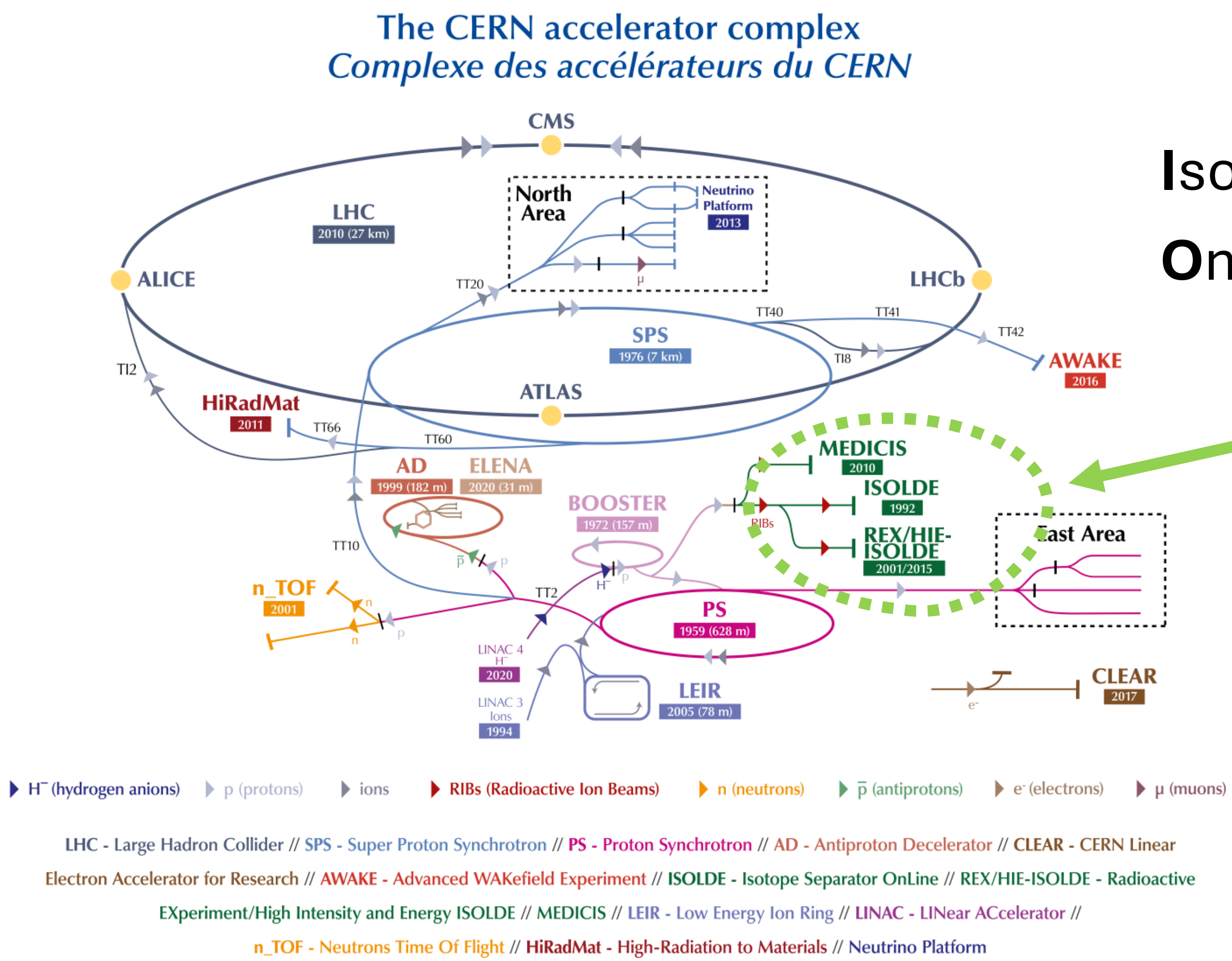
Recent technical developments and precision mass measurements at ISOLTRAP

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

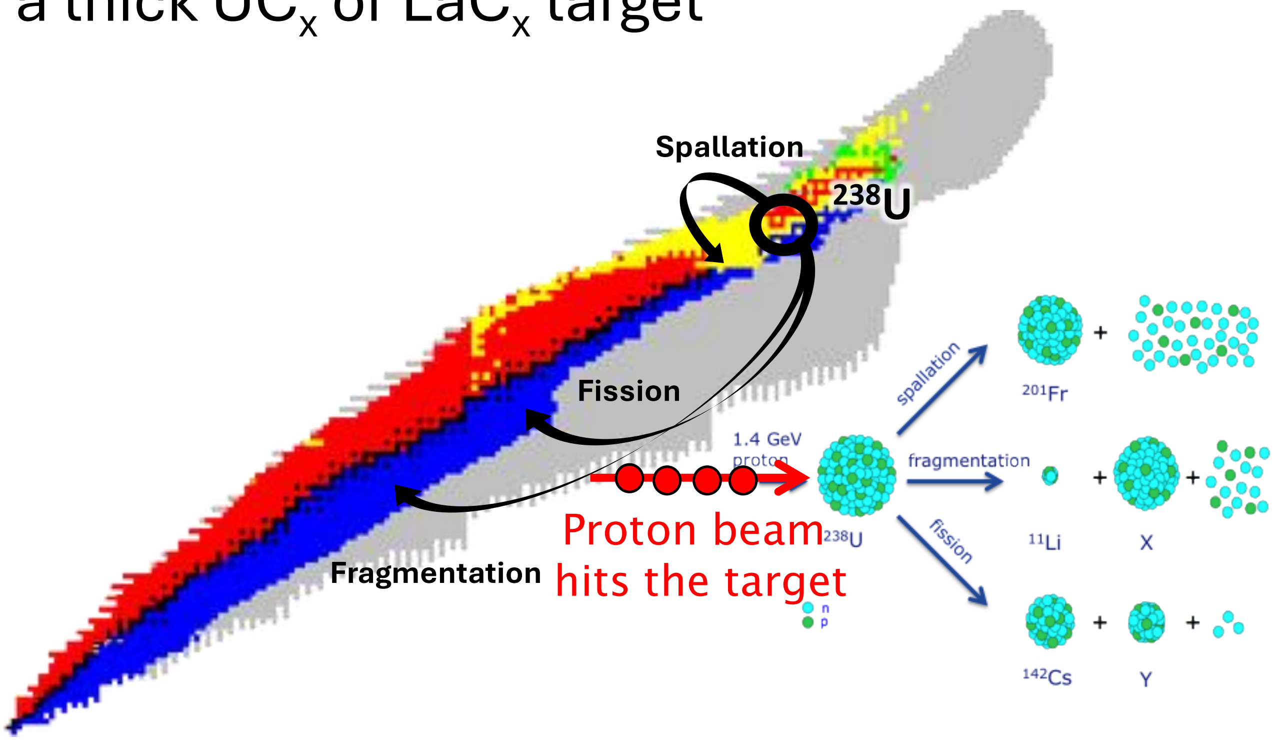


Isotope **S**eparator

On**L**ine **De**vice

ISOLDE facility – RIB production

- **I**sotope **S**eparator **O**n**L**ine **De**vice
- 1.4 (soon 1.7) GeV primary proton beam (2 μA) impacts onto a thick UC_x or LaC_x target



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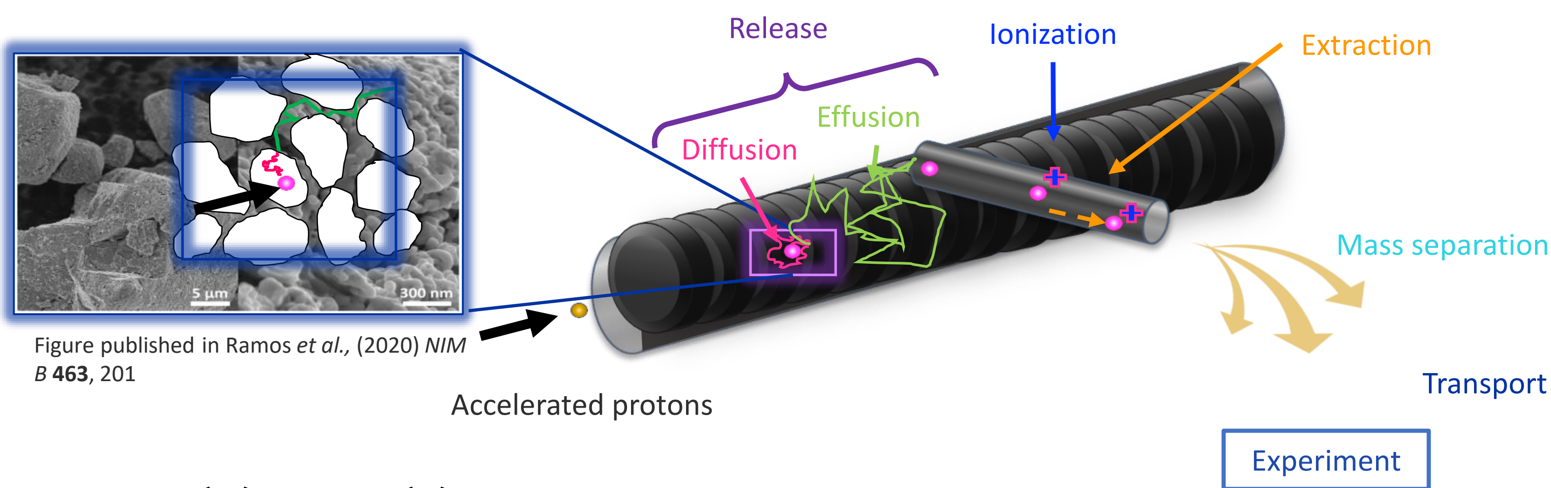


Figure published in Ramos *et al.*, (2020) *NIM B* **463**, 201

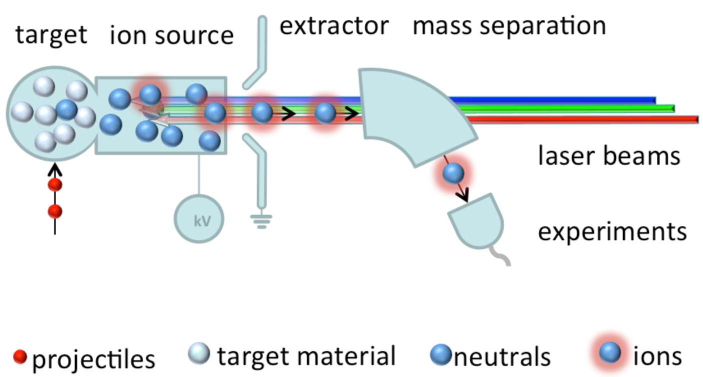
$$Y = Y_0(E)\, I_{\mathrm{p}}\, \varepsilon_{\mathrm{rel}}(\lambda)\, \varepsilon_{\mathrm{form}}\, \varepsilon_{\mathrm{irr}}\, \varepsilon_{\mathrm{ion}}$$

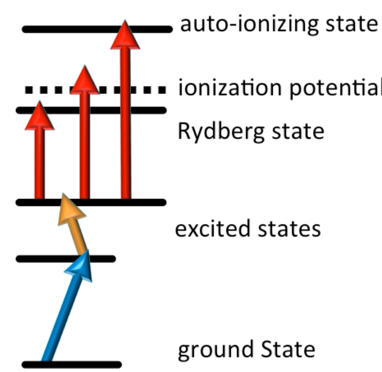
Figure courtesy of Valentina Berlin

MAX-PLANCK-INSTITUT
FÜR KERNPHYSIK

ISOLDE facility – RIB production

- **I**sotope **S**eparator **O**n**L**ine **De**vice
- 1.4 GeV primary proton beam (2 μA) 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)





https://rilis-web.web.cern.ch/

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 µA possible

Tailoring target microstructure

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

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

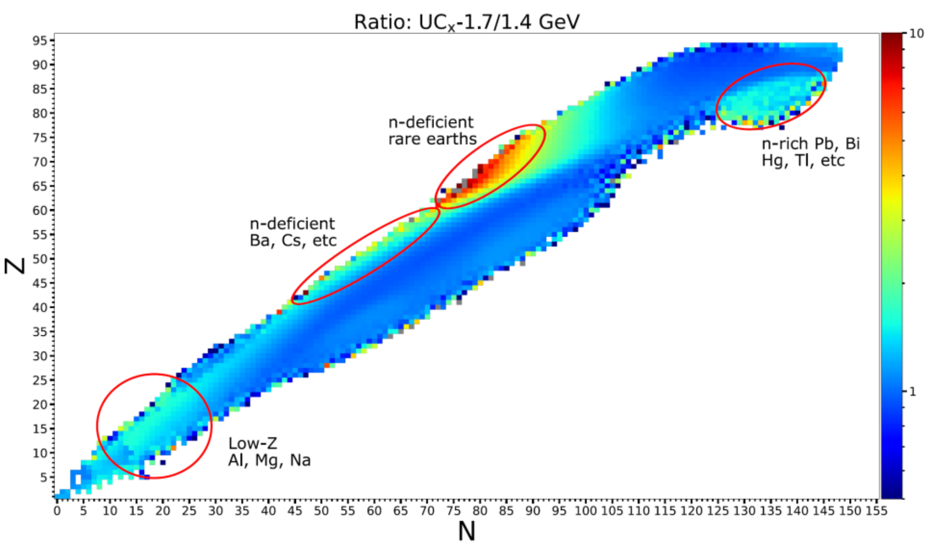


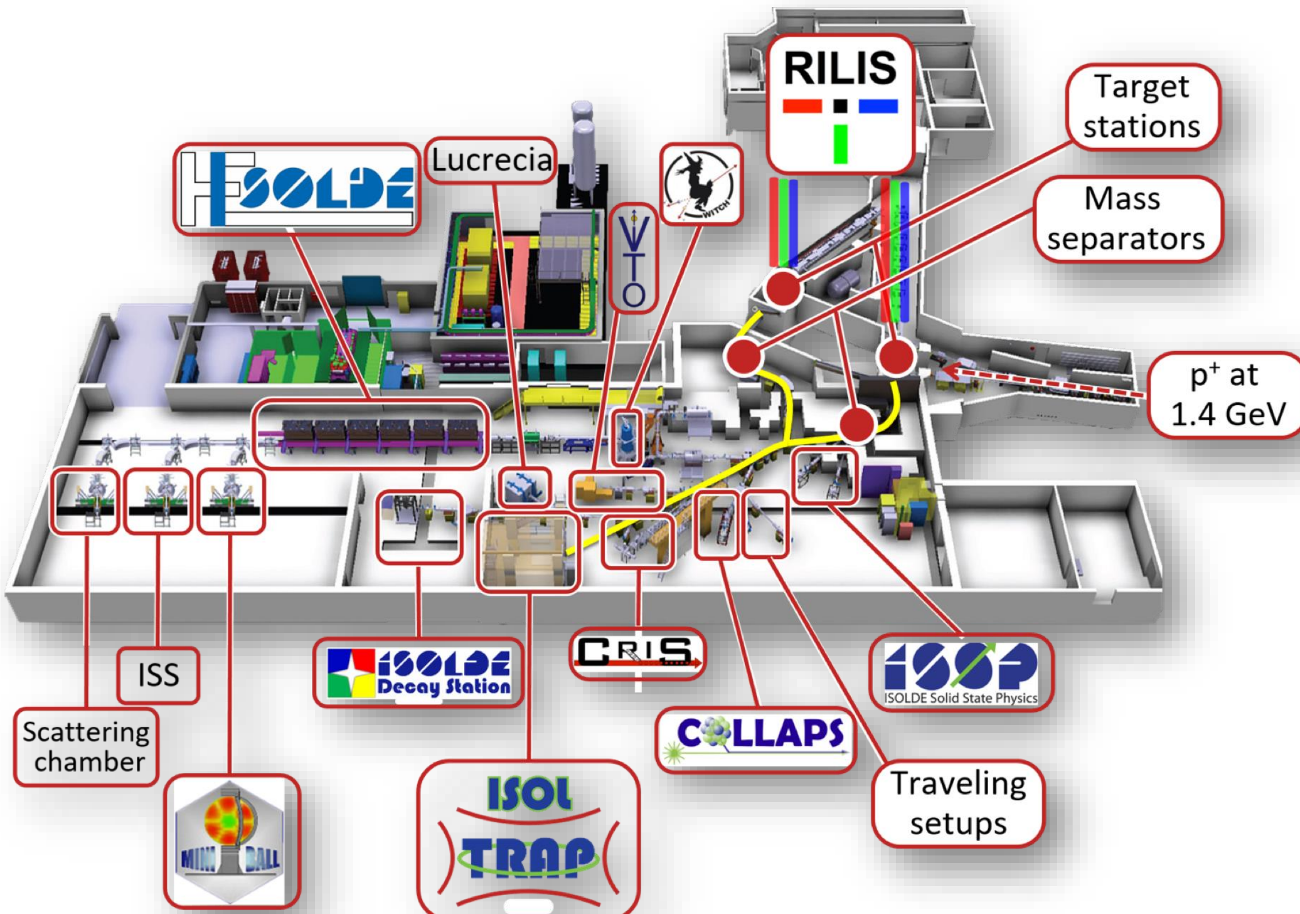
Figure courtesy of Simon Stegemann

Figure courtesy of Valentina Berlin

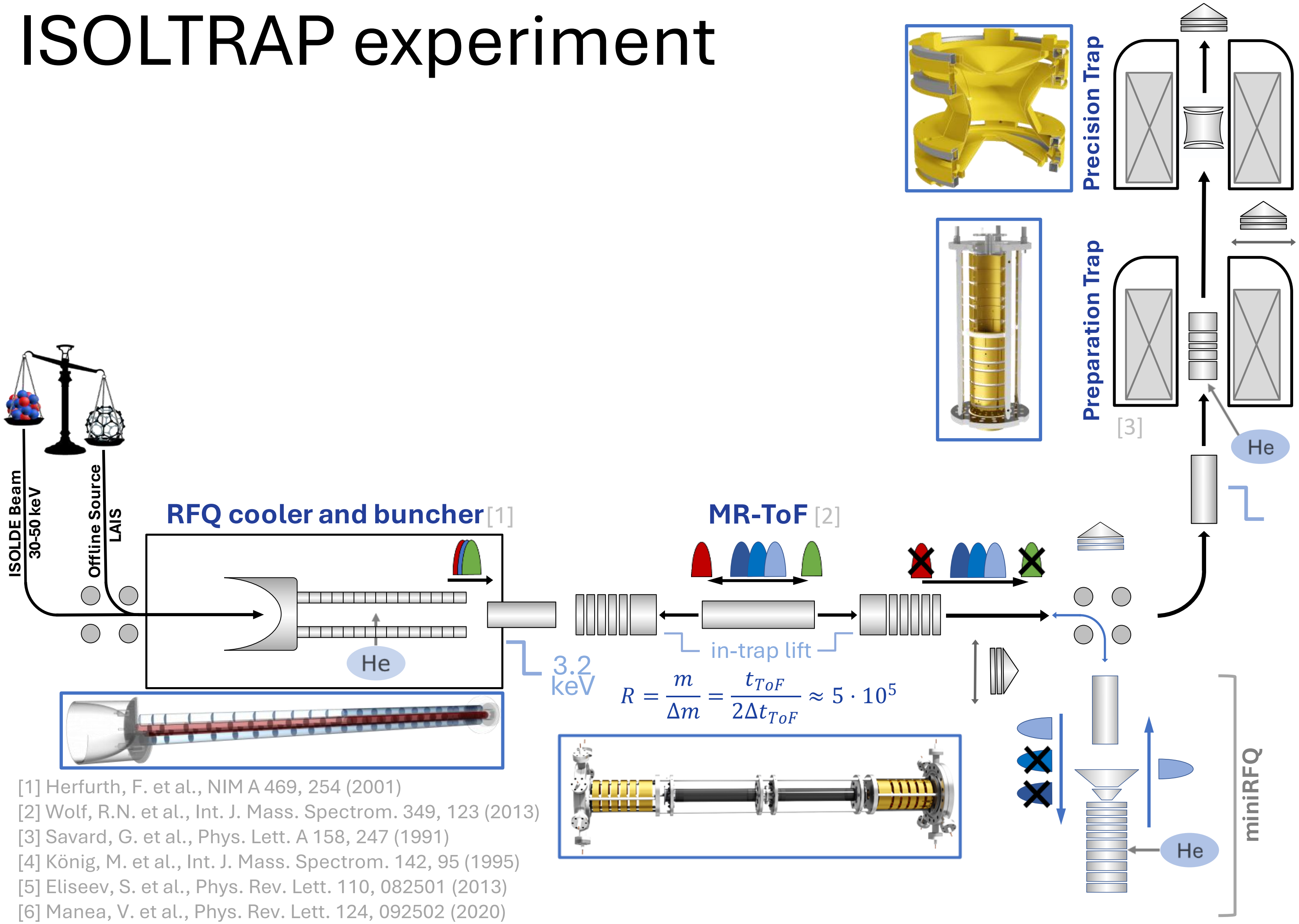
ISOLDE facility – RIB production

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

ISOLDE facility - overview



ISOLTRAP experiment

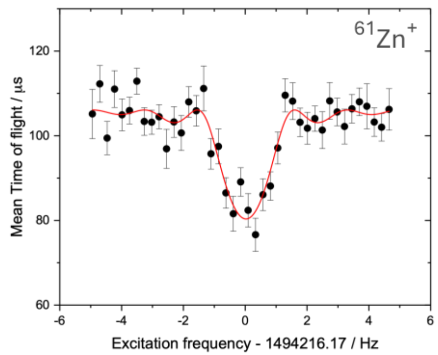


$$R = \frac{m}{\Delta m} = \frac{t_{ToF}}{2\Delta t_{ToF}} \approx 5 \cdot 10^5$$

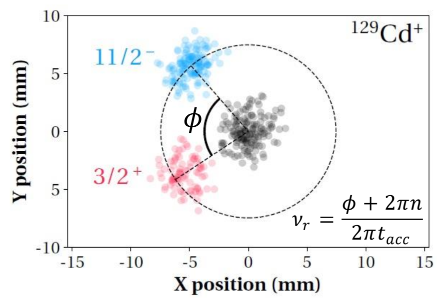
[1] Herfurth, F. et al., NIM A 469, 254 (2001)
[2] Wolf, R.N. et al., Int. J. Mass. Spectrom. 349, 123 (2013)
[3] Savard, G. et al., Phys. Lett. A 158, 247 (1991)
[4] König, M. et al., Int. J. Mass. Spectrom. 142, 95 (1995)
[5] Eliseev, S. et al., Phys. Rev. Lett. 110, 082501 (2013)
[6] Manea, V. et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

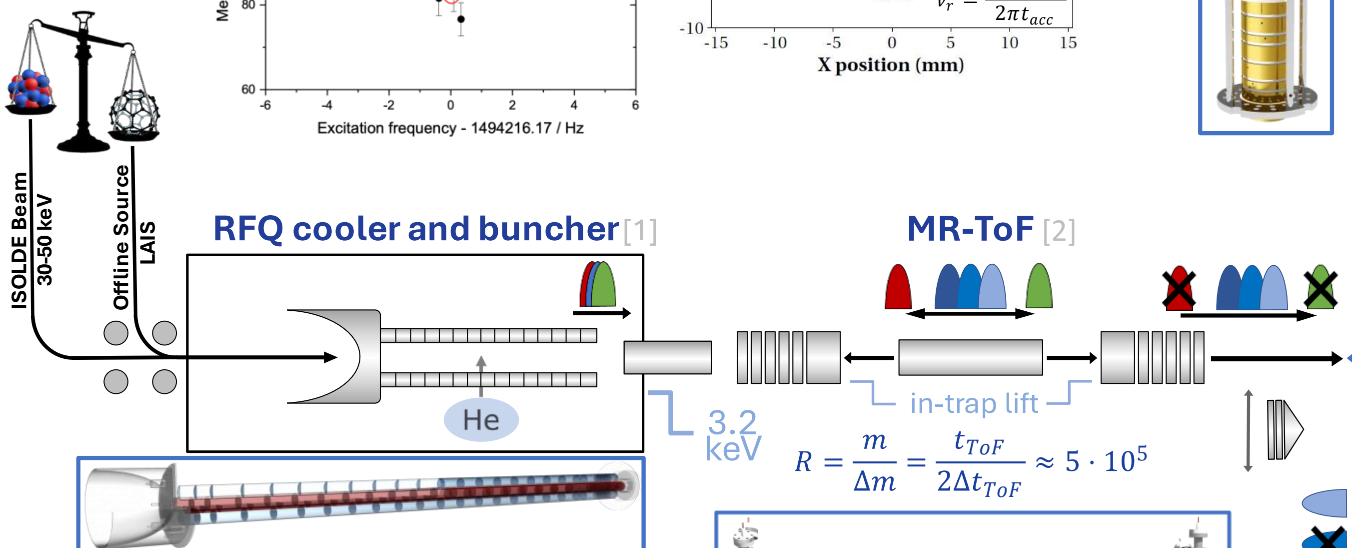
ISOLTRAP experiment

ToF-ICR [4]



PI-ICR [5,6]





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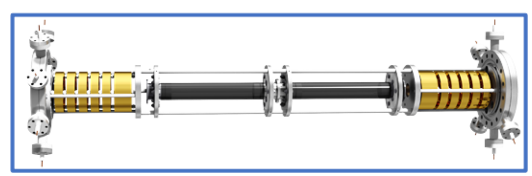

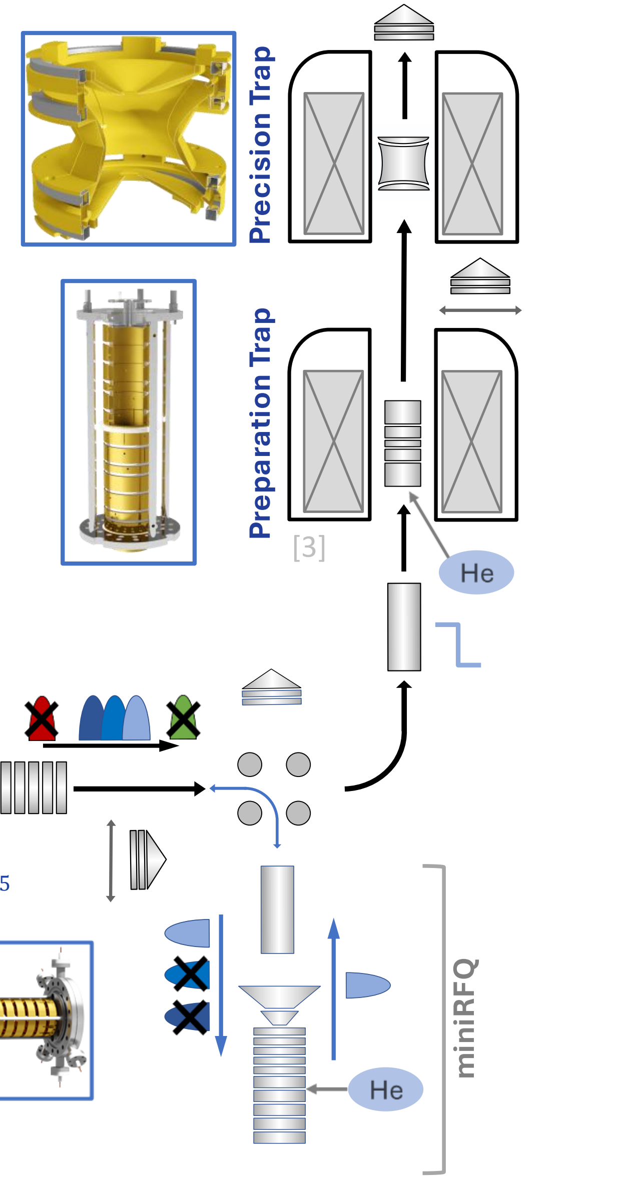

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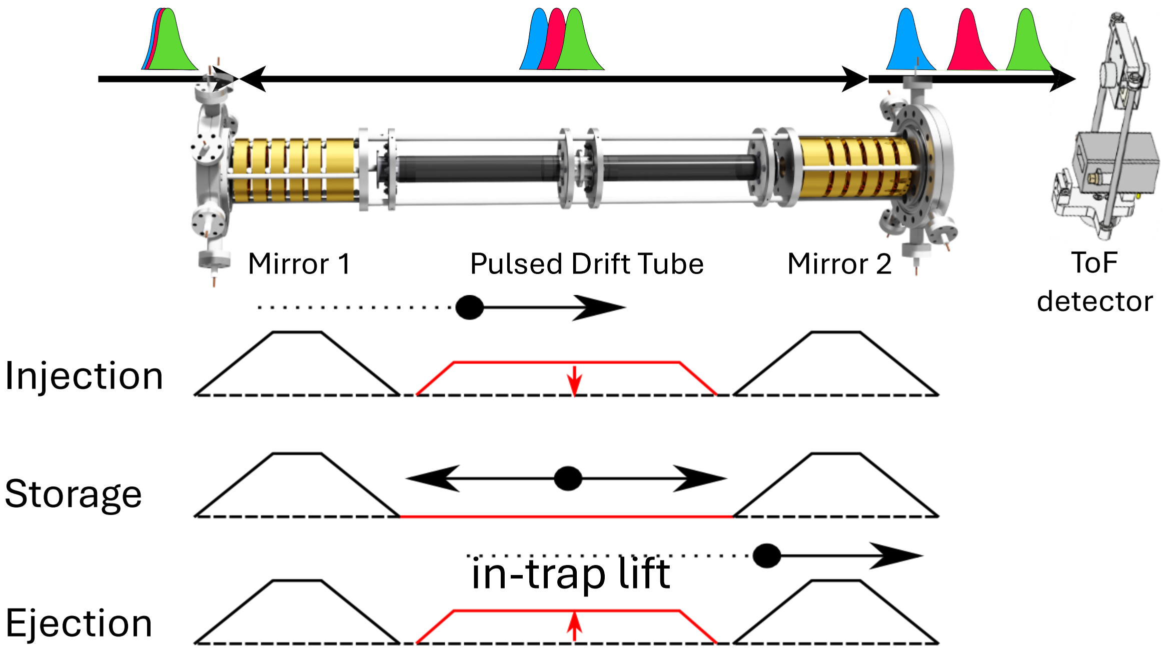
Multi-Reflection Time-of-Flight MS



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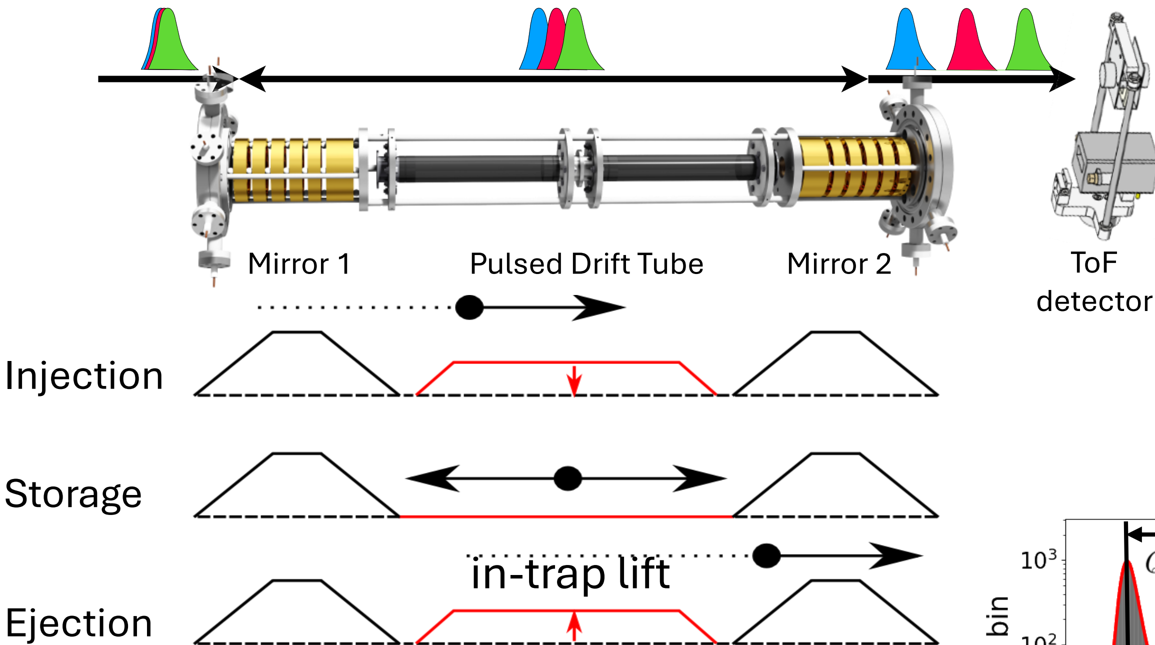
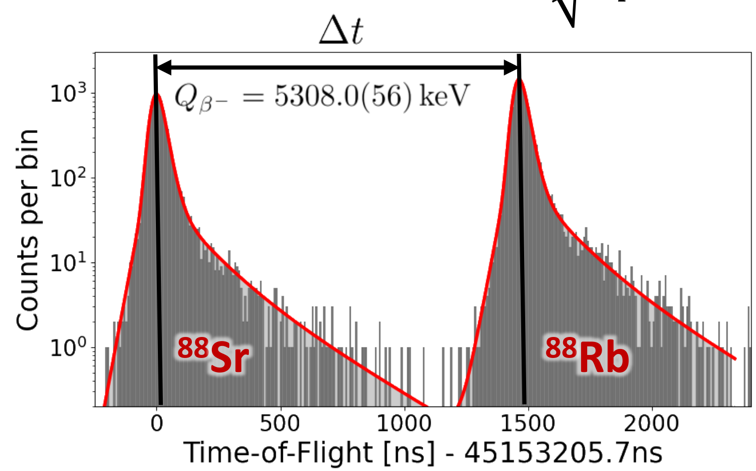


$$t_0 = A\sqrt{\frac{m_0}{q}} + B$$



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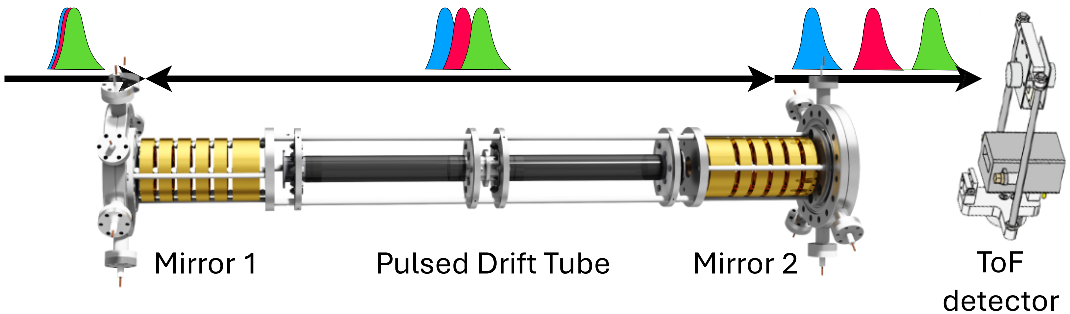

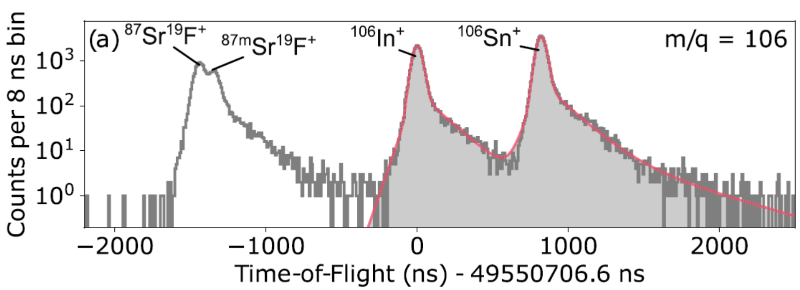

[1] Nies, L. et al., Phys. Rev. C 111, 014315 (2025)

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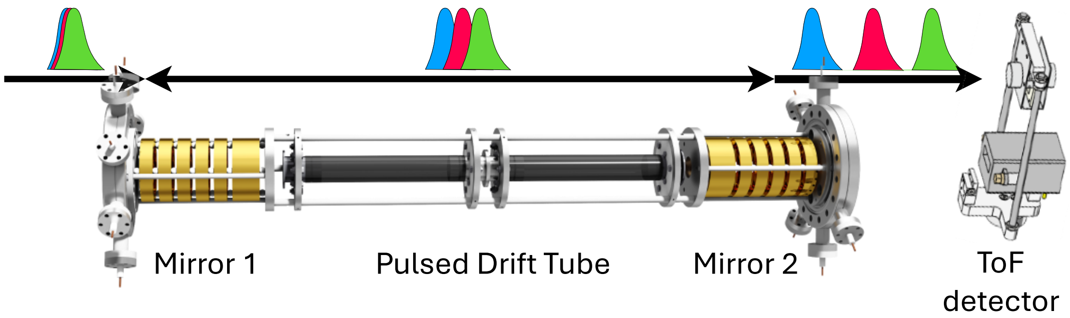

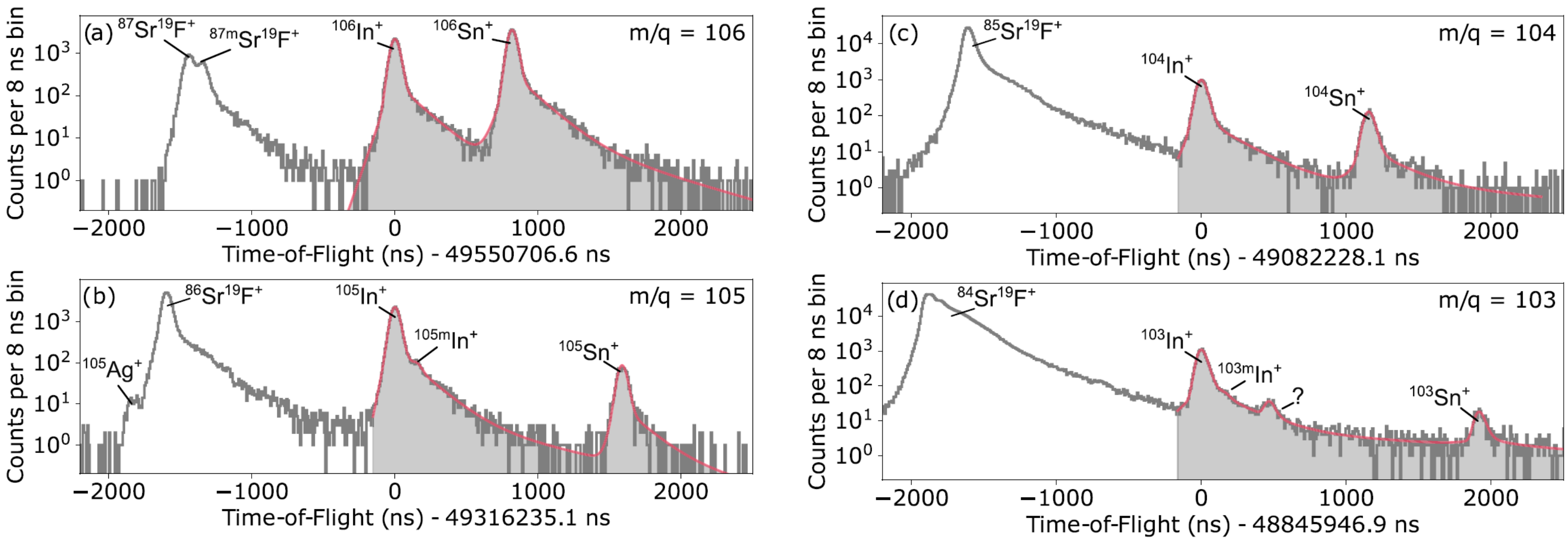

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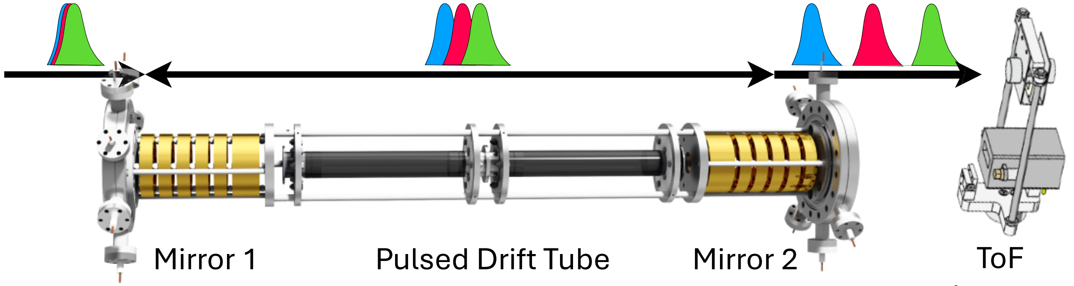
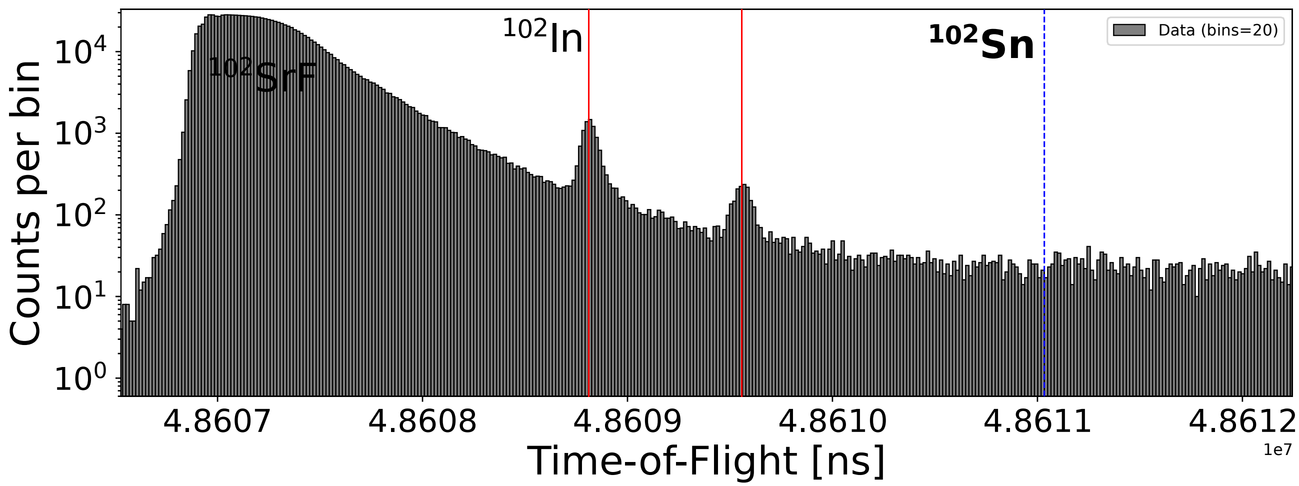
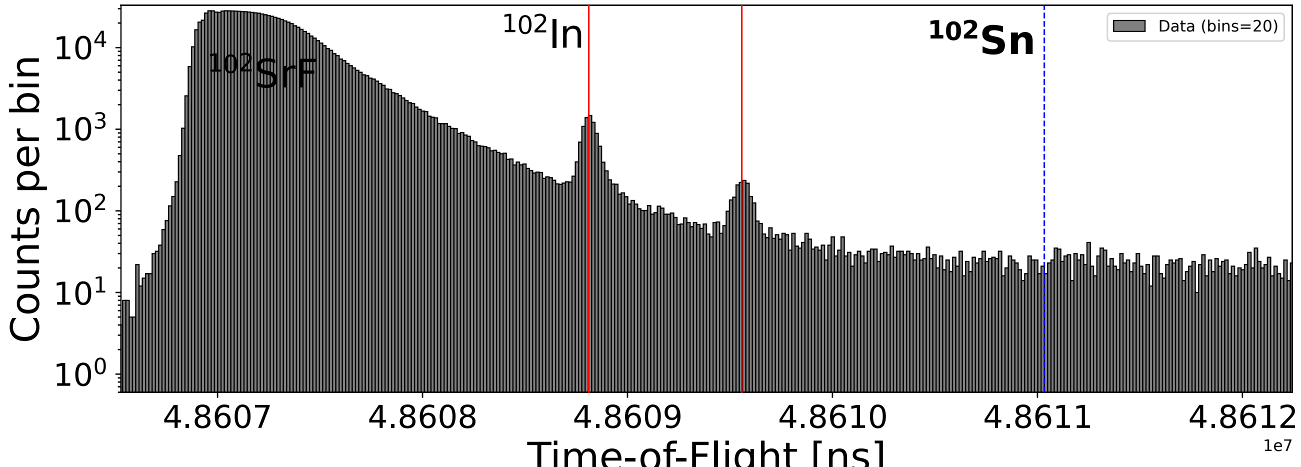




[1] Nies, L. et al., Phys. Rev. C 111, 014315 (2025)

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)
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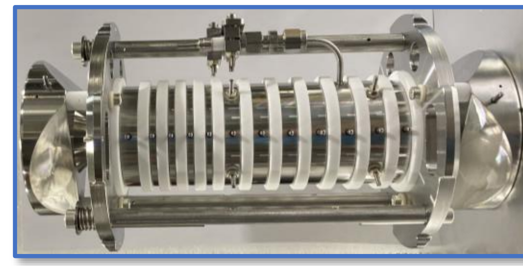

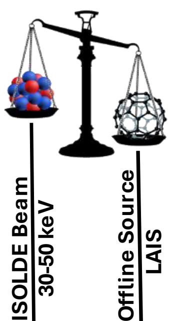

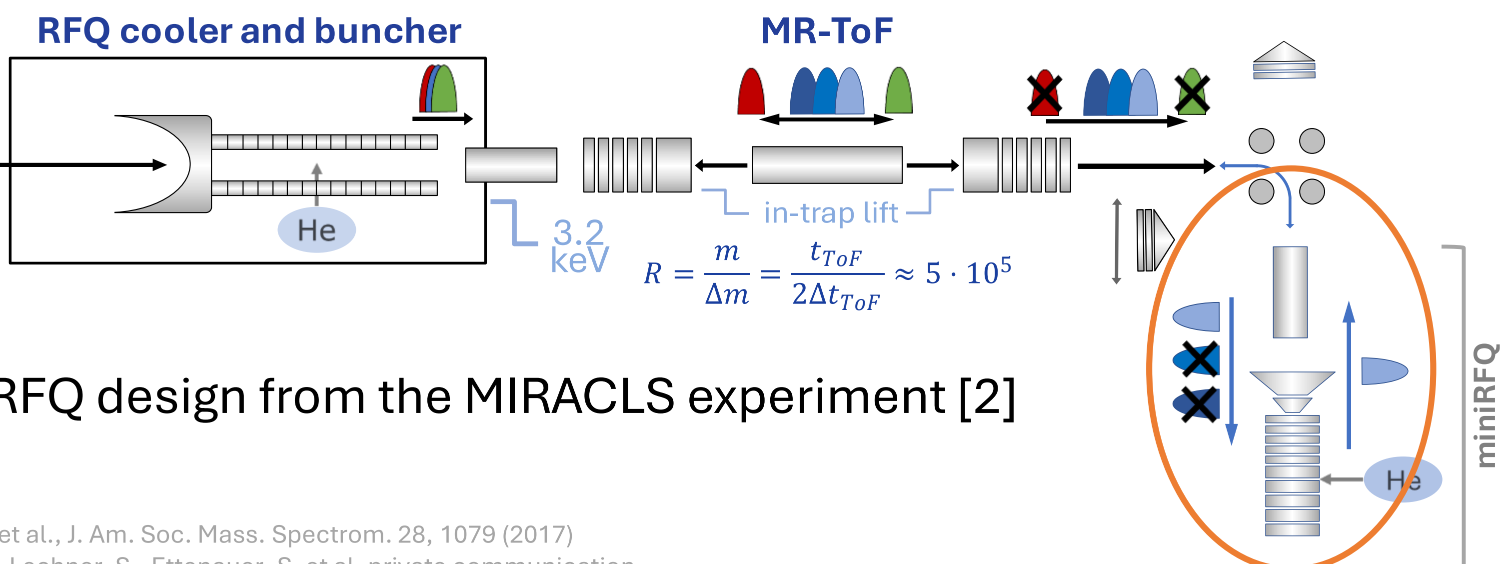

- miniRFQ design from the MIRACLS experiment [2]

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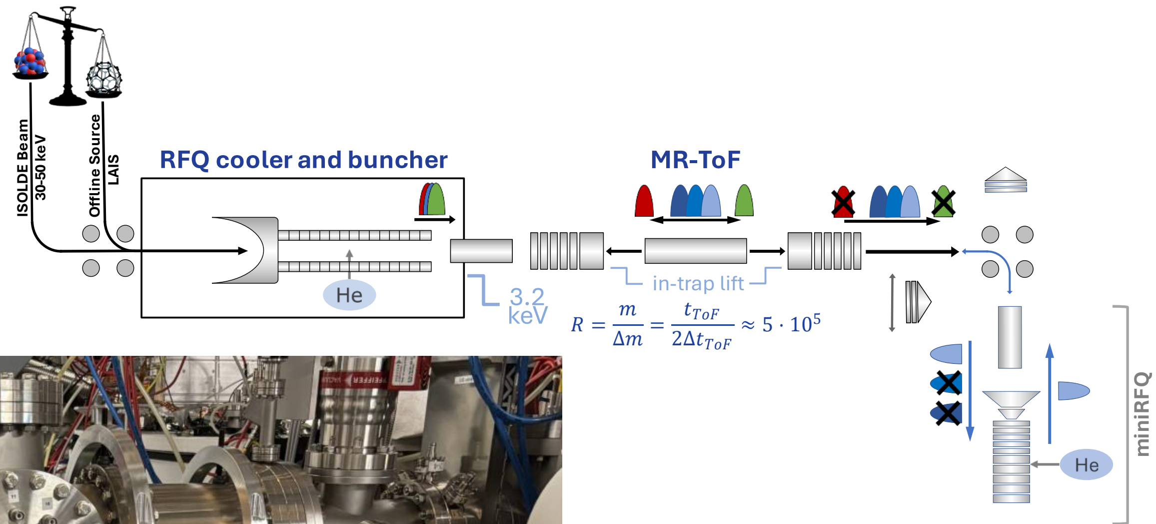

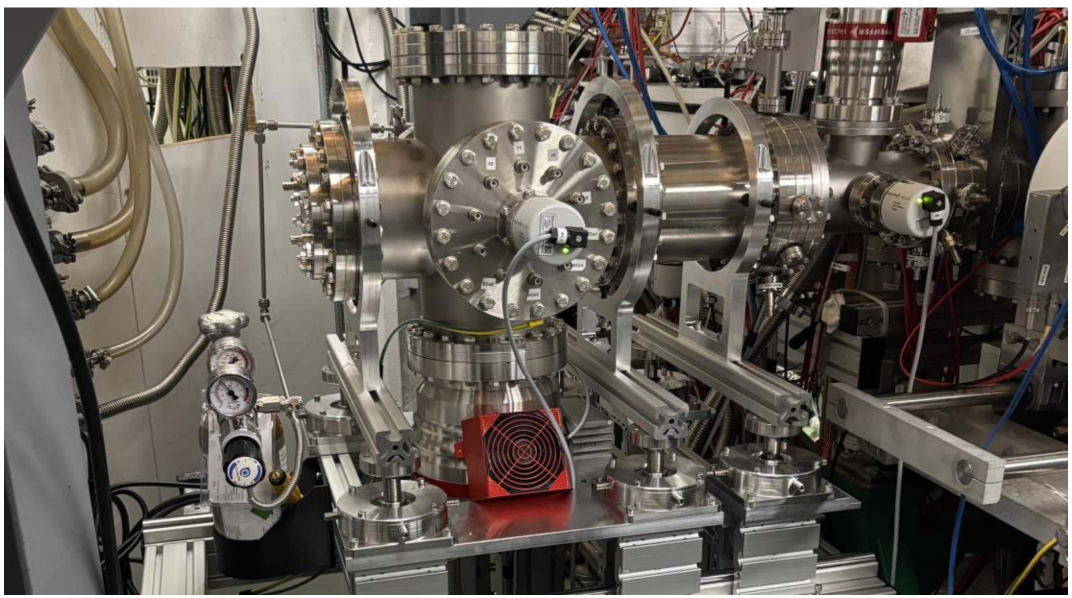

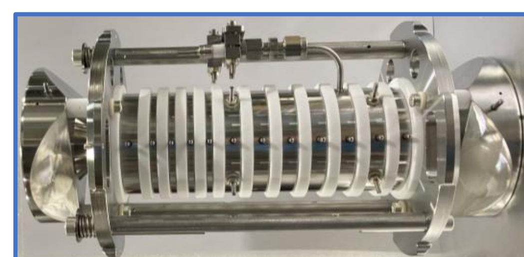

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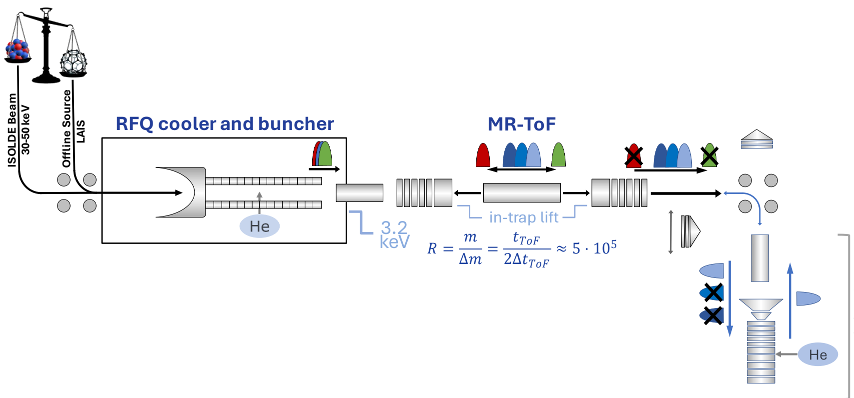
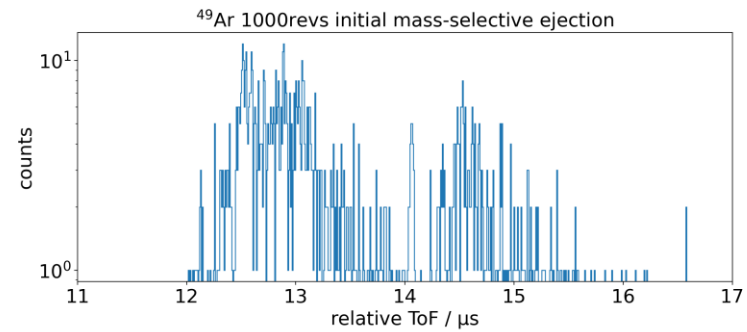
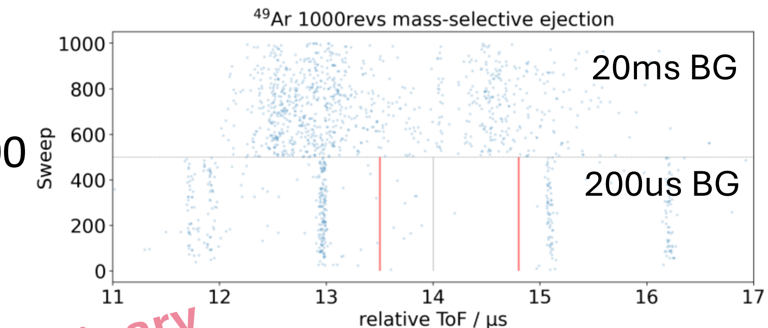


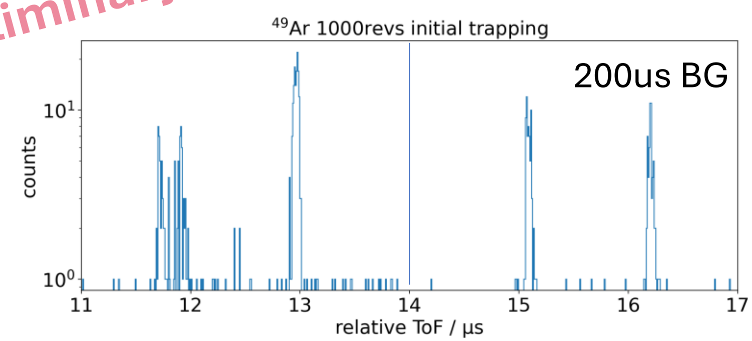
x100

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





Preliminary



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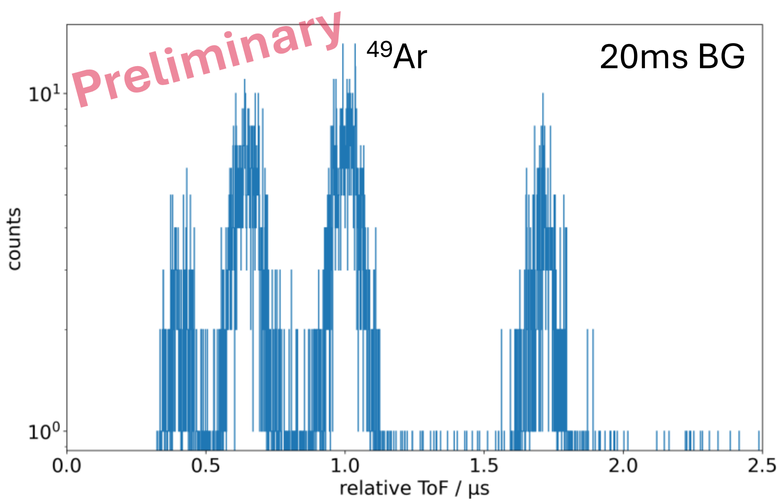

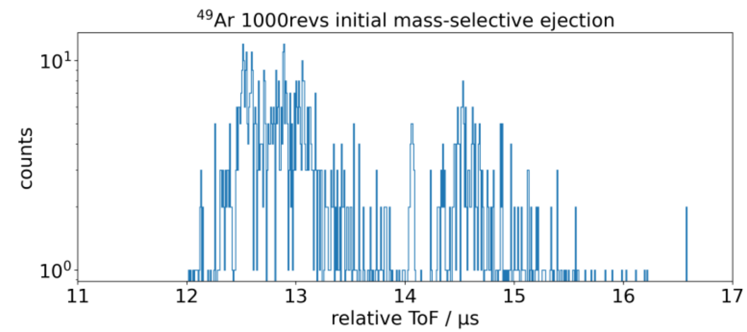

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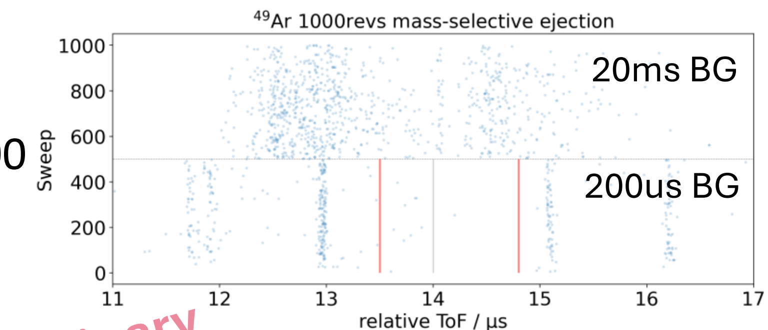

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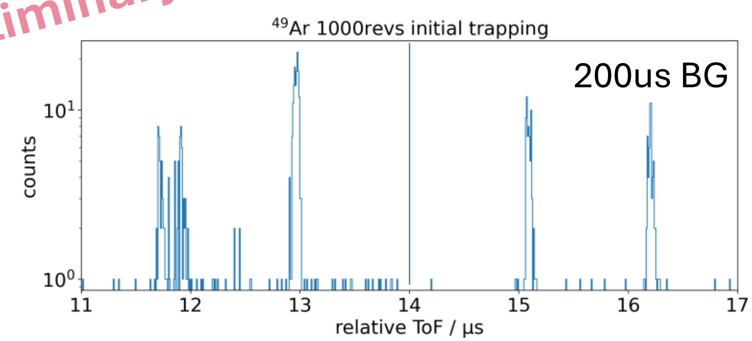
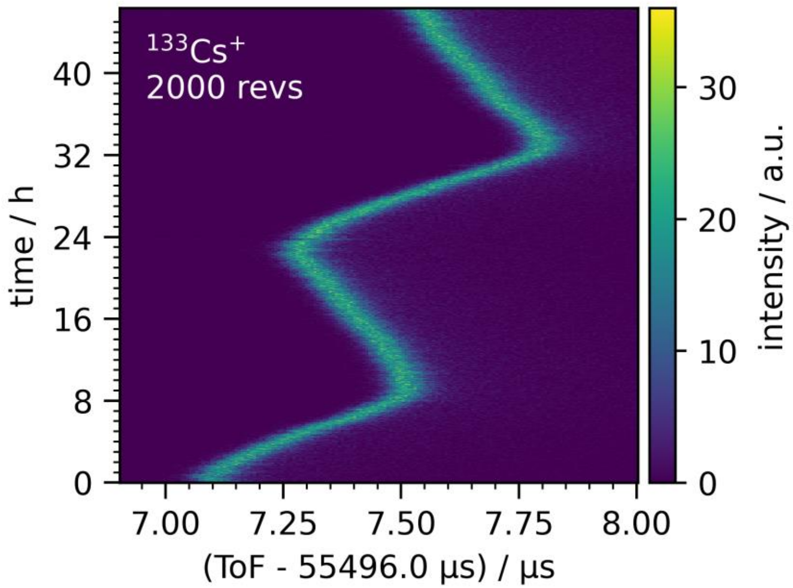


- 50% trapping efficiency in MR-ToF
- Mass separation power ~8400
- 50% efficiency for re-bunching in miniRFQ
- 20% re-trapping efficiency demonstrated with 2000 rev initial separation and 2000 revs measurement

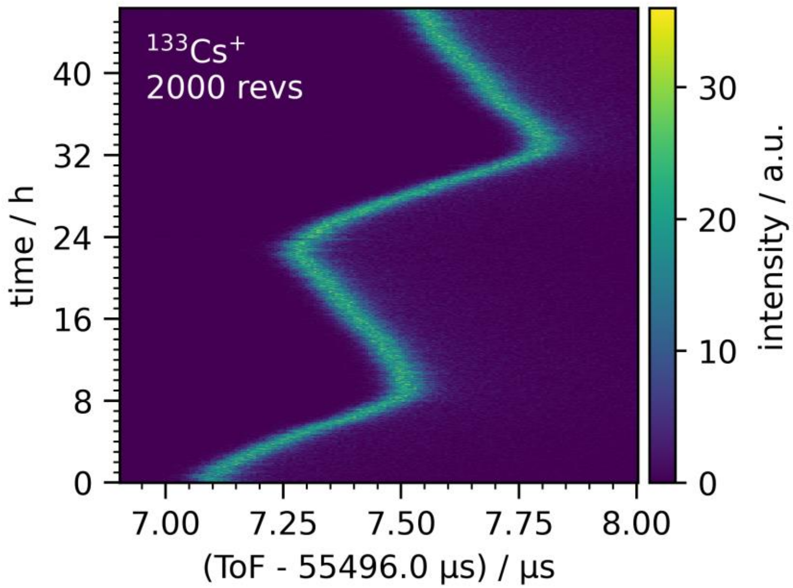
MR-ToF MS temperature stabilization



- 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



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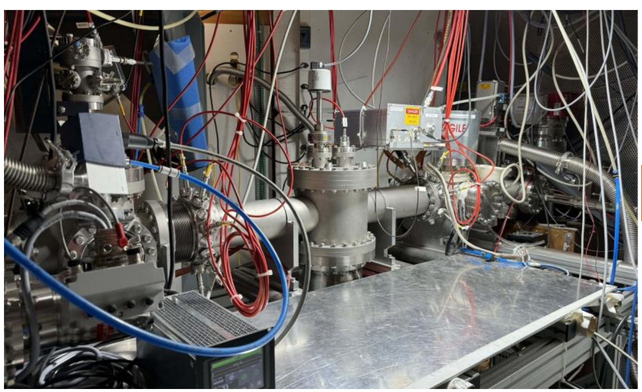
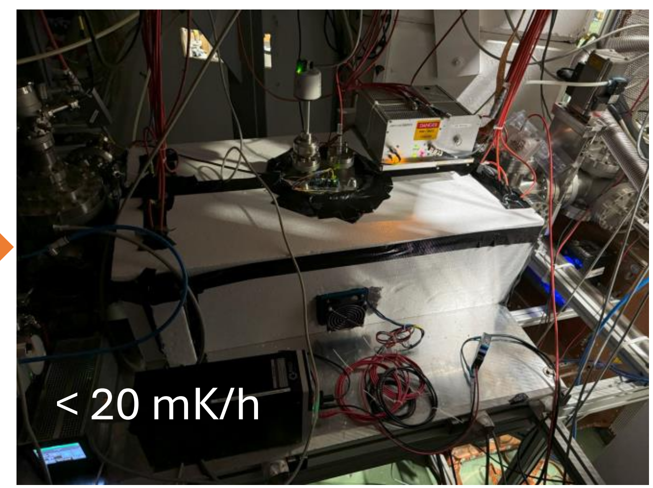


T-Stabilization



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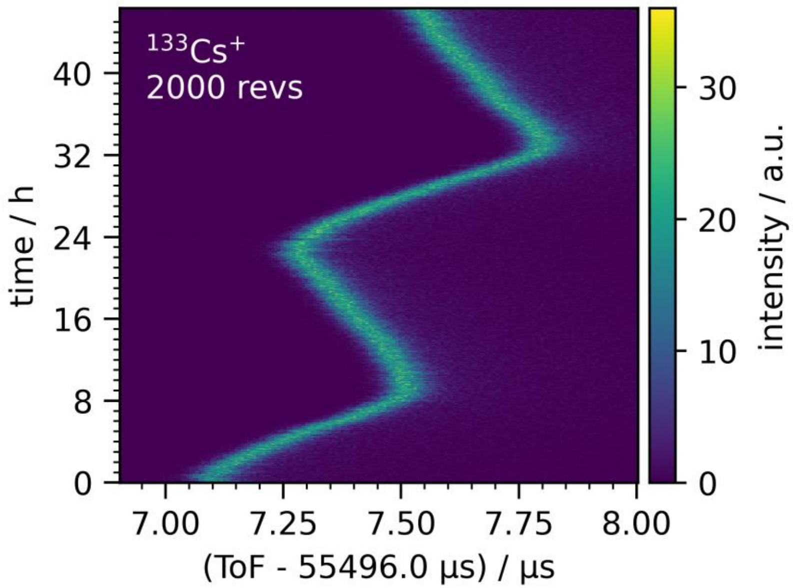
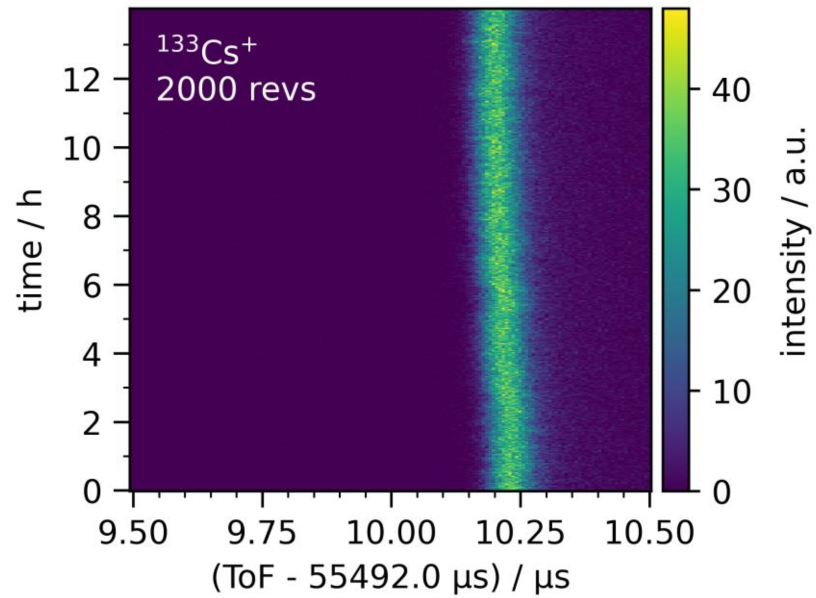
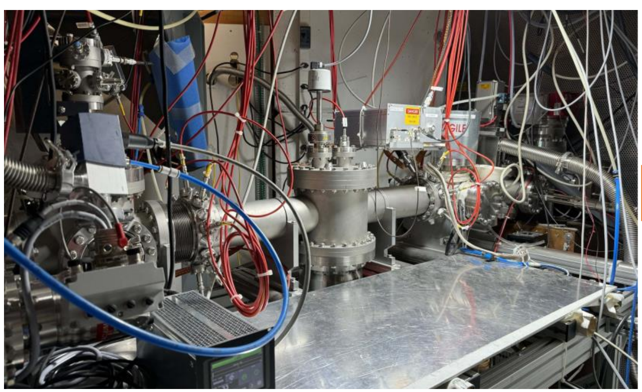
MR-ToF MS temperature stabilization







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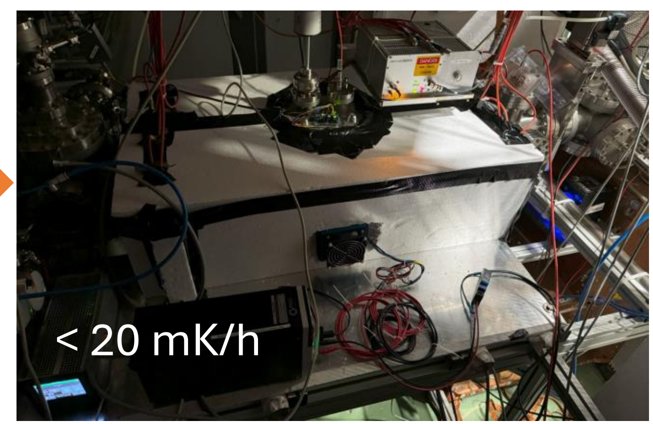

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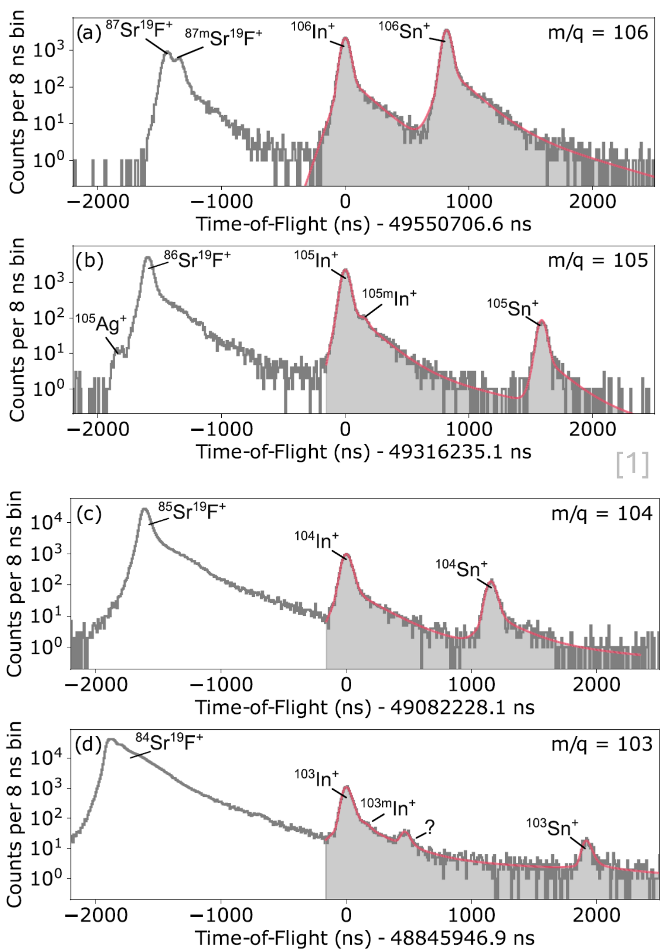
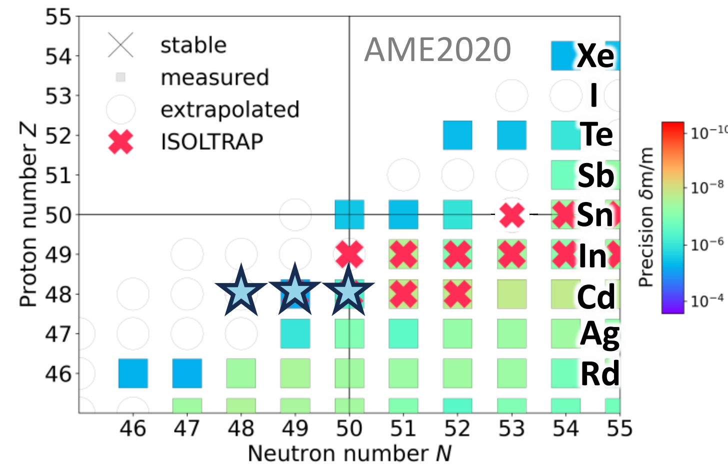
Neutron-deficient Cadmium





- 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)

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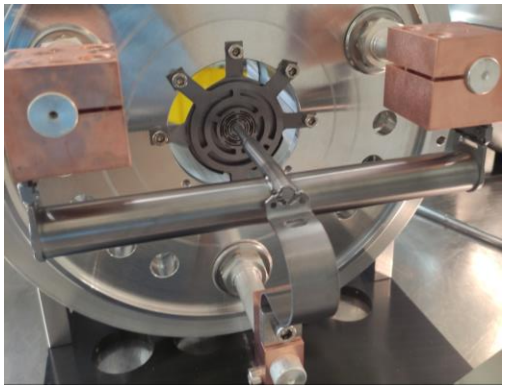
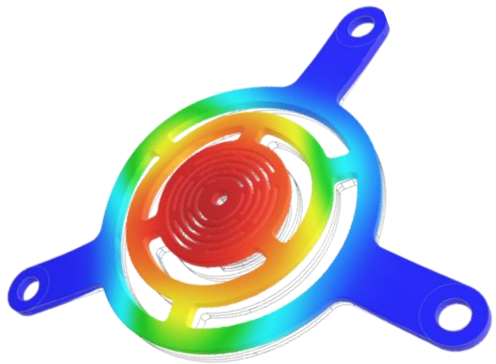
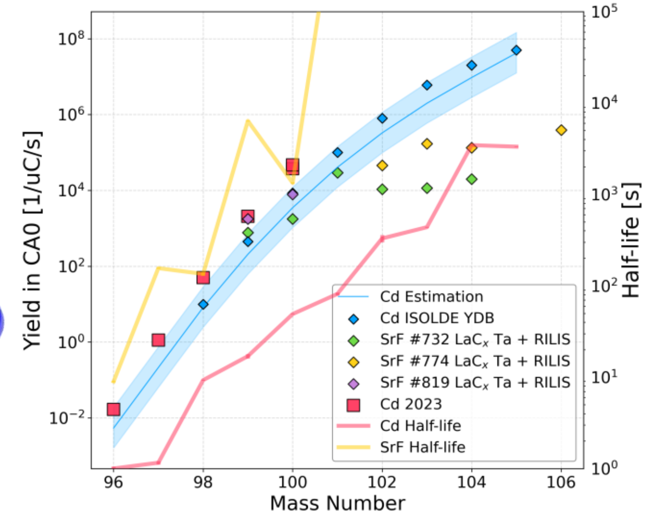
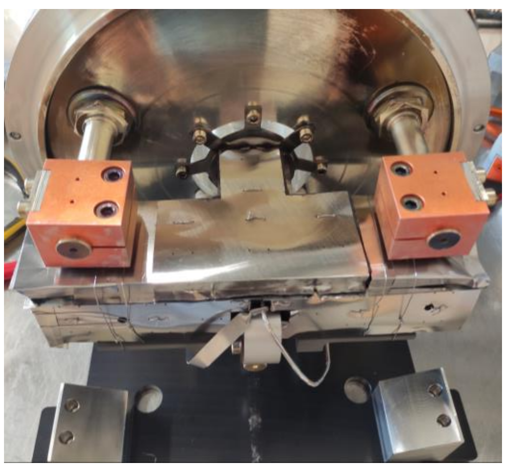


Standard target







Impoved heat-shielding

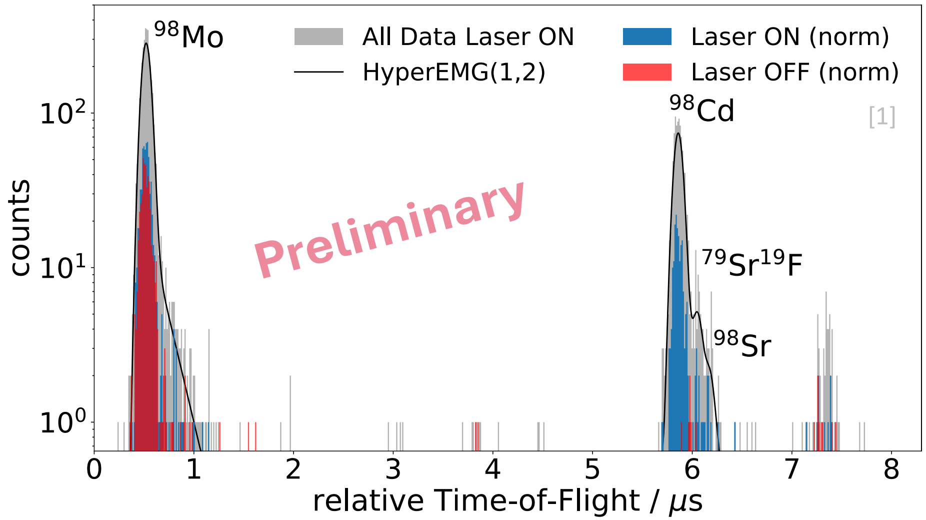
Prototype LaC_x target (tested in 2023) [1]:

- Improved heat-shielding
- „Spider-web" ion source
- Improved ISOLTRAP efficiency: 3 %

=> Factor 5 improvement in yield

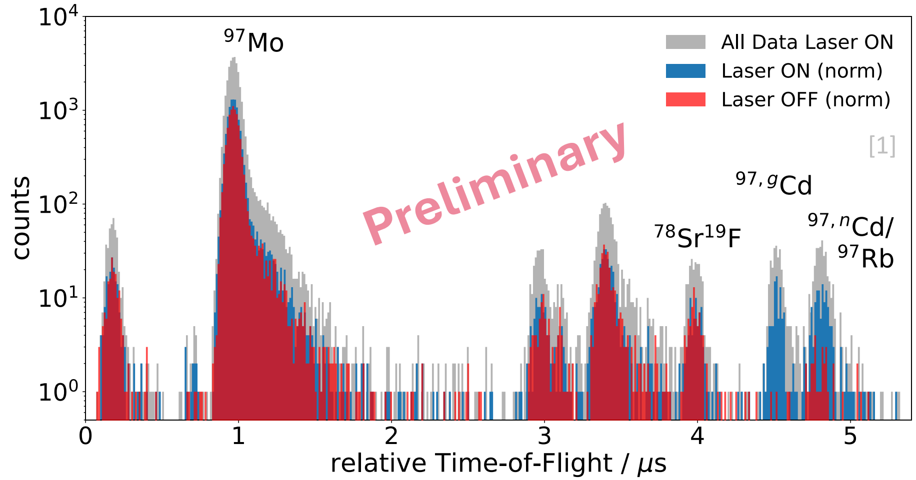
[1] Koliatos, A., TISD-team

Neutron-deficient Cadmium



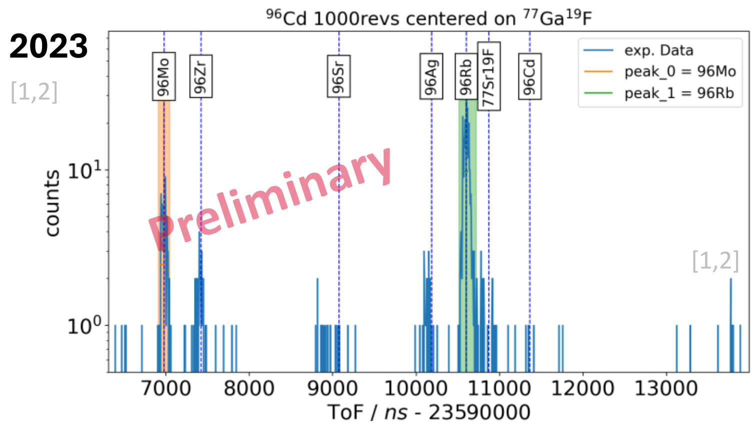
2023 (prototype target):

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



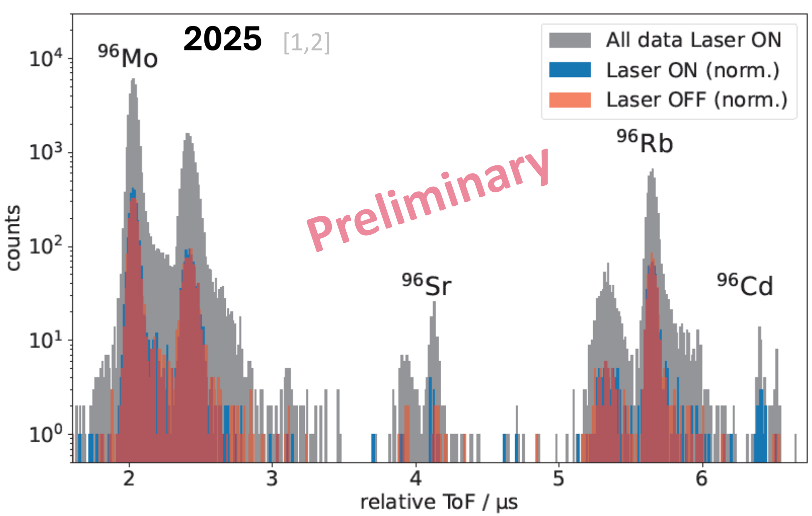
[1] Lange, D. et al., in preparation

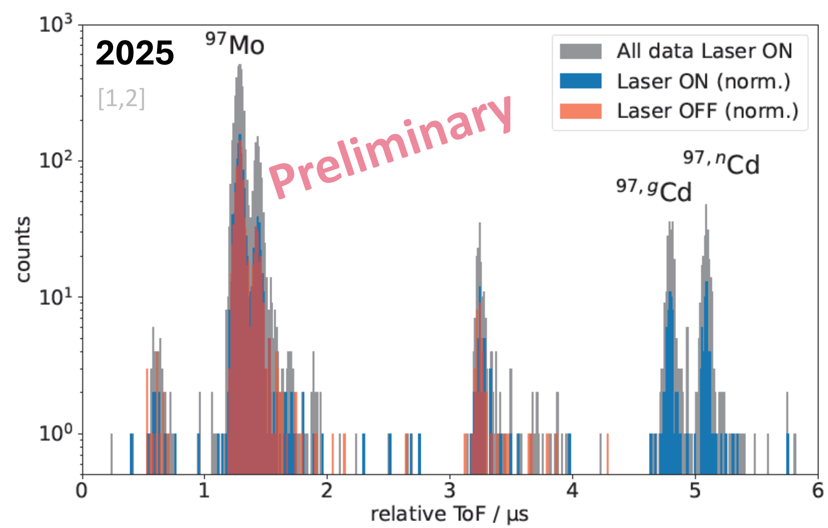
Neutron-deficient Cadmium



2025 run:

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



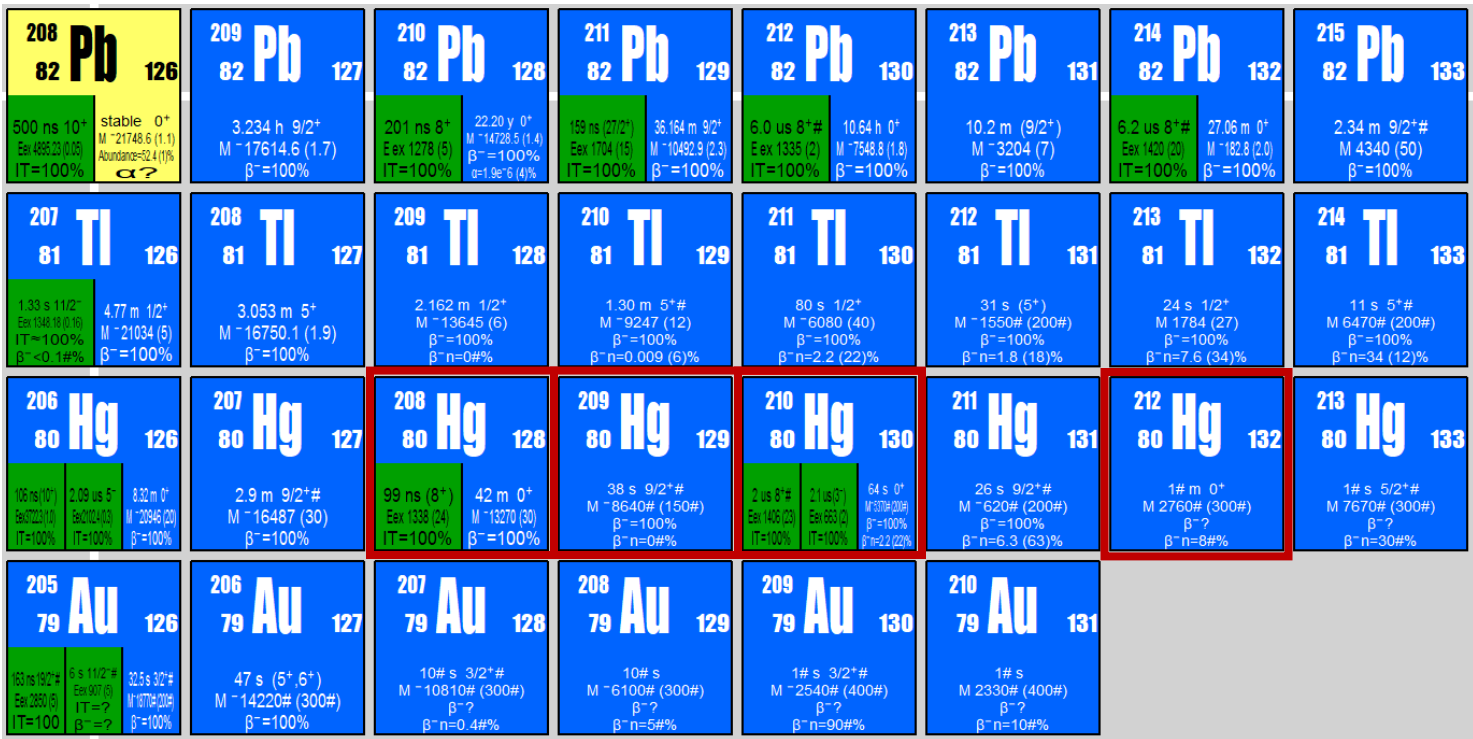


[1] Lange, D. et al., in preparation
[2] Mougeot, M. et al., INTC-P-682

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

Neutron-rich Mercury

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

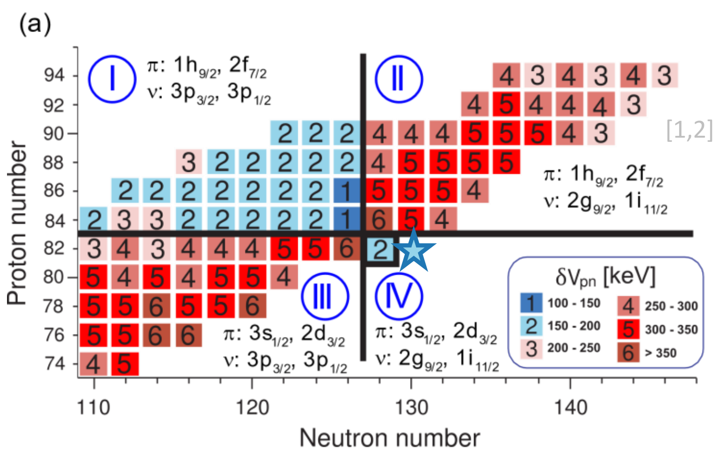


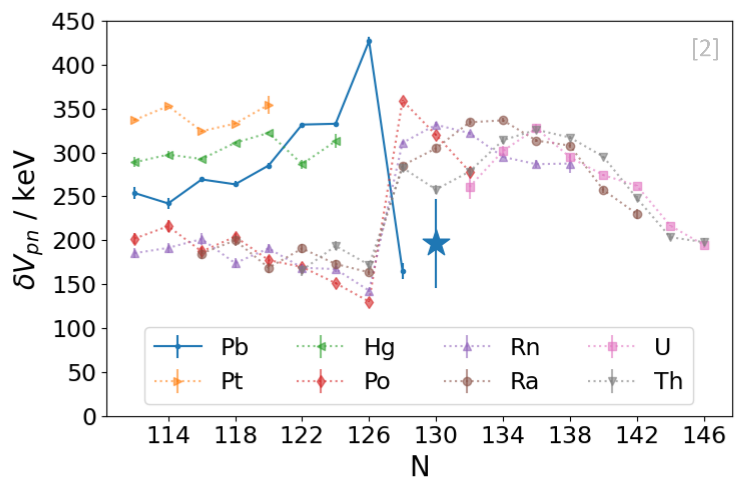
[1] Chen, L. et al., Phys. Rev. Lett. 102, 122503 (2009)
[2] Cubiss, J., Lange, D. et al., INTC-P-698

Neutron-rich Mercury

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

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

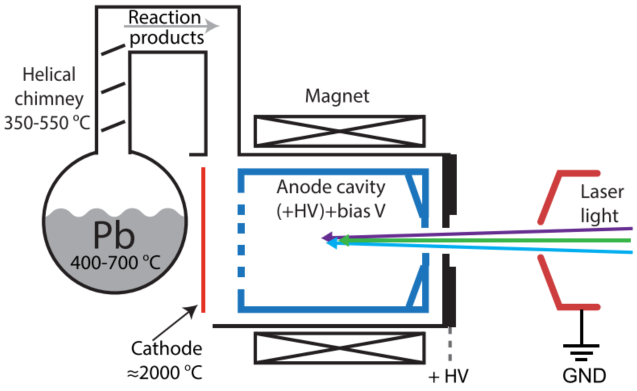


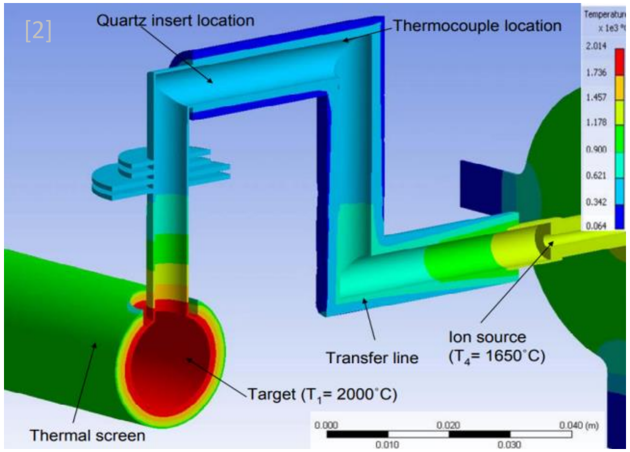


[1] Chen, L. et al., Phys. Rev. Lett. 102, 122503 (2009)
[2] Cubiss, J., Lange, D. et al., INTC-P-698

Neutron-rich Mercury

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

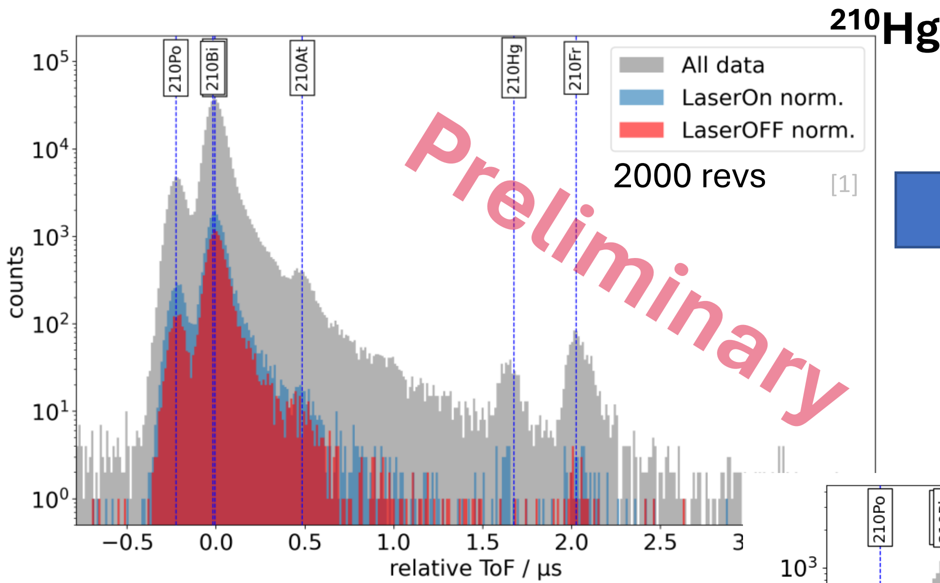




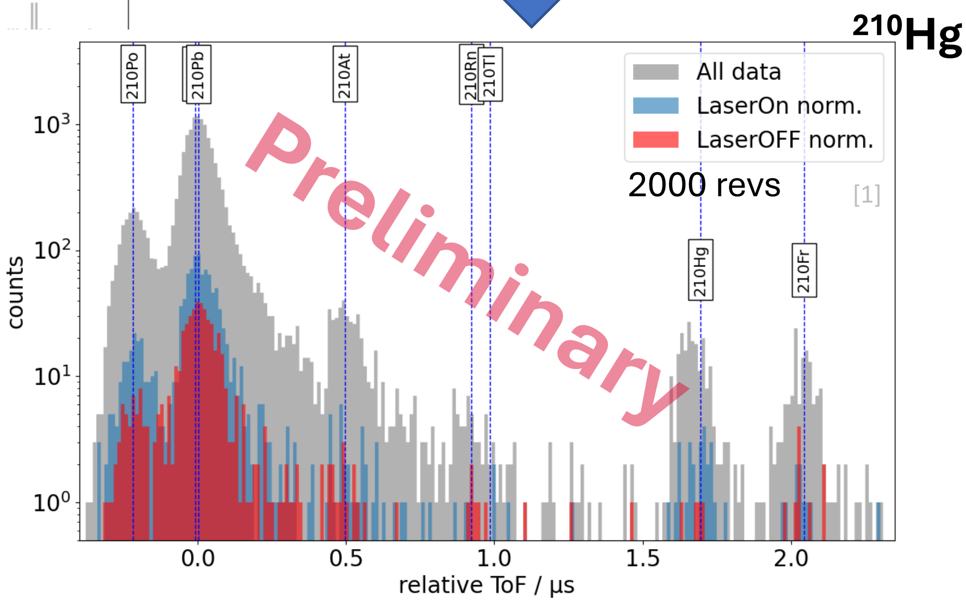
- Lower neg. adsorption enthalpy of Hg vs. Fr: Hg passes cold quartz transfer line

[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

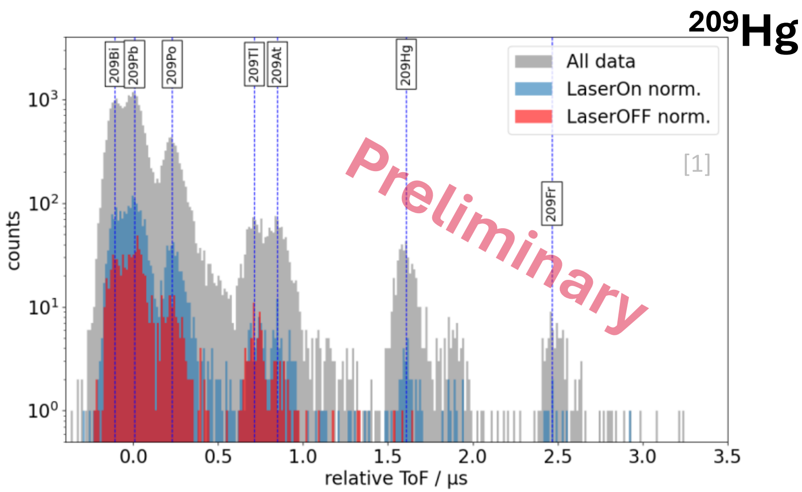


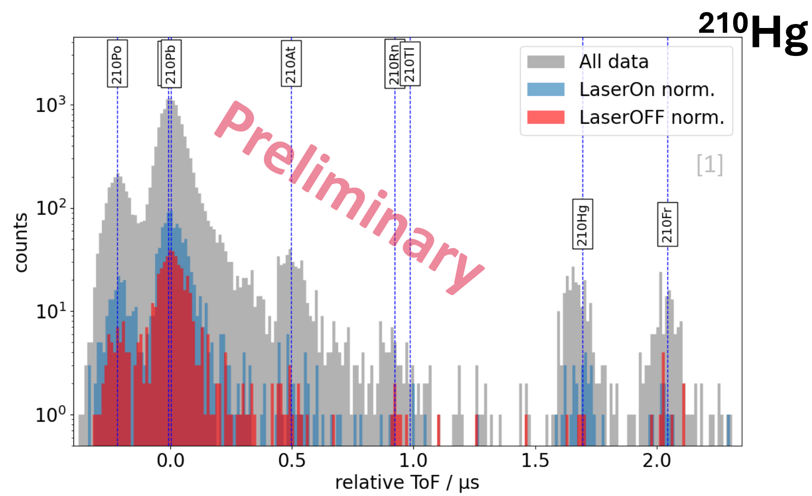
Reduction of target and line temperature



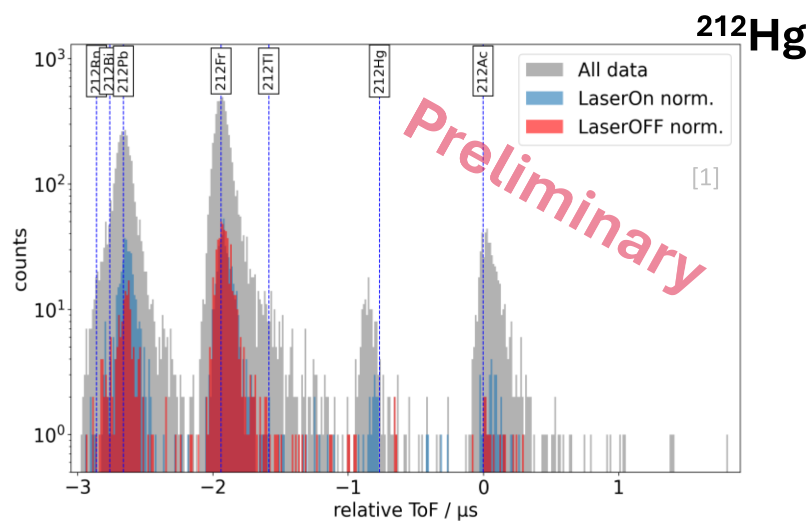
[1] Lange, D. et al., in preparation

Neutron-rich Mercury



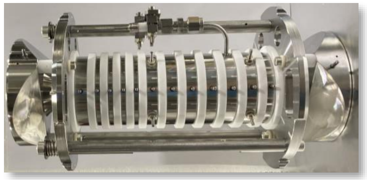


- First direct mass measurements of $^{209, 210, 212}$Hg

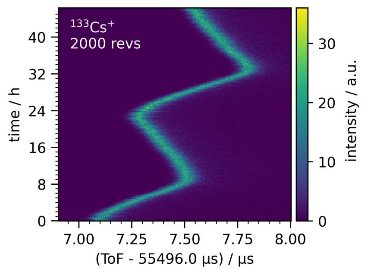


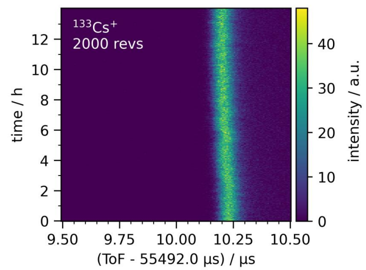
[1] Lange, D. et al., in preparation

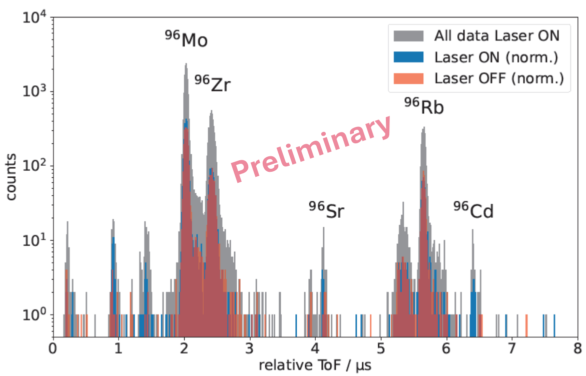
Summary

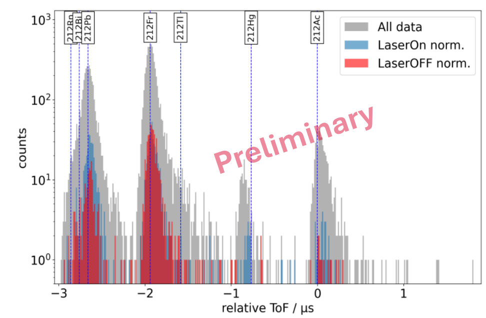


- ISOLDE & ISOLTRAP
- Mass-selective re-trapping in miniRFQ
- MR-ToF temperature stabilization
- Neutron-deficient Cd
- Neutron-rich Hg









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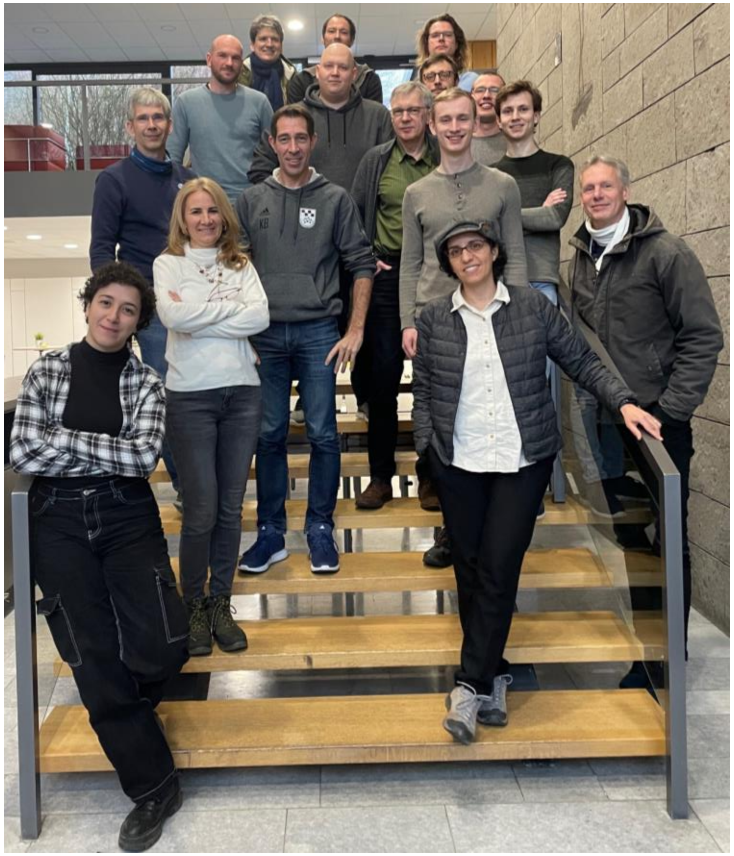
S. Naimi, L. Nies,
Ch. Schweiger, L. Schweikhard,
F. Wienholtz, *et al*.
for the ISOLTRAP collaboration

ISOLDE OPERATIONS TEAM
RILIS TEAM
TARGET TEAM
RP TEAM



Federal Ministry of Education and Research

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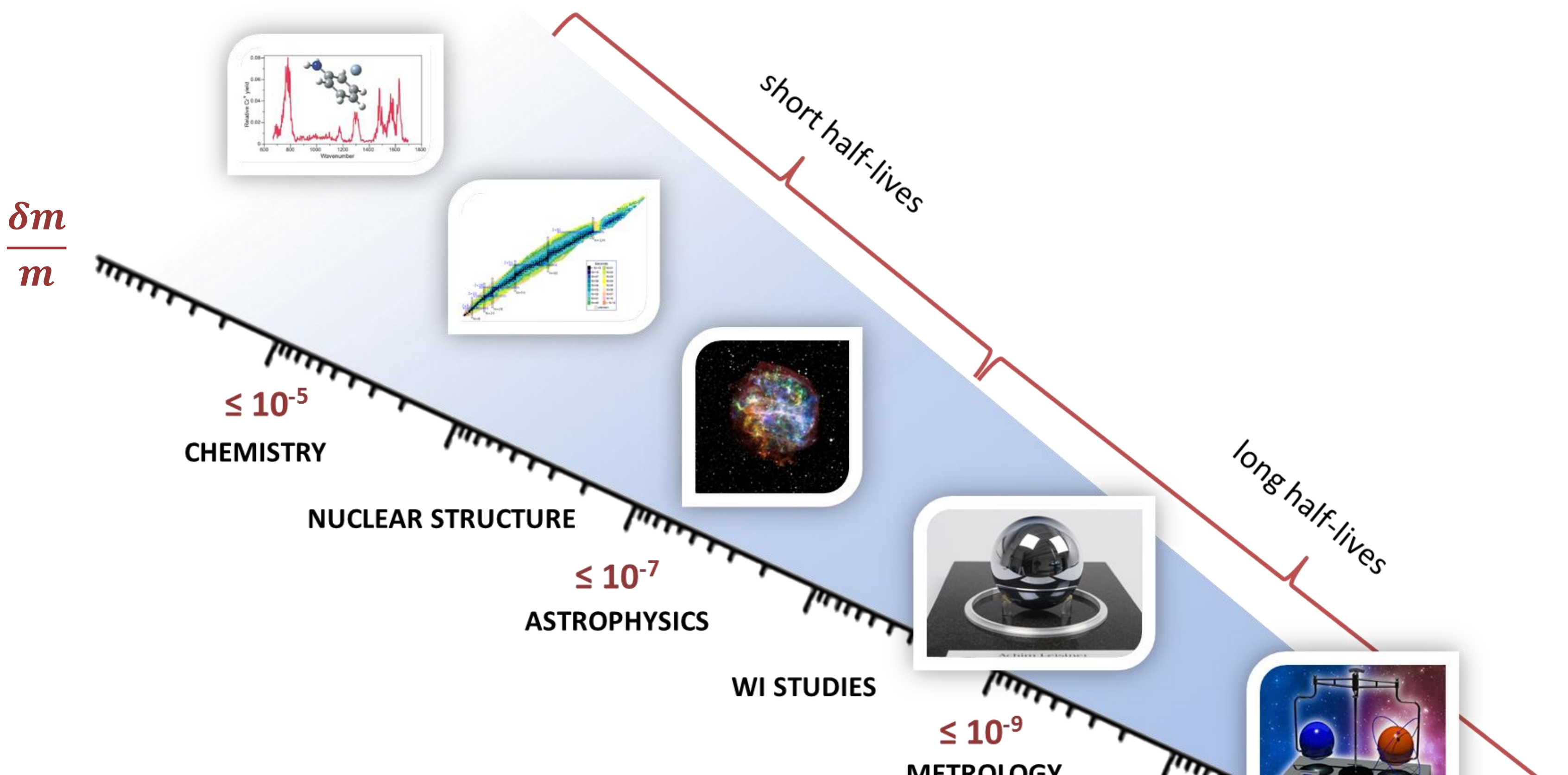
Additional slides

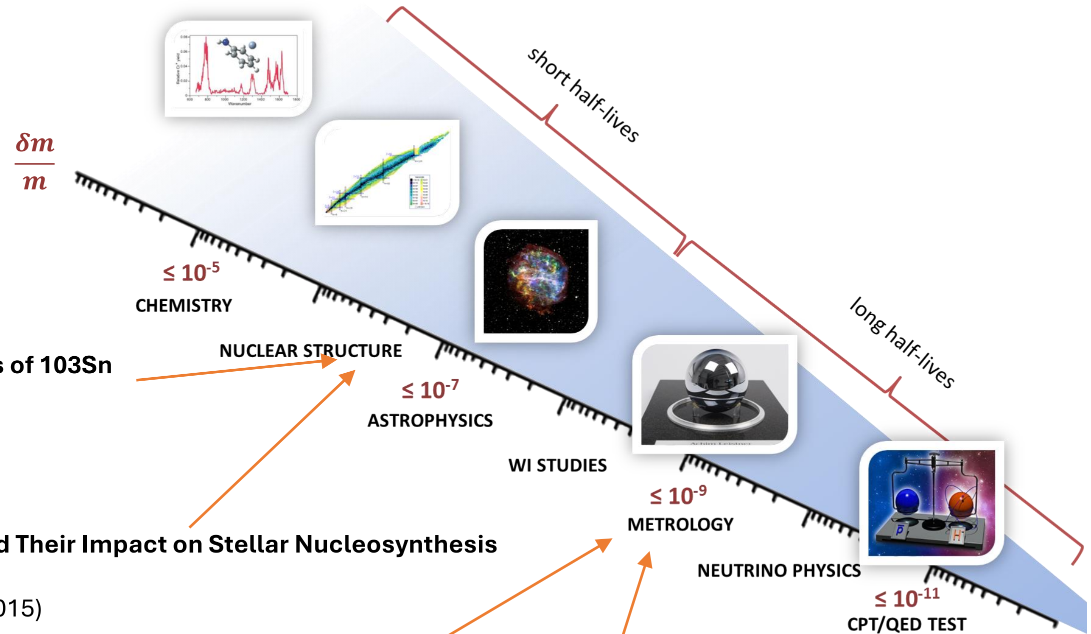
Precision mass spectrometry



$$M_{\text{nuc}}(Z,N) = Z \cdot m_p + N \cdot m_n - B(Z,N)/c^2$$

$$M_{\text{atom}}(Z,N) = M_{\text{nuc}}(Z,N) + Z \cdot m_e - B_e(Z)$$

Precision mass spectrometry



Nuclear structure

Refining the nuclear mass surface with the mass of 103Sn
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Nuclear astrophysics

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

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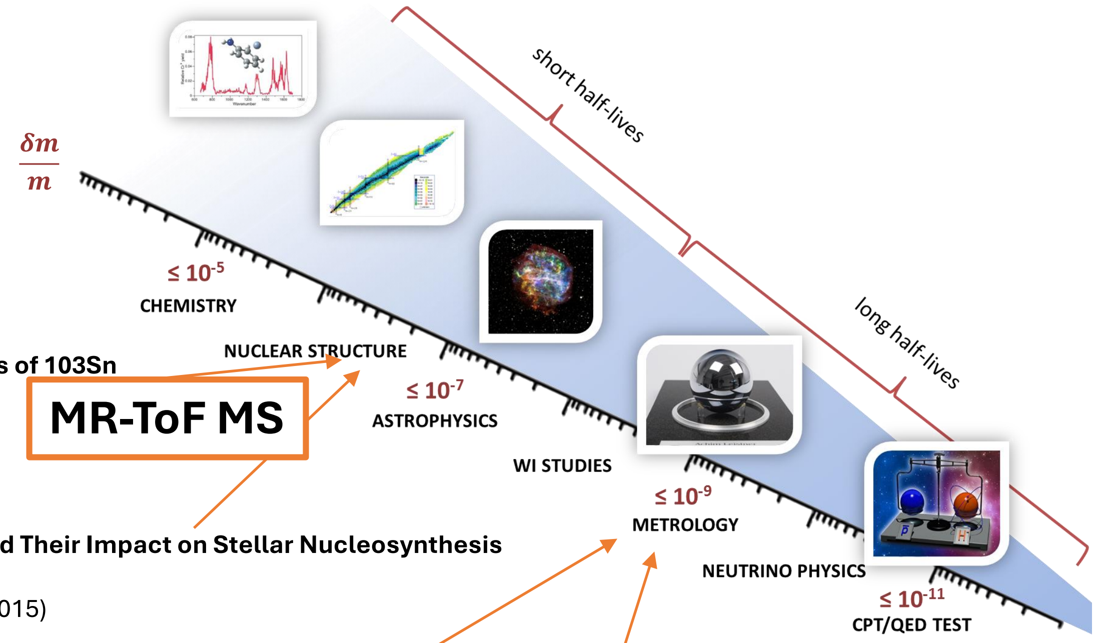
Precision mass spectrometry



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Penning trap MS

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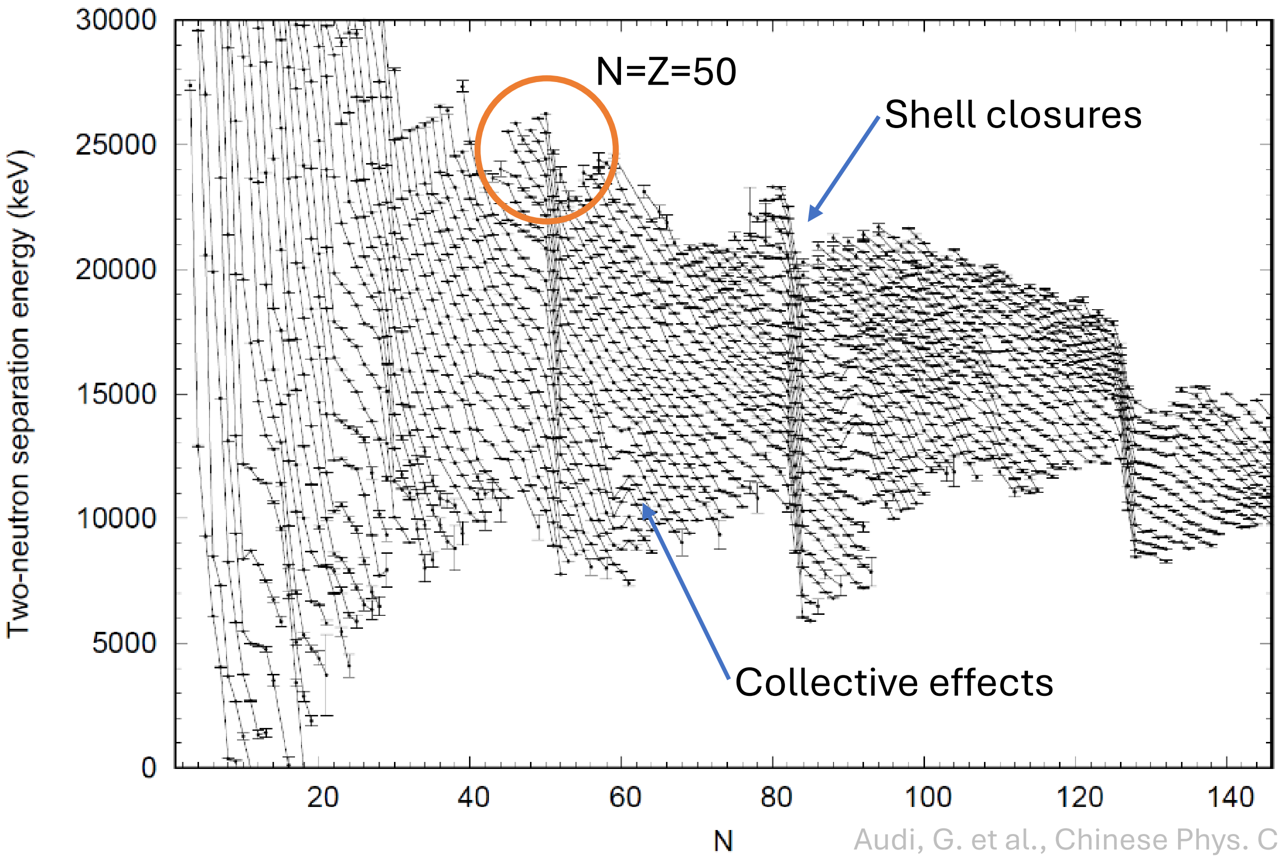
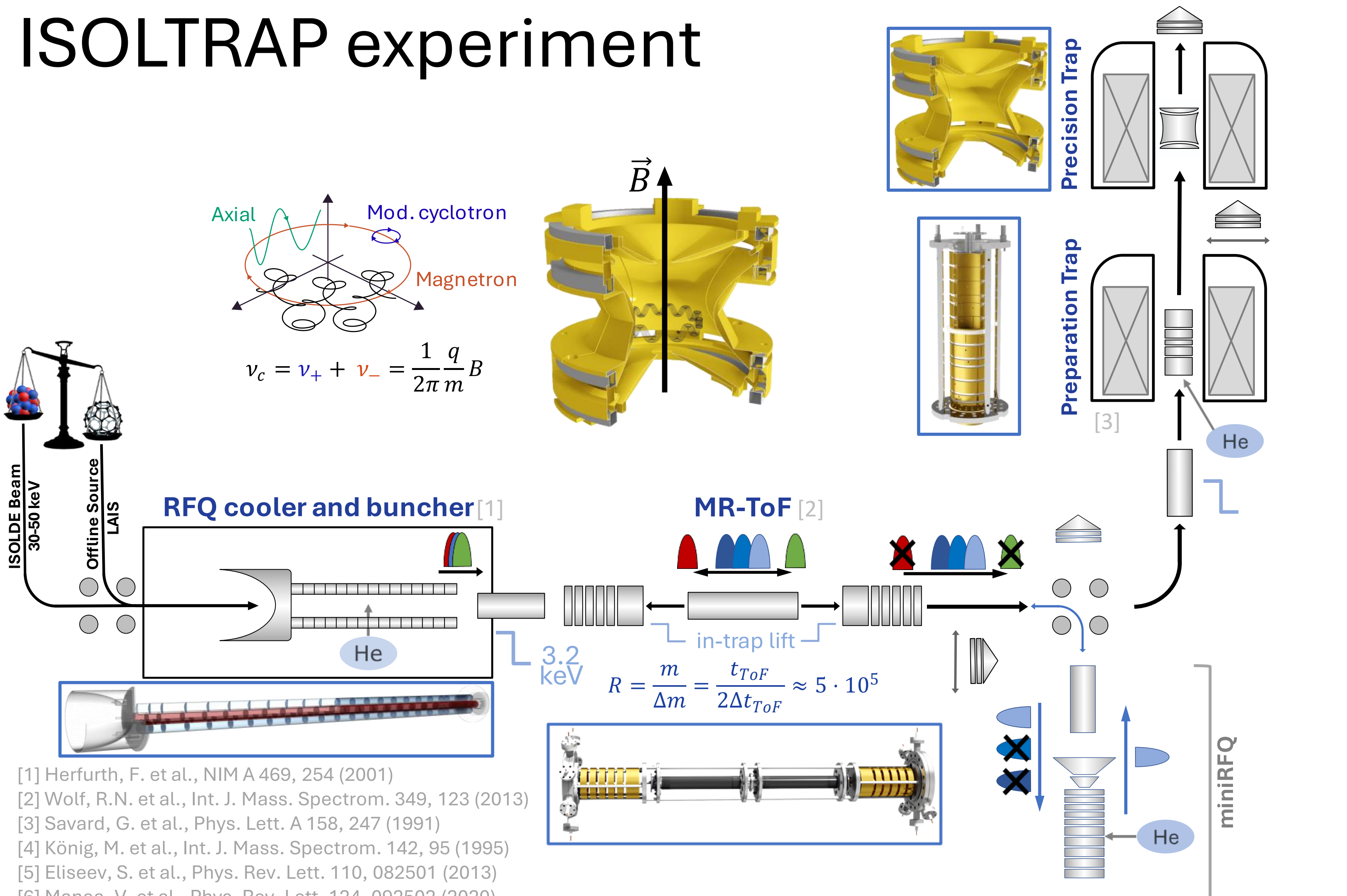
Precision mass spectrometry

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)

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)