The New MARA-LEB Facility and Experimental Prospects

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Joint APP, HEPP and NP Conference - Liverpool 2024

Contents

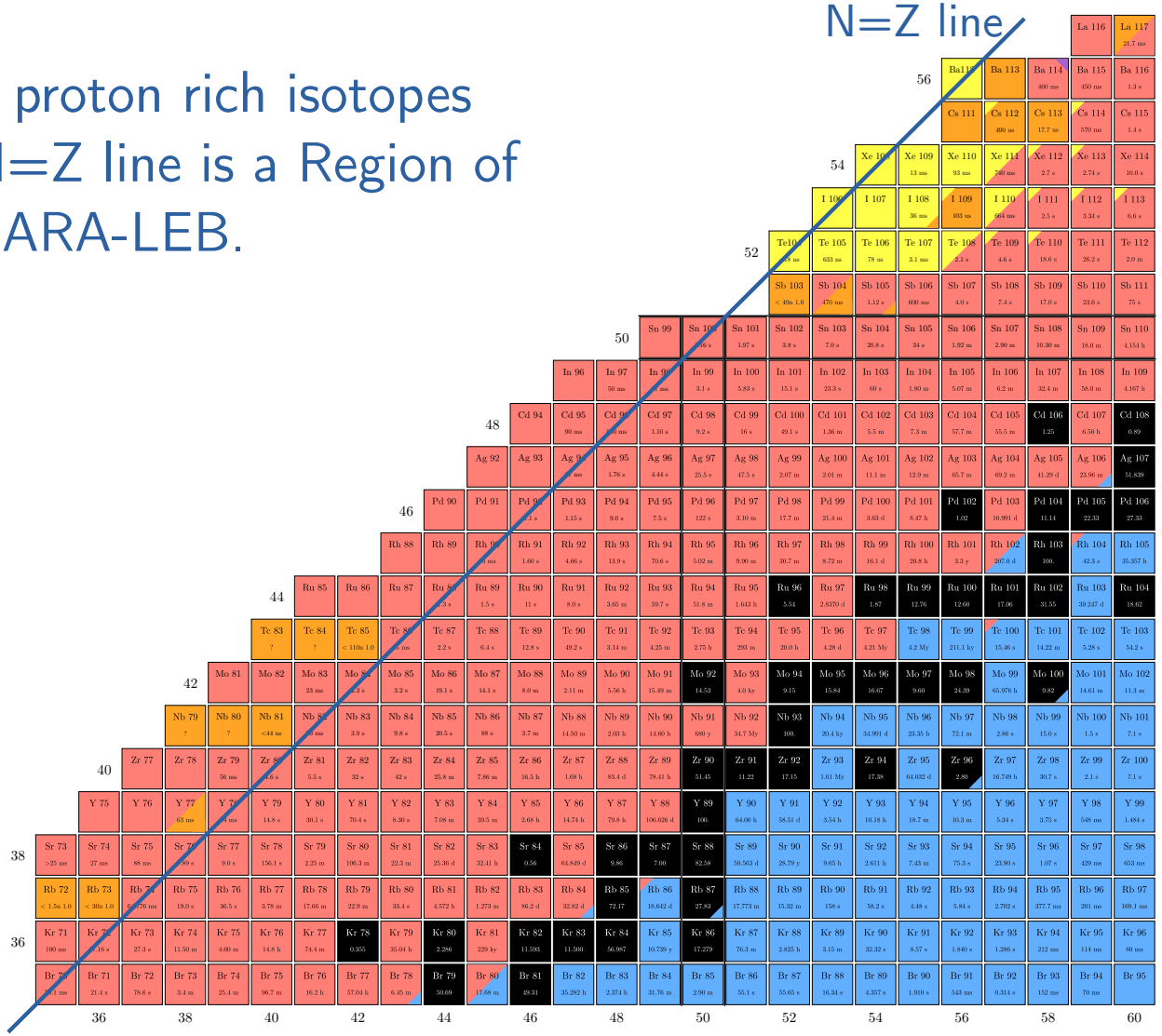
Photo: Arthur Jaries

1

Motivation

Motivation

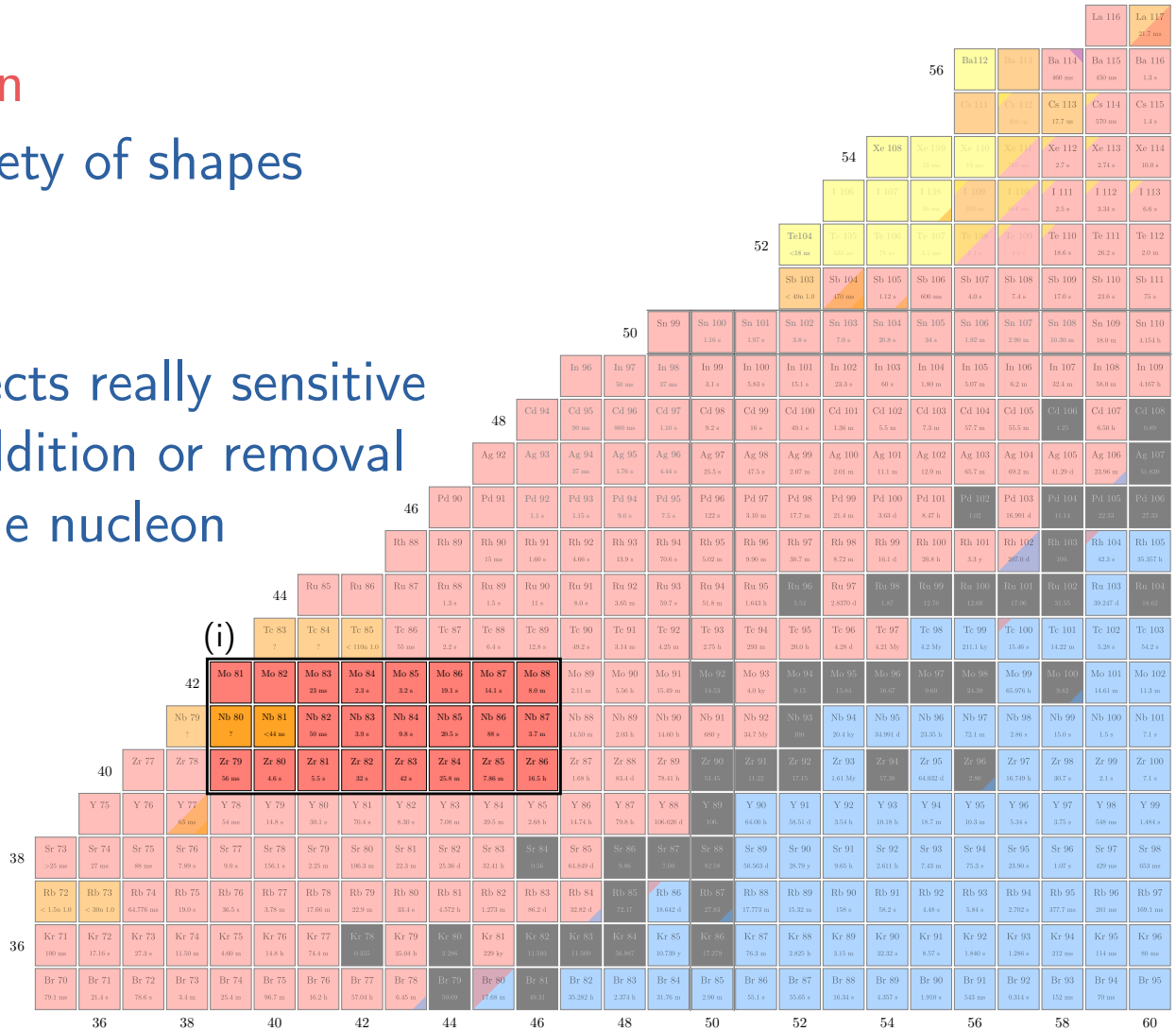
The region of proton rich isotopes close to the N=Z line is a Region of Interest for MARA-LEB.



Testing Theory

$A \sim 80$ Region

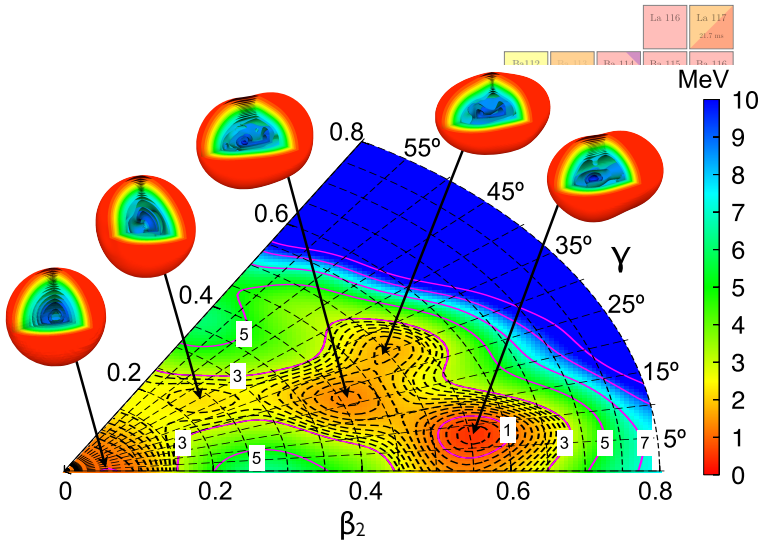
- Rich variety of shapes
- Shell effects really sensitive to the addition or removal of a single nucleon



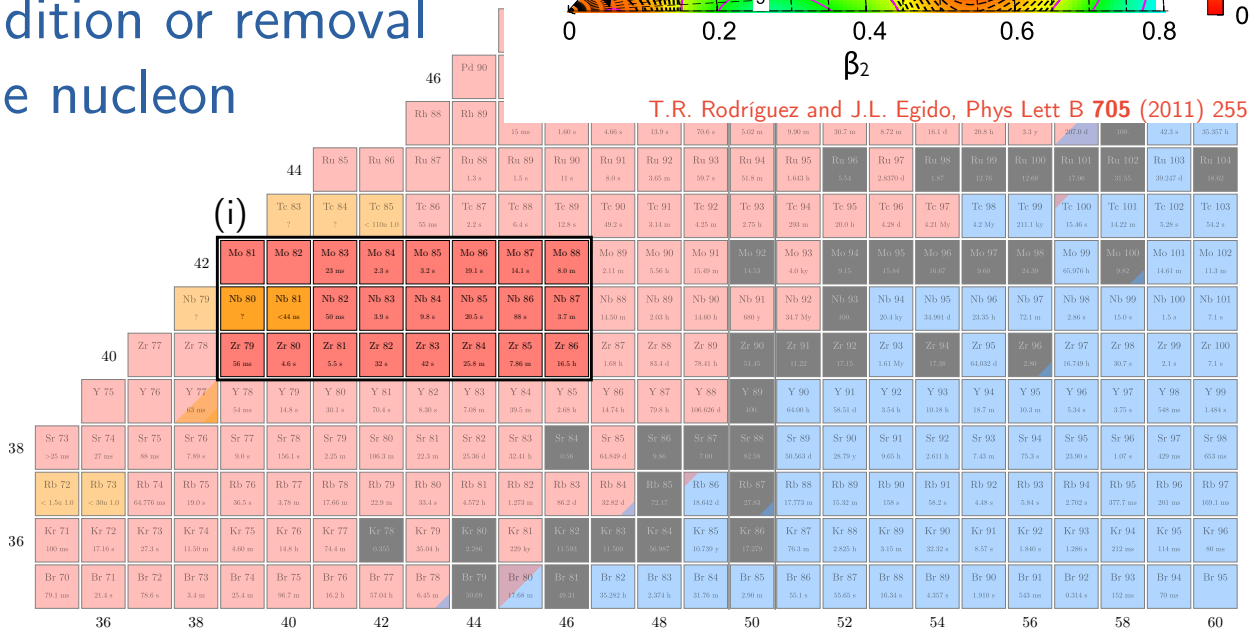
Testing Theory

$A \sim 80$ Region

- Rich variety of shapes
  - ^{80}Zr predicted to have up to 5 different shapes
- Shell effects really sensitive to the addition or removal of a single nucleon



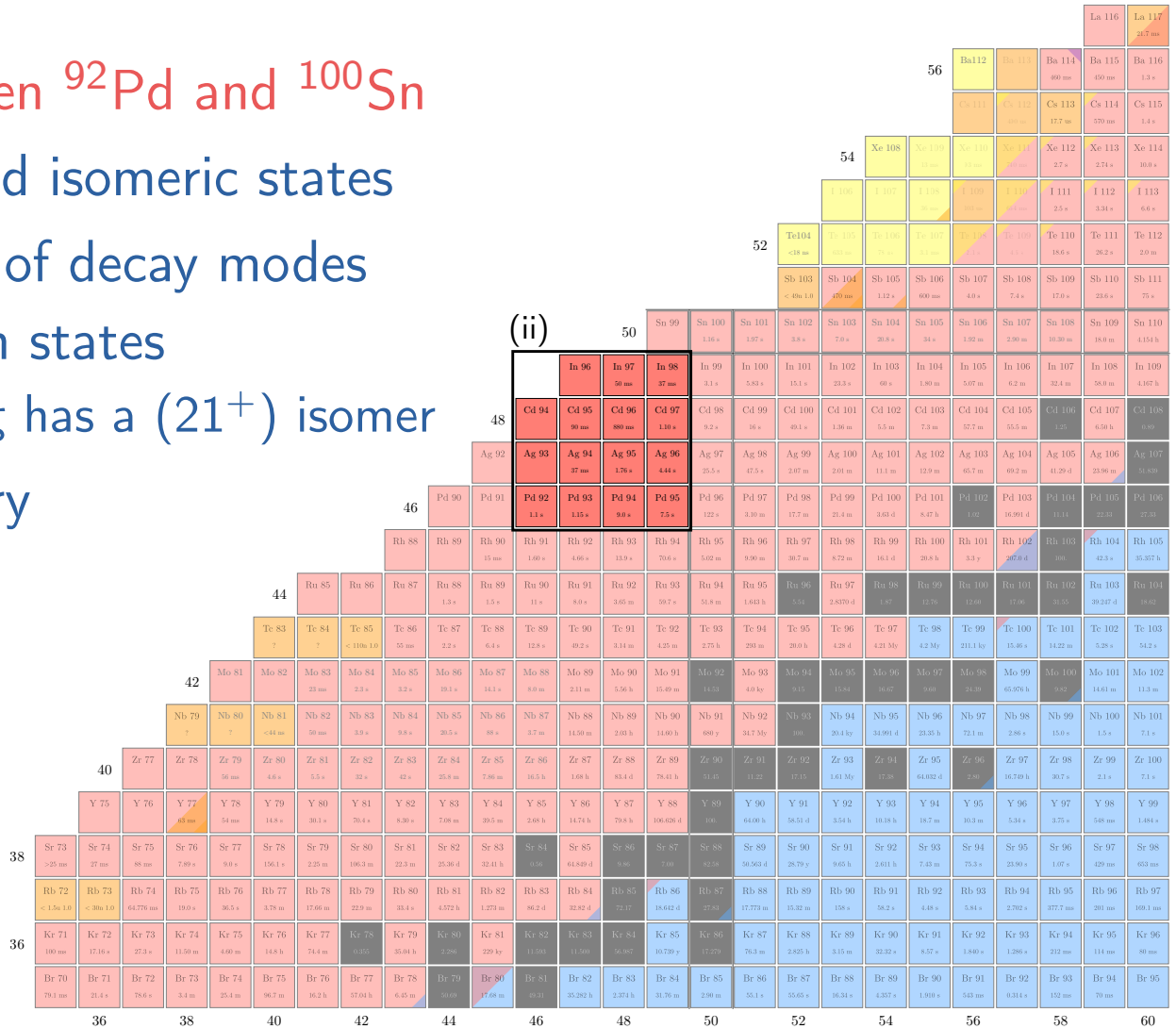
T.R. Rodríguez and J.L. Egido, Phys Lett B **705** (2011) 255



High-Spin Isomers

Region between ^{92}Pd and ^{100}Sn

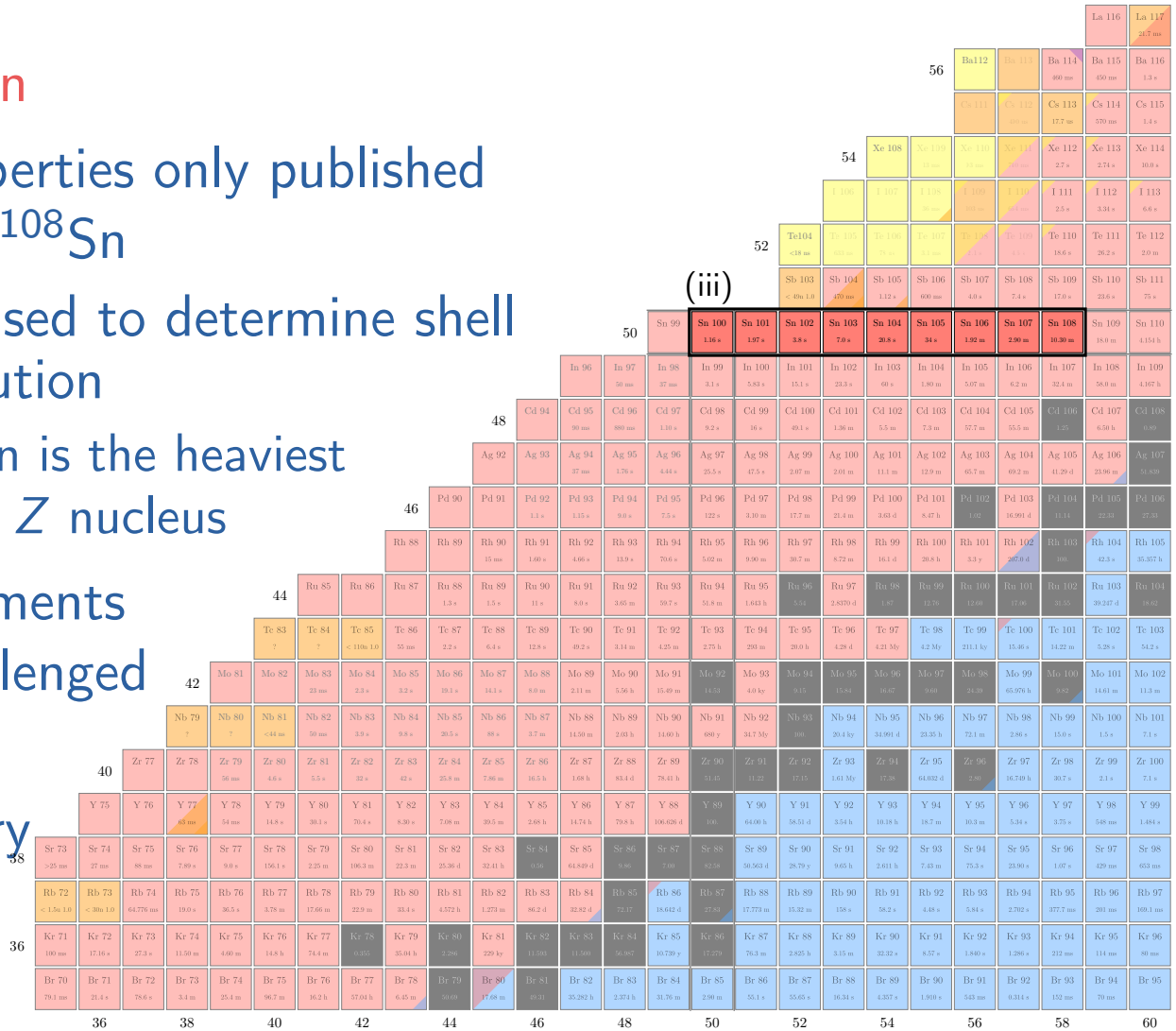
- Long-lived isomeric states
- Plethora of decay modes
- High spin states
  - ^{94}Ag has a (21^+) isomer
- Refractory



Tin Isotopes

$Z = 50$ Region

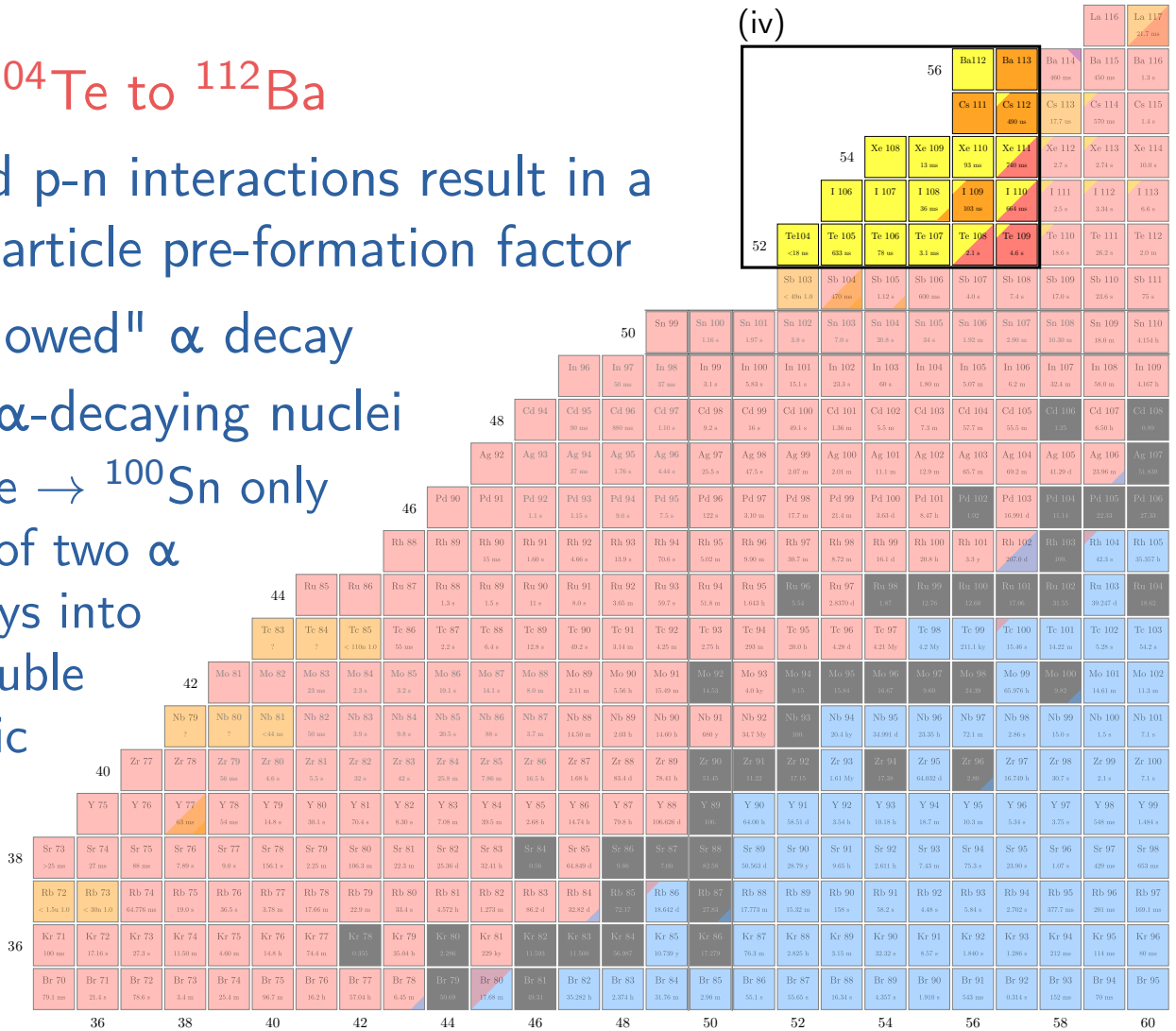
- G.s. properties only published down to ^{108}Sn
- Can be used to determine shell gap evolution
  - ^{100}Sn is the heaviest $N = Z$ nucleus
- Measurements that challenged *ab initio*
- Refractory



Superallowed α Decay

Region from ^{104}Te to ^{112}Ba

- Enhanced p-n interactions result in a large α-particle pre-formation factor
- "Superallowed" α decay
- Lightest α-decaying nuclei
  - $^{104}\text{Te} \rightarrow {}^{100}\text{Sn}$ only one of two α decays into a double magic

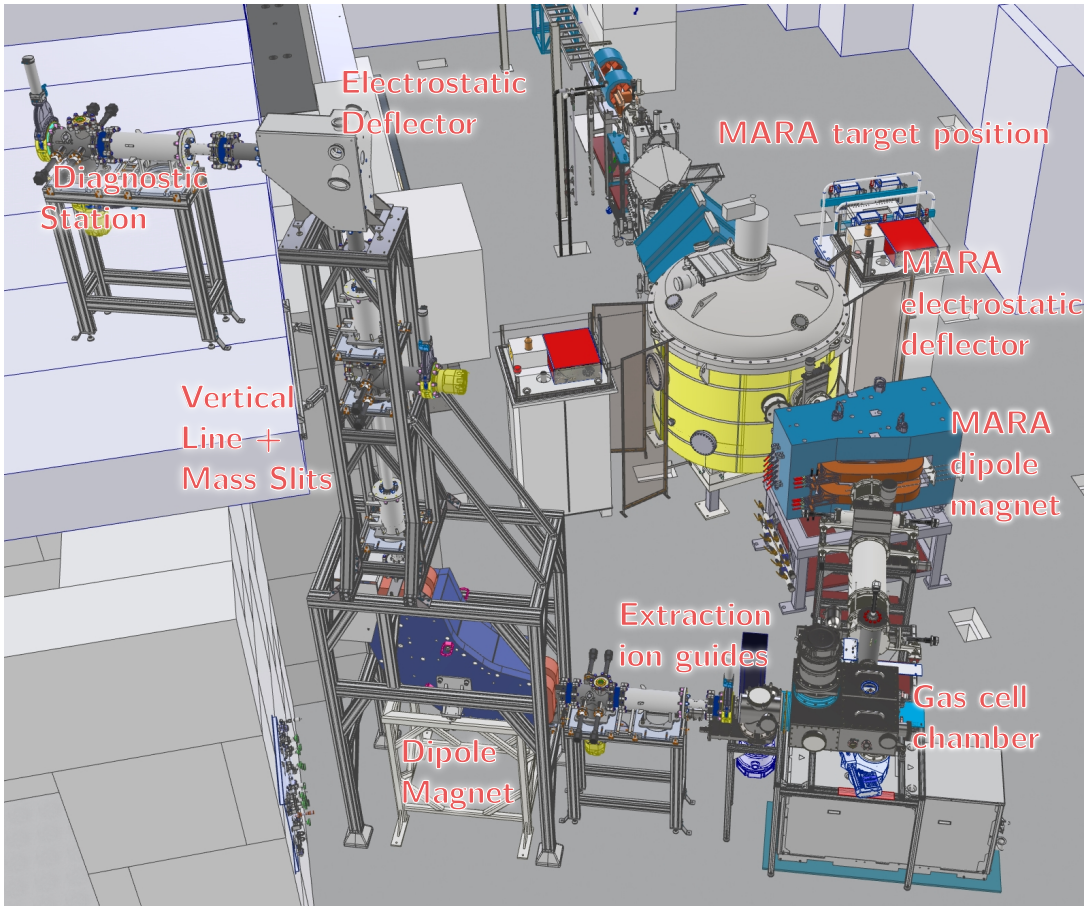


2

Facility

MARA-LEB

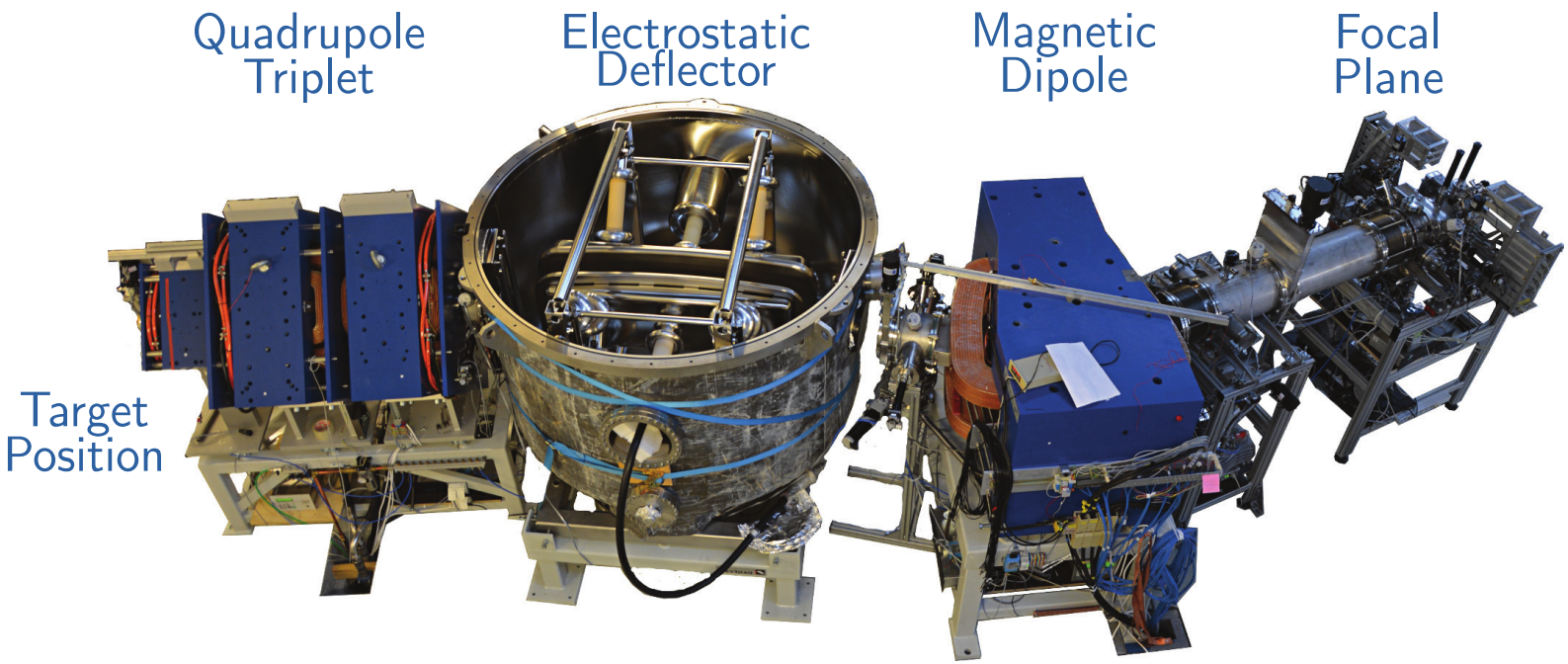
The MARA Low Energy Branch (MARA-LEB) will combine several separation techniques to purify beams of exotic ions produced at MARA and perform total spectroscopy of nuclei.



It is currently under initial construction and testing at the Accelerator Laboratory in Jyväskylä, Finland.

MARA

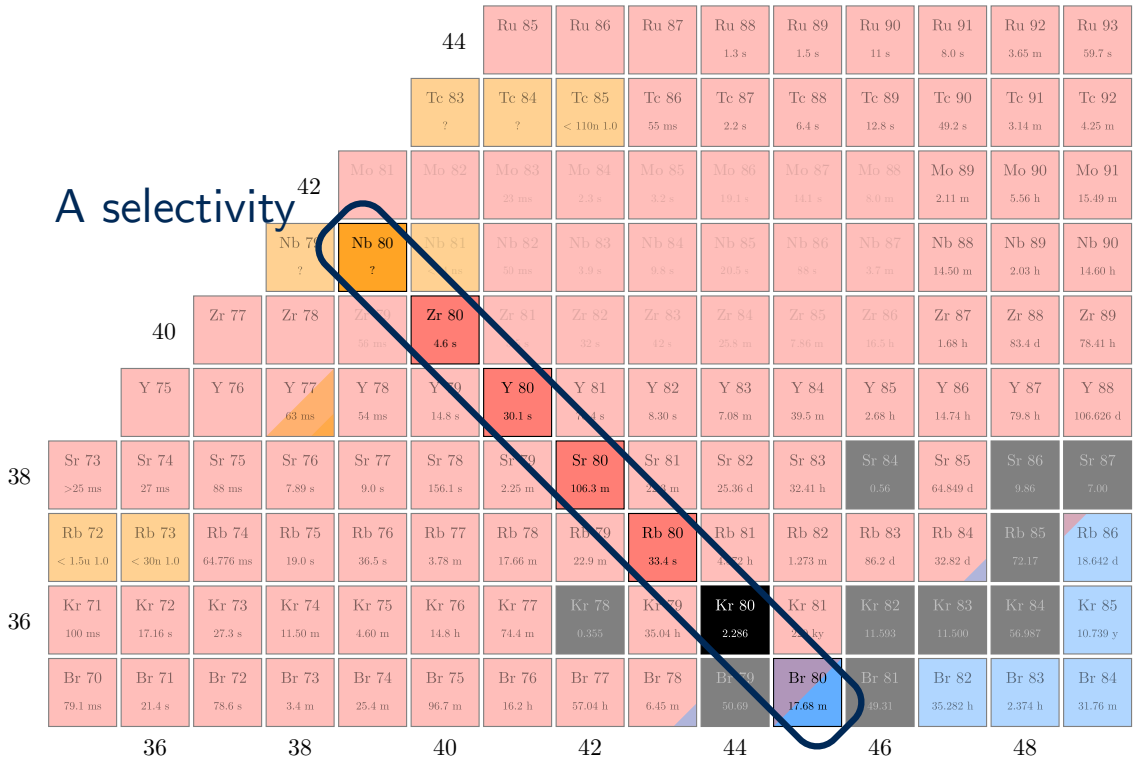
The Mass Analysing Recoil Apparatus (MARA) is a $Q^3D_ED_M$ separator with a mass resolution of 250, mainly used for symmetric fusion-evaporation reactions.



J. Uusitalo, *et al.* Acta Phys. Polonica B 50 (2019) 319.

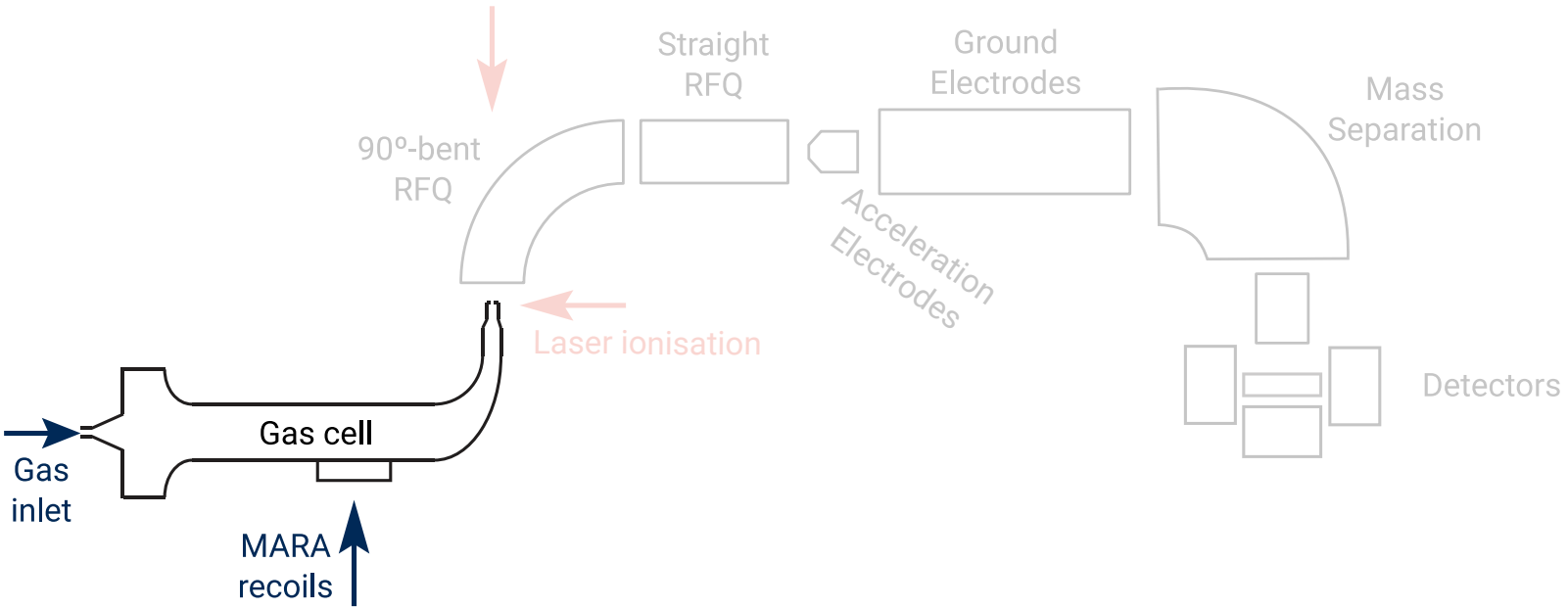
MARA

The combination of electrostatic and magnetic fields provides mass-over-charge selectivity. An isobaric chain is selected for.



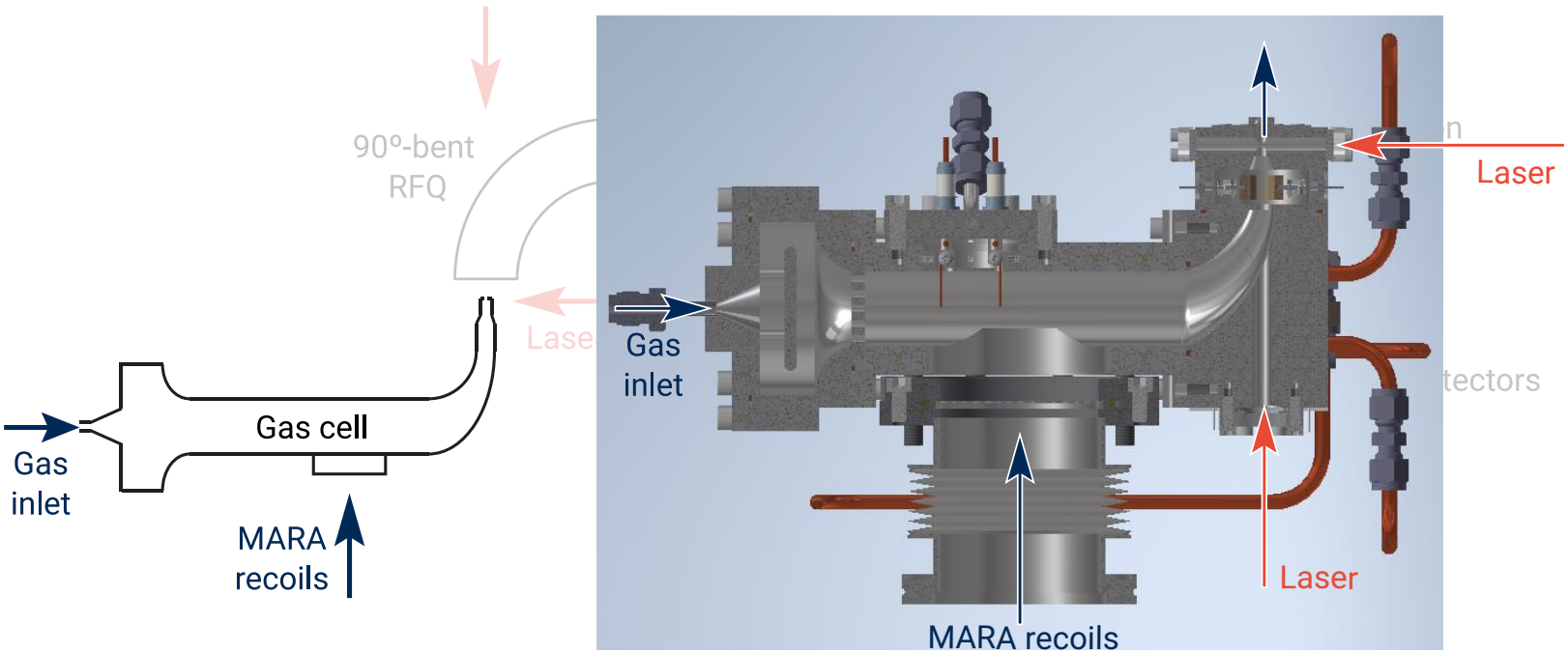
MARA-LEB Gas Cell

Recoils produced at MARA are stopped and neutralised in a small-volume buffer gas cell. Typical buffer gases are helium and argon.



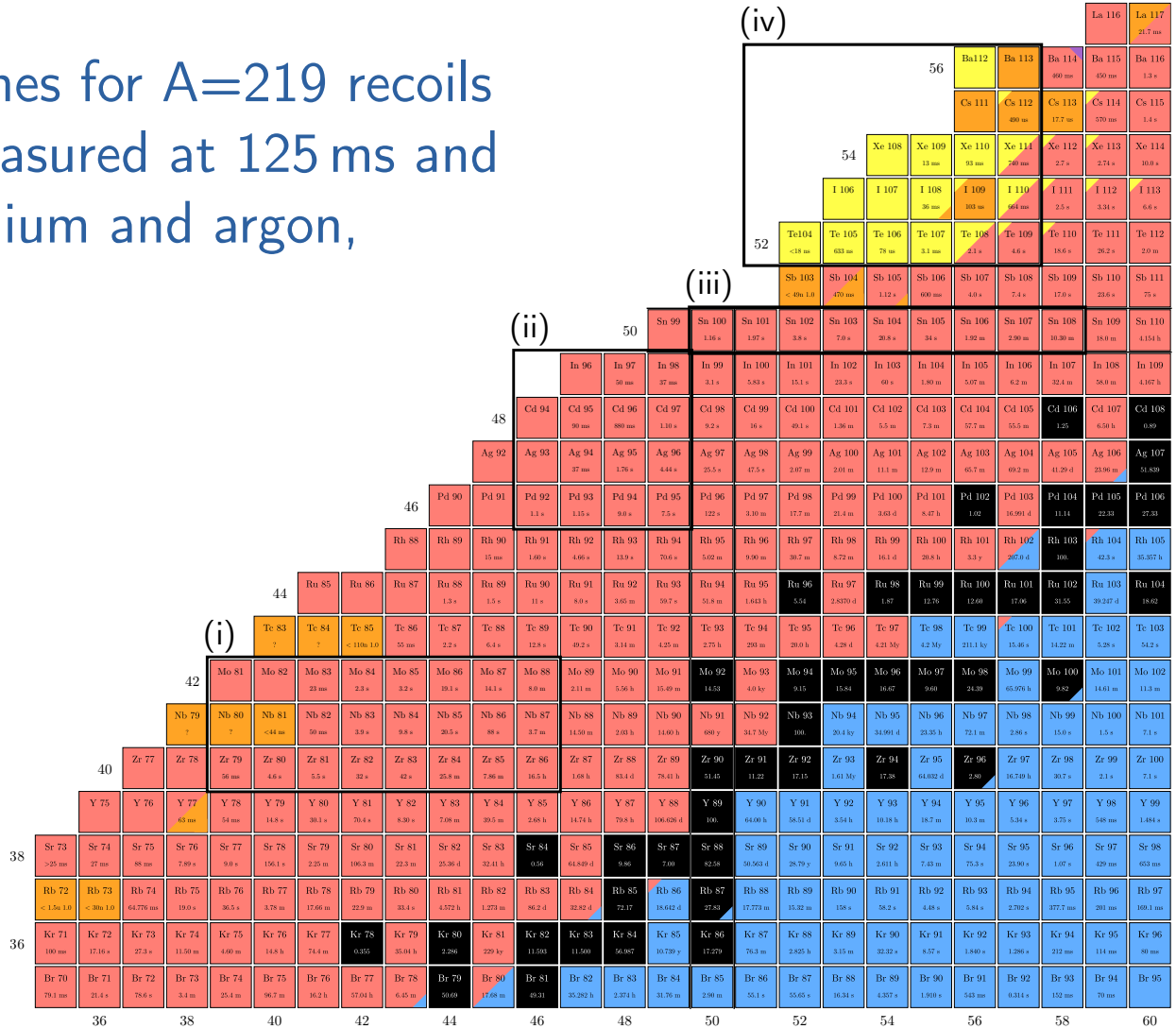
MARA-LEB Gas Cell

Neutralised recoils can be re-ionised via in-gas-cell laser ionisation. The gas is flushed out of the gas cell through a nozzle.



Gas Cell Extraction Time

Extraction times for A=219 recoils have been measured at 125 ms and 370 ms for helium and argon, respectively.



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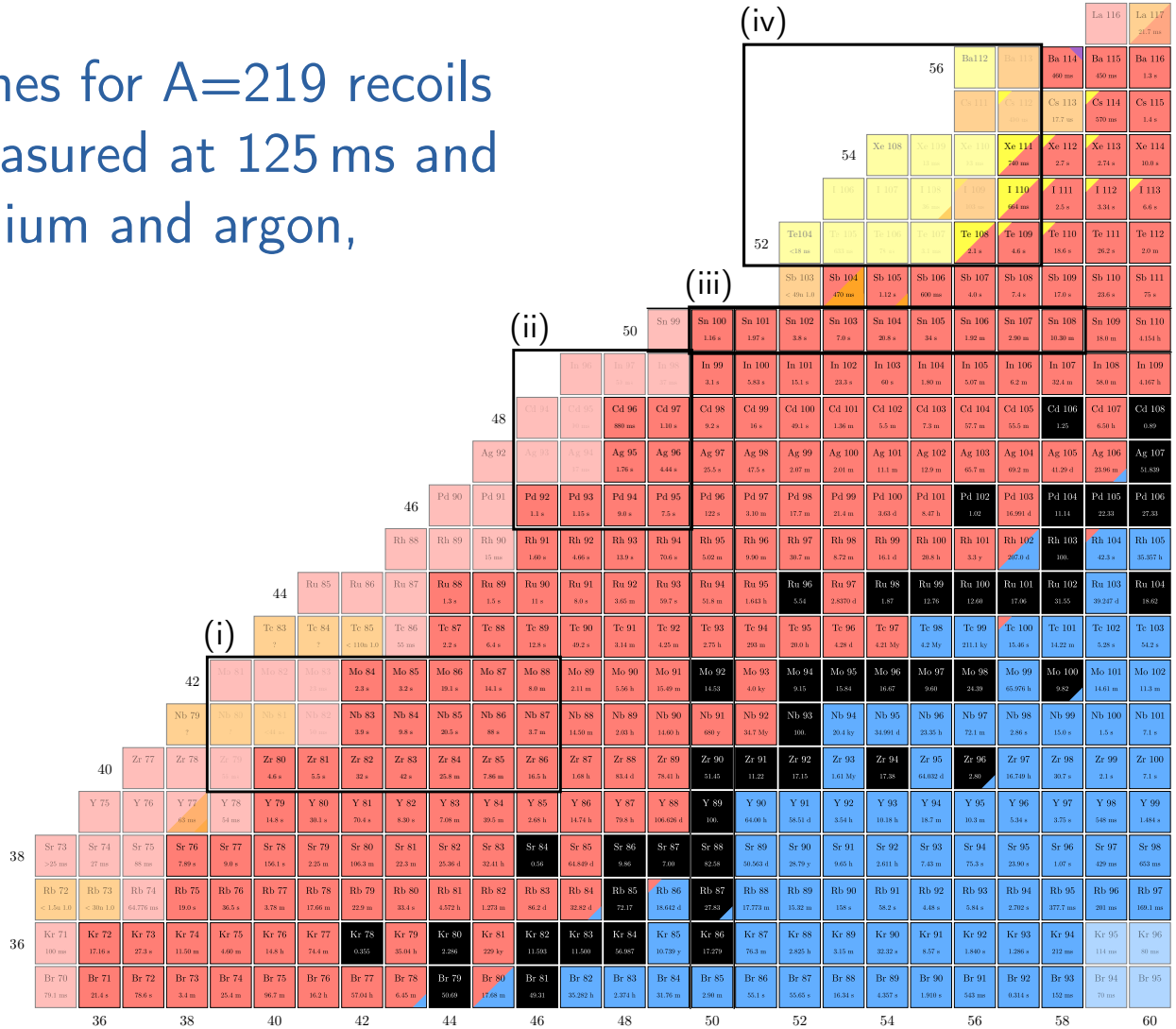
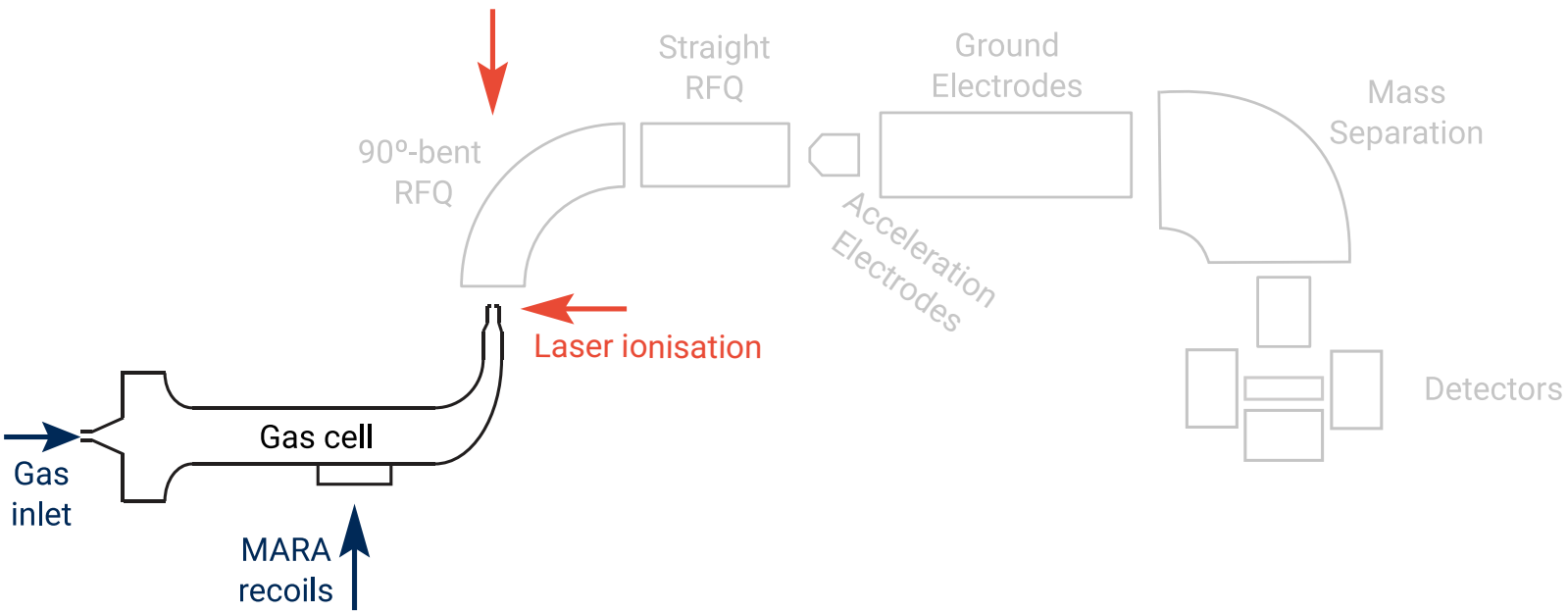


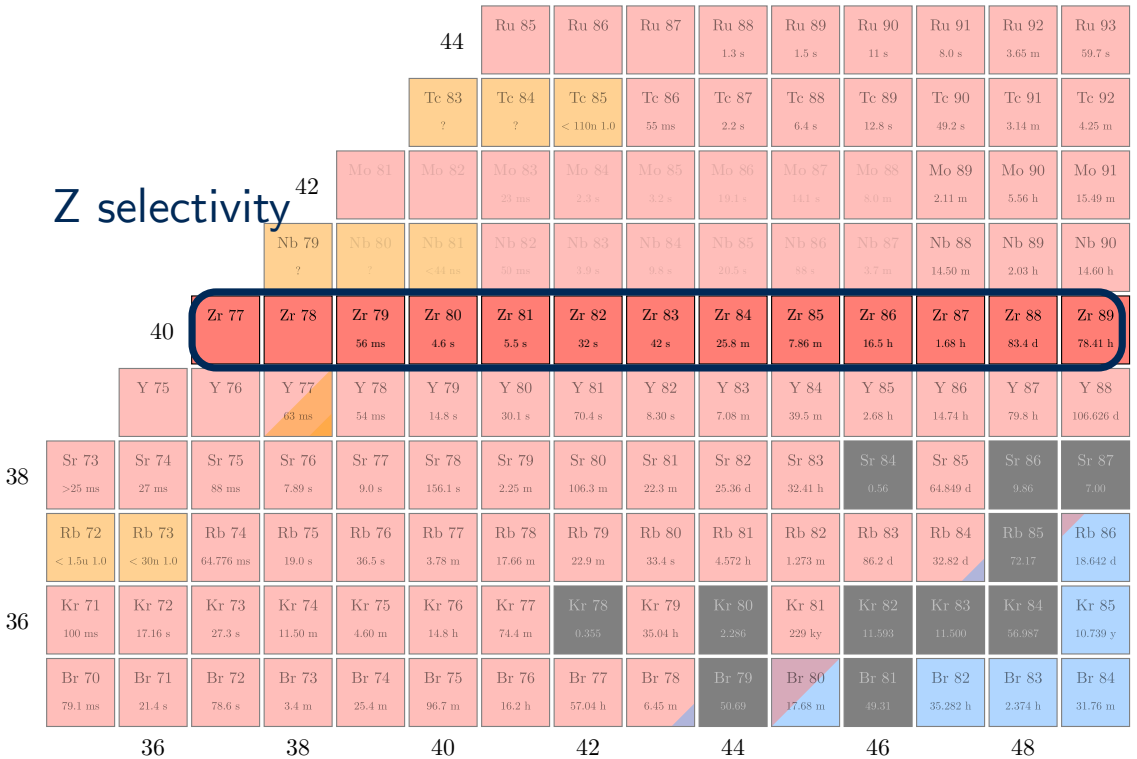
Resonant Laser Ionisation

The nozzle produces a supersonic jet, so in-gas-jet laser ionisation and spectroscopy can also be performed.



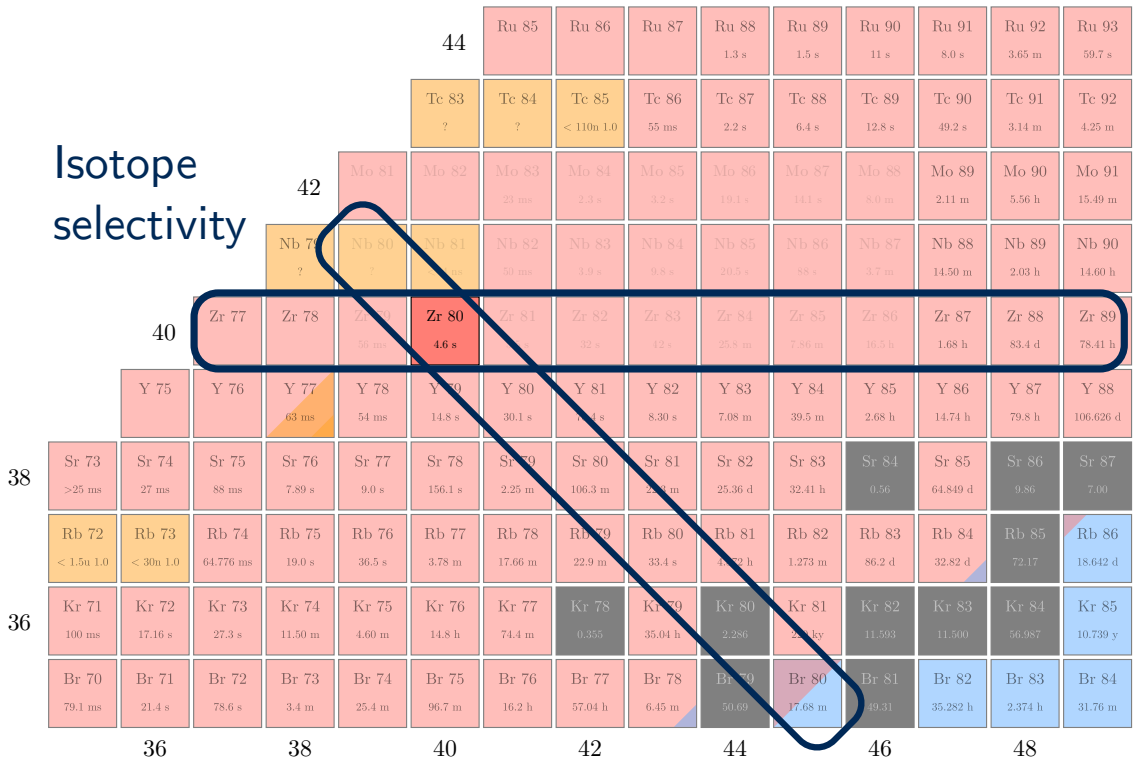
Resonant Laser Ionisation

Because the atomic levels are element-dependant, a multi-step resonant ionisation scheme can serve as a fingerprint to select in Z.



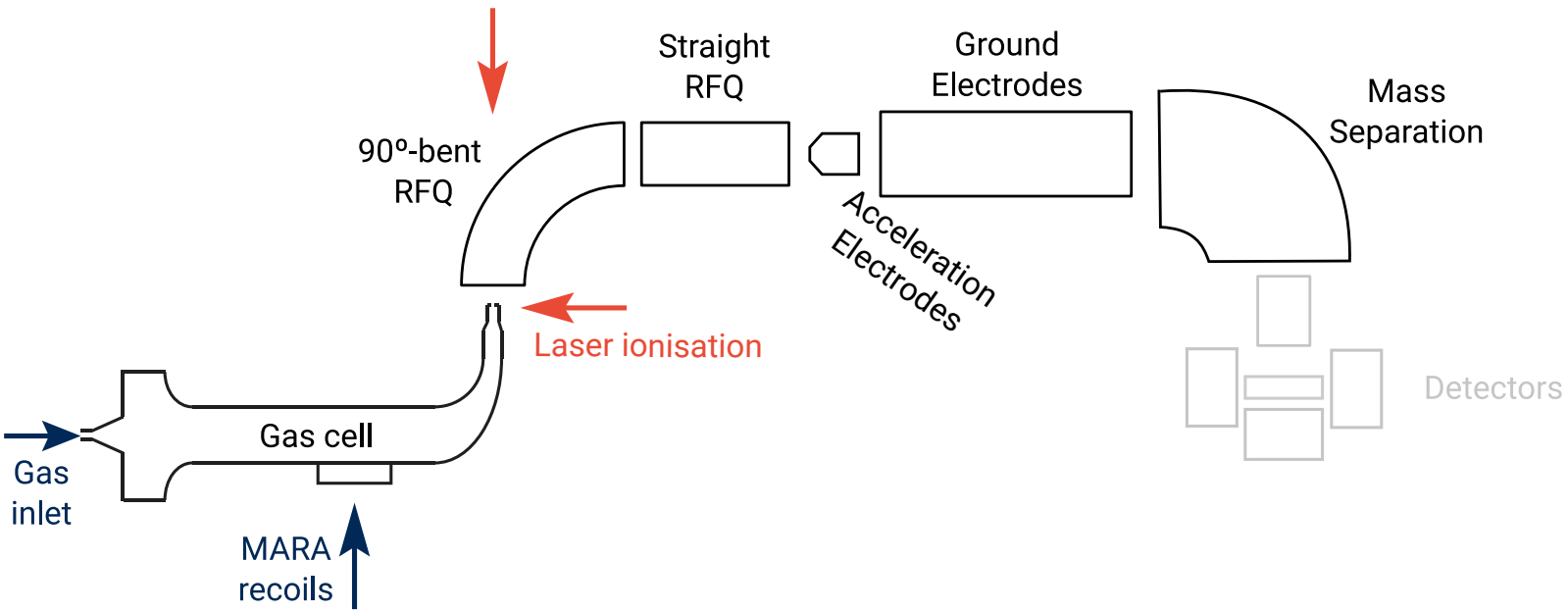
Resonant Laser Ionisation

Combining the mass selectivity of MARA and the element selectivity of resonant laser ionisation allows for clean isotopic selection.



Transport and Separation

Ions are transported and accelerated to 30 kV via the use of Radio-Frequency Quadrupole ion guides and other forms of ion optics. Selected ions are further mass separated by a dipole magnet and an electrostatic deflector.



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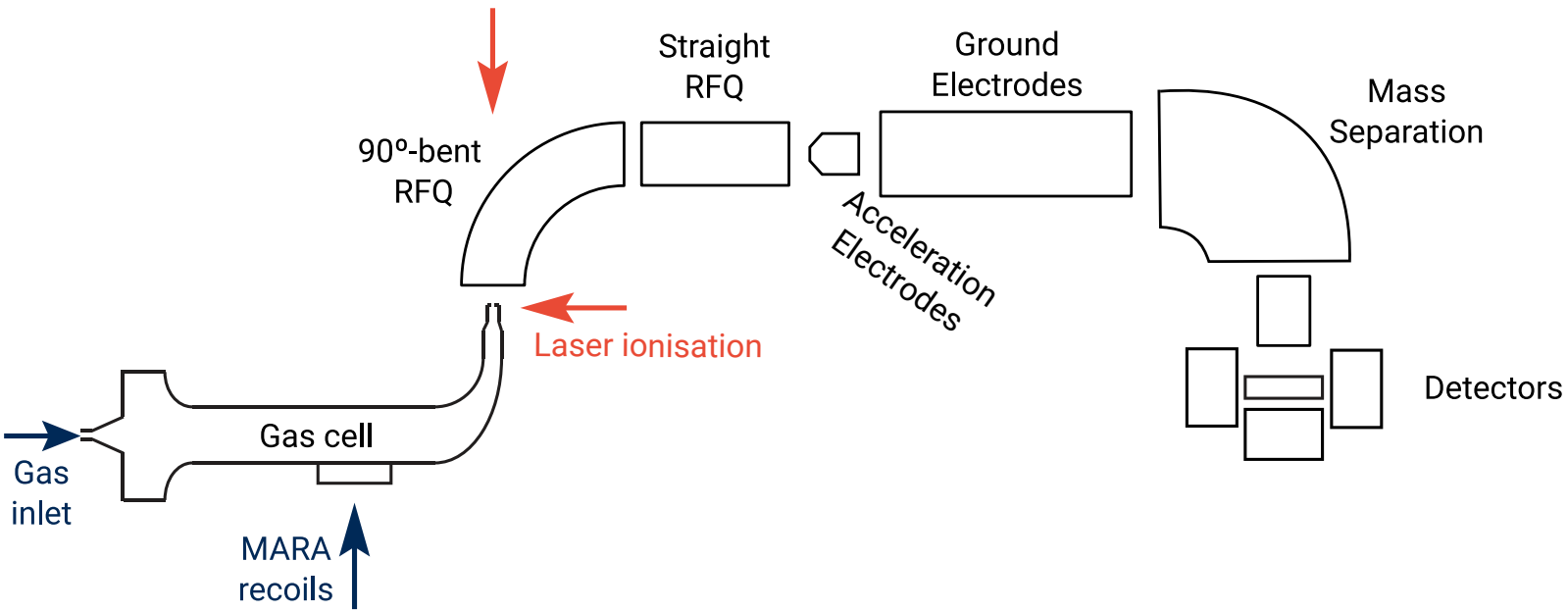
Decay Station

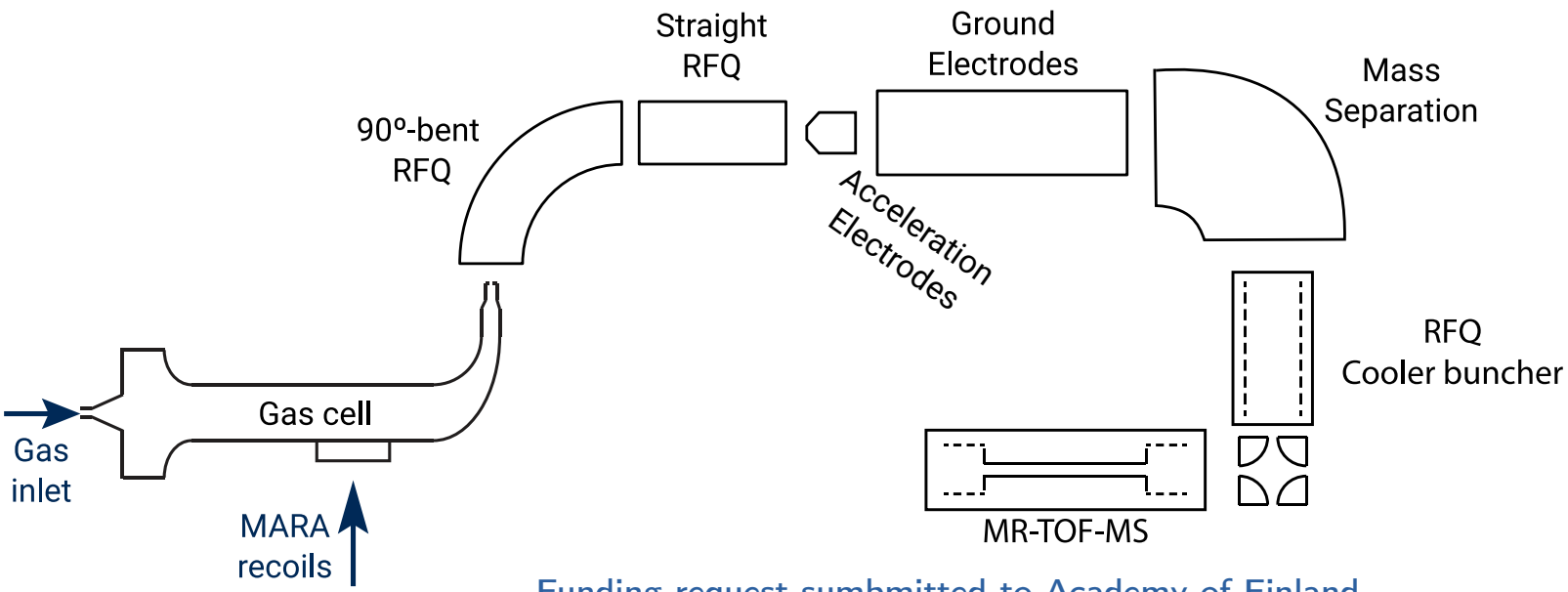
Finally, the purified recoil beam arrives at a detector station that is variable to adapt to individual experiment requirements.



Funding from FIRI has been granted for a detector station (K. Auranen).

Mass Measurement

A mass measurement setup is also planned for future phases, with a cooler-buncher and an MR-TOF-MS based on the IGISOL design.



Funding request sumbmitted to Academy of Finland.

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Experiments

Actinide Region

Experiment JM20 was carried out in the Accelerator Laboratory of the University of Jyväskylä in November 2021.

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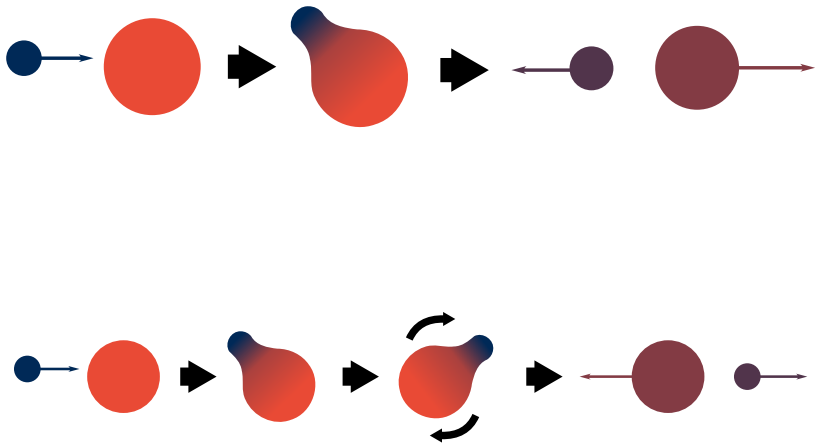

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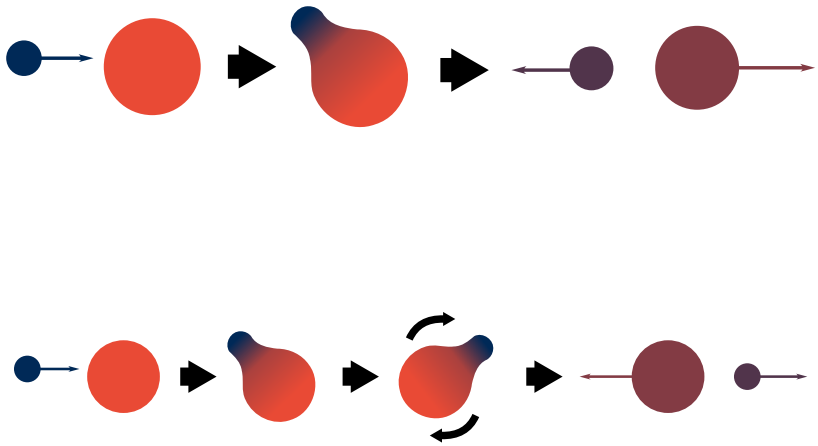
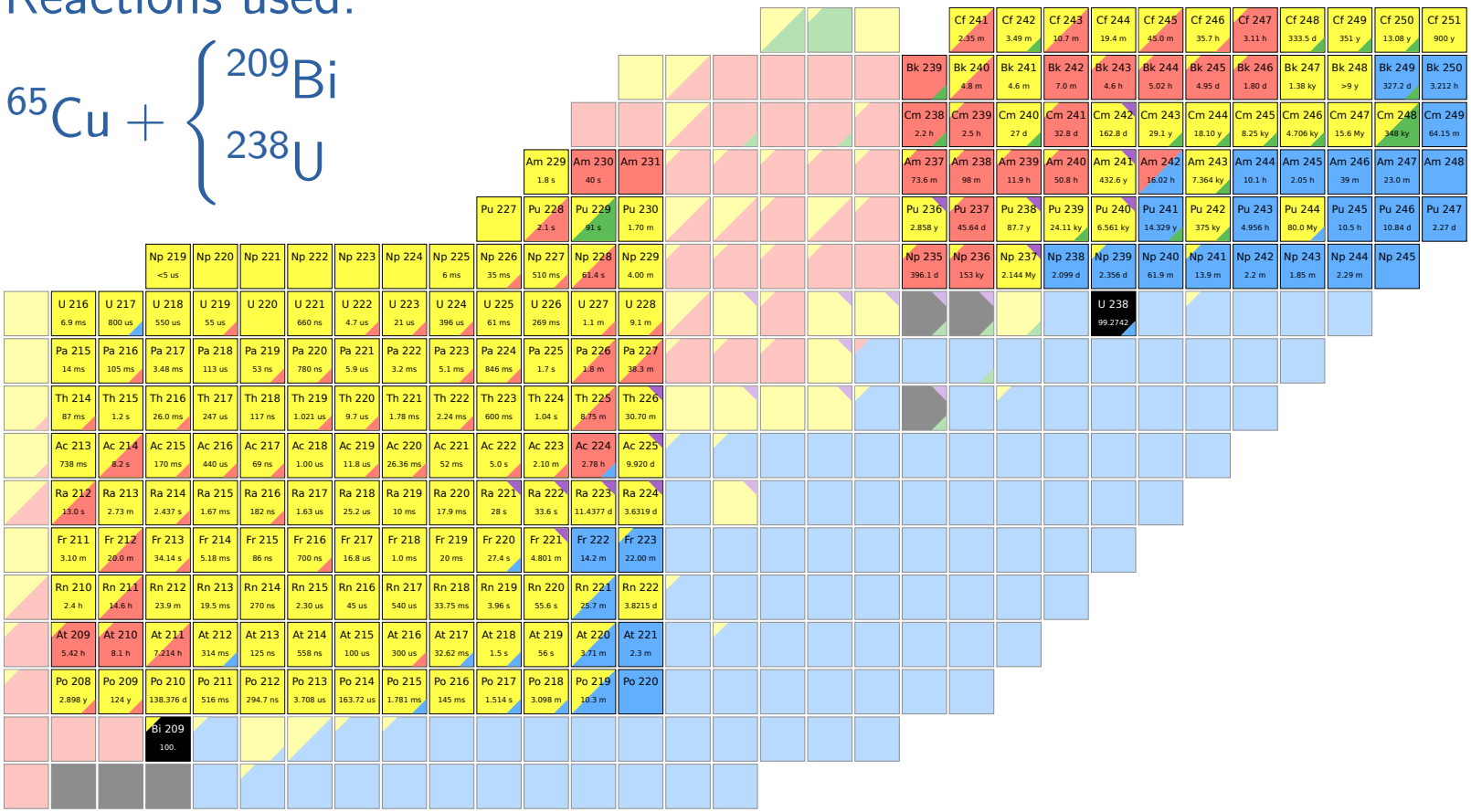


QF may be an alternate production method for actinides, which can be used to perform experiments in MARA-LEB.

Experiment JM20

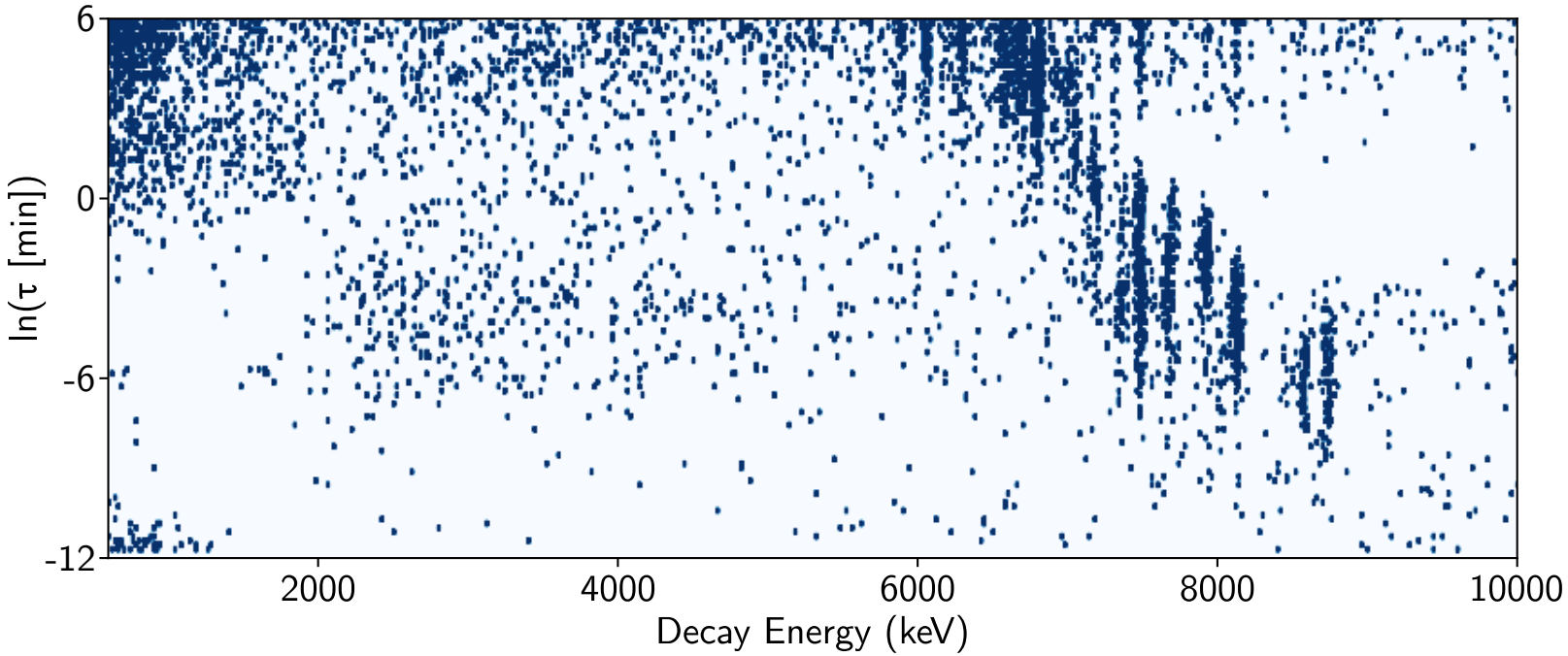
Reactions used:

$$^{65}Cu + \begin{cases} ^{209}Bi \\ ^{238}U \end{cases}$$



Analysis

Alpha decays are identified by their energy and timing.



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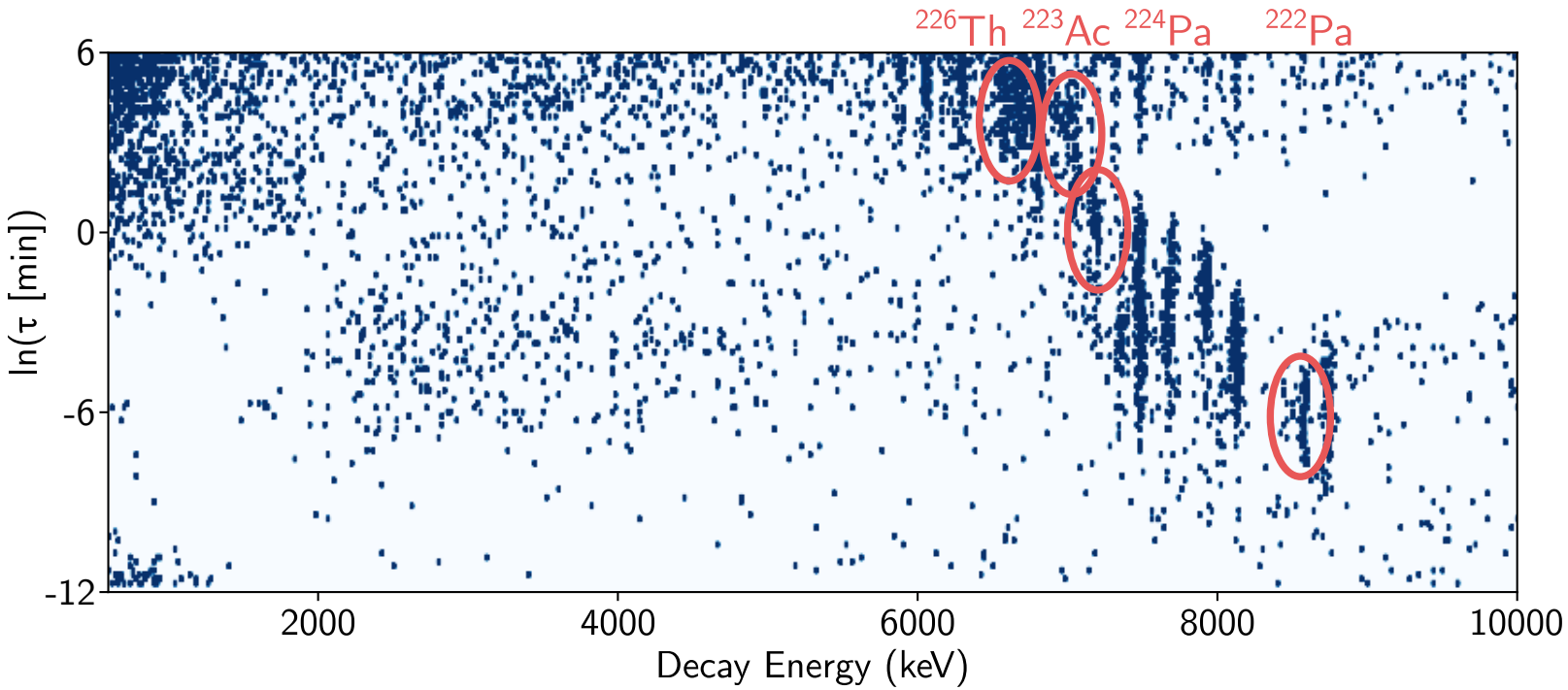
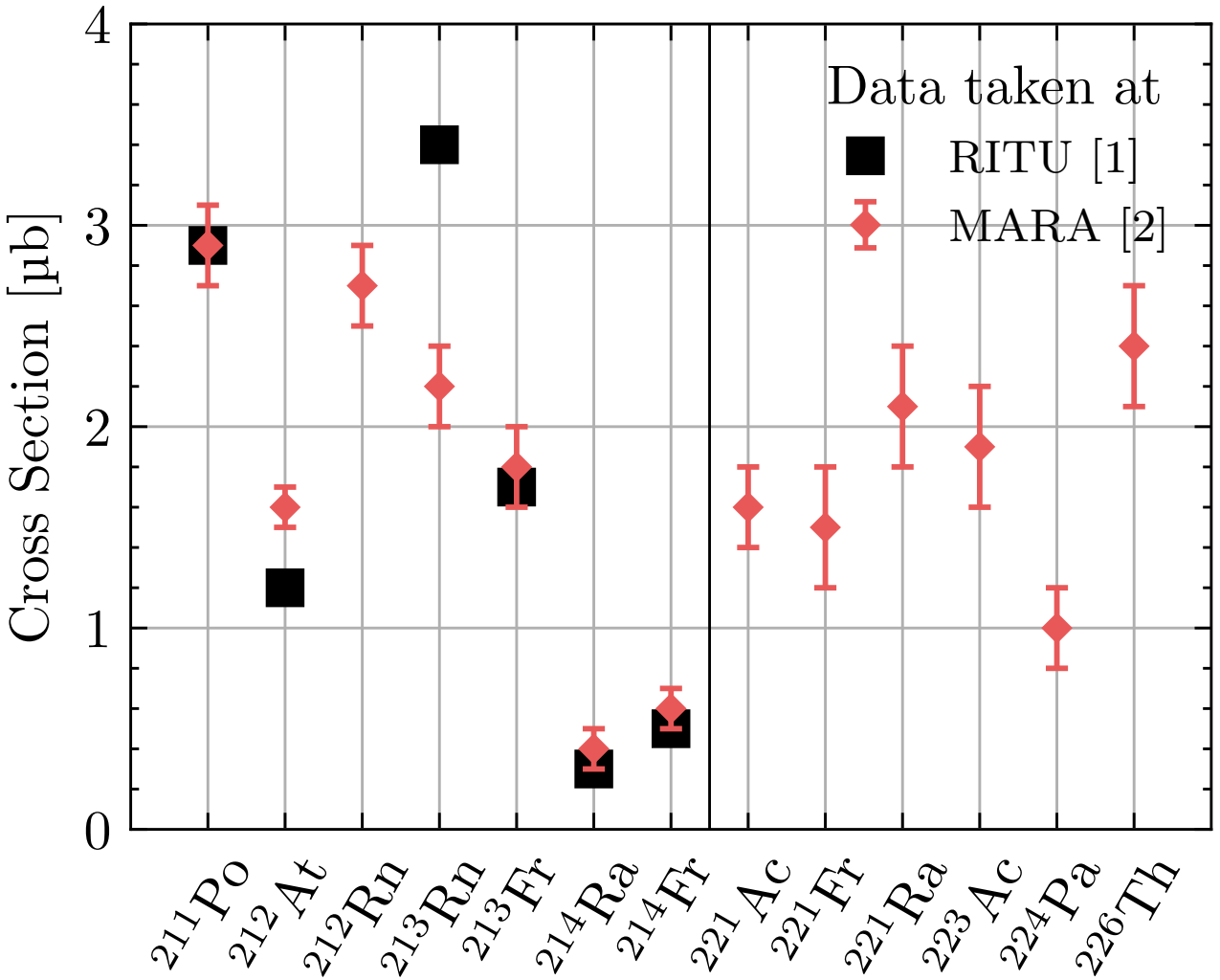


Results



[1] U. Jakobsson, Master's Thesis (2006), University of Jyväskylä

[2] J. Romero, *et al.*, Acta Phys. Pol. B Proc. Suppl. 16 (2023) 4-A12.

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Outlook

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Experimental Prospects

- Actinides produced, opening up a new region of interest for MARA-LEB.
- Cross-sections are compatible with laser spectroscopy.

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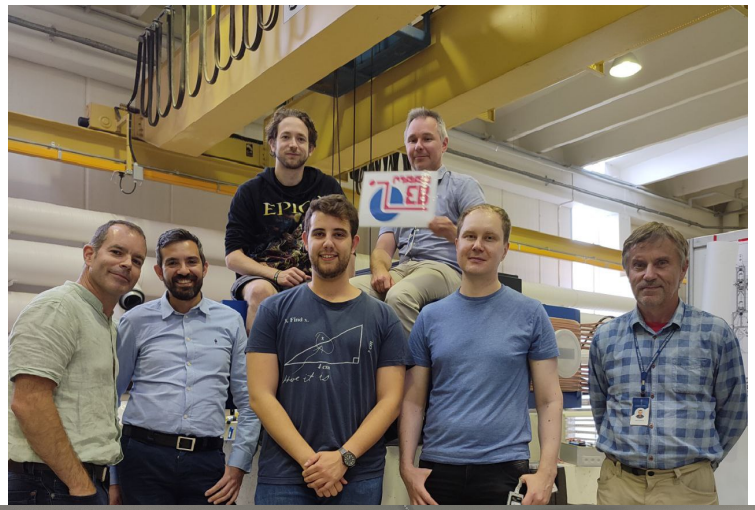
Long-Term Prospects

- Recent funding secured for infrastructure funding.
- New regions of interest have been proposed by collaborators.
  - Strong UK presence with collaborations with Liverpool, Manchester and STFC.
  - Close colaboration with S^3-LEB at Ganil.
- RITU-LEB for the study of Super-Heavies.

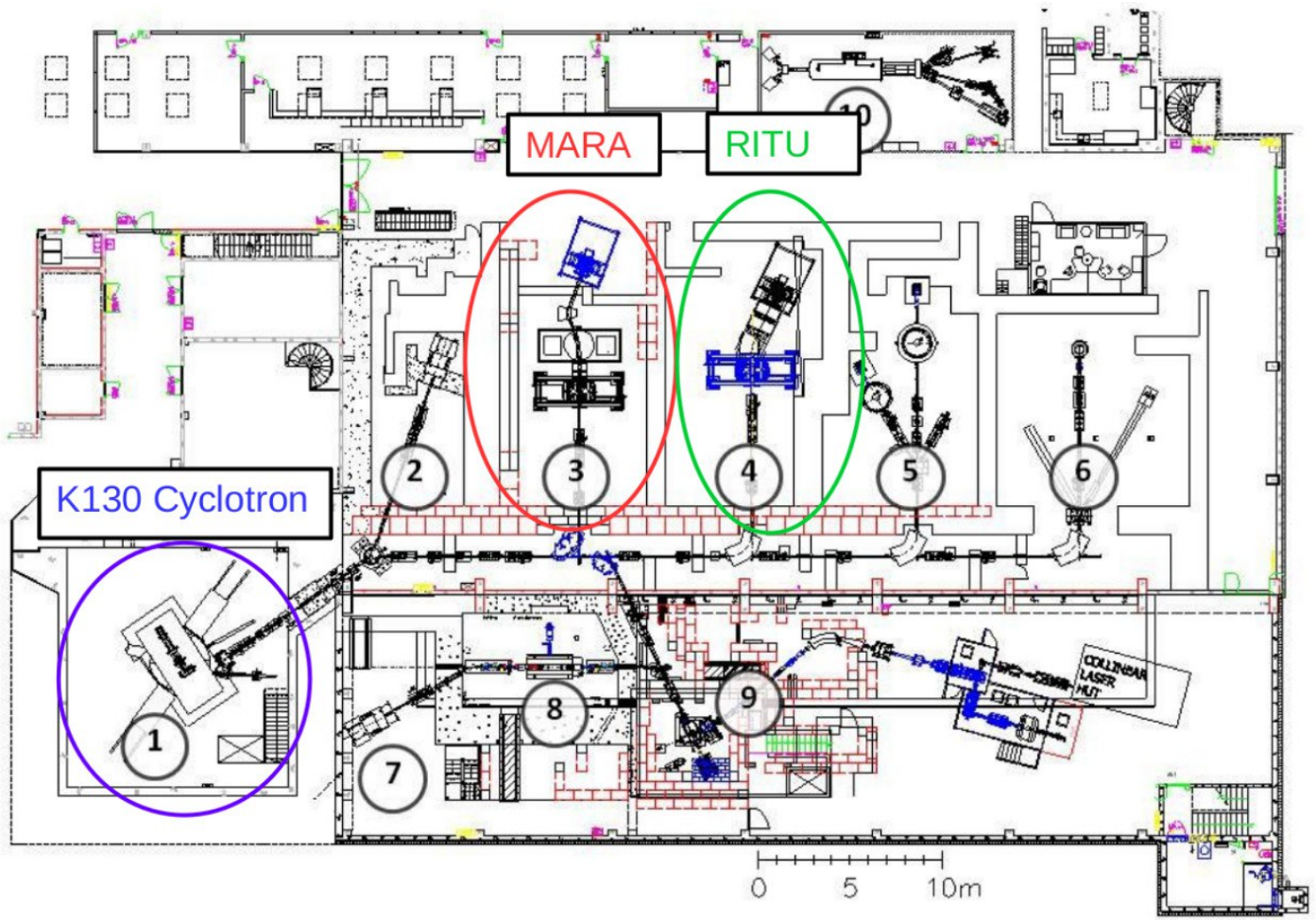
Thank you! Kiitos!



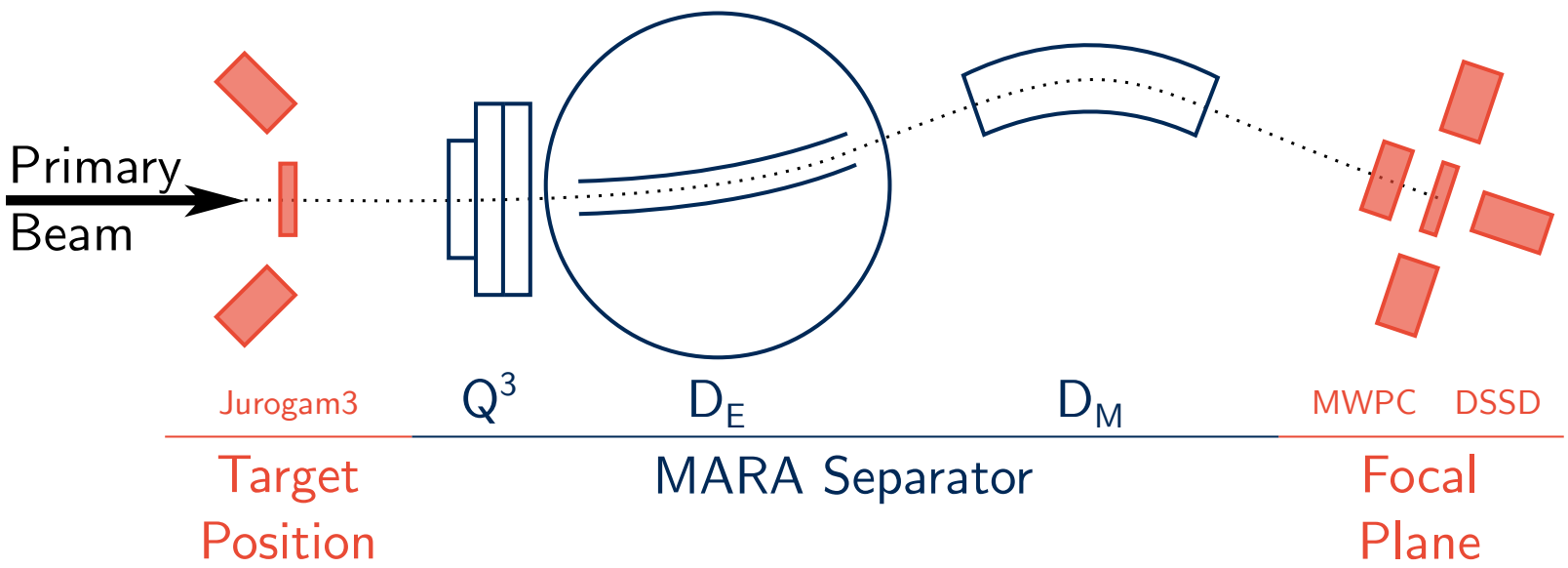
JYVÄSKYLÄN YLIOPISTO
UNIVERSITY OF JYVÄSKYLÄ

Thank you! Kiitos!

Backup - JYFL-ACCLAB

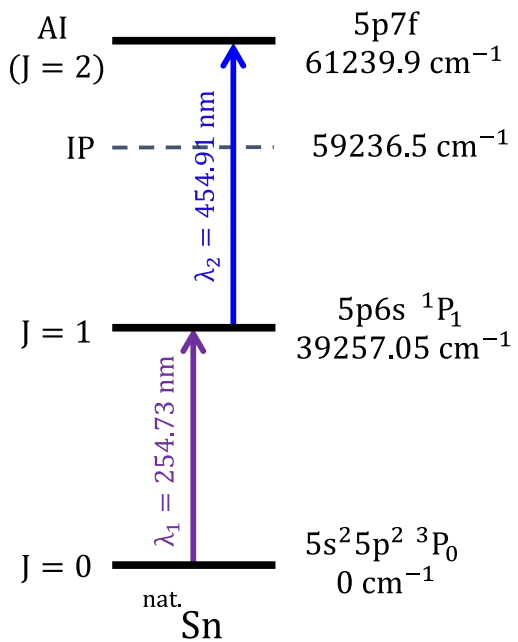


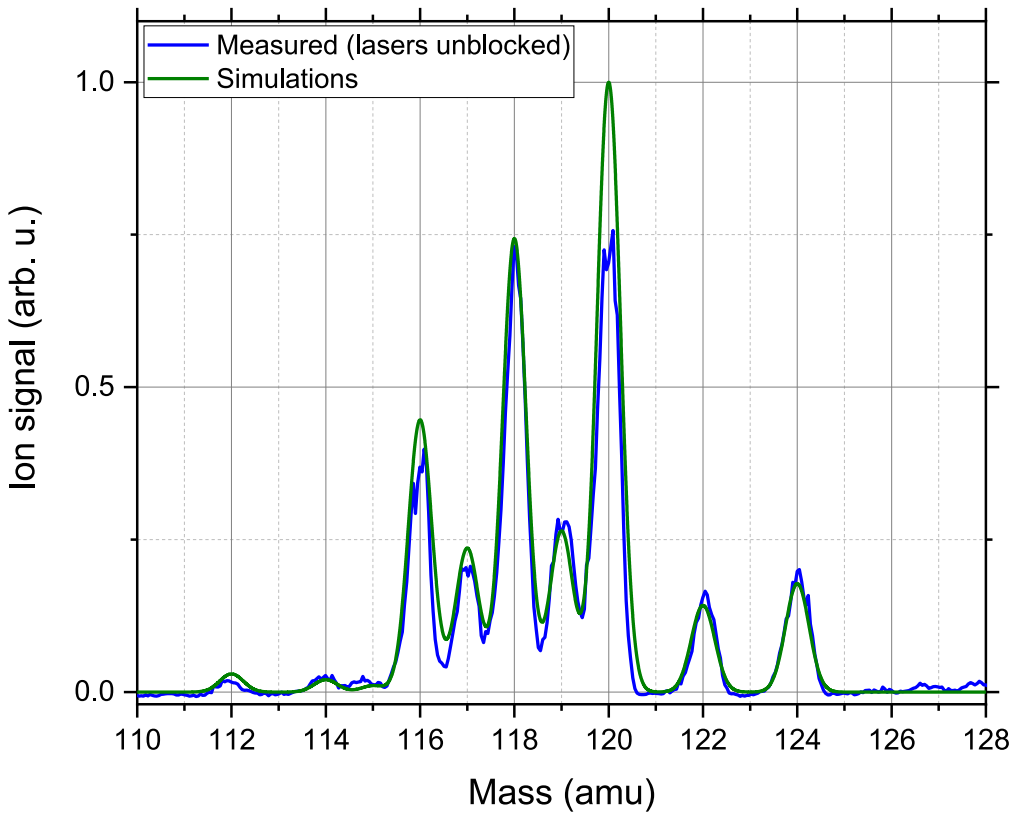
Backup - MARA Diagram



Backup - Laser Ionisation of Sn

Two-step in-gas-cell laser ionisation of natural tin was tested at IGISOL, with good agreement between the experimental data and the nautral abundances of tin isotopes.



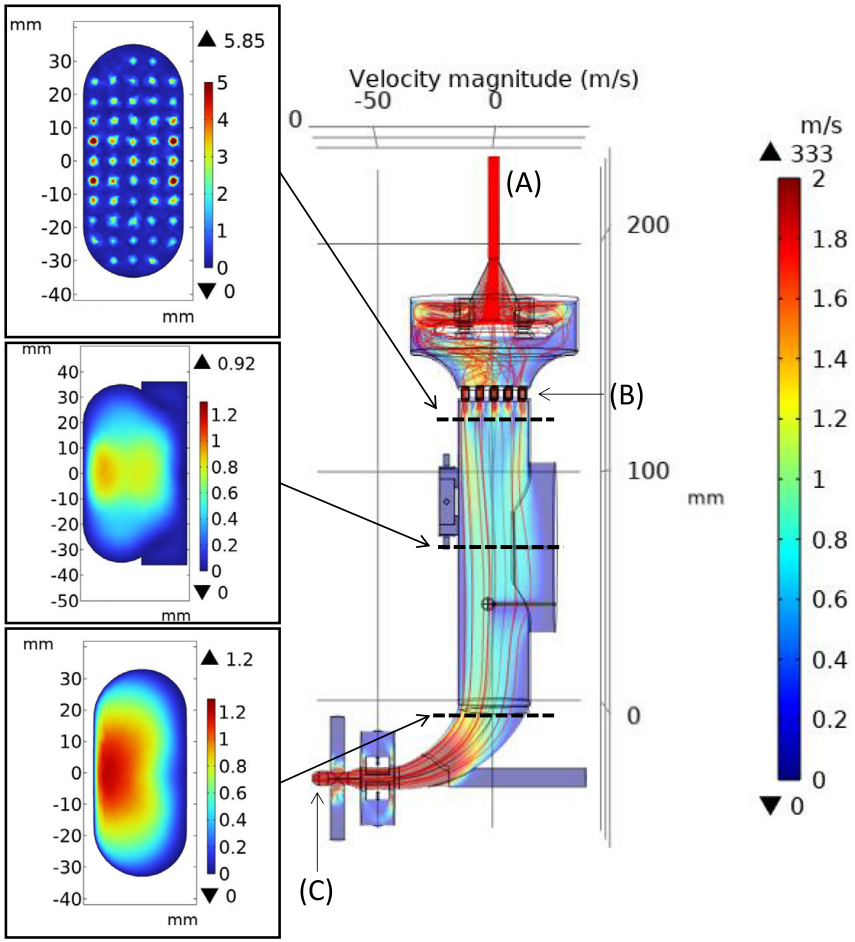


A. Zadvornaya, J. Romero, *et al.* Nucl. Instrum. Meth. B 539 (2023) 33.

Backup - Gas Flow

The gas cell design is informed by Comsol simulations to optimise the laminarity of the gas flow.

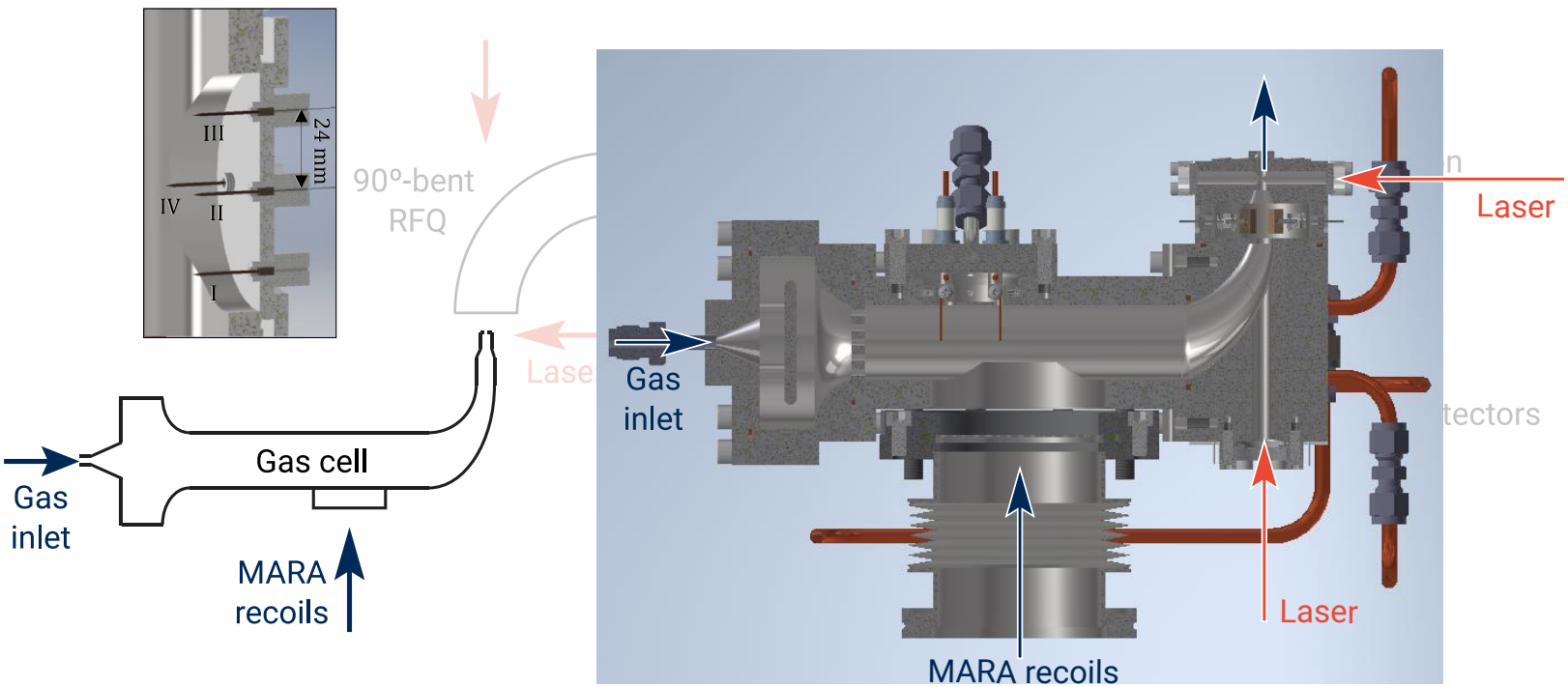
A honeycomb structure is present before the stopping volume to straighten the gas flow.



A. Zadvornaya, J. Romero, *et al.* Nucl. Instrum. Meth. B 539 (2023) 33.

Backup - Extraction

The gas cell has been tested offline at IGISOL, obtaining ion survival and transport efficiencies of up to 12% for an ^{223}Ra needle source.



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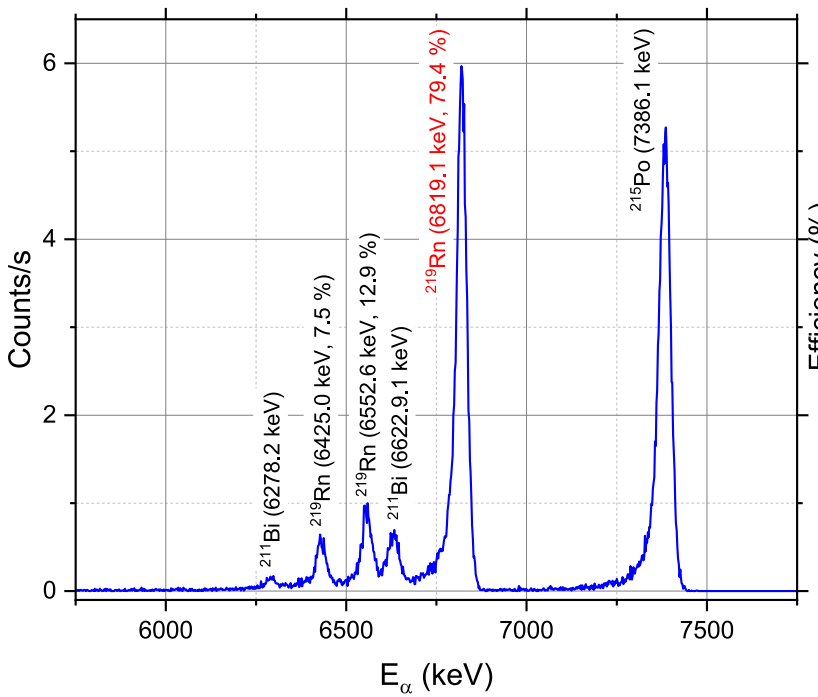
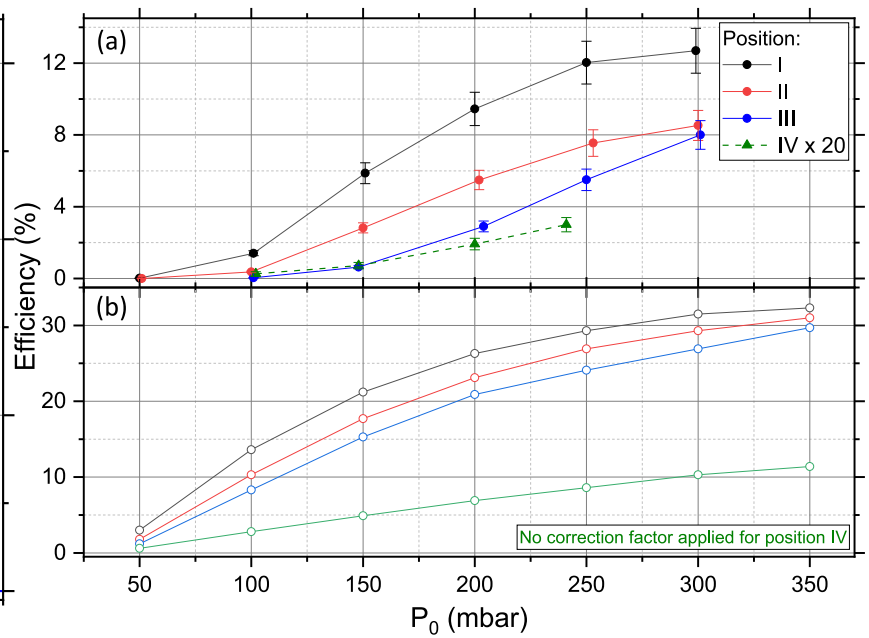


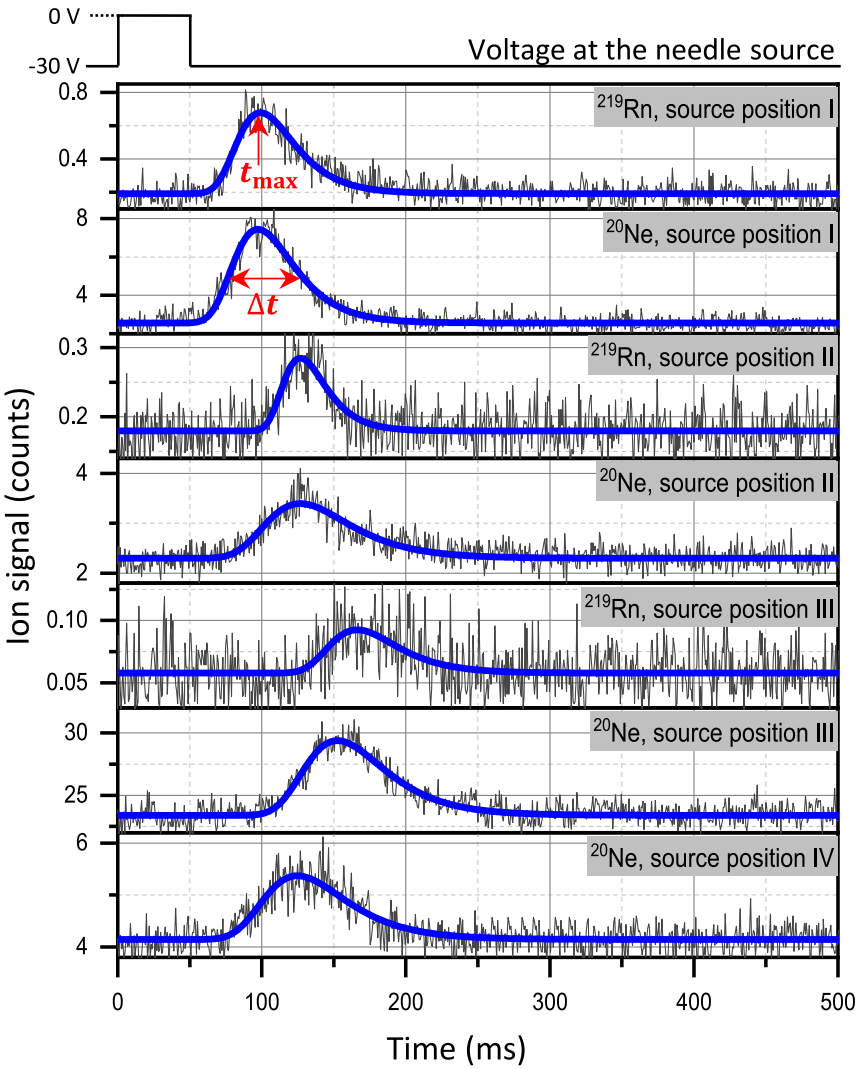


A. Zadvornaya, J. Romero, *et al.* Nucl. Instrum. Meth. B 539 (2023) 33.

Backup - Extraction

By applying a pulsing voltage to the needle source, extraction time profiles can be obtained for ^{219}Rn and gas impurities.

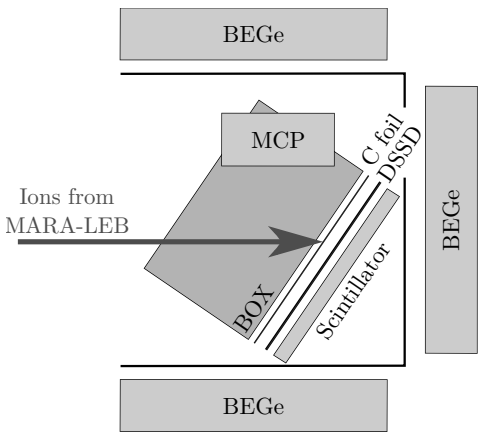
- $t_{He} \approx 125\,ms$
- $t_{Ar} \approx 370\,ms$
- The extraction time ratio: $t_{Ar}/t_{He} = 2.94(2)$ is close to the estimate: $\sqrt{A_{Ar}/A_{He}} = 3.16$.

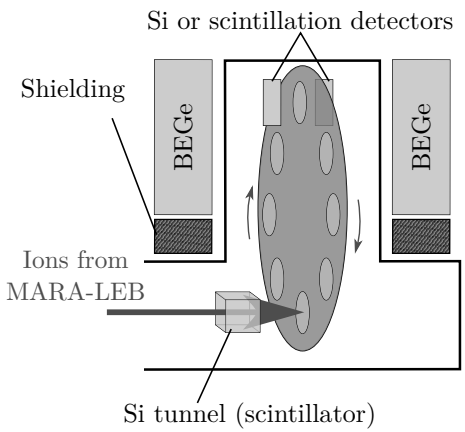


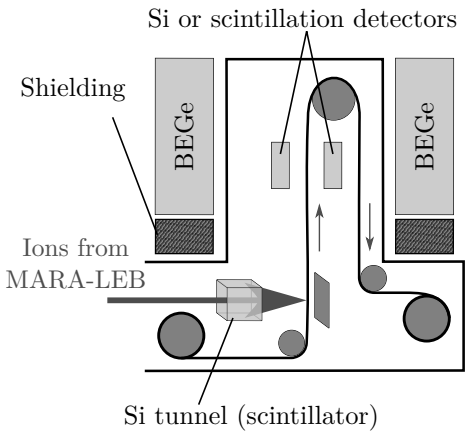
A. Zadvornaya, J. Romero, *et al.* Nucl. Instrum. Meth. B 539 (2023) 33.

Backup - Decay Stations

Three different designs have been suggested for the decay station.

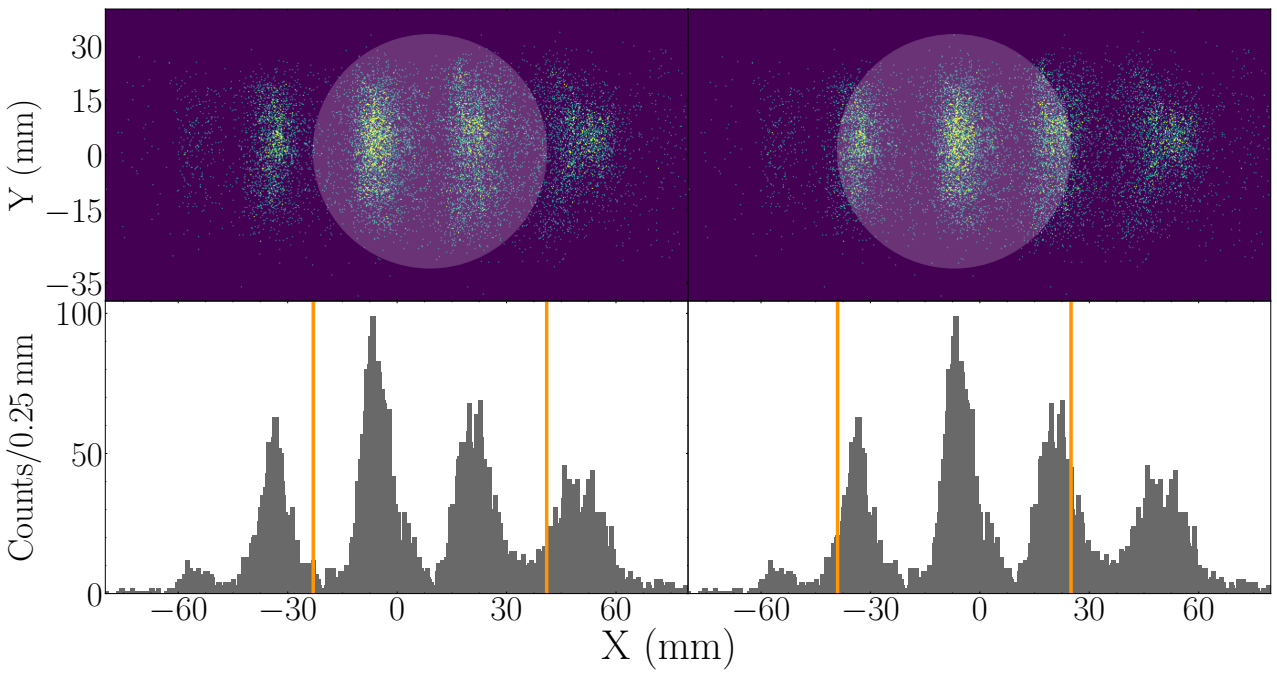






Backup - Gas Cell Window

The $^{40}Ca(^{60}Ni, 2p2n)^{96}Pd$ reaction was used to determine the position of A=96 recoils.



J. Romero, *et al.* Acta Phys. Pol. B Proc. Suppl. 16 (2023) 4-A12.