



MAX-PLANCK-INSTITUT
FÜR KERNPHYSIK



Recent technical developments and precision mass measurements at ISOLTRAP

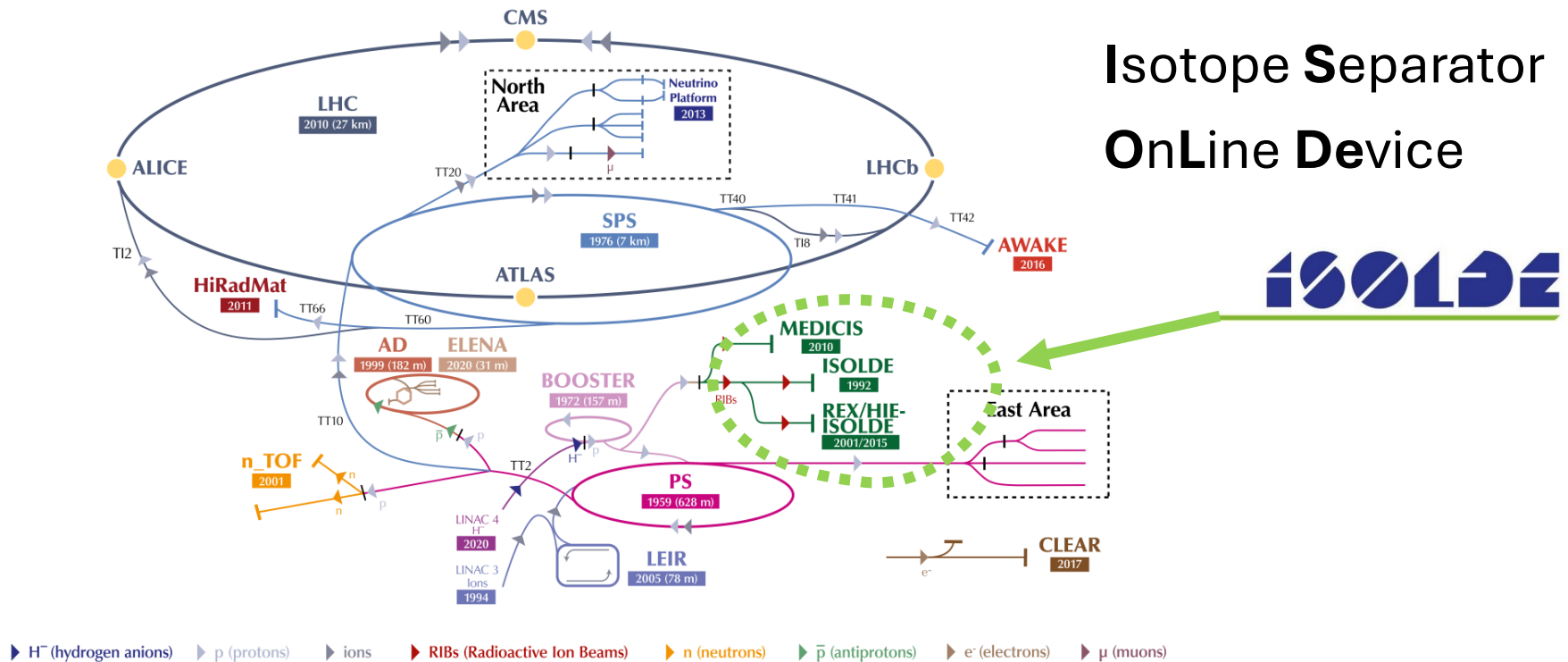
Christoph Schweiger for the ISOLTRAP collaboration
Max-Planck-Institut für Kernphysik, Heidelberg
CERN/ISOLDE, Geneva

Nuclear Masses in Astrophysics for the Next 25 Years
Darmstadt, Germany

ISOLDE @ CERN

The CERN accelerator complex
Complexe des accélérateurs du CERN

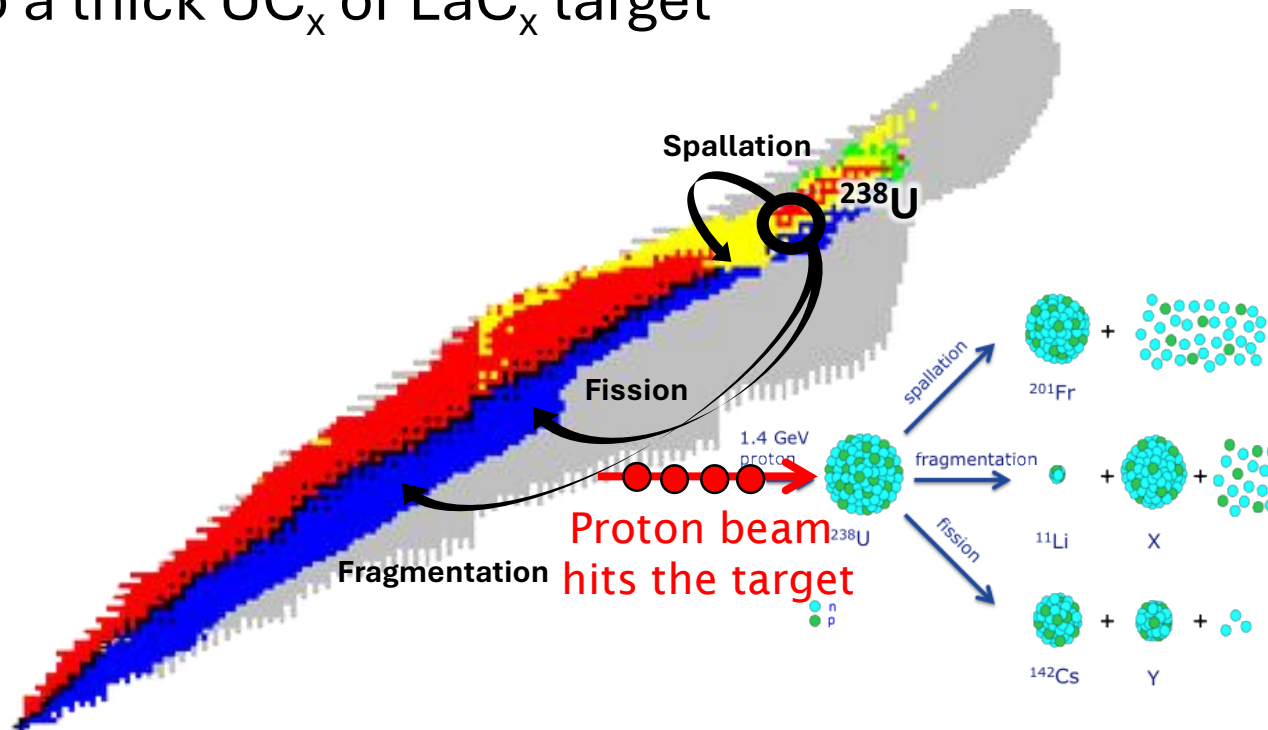
Isotope Separator
OnLine Device



LHC - Large Hadron Collider // SPS - Super Proton Synchrotron // PS - Proton Synchrotron // AD - Antiproton Decelerator // CLEAR - CERN Linear
Electron Accelerator for Research // AWAKE - Advanced WAKEfield Experiment // ISOLDE - Isotope Separator OnLine // REX/HIE-ISOLDE - Radioactive
Experiment/High Intensity and Energy ISOLDE // MEDICIS // LEIR - Low Energy Ion Ring // LINAC - LINear ACcelerator //
 n_TOF - Neutrons Time Of Flight // HiRadMat - High-Radiation to Materials // Neutrino Platform

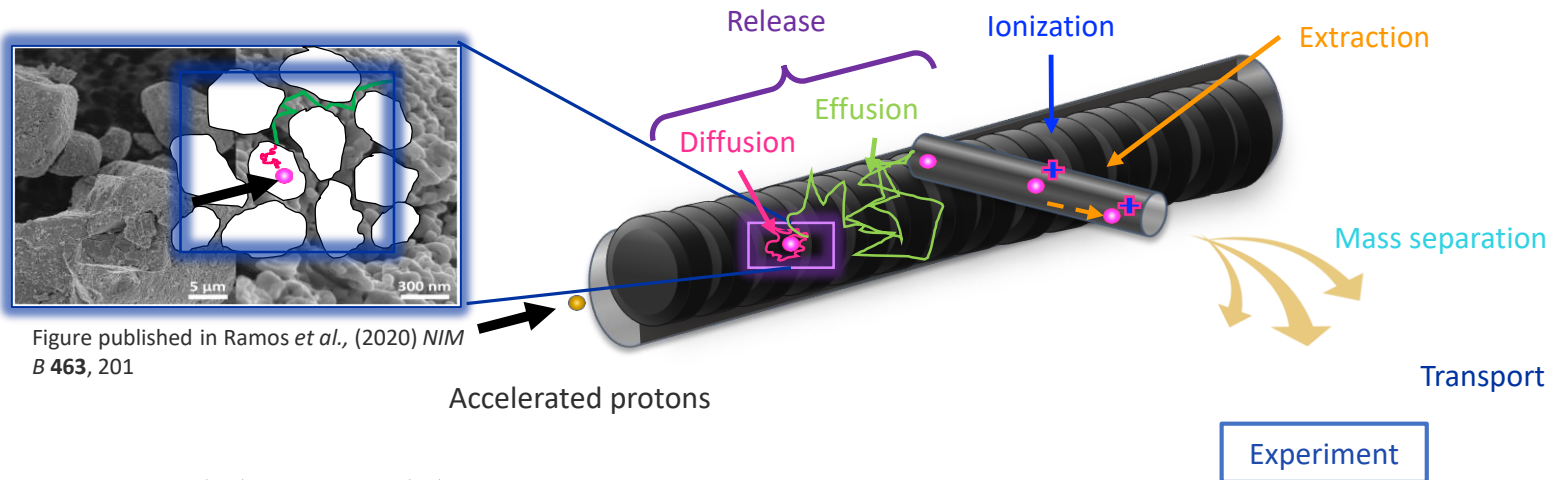
ISOLDE facility – RIB production

- Isotope **S**eparator **O**n**L**ine **D**evice
- 1.4 (soon 1.7) GeV primary proton beam ($2\ \mu\text{A}$) impacts onto a thick UC_x or LaC_x target



ISOLDE facility – RIB production

- Isotope **S**eparator **O**n**L**ine **D**evice
- 1.4 (soon 1.7) GeV primary proton beam ($2 \mu\text{A}$) impacts onto a thick UC_x or LaC_x target

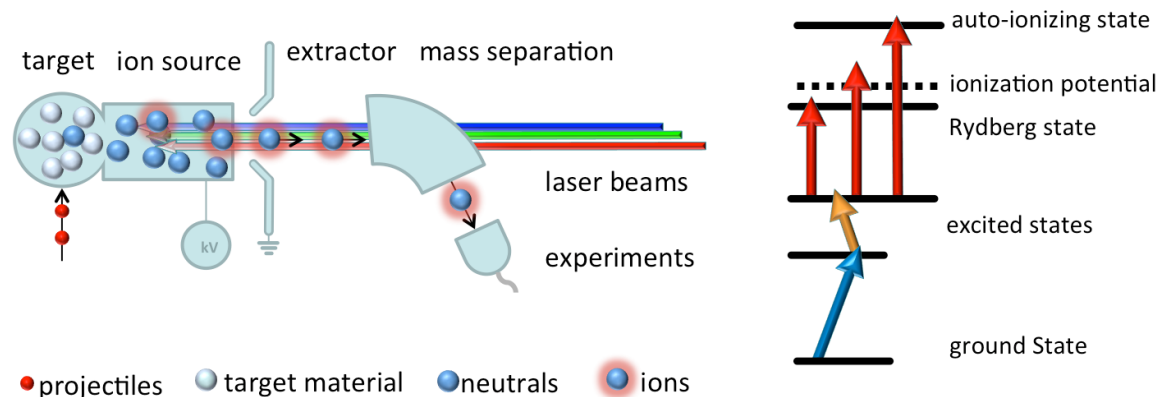


$$Y = Y_0(E) I_p \varepsilon_{\text{rel}}(\lambda) \varepsilon_{\text{form}} \varepsilon_{\text{irr}} \varepsilon_{\text{ion}}$$

Figure courtesy of Valentina Berlin

ISOLDE facility – RIB production

- Isotope **S**eparator **O**n**L**ine **D**evice
- 1.4 GeV primary proton beam ($2 \mu\text{A}$) impacts onto a thick UC_x or LaC_x target
- RIBs produced by Spallation, Fission, Fragmentation
- Isotope of interest selected using sector magnets and Resonance Ionization Laser Ion Source (RILIS)



ISOLDE facility – RIB production

Primary beam energy/current

- First tests with 1.7 GeV proton beam in 2022
- Beam dump upgrade in LS3:
Up to 2 GeV/6 μ A possible

Tailoring target microstructure

$$Y = Y_0(E) I_p \varepsilon_{\text{rel}}(\lambda) \varepsilon_{\text{form}} \varepsilon_{\text{irr}} \varepsilon_{\text{ion}}$$

- Faster, more efficient release: $\varepsilon_{\text{rel}}(\lambda)$
- TISD run 11/2025 nano-UC_x and active proposal for nano-LaC_x
- Actinide NanoLab constructed

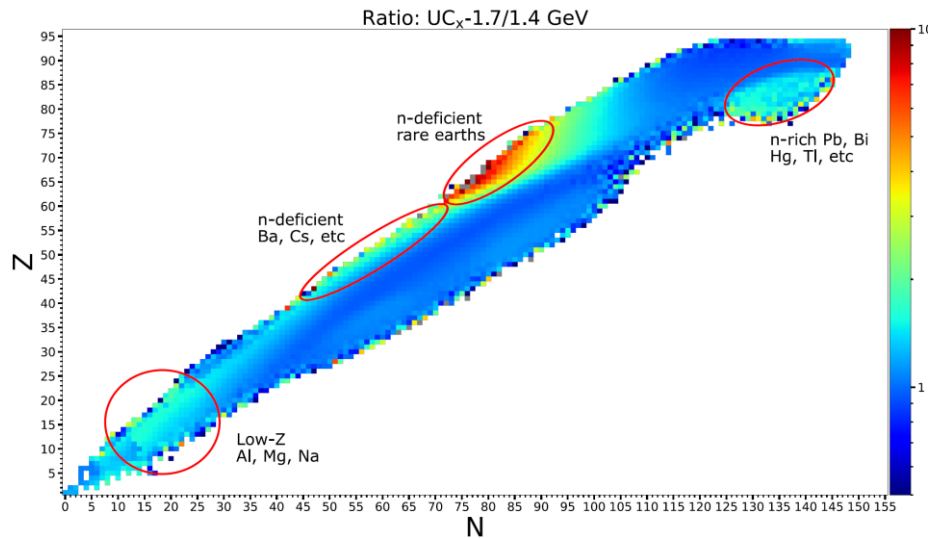


Figure courtesy of Simon Stegemann



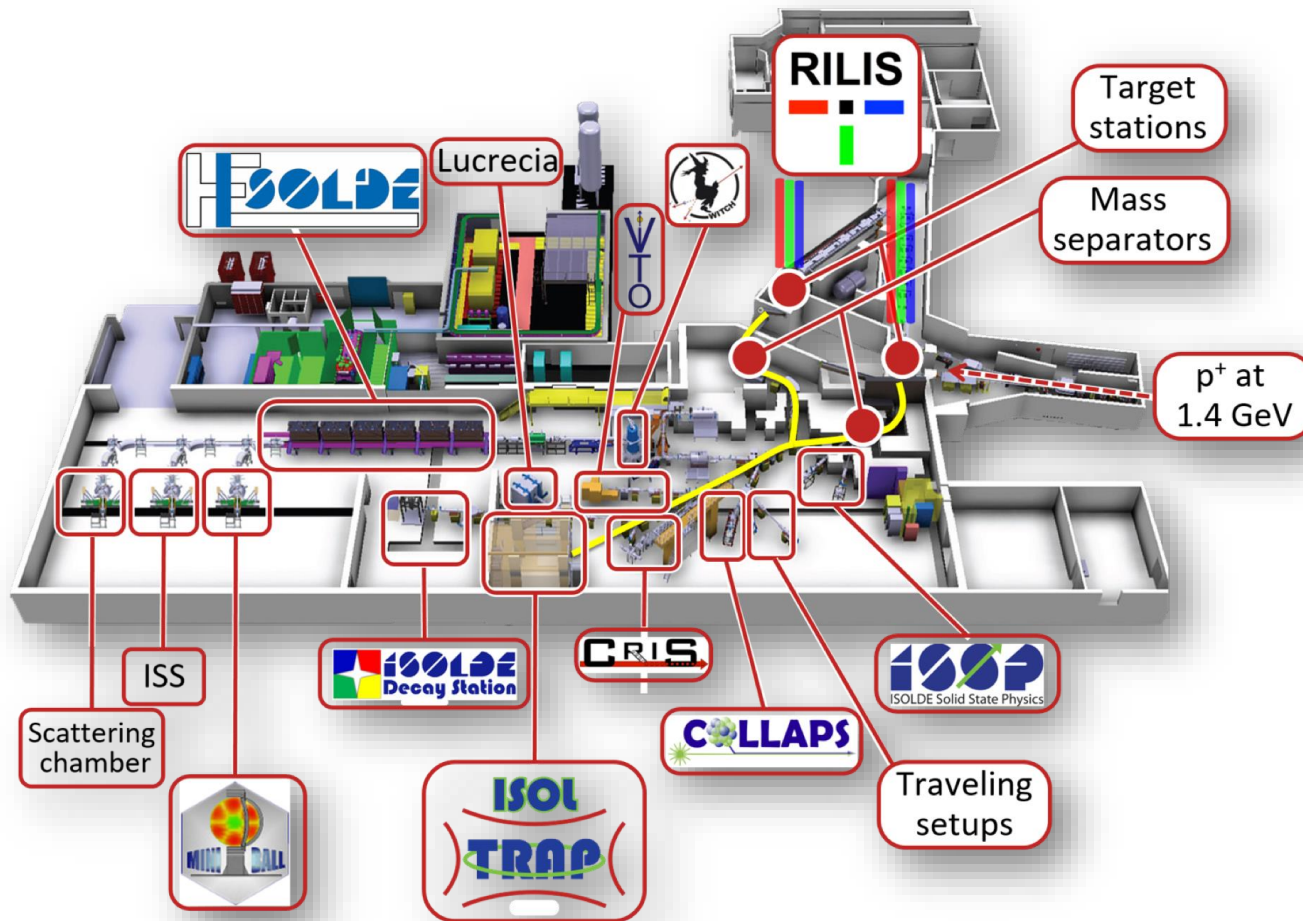
Figure courtesy of Valentina Berlin

ISOLDE facility – RIB production

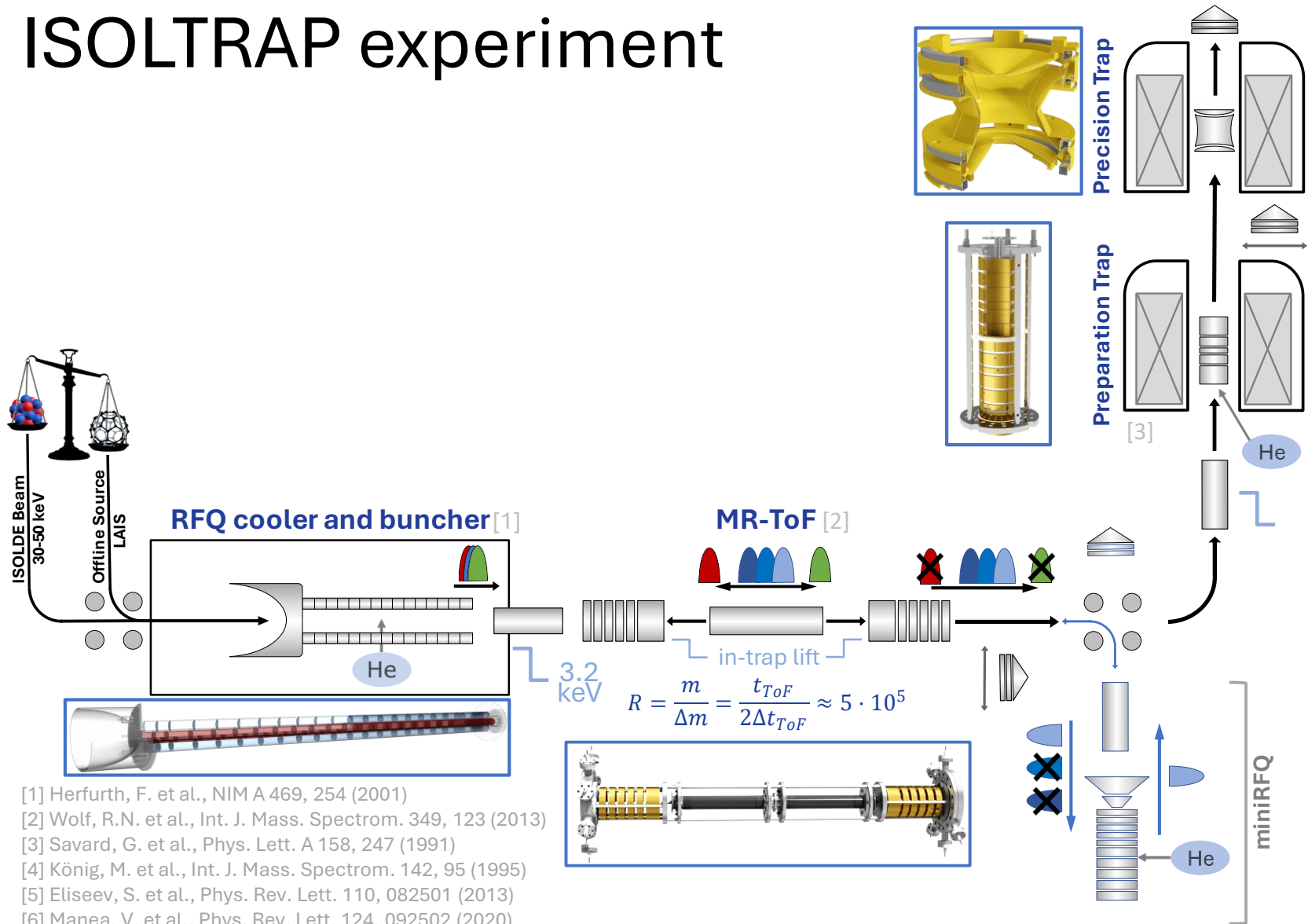


<http://dx.doi.org/10.17181/cds.2289929>

ISOLDE facility - overview

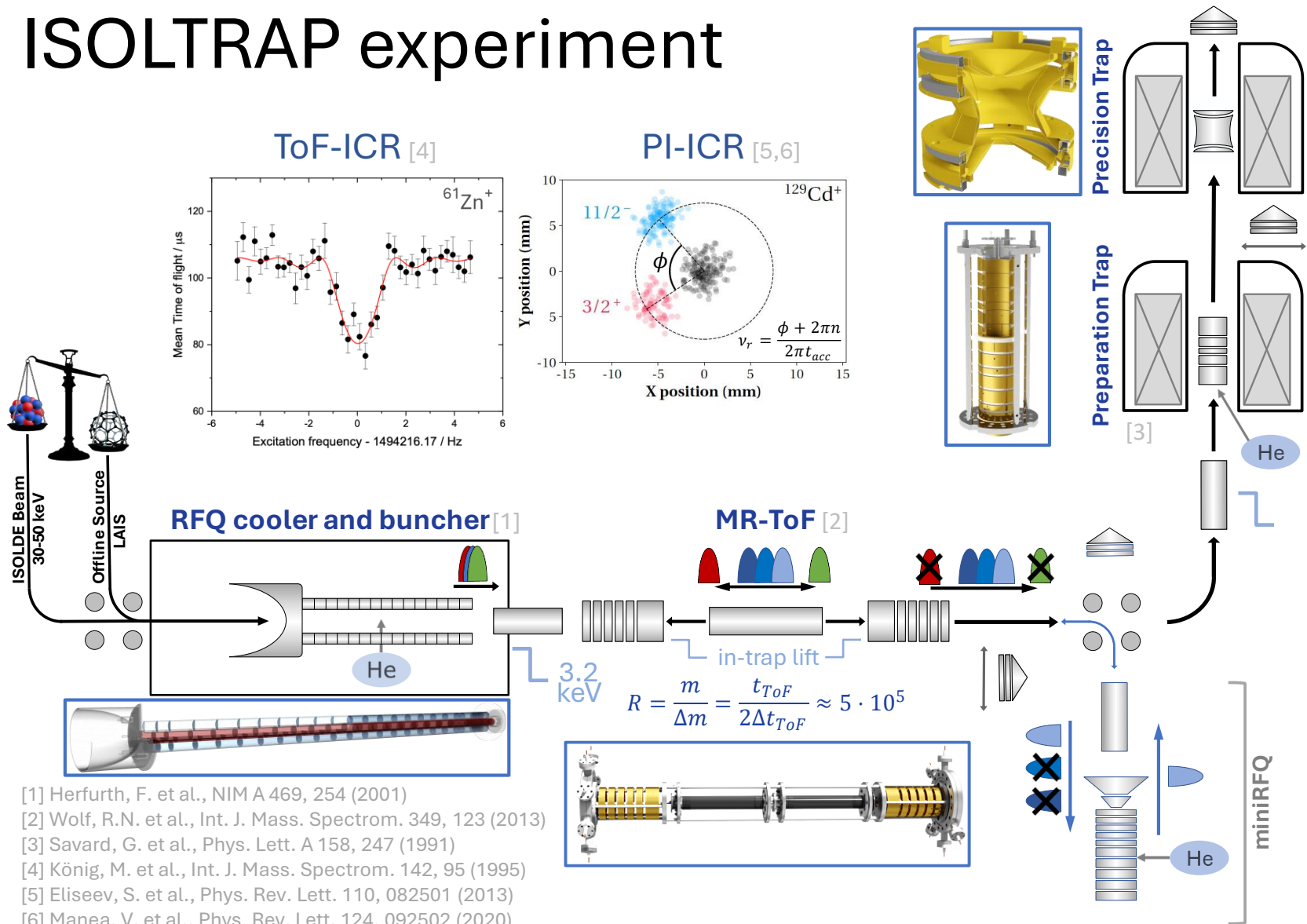


ISOLTRAP experiment



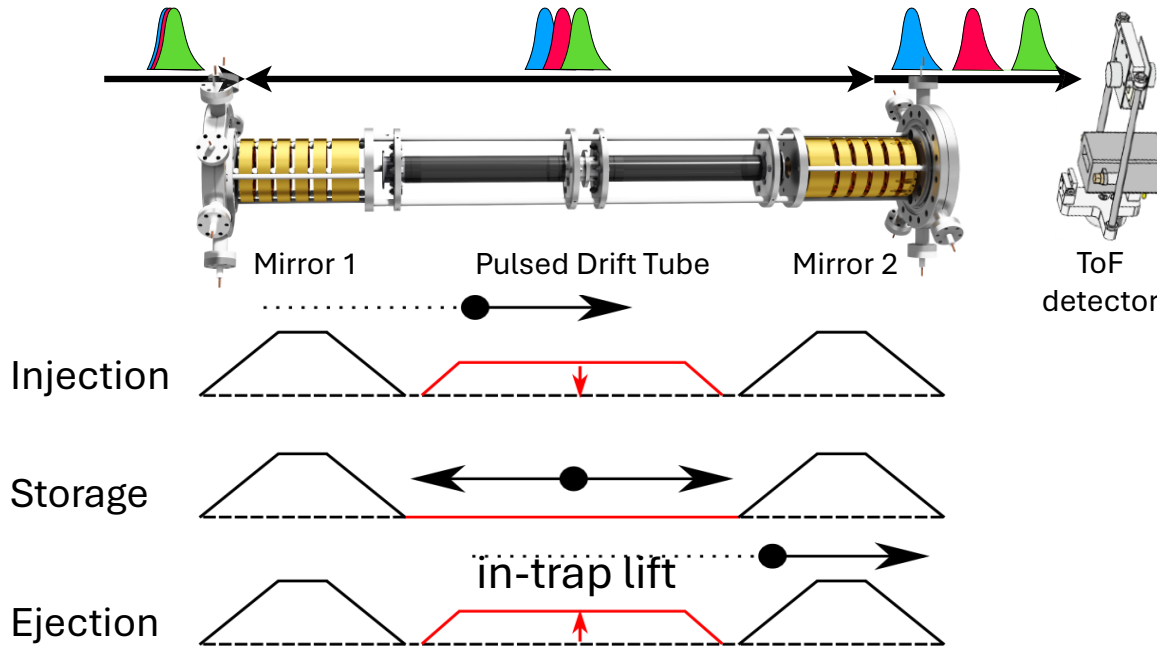
- [1] Herfurth, F. et al., NIM A 469, 254 (2001)
- [2] Wolf, R.N. et al., Int. J. Mass. Spectrom. 349, 123 (2013)
- [3] Savard, G. et al., Phys. Lett. A 158, 247 (1991)
- [4] König, M. et al., Int. J. Mass. Spectrom. 142, 95 (1995)
- [5] Eliseev, S. et al., Phys. Rev. Lett. 110, 082501 (2013)
- [6] Manea, V. et al., Phys. Rev. Lett. 124, 092502 (2020)

ISOLTRAP experiment

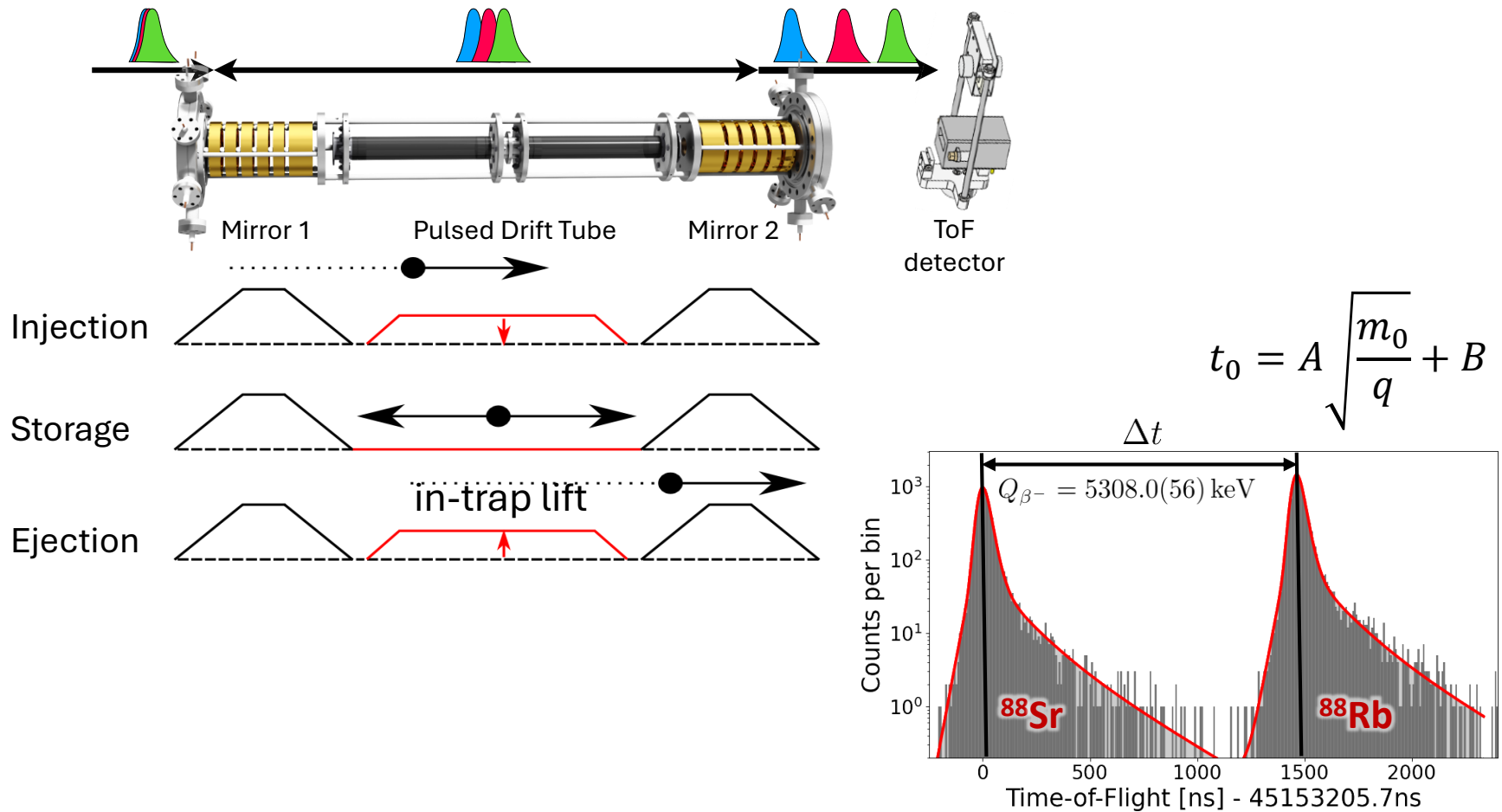


- [1] Herfurth, F. et al., NIM A 469, 254 (2001)
 [2] Wolf, R.N. et al., Int. J. Mass. Spectrom. 349, 123 (2013)
 [3] Savard, G. et al., Phys. Lett. A 158, 247 (1991)
 [4] König, M. et al., Int. J. Mass. Spectrom. 142, 95 (1995)
 [5] Eliseev, S. et al., Phys. Rev. Lett. 110, 082501 (2013)
 [6] Manea, V. et al., Phys. Rev. Lett. 124, 092502 (2020)

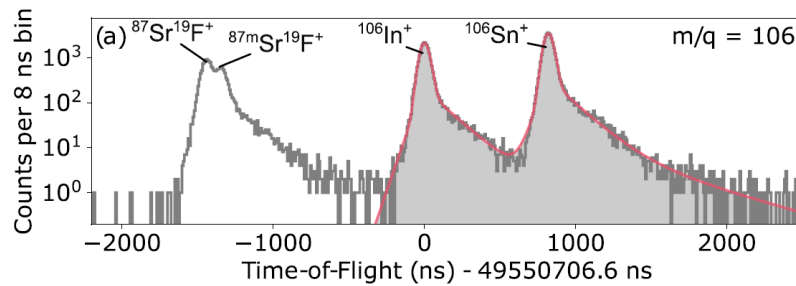
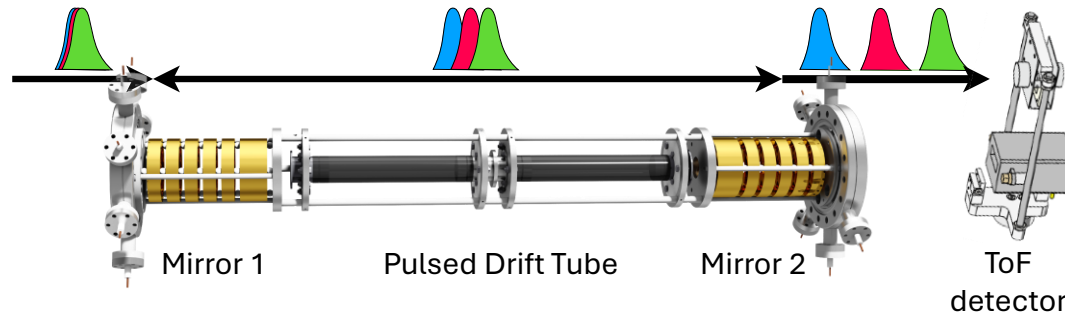
Multi-Reflection Time-of-Flight MS



Multi-Reflection Time-of-Flight MS

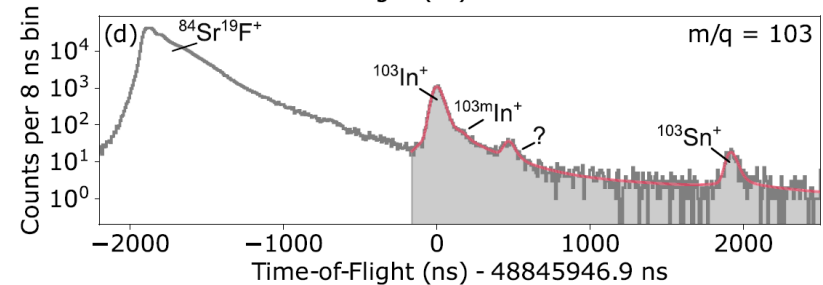
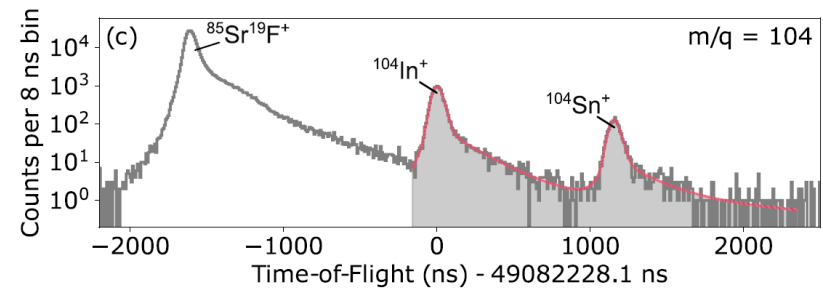
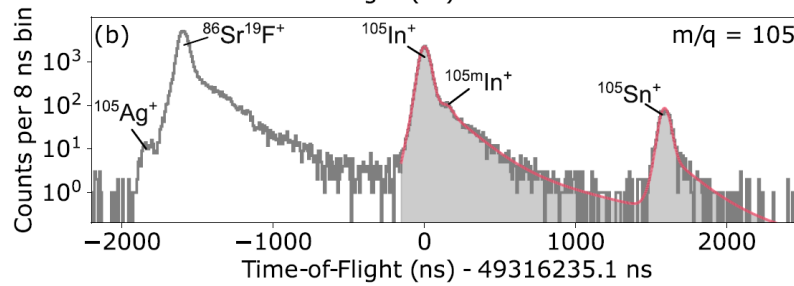
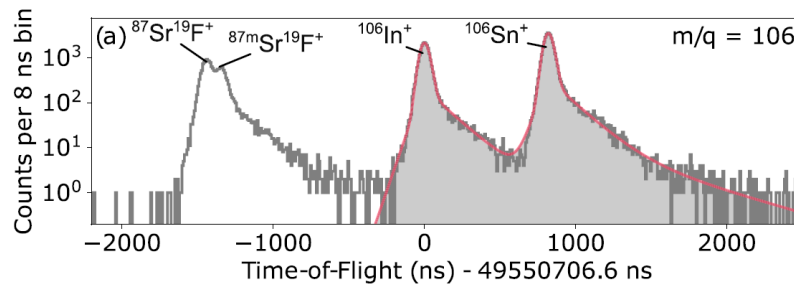
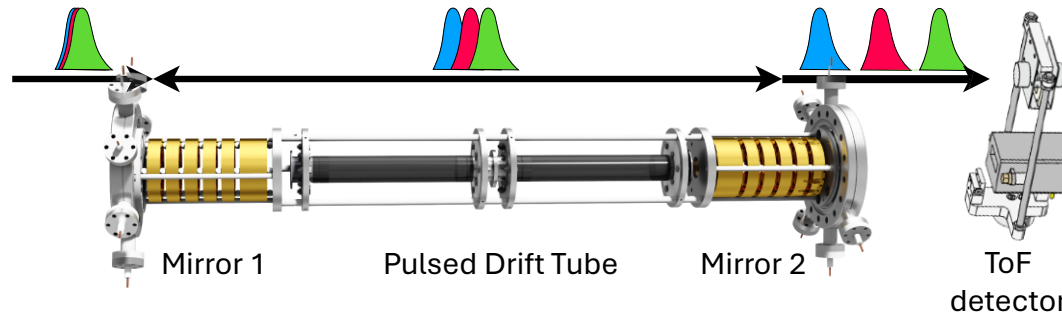


Multi-Reflection Time-of-Flight MS



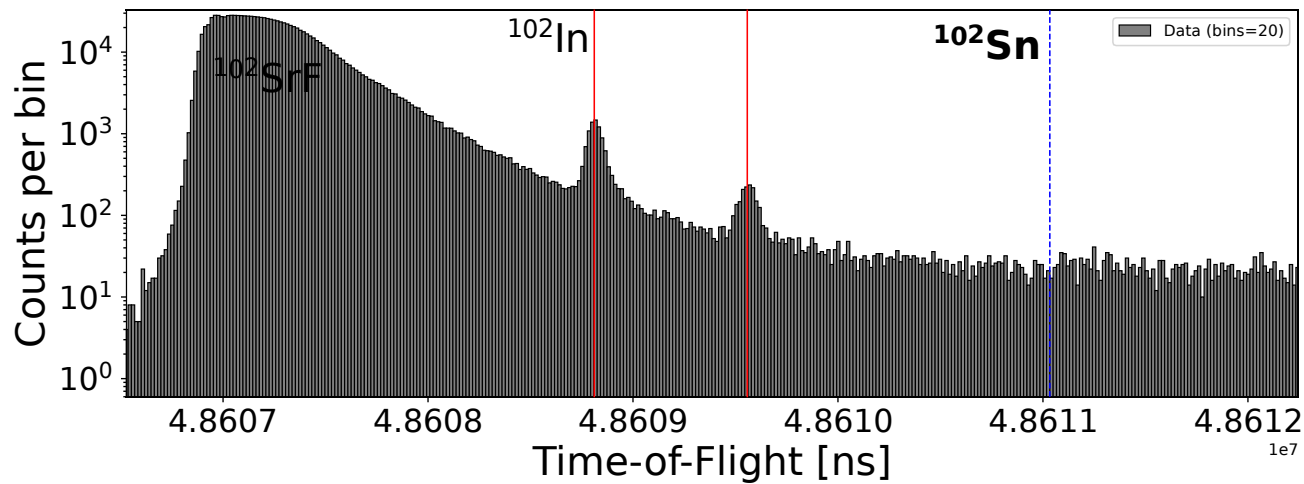
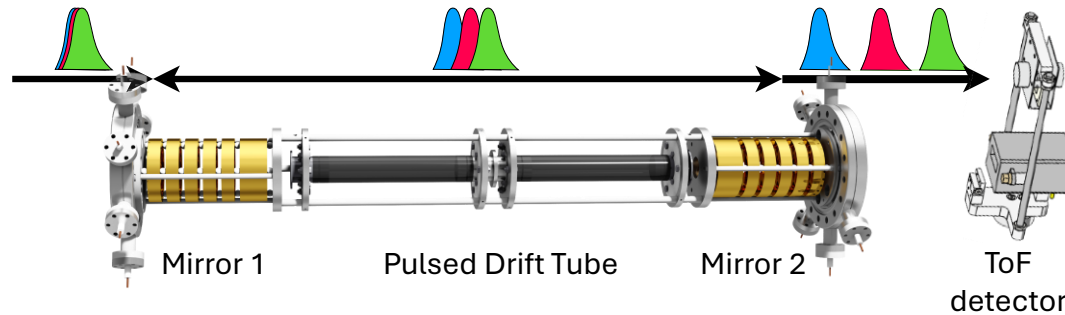
[1] Nies, L. et al., Phys. Rev. C 111, 014315 (2025)

Multi-Reflection Time-of-Flight MS



[1] Nies, L. et al., Phys. Rev. C 111, 014315 (2025)

Multi-Reflection Time-of-Flight MS

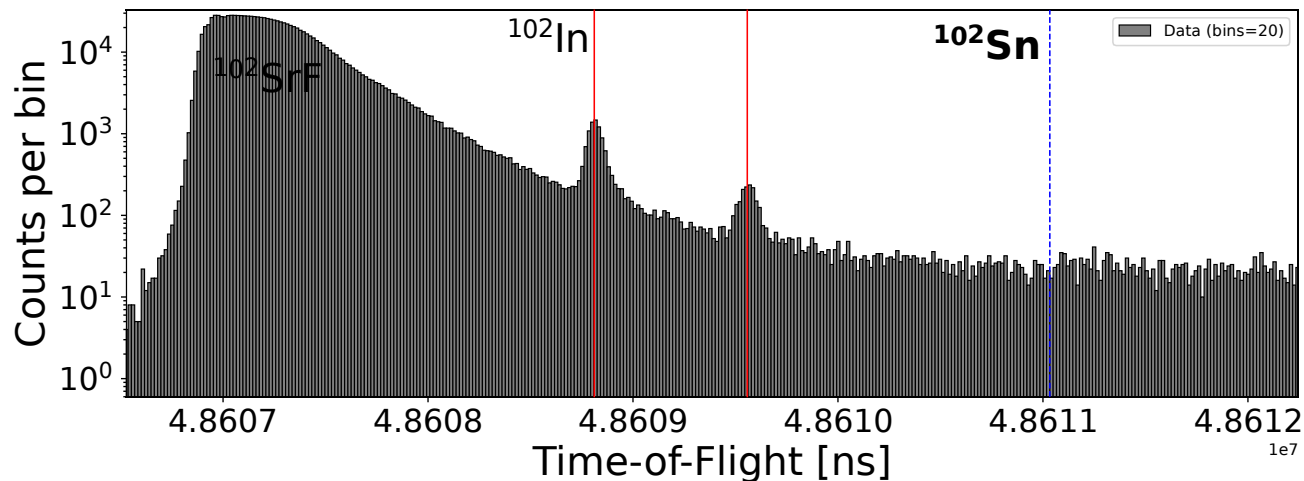


[1] Nies, L. et al., Phys. Rev. C 111, 014315 (2025)



MiniRFQ: Mass-selective re-trapping

- Low production cross section combined with isobaric and molecular contamination
- Mass-selective re-trapping [1]:
 - Contamination suppression
 - Collision-induced dissociation (CID)

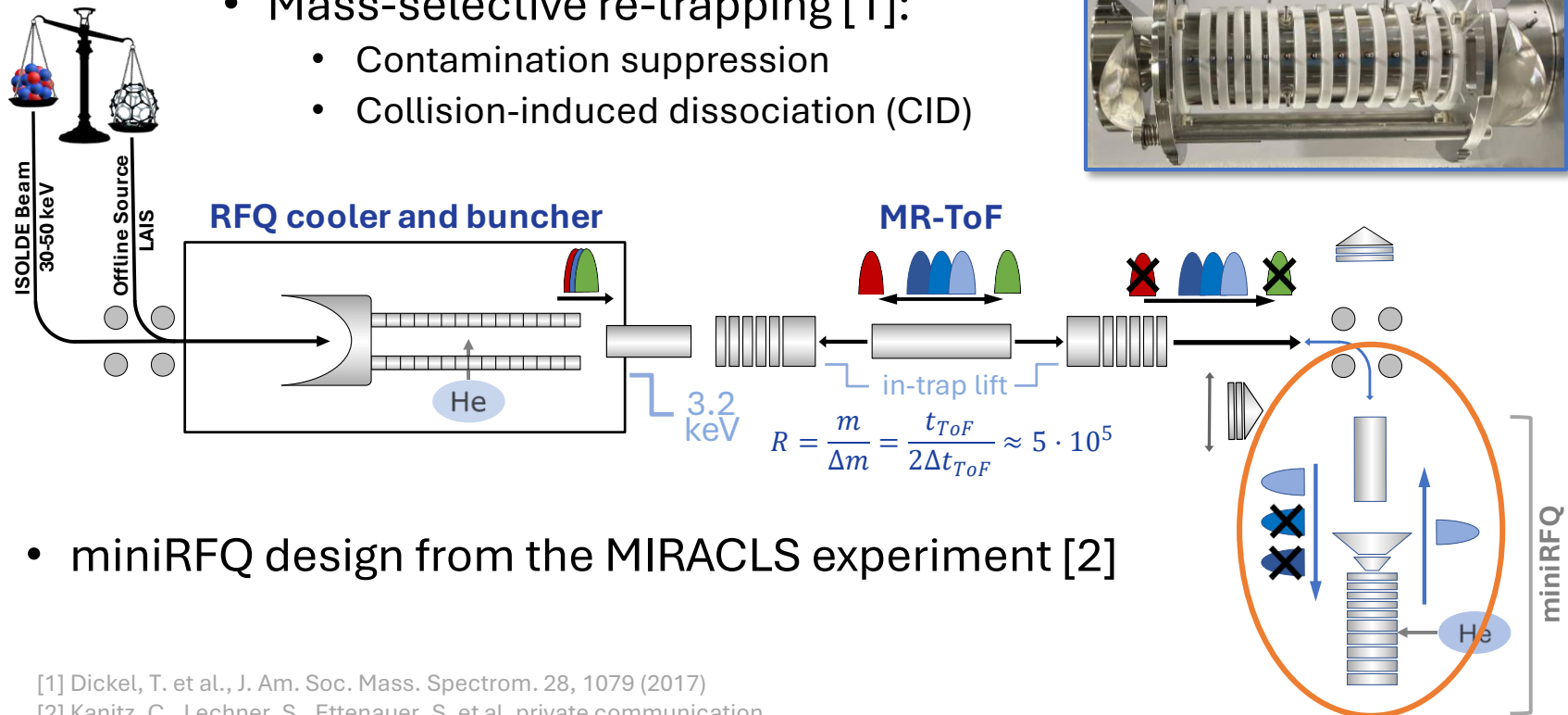
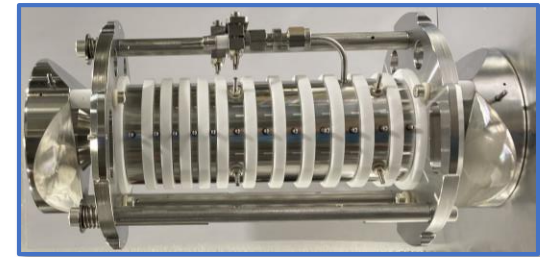


[1] Dickel, T. et al., J. Am. Soc. Mass. Spectrom. 28, 1079 (2017)

[2] Kanitz, C., Lechner, S., Ettenauer, S. et al. private communication

MiniRFQ: Mass-selective re-trapping

- Low production cross section combined with isobaric and molecular contamination
- Mass-selective re-trapping [1]:
 - Contamination suppression
 - Collision-induced dissociation (CID)

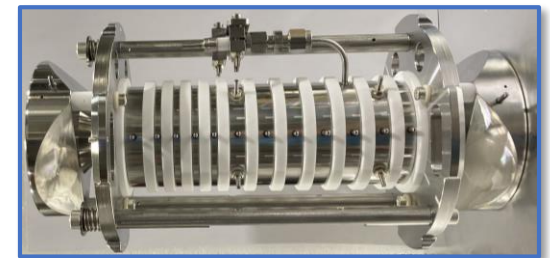
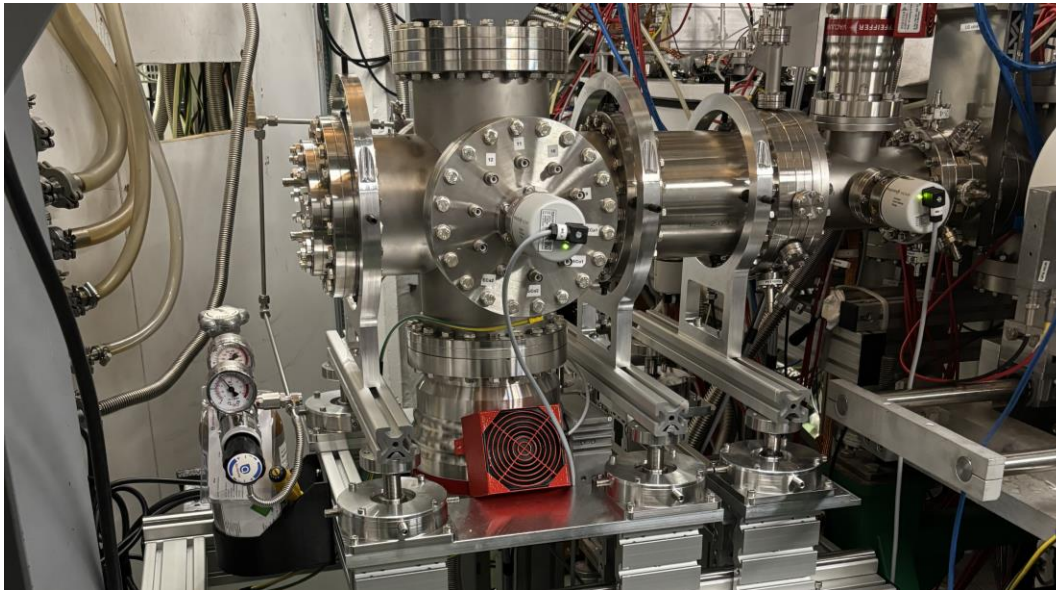
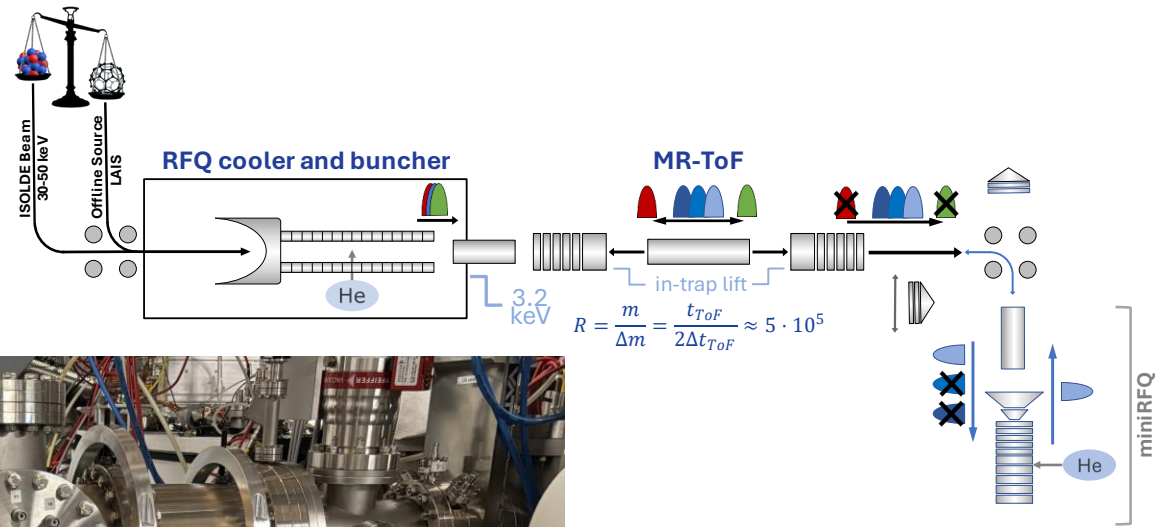


- miniRFQ design from the MIRACLS experiment [2]

[1] Dickel, T. et al., J. Am. Soc. Mass. Spectrom. 28, 1079 (2017)

[2] Kanitz, C., Lechner, S., Ettenauer, S. et al. private communication

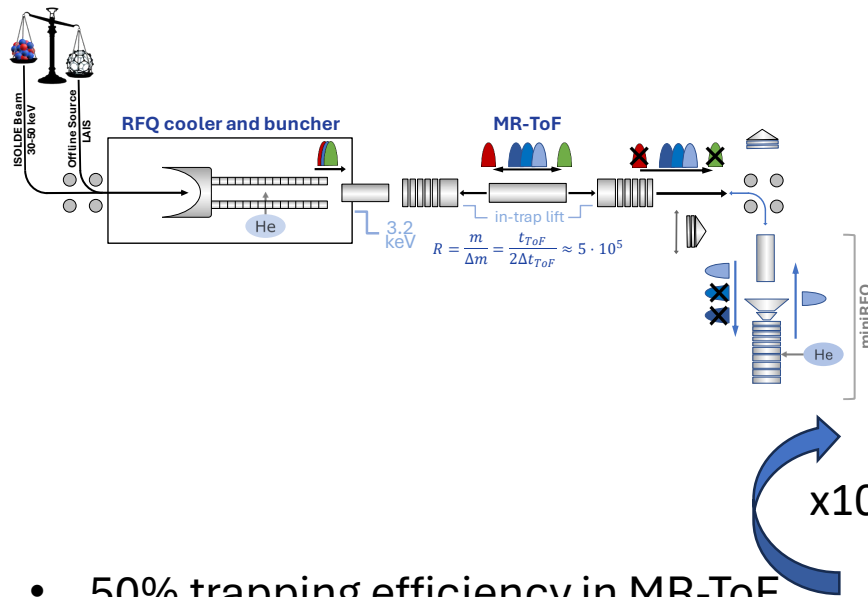
MiniRFQ: Mass-selective re-trapping



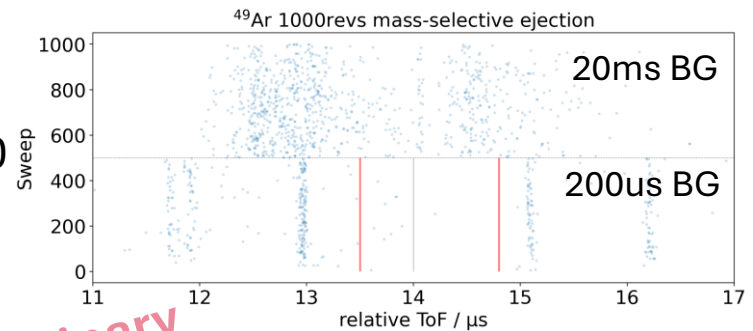
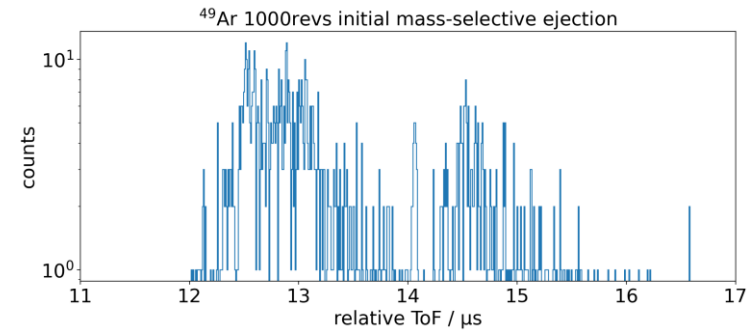
[1] Dickel, T. et al., J. Am. Soc. Mass. Spectrom. 28, 1079 (2017)

[2] Kanitz, C., Lechner, S., Ettenauer, S. et al. private communication

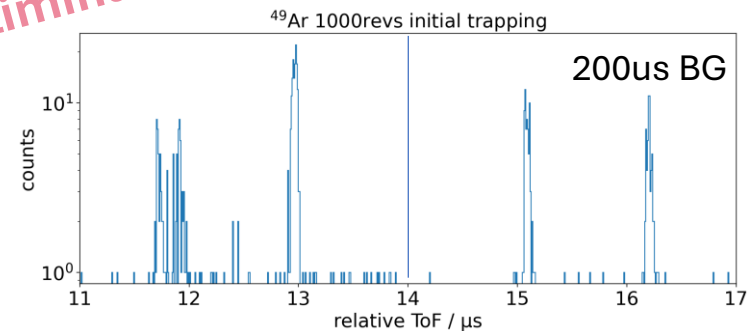
MiniRFQ: Mass-selective re-trapping



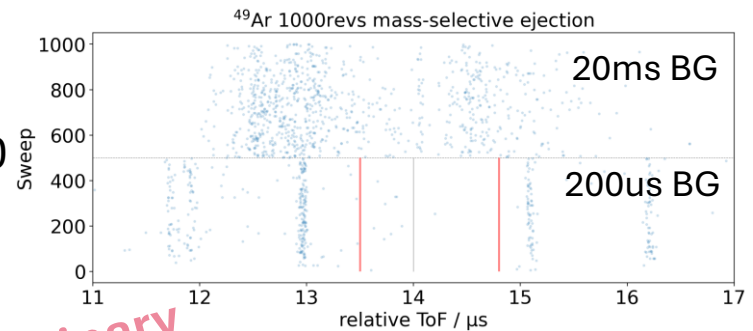
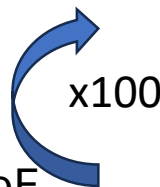
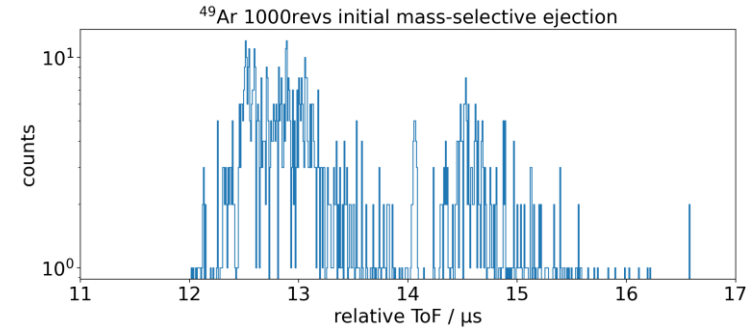
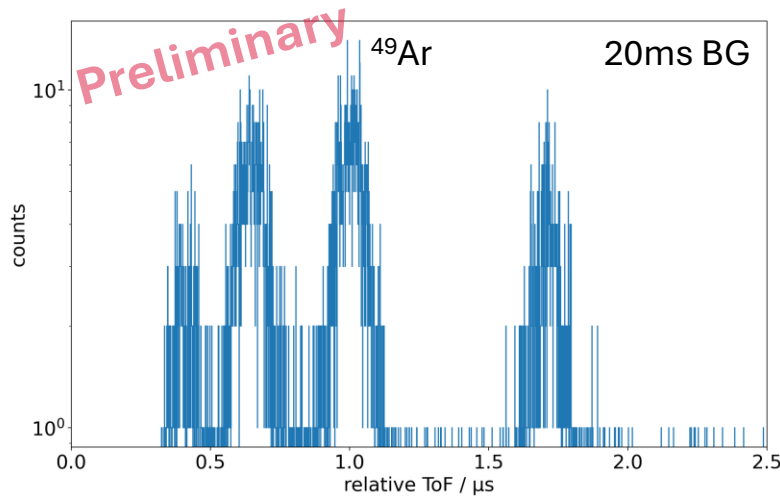
- 50% trapping efficiency in MR-ToF
- Mass separation power ~ 8400



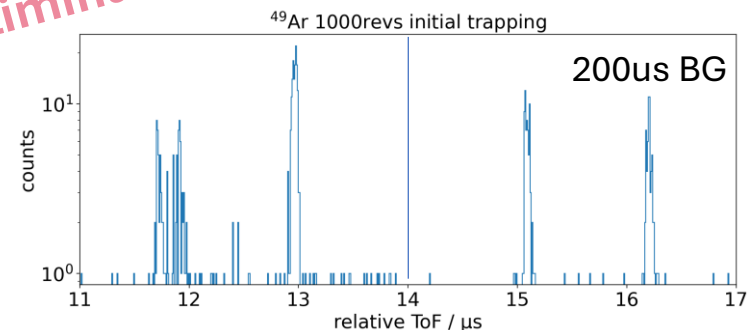
Preliminary



MiniRFQ: Mass-selective re-trapping

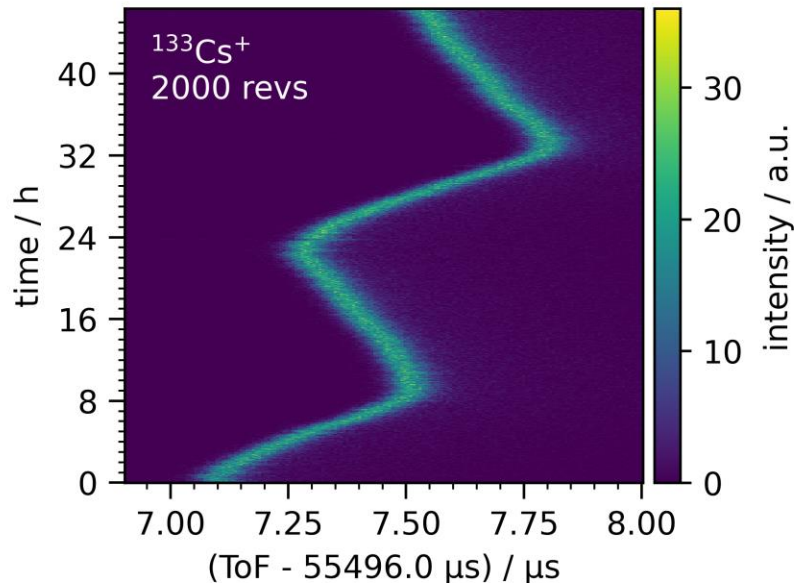


Preliminary



- 50% trapping efficiency in MR-ToF
- Mass separation power ~ 8400
- 50% efficiency for re-bunching in miniRFQ
- 20% re-trapping efficiency demonstrated with 2000 rev initial separation and 2000 revs measurement

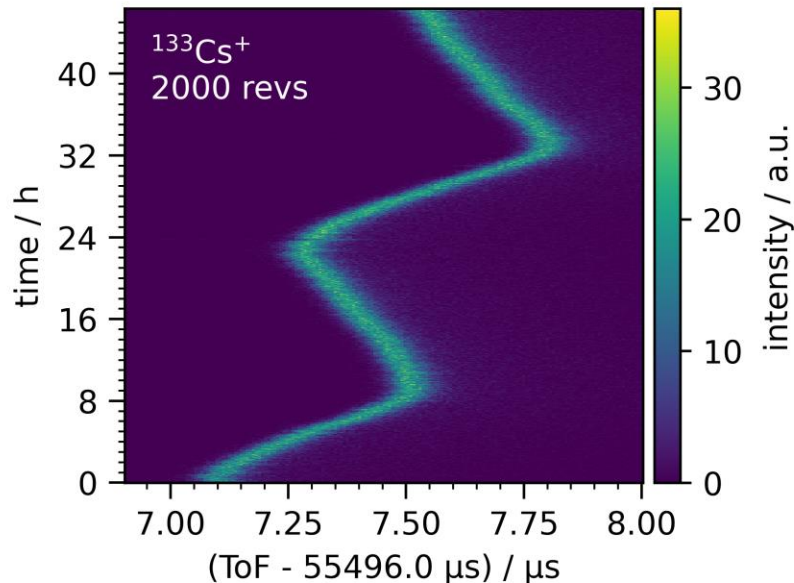
MR-ToF MS temperature stabilization



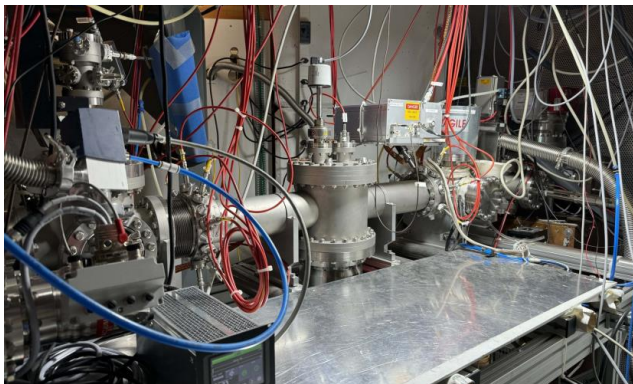
- ToF drift correlated with temperature ~ 500 ns/K
- Stability crucial for low-yield cases and identification
- Active temperature stabilization system based on Peltier elements & PID loop [1]

[1] Mehlhorn, F., BSc thesis, University Heidelberg

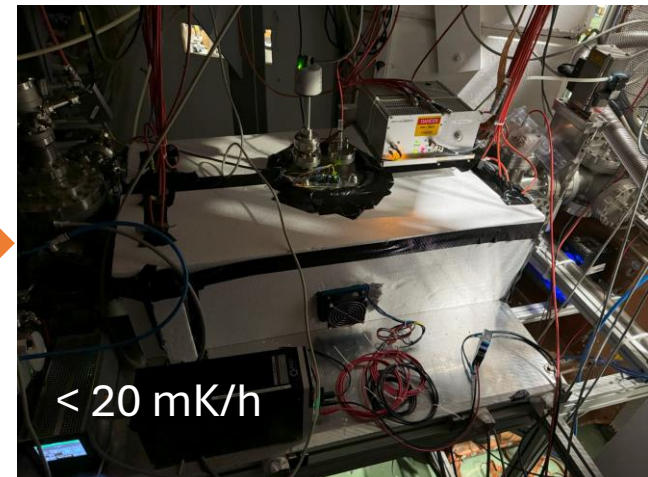
MR-ToF MS temperature stabilization



- ToF drift correlated with temperature ~ 500 ns/K
- Stability crucial for low-yield cases and identification
- Active temperature stabilization system based on Peltier elements & PID loop [1]

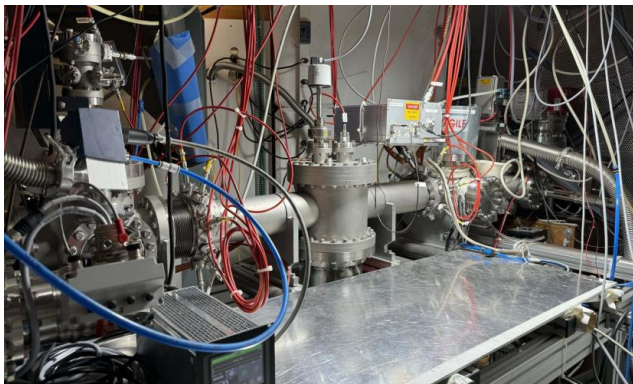
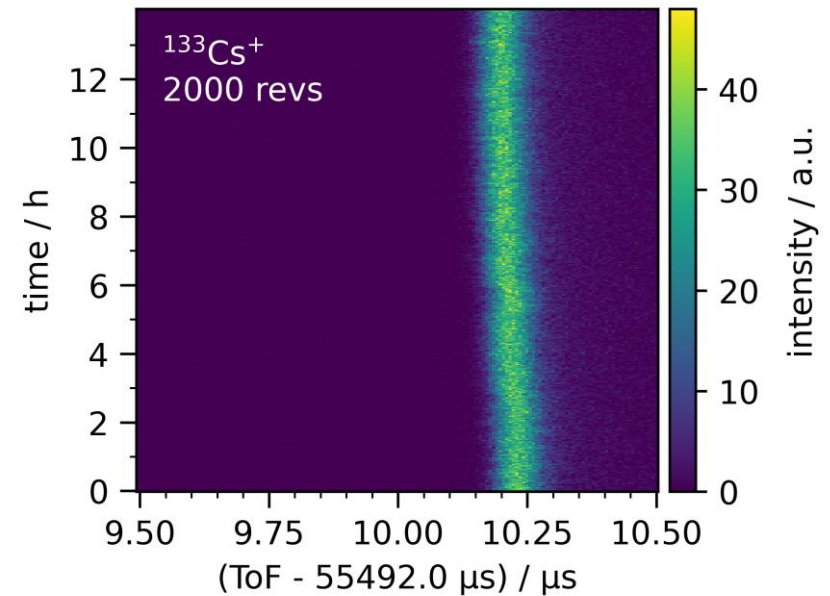
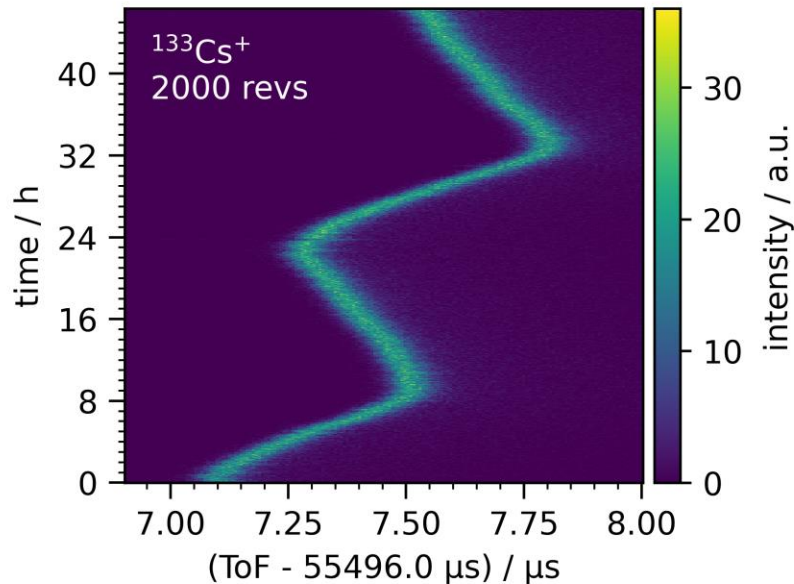


T-Stabilization

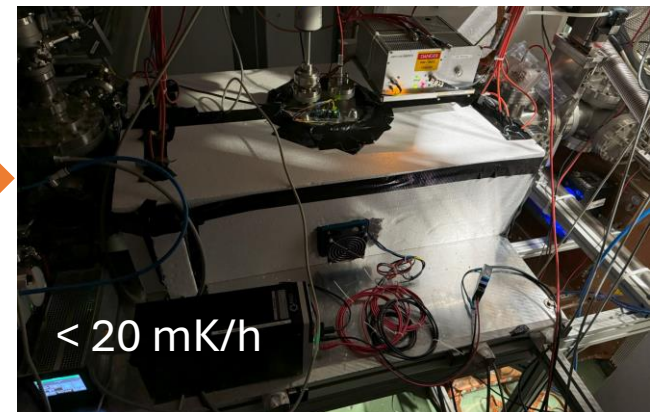


[1] Mehlhorn, F., BSc thesis, University Heidelberg

MR-ToF MS temperature stabilization



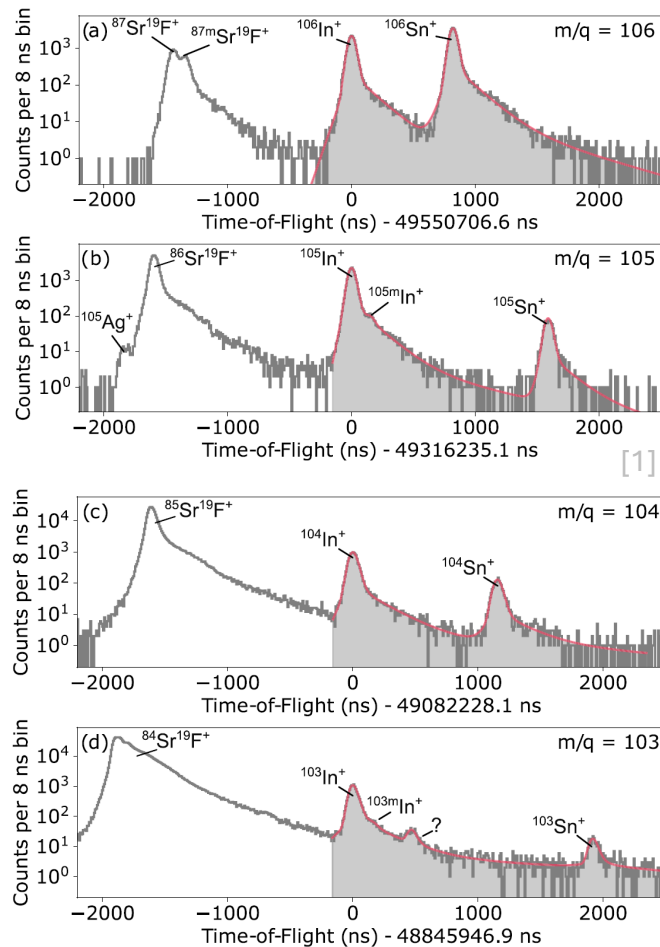
T-Stabilization



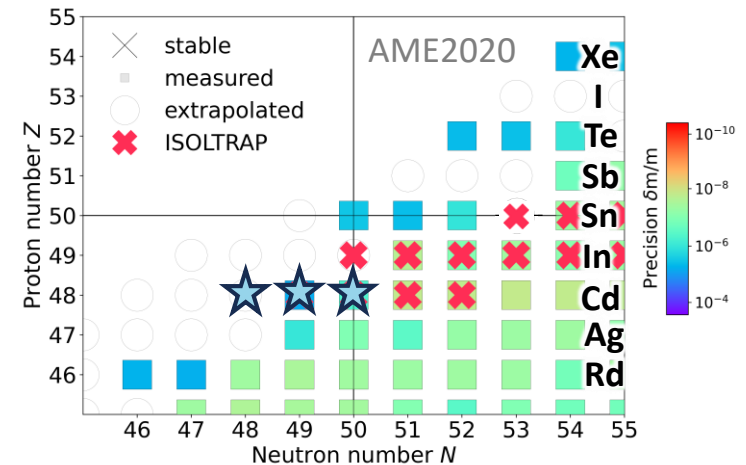
[1] Mehlhorn, F., BSc thesis, University Heidelberg



Neutron-deficient Cadmium



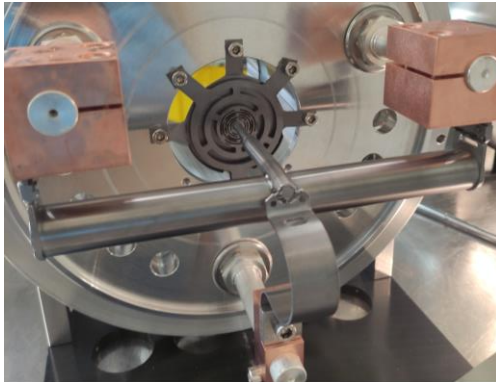
[1]



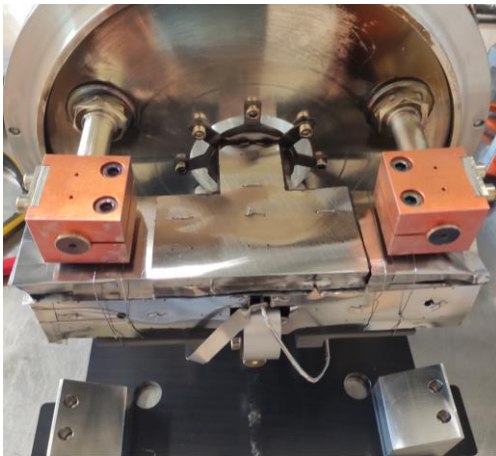
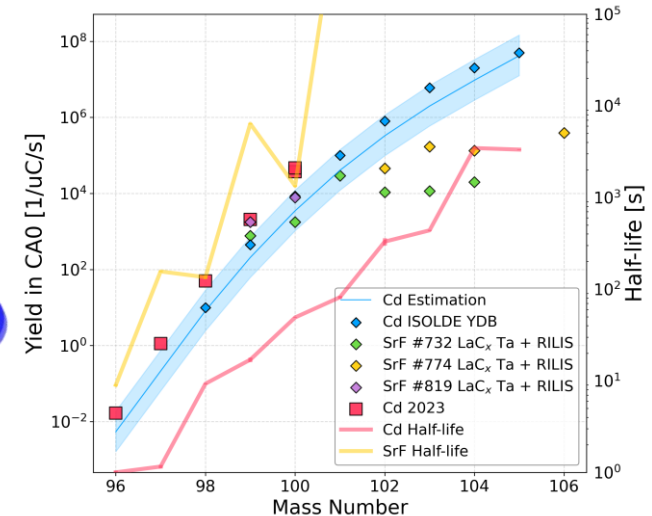
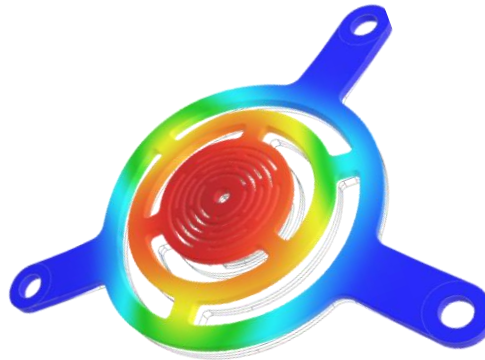
- Evolution of nuclear structure in vicinity of ^{100}Sn ($N=Z=50$)
- Close to p-dripline/rp-process nuclei
- ISOLTRAP runs up to ^{99}In [2,3] and ^{103}Sn [1]

[1] Nies, L. et al., Phys. Rev. C 111, 014315 (2025)
 [2] Mougeot, M. et al., Nat. Phys. 17, 1099 (2021)
 [3] Nies, L. et al., Phys. Rev. Lett. 131, 022502 (2023)

Neutron-deficient Cadmium



Standard target



Improved heat-shielding

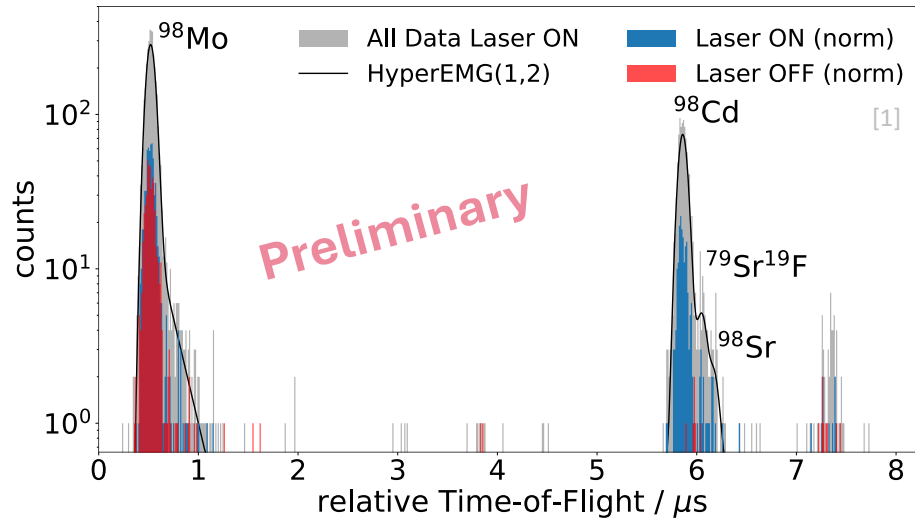
Prototype LaC_x target (tested in 2023) [1]:

- Improved heat-shielding
 - „Spider-web“ ion source
 - Improved ISOLTRAP efficiency: 3 %
- => Factor 5 improvement in yield

[1] Koliatos, A., TISD-team

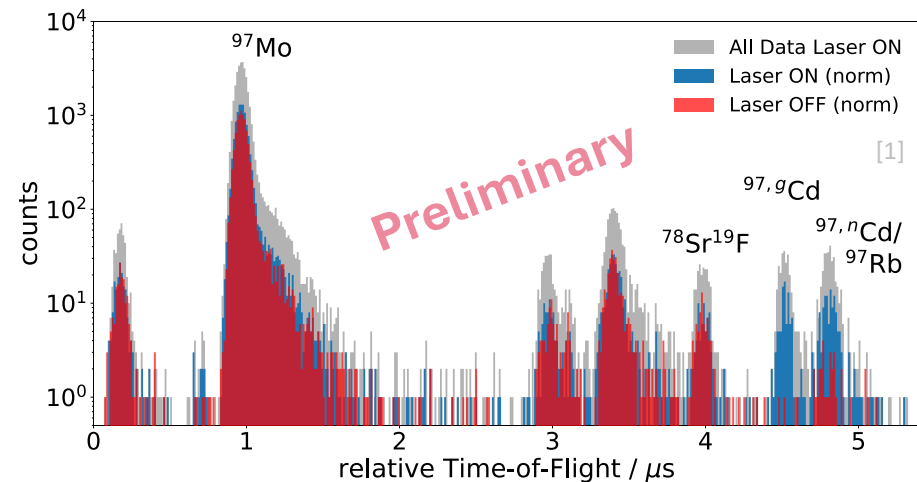


Neutron-deficient Cadmium



2023 (prototype target):

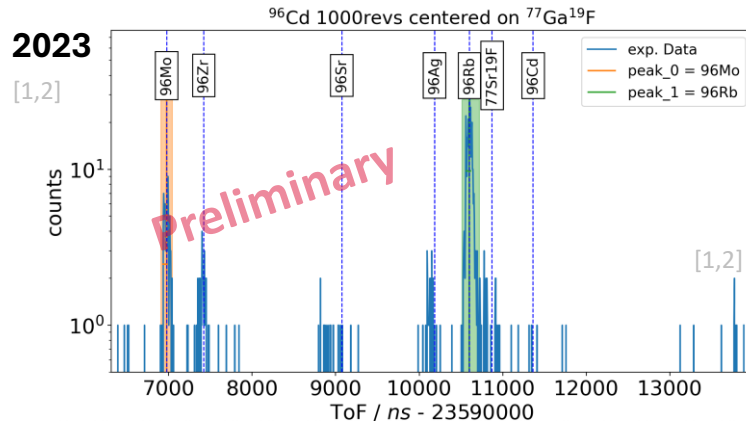
- Improved precision on ^{98}Cd
- First measurement of ^{97}Cd and 25/2+ spin-gap isomer $^{97,n}\text{Cd}$ overlapping with ^{97}Rb



[1] Lange, D. et al., in preparation

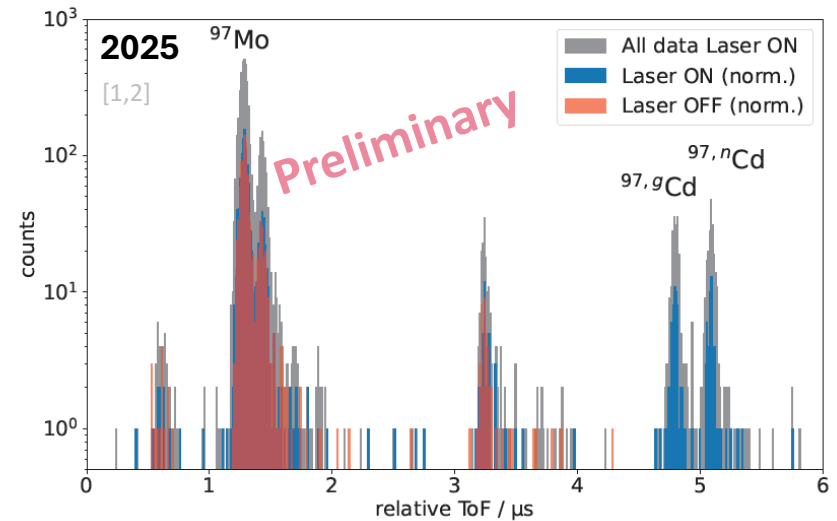
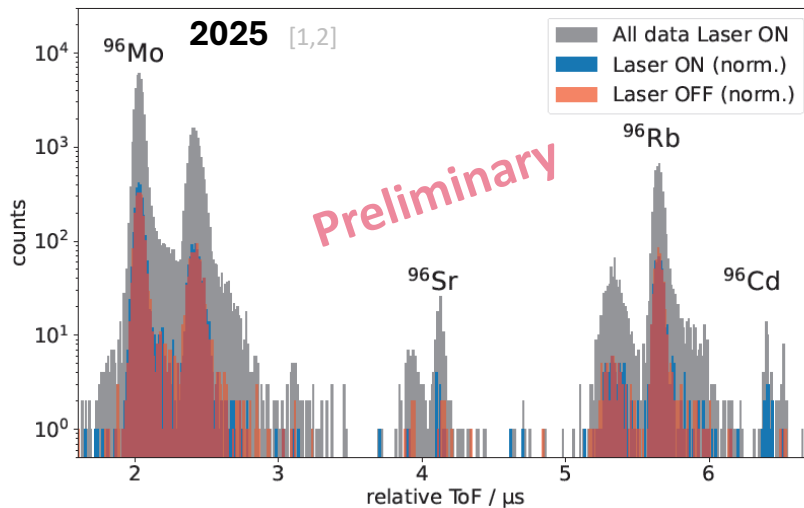


Neutron-deficient Cadmium



2025 run:

- First measurement of ⁹⁶Cd
- Consolidate data for ⁹⁸Cd and ^{97g,n}Cd from 2023



[1] Lange, D. et al., in preparation
[2] Mougeot, M. et al., INTC-P-682

Open proposal on ⁹⁸In: Nies, L. et al., INTC-P-553



Neutron-rich Mercury

- Measured masses for Hg extend up to ^{208}Hg (SMS [1])

^{208}Pb 82 126 500 ns 10^+ Ex 4892.33 (0.03) IT=100% stable 0^+ M $\sim$ 21748.6 (1.1) Abundance=52.4 (11%) $\alpha?$	^{209}Pb 82 127 3.234 h $9/2^+$ M $\sim$ 17614.6 (1.7) β^- =100%	^{210}Pb 82 128 201 ns 8^+ Ex 1278 (5) IT=100% 22.20 y 0^+ M $\sim$ 14728.5 (1.4) β^- =100% α =1.9e-6 (4%)	^{211}Pb 82 129 159 ns (27/2) Ex 1704 (15) IT=100% 36.164 m $9/2^+$ M $\sim$ 10492.9 (2.3) β^- =100%	^{212}Pb 82 130 6.0 us 8^+ # Ex 1335 (2) IT=100% 10.64 h 0^+ M $\sim$ 7548.8 (1.8) β^- =100%	^{213}Pb 82 131 10.2 m ($9/2^+$) M $\sim$ 3204 (7) β^- =100%	^{214}Pb 82 132 6.2 us 8^+ # Ex 1420 (20) IT=100% 27.06 m 0^+ M $\sim$ 182.8 (2.0) β^- =100%	^{215}Pb 82 133 2.34 m $9/2^+$ # M 4340 (50) β^- =100%
^{207}Tl 81 126 1.33 s $11/2^-$ Ex 1348.18 (0.15) IT=100% β^- <0.1#% 4.77 m $1/2^+$ M $\sim$ 21034 (5) β^- =100%	^{208}Tl 81 127 3.053 m 5^+ M $\sim$ 16750.1 (1.9) β^- =100%	^{209}Tl 81 128 2.162 m $1/2^+$ M $\sim$ 13645 (6) β^- =100% β^- n=0#%	^{210}Tl 81 129 1.30 s 5^+ # M $\sim$ 9247 (12) β^- =100% β^- n=0.009 (6)%	^{211}Tl 81 130 80 s $1/2^+$ M $\sim$ 6080 (40) β^- =100% β^- n=2.2 (22)%	^{212}Tl 81 131 31 s (5^+) M $\sim$ 1550# (200#) β^- =100% β^- n=1.8 (18)%	^{213}Tl 81 132 24 s $1/2^+$ M 1784 (27) β^- =100% β^- n=7.6 (34)%	^{214}Tl 81 133 11 s 5^+ # M 6470# (200#) β^- =100% β^- n=34 (12)%
^{206}Hg 80 126 106 ns (0^+) Ex 1072.1 (1.0) IT=100% 2.09 us 5^- Ex 1012.4 (3) IT=100% 8.32 m 0^+ M $\sim$ 20946 (20) β^- =100%	^{207}Hg 80 127 2.9 m $9/2^+$ # M $\sim$ 16487 (30) β^- =100%	^{208}Hg 80 128 99 ns (8^+) Ex 1338 (24) IT=100% 42 m 0^+ M $\sim$ 13270 (30) β^- =100%	^{209}Hg 80 129 38 s $9/2^+$ # M $\sim$ 8640# (150#) β^- =100% β^- n=0#%	^{210}Hg 80 130 2 us 8^+ # Ex 1406 (23) IT=100% 21 us (3^+) Ex 1663 (2) IT=100% 64 s 0^+ M $\sim$ 2178# (20#) β^- =100% β^- n=12 (22)%	^{211}Hg 80 131 26 s $9/2^+$ # M $\sim$ 620# (200#) β^- =100% β^- n=6.3 (63)%	^{212}Hg 80 132 1# m 0^+ M 2760# (300#) β^- ? β^- n=8#%	^{213}Hg 80 133 1# s $5/2^+$ # M 7670# (300#) β^- ? β^- n=30#%
^{205}Au 79 126 163 ns ($19/2^+$) Ex 2830 (5) IT=100% 5 s $11/2^-$ # Ex 107 (5) IT=? β^- ? 32.5 s $3/2^+$ # M $\sim$ 10778# (20#) β^- =100%	^{206}Au 79 127 47 s ($5^+, 6^+$) M $\sim$ 14220# (300#) β^- =100%	^{207}Au 79 128 10# s $3/2^+$ # M $\sim$ 10810# (300#) β^- ? β^- n=0.4#%	^{208}Au 79 129 10# s M $\sim$ 6100# (300#) β^- ? β^- n=5#%	^{209}Au 79 130 1# s $3/2^+$ # M $\sim$ 2540# (400#) β^- ? β^- n=90#%	^{210}Au 79 131 1# s M 2330# (400#) β^- ? β^- n=10#%		

[1] Chen, L. et al., Phys. Rev. Lett. 102, 122503 (2009)

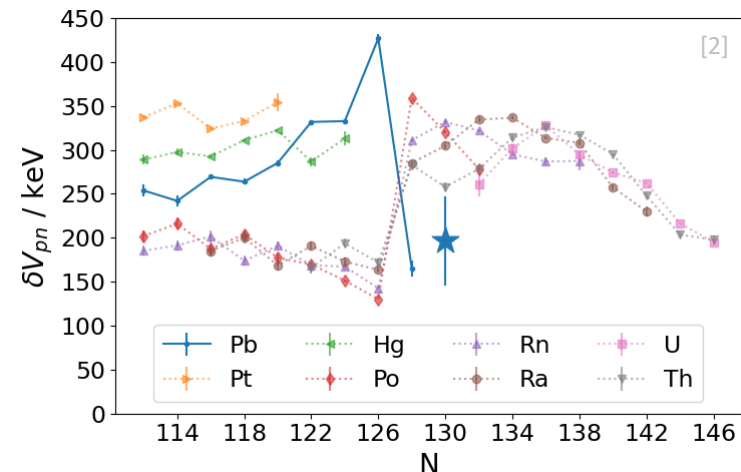
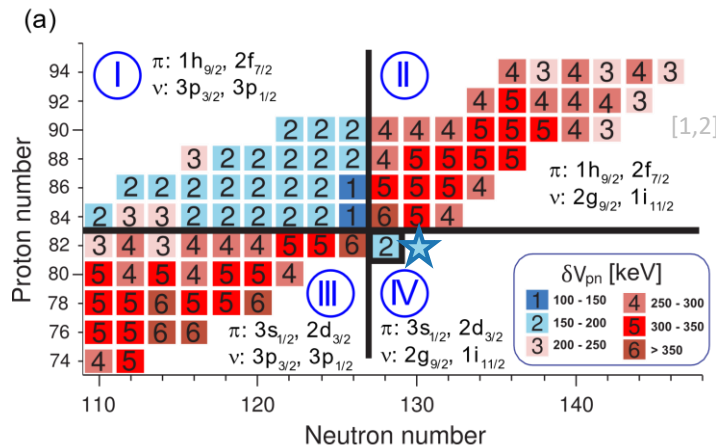
[2] Cubiss, J., Lange, D. et al., INTC-P-698

Neutron-rich Mercury

- Measured masses for Hg extend up to ^{208}Hg (SMS [1])
- Empirical interaction strength of the last proton and neutron:

$$\delta V_{pn}^{ee}(Z, N) = 1/4 \cdot [S_{2n}(Z, N) - S_{2n}(Z - 2, N)]$$

$$S_{2n}(Z, N) = B(Z, N) - B(Z, N - 2)$$

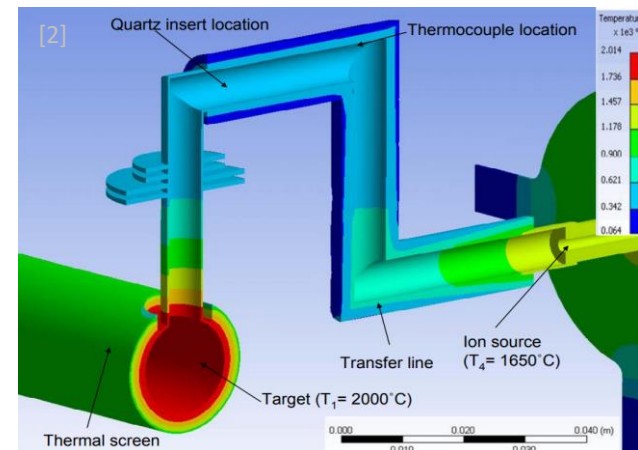
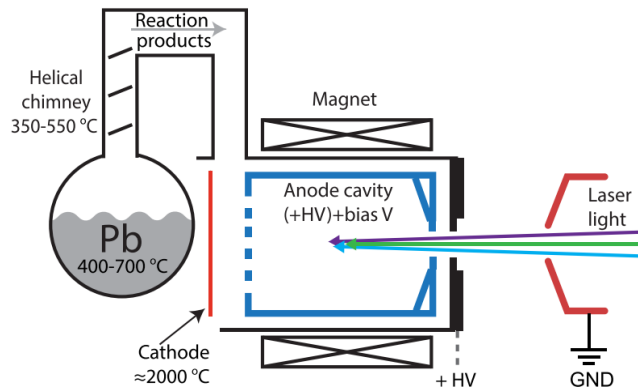


[1] Chen, L. et al., Phys. Rev. Lett. 102, 122503 (2009)

[2] Cubiss, J., Lange, D. et al., INTC-P-698

Neutron-rich Mercury

- INTC-I-244: n-rich Hg beam development [1]

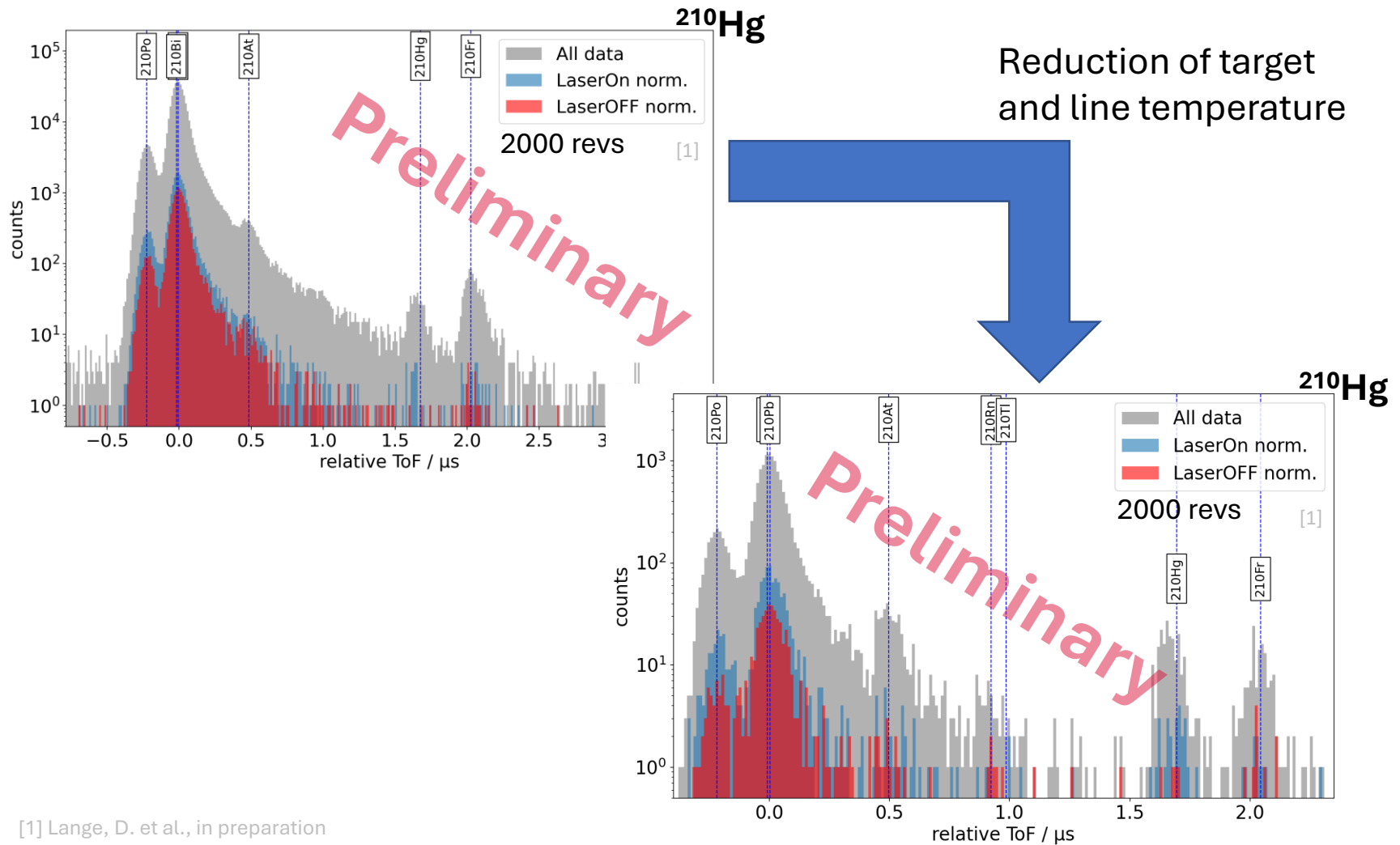


- Lower neg. adsorption enthalpy of Hg vs. Fr:
Hg passes cold quartz transfer line

[1] Andreyev, A.N. and Köster, U., et al., INTC-I-244

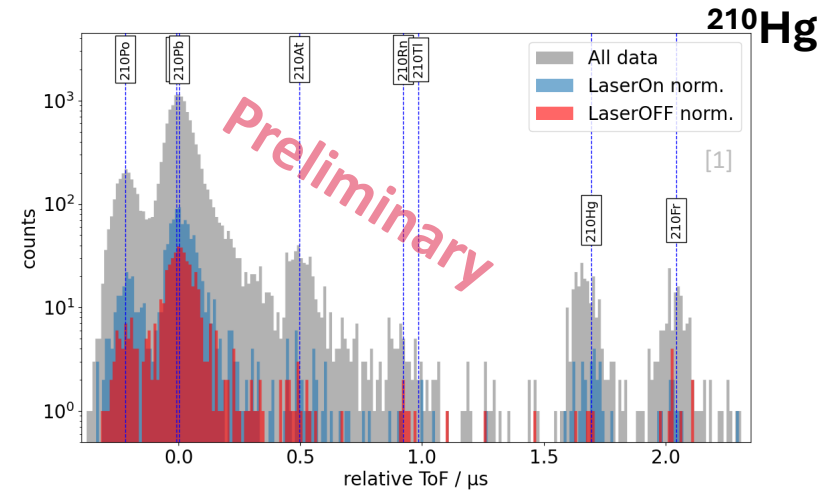
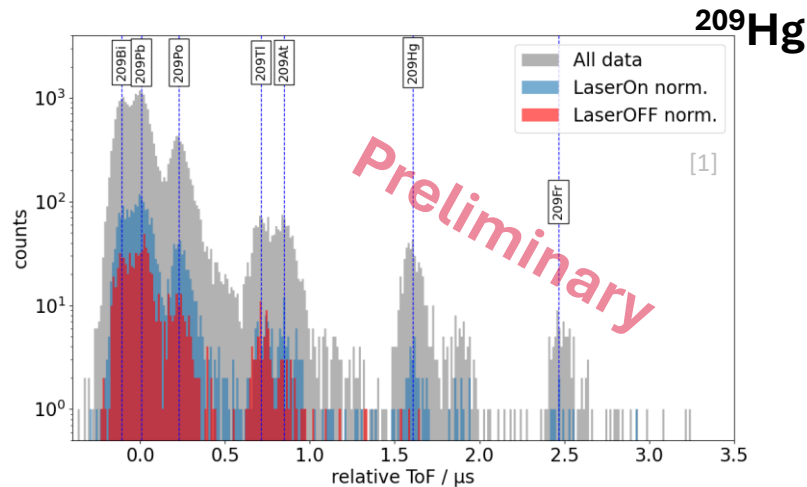
[2] Cubiss, J., Lange, D. et al., INTC-P-698

Neutron-rich Mercury

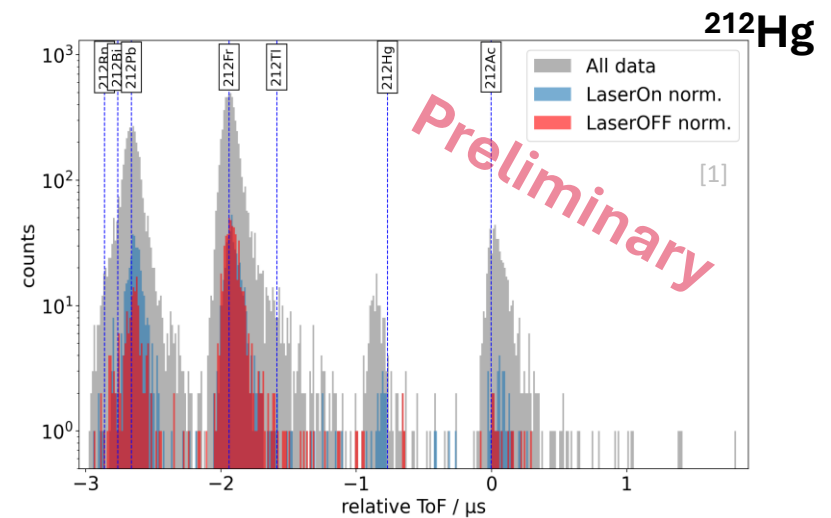


[1] Lange, D. et al., in preparation

Neutron-rich Mercury



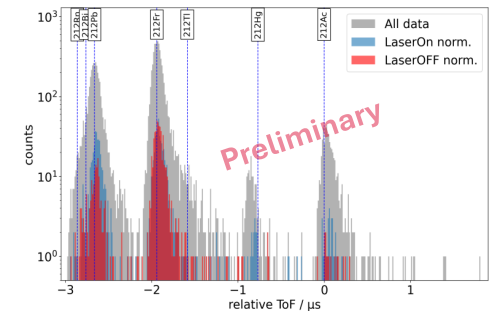
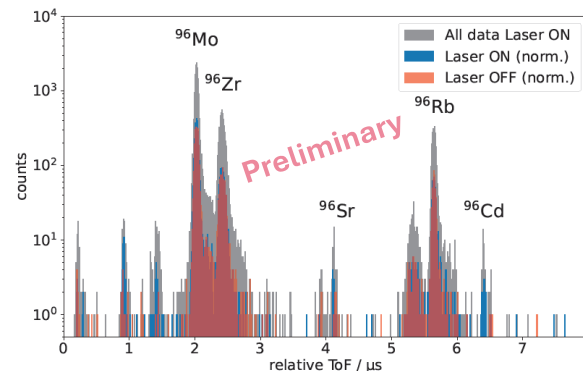
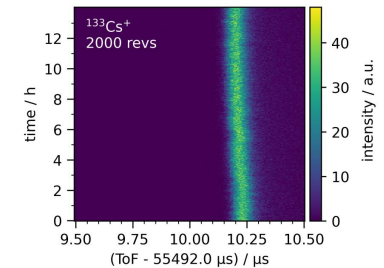
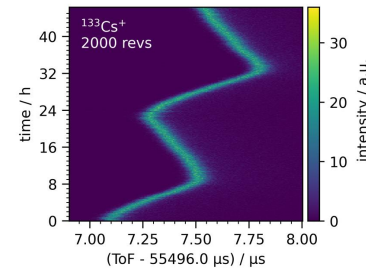
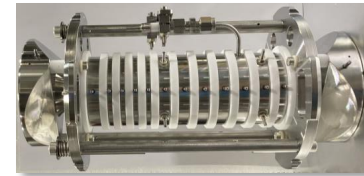
- First direct mass measurements of $^{209}, ^{210}, ^{212}\text{Hg}$



[1] Lange, D. et al., in preparation

Summary

- ISOLDE & ISOLTRAP
- Mass-selective re-trapping in miniRFQ
- MR-ToF temperature stabilization
- Neutron-deficient Cd
- Neutron-rich Hg



Acknowledgements

D. Antanasov, M. Benhatchi,
K. Blaum, R. B. Cakirli,
P. F. Giesel, P. Fischer,
D. Lange, Yu. Litvinov,
D. Lunney, V. Manea,
S. Naimi, L. Nies,
Ch. Schweiger, L. Schweikhard,
F. Wienholtz, *et al.*
for the **ISOLTRAP** collaboration

ISOLDE OPERATIONS TEAM
RILIS TEAM
TARGET TEAM
RP TEAM



Federal Ministry
of Education
and Research

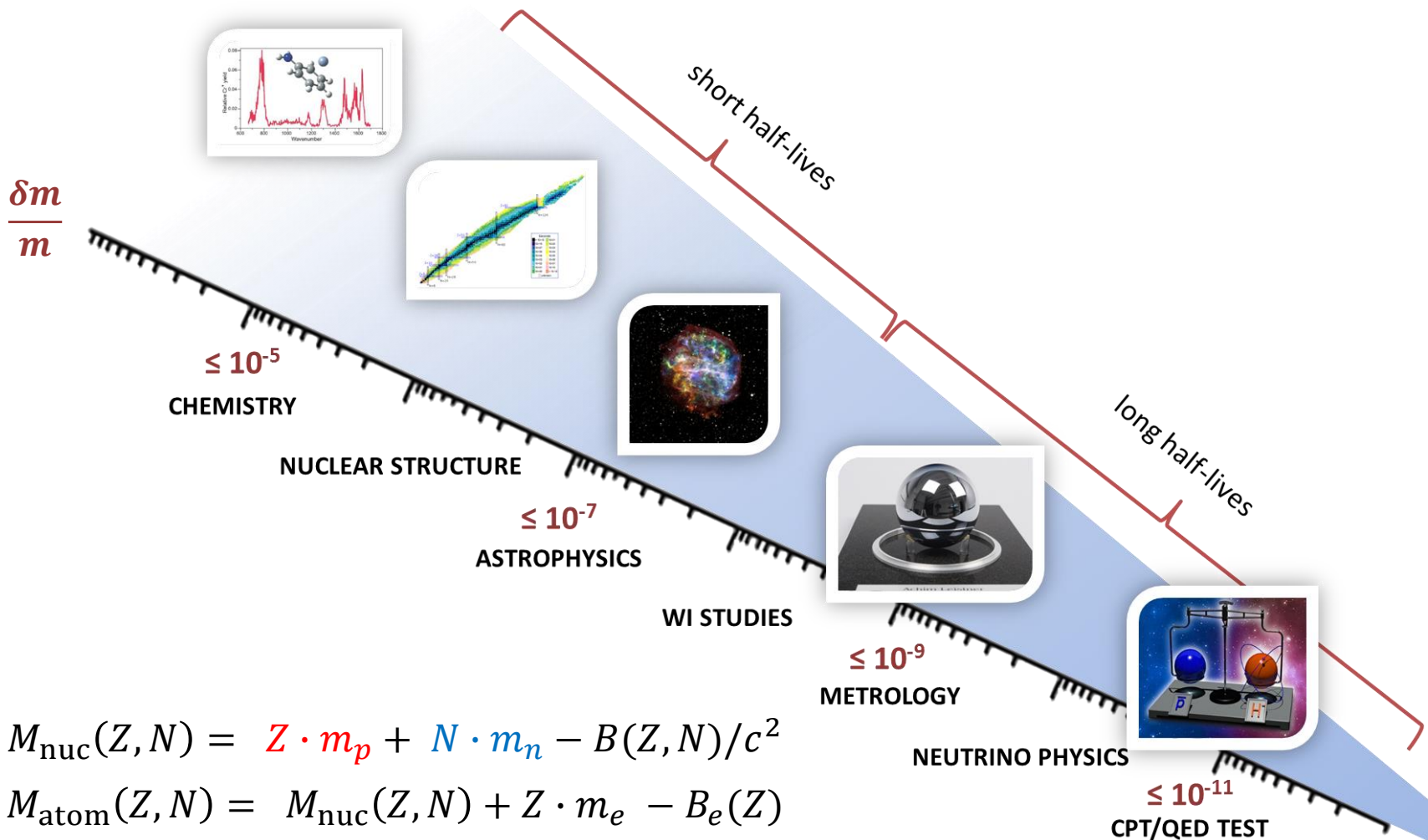


MAX-PLANCK-INSTITUT
FÜR KERNPHYSIK



Additional slides

Precision mass spectrometry



Precision mass spectrometry

Nuclear structure

Refining the nuclear mass surface with the mass of ^{103}Sn

Nies, L. et al., Phys. Rev. C **111**, 014315 (2025)

Nuclear astrophysics

Precision Mass Measurements of $^{129}\text{--}^{131}\text{Cd}$ and Their Impact on Stellar Nucleosynthesis via the Rapid Neutron Capture Process

Atanasov, D. et al., Phys. Rev. Lett. **115**, 232501 (2015)

Neutrino physics

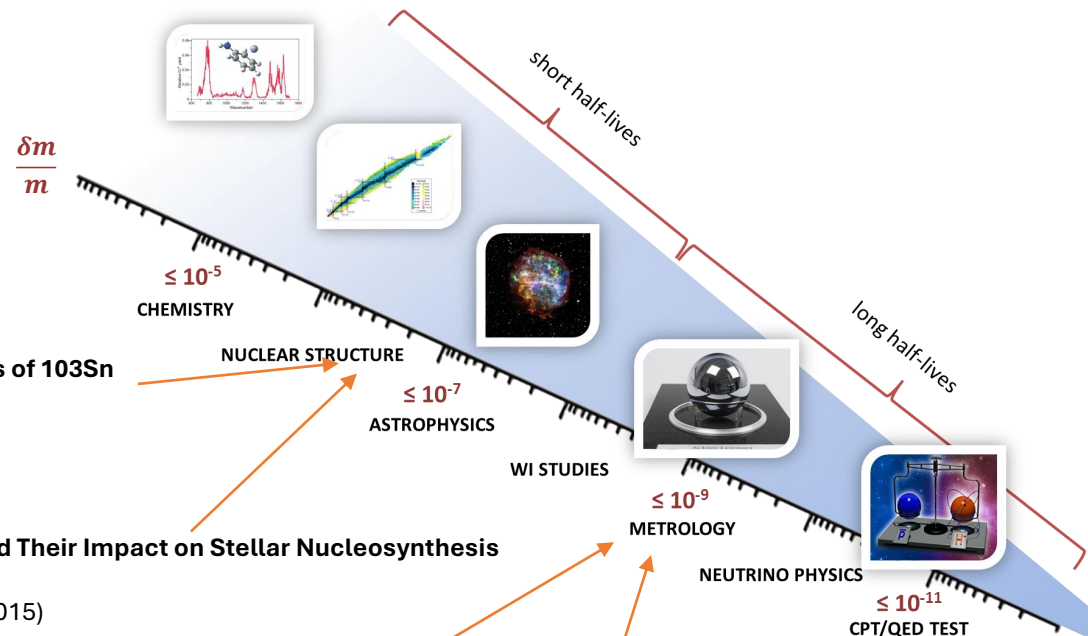
Direct decay-energy measurement as a route to the neutrino mass.

Karthein, J. et al., Hyperfine Interact. **240**, 61 (2019)

Weak interaction physics

QEC -value determination for $\text{Na}^{21} \rightarrow \text{Ne}^{21}$ and $\text{Mg}^{23} \rightarrow \text{Na}^{23}$ mirror-nuclei decays using high-precision mass spectrometry with ISOLTRAP at the CERN ISOLDE facility.

Karthein, J. et al., Phys. Rev. C **100**, 015502 (2019)



Precision mass spectrometry

Nuclear structure

Refining the nuclear mass surface with the mass of ^{103}Sn

Nies, L. et al., Phys. Rev. C **111**, 014315 (2025)

Nuclear astrophysics

Precision Mass Measurements of $^{129}\text{--}^{131}\text{Cd}$ and Their Impact on Stellar Nucleosynthesis via the Rapid Neutron Capture Process

Atanasov, D. et al., Phys. Rev. Lett. **115**, 232501 (2015)

Neutrino physics

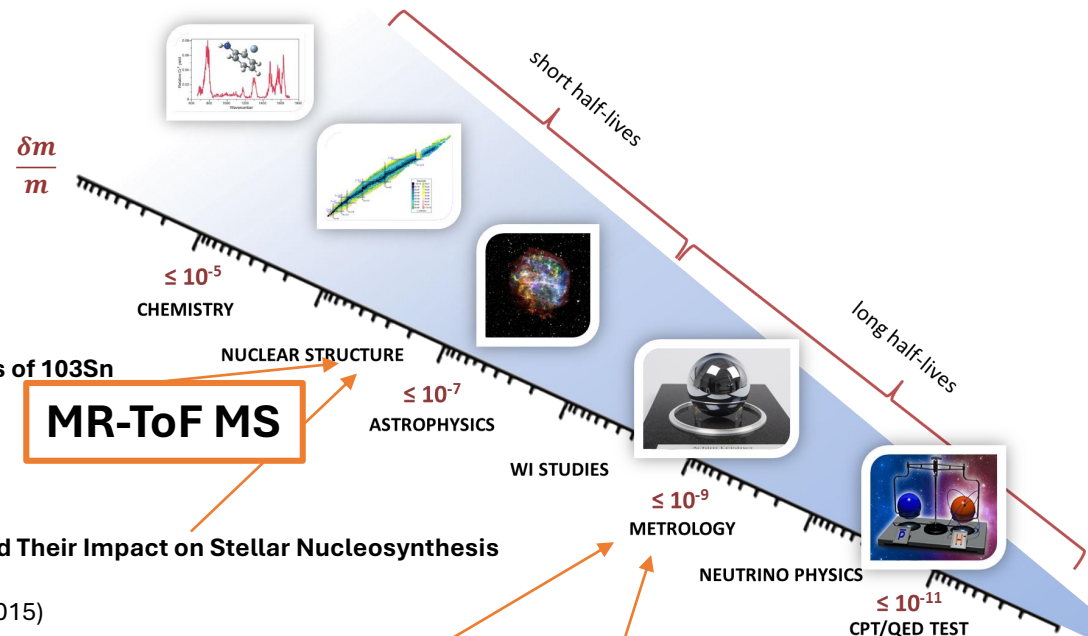
Direct decay-energy measurement as a route to the neutrino mass.

Karthein, J. et al., Hyperfine Interact. **240**, 61 (2019)

Weak interaction physics

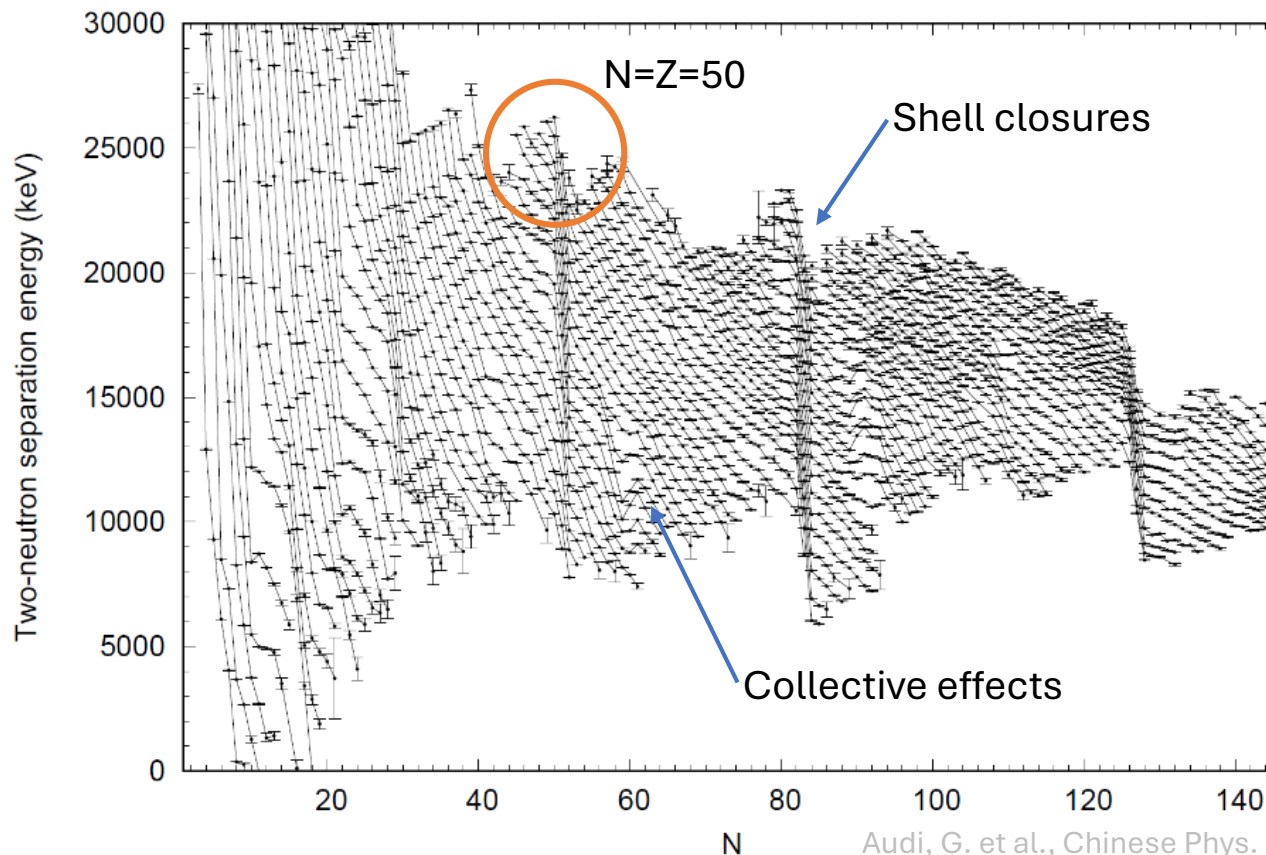
QEC -value determination for $\text{Na}^{21} \rightarrow \text{Ne}^{21}$ and $\text{Mg}^{23} \rightarrow \text{Na}^{23}$ mirror-nuclei decays using high-precision mass spectrometry with ISOLTRAP at the CERN ISOLDE facility.

Karthein, J. et al., Phys. Rev. C **100**, 015502 (2019)



Precision mass spectrometry

Nuclear structure: Mass filters, e.g. $S_{2n}(Z,N) = B(Z, N) - B(Z, N-2)$



Audi, G. et al., Chinese Phys. C 41, 3 (2017)

$$v_c = v_+ + v_- = \frac{1}{2\pi m} q B$$
