

Addendum to the ISOLDE and Neutron Time-of-Flight Committee

Precision Mass Measurements with ISOLTRAP to Study the Evolution of the $N = 82$ Shell Gap far from Stability



Spokespersons:

Susanne Kreim and Dinko Atanasov

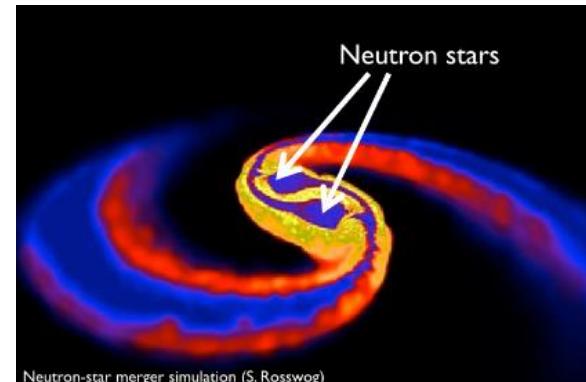
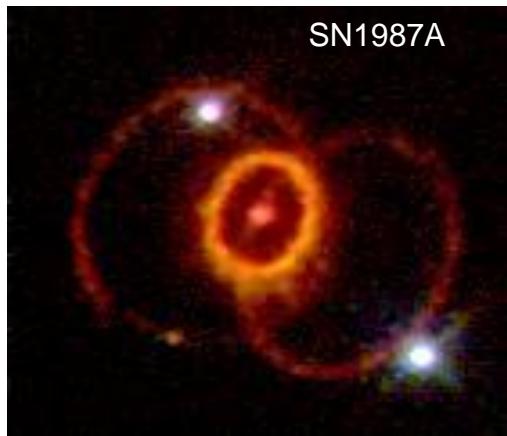
Contact person:

Vladimir Manea



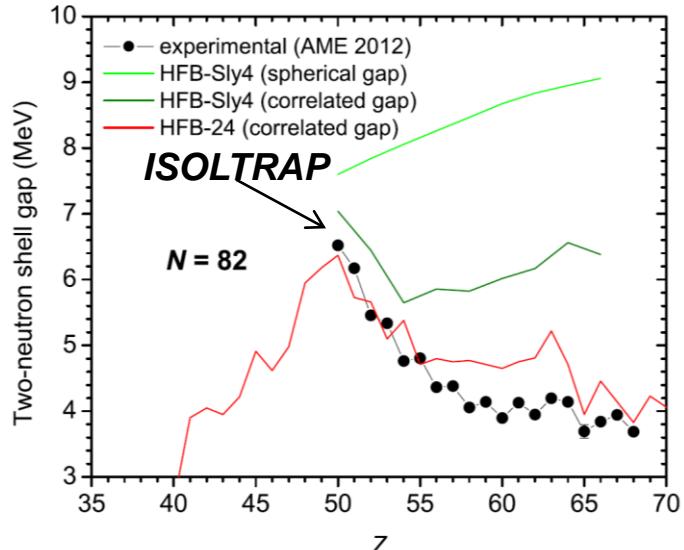
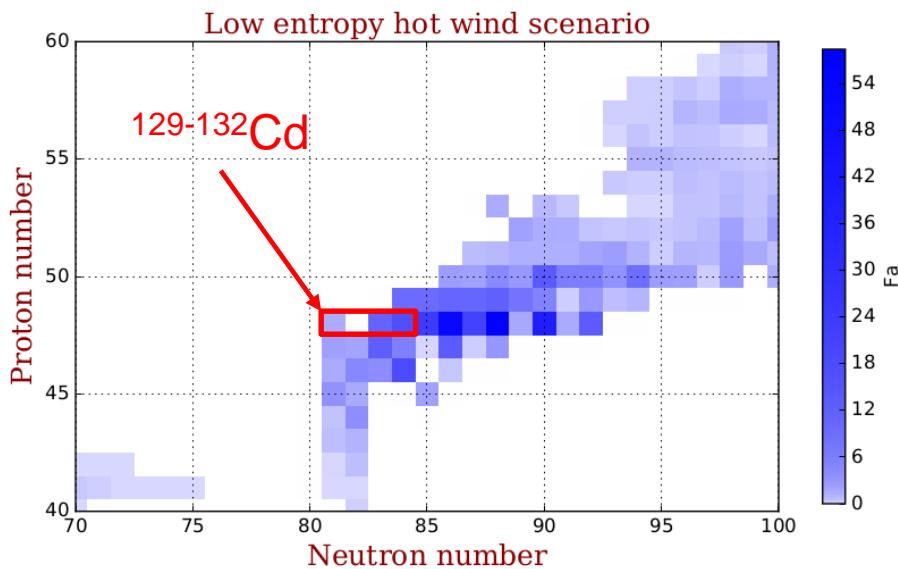
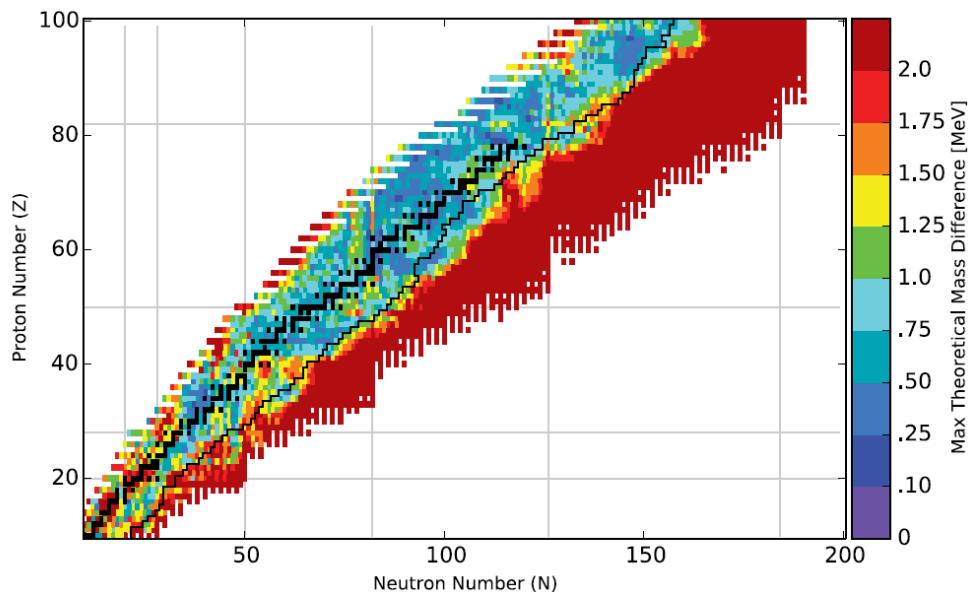
Outline

- Physics case
- Status of IS574
- Results (2014 and 2016 runs)
- Shift Request



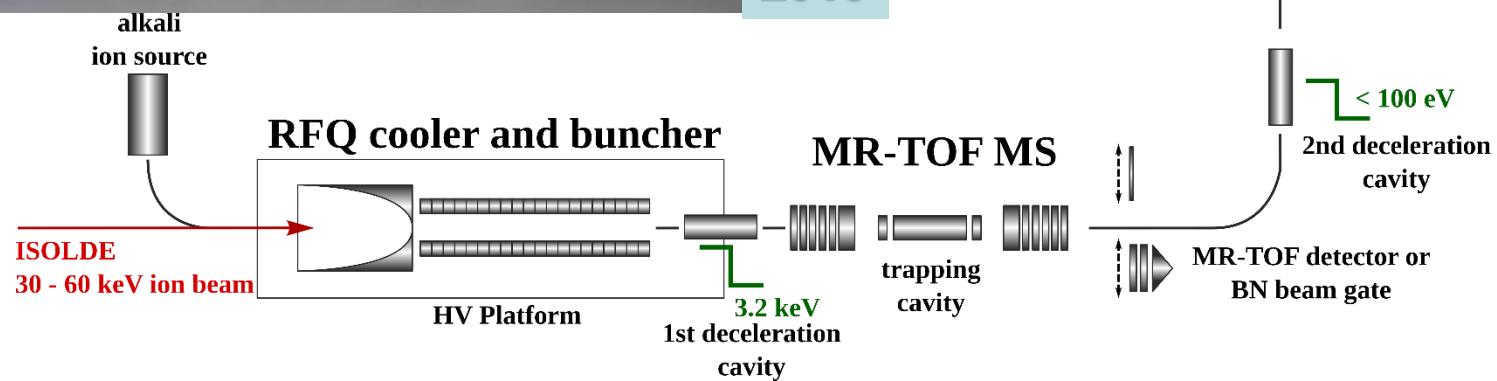
Nuclear mass models - uncertainties

- Experimental data still missing for important r-nuclei
- Rely on theoretical extrapolations
- Shell evolution far from stability puts constraints on nuclear interaction used



ISOLTRAP setup

- Penning Trap Mass Spectrometry
- Multi-Reflection Time-Of-Flight Mass Spectrometry

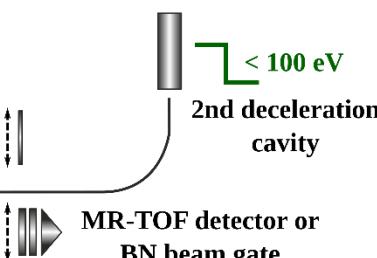
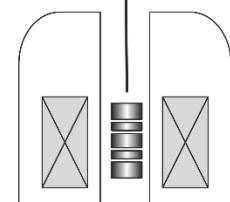
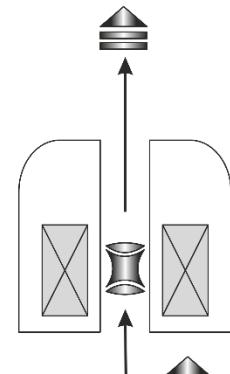


Time of flight detector:
MCP / Channeltron

**precision
Penning trap**

LT detector

**preparation
Penning trap**



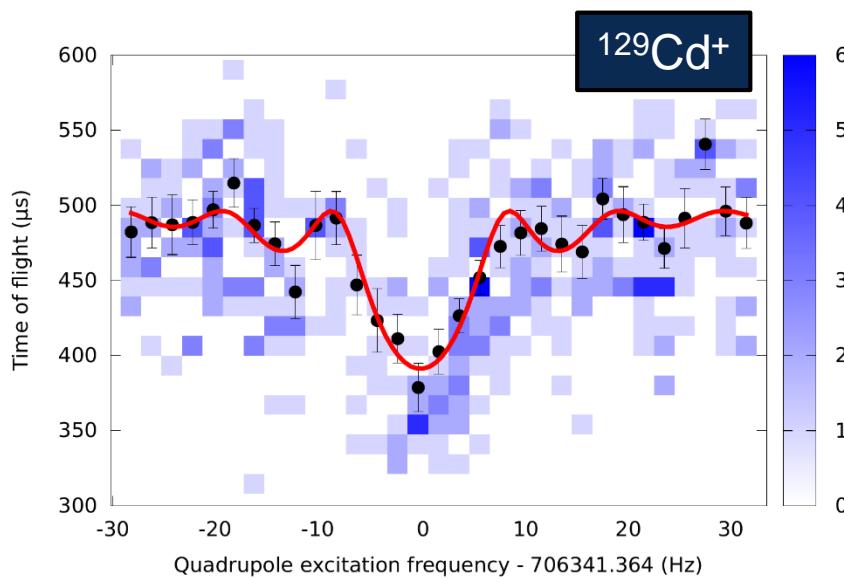
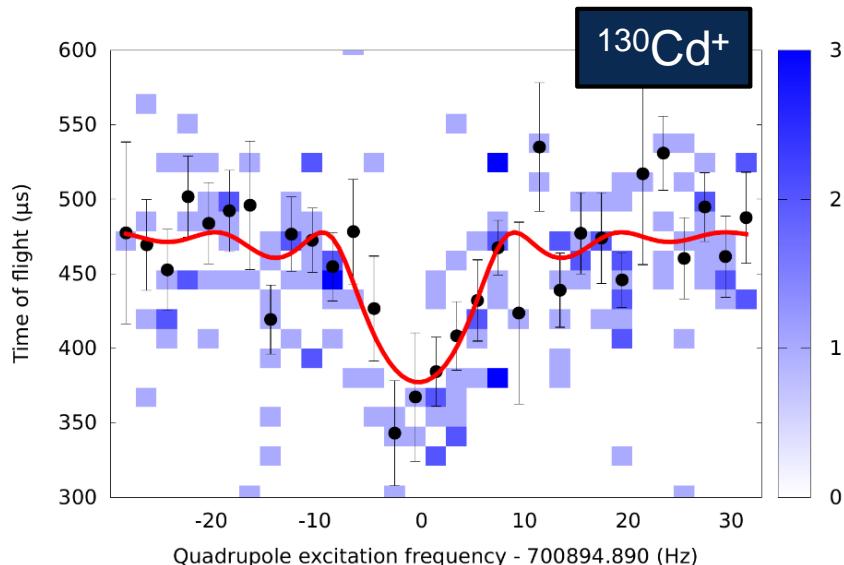
Penning trap measurements of $^{129,130}\text{Cd}^+$

- Quartz insert reduced contamination by 4 orders of magnitude for Cs and In
- $T_{\text{ex}}(^{129}\text{Cd}) = 20\text{-}160\text{-}20 \text{ ms}$
(4 resonances >1500 events)
- $T_{\text{ex}}(^{130}\text{Cd}) = 10\text{-}80\text{-}10 \text{ ms}$
(3 resonances with >550 even)

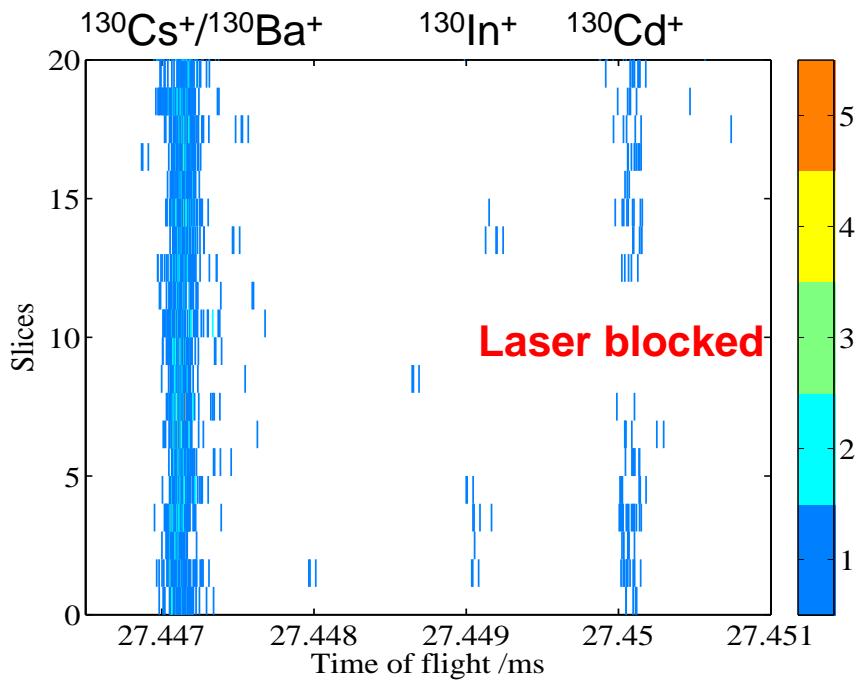
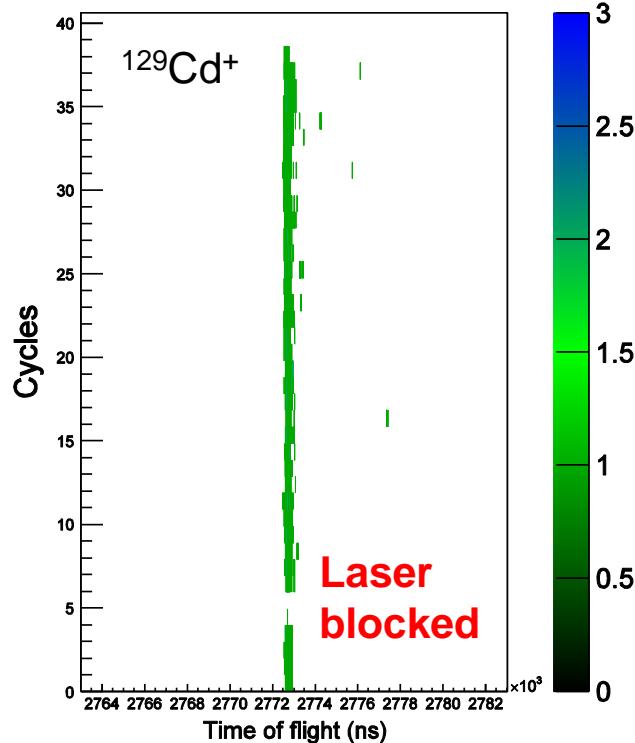
Time-Of-Flight Ion-Cyclotron-Resonance

$$\nu_c = \frac{qB}{2\pi m}$$

rf excitation
 $\nu_c = \nu_+ + \nu_-$

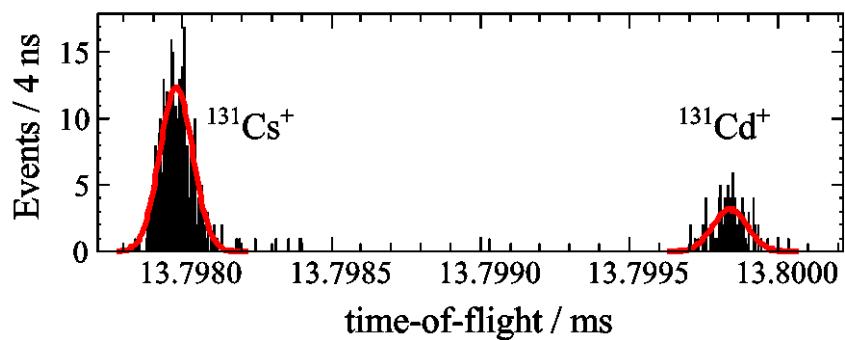


MR-TOF measurements of $^{129,130,131}\text{Cd}^+$



- Clear Identification of Cd nuclides
- Low background
- $^{131}\text{Cd}^+ \approx 88$ ions/s from ISOLDE
- Total of 11 spectra (1366 ions)

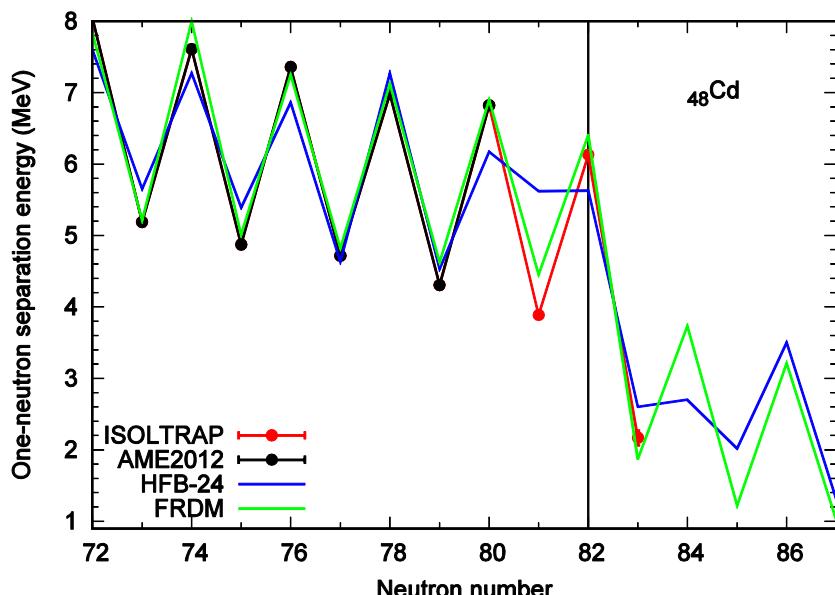
Abundance of contamination in spectra
Ratio of $^{131}\text{Cs}^+ / ^{131}\text{Cd}^+$ = 3:1 (per bg = 160 ms)



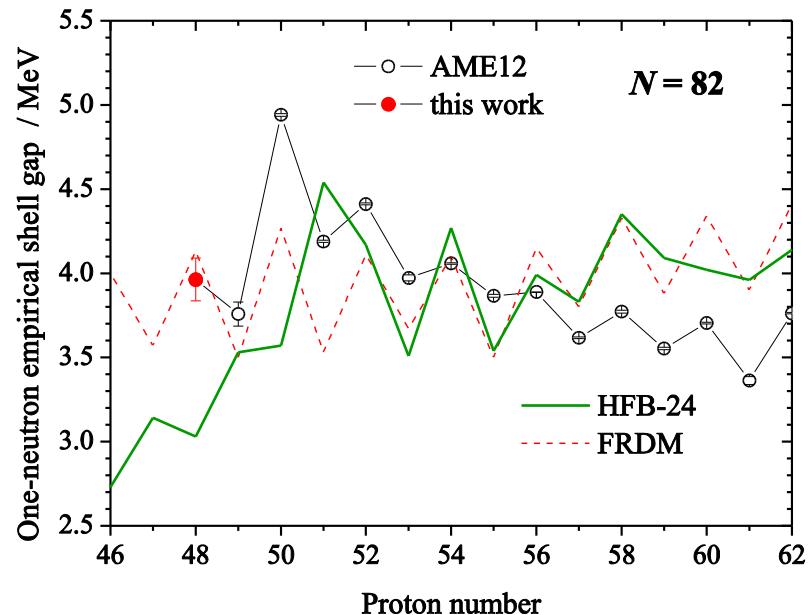
IS574 Results

A	Ratio r or C _{ToF}	ME _{new} (keV)	ME _{AME} (keV)	Δ (AME - new) (keV)
129	0.970 105 338(136)	-63 148(74)	-63 510(200) [#]	-452
130	0.977 645 186(180)	-61 118(22)	-61 530(160)	-412
131	0.482 304 4(539)	-55 215(100)	-55 331(196) [#]	-116

$$S_n(N, Z) = B(N, Z) - B(N-1, Z)$$



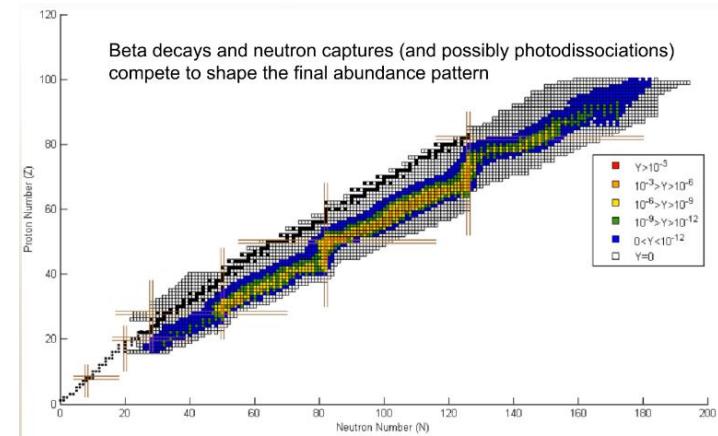
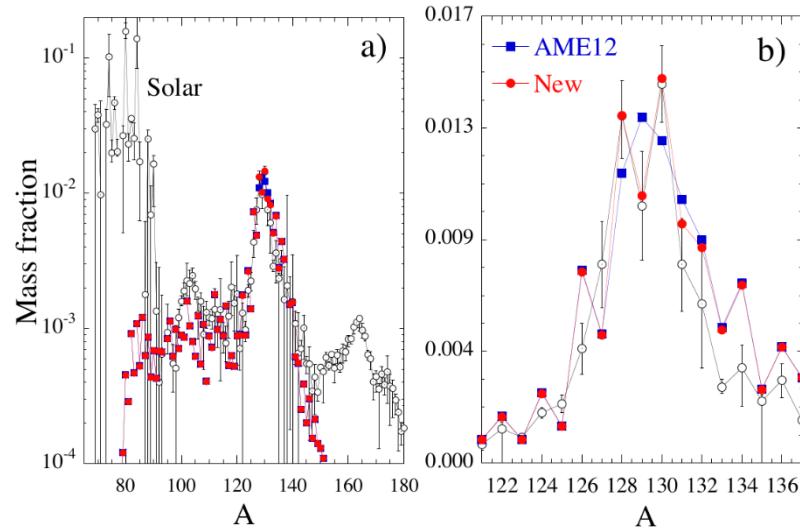
$$\Delta_n = S_n(N, Z) - S_n(N+1, Z)$$



IS574 Results

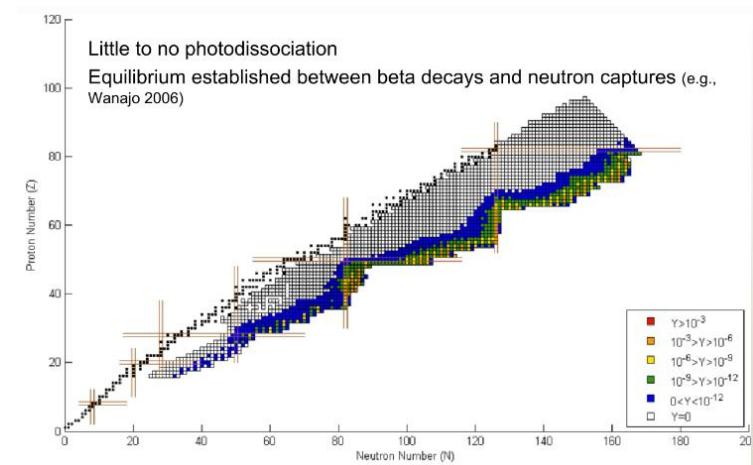
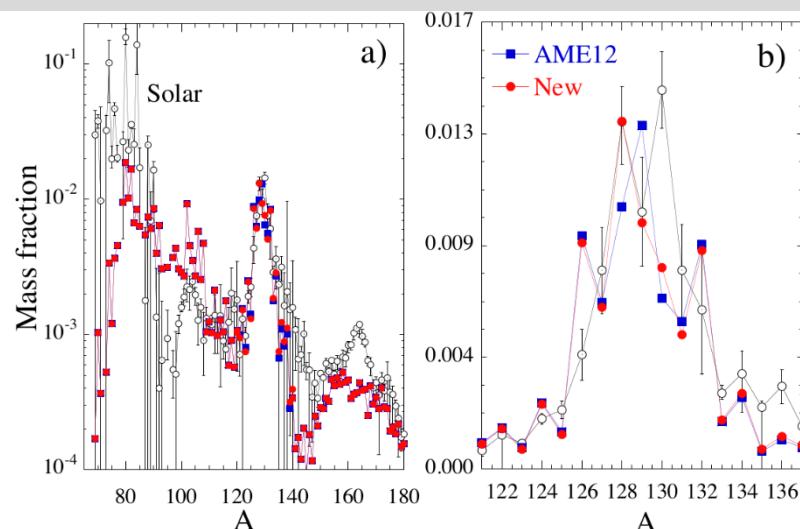
v -driven Core-collapse Supernovae –

Calculations Parameters: Entropy $s/k_B = 193$, electron fraction $Y_e = 0.48$, Mass loss $dM/dt = 6 \cdot 10^{-7} M_{\text{sol}} \text{ s}^{-1}$ and breeze solution $f_w = 3$



Neutron star Mergers –

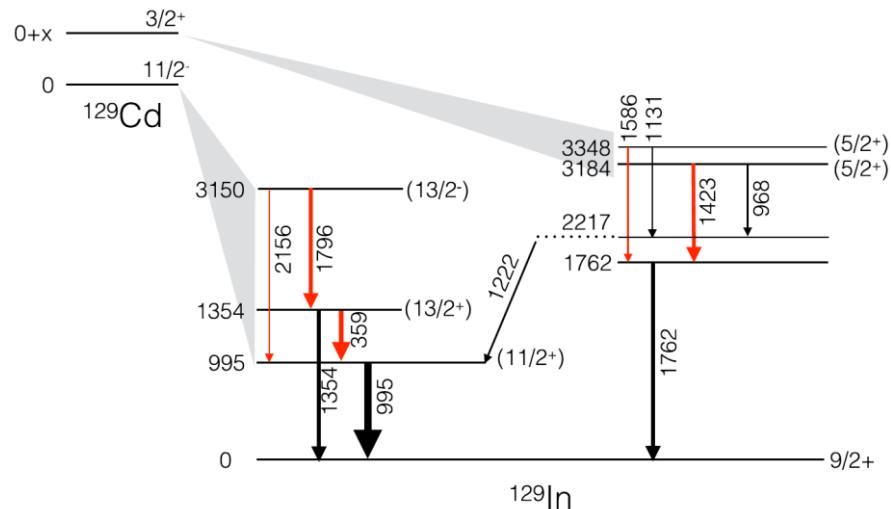
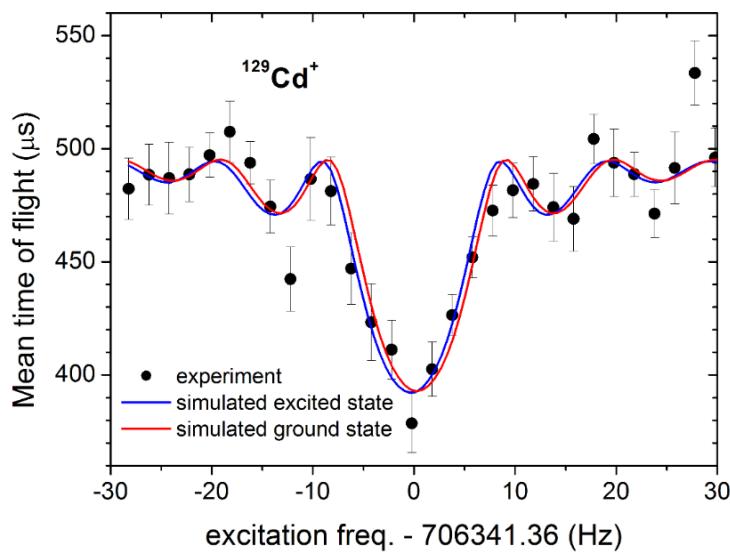
MODEL M3A8m1a5 mean entropy $s/k_B = 28$, electron fraction $Y_e = 0.24$, total mass ejected $M_{\text{ej}} = 2.5 \times 10^{-2} M_{\text{sol}}$



Isomeric state of ^{129}Cd

Estimated energy of the isomer $E = 180(100)$ keV

Simulated ToF-ICR for the isomeric state with $E = 100$ keV



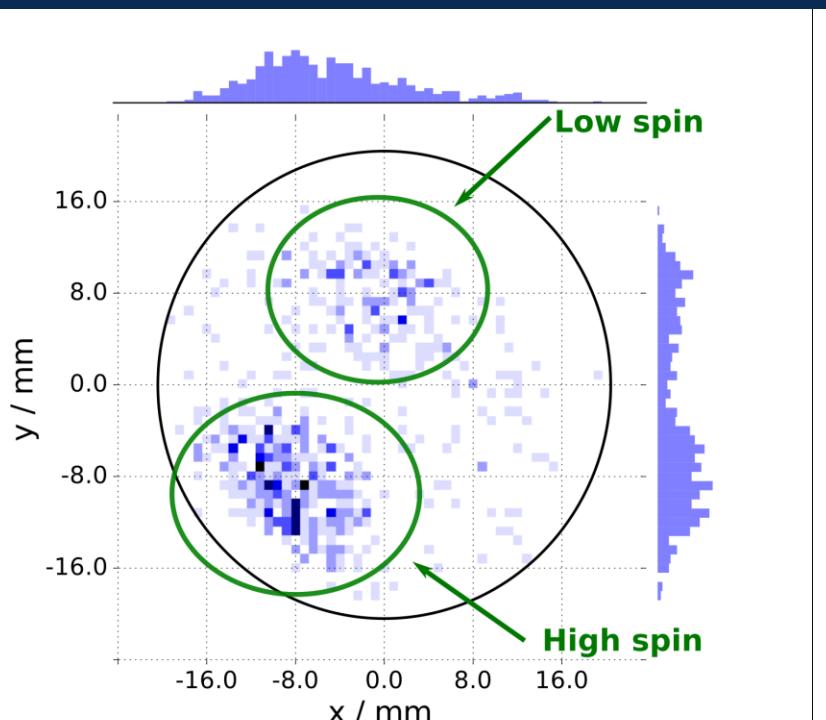
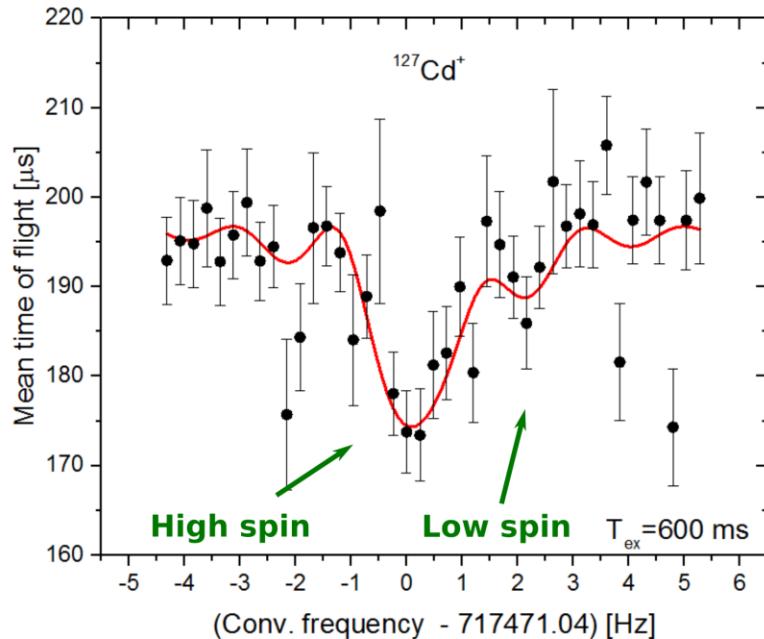
- Two isomeric states with spins $3/2^+$ and $11/2^-$

D. Yordanov et al., PRL 110, 192501 (2013)
- Available data from RIKEN experiment in 2015 yielded $151(15)$ ms, $146(8)$ ms. Confirmed by TITAN in 2016

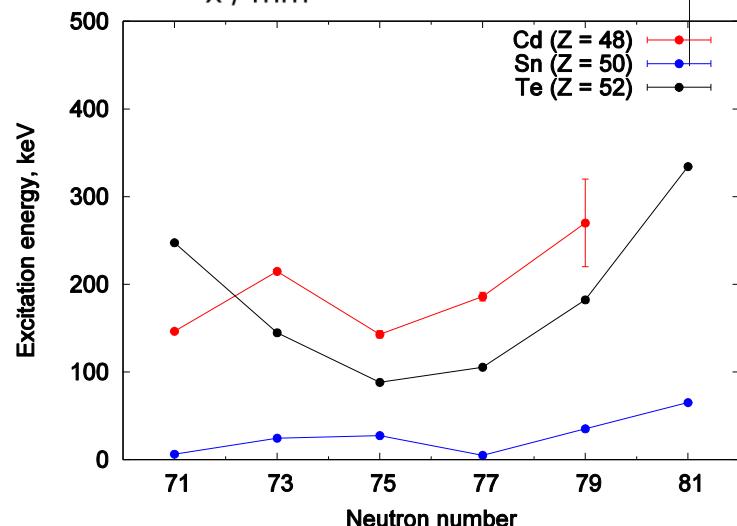
J. Taprogge et al., PRC 91, 054324 (2015)

R. Dunlop et al., PRC 93, 062801(R) (2016)
- Estimate for $E_{\text{ex}}(^{129m}\text{Cd}) = 100$ keV leads to phase difference of $\varphi=12^\circ$ at ISOLTRAP

Isomeric states in $^{123,127}\text{Cd}$

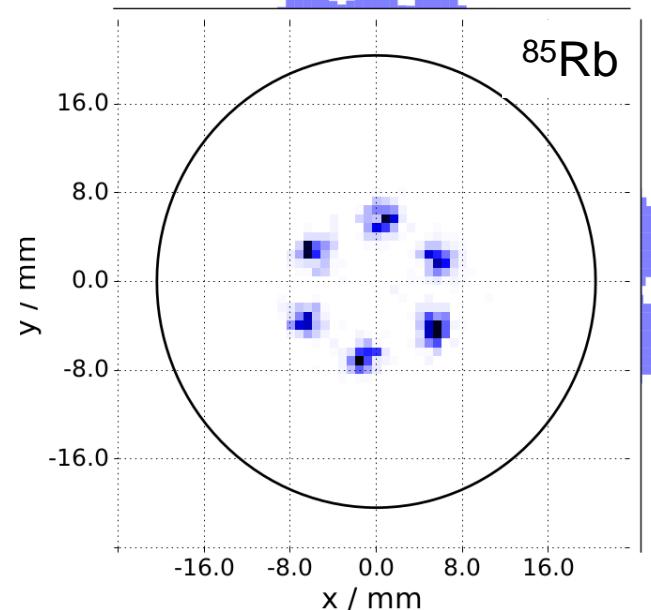
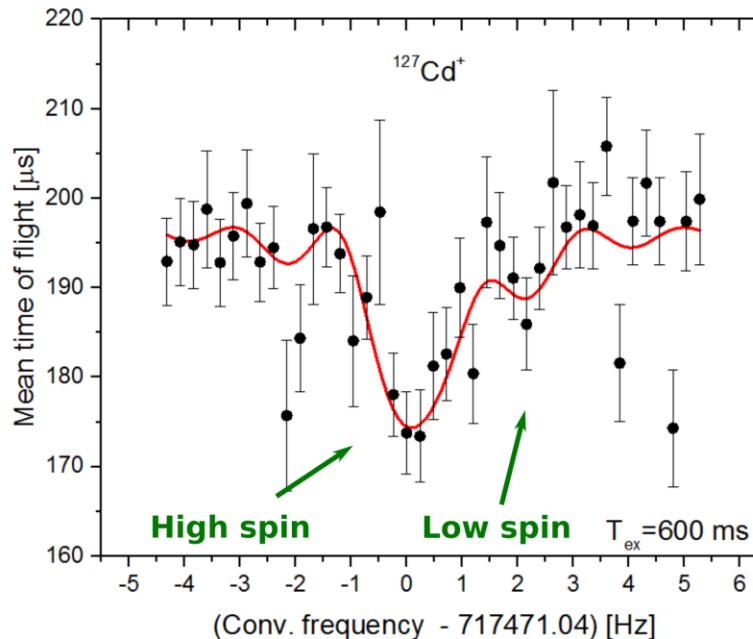


	ISOLTRAP (keV)	AME12 (keV)
$E_{\text{ex}}(^{123}\text{Cd})$	149(50)	143(4)
$E_{\text{ex}}(^{127}\text{Cd})$	270(50)	0#(100#)

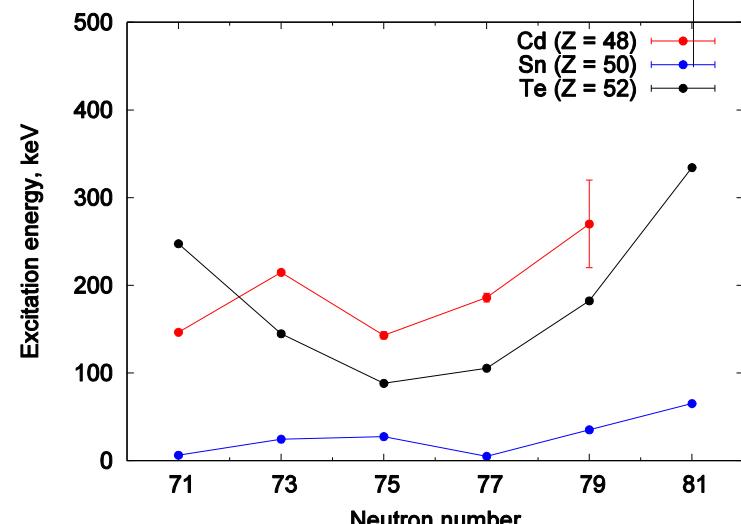


Isomeric states in $^{123,127}\text{Cd}$

Event position on FFC-15



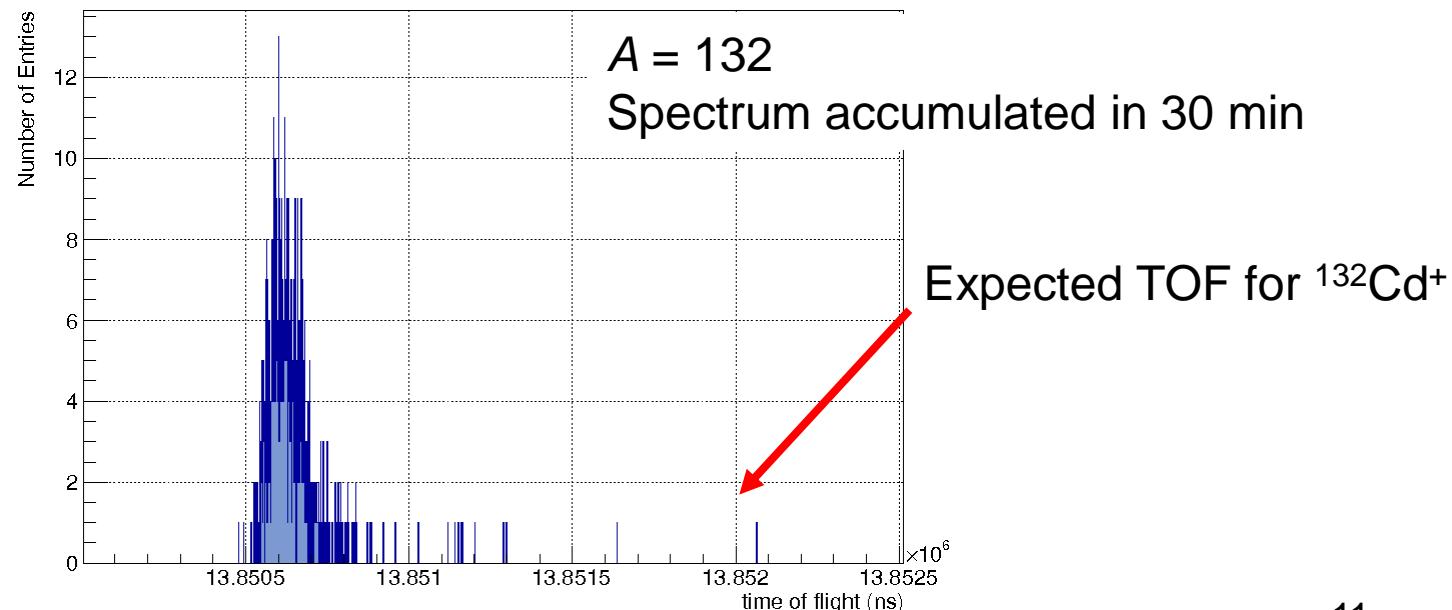
	ISOLTRAP (keV)	AME12 (keV)
$E_{\text{ex}}(^{123}\text{Cd})$	149(50)	143(4)
$E_{\text{ex}}(^{127}\text{Cd})$	270(50)	0#(100#)



IS574 Shift request

- 8 shifts (6 physics + 2 optimizations)

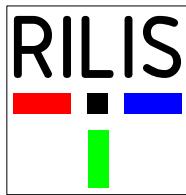
Nuclide	Half-life, ms	Ion/ μ C	Technique	Shifts (8h) Remaining + Requested
$^{127g,m}\text{Cd}$	330(20), 200#	1.2×10^5	PTMS	0 + 2
$^{129g,m}\text{Cd}$	151(15), 146(8)	3×10^4	PTMS	0 + 4
^{132}Cd	97(10)	5×10^0 #	MR-TOF MS	6 + 0



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F. Herfurth, A. Herlert, J. Karthein, J. Kluge, M. Kowalska, S. Kreim,
Yu. A. Litvinov, D. Lunney, V. Manea, E. Minaya-Ramirez, D. Neidherr,
R. Ringle, M. Rosenbusch, A. de Roubin, L. Schweikhard, M. Wang,
A. Welker, F. Wienholtz, R. N. Wolf, K. Zuber
Theoretical calculations: S. Goriely, H. –T. Janka, O. Just



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and Technical Group*

Mikhail Goncharov,
Achim Czasch



<http://isoltrap.web.cern.ch>



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Publications/PhD Thesis by the ISOLTRAP Collaboration for the period 2012-2017

Title	First Author	Journal	Year
A study of octupolar excitation for mass-selective centering in Penning traps	M. Rosenbusch	Int. J. Mass Spectrom. 314, 6-12	2012
Q Value and Half-Lives for the Double- β -Decay Nuclide ^{110}Pd	D. Fink	Phys. Rev. Lett. 108, 062502	2012
On-line separation of short-lived nuclei by a multi-reflection time-of-flight device	R.N. Wolf	Nucl. Instr. and Meth. A 686, 82-90	2012
Trap-assisted decay spectroscopy with ISOLTRAP	M. Kowalska	Nucl. Instr. and Meth. A 689, 102-107	2012
Buffer-gas-free mass-selective ion centering in Penning traps by simultaneous dipolar excitation of magnetron motion and quadrupolar excitation for interconversion between magnetron and cyclotron motion	M. Rosenbusch	Int. J. Mass Spectrom. 325-327, 51-57	2012
Surveying the $N = 40$ island of inversion with new manganese masses	S. Naimi	Phys. Rev. C 86, 014325	2012
Recoil-ion trapping for precision mass measurements	A. Herlert	Eur. Phys. J. A 48, 97	2012
Plumbing Neutron Stars to New Depths with the Binding Energy of the Exotic Nuclide ^{82}Zn	R.N. Wolf	Phys. Rev. Lett. 110, 041101	2013
Masses of exotic calcium isotopes pin down nuclear forces	F. Wienholtz	Nature 498, 346	2013
ISOLTRAP's multi-reflection time-of-flight mass separator/spectrometer	R.N. Wolf	Int. J. Mass. Spectrom. 349-350, 123-133	2013
Mass spectrometry and decay spectroscopy of isomers across the $Z=82$ shell closure	J. Stania	Phys. Rev. C 88, 054304	2013
Collective degrees of freedom of neutron-rich $A \approx 100$ nuclei and the first mass measurement of the short-lived nuclide ^{100}Rb	V. Manea	Phys. Rev. C 88, 054322	2013
Recent exploits of the ISOLTRAP mass spectrometer	S. Kreim	Nucl. Instrum. Methods B 317, 492–500	2013
New developments of the in-source spectroscopy method at RILIS/ISOLDE	B.A. Marsh	Nucl. Instrum. Methods B 317, 550-556	2013
Ion bunch stacking in a Penning trap after purification in an electrostatic mirror trap	M. Rosenbusch	Appl. Phys. B 114, 147-155	2014
Competition between pairing correlations and mean-field effects in heavy, deformed nuclei	S. Kreim	Phys. Rev. C 90, 024301	2014
Evolution of nuclear ground-state properties of neutron-deficient isotopes around $Z=82$ from precision mass measurements	Ch. Böhm	Phys. Rev. C 90, 044307	2014
Experimental tests of an advanced proton-to-neutron converter at ISOLDE-CERN	A. Gottberg	Nucl. Instrum. Methods B 336, 143-148	2014
Probing the $N=32$ Shell Closure below the Magic Proton Number $Z=20$: Mass Measurements of the Exotic Isotopes $^{52,53}\text{K}$	M. Rosenbusch	Phys. Rev. Lett. 114, 202501	2015
Precision Mass Measurements of $^{129-131}\text{Cd}$ and Their Impact on Stellar Nucleosynthesis via the Rapid Neutron Capture Process	D. Atanasov	Phys. Rev. Lett. 115, 232501	2015
Background-free beta-decay half-life measurements by in-trap decay and high-resolution MR-ToF mass analysis	R.N. Wolf	Nucl. Instrum. Meth. B 376, 275–280	2016
Precision mass measurements of cesium isotopes - new entries in the ISOLTRAP chronicles	D. Atanasov	J Phys. G Accepted	2017

Total of 22 publications.

Publications/PhD Thesis by the ISOLTRAP Collaboration for the period 2012-2017

PhD Title	Author	Institute / University	Year
Mass Measurements of Exotic Ions in the Heavy Mass Region for Nuclear Structure Studies at ISOLTRAP	Ch. Borgmann	Ruprecht-Karls-Universität Heidelberg, Germany	2012
Synergy of decay spectroscopy and mass spectrometry for the study of exotic nuclides	J. Stanja	Technische Universität Dresden, Germany	2013
First on-line applications of a multi-reflection time-of-flight mass separator at ISOLTRAP and the mass measurement of ^{82}Zn	R. Wolf	Ernst-Moritz-Arndt-Universität Greifswald, Germany	2013
Penning-trap mass measurements of exotic rubidium and gold isotopes for a mean-field study of pairing and quadrupole correlations	V. Manea	Université Paris-Sud XI, CSNSM-IN2P3-CNRS Orsay, France	2014
High-precision mass measurements of neutron-deficient Tl isotopes at ISOLTRAP and the development of an ultra-stable voltage source for the PENTATRAP experiment	Ch. Böhm	Ruprecht-Karls-Universität Heidelberg, Germany	2015
Development of new ion-separation techniques and the first mass measurement of $^{52,53}\text{K}$	M. Rosenbusch	Ernst-Moritz-Arndt-Universität Greifswald, Germany	2016
Precision mass measurements for studies of nucleosynthesis via the rapid neutron-capture process	D. Atanasov	Ruprecht-Karls-Universität, MPIK, Heidelberg, Germany	2016
Mass measurements of neutron-rich strontium and rubidium isotopes in the $A \approx 100$ region of deformation and development of an electrospray ionization ion source	A. de Roubin	University of Bordeaux	2016

Total of 8 PhD theses completed.