DPG Spring Meeting 2024, Gießen, 11.03.-15.03.2024

Nuclear structure near ^{100}Sn from atomic masses

A challenge to nuclear theory?

Lukas Nies[1] ***for the ISOLTRAP Collaboration***

[1]CERN, Switzerland

Why?
Quick recap on mass surface near ^{100}Sn – 4 slides

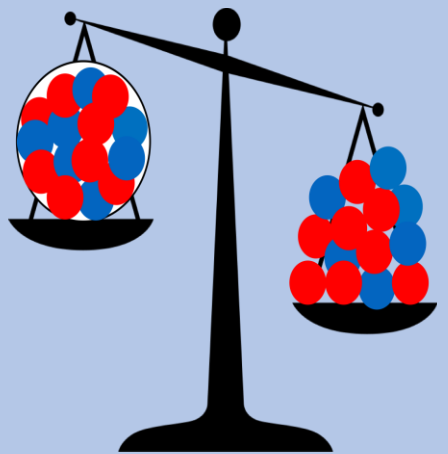
How?
ISOL method and mass spectrometry – 5 slides

So what?
Published and preliminary results from ISOLTRAP – 8 slides

And now?
Outlook and further developments – 3 slides

Atomic physics methods probe nuclear properties

Nuclear Binding Energy



$$M_{atom}(Z,N) = M_{nuc}(Z,N) + Zm_e - B_e(Z)$$

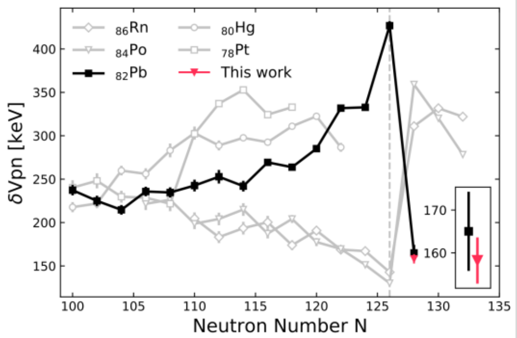
$$M_{nuc}(Z,N) = Zm_p + Nm_n + \frac{E(Z,N)}{c^2}$$

Nuclear Structure

"Mass filters"

Shell model, *ab initio*, etc.

Many-body interactions

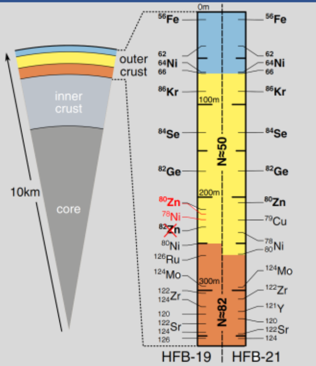


Nuclear Astrophysics

Nucleosynthesis

Light curves

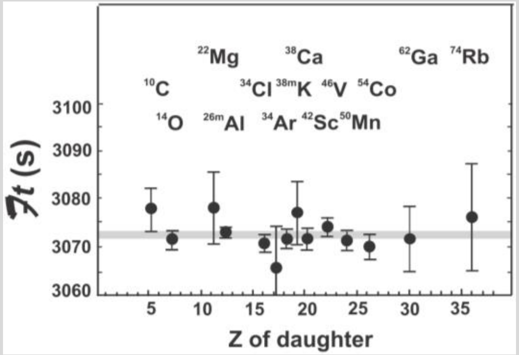
Neutron star compositions



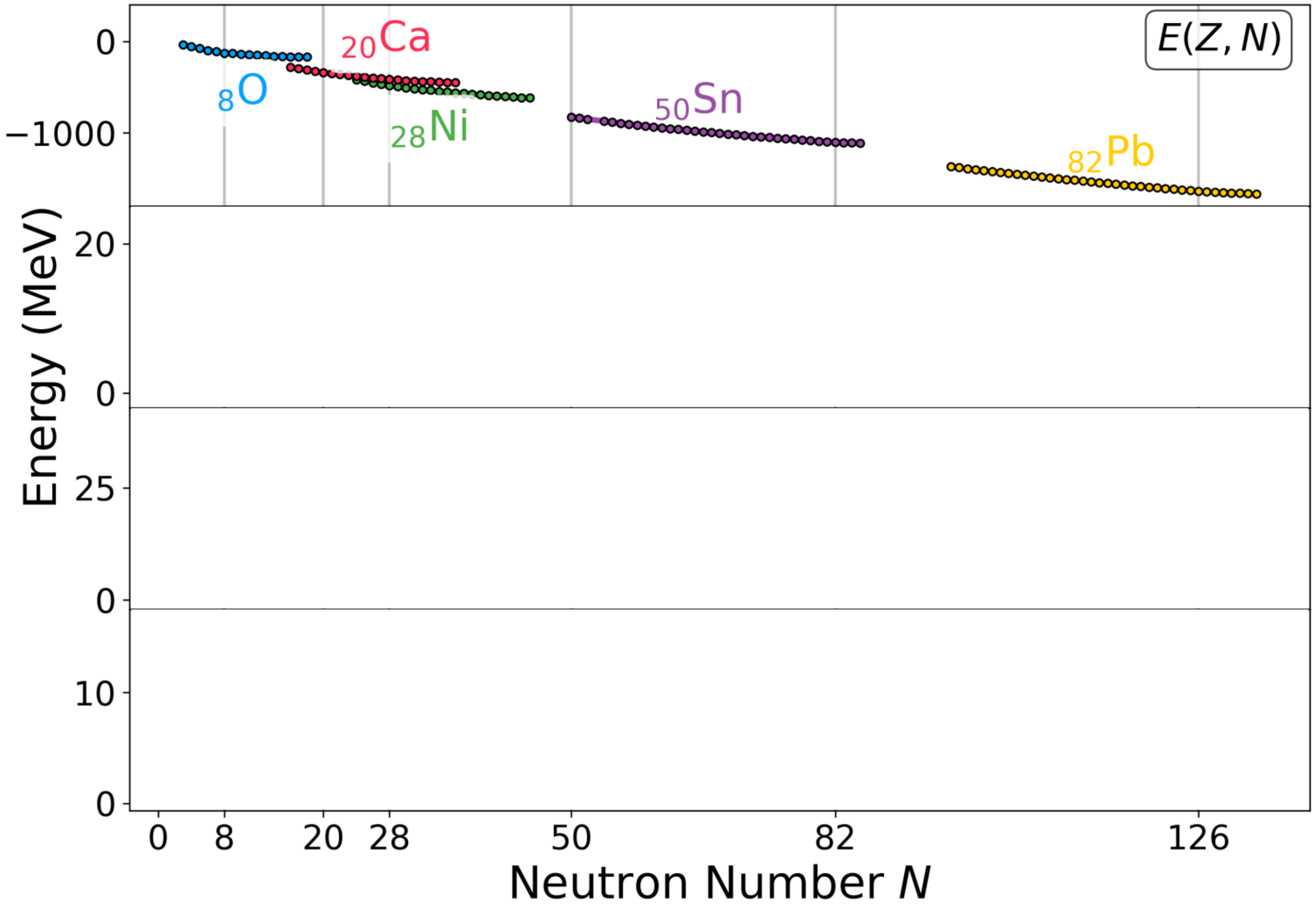
Weak Interaction Physics

Unitarity of CKM Matrix

ν_e mass searches



Tool of choice: mass filters



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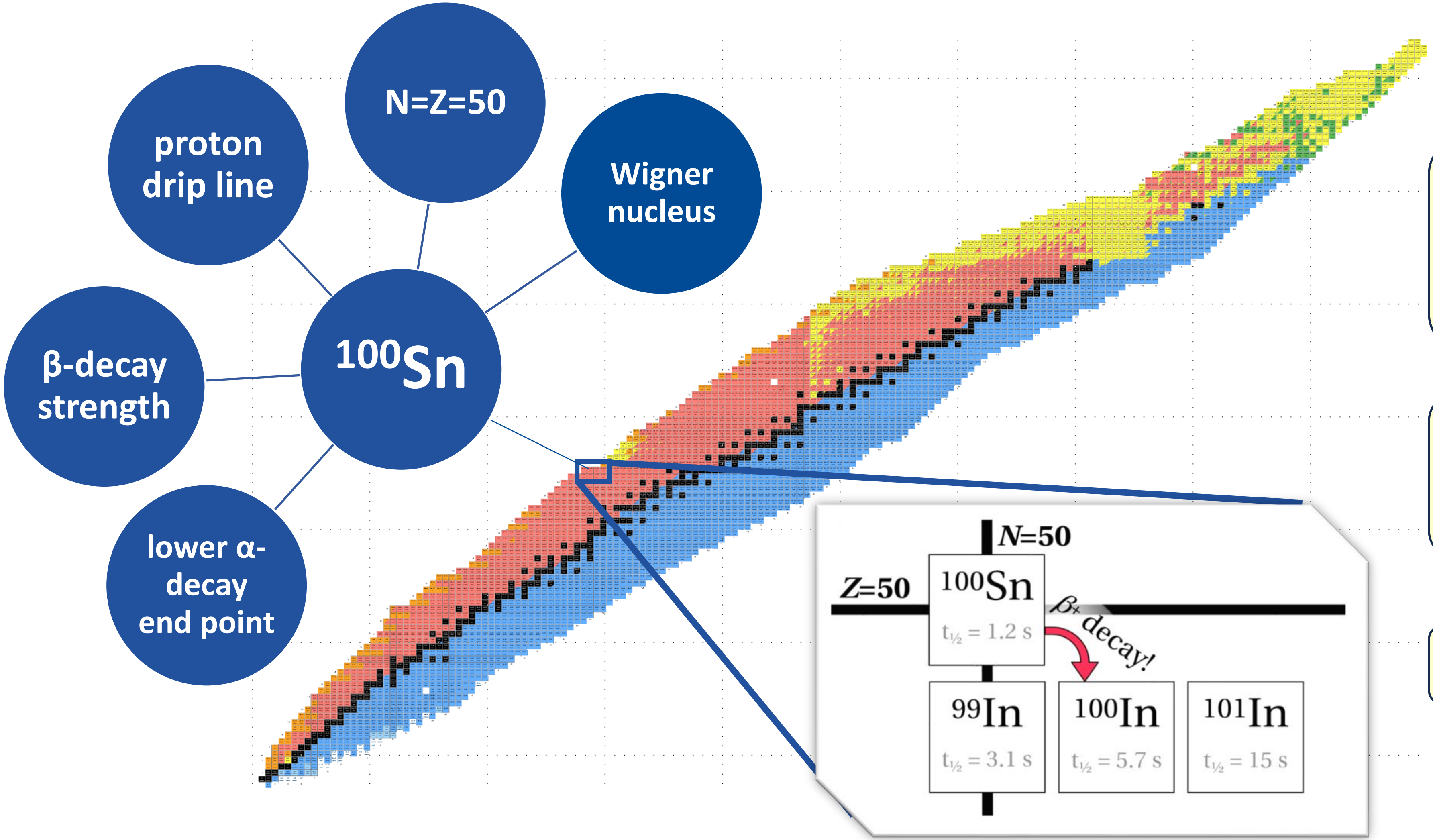
Physics Motivation Near ^{100}Sn



Q-value tension

C. B. Hinke et al., Nature 486, 341 (2012)
D. Lubos et al., Phys. Rev. Lett. 122, 222502 (2019)
M. Mougeot et al., Nat. Phys. 17, 1099 (2021).
A. Mollaebrahimi et al., PLB 839 (2023), 137833

Single-nucleon orbitals

Z. H. Sun et al., Phys. Rev. C 104, 064310 (2021)
J. Park et al., Phys. Rev. C 102, 014304 (2020)
L. Nies et al., Phys. Rev. Lett. 131, 022502 (2023)

Separation energies

Direct/Indirect Measurements Near ^{100}Sn

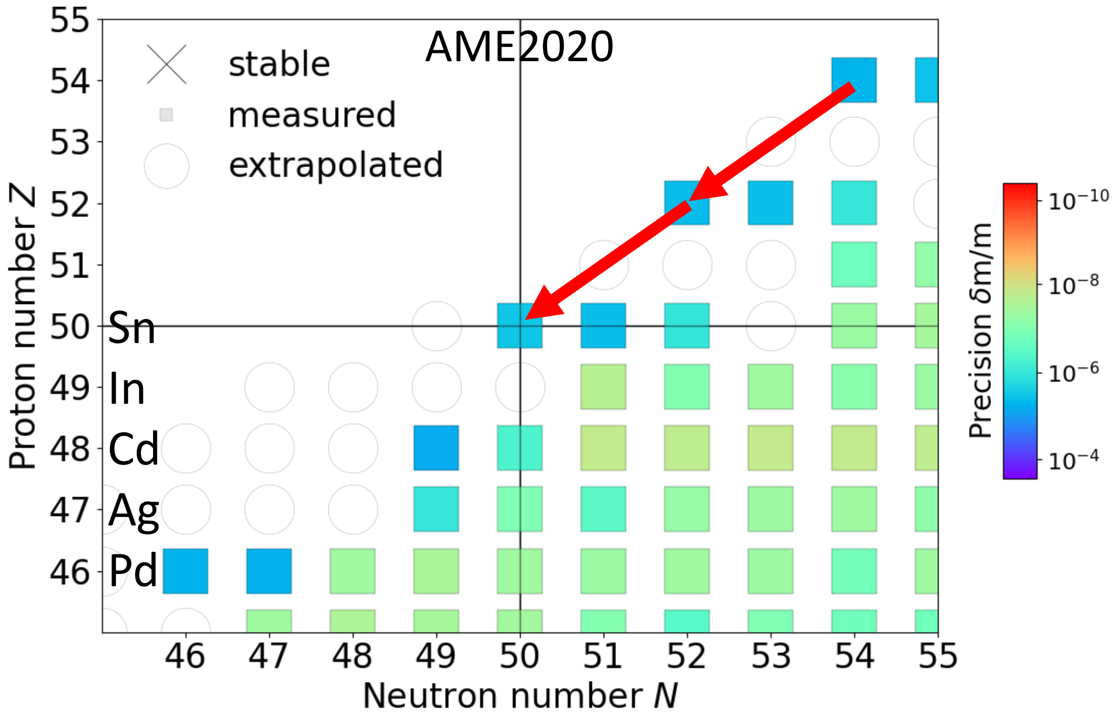
Featured in Physics | Editors' Suggestion

Superallowed α Decay to Doubly Magic ^{100}Sn

K. Auranen, D. Seweryniak, M. Albers, A. D. Ayangeakaa, S. Bottoni, M. P. Carpenter, C. J. Chiara, P. Copp, H. M. David, D. T. Doherty, J. Harker, C. R. Hoffman, R. V. F. Janssens, T. L. Khoo, S. A. Kuvin, T. Lauritsen, G. Lotay, A. M. Rogers, J. Sethi, C. Scholey, R. Talwar, W. B. Walters, P. J. Woods, and S. Zhu

Phys. Rev. Lett. **121**, 182501 – Published 30 October 2018

Fusion evap.



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ISOL

Letter | Open access | Published: 23 September 2021

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Nature Physics 17, 1099–1103 (2021) | Cite this article

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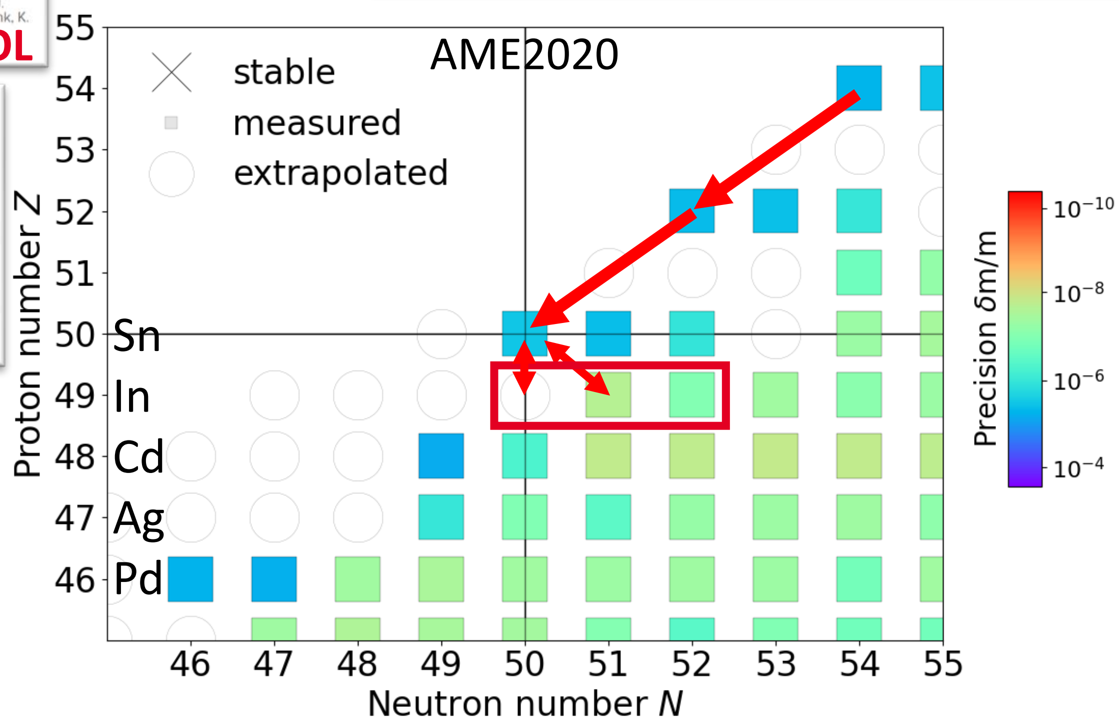

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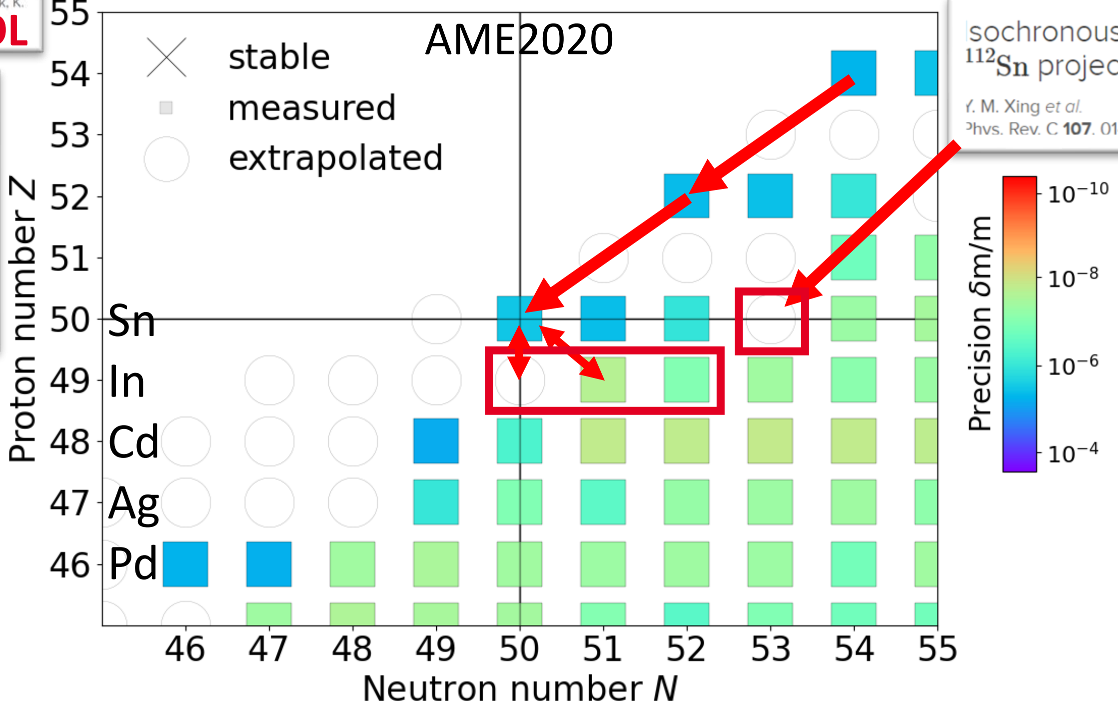
Fusion evap.

Isochronous mass measurements of neutron-deficient nuclei from ^{112}Sn projectile fragmentation

Y. M. Xing et al.

Phys. Rev. C 107, 014304 – Published 11 January 2023

Proj. frag.



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ISOL

Studying Gamow-Teller transitions and the assignment of isomeric and ground states at $N = 50$

Ali Mollaebrahimi, Christine Hornung, Timo Dickel, Daler Amanbayev, Gabriella Kripko-Koncz, Wolfgang R. Plaß, Samuel Ayet San Andrés, Sönke Beck, Andrey Blazhev, Julian Bergmann, Hans Geissel, Magdalena Górska, Hubert Grawe, Florian Greiner, Emma Haettner, Nasser Kalantar-Nayestanaki, Ivan Miskun, Frédéric Nowacki, Christoph Scheidenberger, Soumya Bagchi, ...

Proj. frag.

Mass Measurements and Implications for the Energy of the High-Spin Isomer in ^{94}Ag

A. Kankainen, V.-V. Elomaa, L. Batist, S. Eliseev, T. Eronen, U. Hager, J. Hakala, A. Jokinen, I. D. Moore, Yu. N. Novikov, H. Penttilä, A. Popov, S. Rahaman, S. Rinta-Antila, J. Rissanen, A. Saastamoinen, D. M. Seliverstov, T. Sonoda, G. Vorobjev, C. Weber, and J. Äystö

Phys. Rev. Lett. 101, 142503 – Published 1 October 2008

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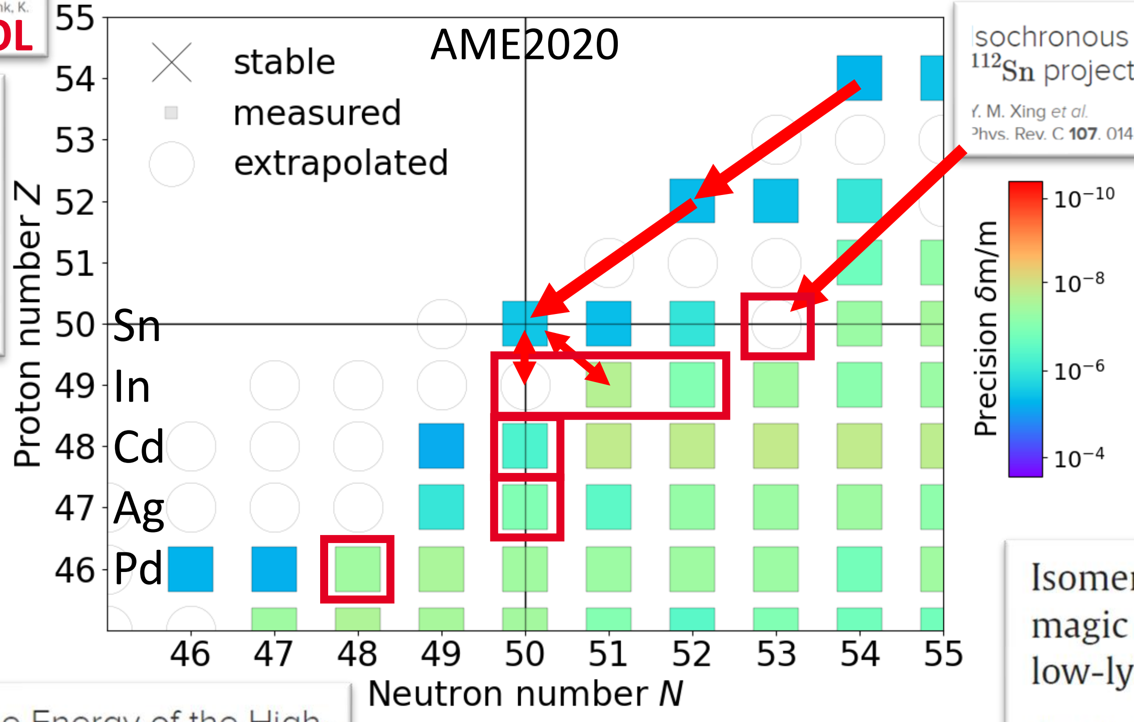

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Proj. frag.

Isomer studies in the vicinity of the doubly-magic nucleus ^{100}Sn: Observation of a new low-lying isomeric state in ^{97}Ag

Christine Hornung, Daler Amanbayev, Irene Dedes, Gabriella Kripko-Koncz, Ivan Miskun, Noritaka Shimizu, Samuel Ayet San Andrés, Julian Bergmann, Timo Dickel, Jerzy Dudek, Jens Ebert, Hans Geissel, Magdalena Górska, Hubert Grawe, Florian Greiner, Emma Haettner, Takaharu Otsuka, Wolfgang R. Plaß, Sivaji Purushothaman, Ann-Kathrin Rink ... John S. Winfield

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Lukas Nies
ISOLTRAP Collaboration

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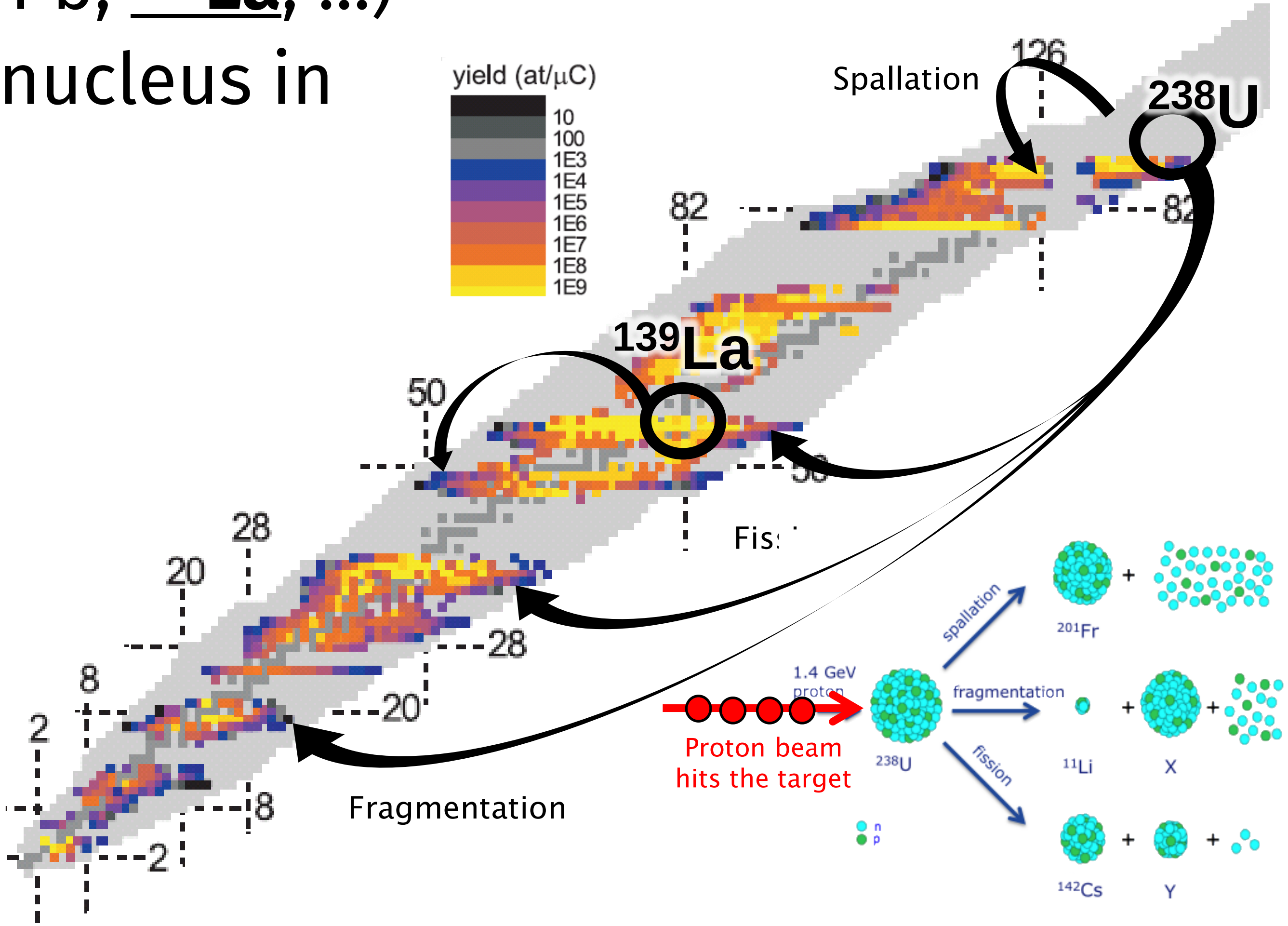
Fragmentation at ISOLDE

- High energy (1.4 GeV) protons are impacted onto a thick target (e.g. ^{238}U, ^{232}Th, ^{208}Pb, **^{139}La**, ...)
- The protons split up the heavy nucleus in one of three ways
  - Fission
  - Fragmentation
  - Spallation



~6000 isotopes predicted by theory
~3000 isotopes already discovered
~1000 isotopes produced by ISOLDE
74 different elements available
as of 2017

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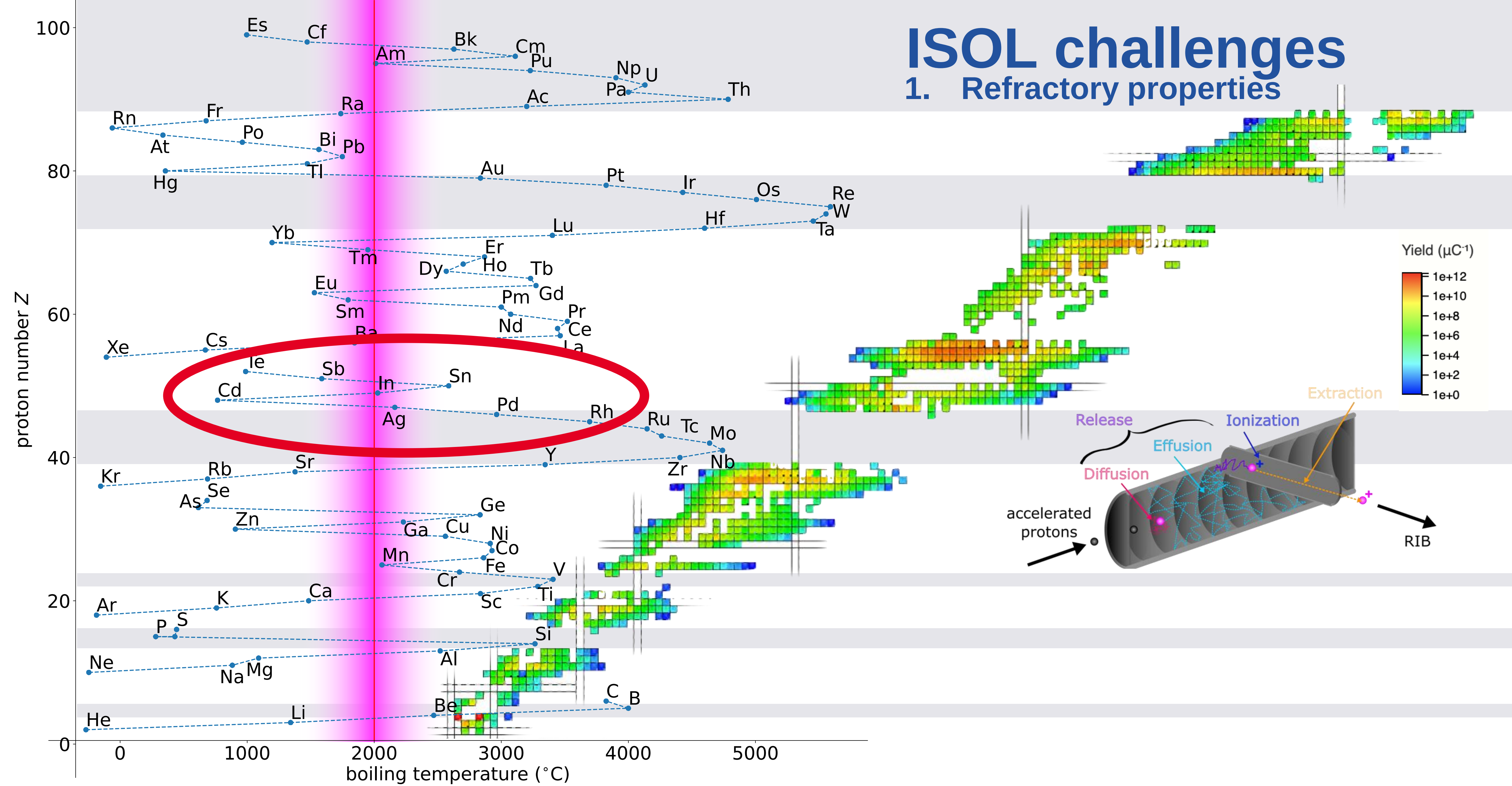
Collaboration

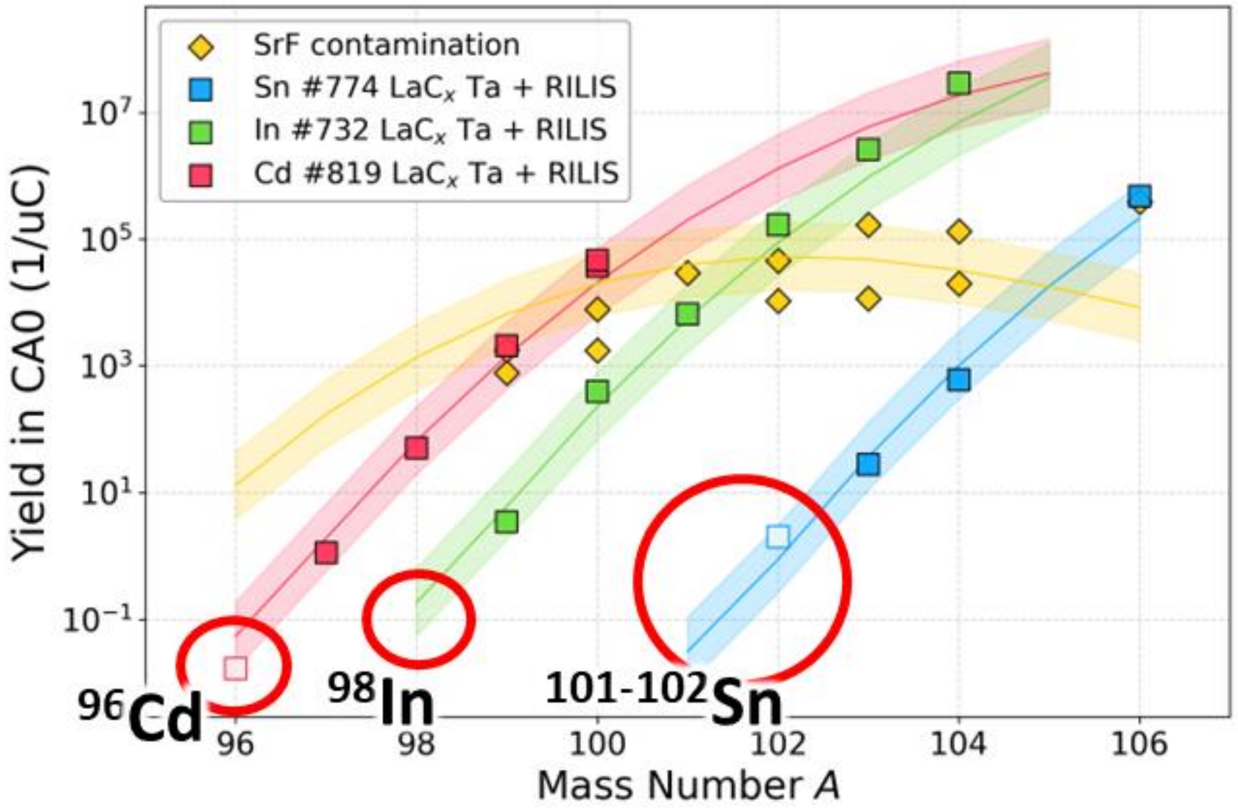
ISOL challenges

1. Refractory properties

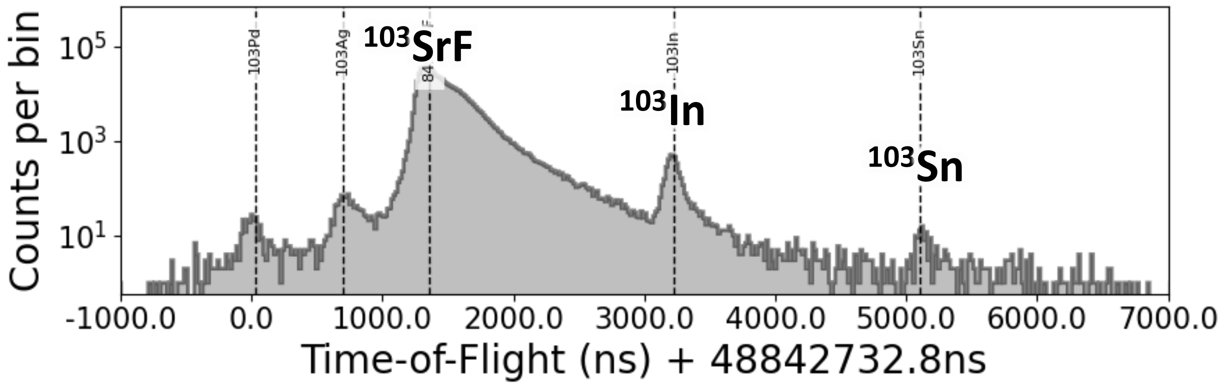


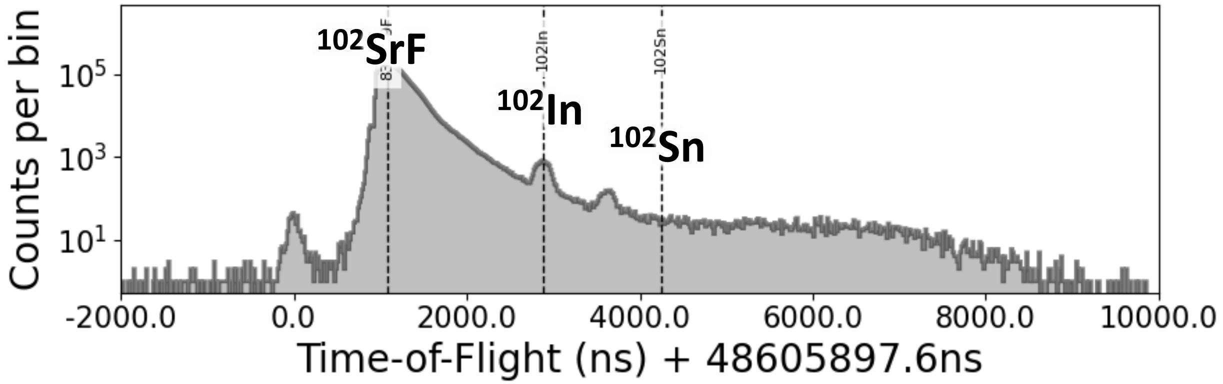
ISOL challenges

2. Low yields



3. Contamination





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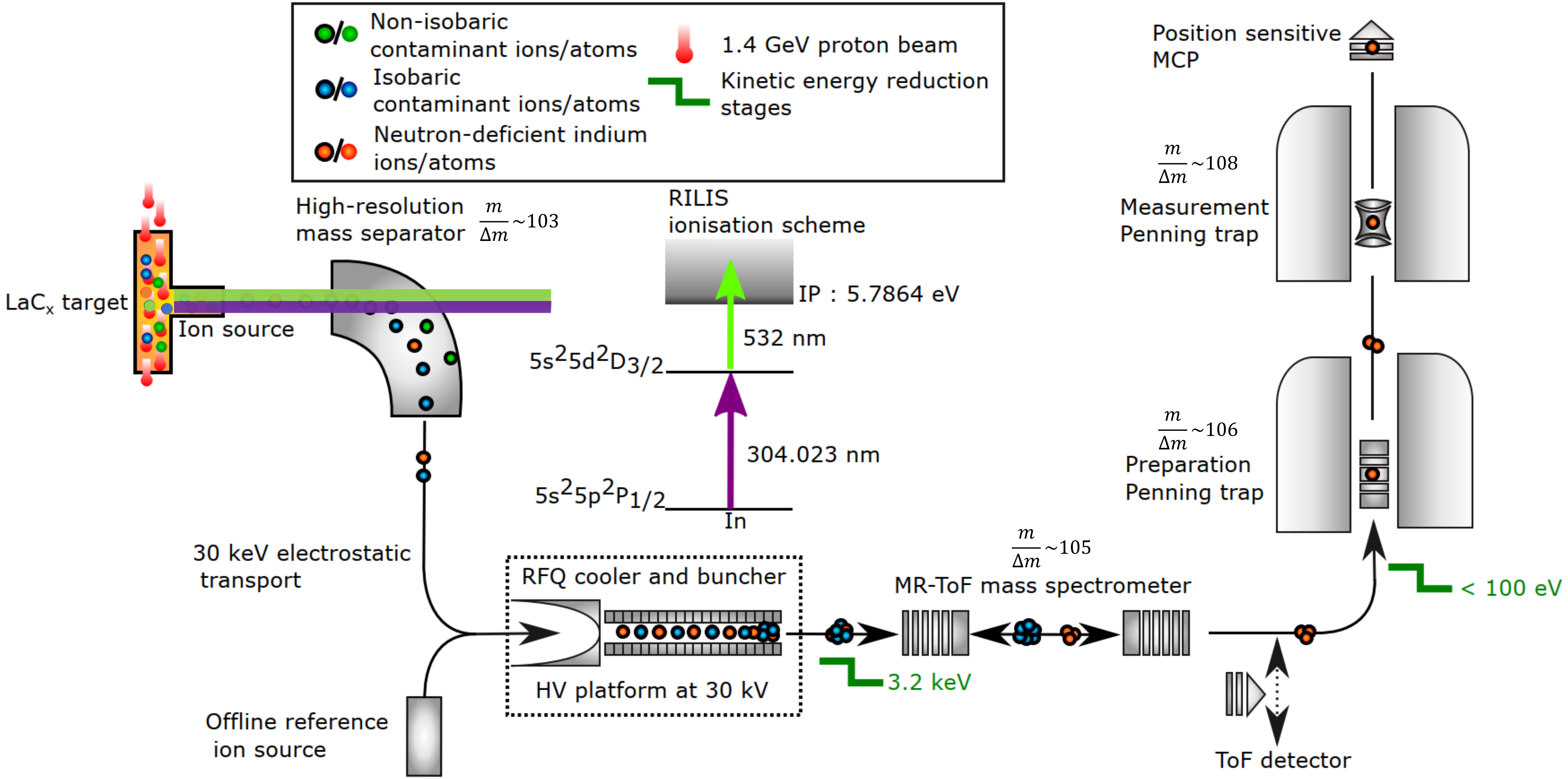
ISOLTRAP Mass Spectrometer



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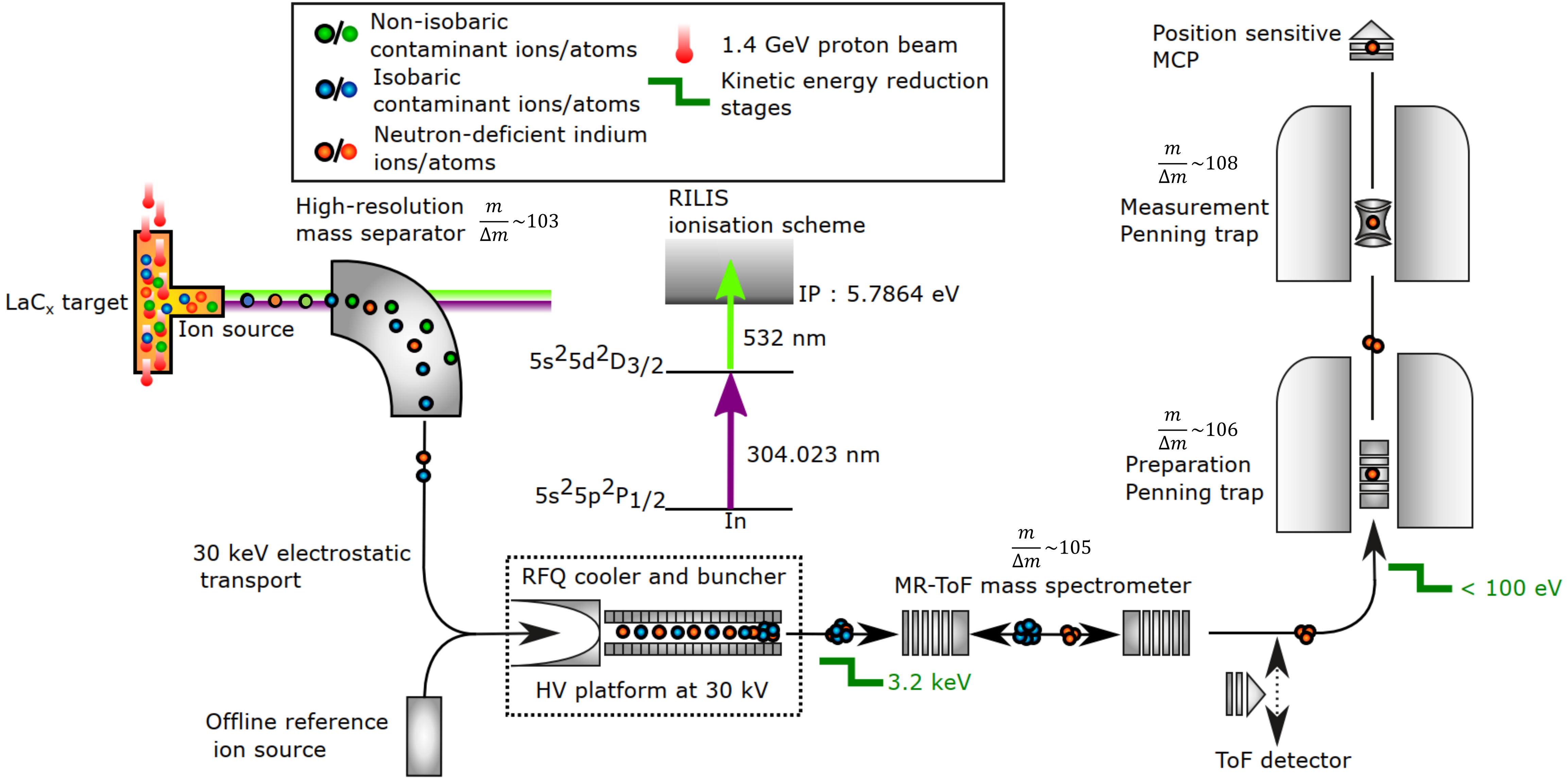

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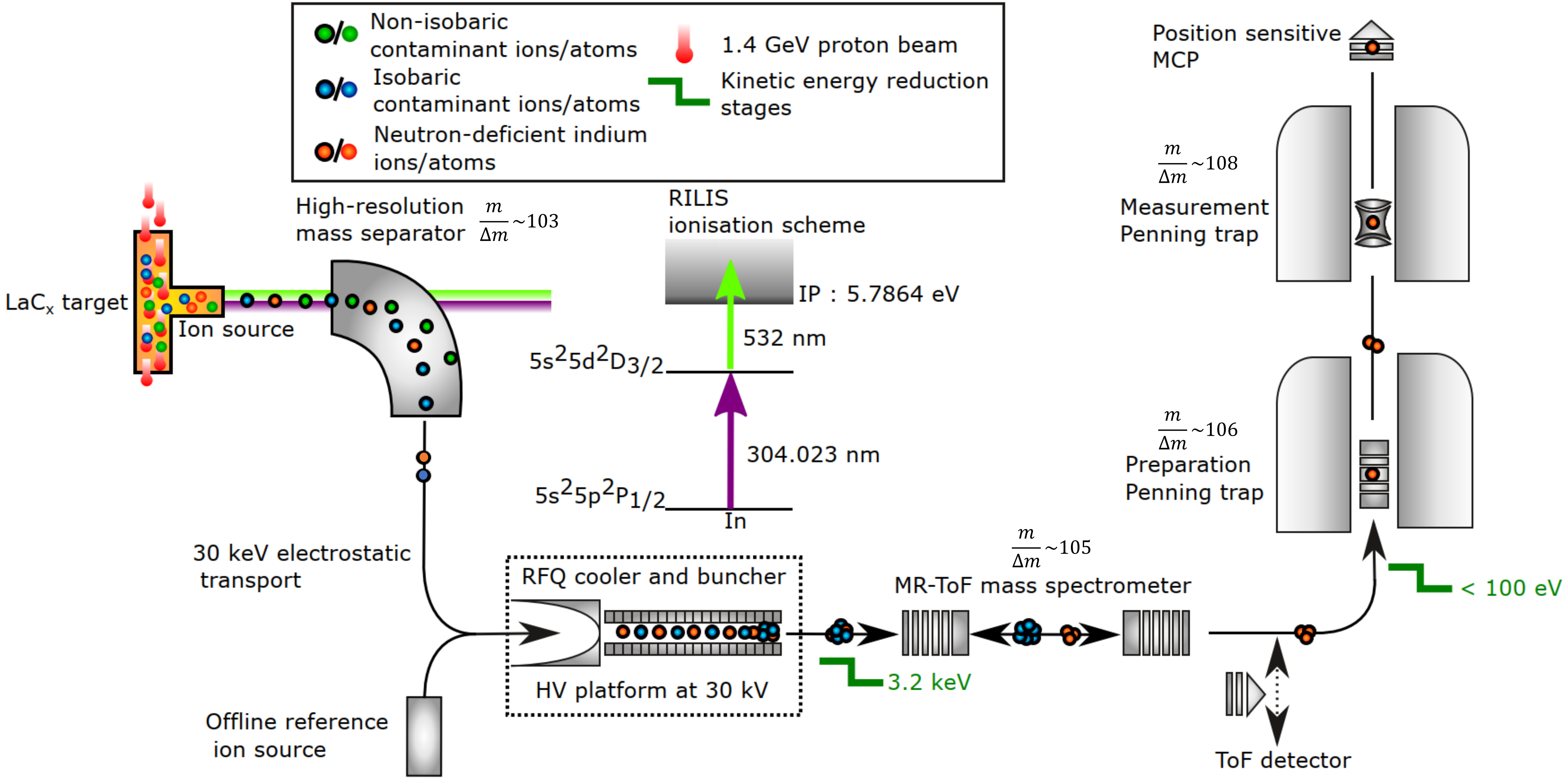

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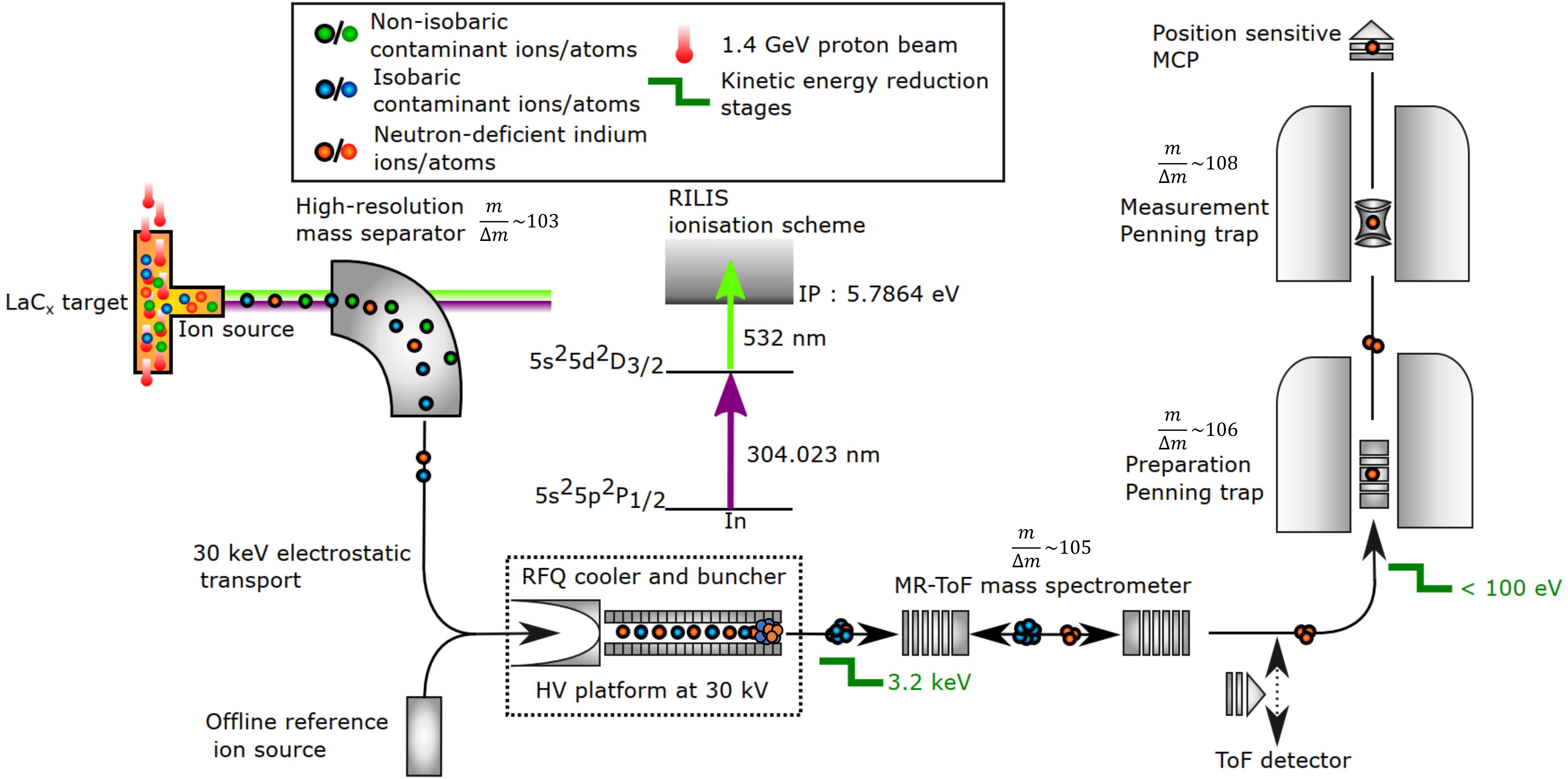
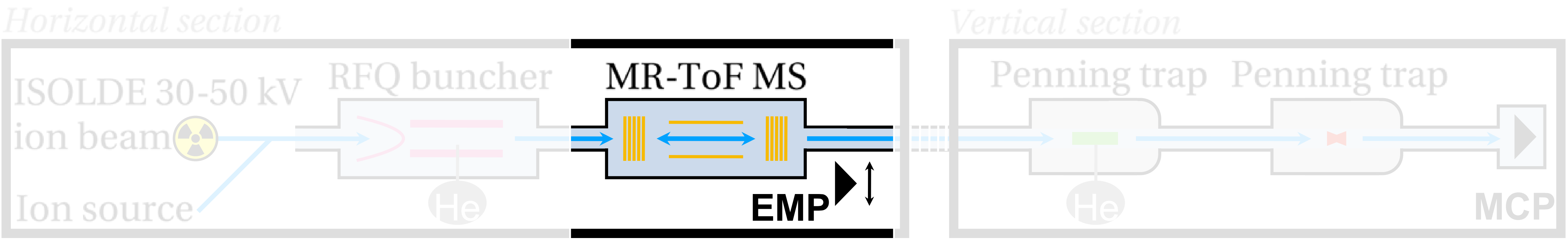
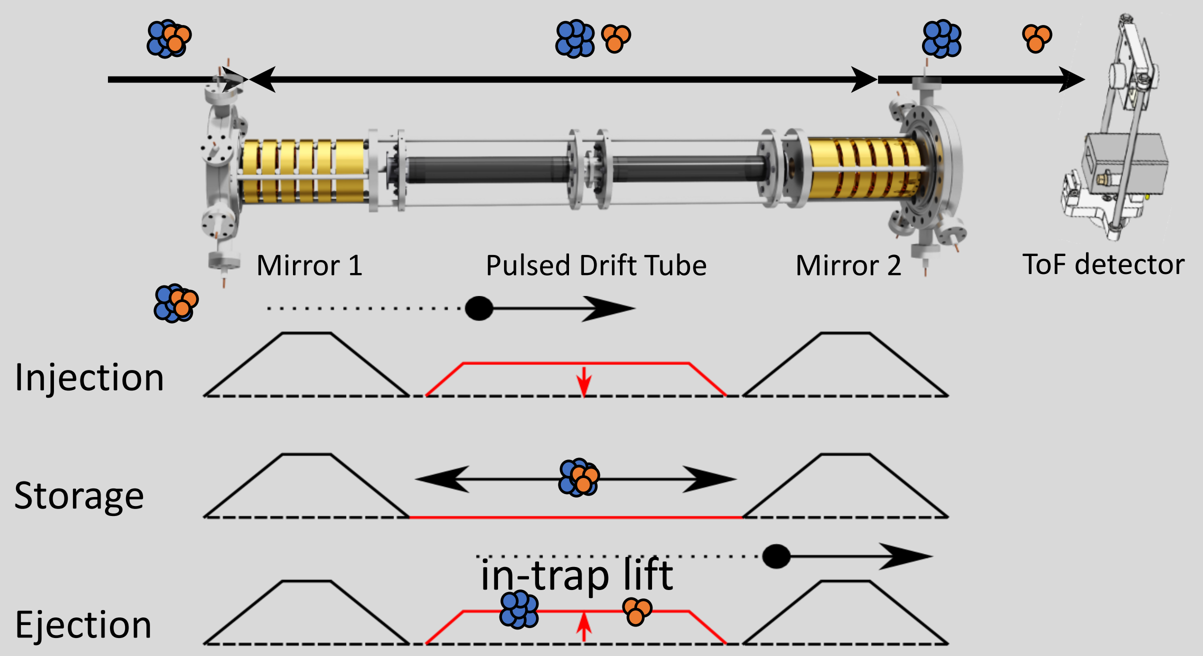


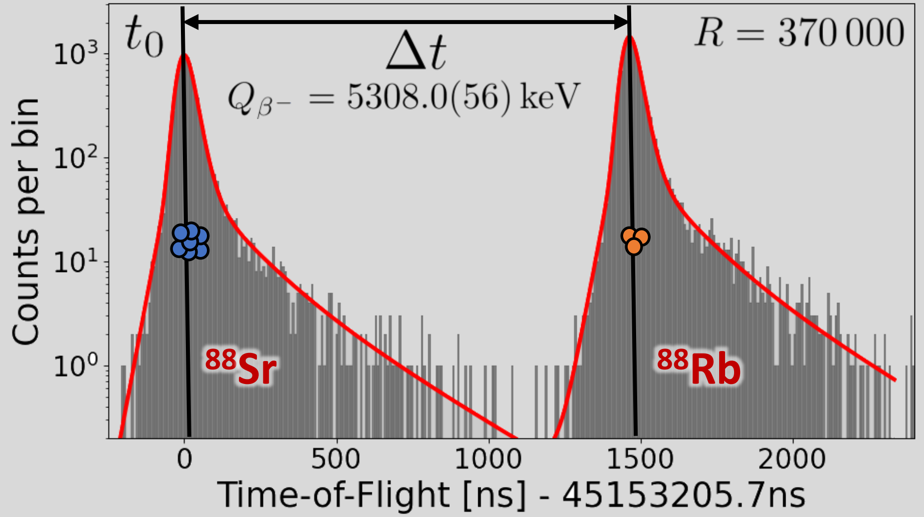
Multi-Reflection Time-of-Flight Device





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

$$E = \left[\left(\frac{\Delta t}{t_0}\right)^2 + 2\frac{\Delta t}{t_0}\right] m_0c^2 \approx 2\frac{\Delta t}{t_0}m_0c^2$$



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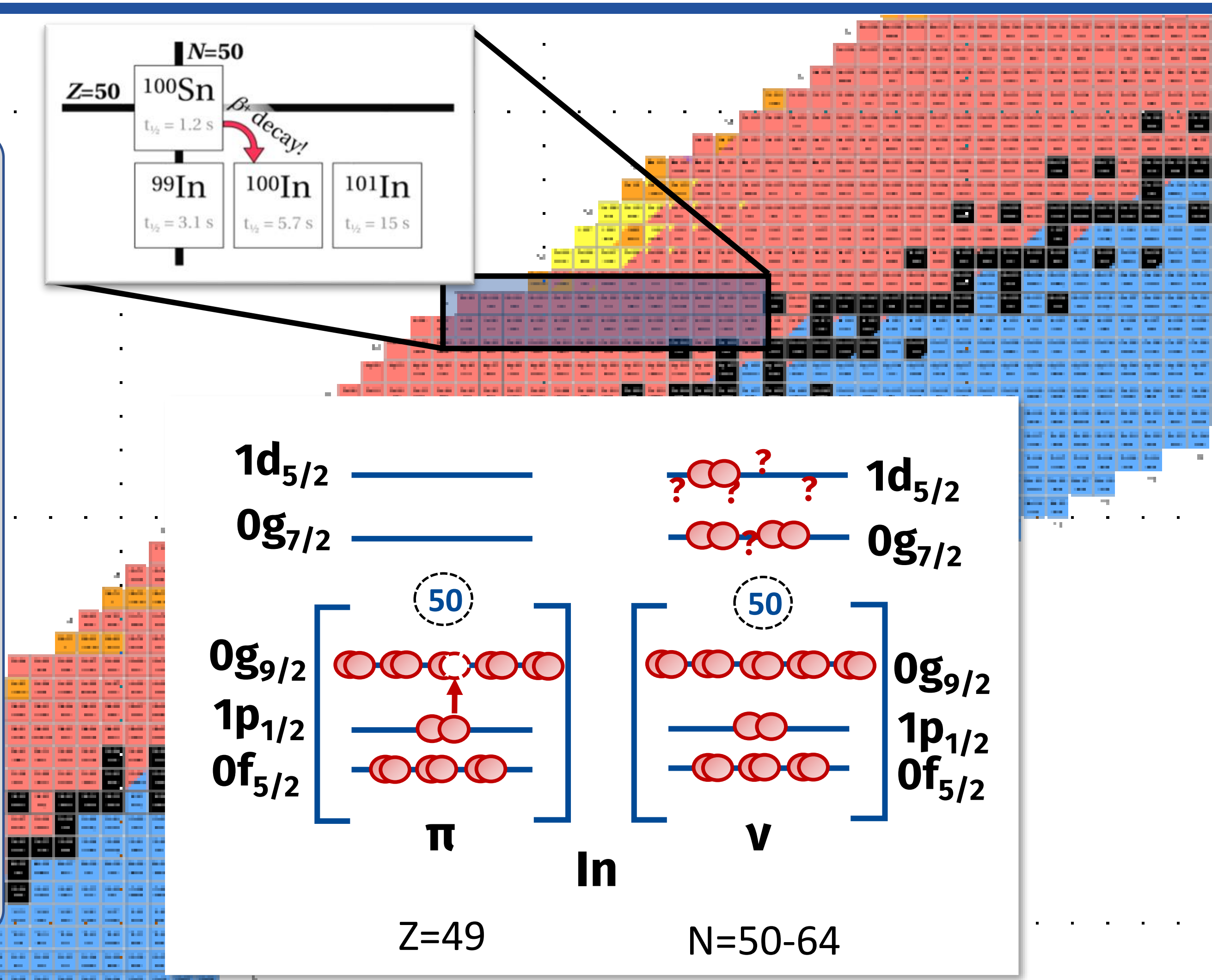
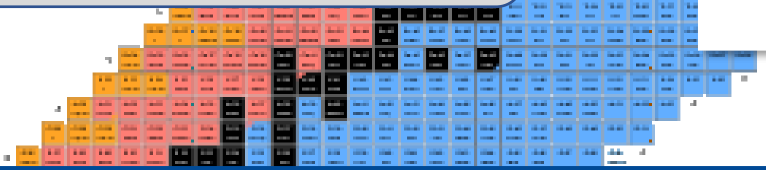
Excitation energy systematics down to N=50

Neutron deficient In isotopes as **^{100}Sn** core with single p-hole and gradual $\nu g_{7/2}$ - $\nu d_{5/2}$ filling

- ➡ single-particle states in ^{100}Sn
- ➡ core-excitation dependent energy shifts
- ➡ particle-hole interactions





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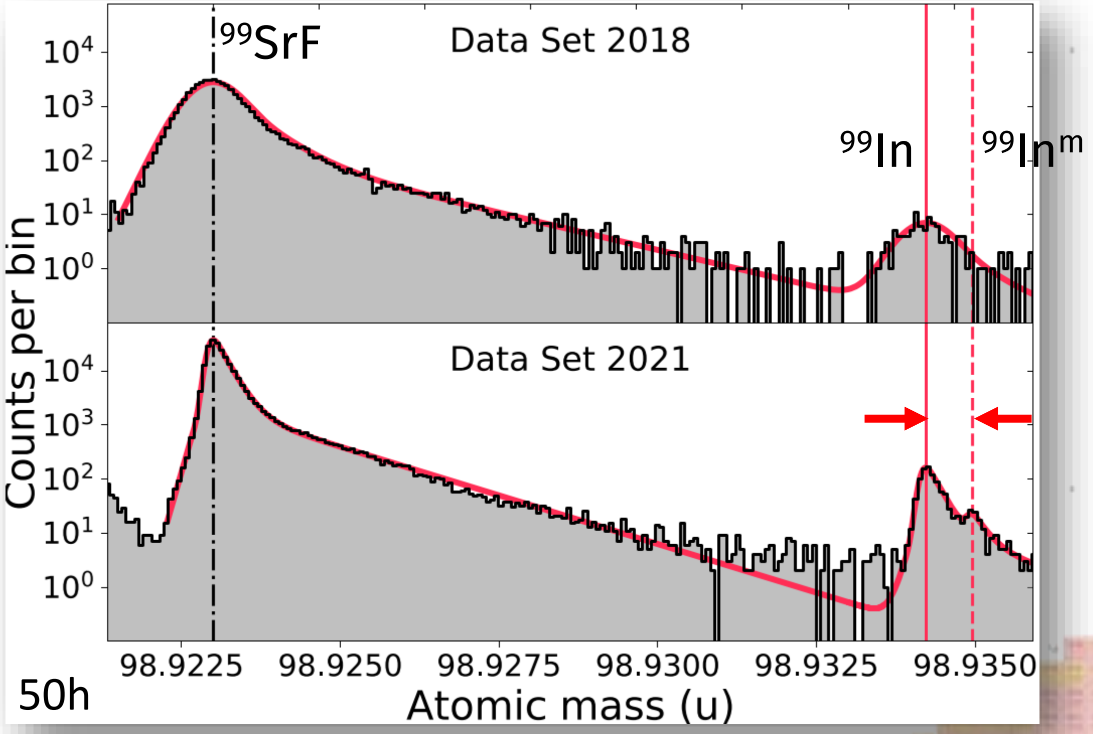
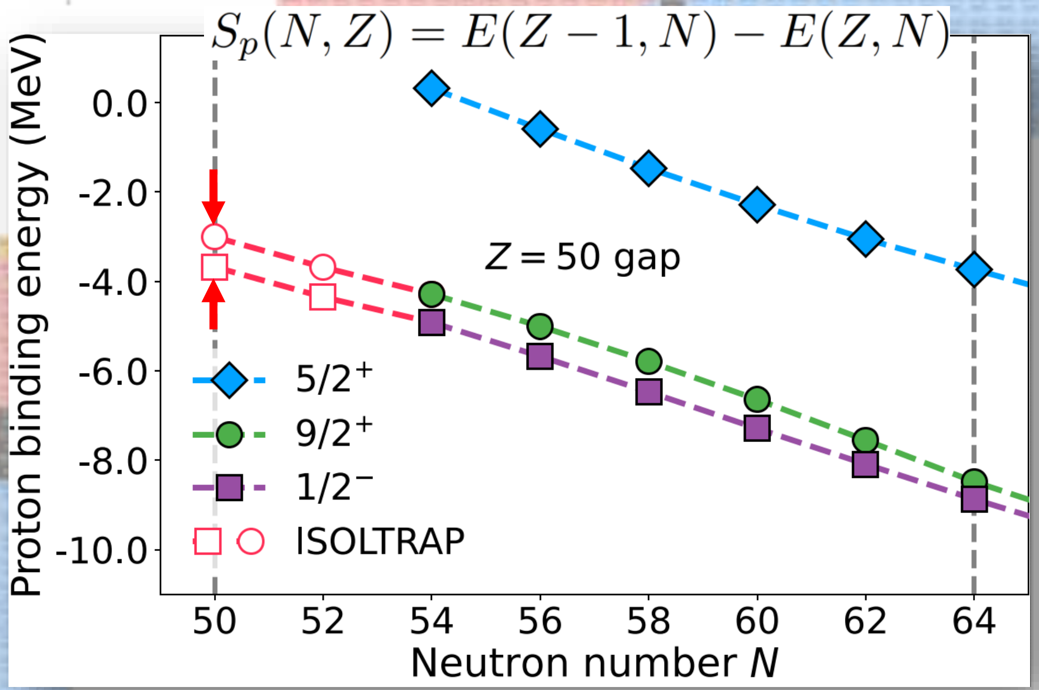
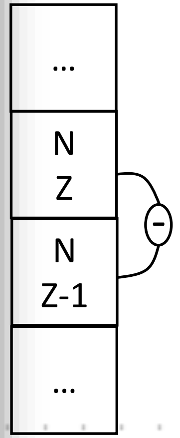


- First direct measurement of $^{99m,gs}In$
- Most sensitive experiment at ISOLTRAP yet (yield <10^{-1} cts./s)

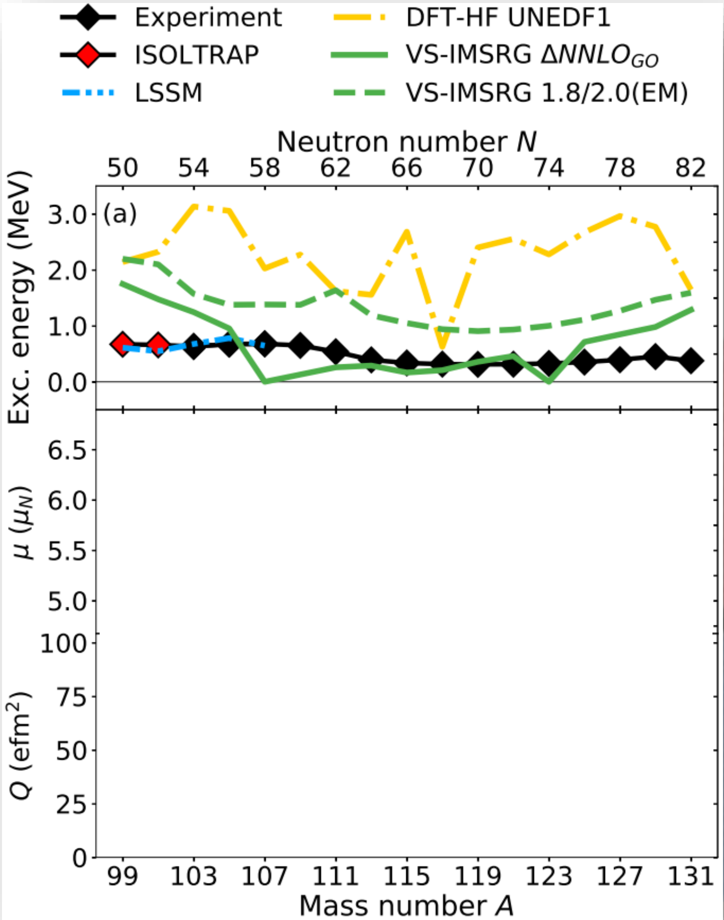


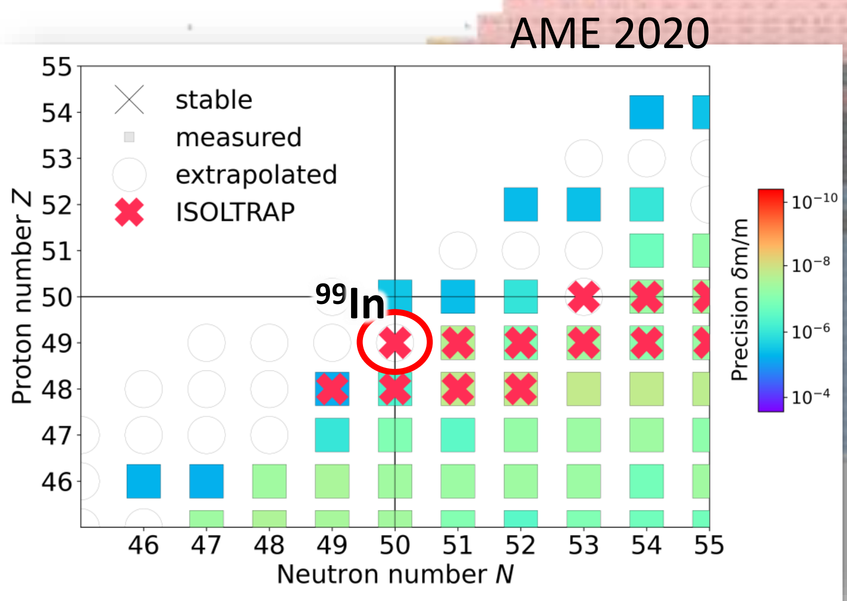


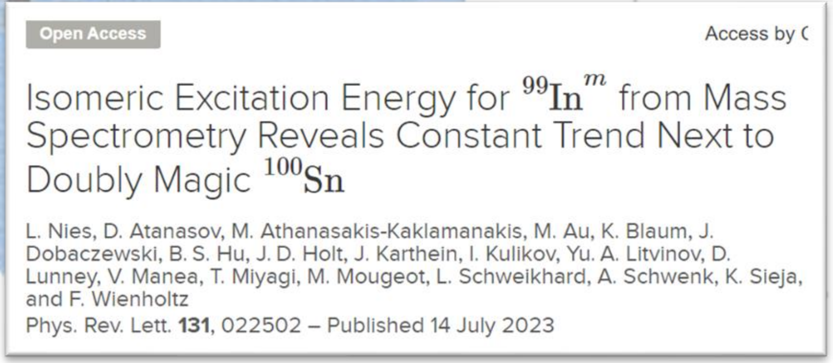
Excitation energy constant over many mass numbers

Nuclear Structure Near ^{100}Sn: Indium ½⁻ states

- Most sensitive ISOLTRAP experiment yet (~ 0.1 pps)
- Nearly constant excitation energies down to N=50 challenge for nuclear models



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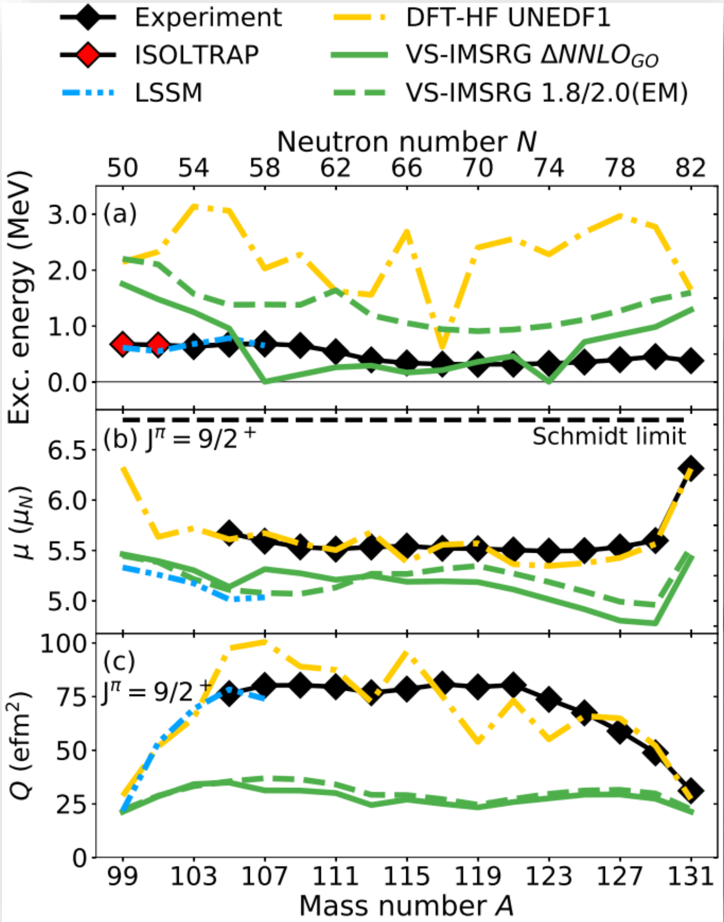

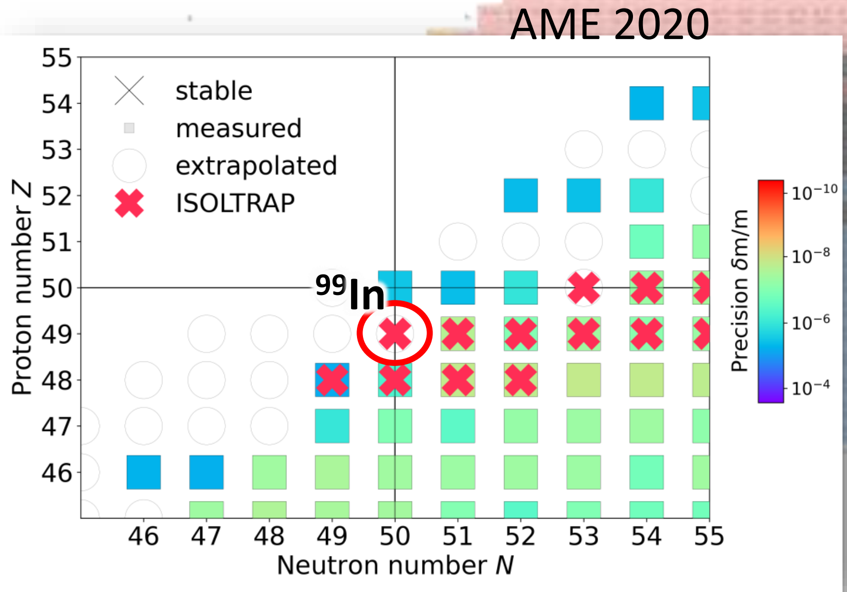

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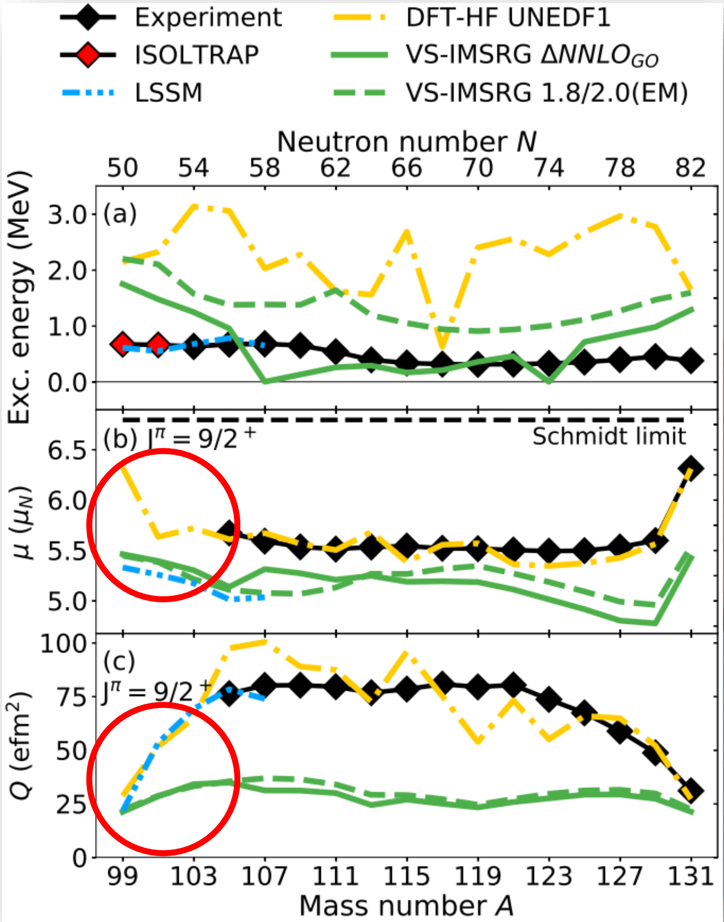
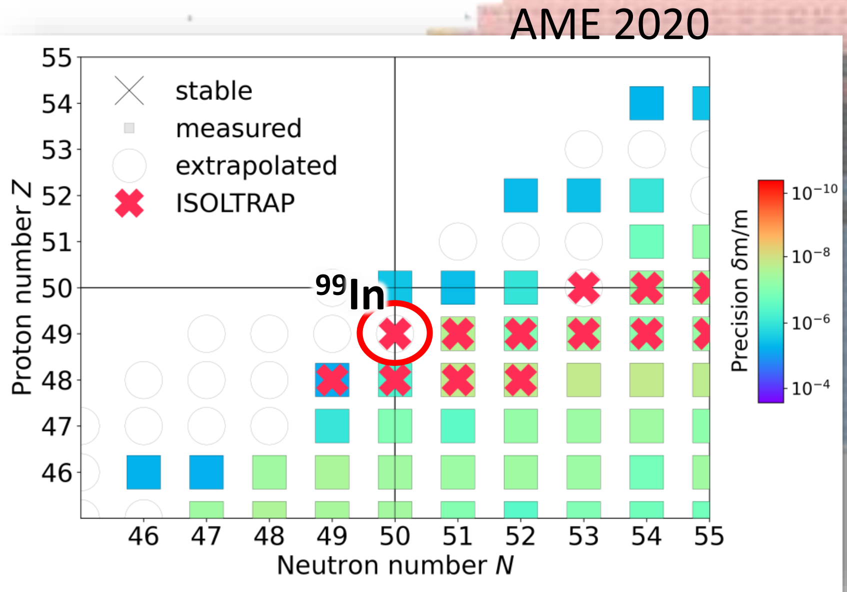
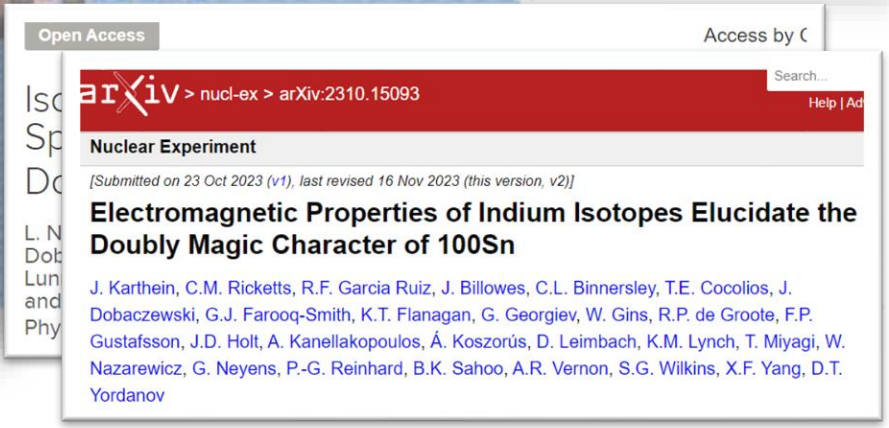
- Nearly constant excitation energies down to N=50 challenge for nuclear models
- Direct comparison of calculations to nuclear moments
- How will the moments evolve towards N=50?



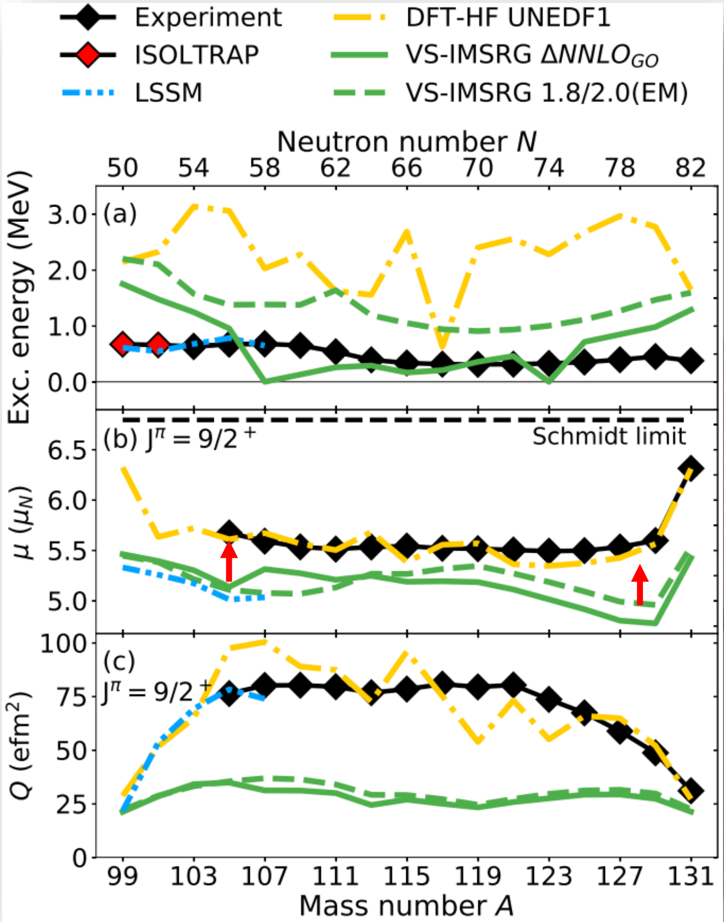


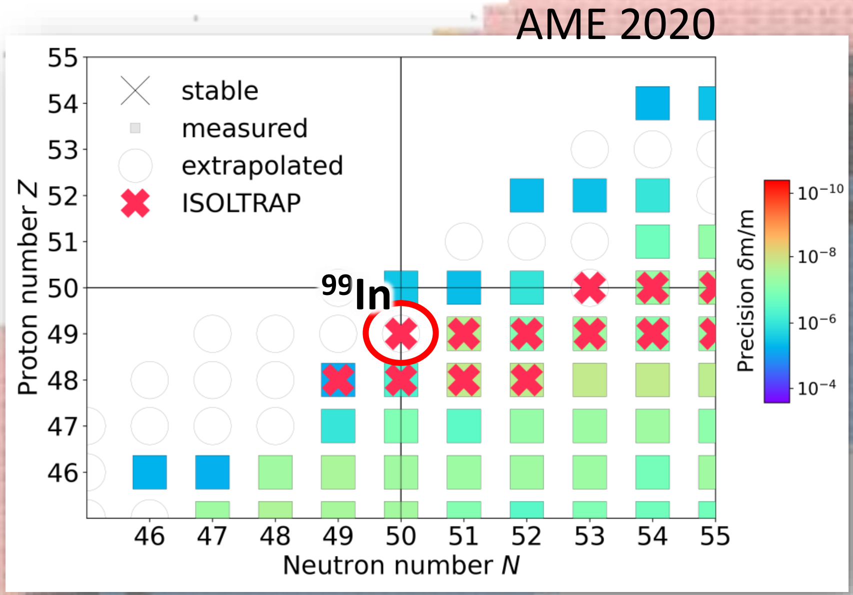


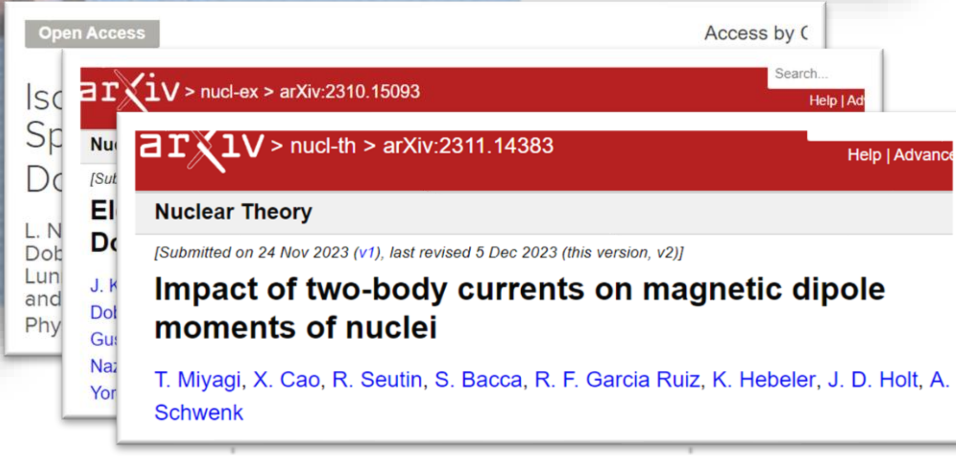
M. Mougeot *et al.*, *Nature Physics* **17**, p. 1099–1103 (2021)
L. Nies et al., PRL **131**, 022502 (2023)

Nuclear Structure Near ^{100}Sn: Indium ½⁻ states

- Most sensitive ISOLTRAP experiment yet (~ 0.1 pps)
- Nearly constant excitation energies down to N=50 challenge for nuclear models
- Direct comparison of calculations to nuclear moments
- How will the moments evolve towards N=50?
- Inclusion of two-body current improves accuracy of *ab-initio* technique

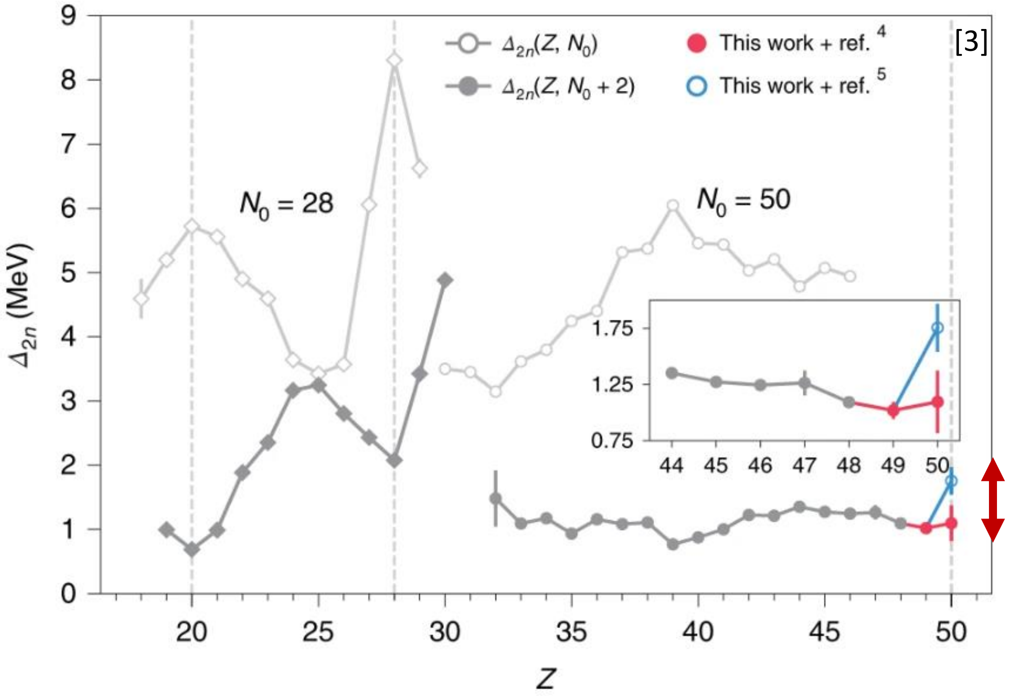






Nuclear Structure Near ^{100}Sn: Indium 9/2^{+} states

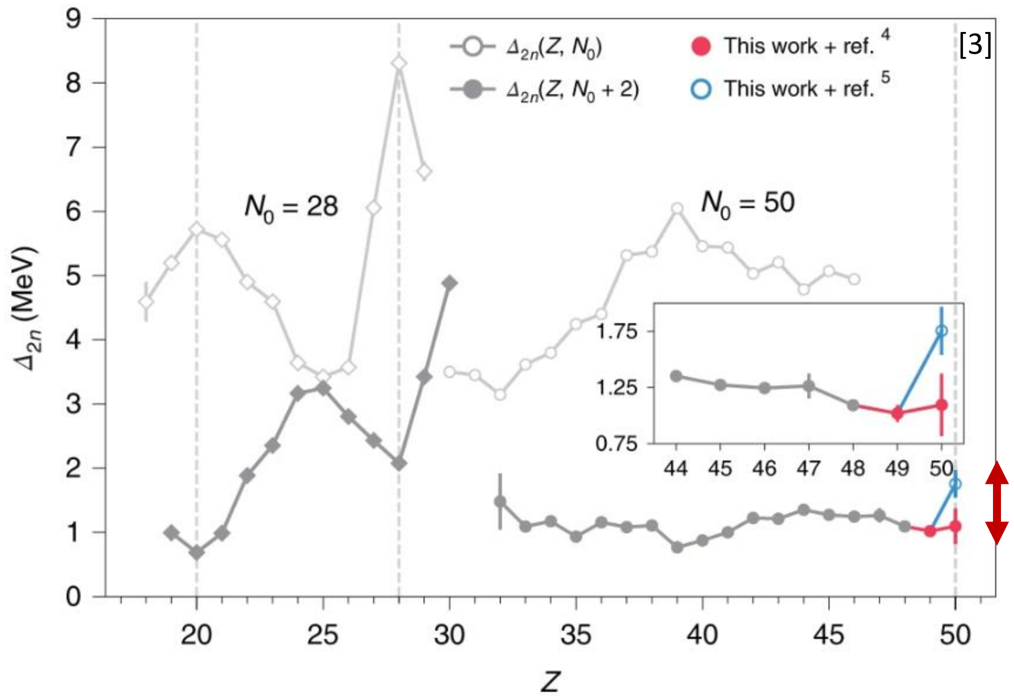
- Mass of **^{100}Sn** improved by 60 keV based on Q-value to ^{100}In [1-2], confirms slight tension between values



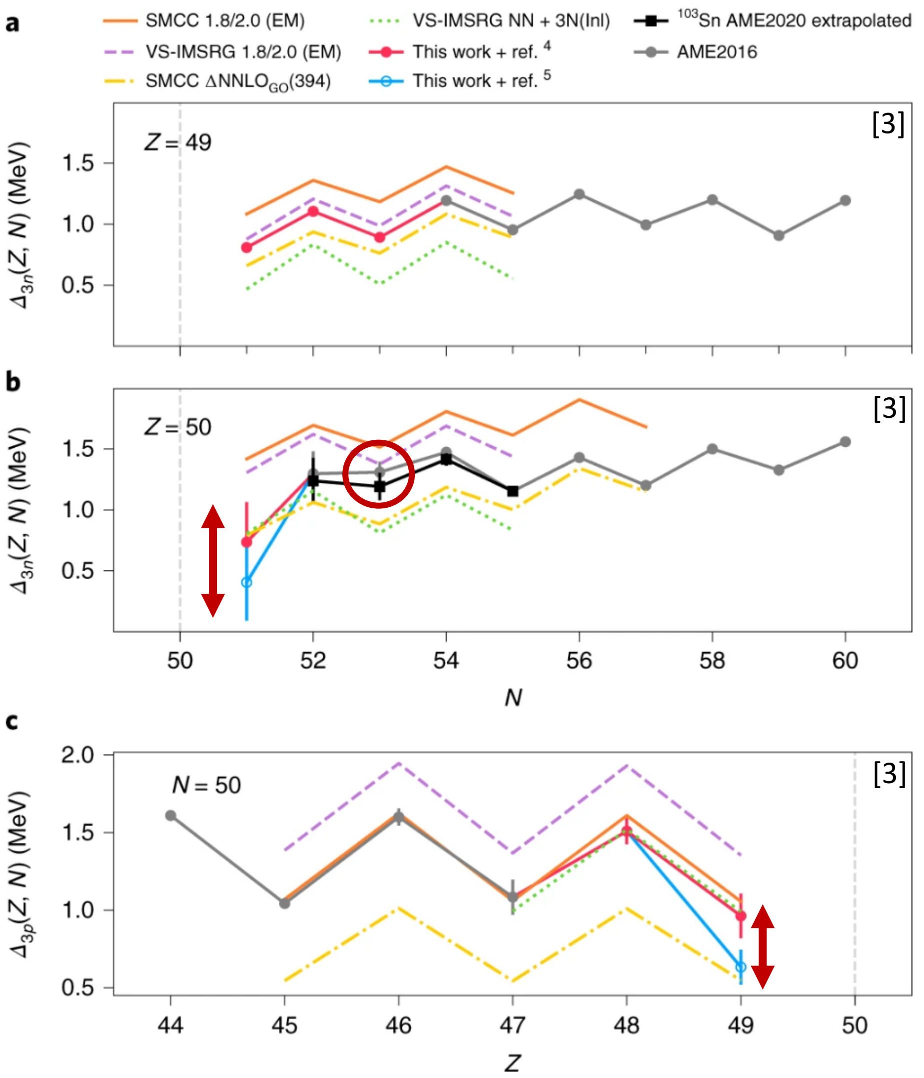
[1] Hinke et al., Nature **486,** 341-345 (2012)
[2] Lubos et al, PRL **122**, 222502 (2019)
[3] M. Mougeot et al., Nature Physics 17, 1099–1103 (2021)

Nuclear Structure Near ^{100}Sn: Indium 9/2^{+} states

- Mass of **^{100}Sn** improved by 60 keV based on Q-value to ^{100}In [1-2], confirms slight tension between values
- in-accurate **mass** for ^{103}Sn derived from Q-values **rejected** from AME2020
- extrapolated masses yield more consistent behavior
- direct mass-measurement to confirm expected behavior of mass filters



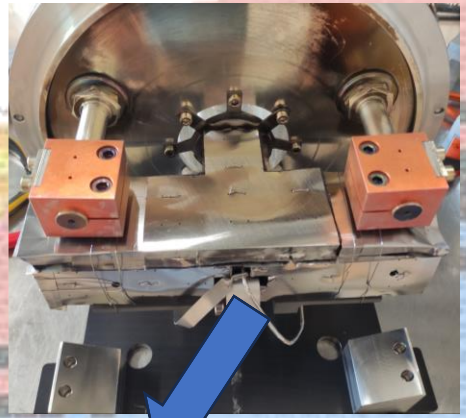
$$\Delta_{3n}(Z,N) = 0.5\times(-1)^{N}\,[B(Z,N-1) - 2B(Z,N) + B(Z,N+1)]$$

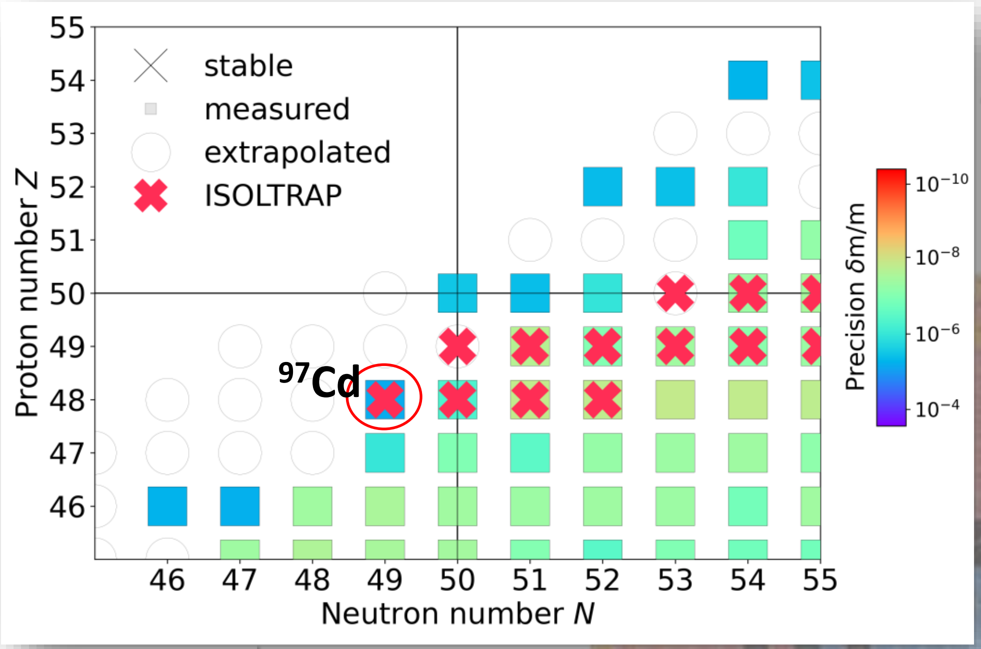


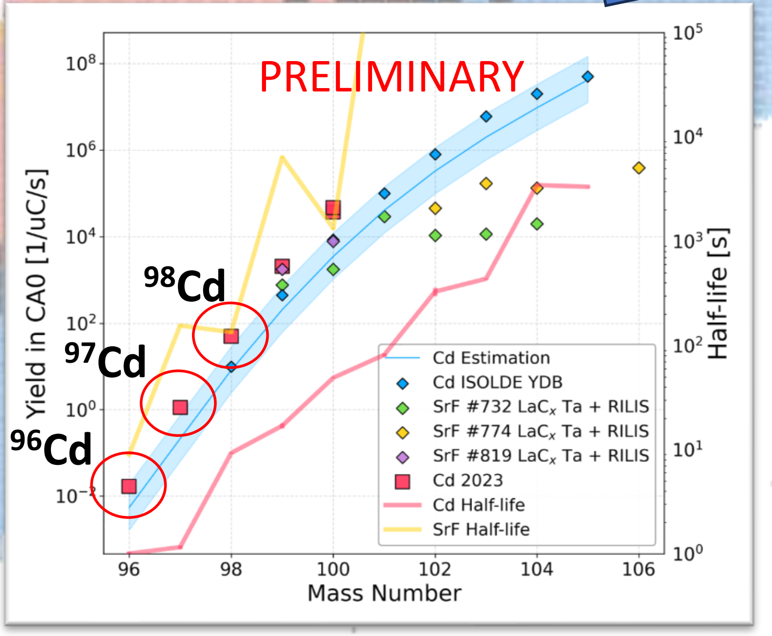
Nuclear Structure Near ^{100}Sn: Cadmium

- Testing "spider-web" ion source mount, thermal shielding, and back-of-the-line heating
- Factor 5-20 higher extracted yield than previously measured

A. Koliatos, thermal optimization, design and prototype



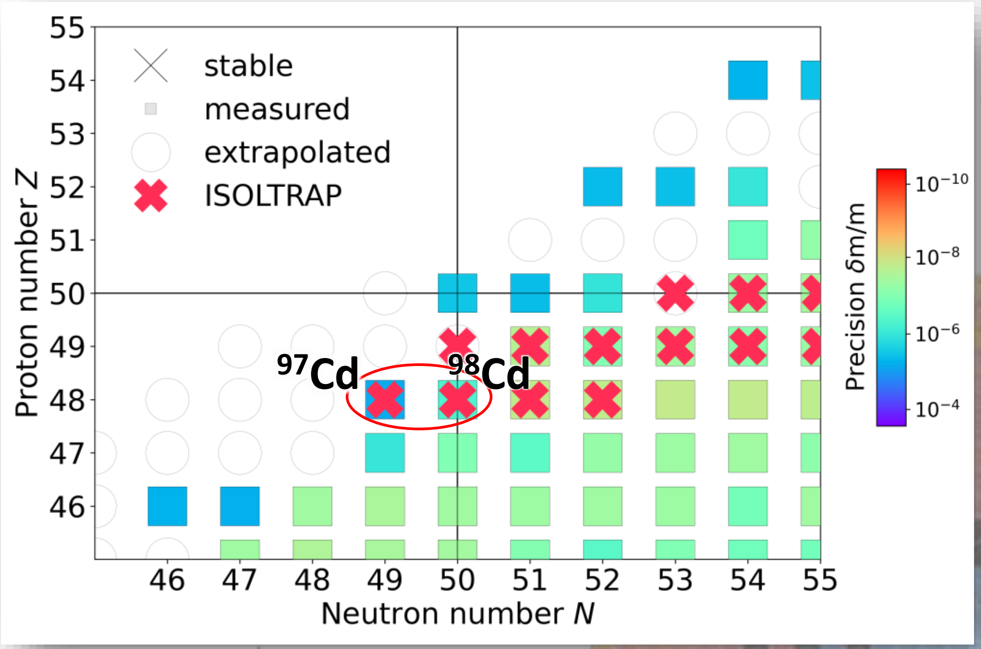


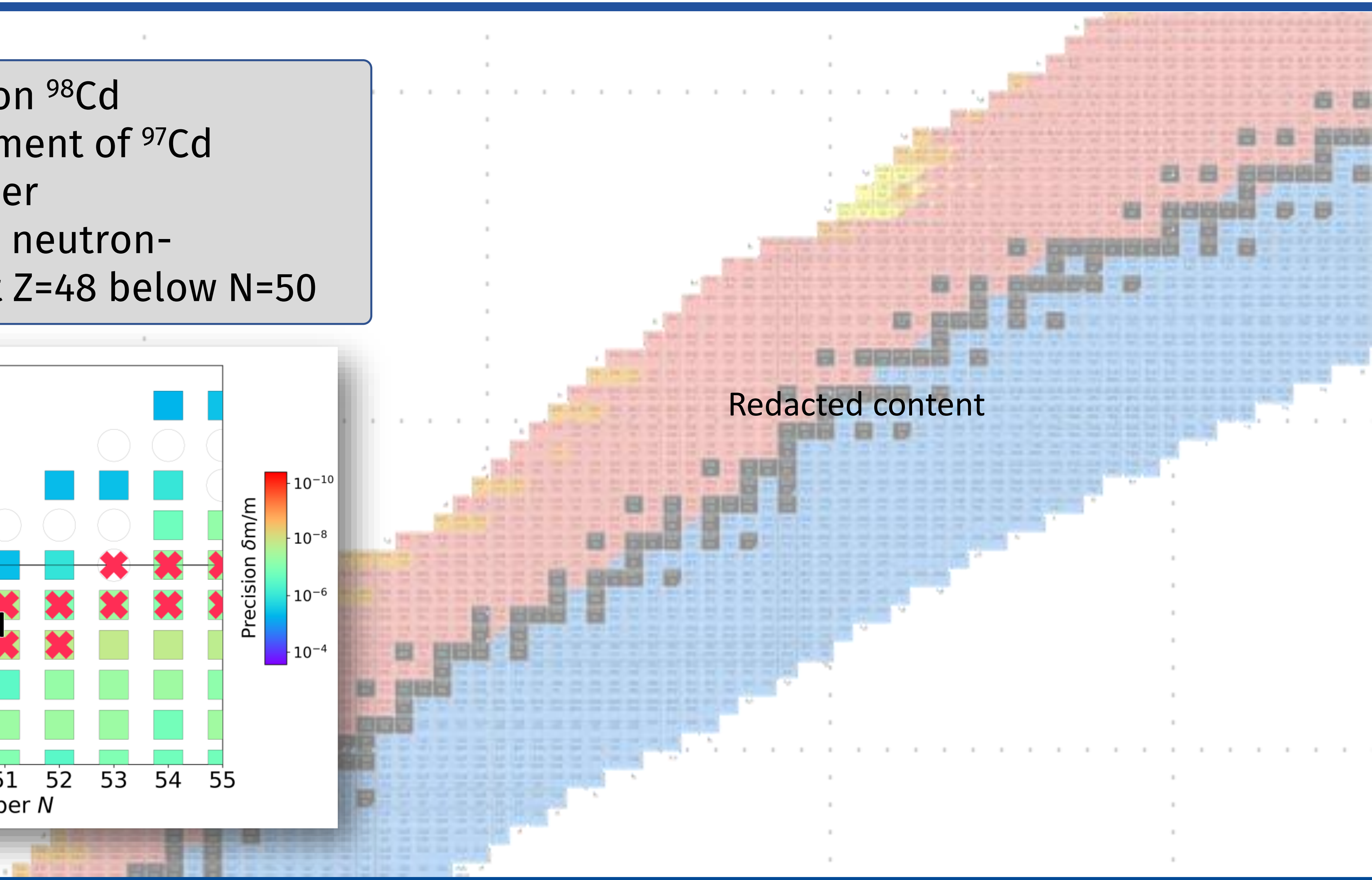


Lukas Nies
ISOLTRAP
Collaboration

Nuclear Structure Near ^{100}Sn: Cadmium

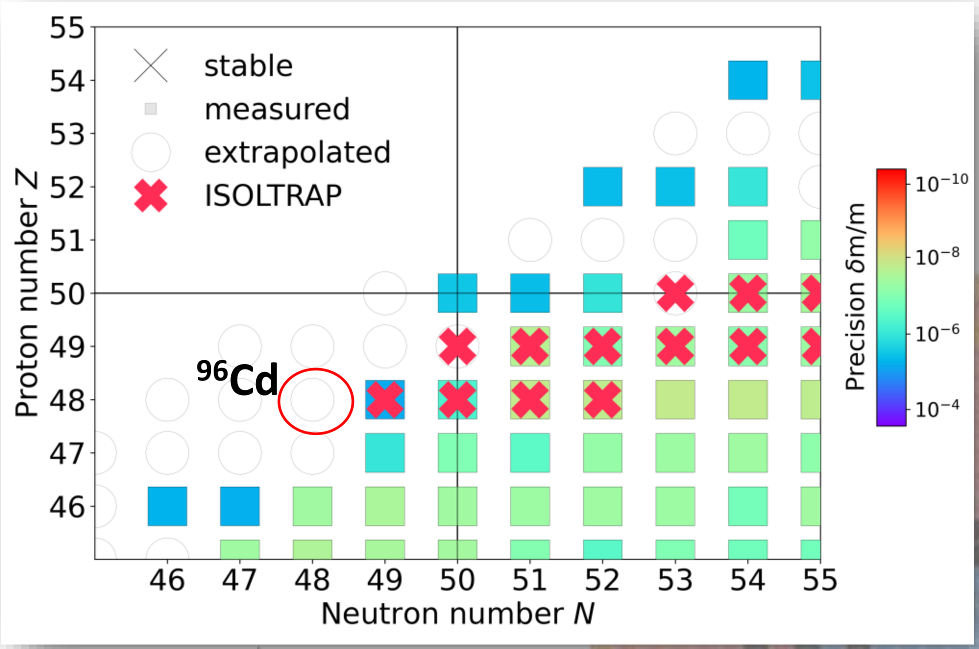
- Improved precision on ^{98}Cd
- First direct measurement of ^{97}Cd including $25/2^{+}$ isomer
- Adding data point to neutron-separation energy at Z=48 below N=50

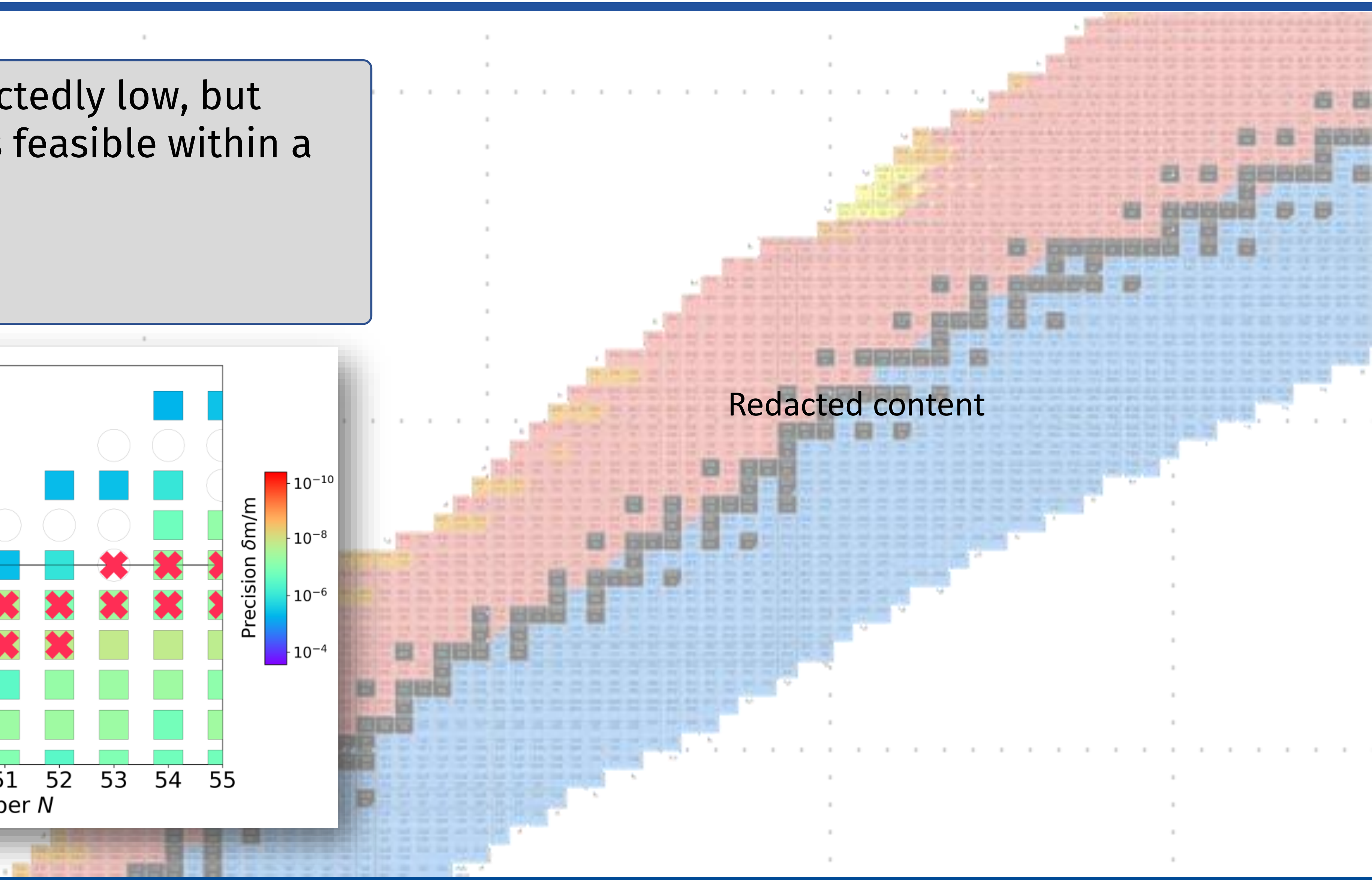




Nuclear Structure Near ^{100}Sn: Cadmium

- Yields for 96Cd expectedly low, but measurement seems feasible within a few shifts





Lukas Nies
ISOLTRAP Collaboration

Nuclear Structure Near ^{100}Sn: Tin

- in-accurate mass for ^{103}Sn derived from Q-values rejected from AME2020
- direct mass-measurement pushes data point towards expected value and confirms AME20 extrapolation

Redacted content

Lukas Nies
ISOLTRAP Collaboration

Nuclear Structure Near ^{100}Sn: Tin

- in-accurate mass for ^{103}Sn derived from Q-values rejected from AME2020
- direct mass-measurement pushes data point towards expected value and confirms AME20 extrapolation
- Ab-inition calculations from [1] suggest ^{101}Sn to be +300keV more bound than extrapolated

Redacted content

[1] Mougeot *et al.*, *Nature Physics* **17**, p. 1099–1103 (2021)

Why?

Quick recap on mass surface near ^{100}Sn – 3 slides

How?

ISOL method, progress at ISOLDE, and mass spectrometry – 7 slides

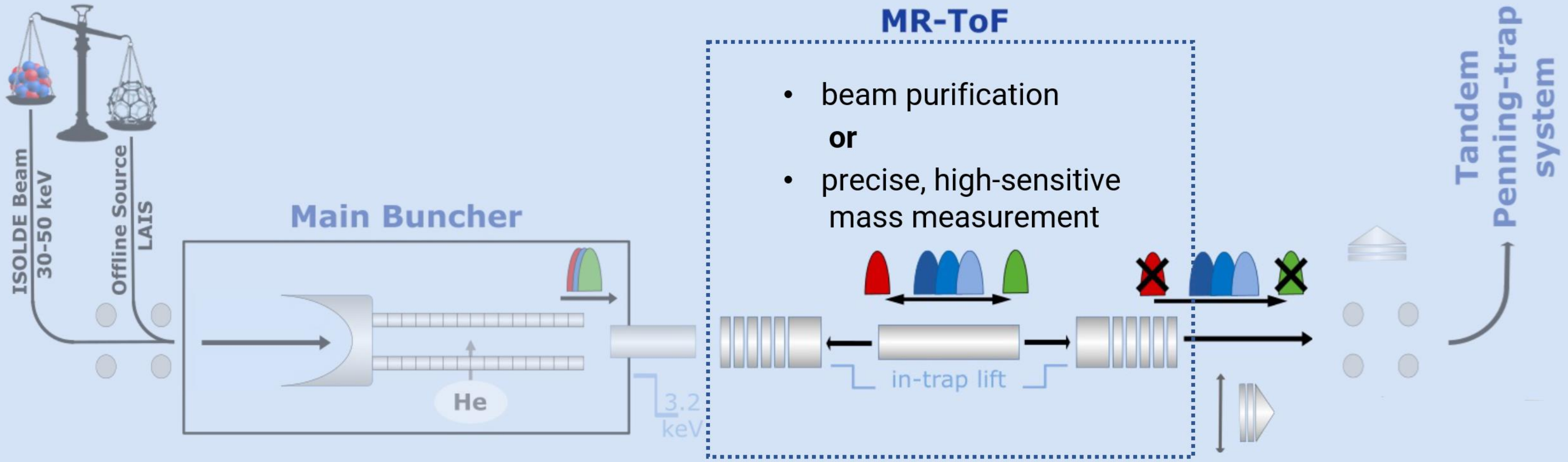
So what?

Published and preliminary results from ISOLTRAP – 8 slides

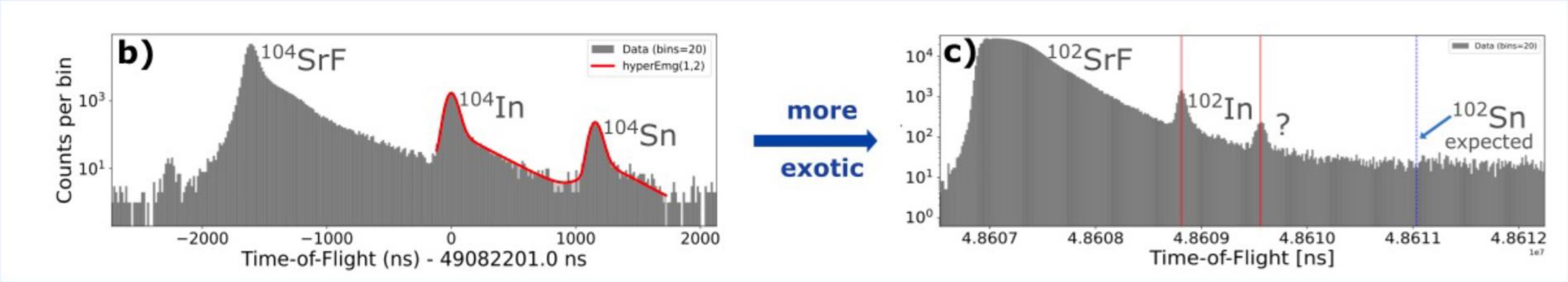
And now?

Outlook and further developments – 3 slides

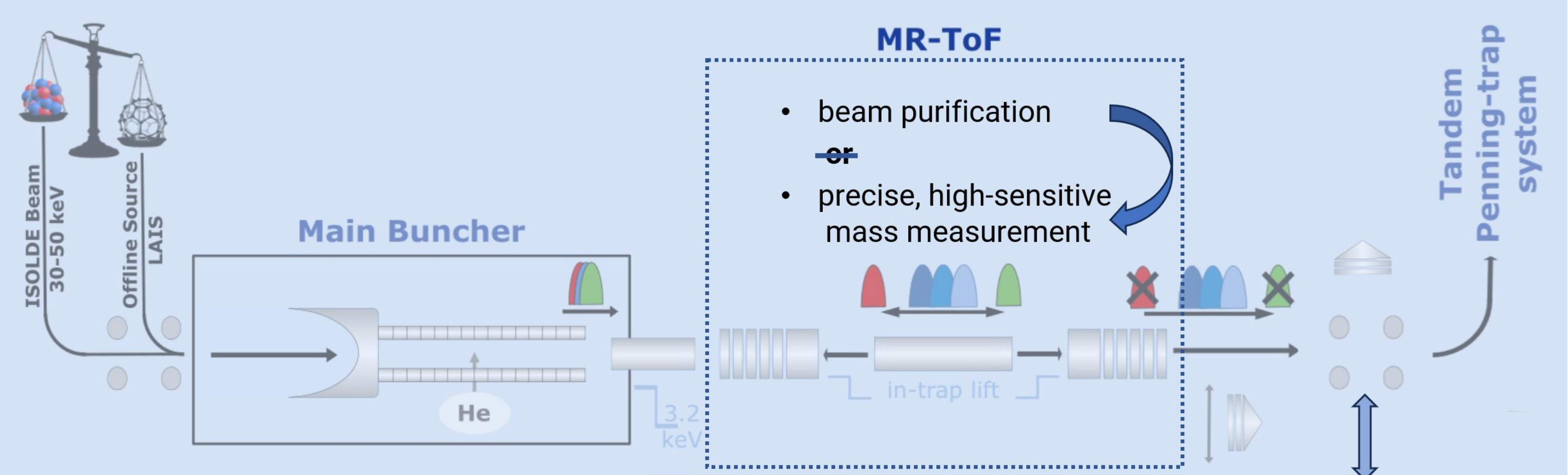
Outlook: Mass selective re-trapping



Challenge: Low production cross-sections and isobaric and molecular contamination

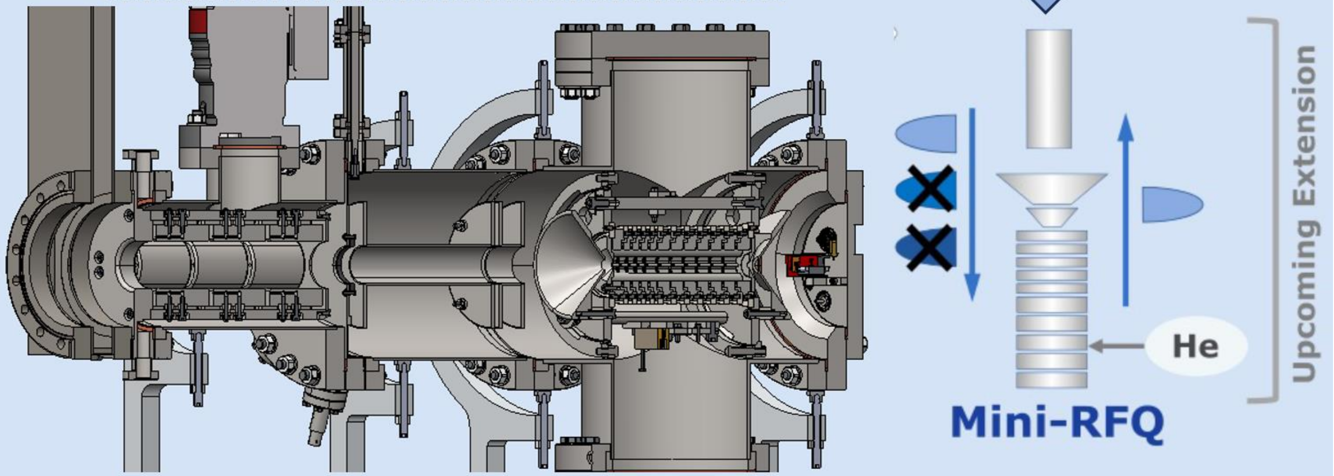


Outlook: Mass selective re-trapping



→ **Mass-selective Re-Trapping** [1]

- Contaminants suppressed by factor 10^4 [2]
- Collision-induced dissociation



[1] T.Dickel, et al., J. Am. Soc. Mass Spectrom. **28**, 1079-1090 (2017)
[2] M.P. Reiter, et al., Nuc. Instrum. Methods in Phys. Res. A **1018**, 165823 (2021)

Outlook: The Edge of Sensitivity

Scientific Committee Paper — **8 shifts remaining**

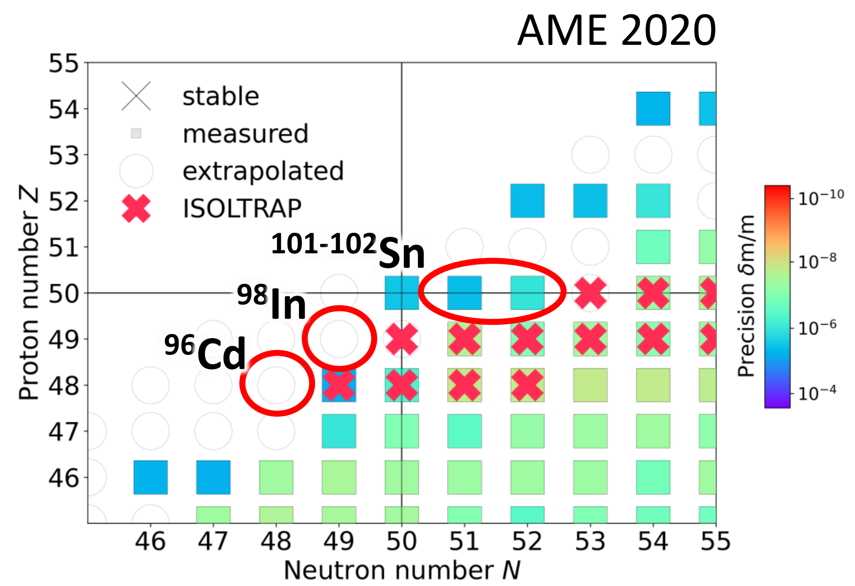
Report number	CERN-INTC-2020-025 ; INTC-P-553
Title	**Mass measurement of the proton-rich ^{99}In and self-conjugate ^{98}In nuclides for nuclear and astrophysical studies**
Project Manager/Technical Coordinator	Nies, Lukas
Author(s)	Nies, L (CERN; Greifswald U.) ; Blaum, K (Heidelberg, Max Planck Inst.) ; Karthein, J (CERN; Heidelberg, Max Planck Inst.) ; Kulikov, I (Darmstadt, GSI) ; Litvinov, Yu A (Darmstadt, GSI) ; Lunney, D (IJCLab, CNRS, Orsay) ; Manea, V (IJCLab, CNRS, Orsay) ; Mougeot, M (CERN) ; Ong, W J (LLNL, Livermore; JINA) ; Schatz, H (JINA; Michigan State U., NSCL ; Michigan State U.) *Show all 14 authors*

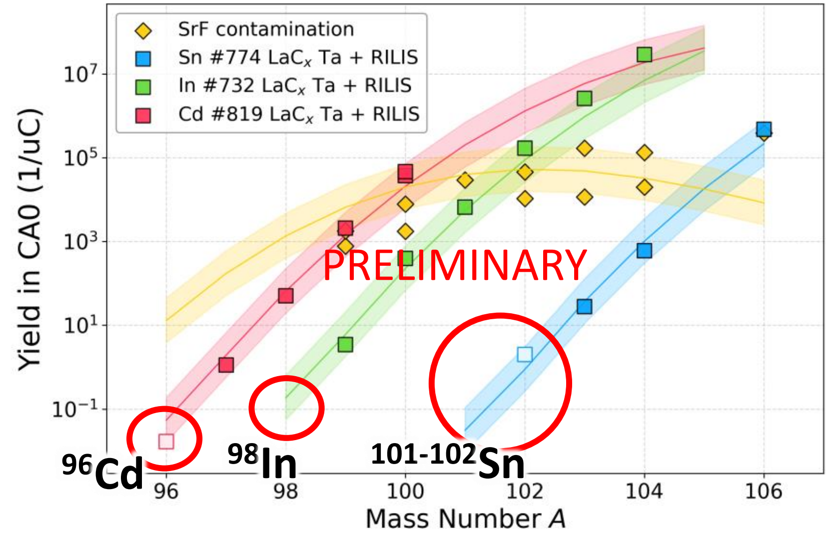
Scientific Committee Paper — **8 shifts remaining**

Report number	CERN-INTC-2022-031 ; INTC-P-637
Title	**Closing in on ^{100}Sn: Mass Measurements of the Neutron Deficient N=51-53 Tin Isotopes**
Project Manager/Technical Coordinator	Nies, Lukas
Author(s)	Nies, L (CERN/University of Greifswald (DE)) ; Blaum, K (Heidelberg, Max Planck Inst.) ; Huang, W J (Advanced Energy Science and Technology Guangdong Laboratory, Huizhou 516003, China) ; Karthein, J (Massachusetts Institute of Technology, Cambridge MA 02139, USA) ; Litvinov, Yu A (GSI Helmholtzzentrum für Schwerionenforschung GmbH, Planckstraße 1, 64291 Darmstadt, Germany) ; Lunney, D (Université Paris-Saclay, CNRS/IN2P3, IJCLab, 91405 Orsay, France) ; Manea, V (Université Paris-Saclay, CNRS/IN2P3, IJCLab, 91405 Orsay, France) ; Mougeot, M (Heidelberg, Max Planck Inst.) ; Naimi, S (Université Paris-Saclay, CNRS/IN2P3, IJCLab, 91405 Orsay, France and RIKEN, Japan) ; Schweiger, Ch (Heidelberg, Max Planck Inst.) *Show all 13 authors*

Scientific Committee Paper — **New: 18 shifts**

Report number	CERN-INTC-2023-075 ; INTC-P-682
Title	**Mass measurement of the neutron-deficient ^{96}Cd with ISOLTRAP**
Project Manager/Technical Coordinator	Mougeot , Maxime
Author(s)	Mougeot, Maxime (University of Jyväskylä)





Summary

- Overview of the current state of **ISOL production of RIBs** near ^{100}Sn and their limitations
- Current status of the **ISOLTRAP** MR-ToF MS performance
- **Nuclear structure** investigation near doubly-magic ^{100}Sn through atomic masses
- Design of sensitivity-enhancing **mass-selective re-trapping** Paul trap