Mass measurements of exotic neutron-deficient nuclides below ^{100}Sn at the FRS Ion Catcher and at JYFLTRAP

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for the IGISOL and FRS Ion Catcher Collaboration

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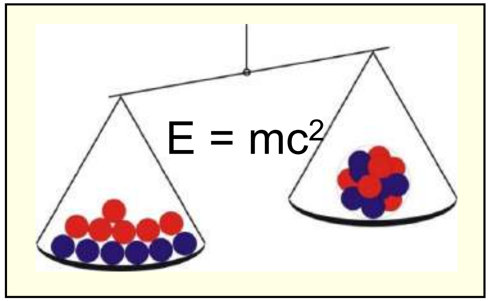
- Motivation
- Mass measurements at the JYFLTRAP @ IGISOL
- Mass measurements at the FRS Ion Catcher @ GSI
- Summary and Outlook

Motivation for mass measurements

Mass excess



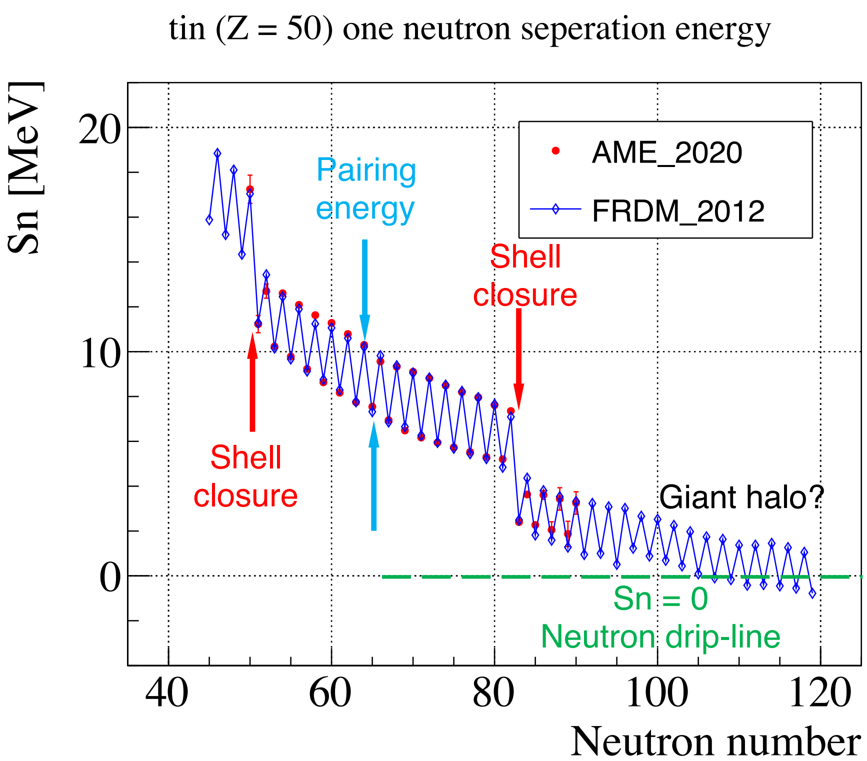
Nuclear mass ↔ nuclear binding energy:

$$M(N,Z) = Z \cdot m_p + N \cdot m_n - B(N,Z)/c^2$$

Several masses ↔ Binding energy derivatives, such as S_n, S_{2n}….:

$$S_n(N,Z) = M(N-1,Z) + m_n - M(N,Z) = B(N,Z)/c^2 - B(N-1,Z)/c^2$$

Nuclear structure



Nuclear astrophysics

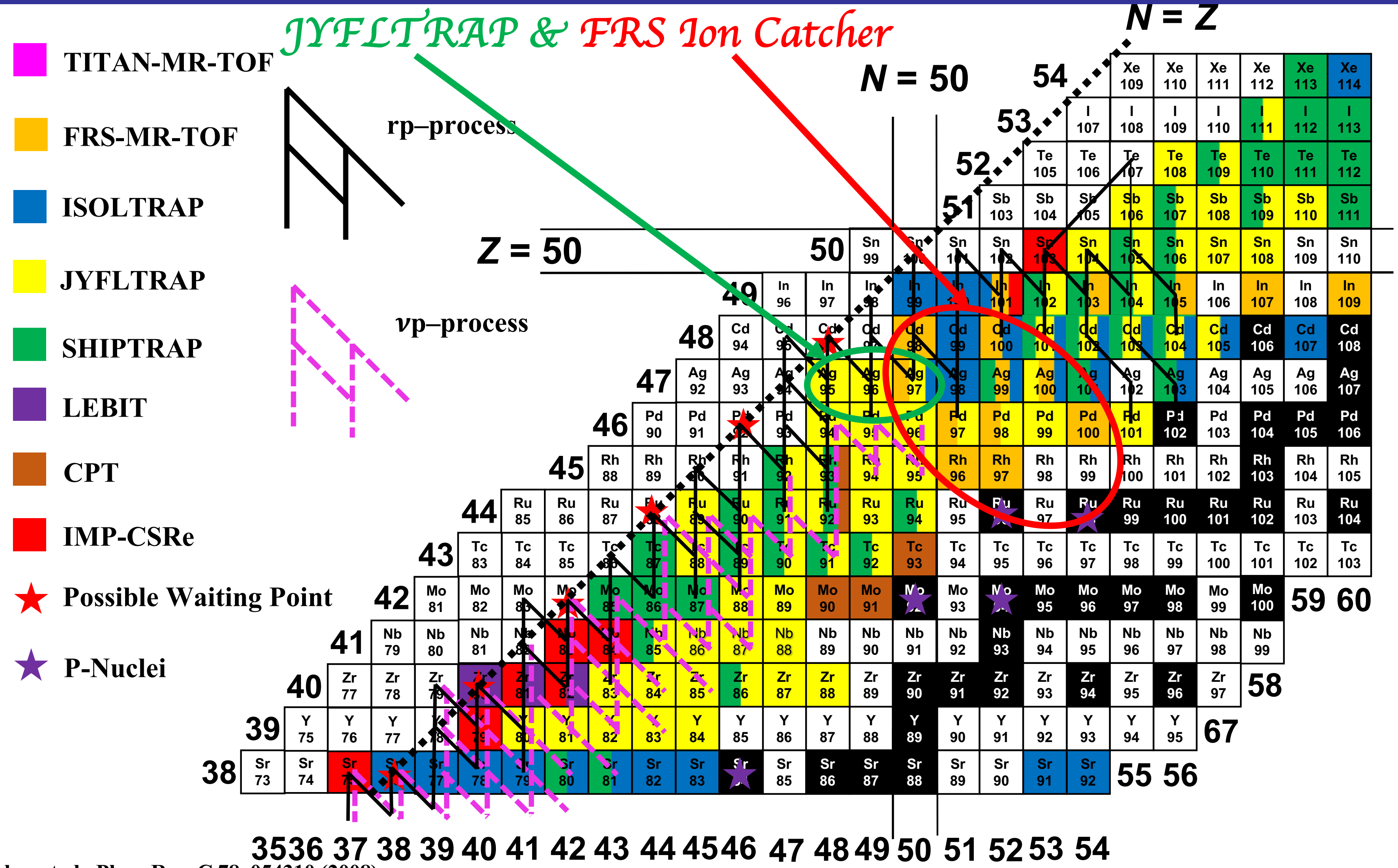
For example:
Rp process

X-ray burst

J. Grindlay et al., Astrophys. J. 205 (1976) L127.

time−scale $\propto e^{(Q/kT)} / A(Q)$
isotope production $\propto A(Q) \cdot e^{(Q/kT)}$
energy production $\propto A(Q) \cdot Q \cdot e^{(Q/kT)}$
Common parameter: Q (mass difference)

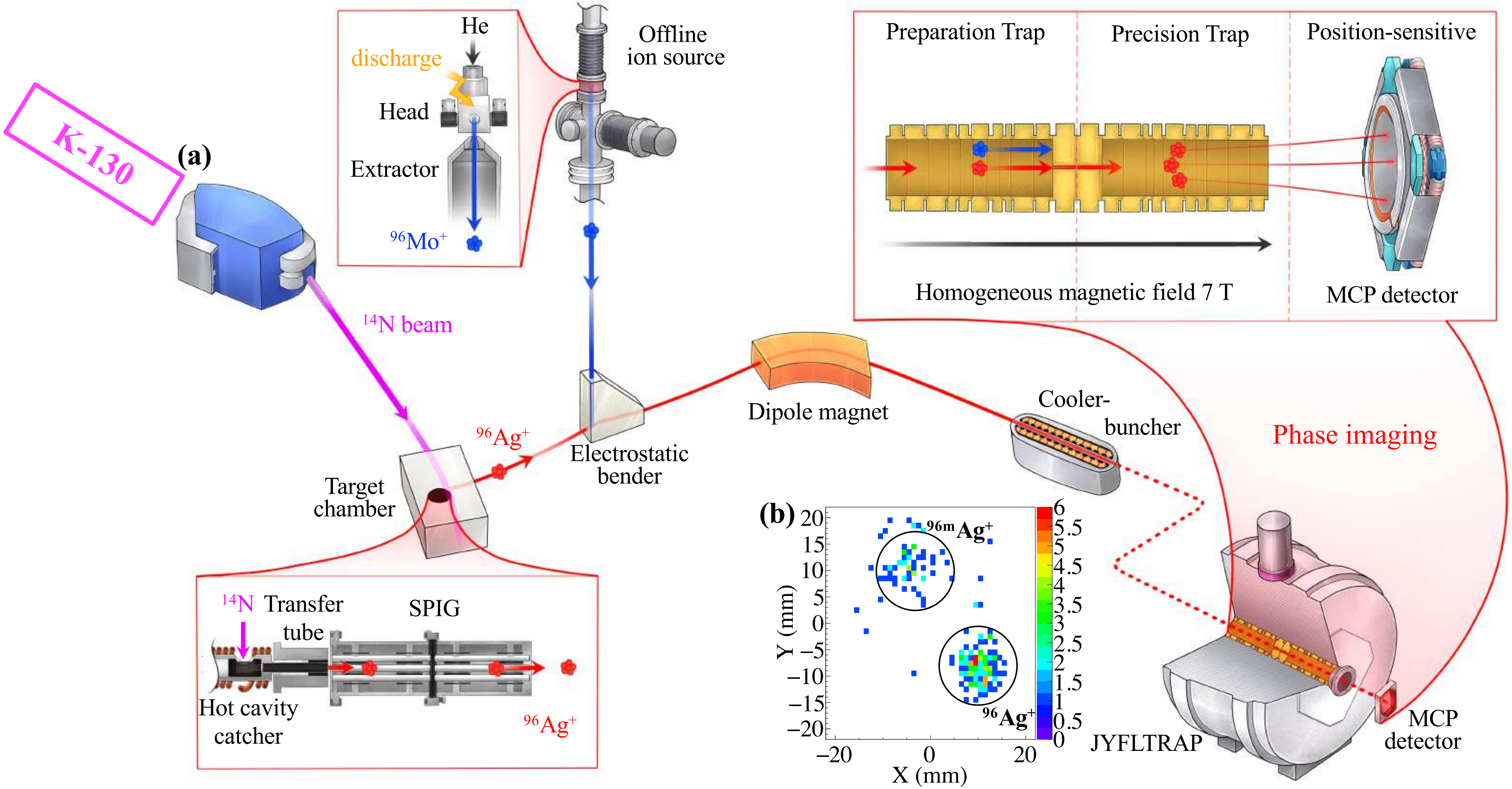
Current status of Mass measurements of *N*=*Z* nuclei and the vicinity



C. Weber et al., Phys. Rev. C 78, 054310 (2008)
A. Kankainen et al., Phys. Rev. Lett. 101, 142503
V.-V. Elomaa et al., Phys. Rev. Lett. 102, 252501 (2011)
E. Haettner et al., Phys. Rev. Lett. 106, 122501 (2011)
F. Herfurth et al., Eur. Phys. J. A, 47,75 (2011)
X. Tu et al., Phys. Rev. Lett. 106, 112501 (2011)
Y.M. Xing, et al., Physics Letters B 781 358–363 (2018)

M. Vilén et al., Phys. Rev. C 100, 054333 (2019)
C. Hornung et al., Physics Letters B 802, 135200 (2020)
M. Mougeot et al., Nature Physics 17, 1099 (2021)
A. Hamaker, et al., Nat. Phys. 17, 1408–1412 (2021).
A. Mollaebrahimi et al., Physics Letters B 839, 137833 (2023)
L. Nieset al., PRL, accepted (2023)

The Ion Guide Isotope Separator On-Line facility (IGISOL)

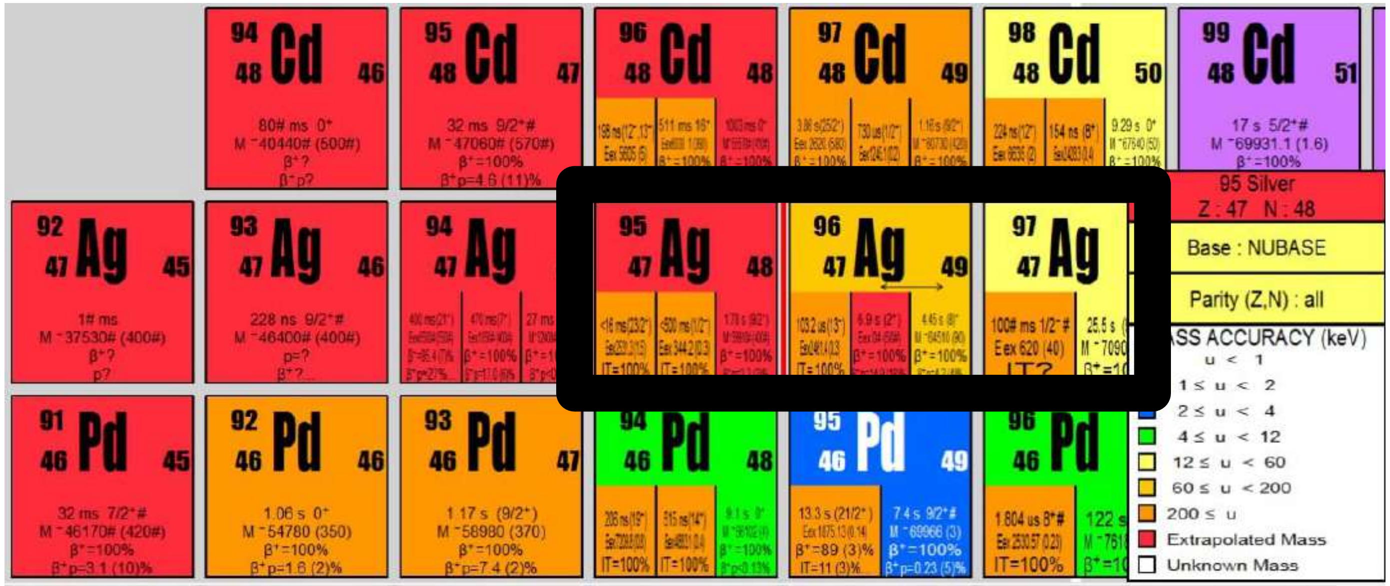


- **Production of ions of interest:**
  - **Heavy ion induced fusion-evaporation**
  - **Target**
    - **natural-abundance/enriched target: ~ few mg/cm^2**

- **Production of reference nucleus:**
  - **Co-produced from the Target chamber**
  - **Electrode of reference material installed in the spark source**

95-97Ag mass measurements

Mass measurements: ground-state nuclei 95–97Ag and an isomeric state of ^{96m}Ag



Eronen et al., EPJA 48 (2012) 46

Cyclotron frequency:

$$\nu_c = \nu_+ + \nu_- = \frac{qB}{2\pi m}$$

Frequency ratio *r*:

$$r = \frac{\nu_1}{\nu_2}$$

***Q*-value:**

$$Q = M_2 - M_1 = (r-1)(M_1 - m_e) + m_e$$

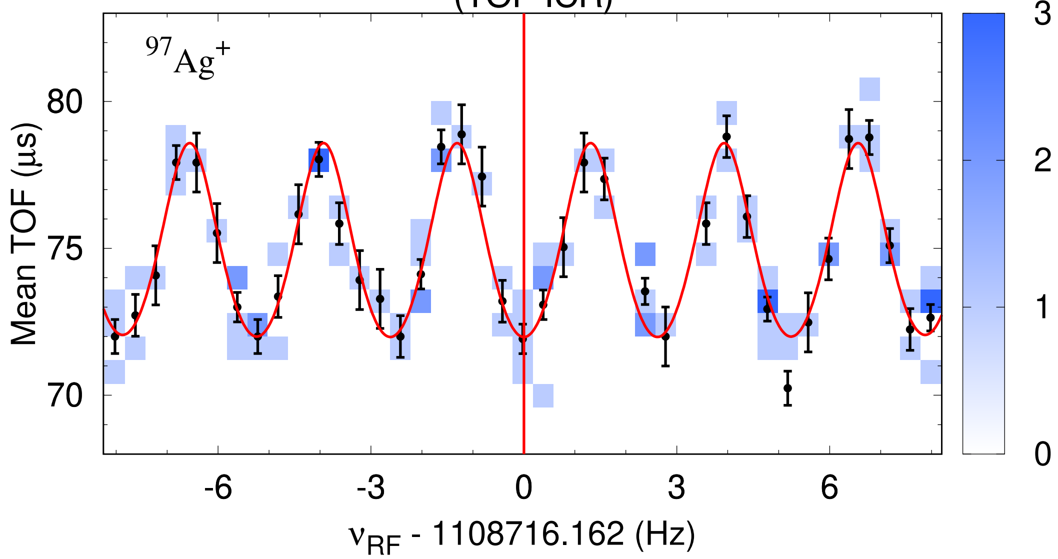
Mass:

$$M_2 = r(M_1 - m_e) + m_e$$

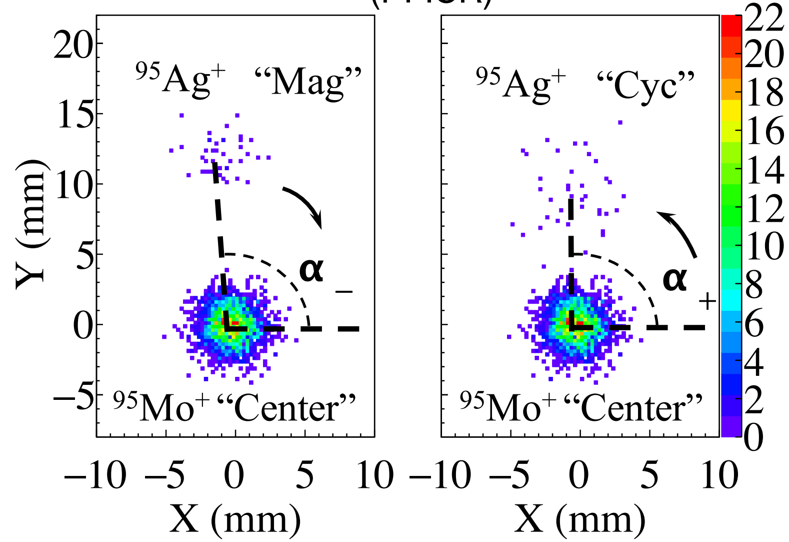
S. Eliseev et al., Phys. Rev. Lett. **110**, 082501 (2013).
D. A. Nesterenko, et al., European Physical Journal A 54, 0 (2018).

Uncertainty of around 1 keV

Time-of-Flight Ion-Cyclotron-Resonance (TOF-ICR)



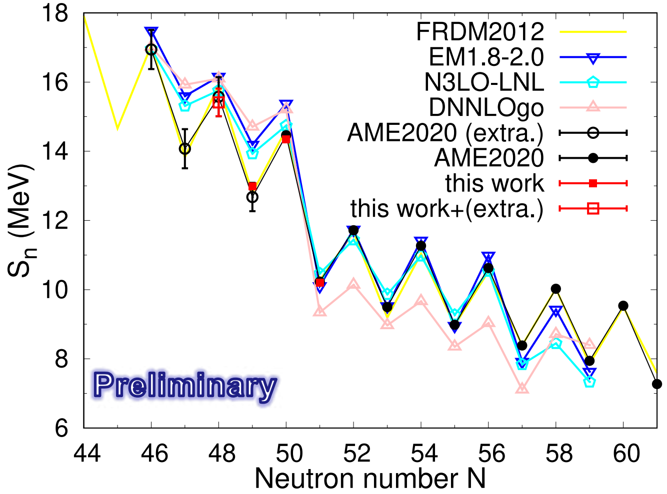
Phase-imaging Ion-Cyclotron-Resonance (PI-ICR)

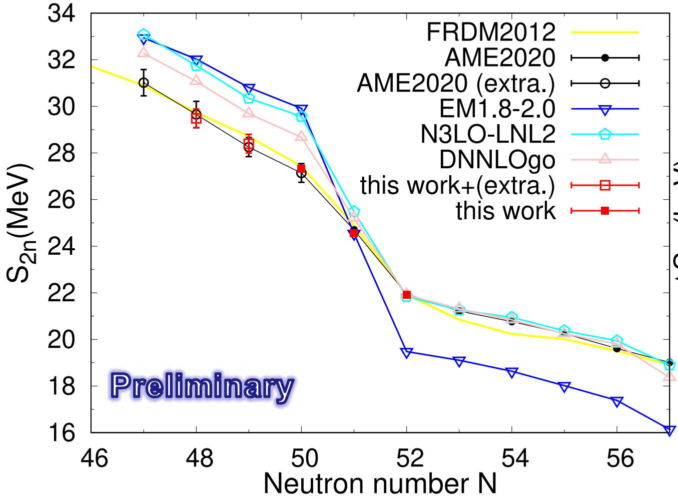


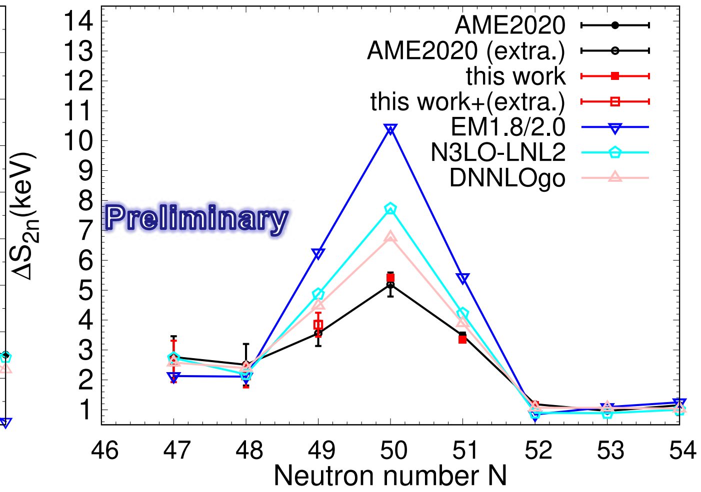
ab initio calculations

ab-initio calcluation cross the N=50 shell

B. Hu, J. D. Holt et al.

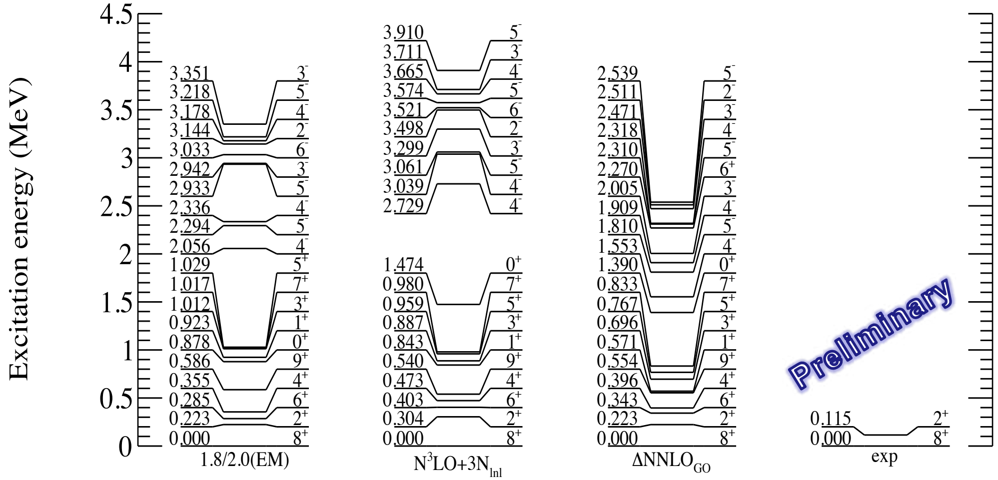






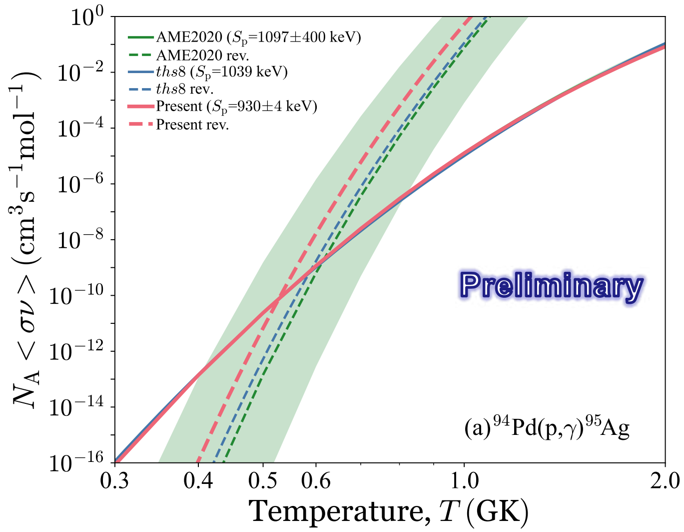
Z. Ge, M. Reponen, T. Eronen et al. in preparation

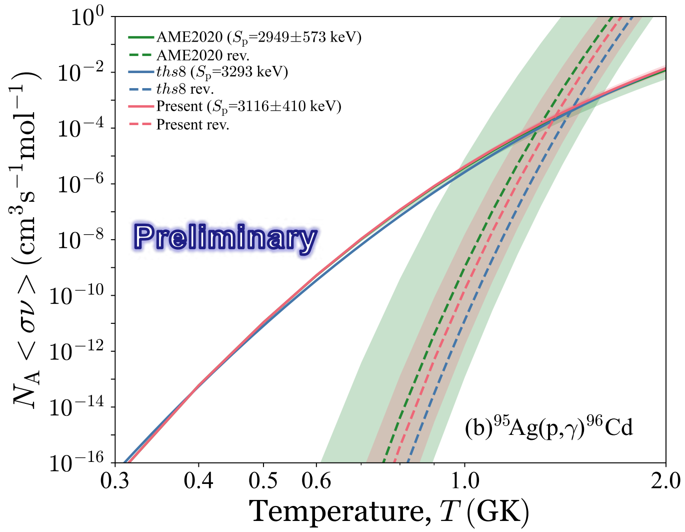
- Identification of **nuclear isomer of ^{96m}Ag**
- understanding of the **nuclear structure at N=50 shell**
- **Benchmark** nuclear models and shell model calculations



energy level of 96Ag isomeric state

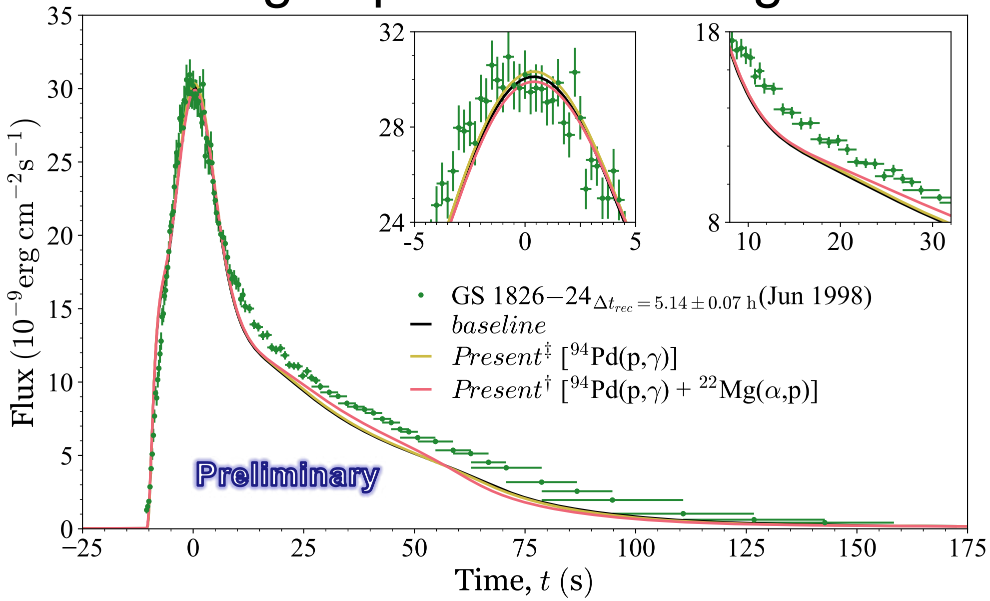
Influence on Forward and reverse thermonuclear reaction rates





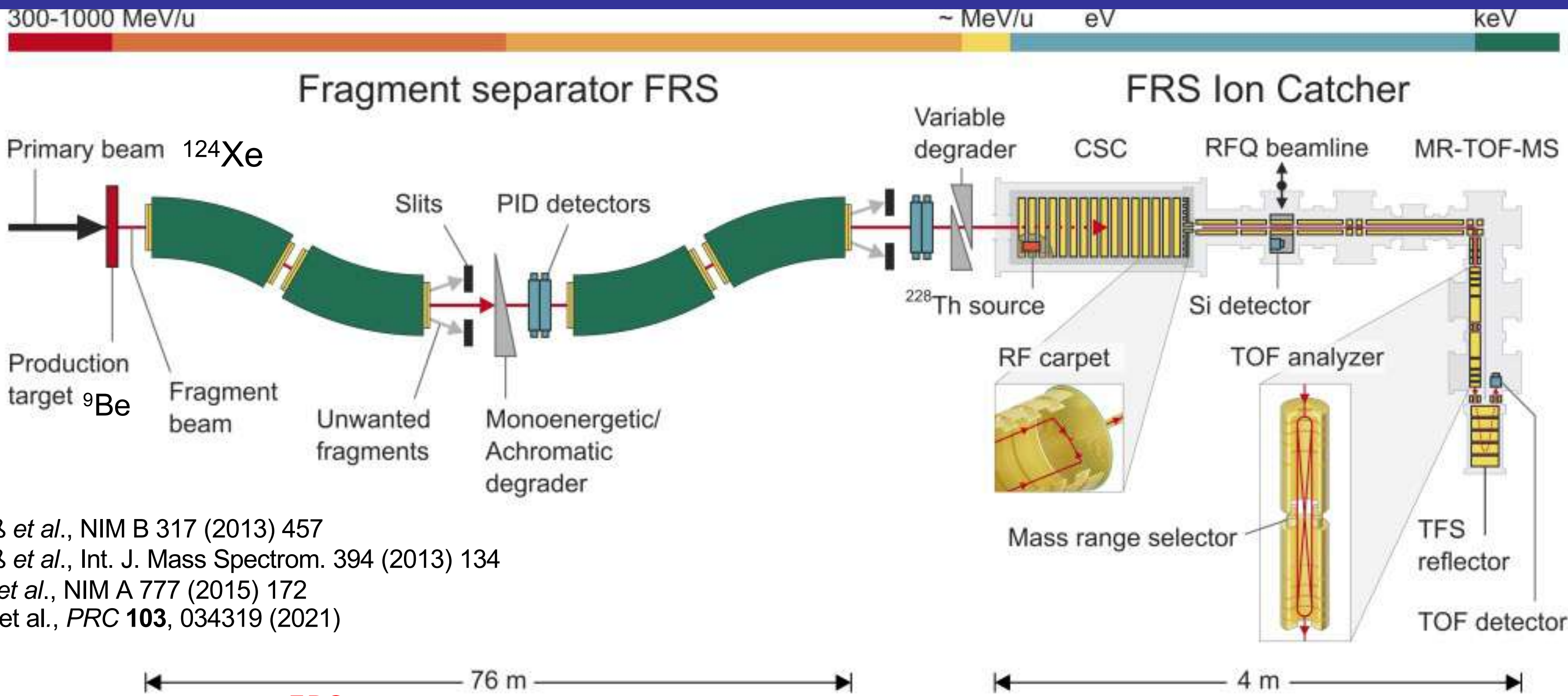
Impact on averaged periodic burst light curves

- Refined the reaction rate of rp-process
- *Good agreement between the modelled and observed burst light curves*
- *Influence on the final abundance of the burst ash composition*
- *Impact on neutron star crusts*



Y. Lam, A. Heger, S. E. Woosley et al.,GS 1826−24 clocked burster

The FRS Ion Catcher at GSI



W.R. Plaß *et al.*, NIM B 317 (2013) 457
W.R. Plaß *et al.*, Int. J. Mass Spectrom. 394 (2013) 134
T. Dickel *et al.*, NIM A 777 (2015) 172
I. Mardor et al., *PRC* **103**, 034319 (2021)

- Fragment separator FRS:
  - Production & separation & PID of exotic nuclei via projectile fragmentation/fission
- Cryogenic Stopping cell (CSC):
  - universal, fast, efficient stopping and extraction of cooled short-lived ($T_{1/2}$ ~ ms) exotic nuclei
- RF Quadrupole beamline:
  - for low-energy ion transport
  - Operate as a mass filter
  - Background Suppression (molecular and ions)

- MR-TOF-MS

fast, sensitive, broadband and non-scanning
  - Resolving power: up to 1,000,000
  - resolve isomers (hundreds of keV)
  - Best mass accuracy: 1.7×10^{-8}
  - Sensitivity: a few detected ions
  - Rate capacity: 10^6 ions/s
  - Cycle times: a few ms

Mass measurements from Projectile Fragmentation of ^{124}Xe

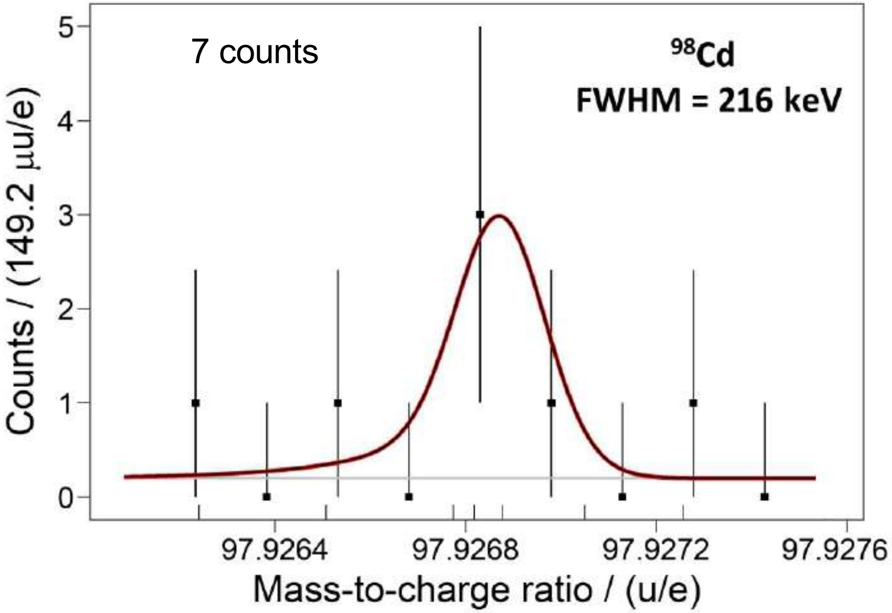
Measurements from recent two Projectile Fragmentation experiments:

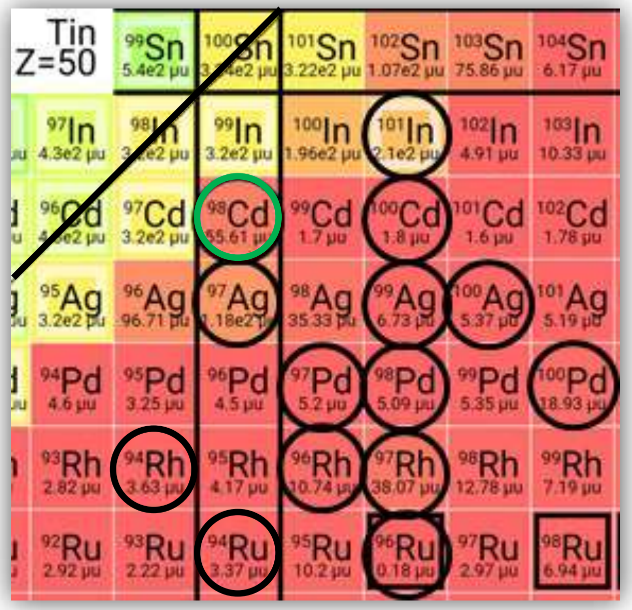
14 ground states

2 isomers: ^{94m,97m}Rh

- **High sensitivity** and **high accuracy** of MR-TOF-MS
- MR-TOF-MS Resolving power about 400,000

ME: –67633 ± 60 keV

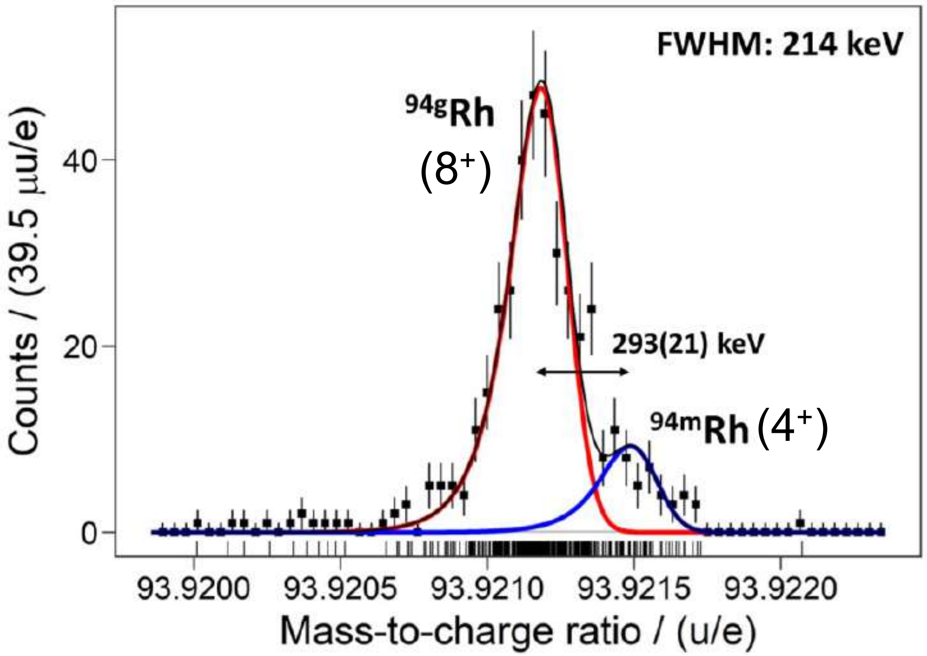


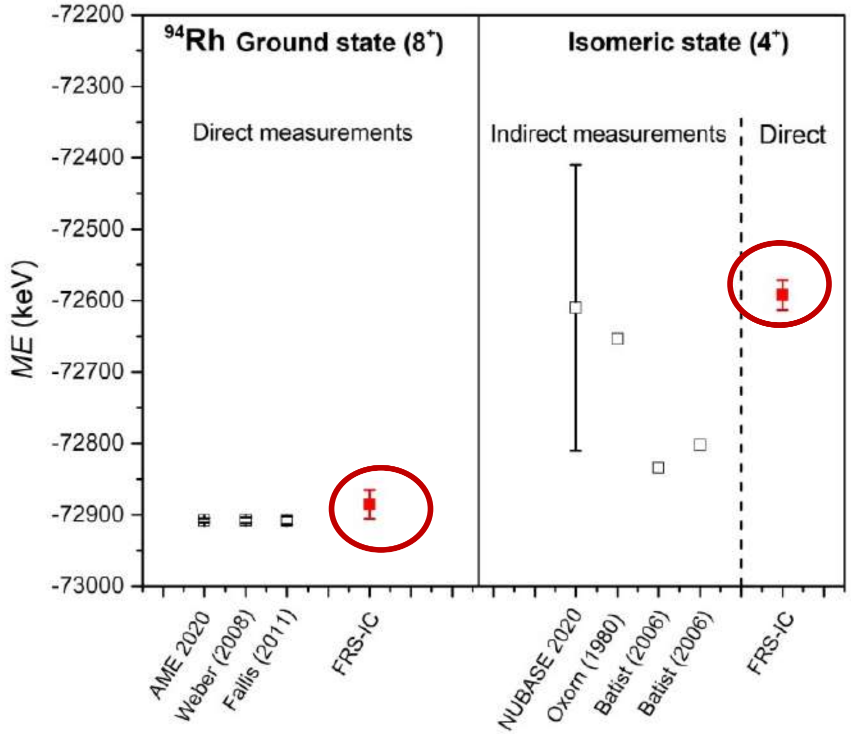


A. Mollaebrahimi et al., Physics Letters B 839 (2023) 137833

Due to the **high sensitivity** and **non-scanning** measurement technique, MR-TOF-MS is **an ideal device for new isomers search**

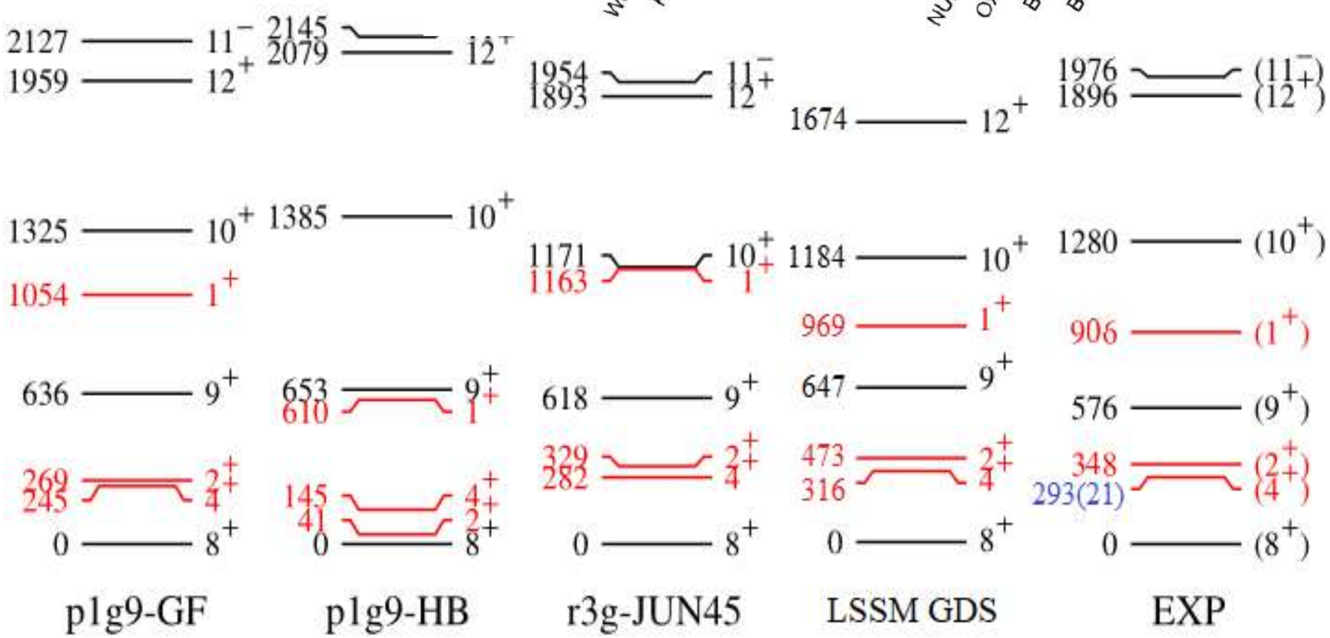
^{94}Rh ground state and Isomeric state





relative order of states and assigned spins are concluded

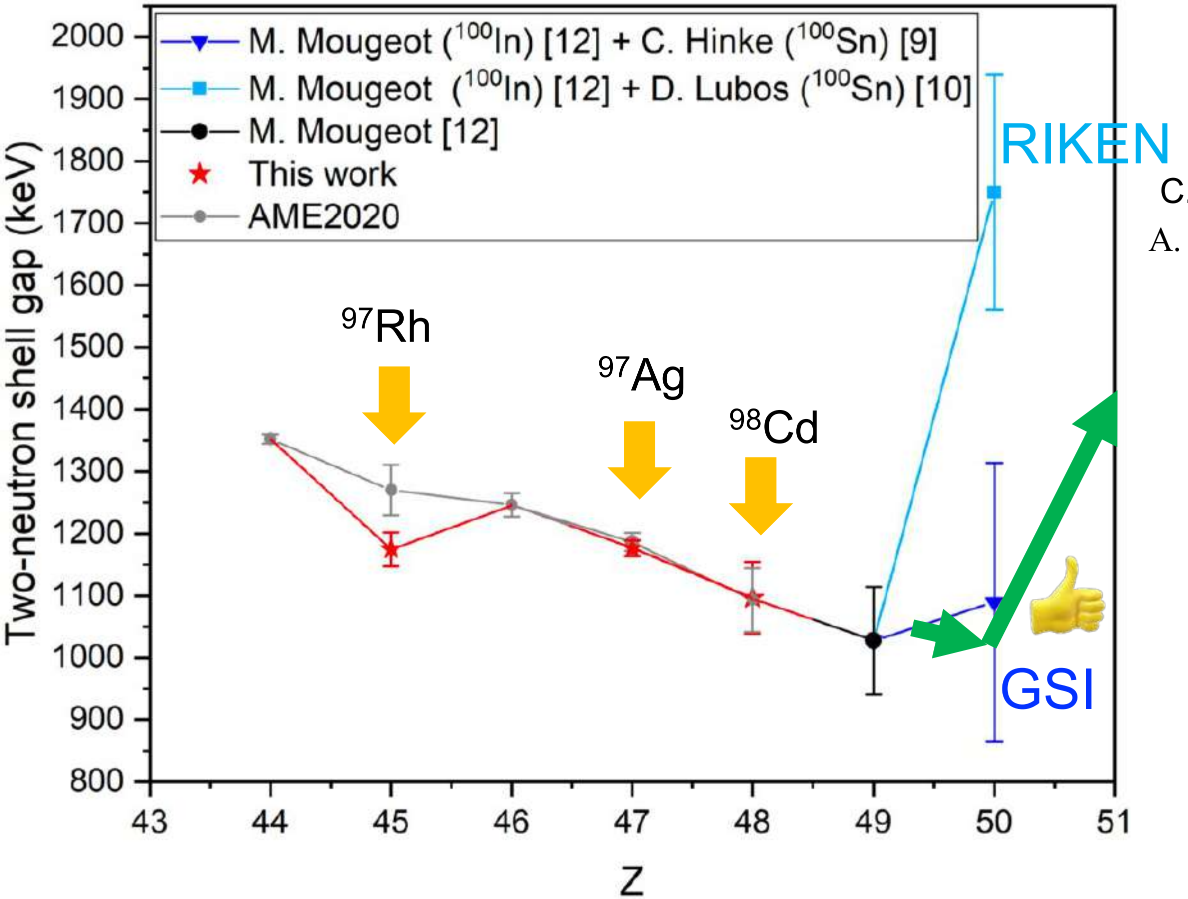
Shell model calculations



K. Oxorn et al., *Physik A* **294** (1980)
C. Weber et al., *Physical Review C* **78** (2008)
L. Batist et al., *Eur. Phys. Jour. A* **29** (2006)

R. Gross et al., *Nuclear Physics A* **267** (1976)
H. Herndi et al., *Nuclear Physics A* **627** (1997)
M. Honma et al., *Physical Review C* **80** (2009)

Two-neutron shell gap (shifted for N+2)



C. Hornung et al., *Physics Letters B* **802** (2020)

A. Mollaebrahimi et al., Physics Letters B 839 (2023)

$$\Delta_{2n}(Z, N+2) = ME(Z, N) - 2ME(Z, N+2) + ME(Z, N+4)$$

- The mass of ^{100}In is measured in CERN [**M. Mougeot et al**] paper and then the mass of ^{100}Sn is derived by using two Q_{EC} values from GSI [**C. Hinke et al.**] and RIKEN [**D. Lubos et al.**]
- The Q_{EC} from RIKEN **[D. Lubos et al.] was unfavorable** in comparison to ab-initio calculation done in CERN [M. Mougeot et al.]

M. Mougeot et al., *Nature Physics* (2021)
C. Hinke et al., *Nature* 486 (2012)
D. Lubos at al., *Physical Review* Letters 122 (2019)
A. Mollaebrahimi et al., Physics Letters B 839 (2023) 137833

Gamow-Teller strength for even-even isotones at *N=50*

Gamow-Teller strength of ^{98}Cd

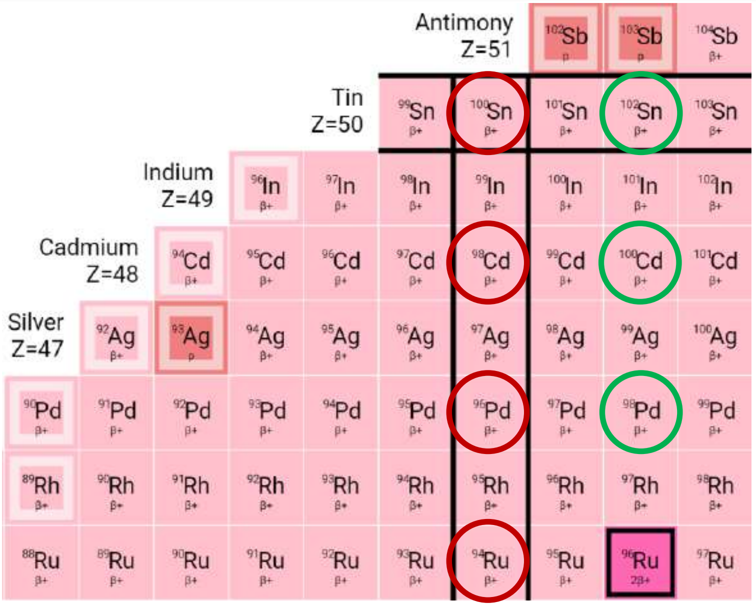
- New half-life measured
  $t_{1/2} = 9.29 \pm 0.1$ s [1]
- Latest decay scheme [2]
- Direct measurement of Q-Value ($\boldsymbol{Q_{EC}}$)

Direct mass measurement in this work:

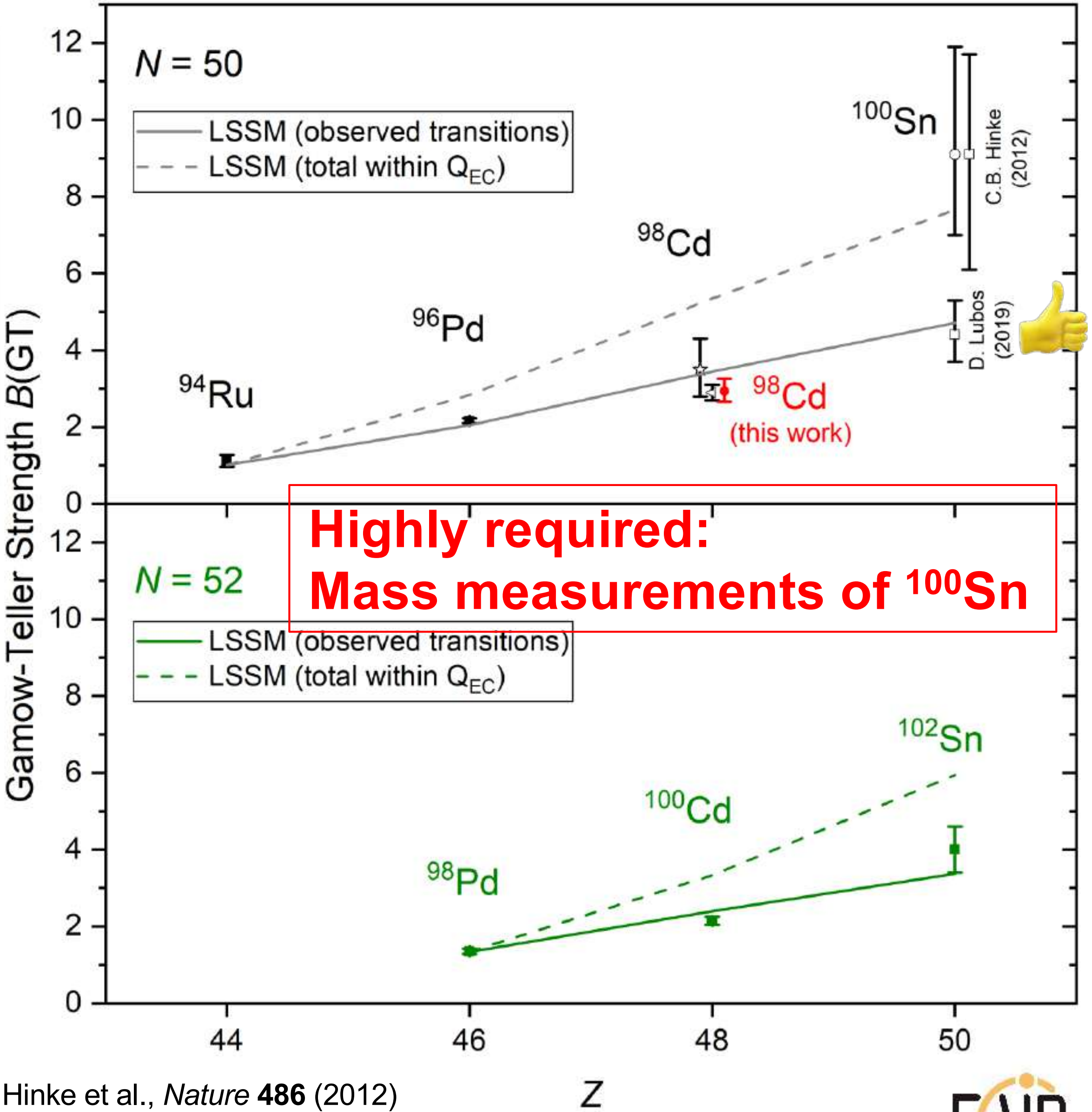
$$\boldsymbol{Q_{EC} = 5437 \pm 67\ \text{keV}}$$

The summed Gamow-Teller strength:

$$\boldsymbol{B(\text{GT}) = 2.94\,^{+0.32}_{-0.28}}$$



[1] J. Park et al., *Physical Review C* **99** (2019)
[2] J. Chen et al., *Nuclear data sheets* **164** (2020)



Highly required:
Mass measurements of ^{100}Sn

A. Plochocki et al., *Zeitschrift fur Physik A* **342** (1992)
A. Stolz at al., *GSI Scientific Reports* **1** (2001)
A. Stolz at al., AIP conference proceeding **610** (2002)

C. Hinke et al., *Nature* **486** (2012)
D. Lubos at al., *Physical Review Letters* **122** (2019)
A. Mollaebrahimi et al., Physics Letters B 839 (2023) 137833

Summary and outlook

- Mass measurements of ground states and isomers by fusion evaporation reactions at IGISOL with JYFLTRAP
  - mass measurements of ^{95}Ag for the first time
  - New direct mass measurement of $^{96-97}$Ag and first direct measurement of the isomer ^{96m}Ag
  - Ab-initio calculations of nuclear biding for the Ag isotopes and implications of N=50 shell
  - Impact on nuclear astrophysics
- Mass measurement of ground states and isomers produced by projectile fragmentation of ^{124}Xe at Fragment Separator (FRS) and FRS-Ion Catcher (FRS-IC)
  - direct mass measurement of 14 ground states and 2 isomers: ^{94m,97m}Rh
  - first direct mass measurements of ^{98}Cd, ^{97}Rh
  - Confirm of the shifted two-neutron shell gap results from CERN
  - Systematic studies on Gamow-Teller transition in even-even isotones at *N=50*
- **Outlook: towards more exotic nuclei for mass measurements of heavy *N=Z* nuclei up to ^{100}Sn @ IGISOL/RIKEN/GSI-FAIR**

(Z. Ge, T. Uesaka) Approved proposal at RIBF----^{100}Sn and the vicinty (2018-12, 2022-12)
Postdoc position: hire from next year for the mass measurements of heavy *N=Z* nuclei up to ^{100}Sn

Acknowledgements

FRS Ion Catcher and IGISOL Collaborations

D. Amanbayev, B. Ashrafkhani, O. Aviv, S. Ayet San Andrés, J. Äystö, S. Bagchi, D. Balabanski, S. Beck, J. Bergmann, A. Blazhev, Z. Brencic, S. Cannarozzo, O. Charviakova, P. Constantin, D. Curien, D. Das, I. Dedes, M. Dehghan, T. Dickel, J. Dobaczewski, J. Dudek, T. Eronen, T. Fowler-Davis, Z. Gao, Z. Ge, H. Geissel, S. Glöckner, M. Górska, T. Grahn, F. Greiner, L. Gröf, M. Gupta, E. Haettner, O. Hall, M. Harakeh, B. S. Hu, C. Hornung, J.-P. Hucka, Y. Ito, A. Jokinen, B. Kaizer, N. Kalantar-Nayestanaki, A. Kankainen, A. Karpov, Y. Kehat, L. Kilmartin, D. Kostyleva, G. Kripkó-Koncz, D. Kumar, A. N. Kuzminchuk, Y. H. Lam, K. Mahajan, I. Mardor, A.A. Mehmandoost-Khajeh-Dad, N. Minkov, A. Mollaebrahimi, D. Morrissey, I. Moore, I. Mukha, G. Münzenberg, T. Murböck, M. Narang, D. Nichita, S. Nikas, D. A. Nesterenko, Z. Patyk, A. Perry, S. Pietri, A. Pikhtelev, W.R. Plaß, Pohjalainen, S. Pomp, S. Purushothaman, M.P. Reiter, M. Reponen, S. Rinta-Antila, H. Rösch, A. Rotaru, C. Scheidenberger, T. Schellhaas, P. Schury, A. Shrayer, S.K. Singh, A. Solders, A. Spataru, A. State, Y. Tanaka, P. Thirolf, N. Tortorelli, E.Vardaci, L. Varga, M. Vencelj, V. Virtanen, M. Wada, M. Wasserheß, H. Weick, M. Wieser, M. Will, H. Wilsenach, O. Yaghi, M.I. Yavor, X. Yang, J. Yu, A. Zadvornaya, J. Zhao

The results from GSI presented here are based on the experiment S459+, which was performed at the FRS at the GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt (Germany) in the context of FAIR Phase-0. The IGISOL experiment is carried out at the Accelerator Laboratory of University of Jyväskylä (JYFL-ACCLAB).

Fundings: **Academy of Finland under the Finnish Centre of Excellence Programme** 2012-2017 (Nuclear and Accelerator Based Physics Research at JYFL) and projects No. 306980, 312544, 275389, 284516, 295207, 314733, 315179, 327629, 320062 and 345869. The support by the **EU Horizon 2020 research and innovation programme** under grant No. 771036 (ERC CoG MAIDEN) is acknowledged. This project has received funding from the **European Union's Horizon 2020 research and innovation programme** under grant agreement No. 861198-LISA-H2020-MSCA-ITN-2019.

Fundings: **German Federal Ministry for Education and Research** (05P19RGFN1, 05P21RGFN1), **Hessian Ministry for Science and Art** (LOEWE Center HICforFAIR), **HGS-HIRe**, **JLU Giessen and GSI** (JLU-GSI strategic Helmholtz partnership agreement), **German Research Foundation** (SCHE 1969/2-1), **Polish National Science Centre** (2016/21/B/ST2/01227), **European Union's Horizon 2020** research and innovation programme (654002 via the JRA SAT-NURSE), **Israel Ministry of Energy** (220-11-052), **Israel Science Foundation** (2575/21), **Romanian Government and European Union** (ELI-NP Phase II) (European Regional Development Fund – 1/07.07.2016, COP, ID 1334), **IAEA** (CRP F42007, 24000)

IGISOL collaboration

FRS collaboration & FRS Ion catcher collaboration

Mass measurements of N=Z Nuclei (up to ^{100}Sn) and the vicinity

No. 2

NP2212-RIRING03R1

Approved 9 days

Zhuang GE

GSI Helmholtzzentrum für Schwerionenforschung

Tomohiro UESAKA

RIKEN Nishina Center for Accelerator-Based Science

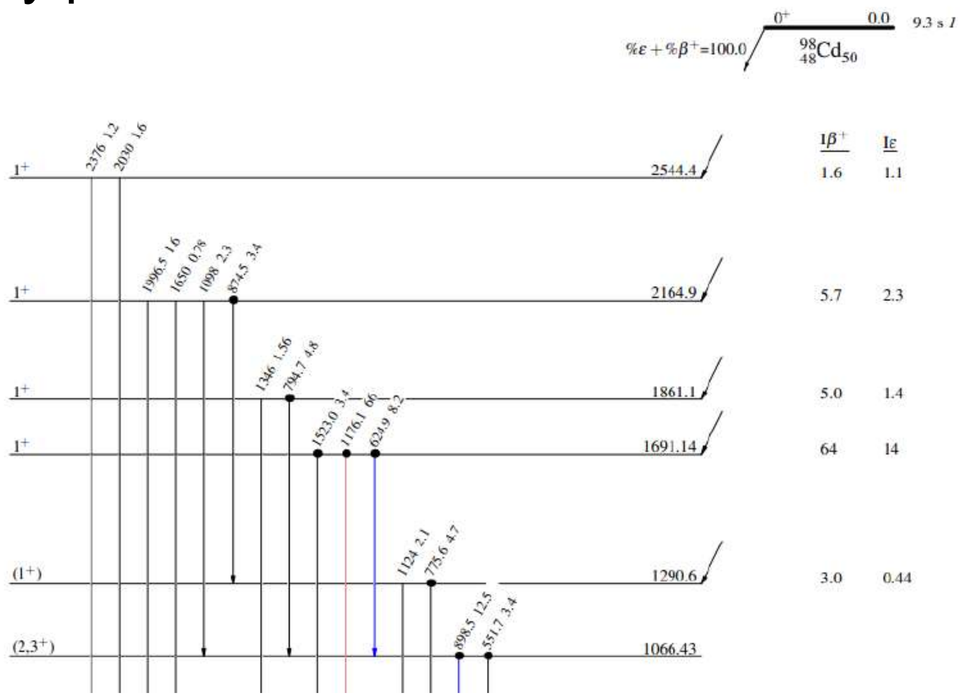
On behalf of the Rare-RI Ring collaboration

20221206

Gamow-Teller strength of ^{98}Cd

Re-evaluation of GT strength to confidently pin-down the value:

- New half-life measured $t_{1/2} = 9.29 \pm 0.1$ s [1]
- Latest decay scheme [2]
- Direct measurement of *Q*-Value



Direct mass measurement in this work:

$$Q_{EC} = 5437 \pm 65 \text{ keV}$$

The summed Gamow-Teller strength:

$$B(\mathrm{GT}) = 2.94\,^{+0.32}_{-0.28}$$

A. Mollaebrahimi et al., Physics Letters B 839 (2023) 137833

Energy (keV)	Branching ratio (%)	Log(*ft*)	B(*GT*)
1290.6	3.4%	4.9	0.05
1691.14	78%	3.29	1.99
1861.1	6.4%	4.27	0.21
2164.9	8%	3.97	0.42
2544.4	2.7%	4.16	0.27

[1] J. Park et al., *Physical Review C* **99** (2019)
[2] J. Chen et al., *Nuclear data sheets* **164** (2020)

Gamow-Teller transitions at *N=50* isotones

In a β-decay, the transition probability or strength of the decay strongly depends on the **underlying shell structure** and it is **usually distributed among several states**.

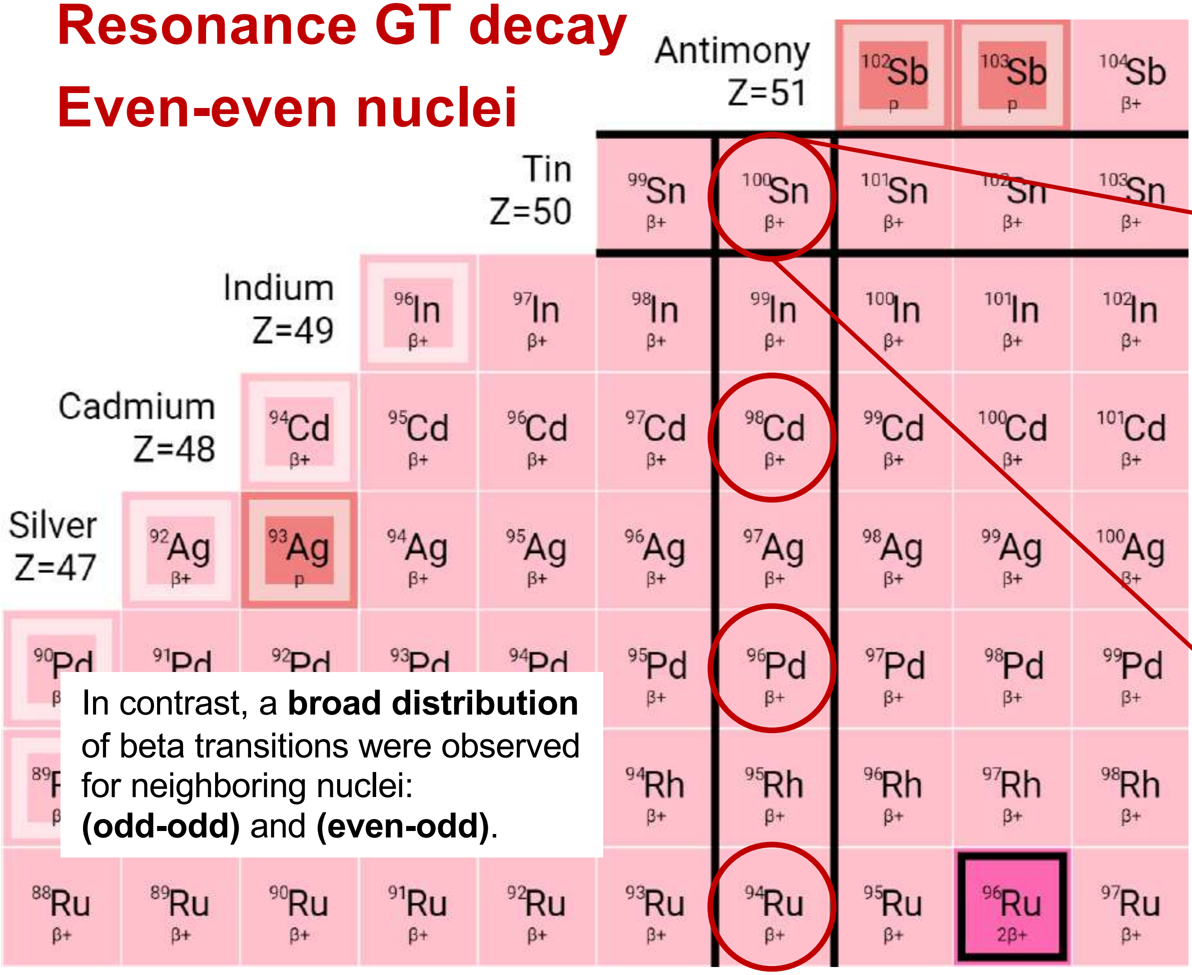
For a single-state transition the strength is:

$$B(\mathrm{GT}) = \frac{2\pi^3\hbar^7 ln(2)}{m_e^2 c^4 G_F^2 V_{ud}^2 (G_A/G_V)^2 f t_{1/2}} = \frac{3885 \pm 14\,s}{f(z,\epsilon_0)t_{1/2}}$$

Comparative half-live ($Q_{EC}, t_{1/2}$ and decay scheme)

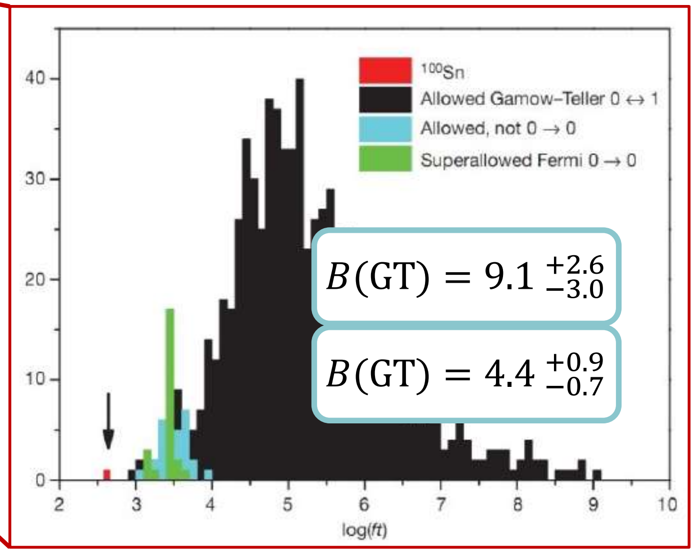
Resonance GT decay

Even-even nuclei



In contrast, a **broad distribution** of beta transitions were observed for neighboring nuclei: **(odd-odd)** and **(even-odd)**.

GT decay ($0^+ \rightarrow 1^+$)



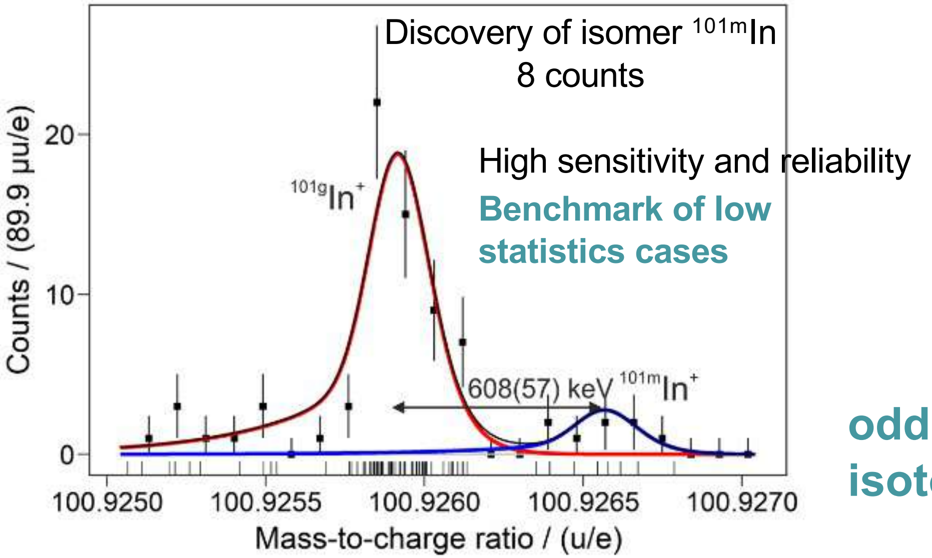
C. B. Hinke et al., *Nature* **486**, 7403 (2012).

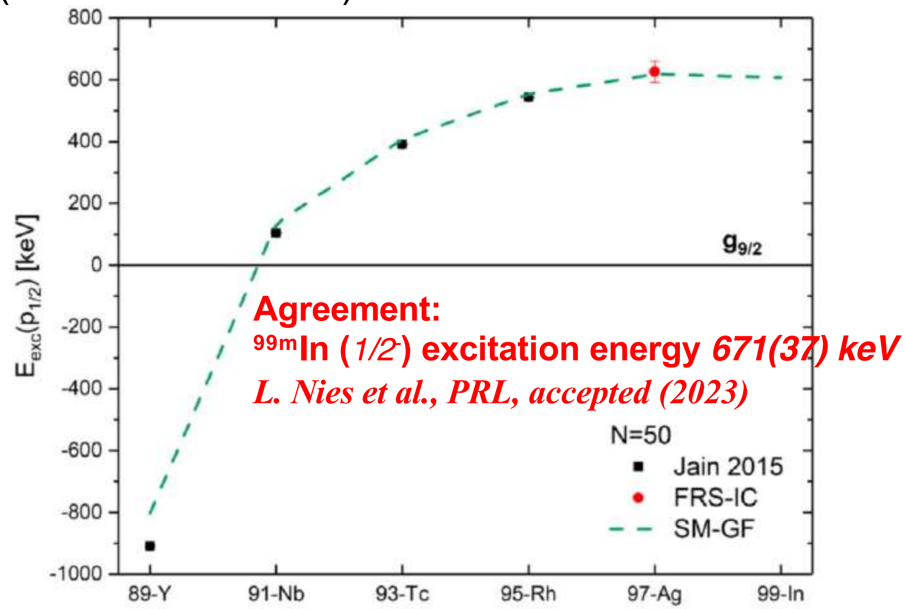
D. Lubos et al., *Physical Review Letters* **122**, 222502 (2019).

***β* end-point energy measurements for Q_{EC}**

Long-lived isomers in this region

- **State-of-art theoretical calculations** for odd-even nuclei on *N=50* isotonic chain ad *Z=49* isotopic chain
- Core excitation for the ^{99m}In excitation energy extrapolation (**Exc.=600-700 keV**)

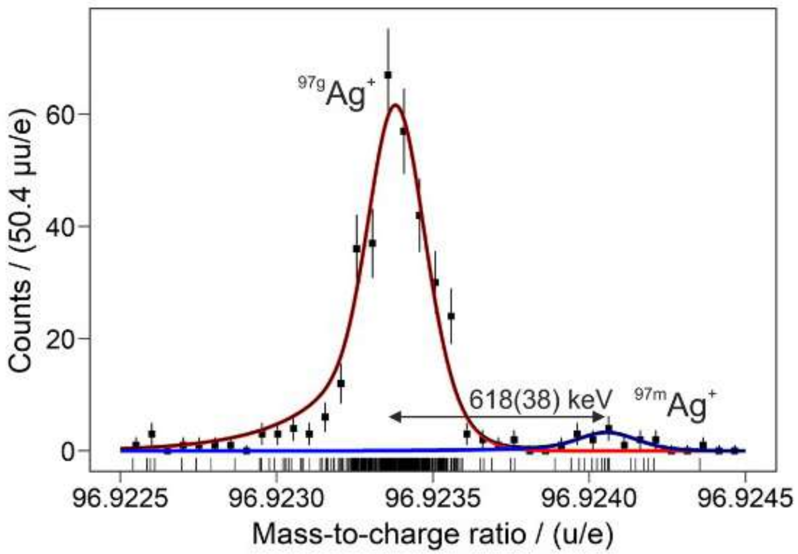




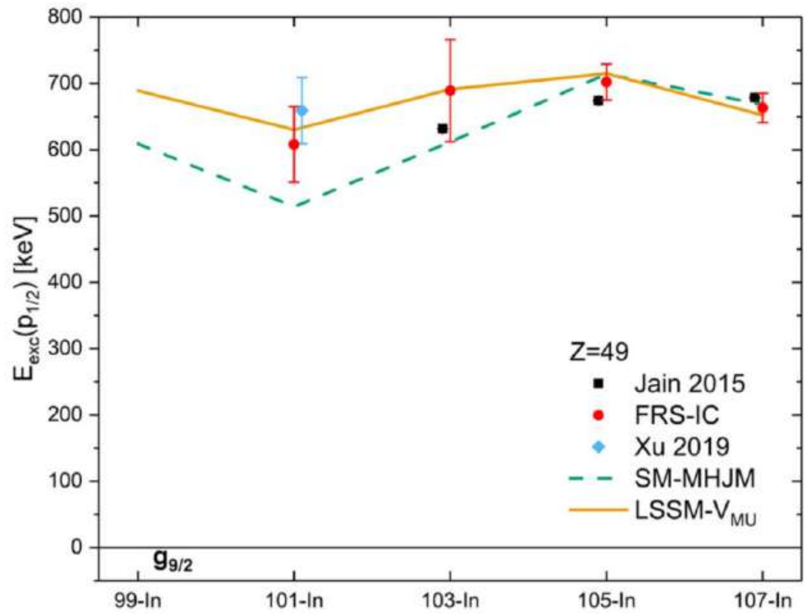
odd-even isotopes :

9/2+ spin at ground state

1/2+ spin for isomers

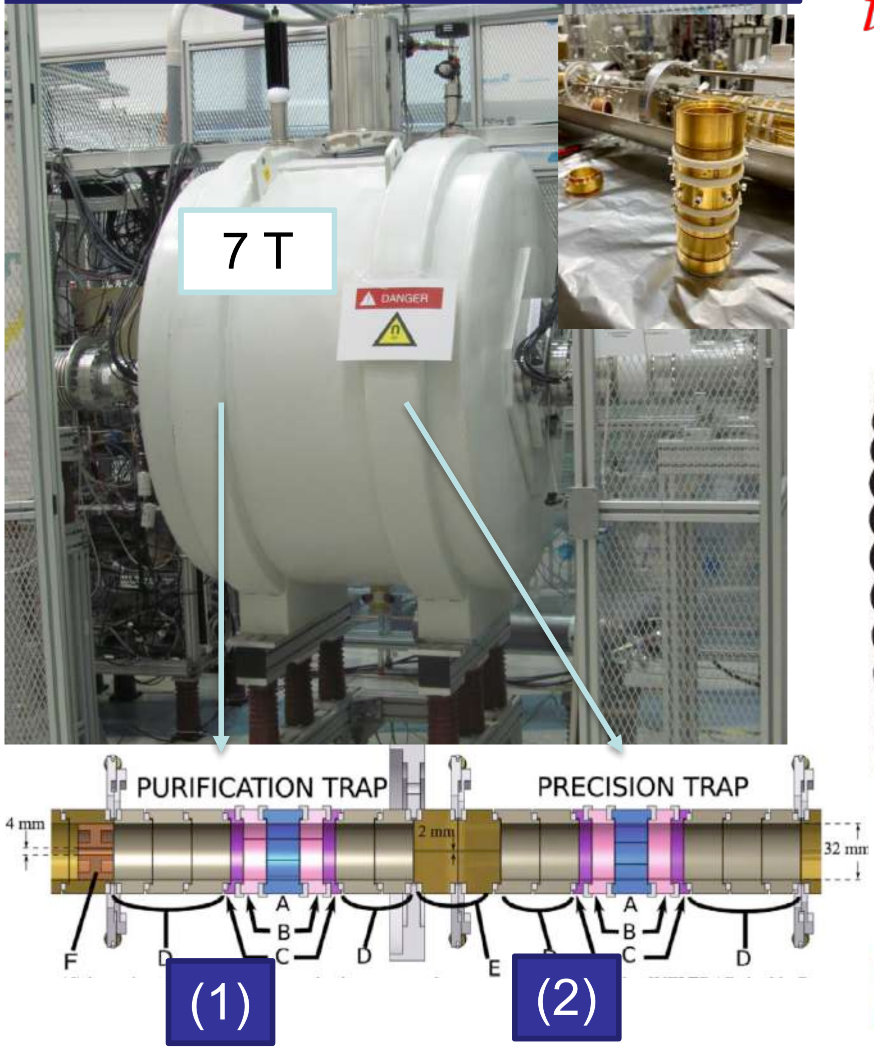


C. Hornung et al., *Physics Letters B* **802** (2020)



JYFLTRAP double Penning trap

JYFLTRAP double Penning trap



Eronen et al., EPJA 48 (2012) 46

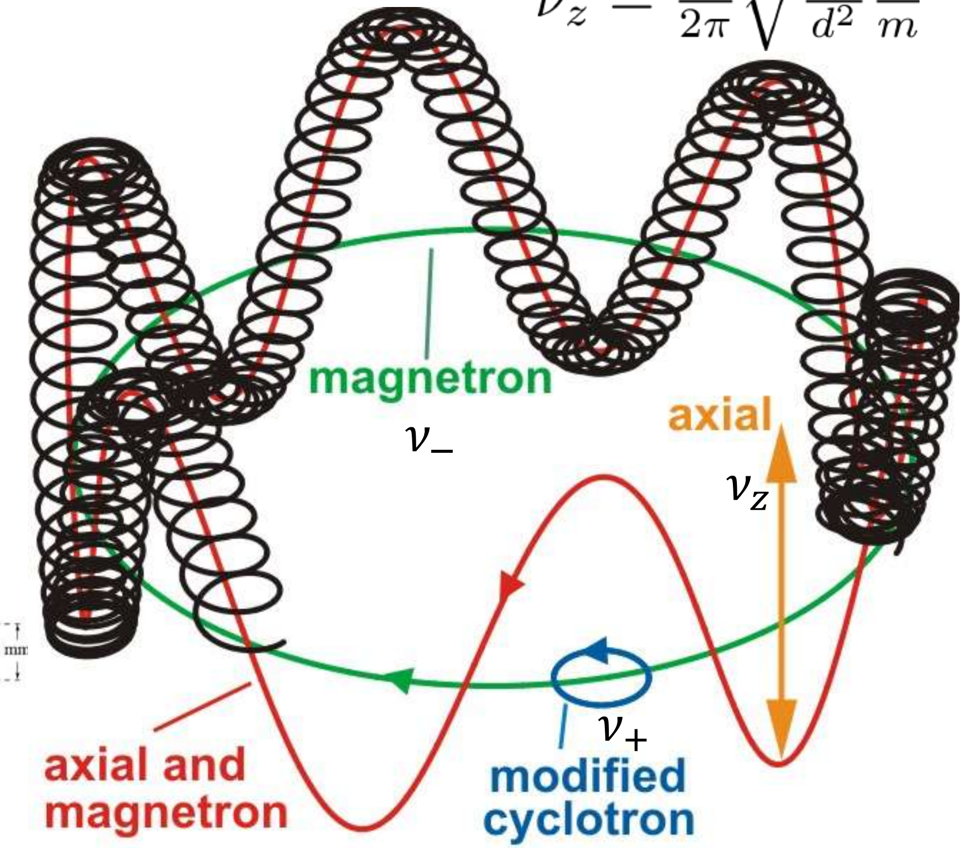
Cyclotron frequency

$$\nu_c = \frac{1}{2\pi}\frac{q}{m}B$$

Penning trap eigenfrequencies:

$$\nu_\pm = \frac{1}{2}\left(\nu_c \pm \sqrt{\nu_c^2 - 2\nu_z^2}\right)$$

$$\nu_z = \frac{1}{2\pi}\sqrt{\frac{U_0}{d^2}\frac{q}{m}}$$



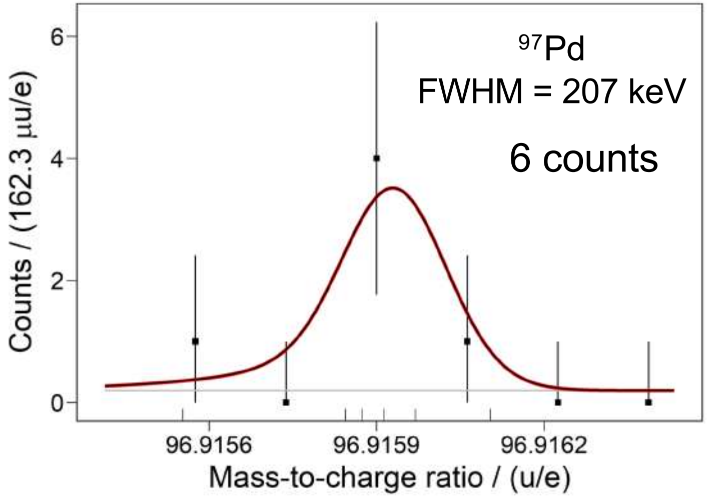
Invariance theorem:

$$\nu_c^2 = \nu_-^2 + \nu_+^2 + \nu_z^2$$

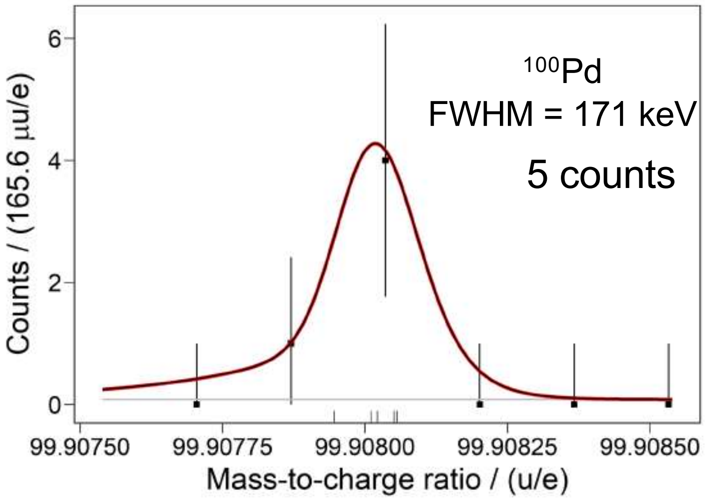
Benchmark of low statistics cases

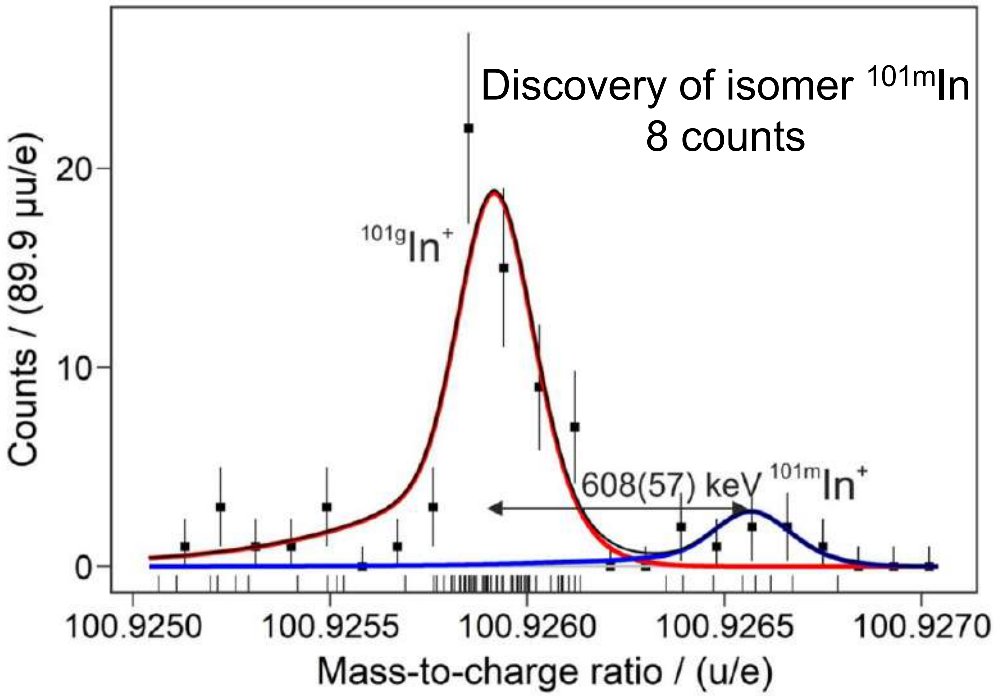
- High sensitivity and reliability of MR-TOF-MS for a very-low number of identified ions

$ME_{\text{FRS-IC}} = -77830 \pm 69$ keV
$ME_{\text{AME20}} = -77806 \pm 5$ keV
$ME_{\text{FRS-IC (old)}} = -77798 \pm 37$ keV



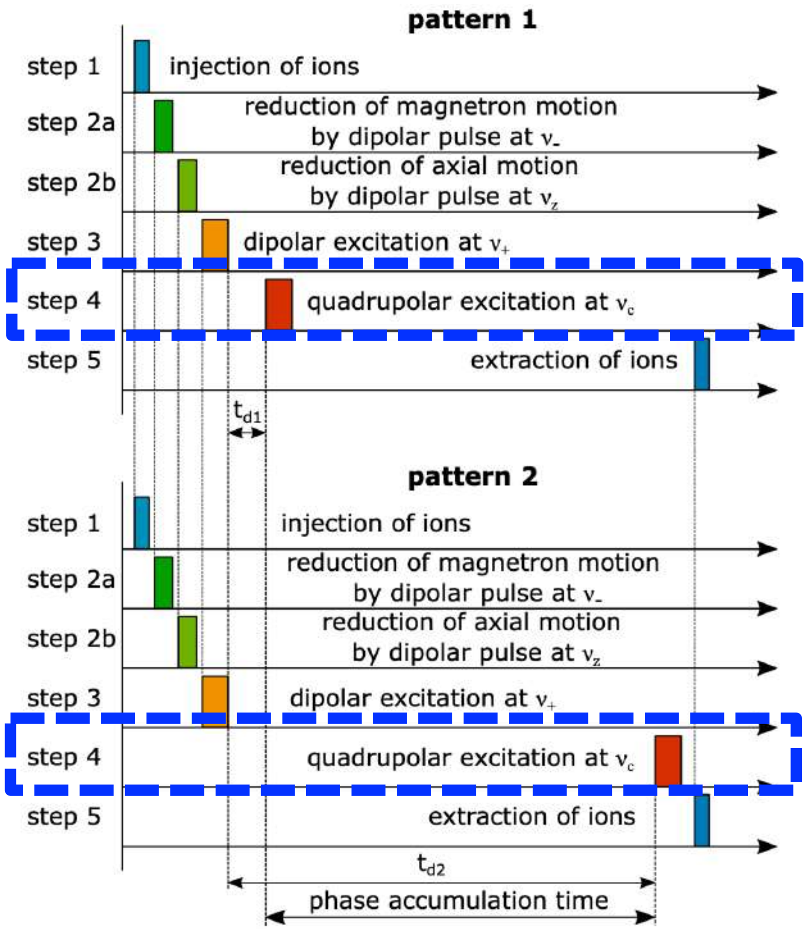
$ME_{\text{FRS-IC}} = -85202 \pm 52$ keV
$ME_{\text{AME20}} = -85213 \pm 18$ keV

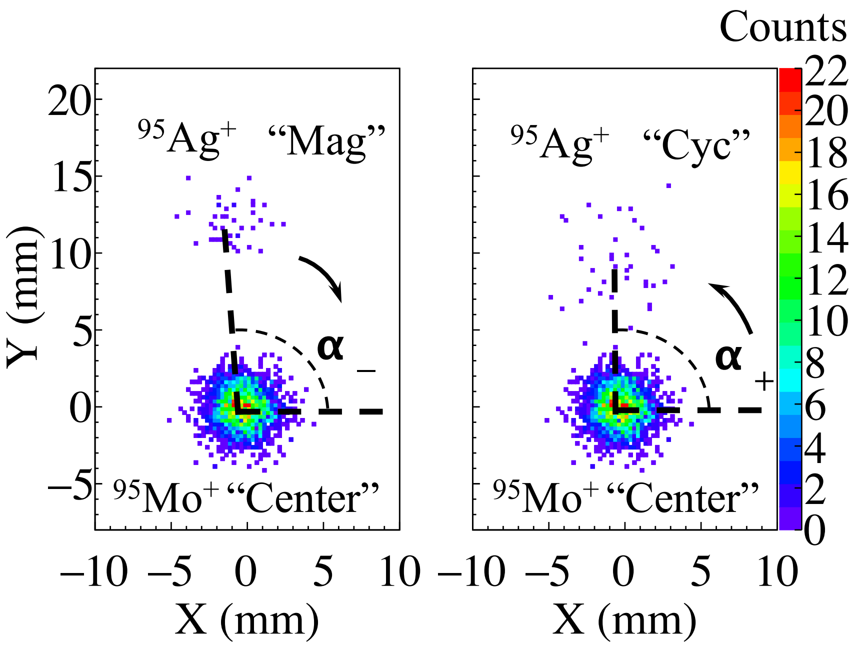




C. Hornung et al., *Physics Letters B* **802** (2020)

Phase-imaging Ion-Cyclotron-Resonance (PI-ICR)





- Dipolar excitation at ν_+
  - Direct conversion to magnetron motion → Magnetron phase
  - Accumulation then conversion to magnetron motion → Modified cyclotron phase

- **Cyclotron frequency:**

$$\nu_c = \nu_+ + \nu_- = \frac{qB}{2\pi m}$$

- **Frequency ratio *r*:**

$$r = \frac{\nu_1}{\nu_2}$$

Determine

- ***Q*-value:**

$$Q = M_2 - M_1 = (r-1)(M_1 - m_e) + m_e$$

- **Mass:**

$$M_2 = r(M_1 - m_e) + m_e$$

methods

Eronen et al., EPJA 48 (2012) 46

1. TOF-ICR

Time-of-Flight Ion-Cyclotron-Resonance (TOF-ICR) technique

G. Gräfft et al.,, Zeitschrift für Physik A: Atoms and Nuclei 297, 35 (1980).

a. Normal TOF-ICR
b. Ramsey TOF-ICR

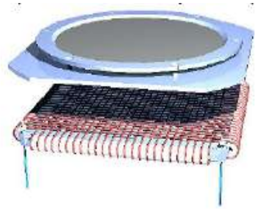
2. PI-ICR

Phase-imaging Ion-Cyclotron-Resonance (PI-ICR) technique

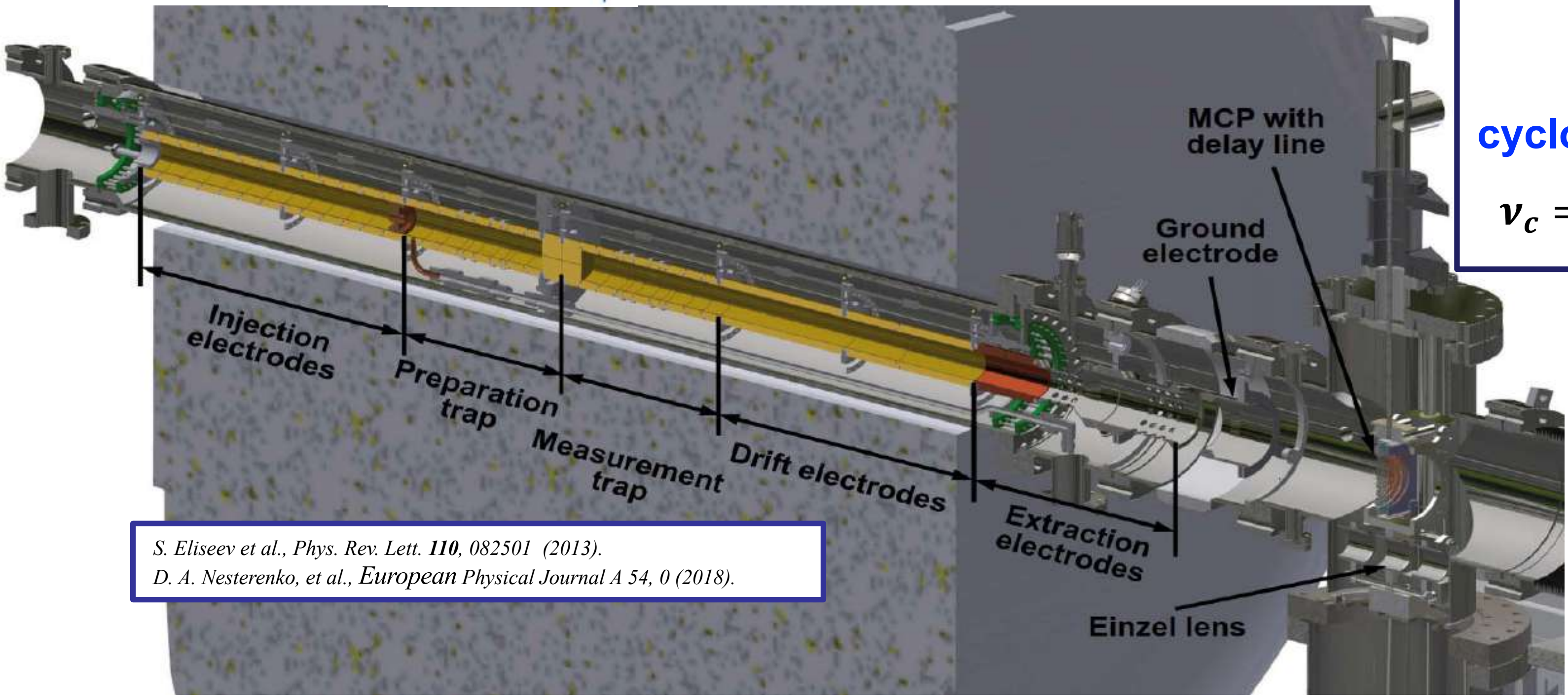
S. Eliseev et al., Phys. Rev. Lett. ***110****, 082501 (2013).*

Phase-imaging Ion-Cyclotron-Resonance (PI-ICR)

Delay-Line Microchanel Channel Plate (MCP) Detector from Roentdek GmbH



Position sensitive detector



S. Eliseev et al., Phys. Rev. Lett. ***110****, 082501 (2013).*
D. A. Nesterenko, et al., European Physical Journal A 54, 0 (2018).

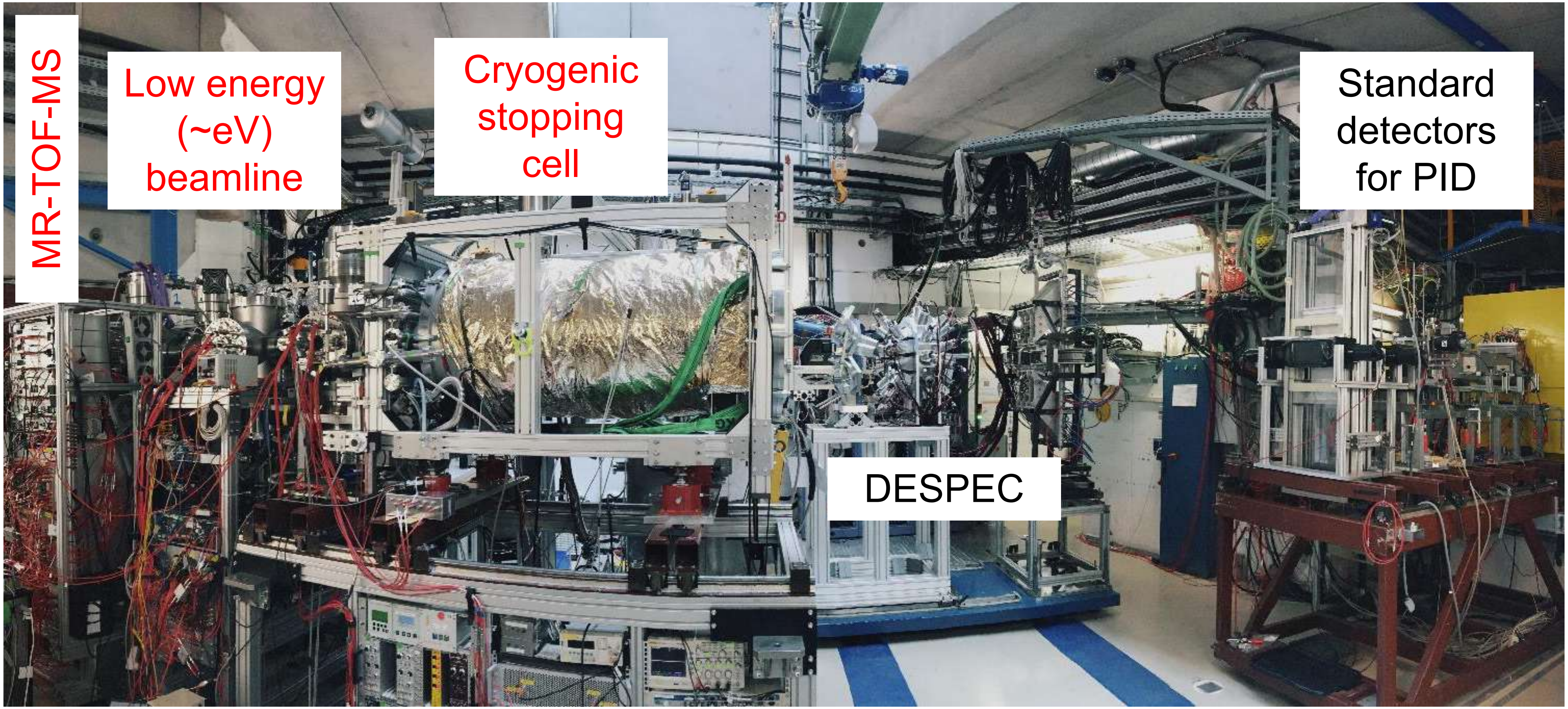
Angle between cyclotron and magnetron motion phases with respect to the center spot:

$$\alpha_c = \alpha_- + \alpha_+$$

cyclotron frequency:

$$\nu_c = \nu_+ + \nu_- = \frac{\alpha_c + 2\pi n}{2\pi t}$$

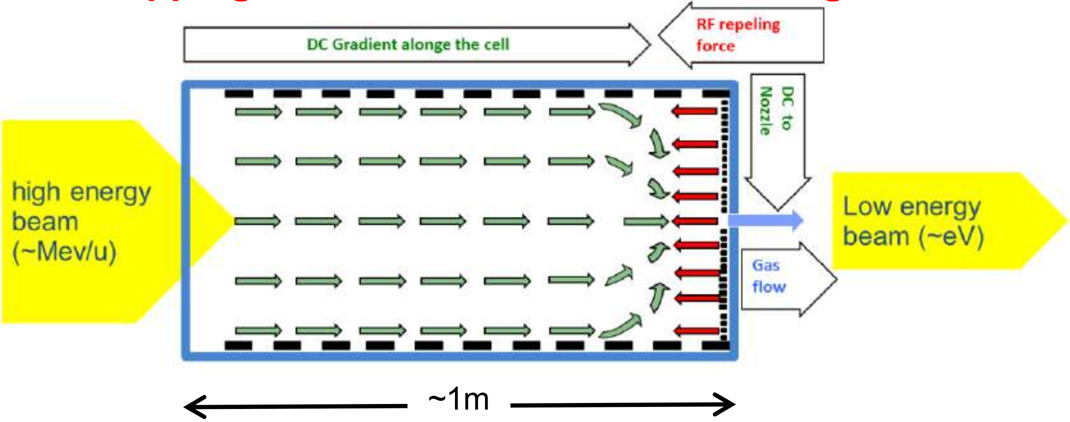
FRS Ion Catcher (FRS-IC) setup



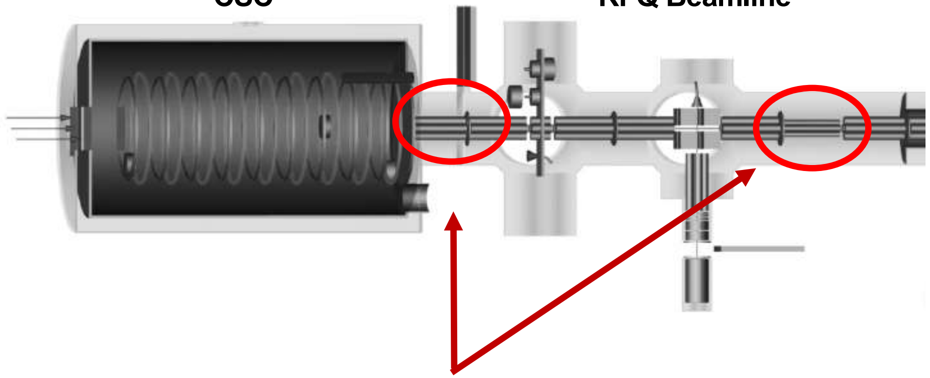
S. Purushothaman et al., *Int. J. Mass Spectrometry* **421** (2017) 245
W.R. Plaß et al, *Hypefine Inter.* **241** (2020) 1
I. Miskun et al., *IJMS* **459** (2021) 116450
W. R. Plaß et al., *Phys. Scr.* **T166** (2015) 014069
E. Haettner et al., *NIM A* **880** (2018) 138
W.R. Plaß et al., *Int. J. Mass Spectrometry* **394** (2013)
M. Ranjan et al., *Europhys. Lett.* **96** (2011) 52001
S. Purushothaman et al., *EPL* **104** (2013) 42001
M. Ranjan et al., *NIM A* **770** (2015) 87
M.P. Reiter et al., *NIM B* **376** (2016) 240
F. Greiner et al., *NIM B* **463** (2020) 324
W.R. Plaß et al., NIM B **266** (2008)

Cryogenic Stopping Cell (CSC) - RFQ beamline - Mass Filters

Stopping and thermalization of ions in gas

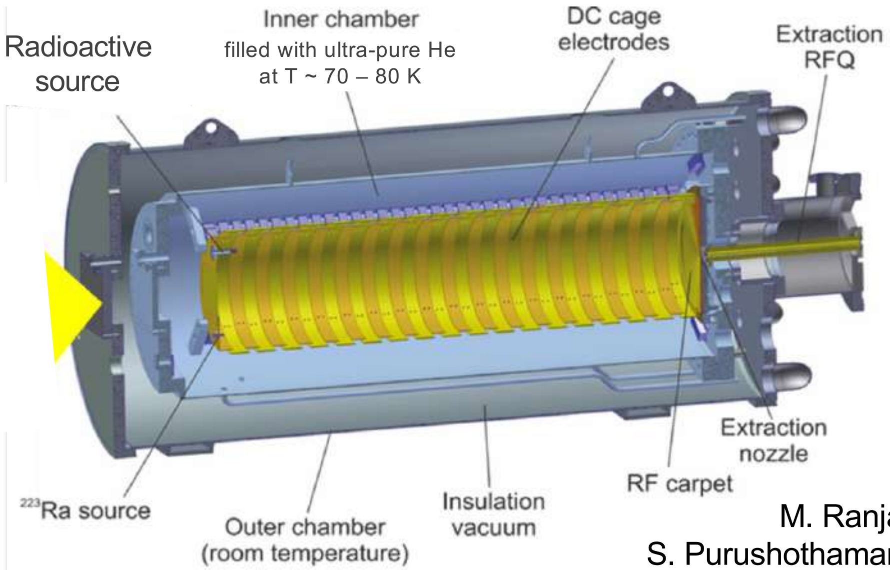


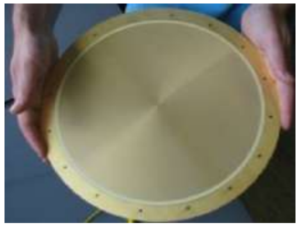
- **Helium-gas at cryogenic temperature**
- **Clean** → cold ion beams of high cleanliness
- **Universal** → element-independent extraction
- **Efficient** → high stopping and extraction efficiency
- **Fast** → access to short-lived exotic nuclides ($T_{1/2}$ ~ ms)



- RF Quadrupole for low-energy ion transport
- Can be used as a mass filter
- Collision-Induced-Dissociation (CID)
- Isolation-Dissociation-Isolation (IDI)

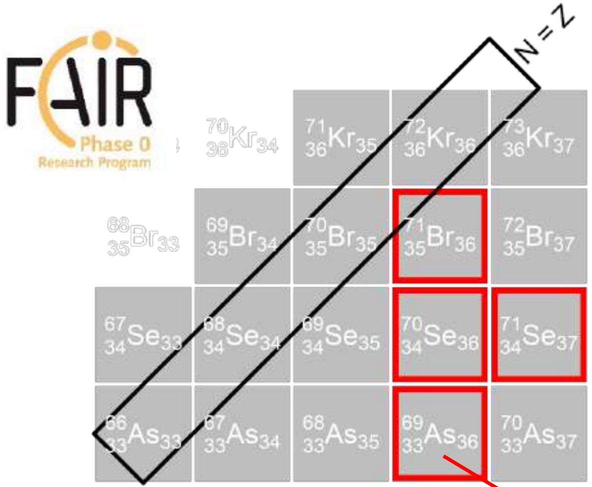
F. Greiner et al., *Nucl. Intr. Meth. B* **463** (2020)





Background Suppression (molecular and ions)

M. Ranjan et al., *Europhys. Lett.* **96** (2011) 52001
S. Purushothaman et al., *Europhys. Lett.* **104** (2013) 42001

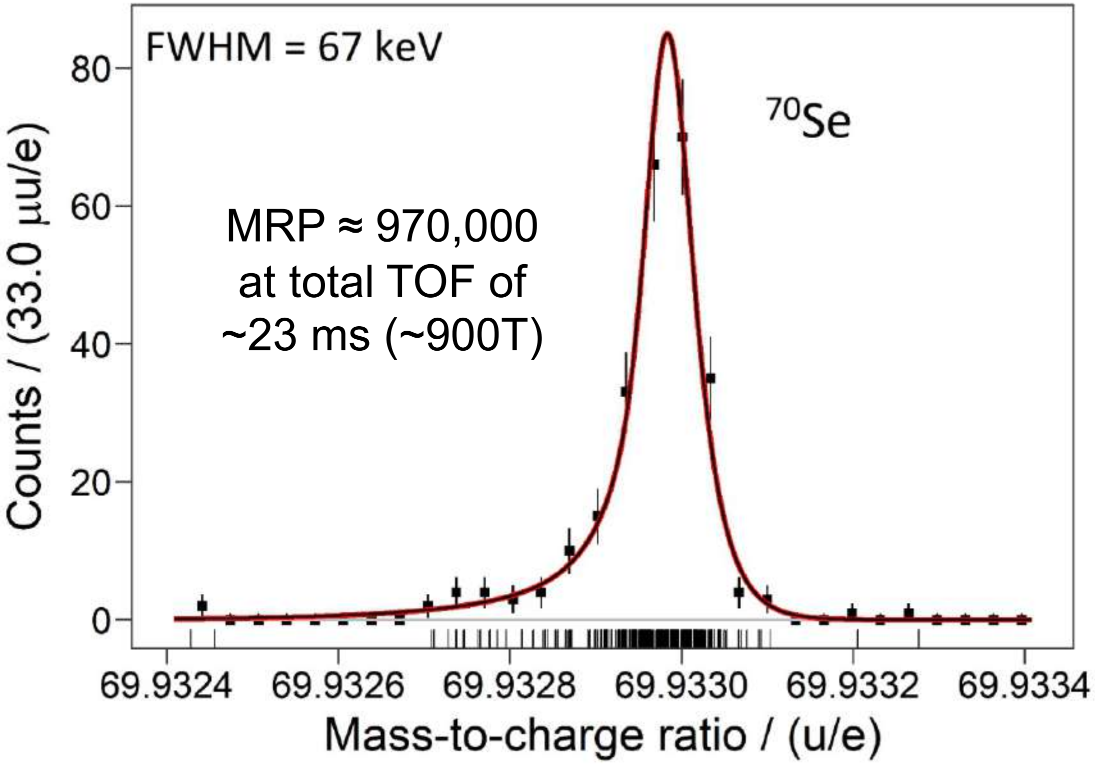


High mass accuracy at low statistics. Is it possible?

Utilized beam alignment procedure → achieved ~1E6 mass resolving power repeatedly

C. Will, Master thesis (2019)
S. Beck, Ph.D thesis (2023)

First direct mass measurement of ^{69}As



^{70}Se:

- 485 events collected
- Mass uncertainty for an unstable nuclide: **2.6 keV** ($\delta m/m$ = $\mathbf{4.0\times10^{-8}}$)
- In comparison: MR-TOF-MS world record for unstable nuclei: $\mathbf{3.5\times10^{-8}}$ with 19,000 events

I. Mardor *et al.*, PRC 103, 034319 (2021)

Experimental challenges and dealing with them

Experimental Challenges:

- Short half-lives (~ ms)
- Small production cross section (~ pbarn-μbarn)
- Low-lying isomeric states

The setup of the FRS-IC and in particular the MR-TOF-MS enables high performance to deal with such challenges

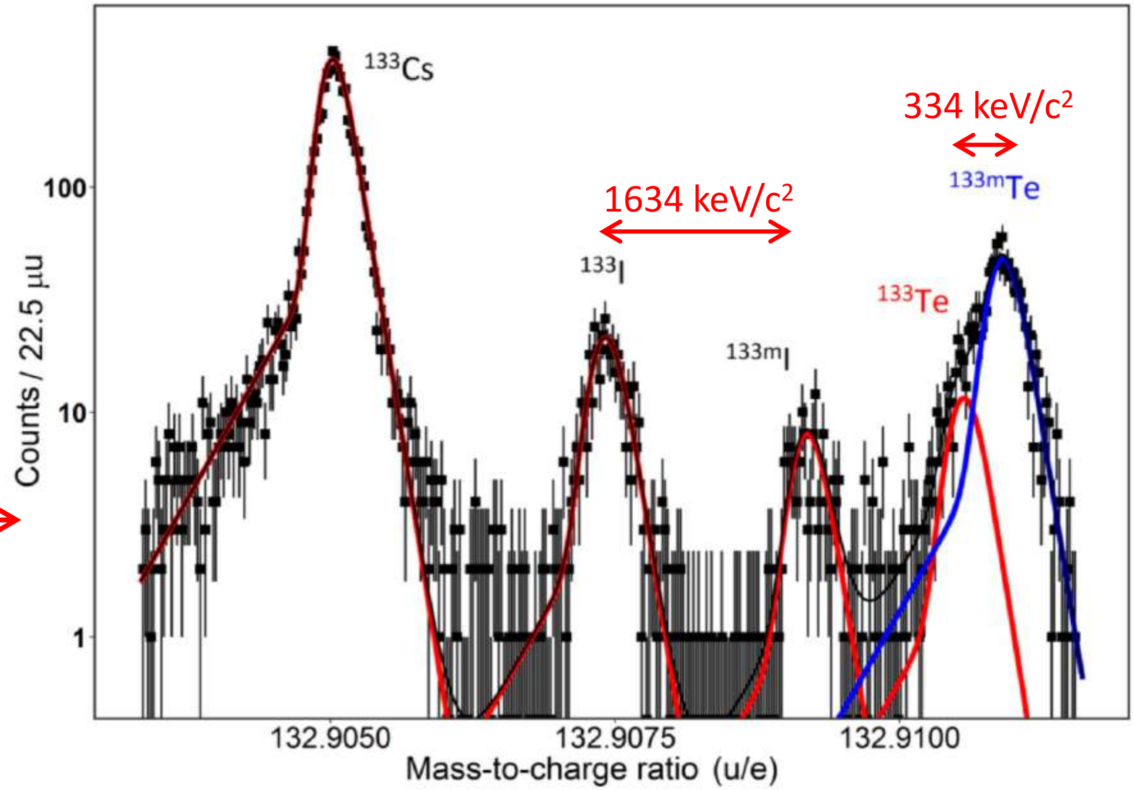
- Fast → access to short-lived ions
- Sensitive, broadband, non-scanning → efficient, access to rare ions
- Enables high mass resolving power and accuracy

Short-lived ions measured at the FRS Ion Catcher:

- With RIB: ^{212}Rn (23.9 ms), ^{213}Rn (19.5 ms), ^{220}Ra (17.9 ms)
- Offline: ^{215}Po (1.8 ms)

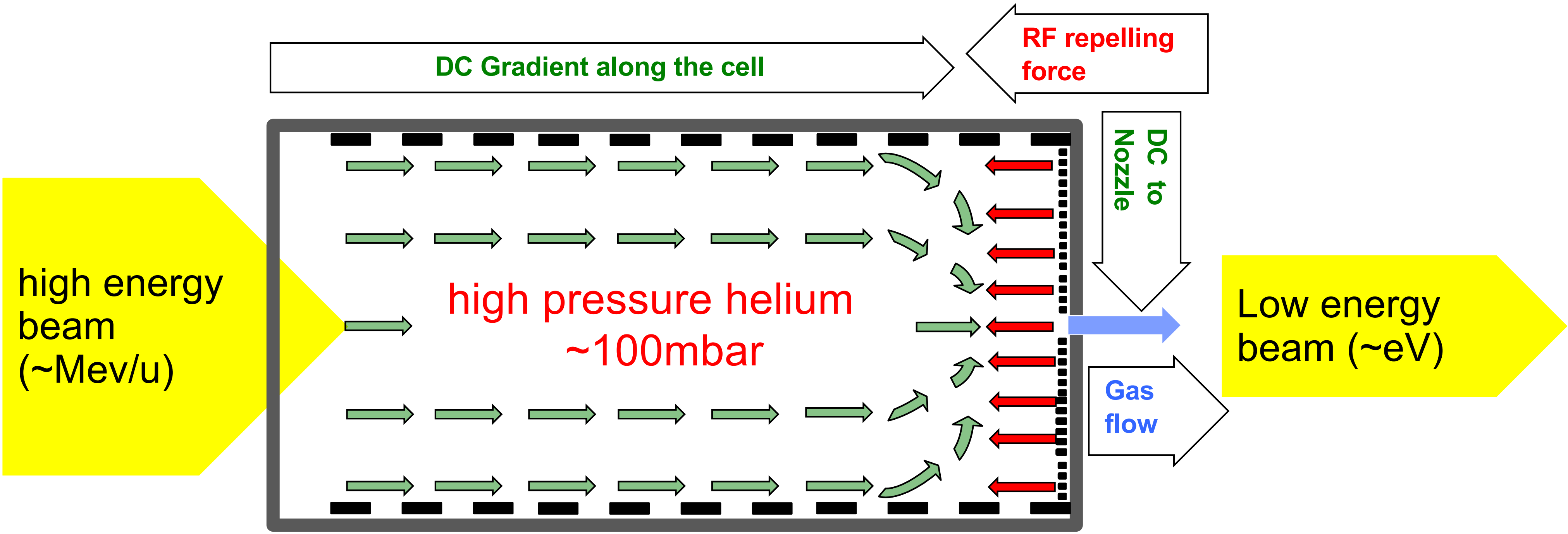
A.-K. Rink, PhD thesis, JLU Gießen (2017)

Resolving power: $m/\Delta m = 410{,}000$



S. Ayet *et al.*, PRC 99 (2019) 064313

Concept: Cryogenic Stopping Cell (CSC)



IGISOL/Stopping cells:

- **Fast** → access to short-lived exotic nuclides ($T_{1/2}$ ~ ms)
- **Universal** → element-independent
- **Efficient** → highest stopping and extraction efficiency

M. Wada NIM B 317 (2013) 450

Cryogenic Operation

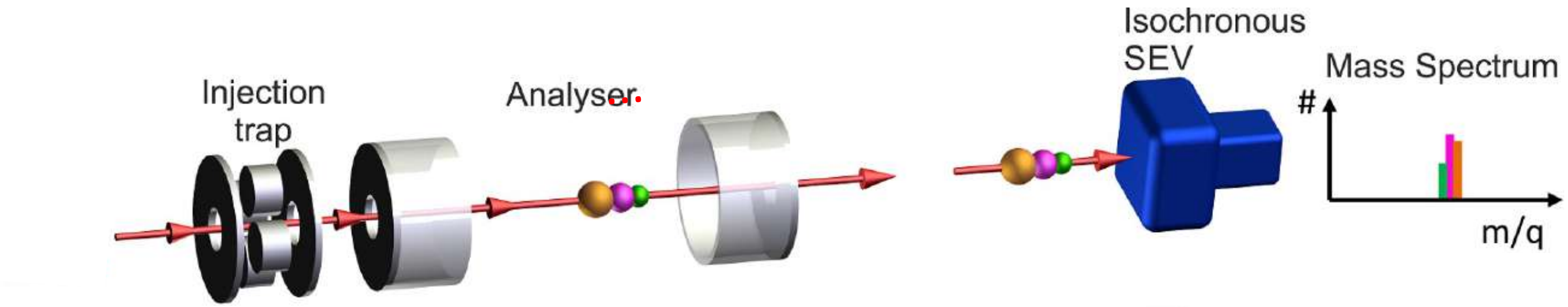
- **Clean** → ion beams of high cleanliness

M. Ranjan *et al.*, Europhys. Lett. 96 (2011) 52001
Purushothaman S. *et al.*, EPL 104 (2013) 42001

Concept: MR-TOF-MS

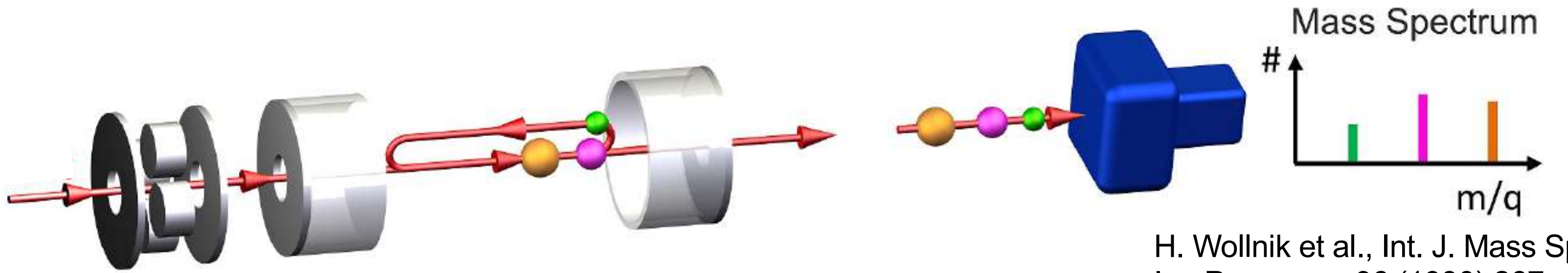
Enables high performance

- Fast → access to very short-lived ions ($T_{1/2}$ ~ ms)
- Sensitive, broadband, non-scanning → efficient, access to rare ions



To achieve high mass resolving power and accuracy:

Multiple-reflection time-of-flight mass spectrometer (MR-TOF-MS)

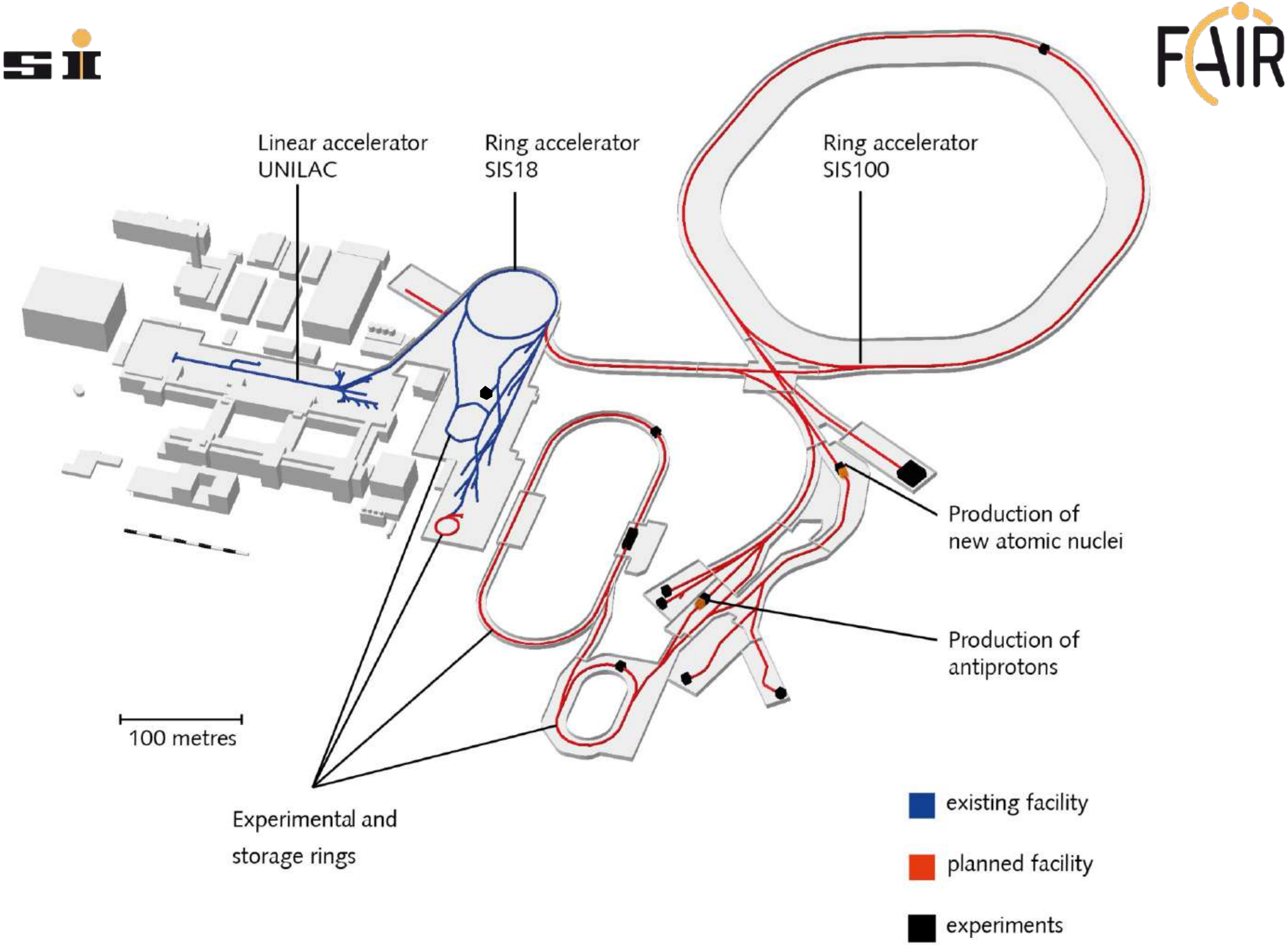


H. Wollnik et al., Int. J. Mass Spectrom. Ion Processes 96 (1990) 267

Applications

- Diagnostics measurements: monitor production, separation and low-energy beam preparation of exotic nuclei — W.R. Plaß et al., Int. J. Mass Spectrom. 394 (2013) 134
- Direct mass measurements of exotic nuclei — C. Scheidenberger et al., Hyperfine Interact. 132 (2001) 531
- High-resolution mass separator — W.R. Plaß et al., NIM B 266 (2008) 4560

The FRS Ion Catcher at GSI/FAIR



The FRS Ion Catcher at GSI/FAIR