Highlights from the JYFL Accelerator Laboratory and future opportunities

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JYFL-ACCLAB and the European landscape

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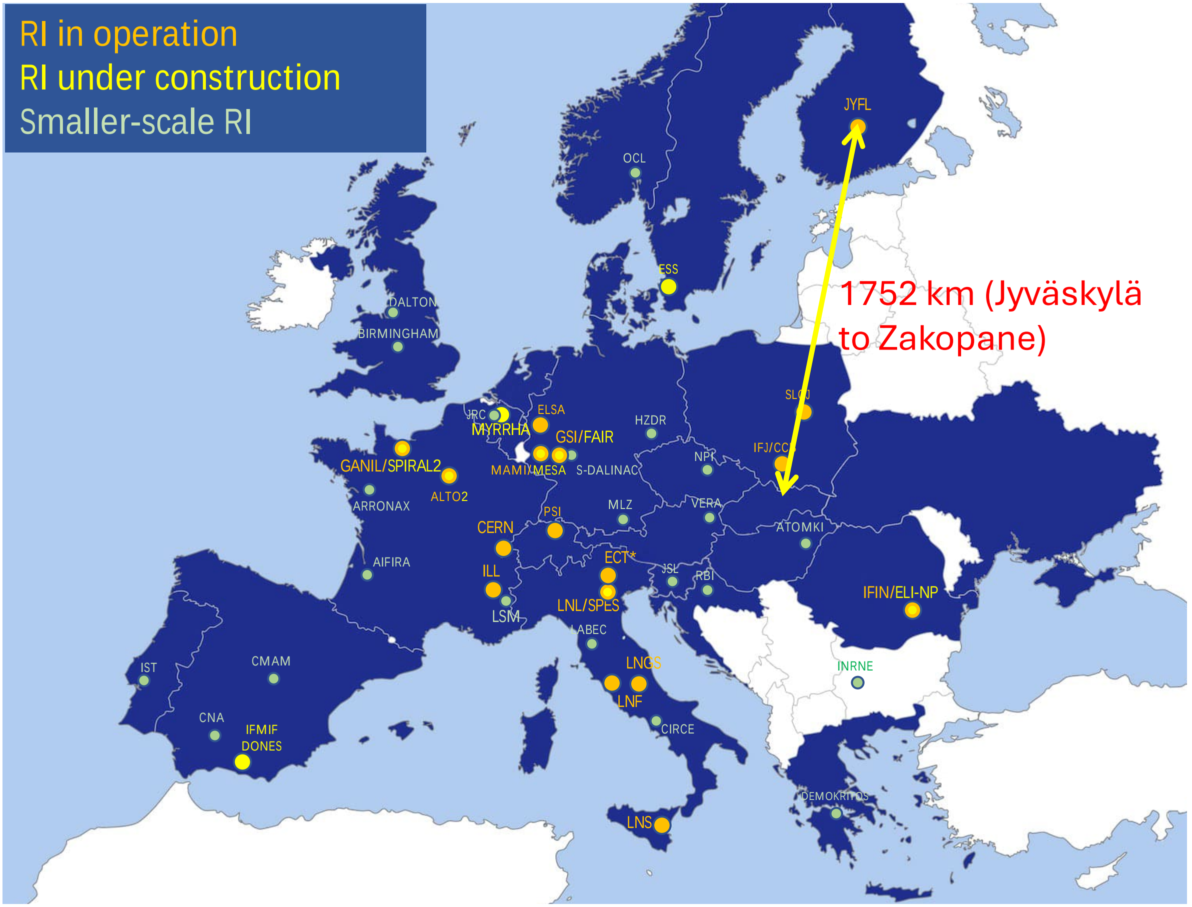

Figure from the NuPECC Long Range Plan 2024

- One of the leading large-scale accelerator facilities in Europe
- One of the largest research infrastructures in Finland
- Highly visible in the new NuPECC Long Range Plan 2024 (partly driving our key scientific questions)
- Beneficiary in several EC and EURATOM Transnational Access Programs (since FP4)
- Reputation as an extremely cost-effective and productive RI, producing high-impact results
- Beam time availability at highest levels in Europe
- Highly important for worldwide aerospace industry
- Continual renewal of scientific program
- ~80 staff (from Professors, researchers, to PhD students and technical support)
- ...we have a lot of fun... !

Accelerators of JYFL-ACCLAB

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K130 Cyclotron

- ECR and light ion sources
- Protons to Au
- Up to 22 MeV/u (Kr)
- “Cocktail” beams

K30 Cyclotron

(PRIORITY 2027)

- 10-30 MeV protons (H^-)
- 9-15 MeV deuterons (d^-)
- Beam current 200/62 μA

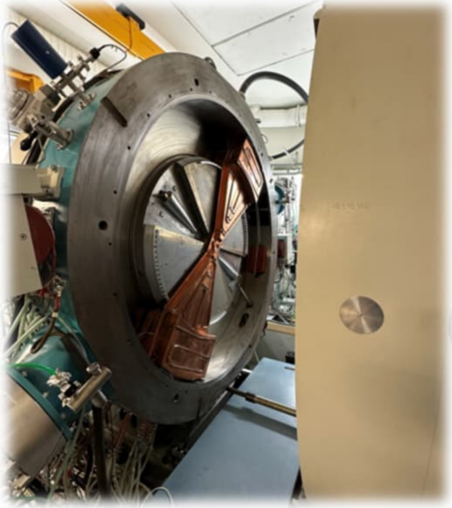
1.7MV Pelletron

- Protons to Au
- 0.2 – 20 MeV
- Multiple beam lines

Linac

- Electro , 20 MeV
- X-r MeV

u



Removed 2026 !

JYFL-ACCLAB layout and core activities - 2025

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IGISOL

Optical Spectroscopy

Exotic Nuclei

Nuclear Astrophysics

A

K=30 MeV

K=130 MeV

RADEF

C-Linac

Radiation Effects
Irradiation Services
-Space
-Microfilters

C

Nuclear Reactions

Nuclear Structure

B

Nuc. spec

Ion Sources / Plasma Physics

Pelletron

D

Materials Characterisation
-ToF-ERDA
-RBS
-Ultra-High Resolution PIXE
-Depth Profiling

Control Centre
Data Analysis
Visitor Hub

Four main research groups

A. Exotic nuclei and beams

B. Nuclear spectroscopy

C. Radiation effects and industrial applications

D. Accelerator-based materials physics

+ Ion source - accelerator team (the backbone for the research groups)

(Last nuclear reactions experiment using Large Scattering Chamber in 2023)

K130 users and Top 10 accelerated ions (2026)

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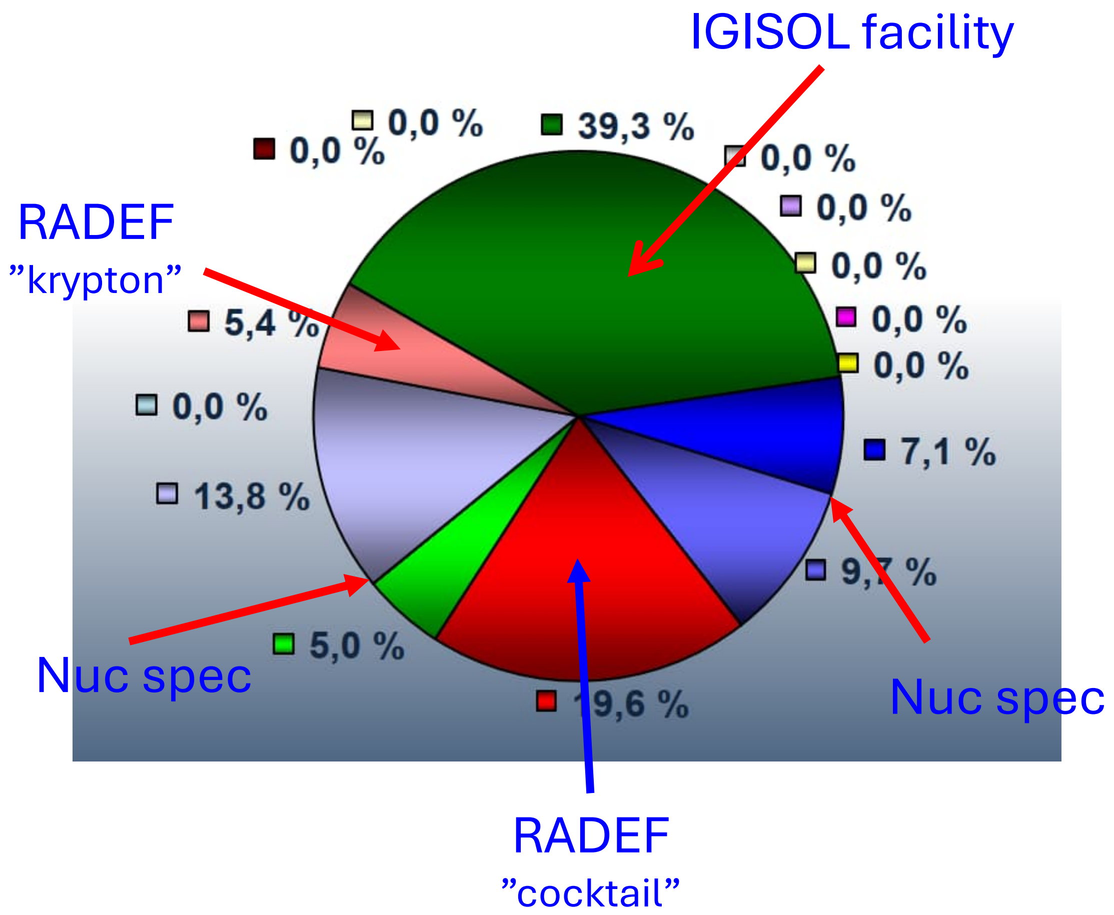
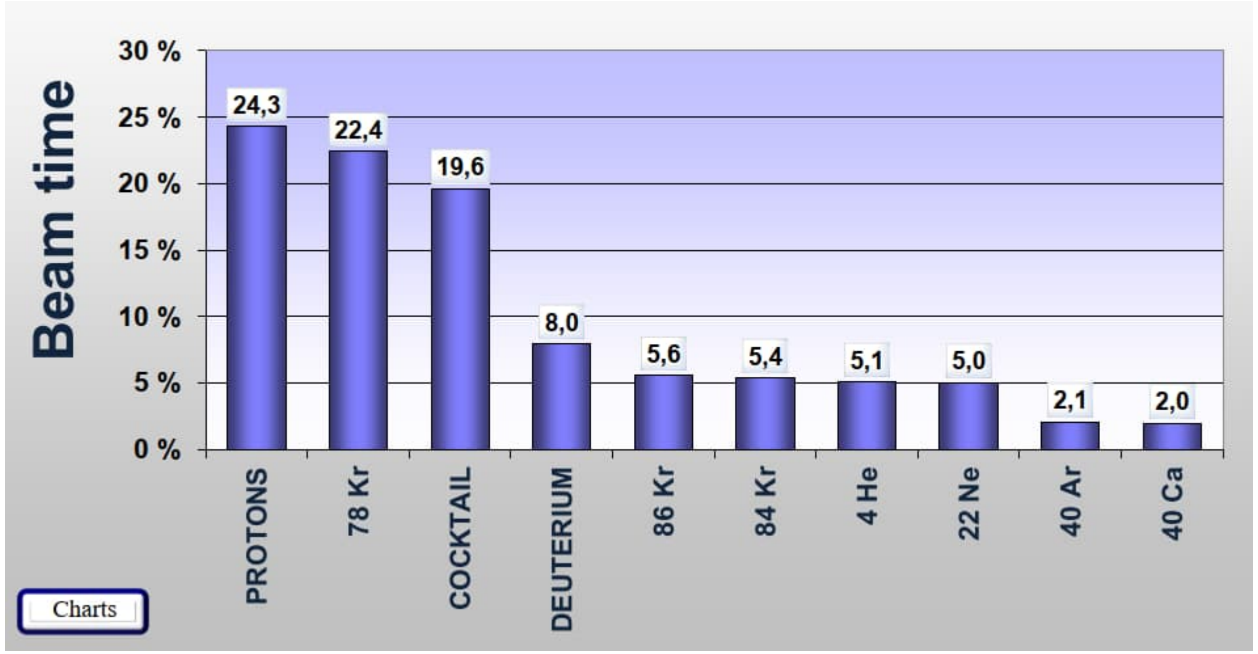
The K130 cyclotron has been operating consistently over 6000 hours annually since 1996
(2011 – IGISOL reconstruction; 2015 – installation of the MARA recoil separator; 2020 – COVID).





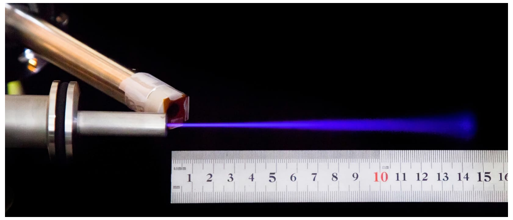
- At the end of 2025, the cocktail beam was a clear winner, with protons taking the silver medal.

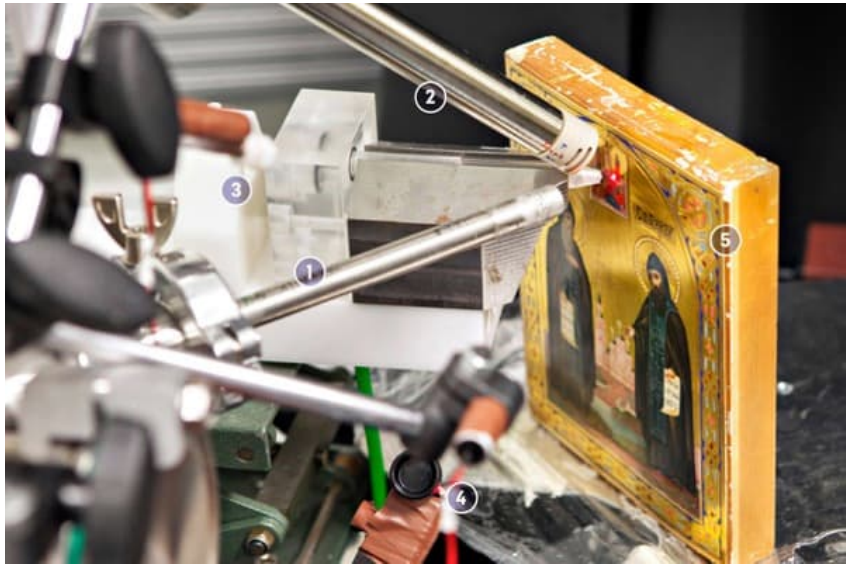
Pelletron facility for materials physics research

Main research fields
- Fundamental ion-matter interactions
  - cross sections, stopping power, straggling
- Ion-beam analysis (IBA) for thin film samples
- Development of IBA techniques
  - detectors, data acquisition, simulation packages

Three ion sources
- PELLIS: H^- filament driven multi cusp
- Alphatross: RF source with Rb charge exchange, He^- ions
- MC-SNICS: Cs sputtering ion source, solid targets. (Cl^-, Cu^-, Br^-, I^-, Au^-, ...)

Three beamlines for ion beam analysis
- ToF-ERDA “workhorse” since 2010
- ToF-ERDA new “commercialized”
- Rutherford backscattering spectrometry & external beam for PIXE

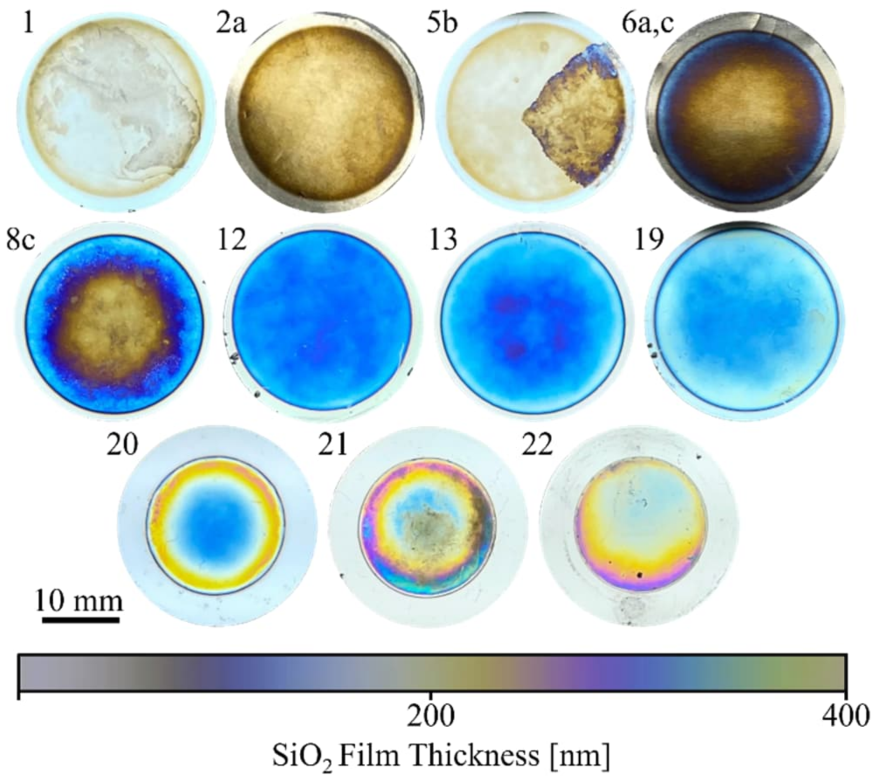


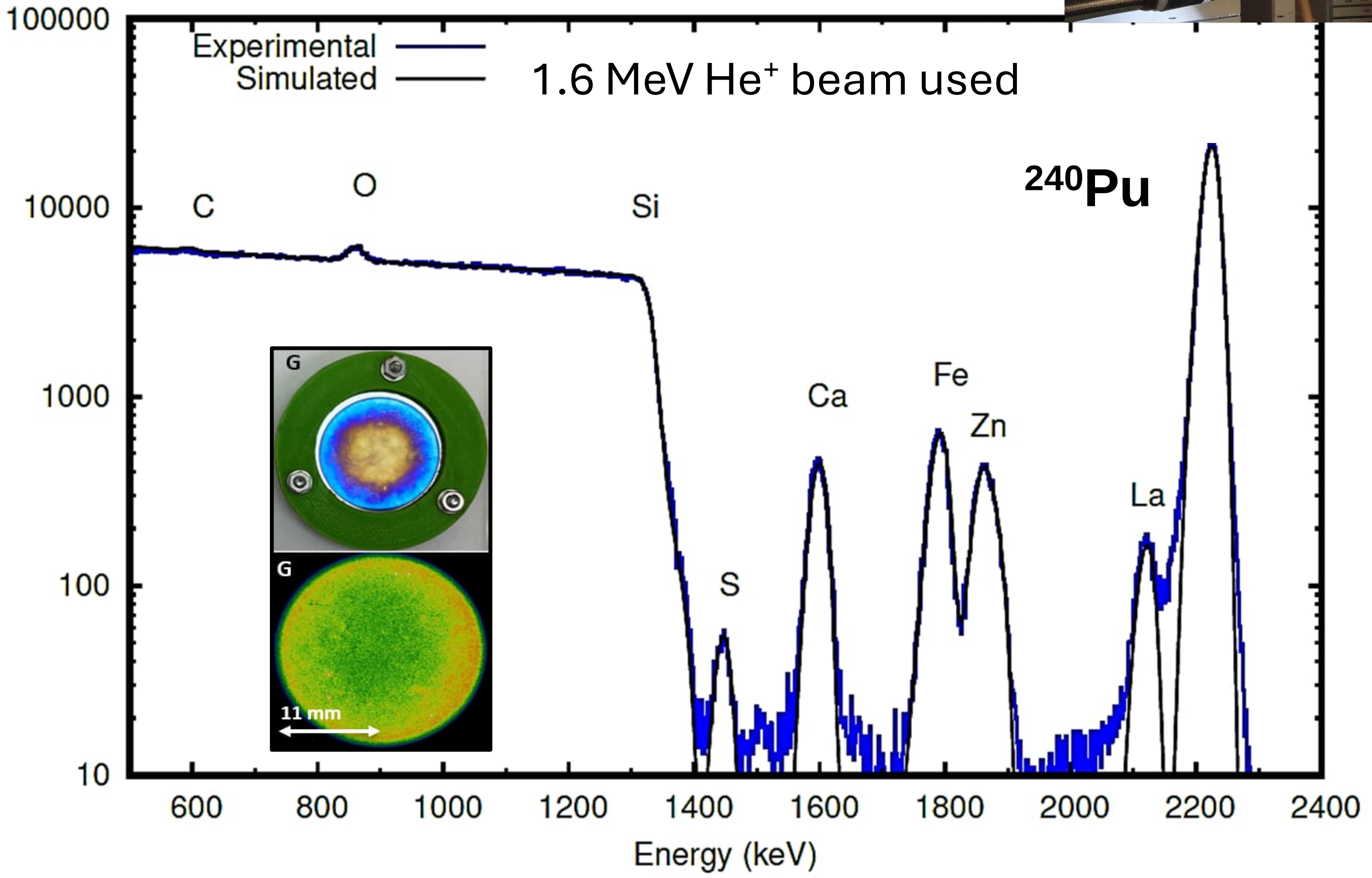


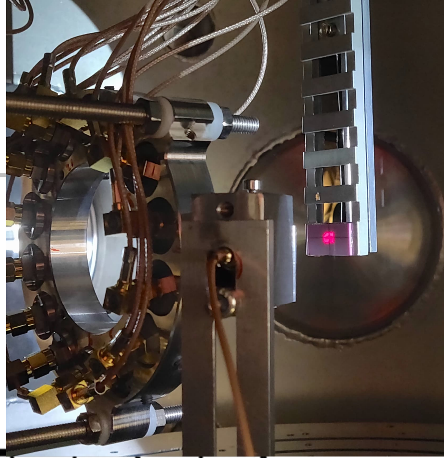
Research for Science and Art:
PIXE (X-ray fingerprints) to examine pigments in artwork

Characterisation of plutonium thin films

Within the Marie Curie ITN LISA network, Rutherford backscattering spectrometry was used to analyze ^{239,240}Pu recoil ion sources prepared using molecular plating at U-Mainz.



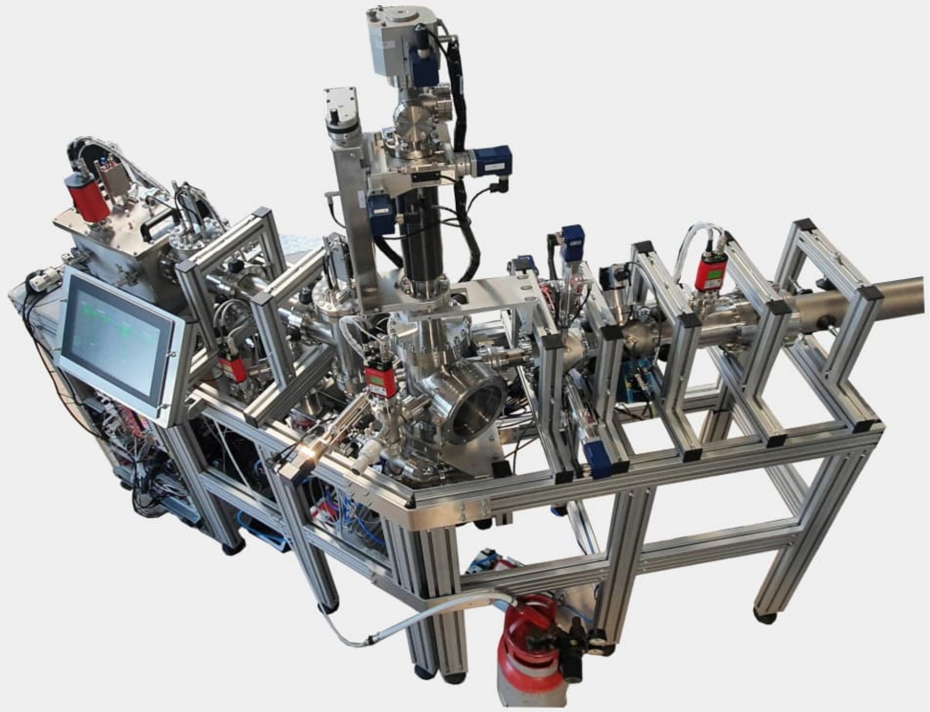




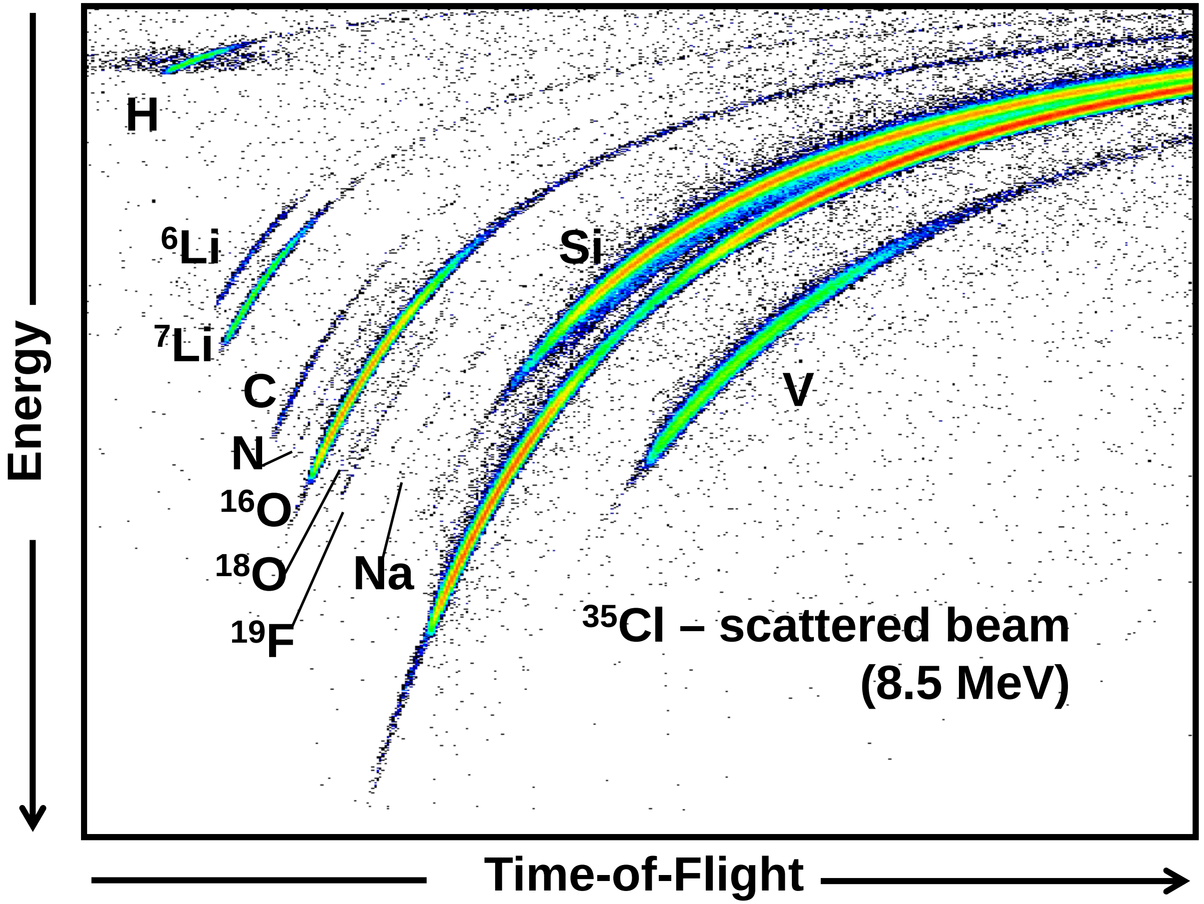
L.E. Reed et al., J. Radioanal. and Nucl. Chem. (2026)
https://doi.org/10.1007/s10967-026-11025-5

Developing state-of-the-art analysis tools

In-house development of a modern ToF-ERDA tool



- Timing detectors with <1 ns pulse rise times – optimized for hydrogen detection efficiency
- Beams of 1-20 MeV Cl, Br, I or Au ions

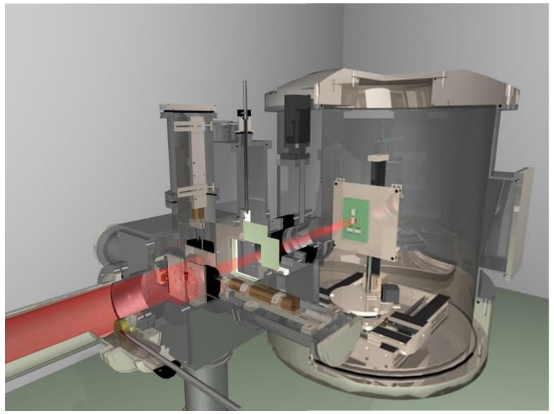


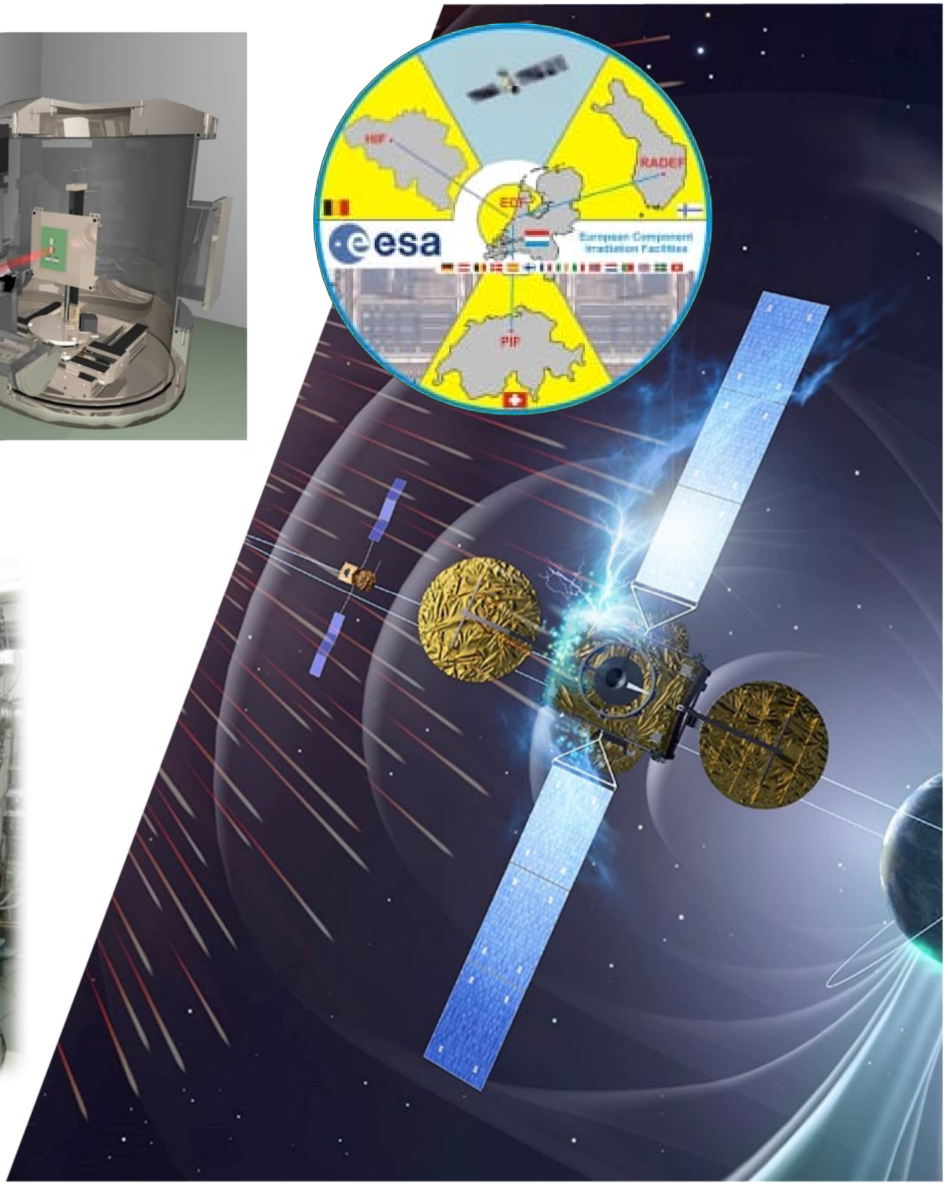
Sample: 100-nm thick $LiVO_x$ solid state battery material on Si substrate

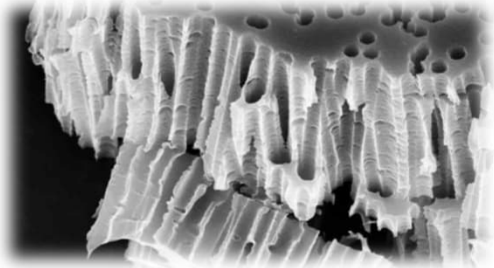
Complete ToF-ERDA beam lines have been delivered to Surrey, Trnava and Oslo

Radiation effects and irradiation services

- Irradiation of components with heavy ion beams to simulate radiation effects in space
- ESA External Component Irradiation Facility
- Cocktail beams 10, 16 and 22 MeV/u
- Proton beams from 0.4 – 55 MeV
- Also, possibility for electron, gamma, neutron
- Typically, 25% of main cyclotron usage
- RADNEXT IA
- RADMEP European Master (ERASMUS+)
- Membrane production (Porsche cayenne headlights, other filters...)







Nuclear structure at the limits of stability

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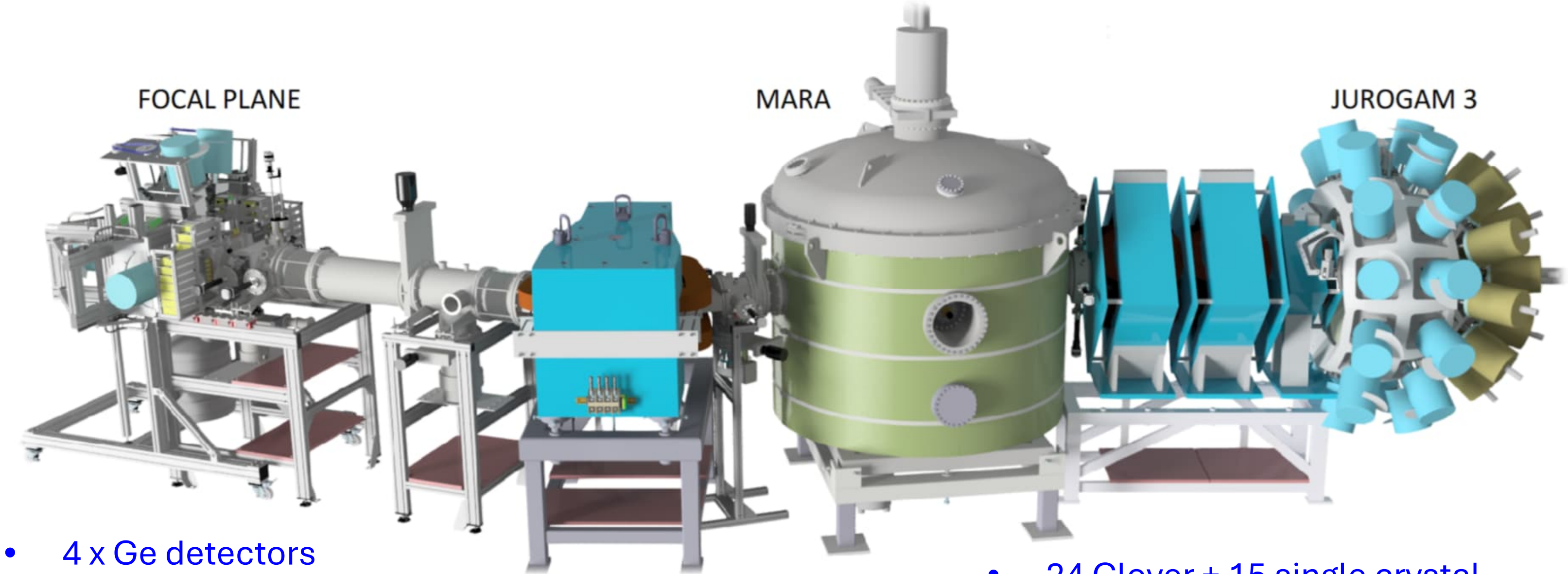
- The nuclear spectroscopy group utilizes γ-ray and electron as well as decay spectroscopy methods to shed light on the microscopic structure of the nucleus
- Two recoil separators, RITU (gas-filled) and MARA (vacuum mode)
- JUROGAM3 for detecting prompt gamma-ray transitions
- Recoil decay tagging methods (TDR systems in use)

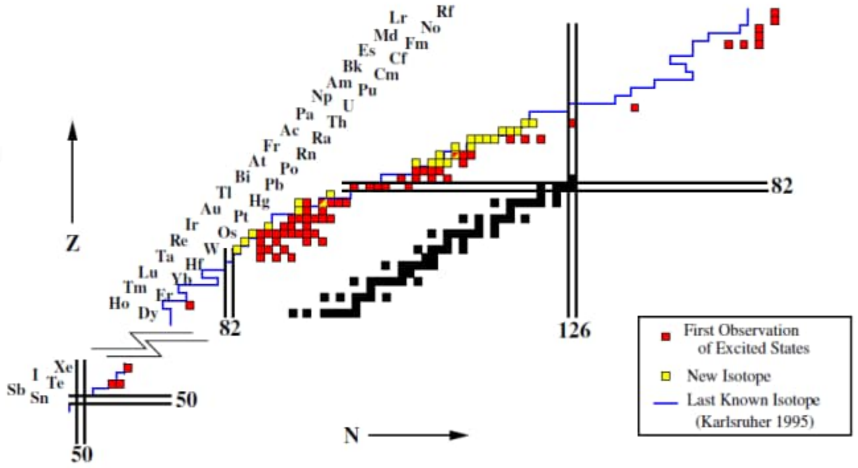
<u>Scientific studies</u>

- Transfermium nuclei
- Shape coexistence
- Proton dripline
- Collectivity close to ^{100}Sn
- *N*=*Z* nuclei, *A* = 70 - 80



- 4 x Ge detectors
- DSSD (charged particles: α, p, e^-_{IC}, β, recoils)
- MWPC

- 24 Clover + 15 single crystal Ge detectors + BGO shields
- Efficiency @1.3 MeV is 5.2%



In-beam studies performed at 10 nbarn level

Mirror Energy Differences in the T = 3/2 pairs

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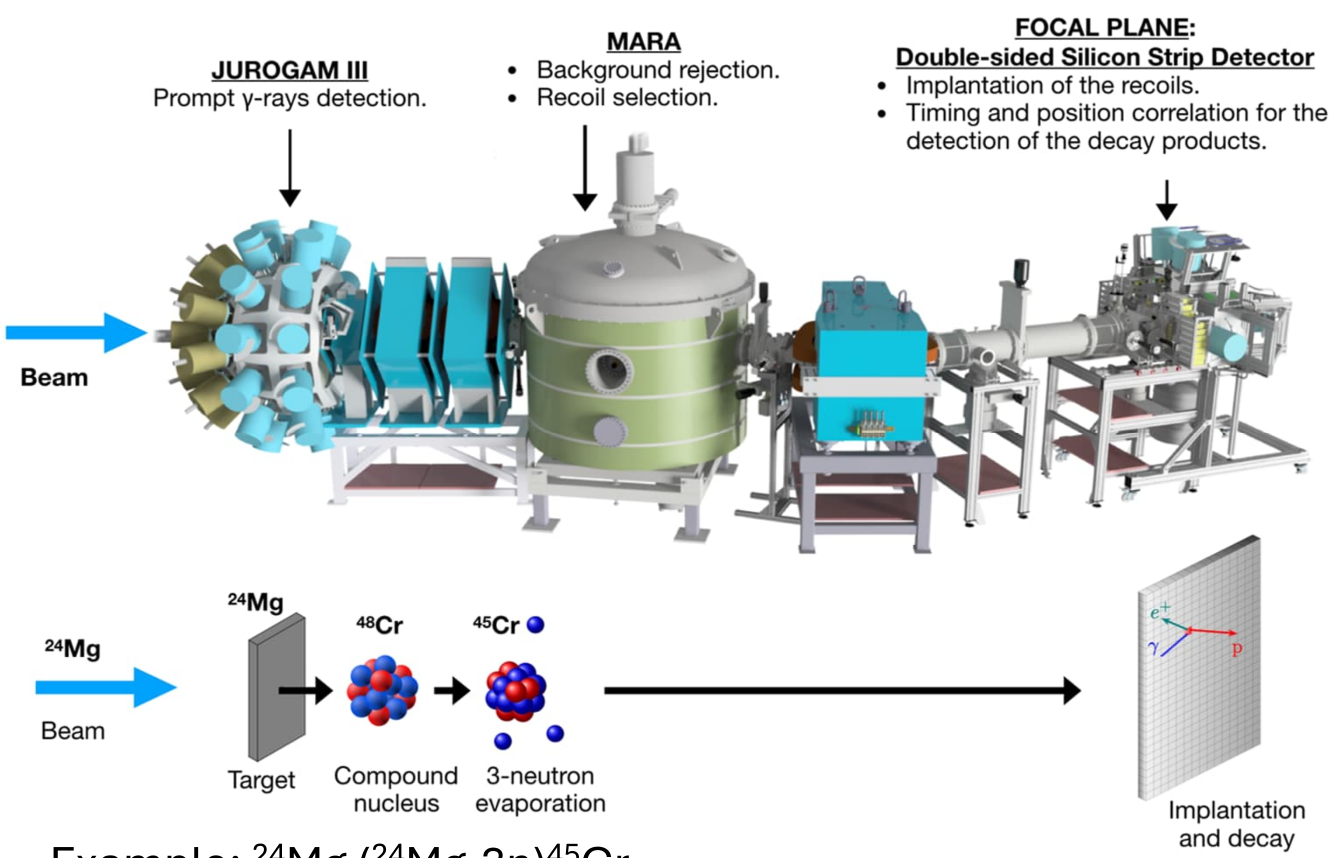
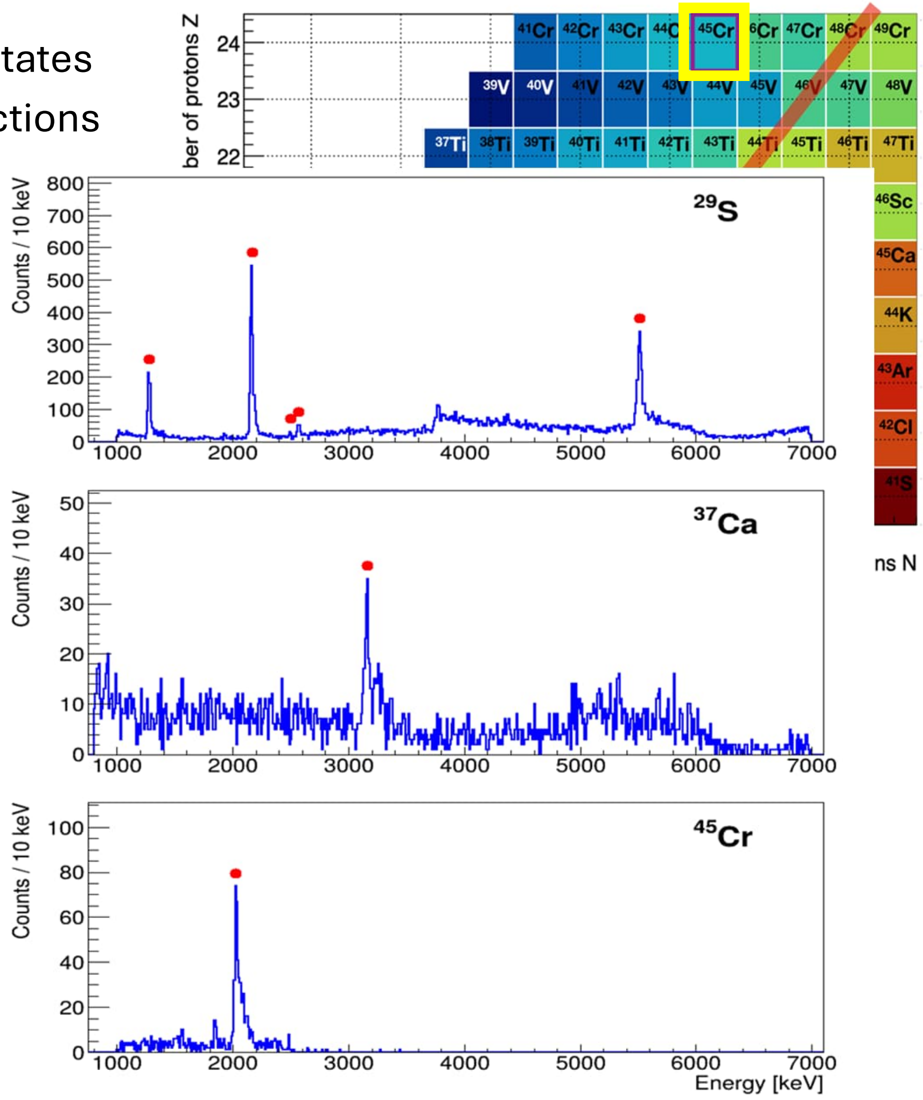
- A recent experimental campaign to produce ^{29}S, ^{37}Ca and ^{45}Cr in high-spin states
- Using 3n evaporation channels of the ^{20}Ne+^{12}C, ^{28}Si+^{12}C and ^{24}Mg+^{24}Mg reactions
- Identification of nuclei via the β-delayed proton emission decay branch



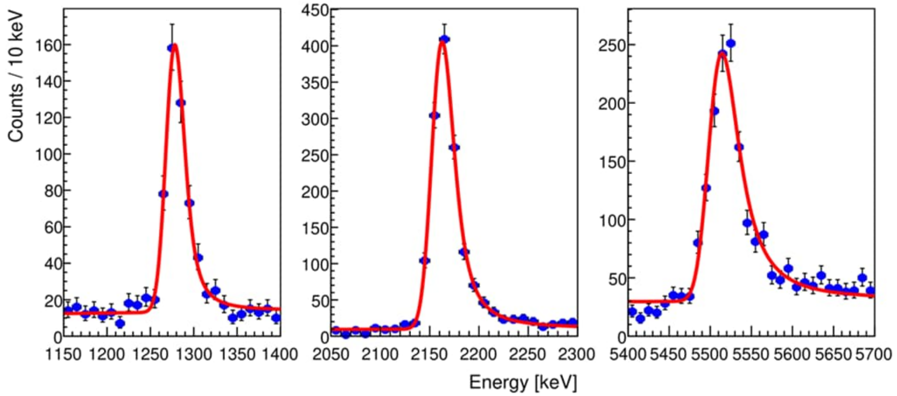
Example: ^{24}Mg (^{24}Mg,3n)^{45}Cr



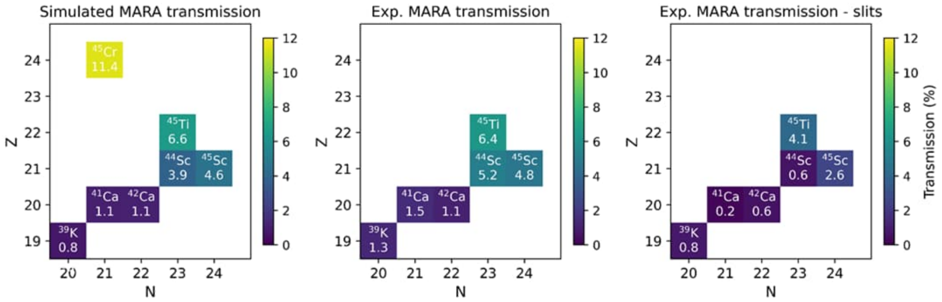
Benchmarking cross sections for 3n channels

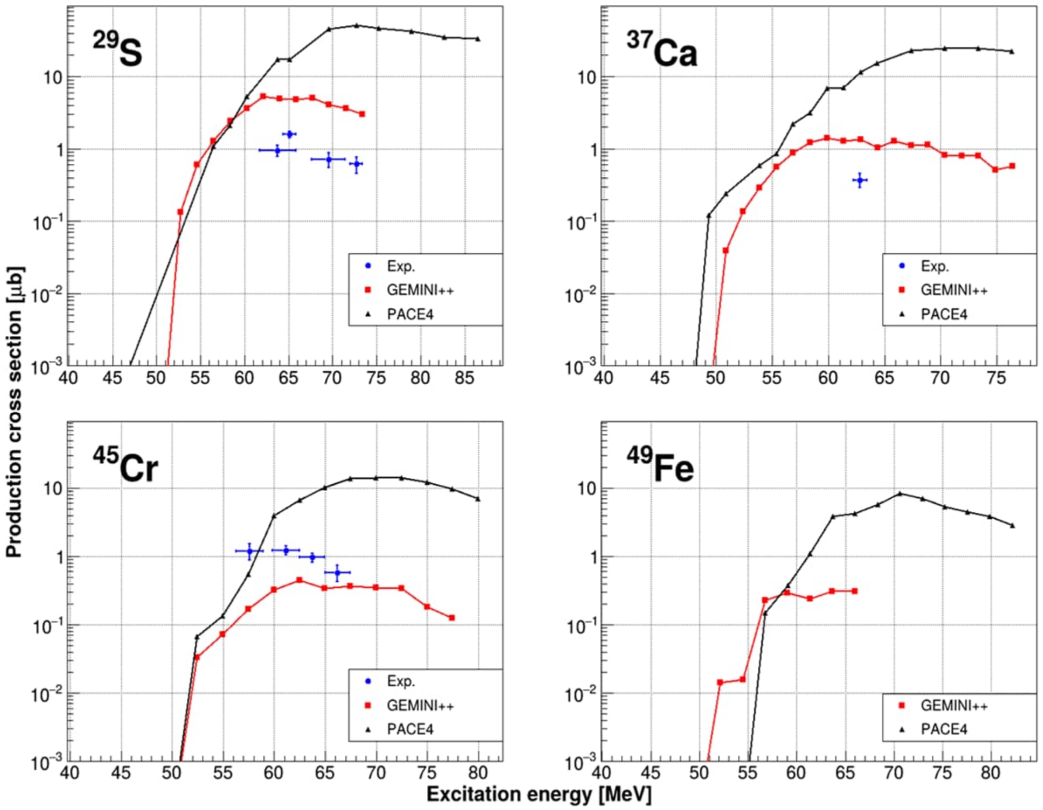
- Fusion-evaporation simulation codes like PACE4 are known to overestimate the production cross sections, especially in pure neutron-evaporation channels
- The experimental excitation function is crucial to determine the feasibility of such experiments and to maximise the statistics of the γ-ray energy spectrum

^{29}S



^{45}Cr





Experimental determination of fusion-evaporation reaction cross sections for 3n channels in the A=29-49 region

18 days of beam time awarded in March to study T = 3/2, ^{37}Ca

PhD work of D. Lazzaretto, and article to be submitted

A new chamber for transfer reaction studies

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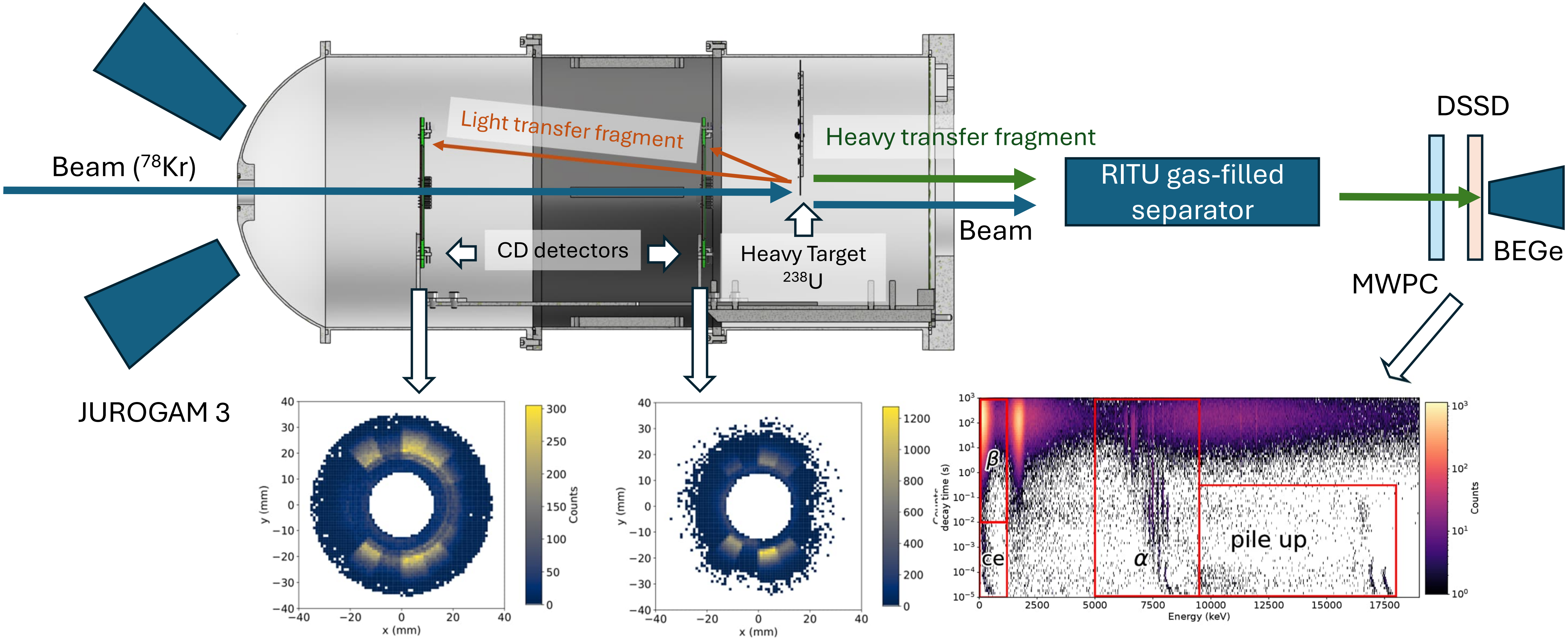
Big Ultra-Large Long Enclosure for Transfer products (BULLET)



MNT and quasi-fission potential at JYFL

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BULLET allows for the correlation between target-like and beam-like fragments for the study of reaction kinematics around 0 degrees and MNT spectroscopy

<u>Heavy fragments</u>

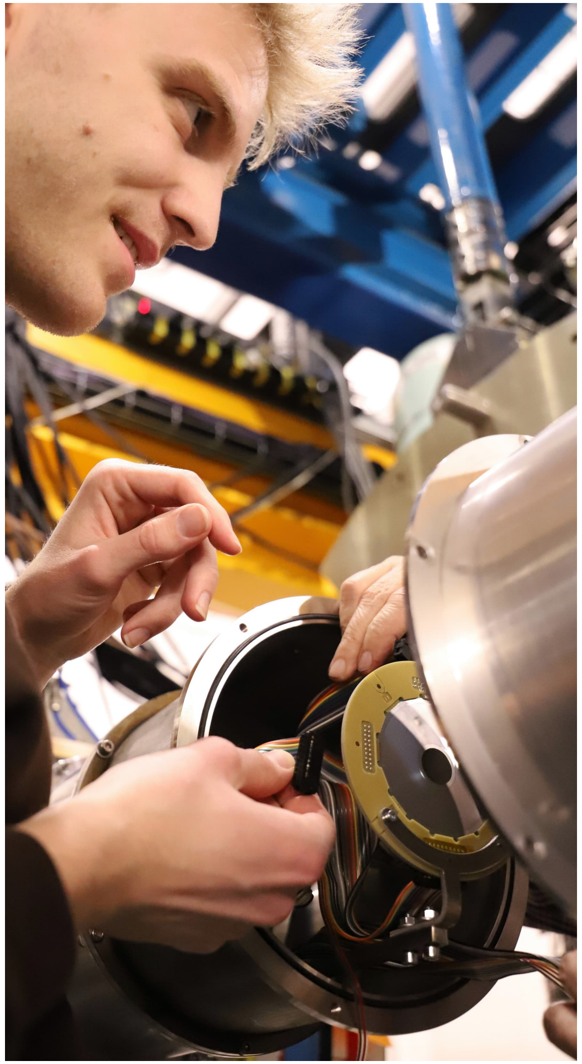
- New isomer studies in the actinide region (manuscript in preparation)
- Quasi-fission product distribution above Pb (experiment performed)

<u>Light fragments</u>

- Detecting isomers of fragments back-scattered into the CD detector with JUROGAM (feasibility proven)

<u>Simultaneous detection of light and heavy fragments</u>

- Using JUROGAM to investigate neutron-evaporation channels in MNT fragments



For an overview of MNT research at RITU:
W.N. Landsman et al., EPJ WoC 368 (2026) 00027

PhD work of N. Landsman

The IGISOL facility of JYFL-ACCLAB

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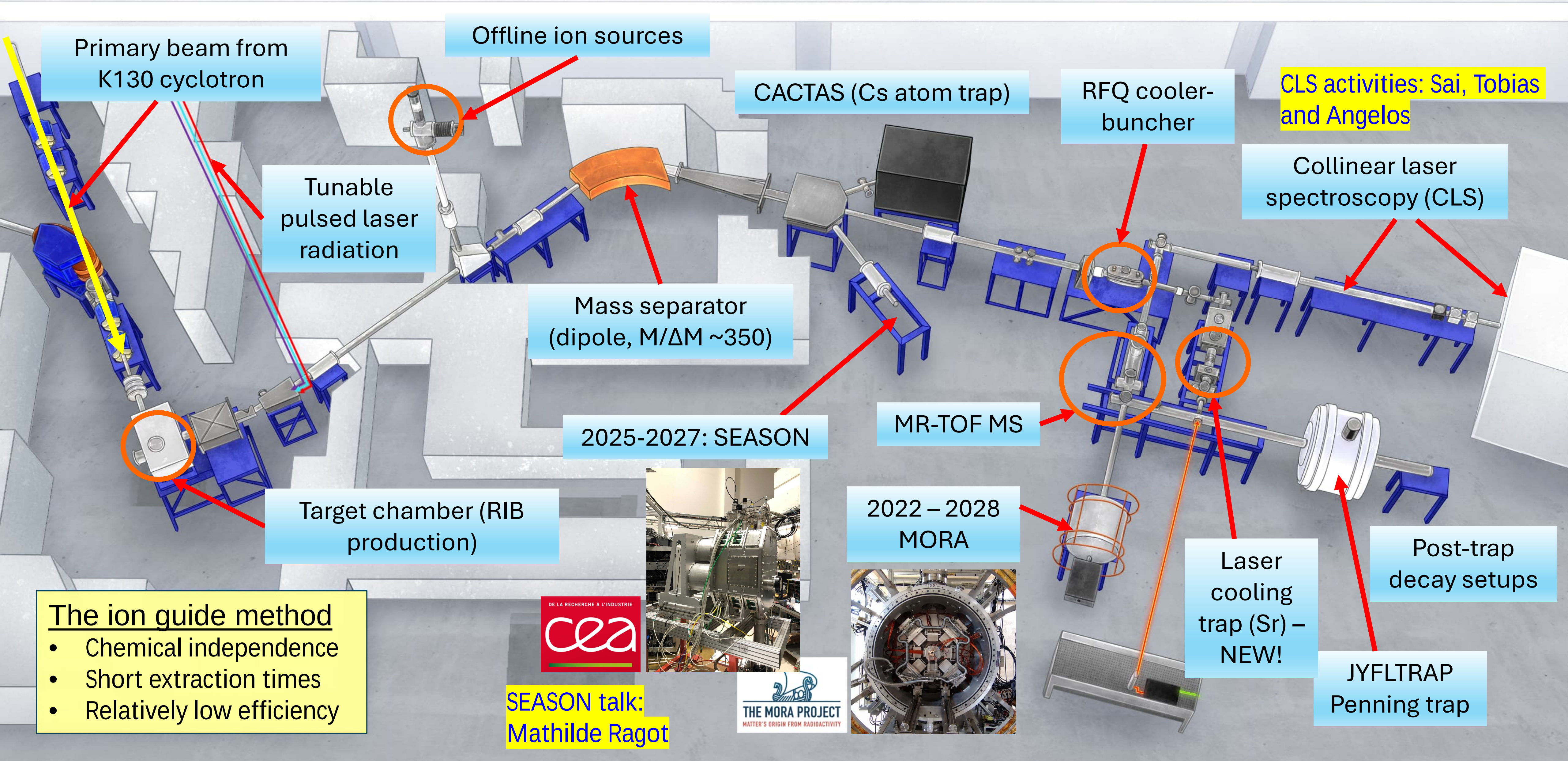


The ion guide method

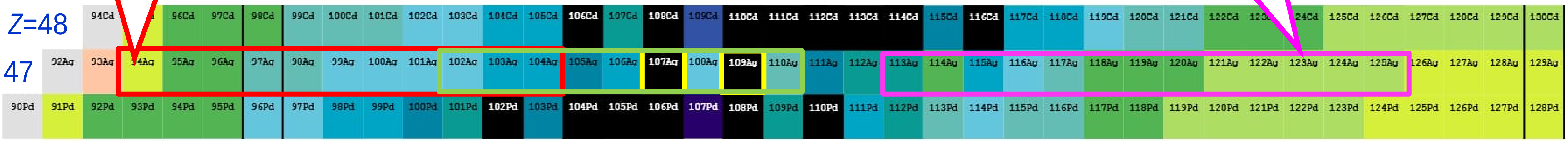
- Chemical independence
- Short extraction times
- Relatively low efficiency

Mechanisms we use for RIB production

N=Z ^{94}Ag (gs): $T_{1/2}$ = 26 ms

Discharge ion source for stable isotopes ^{107,109}Ag

^{125}Ag:$T_{1/2}$ = 176 ms



Heavy-ion fusion-evaporation reactions

$^{92/nat}$Mo(^{14}N,2pxn)$^{104-96}$Ag
^{58}Ni(^{40}Ca,pxn)^{95,94}Ag

Gas cell or
Hot cavity catcher laser ion source

Light-ion fusion-evaporation reactions

^{nat,110}Pd(p,xn)$^{110-102}$Ag

Light ion guide (gas cell)
(Efficiency 1-10%)

Proton-induced fission of U/Th
$^{113-125}$Ag

Fission ion guide (gas cell)
(Efficiency ~0.1%)

In 2026: project to develop a large gas cell for fission (LAGASTI – LArge Gas STopper for IGISOL)

- Fedor Ivandikov (new postdoc)

A hot cavity catcher laser ion source

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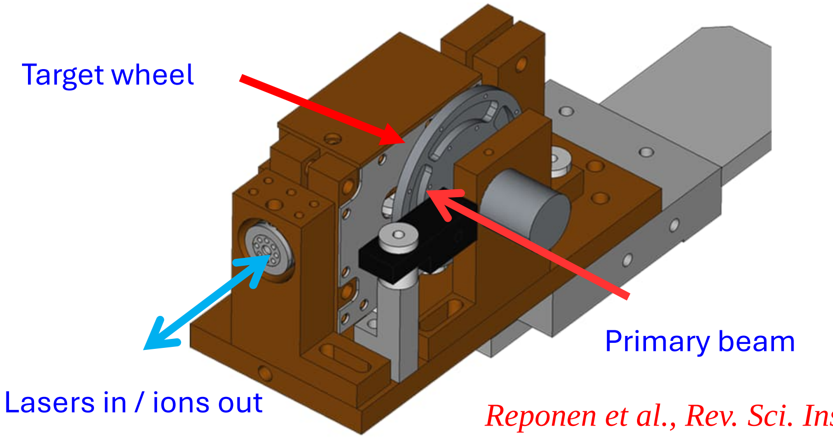
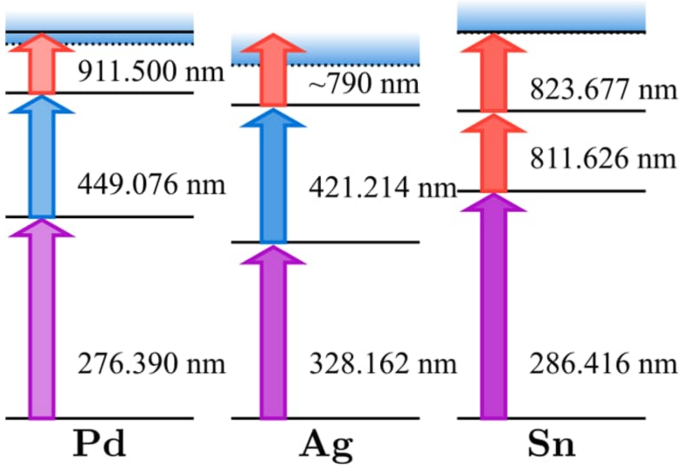
- To access proton-rich nuclei, we use heavy-ion fusion-evaporation reactions, with typical gas cell efficiencies of ~1%

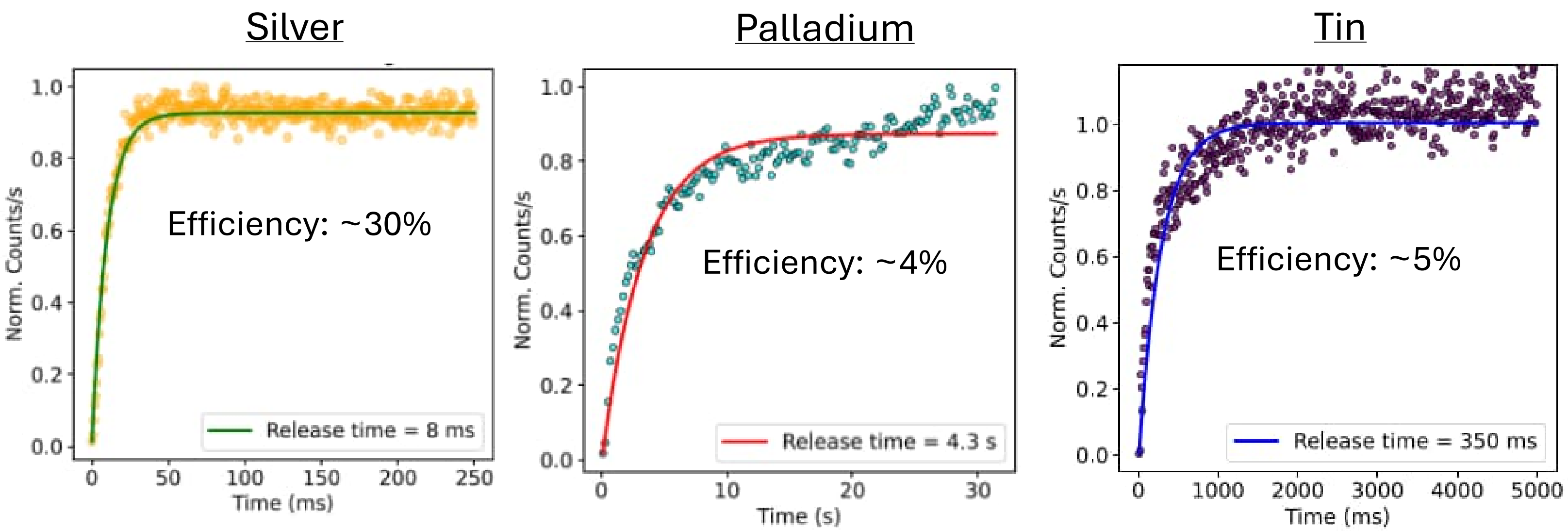
- With a long-standing interest in $N = Z$ ^{94}Ag, an alternative approach was motivated by the FEBIAD ion source from the GSI on-line mass separator. Silver was shown to have exceptional release properties (high extraction efficiency and fast evacuation time) *R. Kirchner et al., NIMB 70 (1992) 186*



Reponen et al., Rev. Sci. Inst. 86 (2015) 123501

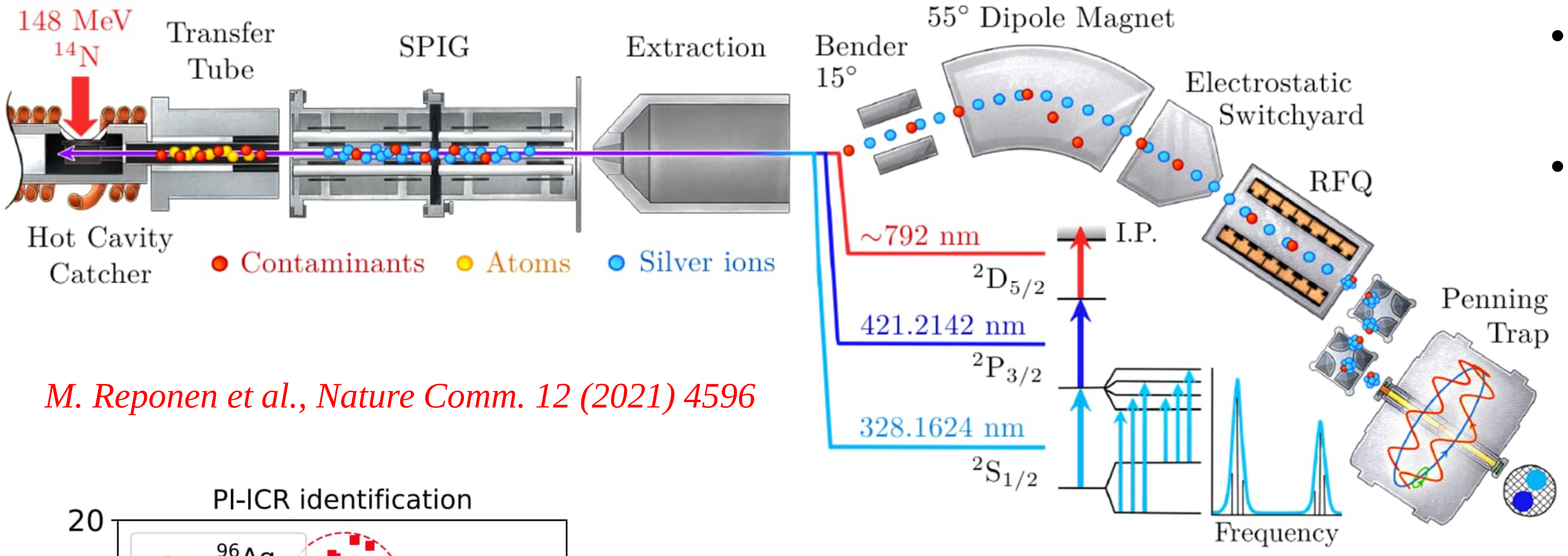


https://rims-code.github.io/



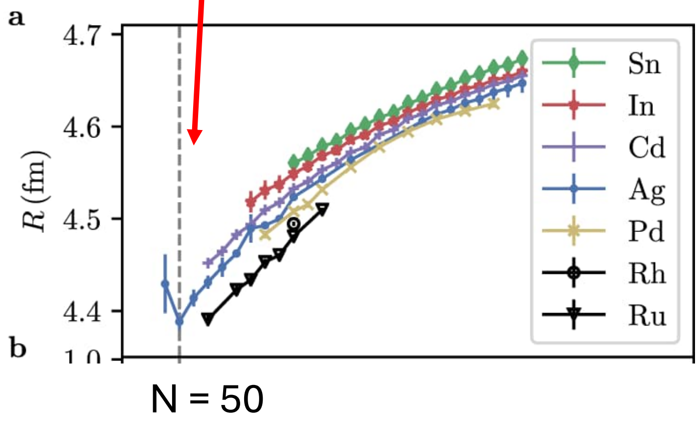
S. Chinthakayala et al., to be submitted

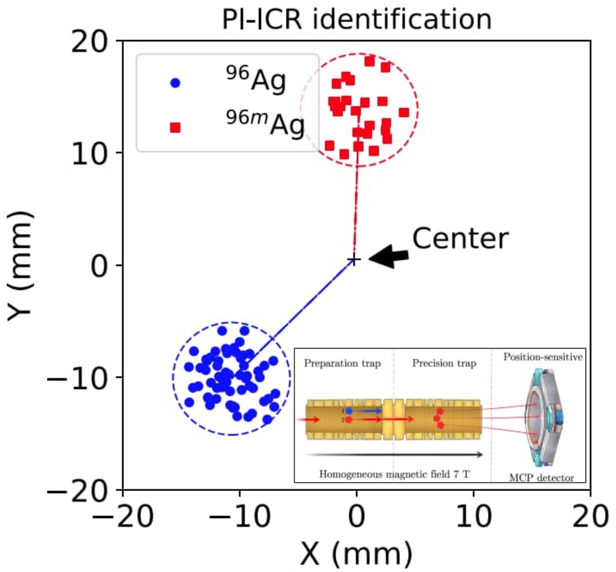
Masses and charge radii towards the $N = Z$ line



M. Reponen et al., Nature Comm. 12 (2021) 4596

- We combined these developments with Penning trap techniques to enable almost complete suppression of background.
- Penning trap-assisted in-source laser spectroscopy facilitated the study of charge radii of A across the $N = 50$ closed shell to ^{96}Ag.



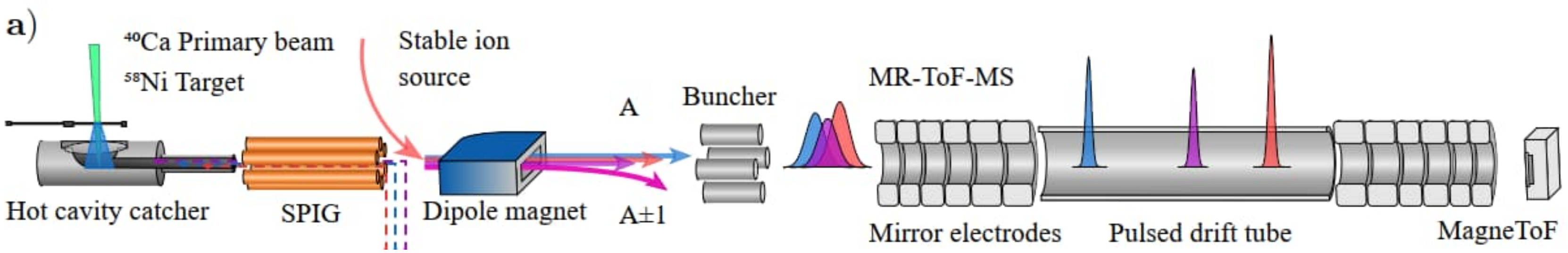


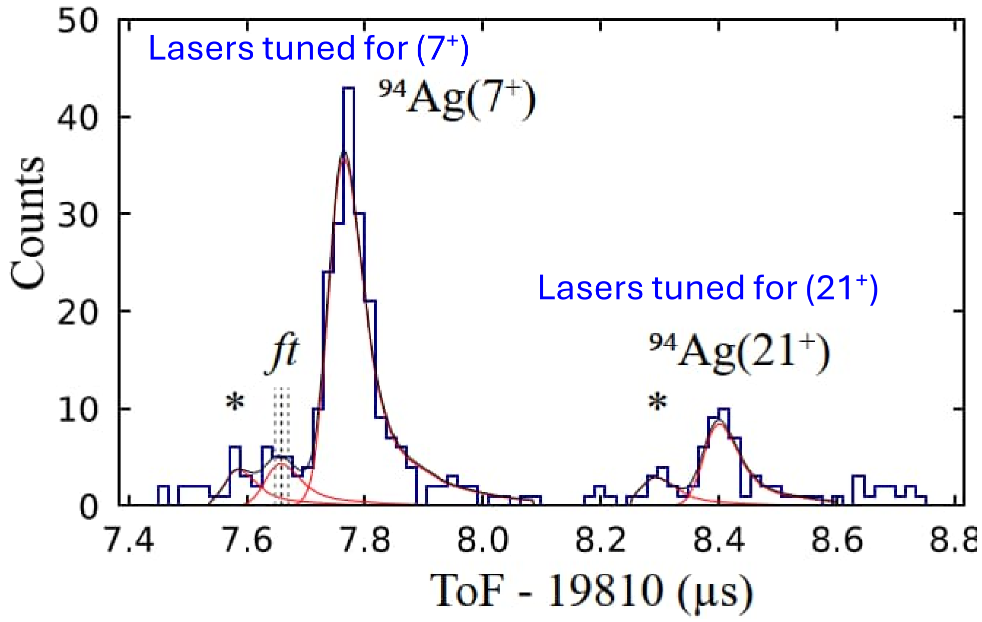
- PI-ICR method for mass measurements of exotic $^{95\text{-}97}$Ag
- Probing the robustness of the N = 50 shell closure
- ^{95}Ag measured for the first time (1 ion / 10 mins)
- Allows for the study of isomeric yield ratios

Z. Ge et al., Phys. Rev. Lett. 133 (2024) 132503

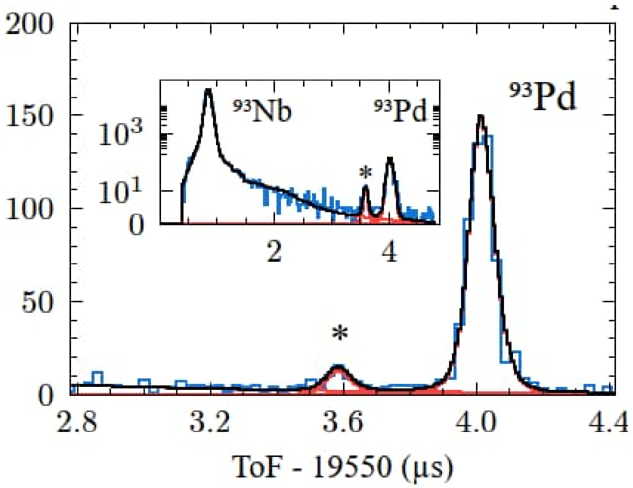
See Prince Parvez talk for details on the PI-ICR method for (high-precision) mass measurements

MR-TOF Mass Spectrometry of $N = Z$ ^{94}Ag

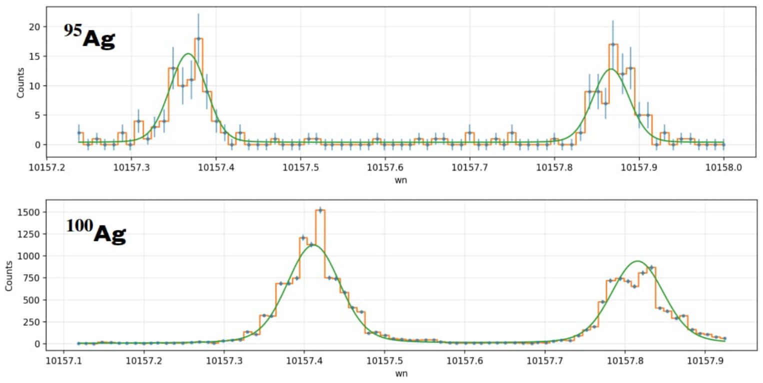




V. Virtanen, M. Reponen et al., submitted to Nature Comm. (2026)



The significantly lower decay Q values derived from the masses rules out the 2-p energy reported for ^{94}Ag



We have extended the charge radii systematics to ^{95}Ag (with the MR-TOF) and in 2027 aim to explore ^{94}Ag – first proton emitter with optical spectroscopy!

The JYFLTRAP double Penning trap

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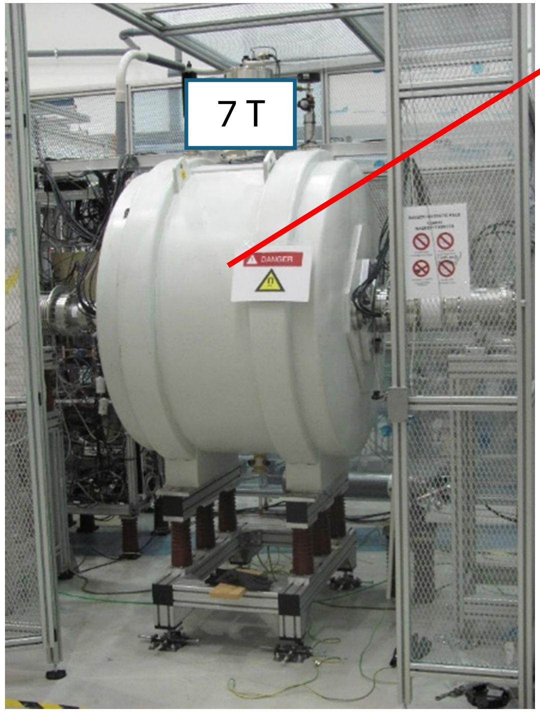
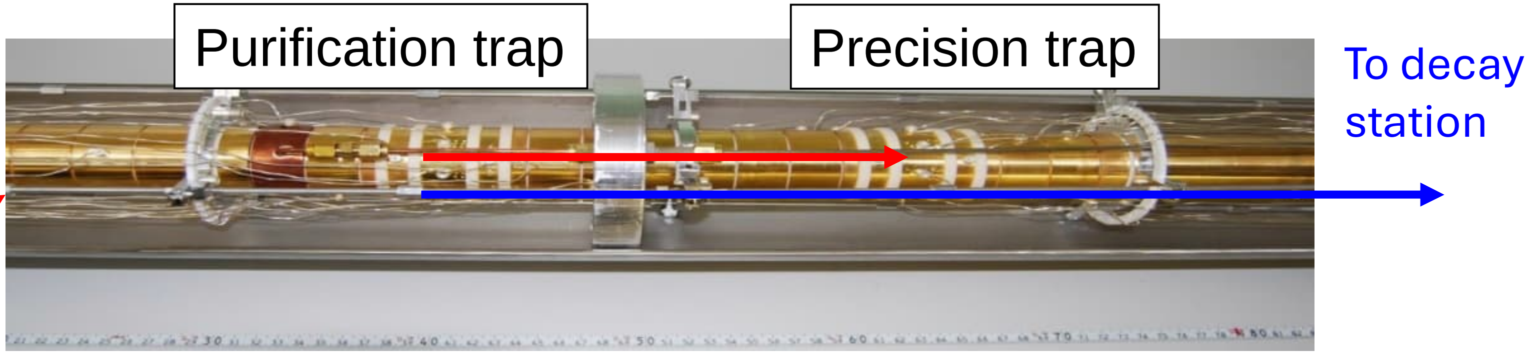
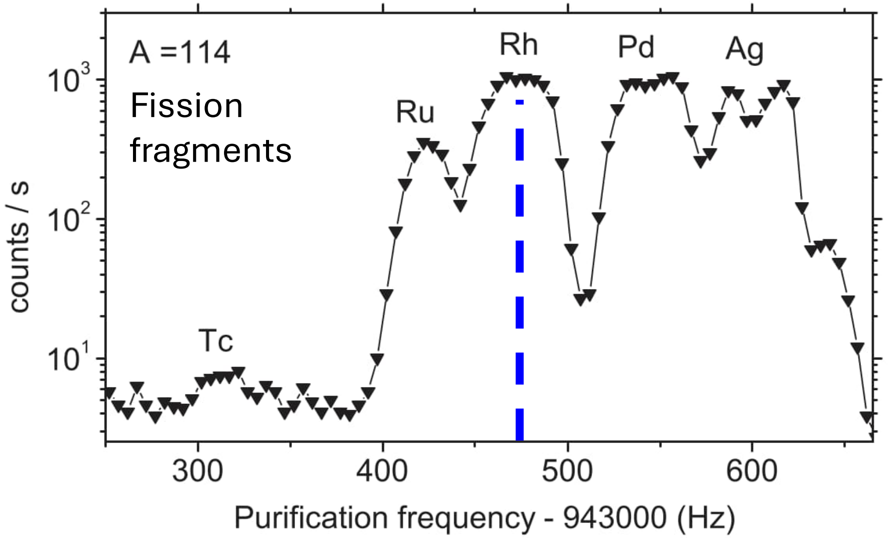
- Homogeneous 7T B field
- 100V deep quadrupole potential
- Cylindrical geometry



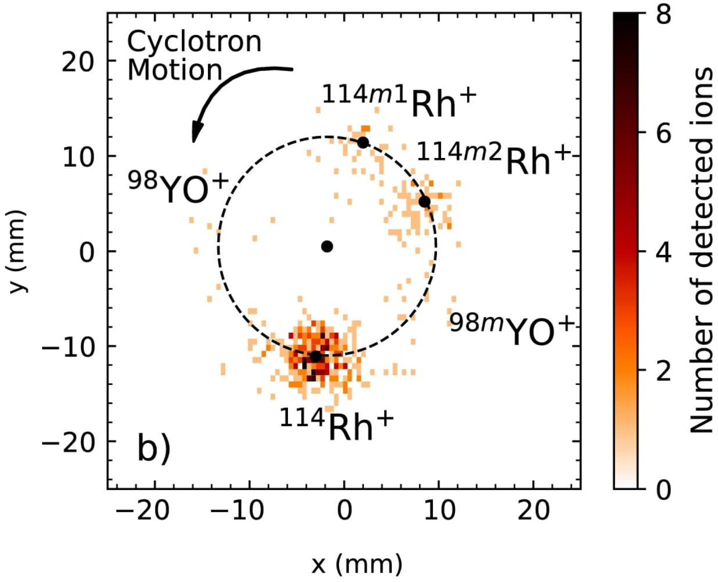
T. Eronen et al., Eur. Phys. J. A 48 (2012) 46





Savard et al., Phys. Lett. A 158, 247 (1991)

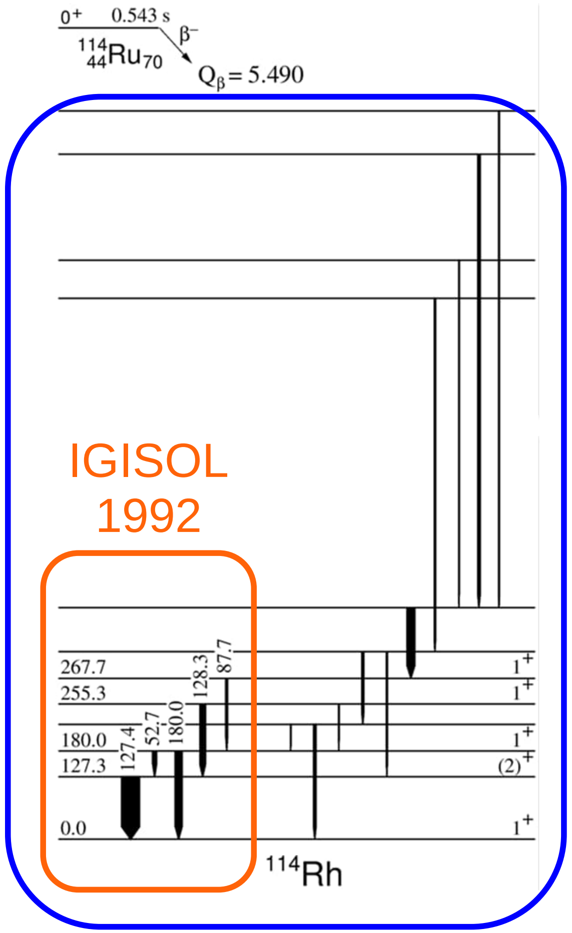
J. Rissanen et al., Phys. Rev. C 83 (2011) 011301(R)



M. Stryjczyk et al., Phys. Lett. B 862 (2025) 139359

Trap-assisted decay spectroscopy

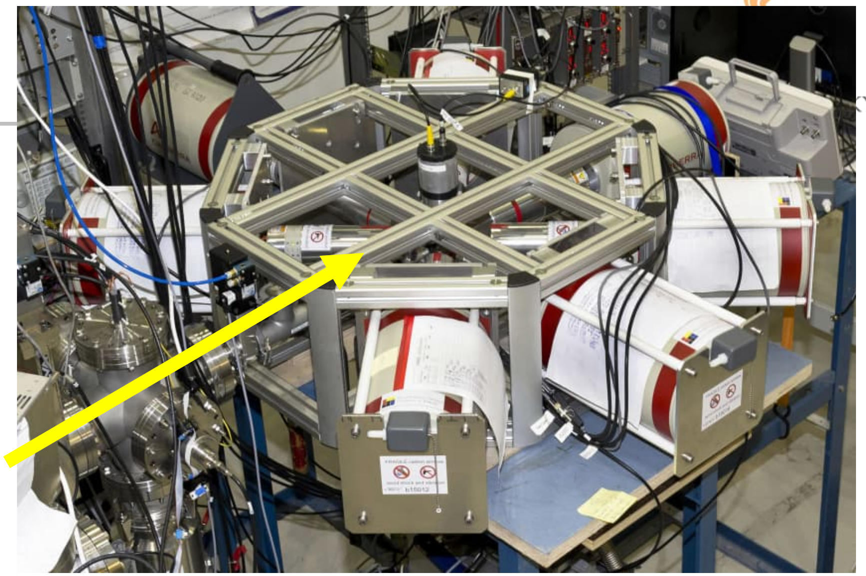
- ^{114}Ru has 10 neutrons more than the nearest stable isotope, ^{104}Rh
- First beta decay study of ^{114}Ru at IGISOL published in 1992 – 4 excited states and 5 gamma-ray transitions.



[Recent study with IGISOL + JYFLTRAP (filter ^{114}Ru)]

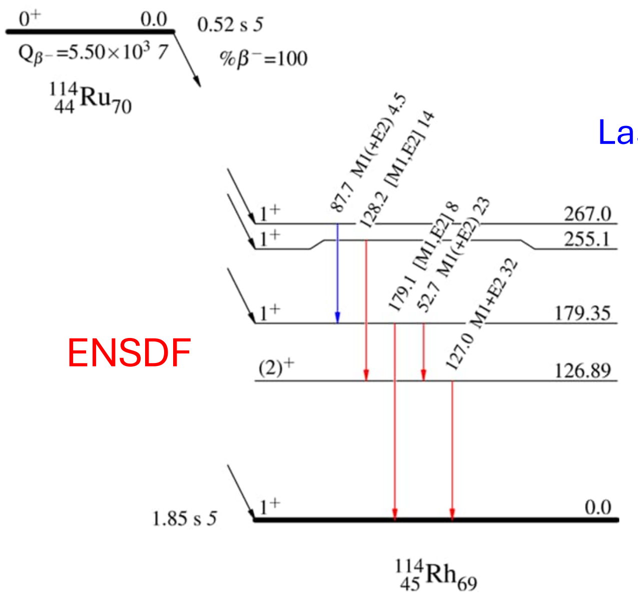
7 more excited levels, 10 more γ lines
+ 14 unplaced γ lines (mostly weak ones).

Master's thesis work of M. Kisiel, University of Warsaw, 2026.



Warsaw Ge array after JYFLTRAP

ENSDF

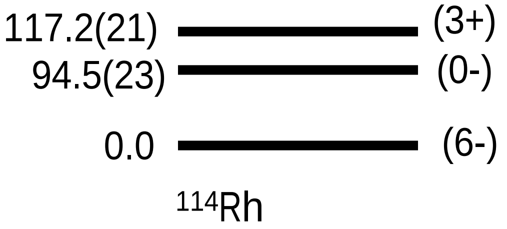


Trap measurements provide data on excited levels that cannot be fed by allowed β decays of the 0⁺ state of ^{114}Ru.

Laser spectroscopy proposal for n-rich Rh chain – complementarity!

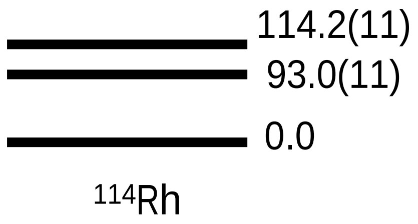
JYFLTRAP

M. Stryjczyk *et al.*, Phys. Lett B 862 2025



Canadian Penning Trap

B. Liu *et al.*, Phys. Rev. C 111 2025



IGISOL beam time (Night shift – 18th August)

- Please note: target chamber should NOT be under water
- Delayed celebration of 50th Anniversay of JAWS (2025)

Current/future laboratory developments

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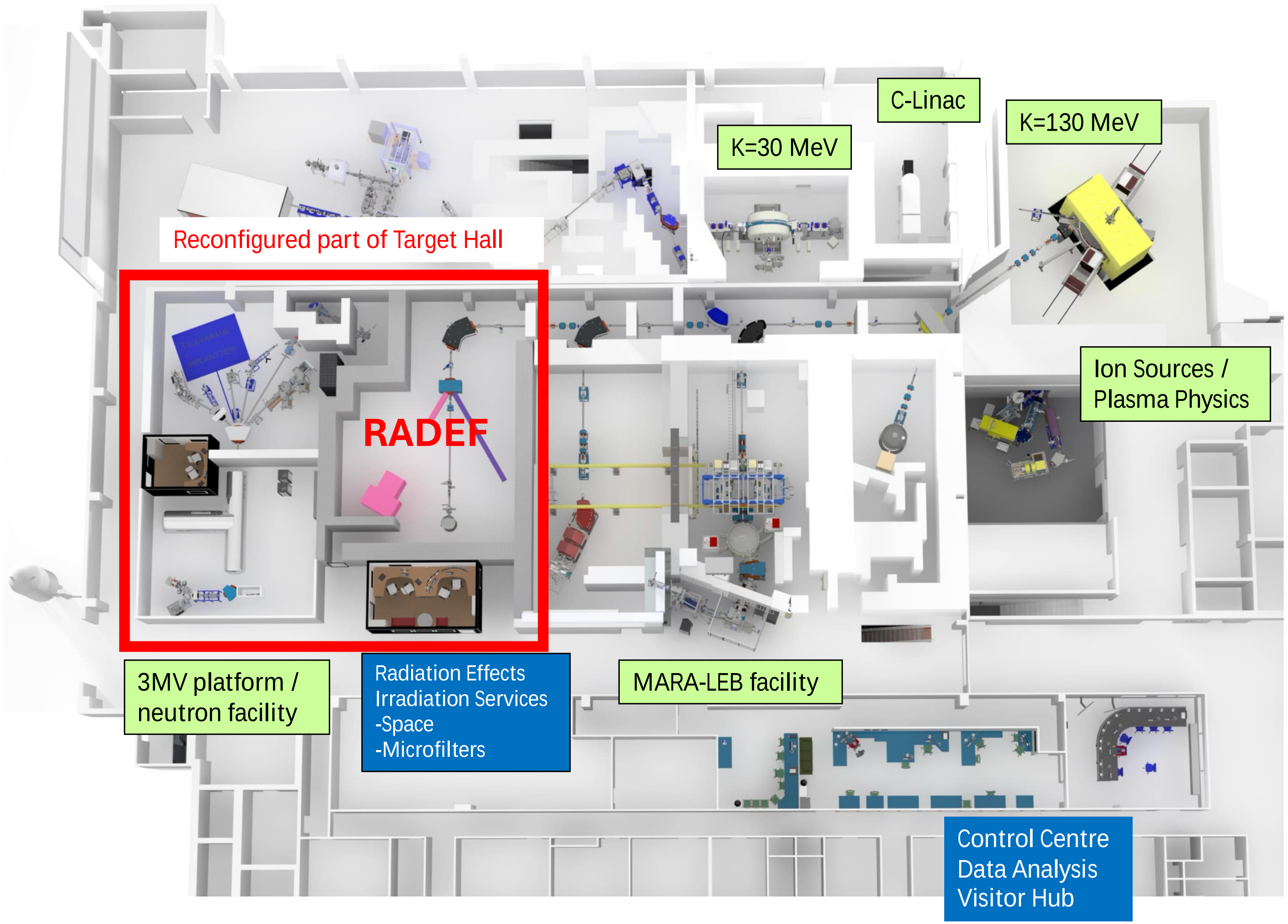
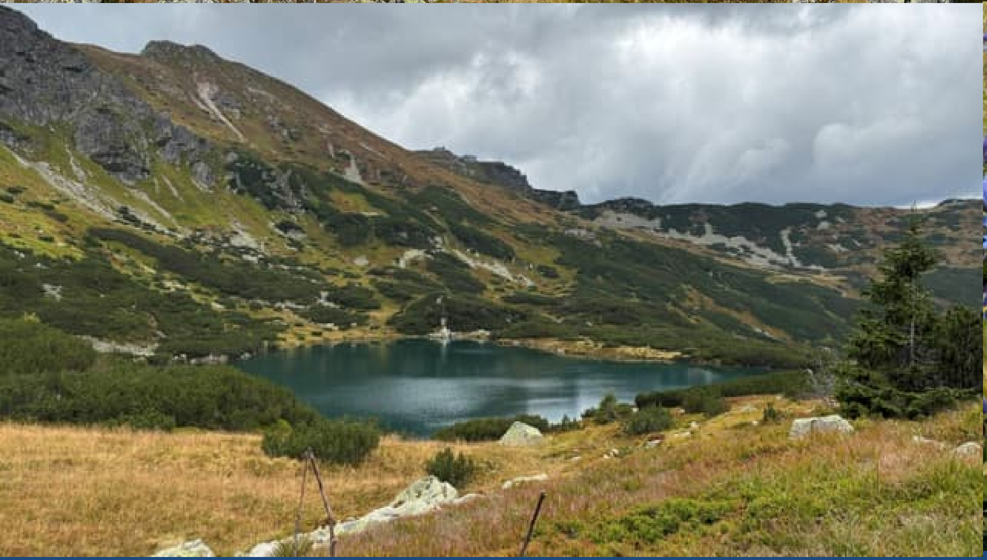


- Major redevelopment of K130 Target Hall in 2026
- New 3MV platform (Tandetron) – Nov. 2026
- Neutron irradiation facility (Tandetron – new opportunities)
- Relocation of RADEF facility - completed
- Completion of MARA-LEB facility
- Ongoing discussions with company for production of ^{211}At for TAT
- K=30 MeV machine recommissioning (2027). Offering parallel operations.
- Pelletron space available for detector hospital and development (2028)



Thanks to all my JYFL colleagues, especially the PhD students for contributed slides.

…and to you for your attention!

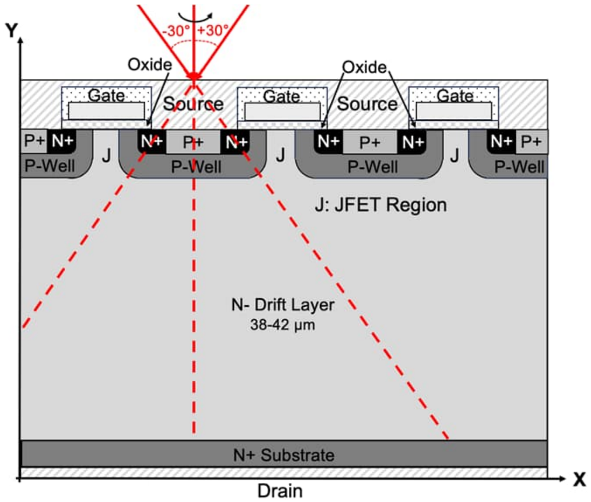
Research into radiation effects on electronics

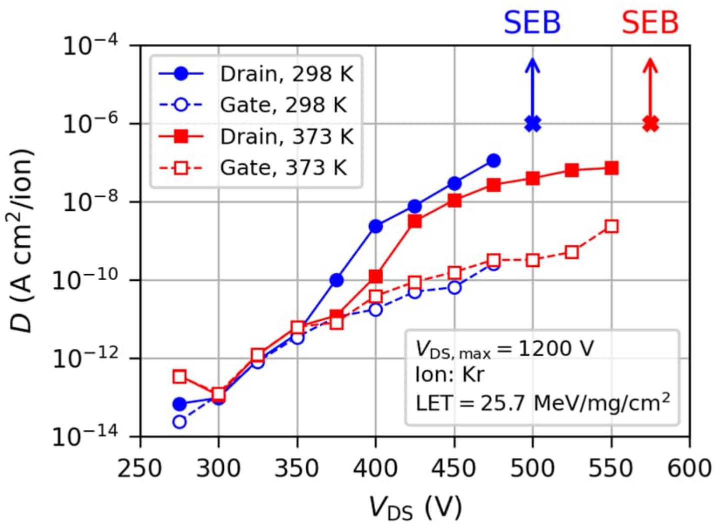
Recent work on heavy-ion radiation effects on silicon carbide- and gallium nitride-based power electronics technologies

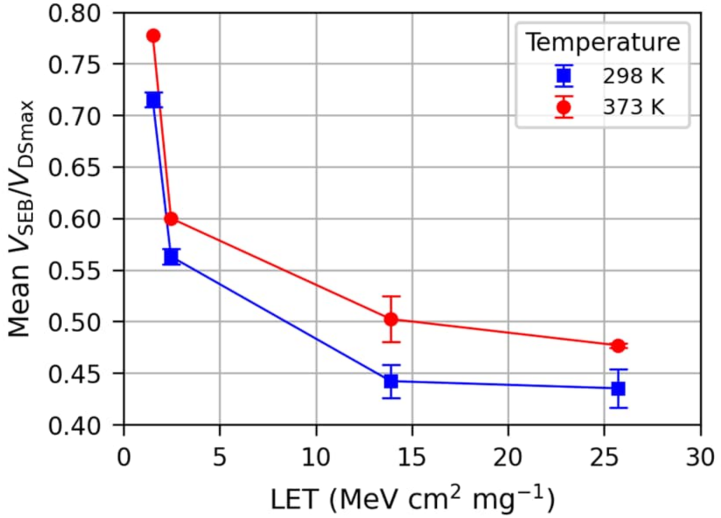
- Device physics under radiation field
- Temperature and angular dependencies
- Material response
- Test methodology development

Key parameters

Voltage, temperature, inclident angle of beam, LET



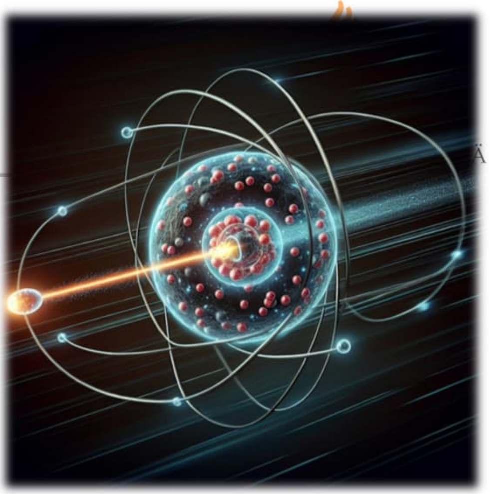




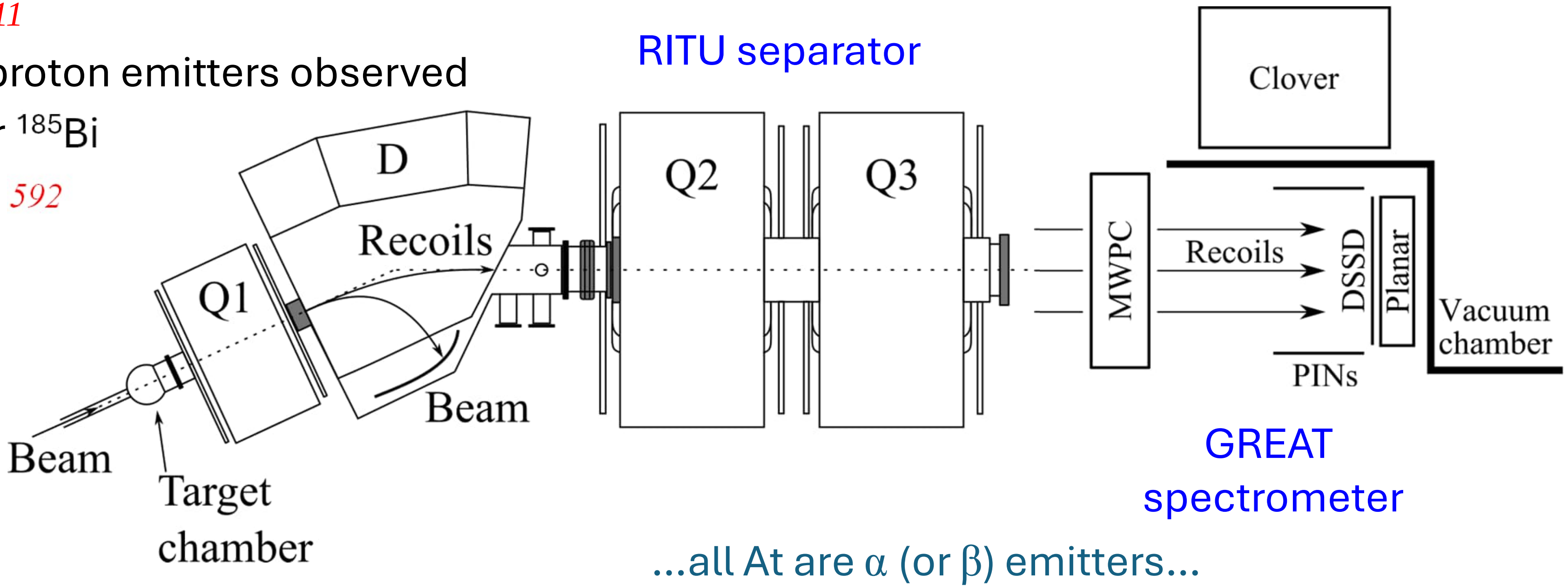
Research collaborations with Vanderbilt University, Indiana University, ETH Zurich, University of Montpellier

K. Niskanen *et al.*, "Temperature Effect on Single Event Burnout and Leakage Current in SiC Power MOSFETs," *IEEE Transactions on Nuclear Science*, 2026.
A. Sengupta *et al.*, "Effects of Incident Angle on Single-Event Leakage Current Degradation in Heavy-Ion Irradiated 1800- and 4500-V SiC Power MOSFETs," *in IEEE Transactions on Nuclear Science*, 2025.

Proton emission in astatine



- A rare type of radioactivity in which a proton is emitted from a nucleus
- First evidence in the 1970's: $19/2^-$ isomeric state in ^{53}Co
  Cerny et al., Phys. Lett. B 33 (1970) 284; Jackson et al., Phys. Lett. B 33 (1970) 281
- First ground-state proton emitter: ^{151}Lu
  Hoffmann et al., Z. Phys. A 305 (1982) 111
- Approximately 30 ground-state proton emitters observed
- Previous heaviest proton emitter ^{185}Bi
  Davids et al., Phys. Rev. Lett. 127 (1996) 592



...all At are α (or β) emitters...

S_p	Astatine Z=85	^{191}At	^{192}At	^{193}At	^{194}At	^{195}At	^{196}At	^{197}At	^{198}At	^{199}At	^{200}At	^{201}At
		-1.14 MeV	-0.71 MeV	-0.71 MeV	-0.32 MeV	-0.25 MeV	0.09 MeV	0.18 MeV	0.6 MeV	0.64 MeV	1.04 MeV	1.14 MeV

$S_p < 0$

New α and p-decaying isotope ^{188}At

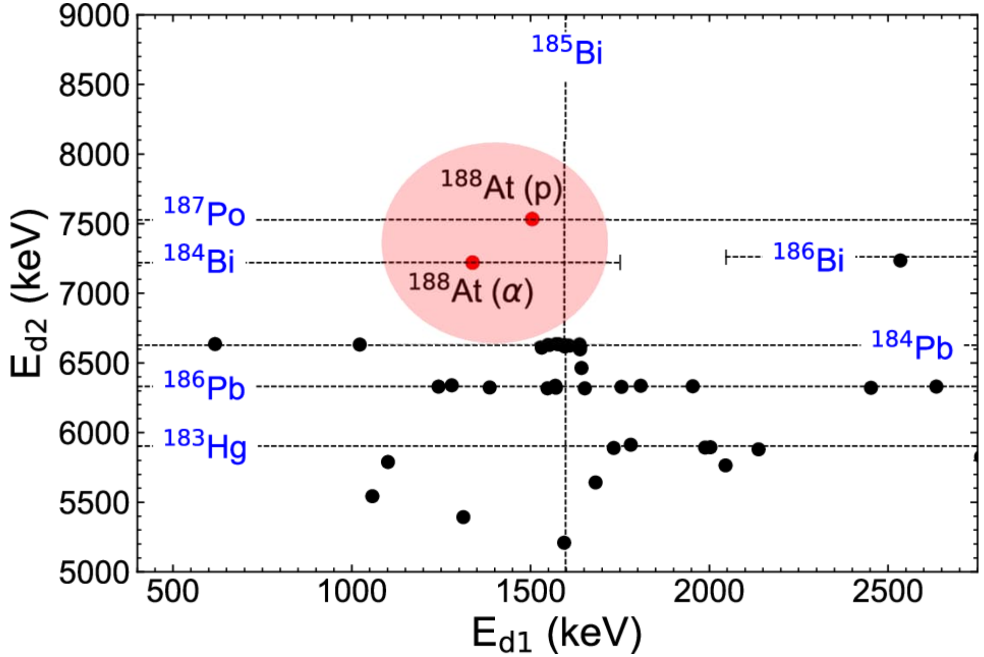
- Almost 30 years after the discovery of ^{185}Bi
- Extreme selectivity of decay spectroscopy

Reactions:

- ^{109}Ag(^{84}Sr, 3n)^{190}At ← New α-decaying isotope
- ^{107}Ag(^{84}Sr, 3n)^{188}At

Kokkonen et al., Phys. Rev. C 107 (2023) 064312
Andreyev et al., Phys. Rev. C 108 (2023) 034303

^{188}At: 1 p-emission + 1 α-emission event!



nature communications
Article
https://doi.org/10.1038/s41467-025-60259-6

New proton emitter ^{188}At implies an interaction unprecedented in heavy nuclei

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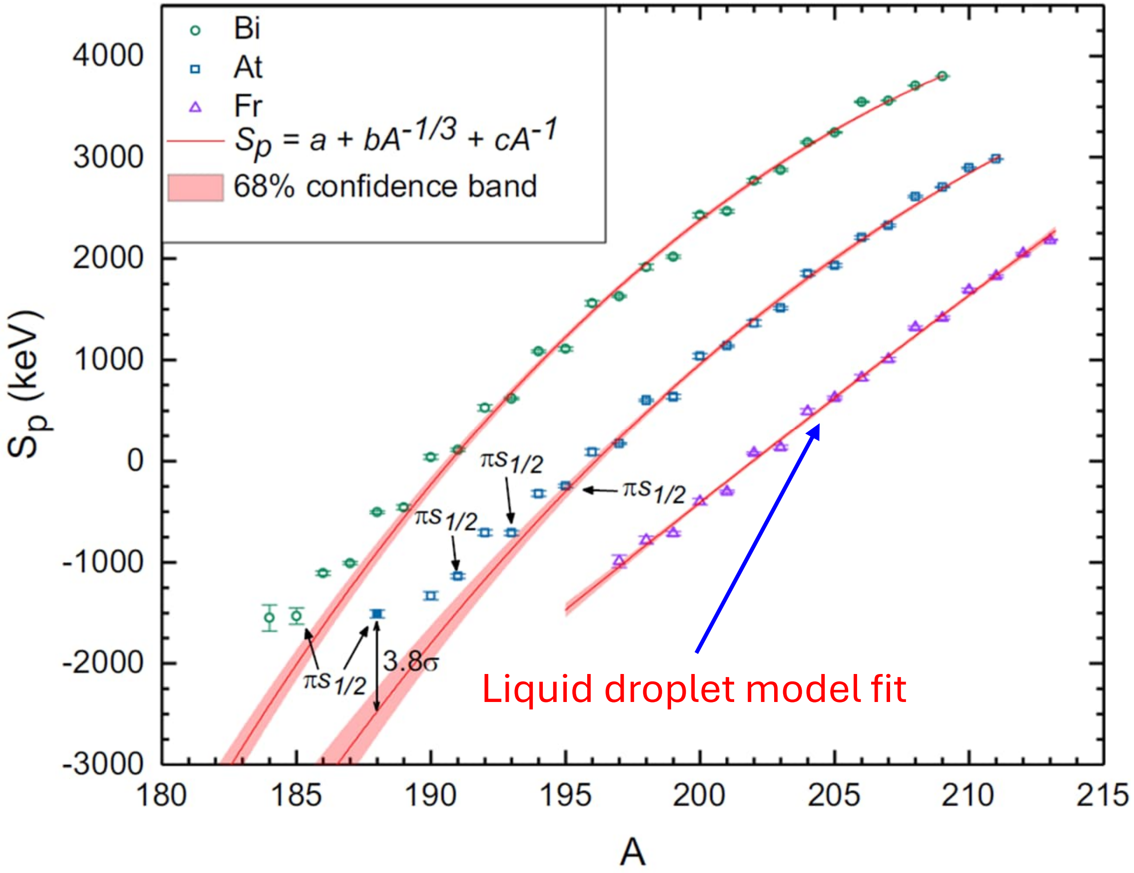
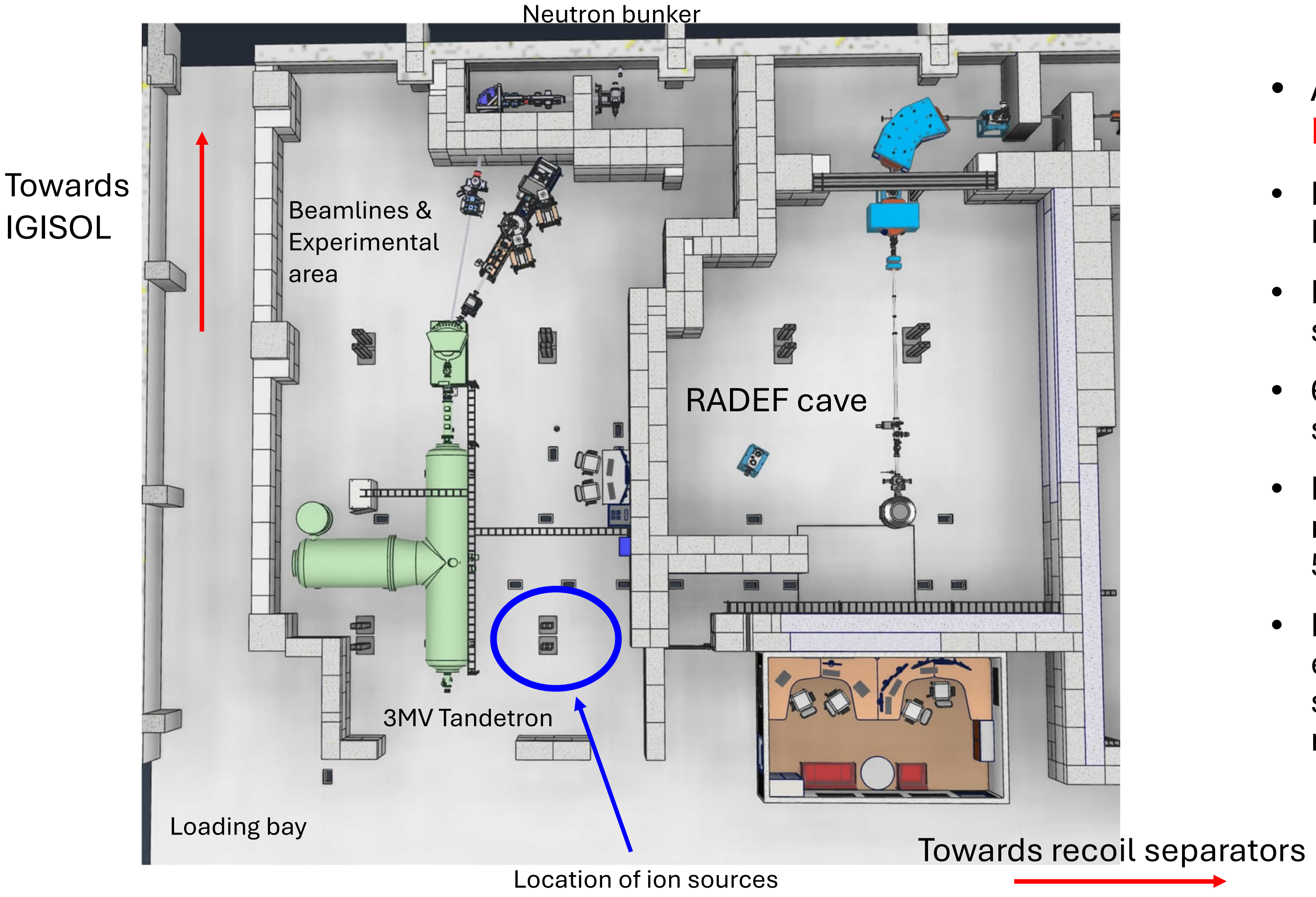


Target hall renovation (2026-2027)



- Arrival of 3MV Tandetron (HVEE) – Nov. 2026
- Day 1 uses PELLIS H^- source from Pelletron and MCC-30 magnet as injector
- Extensive beam line and injector simulations
- 600 kg of SF_6 gas arrived, and gas handling system designed
- Radiation protection simulations for new neutron bunker (NeutronGate – 6-month 50% work contract)
- Basic infrastructure (water cooling, electricity, floor and concrete wall supports, compressed air, exhaust) all needed before arrival of machine