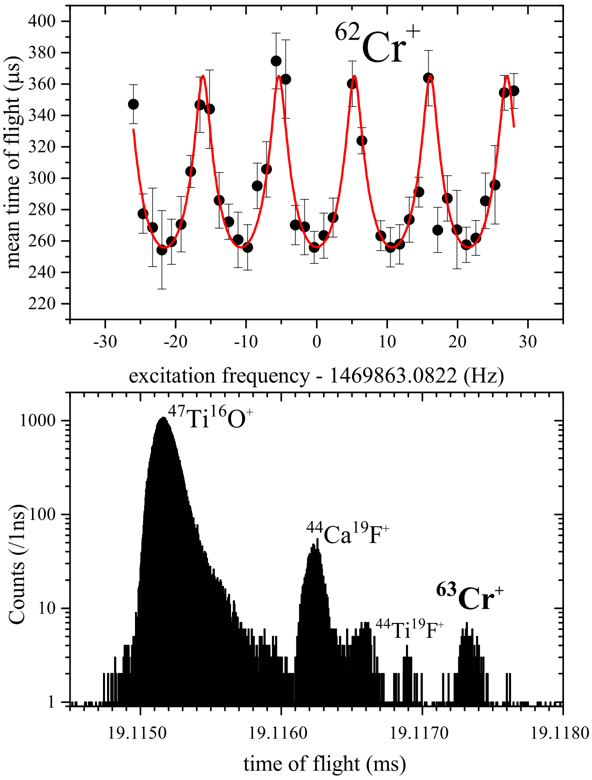

Figure 3: Top: Typical ToF-ICR resonance of ^{62}Cr recorded using the so-called Ramsey-excitation scheme [33]. Bottom: Typical MRToF-MS time-of-flight spectrum obtained on mass $A = 63$.

using ISOLTRAP's MRToF-MS device. As a result, an experiment focused on $^{52-55}$Sc was finally scheduled in 2018. Unfortunately, oders of magnitude more of the stable chromium, vanadium and titanium contaminants were observed on these masses. As a result, only MRToF-MS measurement of $^{49-50}$Sc could be performed. In agreement with the ISOLDE physics coordinator and ISOLDE team leader the beam time was redirected to the measurement of neutron-deficient indium isotopes. The LaC_x target which was used was the one used just weeks before by the CRIS experiment. In only 3 days of measurements, ISOLTRAP was successful in measuring three different isotopes using the three techniques now at its disposal for high-precision mass measurements. Hence, ^{99}In was measured using the MRToF-MS, ^{100}In was measured using the ToF-ICR technique and finally the PI-ICR technique was used to performed a measurement of the ground and isomeric states of ^{101}In. The writing of the corresponding publication is currently ongoing.

A summary of the scientific publications related to the IS532 experiment is provided in the following table :

IS Exp.	Type	Bibliographic information
IS532	Article	M. Rosenbusch *et al.*, "Probing the N=32 shell closure below the magic proton number Z=20: Mass measurements of the exotic isotopes $^{52.53}$K", Phys. Rev. Lett. 115, 232501 (2015)
		R.N. Wolf *et al.*, "Background-free beta-decay half-life measurements by in-trap decay and high-resolution MR-ToF mass analysis", Nucl. Instrum. Meth. B 376, 275-280 (2016)
		A. de Roubin *et al.*, "Nuclear deformation in the A = 100 region : Comparison between new masses and meand-field predictions", Phys. Rev. C 96, 014310 (2017)
		M.Mougeot *et al.*, "Precision mass measurements of $^{58-63}$Cr : nuclear collectivity towards the N=40 Island of Inversion", Phys. Rev. Lett. 120, 232501 (2018)
		W.J Huang *et al.*, " Evaluation of high-precision atomic masses of A $\sim$ 50-80 and rare-earth nuclides measured with ISOLTRAP", Euro. Phys. J. A 55: 96 (2019)
		I. Kulikov *et al.*, "Precision mass measurement of ^{70}As, ^{73}Br and ^{49,50}Sc isotopes", Article in preparation (2019)
	Thesis	M. Rosenbusch, "Development of new ion-separation techniques for short-lived nuclides and the first mass measurement of $^{52.53}$K", PhD Thesis, Greifswald Universität, Germany (2015) [CERN-THESIS-2015-389]
		A. de Roubin, "Mass measurements of neutron-rich strontium and rubidium isotopes in the $a \sim 100$ and development of an electrospray ionization ion source", PhD thesis, PhD Thesis, Université de Bordeaux, France (2016) [CERN-THESIS-2016-355]
		W.J Huang, "Direct mass measurements and global evaluation of atomic masses", PhD Thesis, Université Paris-Saclay, France (2018) [CERN-THESIS-2018-332]

		M.Mougeot, ”Nuclear collectivity studied through high-precision mass measurements of neutron-rich argon and chromium isotopes”, PhD Thesis, Université Paris-Saclay, France (2019) [CERN-THESIS-2019-002]
		F. Wienholtz, ”Measurements of exotic calcium isotopes by multi-reflection time-of-flight mass spectrometry and further developments and applications”, PhD Thesis, Greifswald Universität, Germany (2019) [CERN-THESIS-2019-216]
		I. Kulikov, *In preparation*, PhD Thesis, Heidelberg Universität, Germany, (2021)

3.2 Future plans with available shifts

There are no shifts remaining and we consider the scientific program of this experiment completed. We therefore request this experiment to be closed.

4 Status report of IS542

- Title: Remeasurement of Ar-32 to test the IMME
- Spokesperson : S. Kreim
- Accepted isotopes : ^{32}Ar

4.1 Performed studies

The IS542 experiment was proposed in 2012 (INTC-P332) and 9 shifts were approved for the ^{32}Ar mass to investigate the accuracy of the predictions of the Isobaric Multiplet Mass Equation (IMME). Indeed, for the quintet of nuclei involved the predicted quadratic form predicted by the IMME could not be confirmed. This experiment was scheduled once in 2014 but never re-scheduled since. A CaO nanostructured target was used. It had already been used by other users. As such targets tend to degrade rapidly with time, the yields of $^{32}Ar^{+}$ were so low that only severe table O_2^+ contamination was observed.

4.2 Future plans with available shifts

The measurement has not been performed elsewhere and since all the allocated shifts are remaining and the physics program has not been scheduled since 2014 we would like to keep this proposal open. Furthermore, the need for a nano-structured target for this experiment is timely a nano-laboratory dedicated to making such nano-structured target will soon be implemented at ISOLDE.

In summary we request :

Isotope	Half-life	Yield (ions/μC^{-1})	Target	Ionisation Method	Shifts (8H)
^{32}Ar	98.0 ms	800	nano-CaO	Hot Plasma	8
					Total Shifts: 8(+1 for tuning)

5 Status report of IS565

- Title: Q-values of Mirror Transitions for fundamental interaction studies

- Spokesperson : M. Breitenfeld

- Accepted isotopes : ^{23}Mg/Na, ^{21}Na/Ne

5.1 Performed studies

The IS565 experiment was proposed in 2013 [34] (INTC-P-369) and is dedicated to the high-precision determination of the Q-value between mirror nuclei. The $\mathcal{F}$t-values for the superallowed β-transitions currently provide the best test of the Conserved Vector Current (CVC) hypothesis, and the most precise determination of the V_{ud} element of the CKM matrix. The precision in the corrected $\mathcal{F}$t-values is currently being entirely dominated by the theoretical corrections rather than by experimental uncertainties. An alternative method was recently proposed involving the isospin T=1/2 mirror transitions [35]. Such transitions can provide an independent test of the CVC hypothesis, and ultimately and independent evaluation of V_{ud}, but experimental uncertainties still dominate over the theoretical inputs. Among other observables, the Q-value of the involved transition contribute significantly to the determination of the corrected $\mathcal{F}$t-value. Of the original 20 shifts only 8 were approved for the measurement of the pairs ^{23}Mg/Na and ^{21}Na/Ne.

The corresponding experiment was carried out in 2016 when both ^{23}Mg/Na and ^{21}Na/Ne pairs were measured using the ToF-ICR technique. A total of 30 and 19 ToF-ICR resonance pairs were recorded for the ^{23}Mg and ^{21}Na transitions respectively. The uncertainty on both Q_{EC} values was improved by a factor of 5 making them the most precise experimental input data for the calculation of the corrected $\mathcal{F}$t-value of these mixed Fermi and Gamow-Teller transitions. The results were published in [36] and are part of the PhD of J. Karthein.

Such an experimental program will undoubtedly benefit from the recent implementation of the PI-ICR technique at ISOLTRAP. Nonetheless, a careful assessment of the systematics of this measurement technique is a pre-requisite.

A summary of the scientific publications related to the IS565 experiment is provided in the following table :

IS Exp.	Type	Bibliographic information
IS565	Article	J. Karthein *et al.*, "Q_{EC}-value determination for ^{21}Na $\rightarrow^{21}$ Ne and ^{23}Mg $\rightarrow^{23}$ Na mirror nuclei decays using high-precision mass spectrometry with ISOLTRAP at the CERN ISOLDE facility", Phys. Rev. C 100, 015502 (2019)
	Thesis	J. Karthein, "Precision mass measurements using the Phase-Imaging Ion-Cyclotron-Resonance detection technique", Master's Thesis, Heidelberg Universität, Germany (2019) [CERN-THESIS-2017-281]
		J. Karthein, *In preparation*, PhD Thesis, Heidelberg Universität, Germany, (2020)

5.2 Future plans with available shifts

There are no shifts remaining. We therefore request to close this experiment.

6 Status report of IS567

• Title: Energy of the 2p1h intruder state in ^{34}Al: an extension of the "island of inversion"?

• Spokesperson : P. Ascher

• Accepted isotopes : ^{34}Mg/Al

6.1 Performed studies

The experiment IS567 was accepted in 2013 [37]. This experiment aimed at the mass measurement of the ordering between the 4^- and 1^+ states in ^{34}Al trapped after the decay of ^{34}Mg inside ISOLTRAP's preparation Penning-trap. At $N = 21$, the two-neutron separation energy value of the aluminium chain crosses locally the two-neutron separation energy of ^{33}Mg. This a unique feature over the whole nuclear chart and is highly unexpected. Scheduled in 2015, the corresponding experiment succeeded in measuring the masses of ^{34}Si, $^{33-34}$Mg and ^{34}Al. Noteworthy, is the fact that the mass of the refractory ^{34}Si isotope was measured directly for the first time following two consecutive ion-recoil capture inside the preparation trap. The ^{34}Al was measured in two different configurations. First, a beam of ^{34}Al, expected to be the 4^- ground-state, produced at ISOLDE was measured. Secondly, this isotope was measured following the ^{34}Mg in-trap decay. In this case, the 1^+ state is expected to be mostly produced but some contributions from 4^- are expected as well. Due to experimental difficulties one could not extract the exact ratio of the two states in this configuration and the excitation energy could therefore not be measured. Nonetheless, the performed studies were sufficient to confirm the crossover of the two separation energies of ^{33}Mg and ^{34}Al. The results were published in [38].

A summary of the scientific publications related to the IS567 experiment is provided in the following table :

IS Exp.	Type	Bibliographic information
IS567	Article	P. Ascher *et al.*, "Mass measurements of neutron-rich isotopes near $N = 20$ by in-trap decay with the ISOLTRAP spectrometer", Phys. Rev. C 100, 014304 (2019)

6.2 Future plans with available shifts

There are no shifts remaining and the isomer's excitation energy was measured by the IDS collaboration [39], therefore we request to close this experiment.

7 Status report of IS574

• Title: Precision mass measurements with ISOLTRAP to study the evolution of the $N = 82$ shell gap for from stability

• Spokesperson : S. Kreim, D. Atanasov

• Accepted isotopes : $^{129-132}$Cd

7.1 Performed studies

The IS574 experiement was proposed in 2013 [40] to study the evolution of $N = 82$ shell closure below the doubly-magic ^{132}Sn. Out of the requested isotopes, only $^{129-132}$Cd were accepted. The question of the strength of the $N = 82$ shell closure is also of prime importance to clarify the long standing question whether ^{130}Cd is a strong r-process waiting point. An experiment was carried out in 2014 and was successful in measuring the masses of $^{129-131}$Cd. The measured masses showed a reduction of one-neutron empirical shell-gap south of ^{132}Sn of about 1 MeV. Hydrodynamics simulations were carried out in two likely r-process scenarios, that of two-compact neutron stars mergers and that of ν-driven wind ejecta following supernovae explosions. The measured masses were shown to have a direct impact on the calculated abundance patterns in the $A = 130$

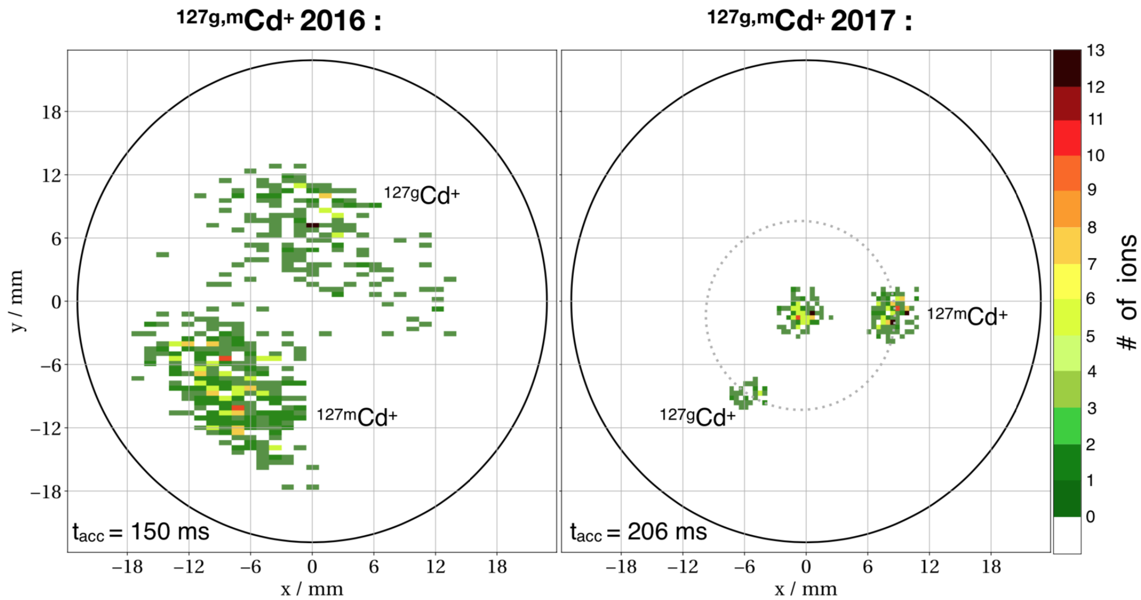

Figure 4: Left: PI-ICR spatial isomeric separation figure for ^{127g,m}Cd obtained in 2016. A phase accumulation time t_{acc} = 150 ms was used. Right: PI-ICR spatial isomeric separation figure for ^{127g,m}Cd obtained in 2017 after the modifications proposed in [21]. The unmarked spot corresponds to a reference measurement marking the center of the PI-ICR figure. A phase accumulation time t_{acc} = 206 ms was used.

abundance peak. The results of this study were published in Physical Review Letters [41].

A subsequent experiment was scheduled and carried out in 2016. This campaign provided the first online application of the PI-ICR measurement technique at the ISOLTRAP setup and with it the first demonstration of the isomeric separation capabilities of this technique. The left panel of Figure 4 shows a typical example of a spatial isomeric-separation figure obtained using PI-ICR during this run. Though no mass values could be extracted from this particular measurement, this was enough to trigger the submission of an addendum, accepted in 2017 [42]. The addendum was motivated by systematic studies showing the astrophysics impact by single mass measurements of ^{132}Cd [43] on the abundance curve as well as a first measurement of the excitation energy between the $\frac{3}{2}^+$ and $\frac{11}{2}^-$ isomeric states in ^{129}Cd.

Within the same year, another cadmium experiment was performed. Benefiting from very favorable experimental conditions, an MRToF-MS measurement of ^{132}Cd was carried out. Following the successful and complete commissioning of the PI-ICR technique [36] this experiment was also successful in measuring the excitation energy between the two $\frac{3}{2}^+$ and $\frac{11}{2}^-$ isomeric states in ^{127,129}Cd. A typical example of the spatial separation between the two states in ^{127}Cd is shown in the right panel of Figure 4. In this case, a mass resolving power $R = \frac{m}{\Delta m}$ in excess of 10^6 was reached in a phase accumulation time t_{acc} as short as 206 ms. The PI-ICR result for the ^{127}Cd measurement is in good agreement with a recent measurement performed by the TITAN Penning-trap group at TRIUMF, Canada [44]. From the intensity ratios of the two states observed in a high-precison laser spectroscopy experiment performed at ISOLDE [45], a spin could be attributed to each state for both ^{127}Cd and ^{129}Cd. Surprisingly, this assignment unveils a sudden inversion of the ordering of the two states in ^{129}Cd compared to lighter odd-even cadmium isotopes. These results have just been submitted to Physical Review Letters.

A summary of the scientific publications related to the IS574 experiment is provided in the following table :

IS Exp.	Type	Bibliographic information
IS574	Article	D. Atanasov *et al.*, "Precision mass measurements of $^{129-131}$Cd and their impact on stellar nucleosynthesis via the rapid neutron capture process", Phys. Rev. Lett. 115 232501 (2015)
		V.Manea, J. Karthein *et al.*, "Evolution of the $N = 82$ shell closure below $Z = 50$ from masses of neutron-rich cadmium isotopes and isomers", Submitted to Phys. Rev. Lett. (2019)
	Thesis	D. Atanasov, "Precision mass measurements for studies of nucleosynthesis via the rapid neutron-capture process : Penning-trap mass measurements of neutron-rich cadmium and caesium isotopes", PhD thesis, Heidelberg Universität, Germany (2019) [CERN-THESIS-2016-251]
		J. Karthein, "Precision mass measurements using the Phase-Imaging Ion-Cyclotron-Resonance detection technique", Master's Thesis, Heidelberg Universität, Germany (2019) [CERN-THESIS-2017-281]
		A. Welker, "Implementation and commissioning of the phase-imaging ion-cyclotron-resonance method and mass measurements of exotic copper isotopes with ISOLTRAP", PhD Thesis, Technische Universität Dresden, Germany (2018) [CERN-THESIS-2018-183]
		J. Karthein, *In preparation*, PhD Thesis, Heidelberg Universität, Germany, (2020)

7.2 Future plans with available shifts

There are no shifts remaining and we consider the part of the scientific program approved by the INTC completed. We therefore request this experiment to be closed. If the decision is taken to carry on with the original program, which included n-rich In and Ag masses, a new proposal will be brought to the INTC committee.

8 Status report of IS592

• Title: Search for beta-transitions with the lowest decay energy for a determination of the neutrino mass
• Spokesperson : S. Eliseev
• Accepted isotopes : ^{131}Cs/Xe

8.1 Performed studies

The IS592 experiment was proposed in 2014 [46] (INTC-P410) with the aim to search for β-decay transitions with the lowest possible decay-energy. The interest in such transitions is for the determination of the neutrino mass on a sub-eV level. As the neutrino mass sensitivity of most modern micro-calorimeter experiments depends on the fraction of events close to the end-point of the decay . This fraction in turn depends on the Q-value (functional dependence $\propto 1/Q^3$ for beta-decays and even steeper dependance for electron capture transitions). The direct measurement of the neutrino is of paramount importance not only for the field of particle physics but also has significant consequences on the formation of large scale structures in cosmology. Hence, within the INTC-P410 proposal, 12 transition pairs were identified. All of these, transition are in the medium-heavy mass region of the chart of nuclides which due to the precision required for these measurements is a real challenge for the traditional ToF-ICR technique. Hence, this program was a prime motivation to push for the implementation of the PI-ICR technique at ISOLTRAP.

Among the 12 transitions identified, 4 are unstable and therefore required shifts to be approved by the INTC and among those only the less demanding pair ^{131}Cs/Xe was accepted. In 2017, spare time in the ISOLDE schedule allowed for online experimental time to be dedicated to the commissioning of the PI-ICR mass measurement method. During this experiment, the choice was made to use the pair ^{88}Rb/Sr to study the PI-ICR measurement procedure and its performance in various conditions. All in all, with this study we demonstrated that we could reliably perform a Q-value measurement of a decay pair with the PI-ICR technique and reach uncertainties on the $\sim$ 200 eV level.

When a dedicated IS592 run was scheduled the PI-ICR technique was thus used in combination with the ToF-ICR technique to perform the mass determination of the atomic mass of ^{131}Cs. Indeed, the mass of ^{131}Xe is known with enough precision such that only a measurement of ^{131}Cs to the same precision is required to address the proposed physics case. A relative mass uncertainty $\frac{\delta m}{m} = 1.9 \times 10^{-9}$ was achieved and the new measurement improves the uncertainty on the ground-to-ground-state Q_{EC}-value by a factor 25 precluding the ^{131}Cs/Xe pair as a possible candidate for the direct determination of the electron neutrino mass. These results was published in [47] and are part of J. Karthein thesis.

A summary of the scientific publications related to the IS592 experiment is provided in the following table :

IS Exp.	Type	Bibliographic information
IS592	Article	J. Karthein *et al.*, "Direct decay-energy measurement as a route to the neutrino mass", Hyper. Int. 240: 61 (2019)
	Thesis	J. Karthein, *In preparation*, PhD Thesis, Heidelberg Universität, Germany, (2020)

8.2 Future plans with available shifts

The present experimental program is intimately connected to the exploitation of the novel PI-ICR technique at ISOLTRAP. Following the successful implementation of this very promising technique in 2017 and as there are 10 shifts remaining, we would like to keep the IS592 experiment open. In 2017, the INTC called for Letters of Intent describing measurements that could be performed with long-lived activity during LS2. We responded with an LOI describing our interest to perform Q-value measurements of the ^{159}Dy/Tb and ^{175}Hf/Lu pairs [48]. This highlights the importance, continued interest and commitment of our collaboration to this scientific program. It is noteworthy that these two pairs were part of the original INTC-P-410 proposal but the INTC denied allocating shifts to these measurements before we could demonstrate our control over the PI-ICR method, which is now achieved.

In addition to the 10 shifts remaining we would require 14 additional shifts to measure the decay energy of the ^{159}Dy/Tb and ^{175}Hf/Lu pairs. This would bring the total amount of shifts allocated for this experiment to 24 shifts i.e 12 shifts for each of the pairs in question.

Isotope	Half-life(d)	Yield (ions/μC^{-1})	Target	Ionisation Method	Shifts (8H)
^{159}Dy	144	10^8	Ta	Surface	12
^{159}Tb	Stable	10^7			
^{175}Hf	70	$>10^7$	Ta	Hot Plasma	12
^{175}La	Stable	Plenty			
					Total Shifts: 24

9 Status report of IS625

• Title: Penning-trap mass measurements of Zn and Cu isotopes relevant for the astrophysical rp-process

• Spokesperson : D. Atanasov; A. Kankainen

• Accepted isotopes : ^{56}Cu, ^{58}Zn

9.1 Performed studies

No studies were performed as this experiment has never been scheduled.

9.2 Future plans with available shifts

The IS625 experiment was accepted in 2016 [49] and is focused on the mass measurement of ^{56}Cu and ^{58}Zn isotopes. These isotopes are of key interest to understand how the rapid proton capture process (rp-process) proceeds beyond the ^{56}Ni waiting point in type I X-ray bursts. These nuclei are especially important as they influence both the observed light curves as well as the composition of the burst ashes which contribute to the composition of the underlying neutron star crust and their modification via the accretion process. Unfortunately, this beam time was never scheduled and in the meantime the mass of ^{56}Cu was measured by the LEBIT Penning-trap group at the NSCL. The fact that their result was published in Physical Review Letters only confirms the importance of the mass measurement campaigns [50] in this region. As a result, we would like to keep this proposal open and we request that the 6 shifts originally awarded for the measurement of ^{56}Cu are transferred to the very challenging measurement of ^{58}Zn, which is also of importance for the study of nuclear structure around the doubly-magic ^{56}Ni. Indeed, ^{58}Zn offers the possibility to study the spin-isospin symmetry in the pf-shell [51]. With the β-decay of ^{58}Zn recently studied at GANIL with high-statistics, a direct high-precision measurement of the ^{58}Zn ground-state mass would undoubtedly result in more precise β-decay strengths which could be compare to that obtained from the (^{3}He,t) charge-exchange reactions.

We request a total of 3 shifts for preparation and 9 shifts for measurement:

Isotope	Half-life (ms)	Yield (ions/μC^{-1})	Target/ion source	Shifts (8H)
^{58}Zn	86.7 (24)	10	ZrO_2/RILIS	3+9
				Total Shifts: 12

10 Status report of IS642

- Title: Q$_{EC}$ value determination of the superallowed β-decay of ^{70}Br
- Spokesperson : A. Algora, F. Wienholtz
- Accepted isotopes : ^{70}Br/Se

10.1 Performed studies

This experiment was accepted in 2017 [52] and aims at the measurement of the Q$_{EC}$ value determination of the superallowed β-decay of ^{70}Br. The corrected $\mathcal{F}$t-value associated to

this transition is not yet included in the set of 14 canonical transitions now used to determine the world-average corrected $\mathcal{F}$t-value. Indeed, if the superallowed branching ratio and the half-life of 0^+ ground state transition were recently measured at RIKEN [53], the Q_{EC} extracted using the result of [54] yields a corrected $\mathcal{F}$t-value which presents serious discrepancy (10 σ) to the world-average value. In an experiment scheduled in 2018, we attempted to measure this Q_{EC} value. However, the experimental conditions were such that the efficiency of the ISOLTRAP apparatus together with the production yield of ^{70}Br/Se$^+$ which were orders of magnitude smaller than expected made the direct measurement of the Q_{EC}-value impossible. An attempt was made to measure this species as the molecular ion ^{70}B^{27}Al$^+$ but these attempts remained unsuccessful. Last but not least, the failure of a crucial turbo-pump controller at ISOLTRAP also cut the experiment short.
Nonetheless, a Penning trap mass measurement of ^{70}As and an MRToF-MS measurement of ^{73}Br were carried out. These will be combined with the scandium masses measured during the 2018 scandium experiment and will be reported in a dedicated publication which is currently in preparation.

A summary of the scientific publications related to the IS642 experiment is provided in the following table :

IS Exp.	Type	Bibliographic information
IS642	Article	I. Kulikov *et al.*, "Precision mass measurement of ^{70}As, ^{73}Br and ^{49,50}Sc isotopes", Article in preparation (2019)

10.2 Future plans with available shifts

We would like to keep this proposal open. With the improvement brought by the PI-ICR technique, 6 shifts might be sufficient to complete the program. In addition, the maintenance work which is now reaching completion should result in an increase in the overall transport efficient of the horizontal part of the ISOLTRAP beam-line. Nonetheless, we would like to request target tests or new yield measurements of the Br$^+$ and AlBr$^+$ molecular ions to be performed before this experiment is re-scheduled.

Six shifts are remaining for this experiment out of a total of 12 (the listed yields are those of [52]) :

Isotope	Half-life	Yield (ions/μC^{-1})	Target	Ionisation Method	Shifts (8H)
^{70}Br	79.1 ms	10^{3-4}	ZrO or Nb foil	Hot Plasma	2.5
^{70}Se	41.1 days				
					Total Shifts: 5(+ 1 for tuning)

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Appendix

The following table provides a list of scientific publications of the ISOLTRAP collaboration within the period concerned by the current status report including closed proposals and publication related to the extensive in-source laser spectroscopy program in the lead-deficient region currently ongoing at ISOLDE.

IS Exp.	Type	Bibliographic information
IS473	Article	A. Welker *et al.*, "Precision electron-capture energy in ^{202}Pb and its relevance for neutrino mass determination", Euro Phys. J. A 53: 153 (2017)
	Thesis	A. Welker, "Implementation and commissioning of the phase-imaging ion-cyclotron-resonance method and mass measurements of exotic copper isotopes with ISOLTRAP", PhD Thesis, Technische Universität Dresden, Germany (2018) [CERN-THESIS-2018-183]
IS490	Article	M. Mougeot *et al.*, "Study of the $N = 28$ shell closure in neutron-rich with high-precision mass measurement of $^{46-48}$Ar", Article in preparation (2019)
	Thesis	M.Mougeot, "Nuclear collectivity studied through high-precision mass measurements of neutron-rich argon and chromium isotopes", PhD Thesis, Université Paris-Saclay, France (2019) [CERN-THESIS-2019-002]
IS498	Article	W.J Huang *et al.*, " Evaluation of high-precision atomic masses of A $\sim$ 50-80 and rare-earth nuclides measured with ISOLTRAP", Euro. Phys. J. A 55: 96 (2019)
	Thesis	W.J Huang, "Direct mass measurements and global evaluation of atomic masses", PhD Thesis, Université Paris-Saclay, France (2018) [CERN-THESIS-2018-332]
IS513	Article	N.A Althubiti *et al.*, "Spectroscopy of the long-lived excited state in the neutron-deficient nuclides ^{195,197,199}Po by precision mass measurements", Phys. Rev. C 96, 044325 (2017)
	Thesis	N.A Althubiti, "Tracking the $\nu i_{13/2}$ orbital in the neutron-deficient polonium isotopes with the high-precision ISOLTRAP mass spectrometer at CERN-ISOLDE", PhD Thesis, The University of Manchester, United Kingdom (2017) [CERN-THESIS-2017-414]
IS518	Article	S. Kreim *et al.*, "Competition between pairing correlations and deformation from the odd-even mass staggering of francium and radium isotopes", Phys. Rev. C 90, 024301 (2014)
		V. Manea *et al.*, "Penning-trap mass spectrometry and mean-field study of nuclear shape coexistence in the neutron-deficient lead region", Phys. Rev. C 95, 054322 (2017)

	Thesis	V. Manea, "Penning-trap mass measurements of exotic rubidium and gold isotopes for a mean-field study of pairing and quadrupole correlations", PhD Thesis, Université Paris-Sud, France (2018) [CERN-THESIS-2014-351]
IS532	Article	M. Rosenbusch *et al.*, "Probing the N=32 shell closure below the magic proton number Z=20: Mass measurements of the exotic isotopes $^{52.53}$K", Phys. Rev. Lett. 115, 232501 (2015)
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		A. de Roubin *et al.*, "Nuclear deformation in the A = 100 region : Comparison between new masses and meand-field predictions", Phys. Rev. C 96, 014310 (2017)
		M.Mougeot *et al.*, "Precision mass measurements of $^{58-63}$Cr : nuclear collectivity towards the N=40 Island of Inversion", Phys. Rev. Lett. 120, 232501 (2018)
		W.J Huang *et al.*, " Evaluation of high-precision atomic masses of A $\sim$ 50-80 and rare-earth nuclides measured with ISOLTRAP", Euro. Phys. J. A 55: 96 (2019)
		I. Kulikov *et al.*, "Precision mass measurement of ^{70}As, ^{73}Br and ^{49,50}Sc isotopes", Article in preparation (2019)
	Thesis	M. Rosenbusch, "Development of new ion-separation techniques for short-lived nuclides and the first mass measurement of $^{52.53}$K", PhD Thesis, Greifswald Universität, Germany (2015) [CERN-THESIS-2015-389]
		A. de Roubin, "Mass measurements of neutron-rich strontium and rubidium isotopes in the a $\sim$ 100 and development of an electrospray ionization ion source", PhD thesis, PhD Thesis, Université de Bordeaux, France (2016) [CERN-THESIS-2016-355]
		W. J. Huang, "Direct mass measurements and global evaluation of atomic masses", PhD Thesis, Université Paris-Saclay, France (2018) [CERN-THESIS-2018-332]
		M.Mougeot, "Nuclear collectivity studied through high-precision mass measurements of neutron-rich argon and chromium isotopes", PhD Thesis, Université Paris-Saclay, France (2019) [CERN-THESIS-2019-002]
		F. Wienholtz, "Measurements of exotic calcium isotopes by multi-reflection time-of-flight mass spectrometry and further developments and applications", PhD Thesis, Greifswald Universität, Germany (2019) [CERN-THESIS-2019-216]
IS534	Article	J. Cubiss *et al.*, "Change in structure between the I =1/2 states in ^{181}Tl and ^{177,179}Au", Phys. Lett. B 786, 355-363 (2018)
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IS535	Article	A. Welker *et al.*, "Binding energy of ^{79}Cu: probing the structure of the doubly magic ^{78}Ni of only one proton away", Phys. Rev. Lett. 119, 192502 (2017)
		D. Atanasov *et al.*, "Precision mass measurement of cesium isotopes - new entries in the ISOLTRAP chronicles", J. Phys. G 44, 064008 (2017)
	Thesis	A. Welker, "Implementation and commissioning of the phase-imaging ion-cyclotron-resonance method and mass measurements of exotic copper isotopes with ISOLTRAP", PhD Thesis, Technische Universität Dresden, Germany (2018) [CERN-THESIS-2018-183]
IS565	Article	J. Karthein *et al.*, "Q_{EC}-value determination for ^{21}Na $\rightarrow^{21}$ Ne and ^{23}Mg $\rightarrow^{23}$ Na mirror nuclei decays using high-precision mass spectrometry with ISOLTRAP at the CERN ISOLDE facility", Phys. Rev. C 100, 015502 (2019)
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