# Commissioning of the S$^3$LEB spectrometer

Antoine de Roubin
S$^3$LEB collaboration

**Outline :**

- S$^3$
- Scientific commissioning
- Scientific commissioning with S$^3$LEB
- Ongoing projects

# $S^3$ – Super Separator Spectrometer

**LINAC beams** : He to U
- 1 mA, < 14,5 MeV/A (A/Q=3)
- 1 mA, < 7,5 MeV/A (A/Q=7)

| | I for A/Q = 3 (pμA) |
|---|---|
| $^{18}O$ | 80 |
| $^{40}Ar$ | 16 |
| $^{36}S$ | 2.3 |
| $^{40}Ca$ | 2.9 |
| $^{48}Ca$ | 1.2 |
| $^{58}Ni$ | 1.1 |
| $^{86}Kr$ | 0.1 |
| $^{136}Xe$ | 0.001 |

X 5 up to 58Ni
X 10 for A > 58

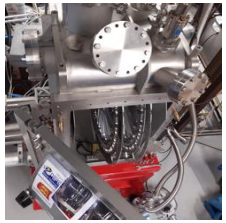
**$S^3$ Project :**
- Budget ≈ 24 M€
- 8 partner laboratories


NEWGAIN
NEW GANIL INJECTOR

**Scientific collaboration:**
- 27 Laboratories
- 12 countries : Belgium, France, Finland, Germany, Hungary, Italy, Poland, Slovakia, Spain, Sweden, U.K., USA

# $S^3$ – Super Separator Spectrometer

**Target system**



*High power rotating targets*

**3 × M-dipoles**

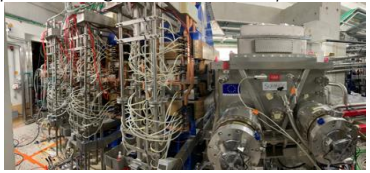
*Large H & V gaps*

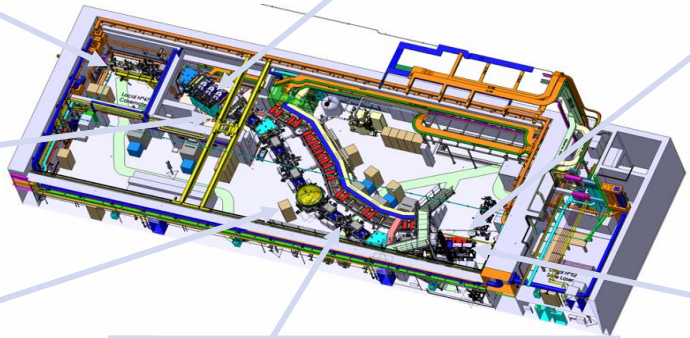
**E-Dipole**

*20 cm gap & +/- 300 kV*
*Open slit in the anode*

**Dispersive zone**

*Open RT magnet & beam dump & Movable fingers*



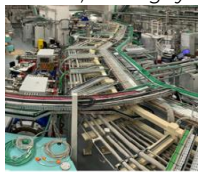


**SC Multipoles**

*SMT, PSS, Coldbox & LTC*

**Infra / Interface**

*Lot C68, Cooling system, Laser room*



**LEB**

*LEB @ LPC & GISELE Laser Lab*

**SIRIUS**

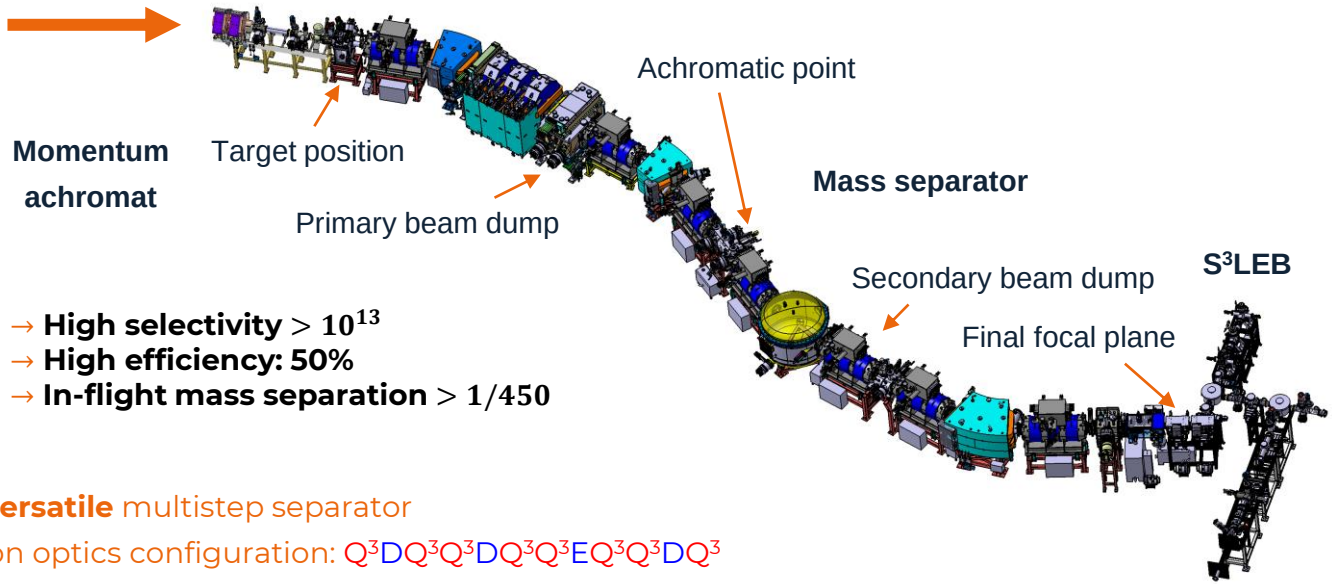
*DSSD, SSD, FEE/BEE, DAQ & Diagbox*

- High selectivity > $10^{13}$ - High efficiency 50% - In flight mass separation > 1/450
- Versatility & unique instrumentation ($S^3$SIRIUS – $S^3$LEB)

# $S^3$ – Optics: basic properties and functionalities

**High beam intensity**

High power target: >> 1pμA (= $6.10^{12}$p/s)




→ **High selectivity** $> 10^{13}$
→ **High efficiency: 50%**
→ **In-flight mass separation** $> 1/450$

**Versatile** multistep separator

Ion optics configuration: $Q^3DQ^3Q^3DQ^3Q^3EQ^3Q^3DQ^3$

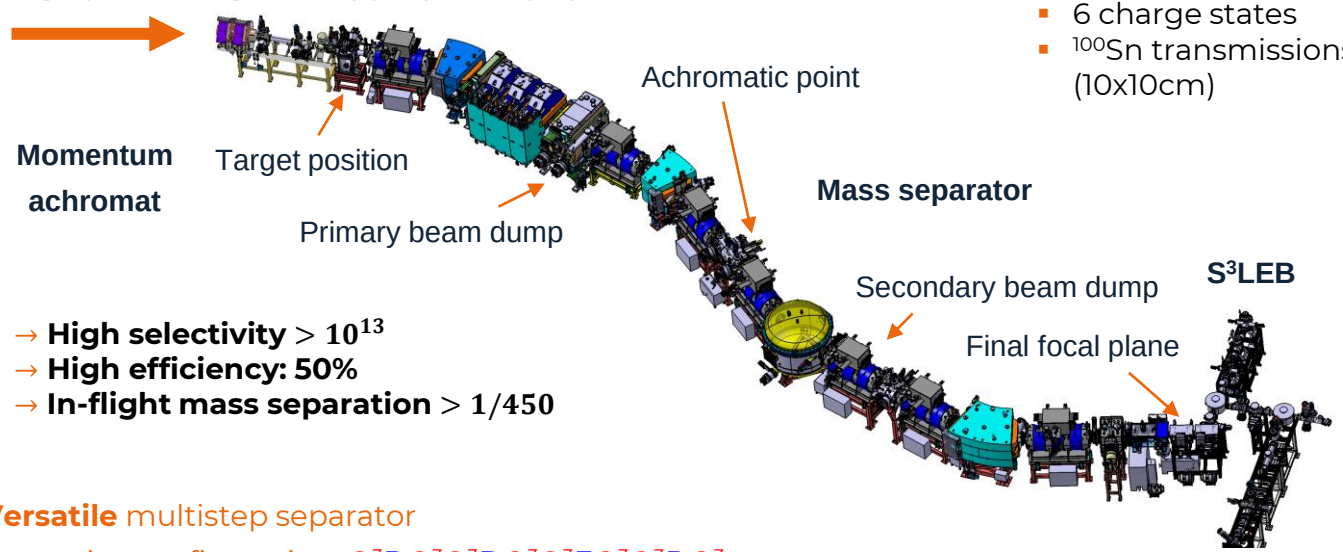
*Courtesy H. Savajols*

# $S^3$ – Optics: basic properties and functionalities

*Reference beam:*
*A=100, Q=24+, $\sigma_p$ = 3.7%, $\sigma_\theta$ = 18mrad*

**High beam intensity**

High power target: >> 1pμA (= $6.10^{12}$p/s)




→ **High selectivity** $> 10^{13}$
→ **High efficiency: 50%**
→ **In-flight mass separation** $> 1/450$

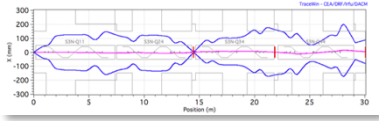
**Versatile** multistep separator

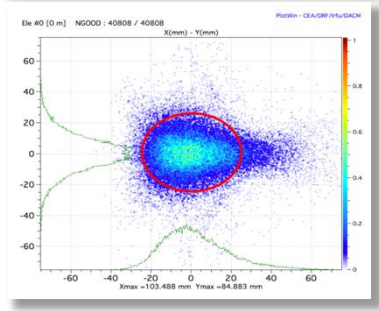
Ion optics configuration: $Q^3DQ^3Q^3DQ^3Q^3EQ^3Q^3DQ^3$

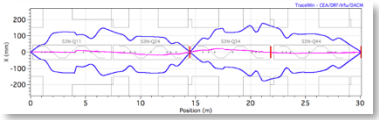
- High primary beam rejection and high acceptance spectrometer
- Two basic optical modes of operation: High transmission vs high mass resolution

Convergent Mode (CM)

- No mass resolution
- 6 charge states
- $^{100}$Sn transmissions 65% (10x10cm)

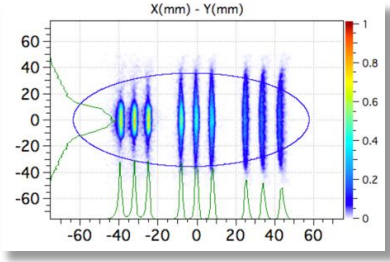






High Resolution Mode (HRM)

- m/q dispersion = 8 mm/%
- 3 charge states
- M/**Δ**M = 500
- $^{100}$Sn transmissions 40% (10x10cm)

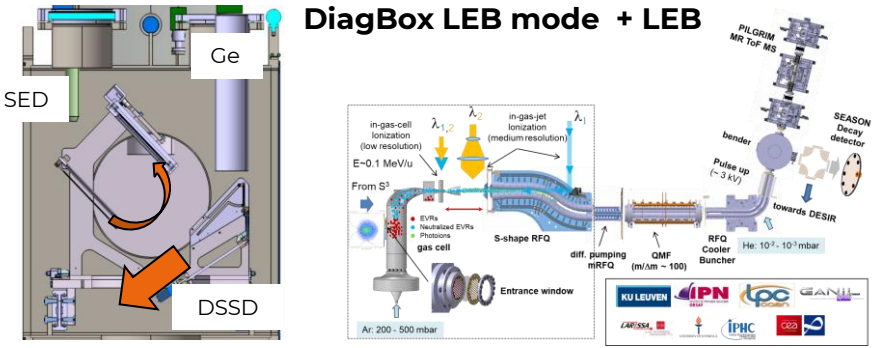


# Scientific commissioning

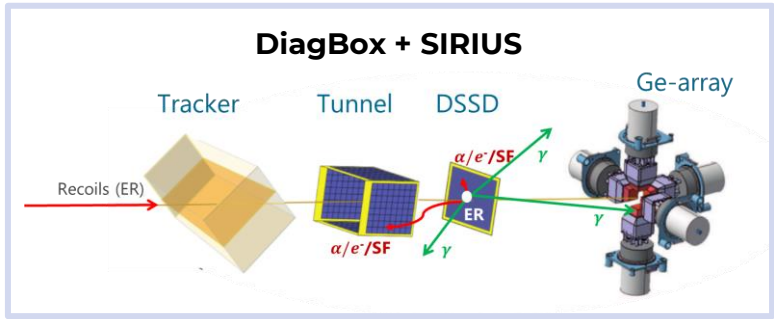
*(courtesy S. Geldhof)*

# $S^3$ – Scientific commissioning

- Easy beam & target
- High and known cross section reactions
- Identification of the reaction products (alpha, gamma tagging, M/Q  in HRM)
- Various kinematics
  - Measure and optimise the rejection (case by case)
  - Estimate transmission
- Tools at focal plane
  - Diagbox + SIRIUS / Diagbox LEB mode + LEB




~ 1.4 mm (s) /3 DSSD 5x5 cm 16x16 strips / low g-ray eff
QMF and PILGRIM




~ 0.7 mm (s) /high DSSD pixelization/ high g-ray eff

*Courtesy H. Savajols*

# $S^3$ – Scientific commissioning

- Easy beam & target
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- Identification of the reaction products (alpha, gamma tagging, M/Q  in HRM)
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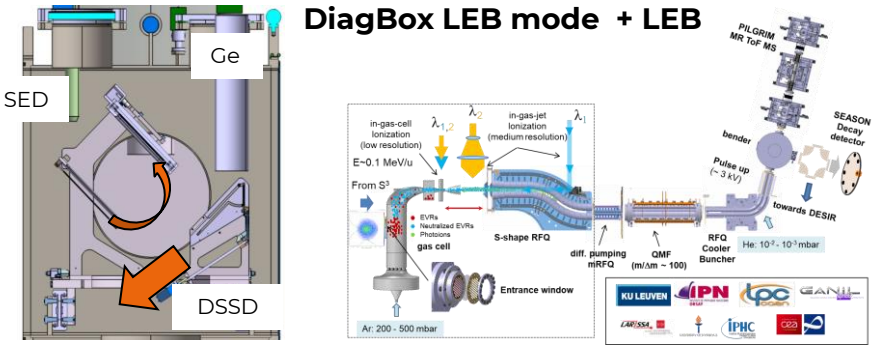
First setup

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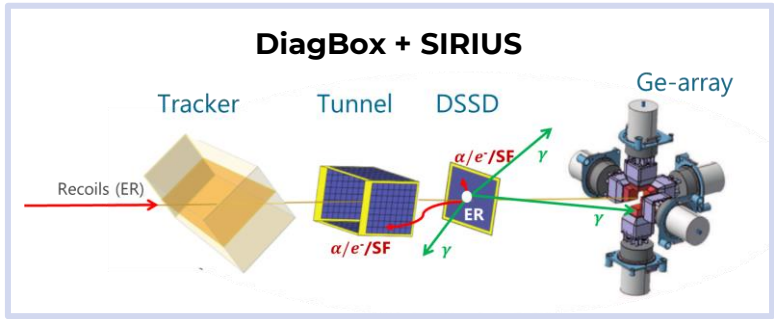


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# $S^3$ – Commissioning plan

**Commissioning plan:**

- **In 2024:**
  - LINAC beam delivery up to the $S^3$ target end 2024
  - Beam spot optimisation on the target (S3N-CF12) and beam synchronisation

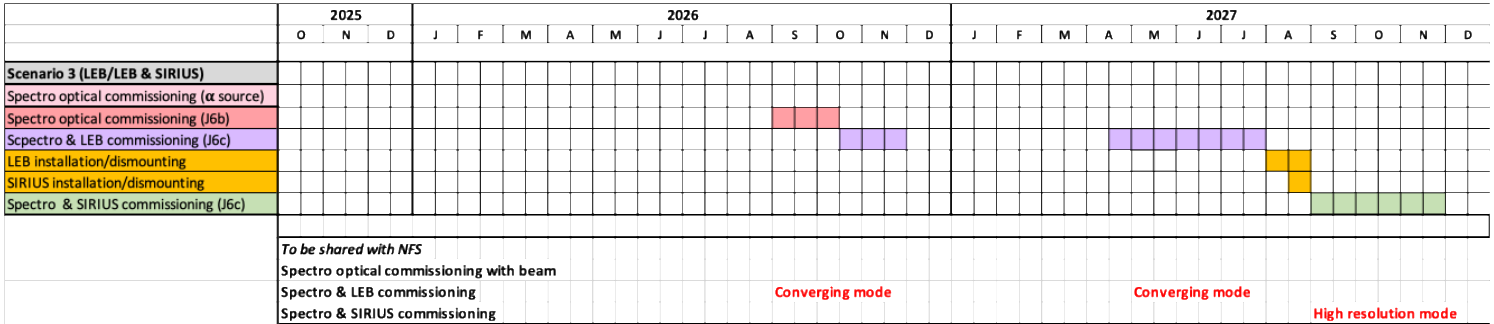
- **In 2026:** Spectrometer optical commissioning
  - Beam at the achromatic point and at the final focal plane

# $S^3$ – Commissioning plan

**Commissioning plan:**

- **In 2024:**
  - LINAC beam delivery up to the $S^3$ target end 2024
  - Beam spot optimisation on the target (S3N-CF12) and beam synchronisation

- **In 2026-2027:** Spectrometer optical commissioning with **$S^3$LEB** at the focal plane
  - $S^3$ in **converging** mode !
    - **Reaction 1:** asymmetric reaction $^{116}Sn(^{40}Ar, 4n)^{151}Er$ to produce **erbium** (N=82)
    - **Reaction 2:** asymmetric reaction $^{40}Ar + ^{175}Lu$ to produce **actinium** (N=126)
    - **Reaction 3:** symmetric reaction $^{50}Cr + ^{58}Ni$ to produce **N = Z** nuclei
    - **Reaction 4:** very asymmetric reaction $^{20}Ne + ^{197}Au$ to produce **actinium**

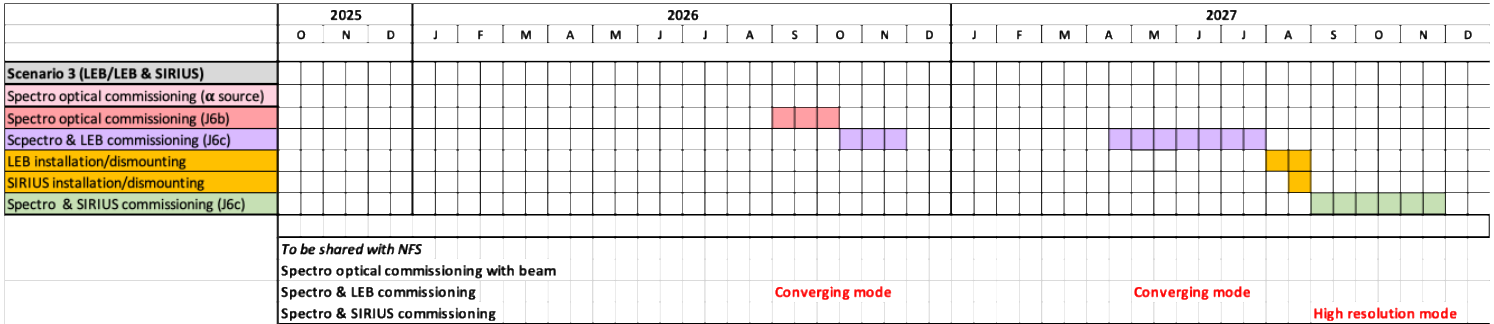


# $S^3$ – Commissioning plan

**Commissioning plan:**

- **In 2024:**
  - LINAC beam delivery up to the $S^3$ target end 2024
  - Beam spot optimisation on the target (S3N-CF12) and beam synchronisation

- **In 2027:** Spectrometer optical commissioning with **$S^3$SIRUS** at the focal plane
  - $S^3$ in **high resolution** mode !
    - **Reaction 1:** asymmetric reaction $^{40}Ar + ^{174}Yb$ to produce **known actinides**
    - **Reaction 2:** asymmetric reaction $^{40}Ar + ^{180}Hf$ to produce **thorium** (N=126)
    - **Reaction 3:** very asymmetric reaction $^{22}Ne + ^{206}Pb$ to produce **thorium**
    - **Reaction 4:** repeat asymmetric reaction $^{40}Ar + ^{116}Sn$ to produce $^{151\text{-}152}$**Er**
    - **Reaction 5:** repeat asymmetric reaction $^{40}Ar + ^{174}Yb$
    - **Reaction 6:** $^{40}Ar + ^{209}Bi$ to populate mendelevium isotopes $^{244\text{-}247}$**Md**



# Scientific commissioning with S$^3$LEB

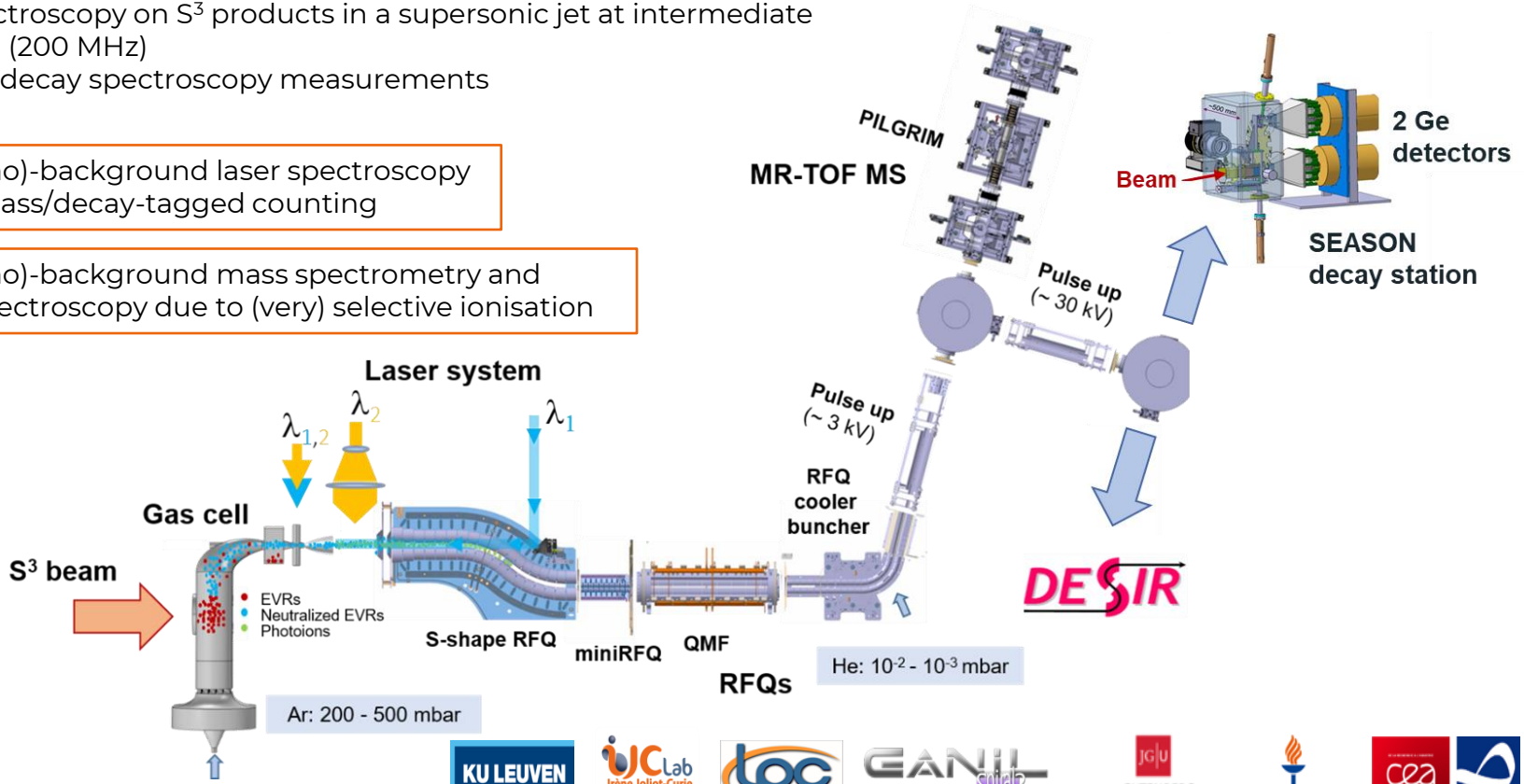
*(courtesy S. Geldhof)*

# $S^3$ Low Energy Branch ($S^3$LEB)

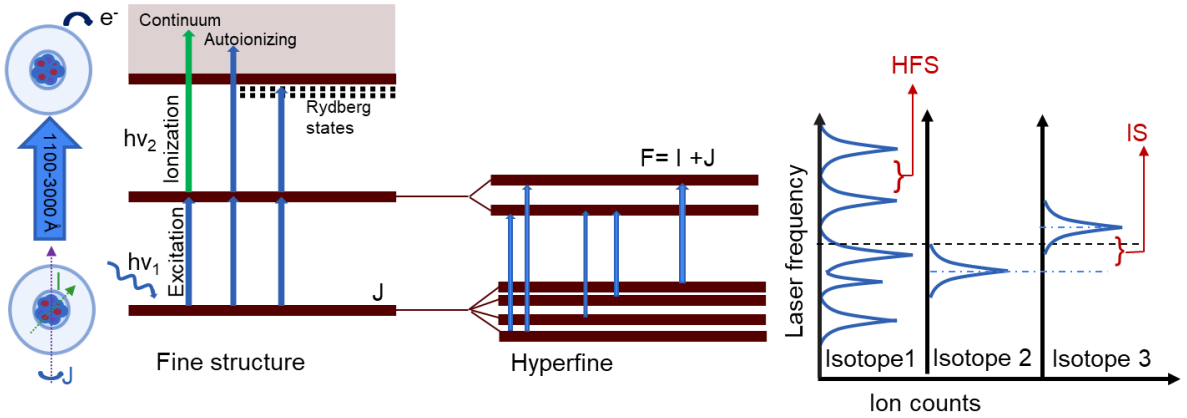
- Laser spectroscopy on $S^3$ products in a supersonic jet at intermediate resolution (200 MHz)
- Mass and decay spectroscopy measurements

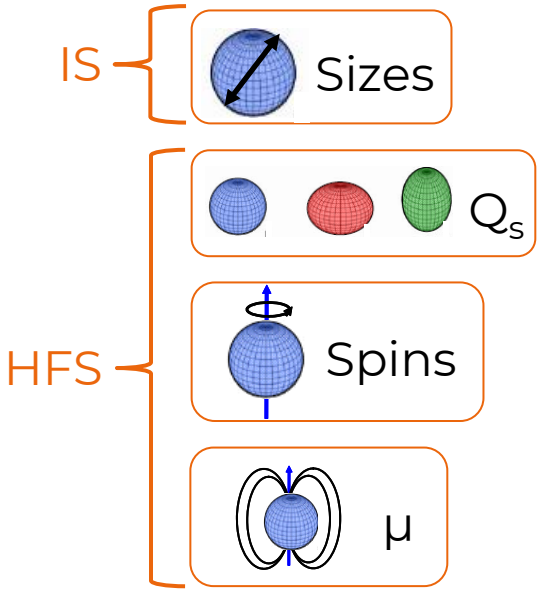
Low (or no)-background laser spectroscopy due to mass/decay-tagged counting

Low (or no)-background mass spectrometry and decay spectroscopy due to (very) selective ionisation



# Resonant laser ionization spectroscopy




**Resonant Laser Ionization method:**

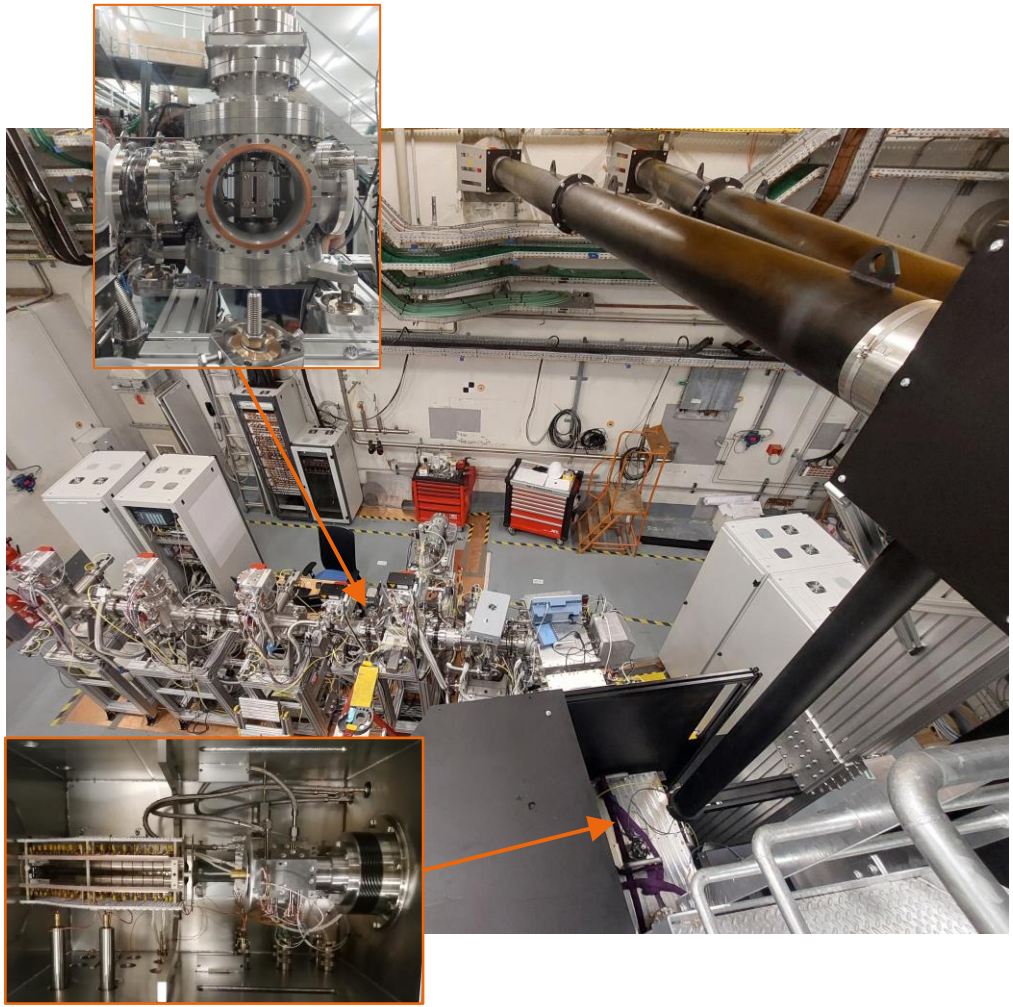
- Hyperfine splitting → Give access to deformation, spins and magnetic moments
- Scan the laser frequency of the transition to measure isotope shifts → Information on charge radii

# S³LEB at GANIL

**2024**: S³LEB moved to the focal plane of S³

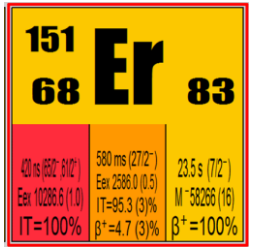
- New laser room and laser transport being set up
- 90° bender installed and tested to connect to PILGRIM and SEASON, DESIR,... in the future
- Transmission re-optimised with 133Cs surface ion source

See presentation from Skyy Pineda !

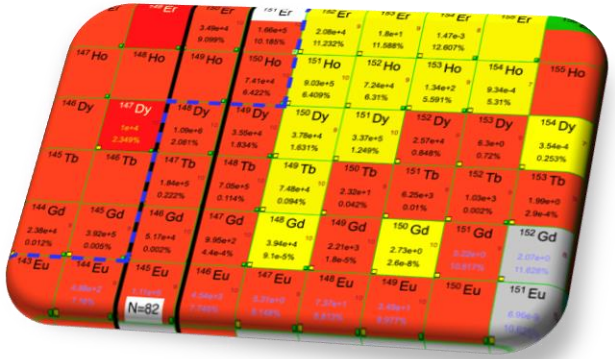


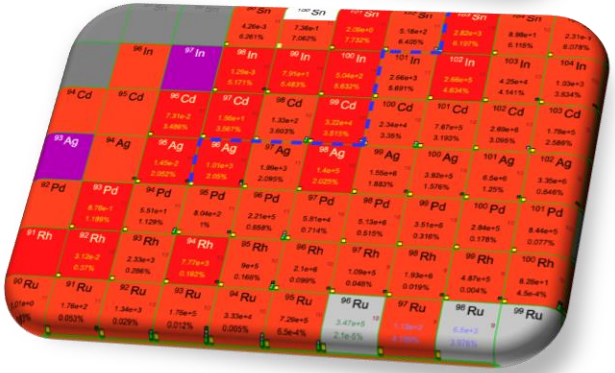
# Online commissioning

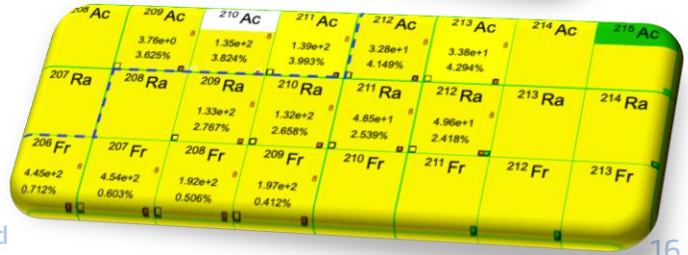
- **2026:** Start physics commissioning of S$^3$ with reaction $^{116}$Sn($^{40}$Ar, 4n)$^{151}$Er:
  - Typical reaction for spectrometer commissioning
  - Well-known cross section
  - Clear $\alpha$ emitters
- Opportunity to study the single-particle states and high-spin isomers around the N = 82 shell closure
- **> 2026:**
- Production of actinium by asymmetric reactions
  ($^{40}$Ar + $^{175}$Lu and $^{20}$Ne + $^{197}$Au)
- Production of *N* = *Z* nuclei ($^{50}$Cr + $^{58}$Ni)
  + study of direct ion extraction from gas cell




*(courtesy S. Geldhof)*



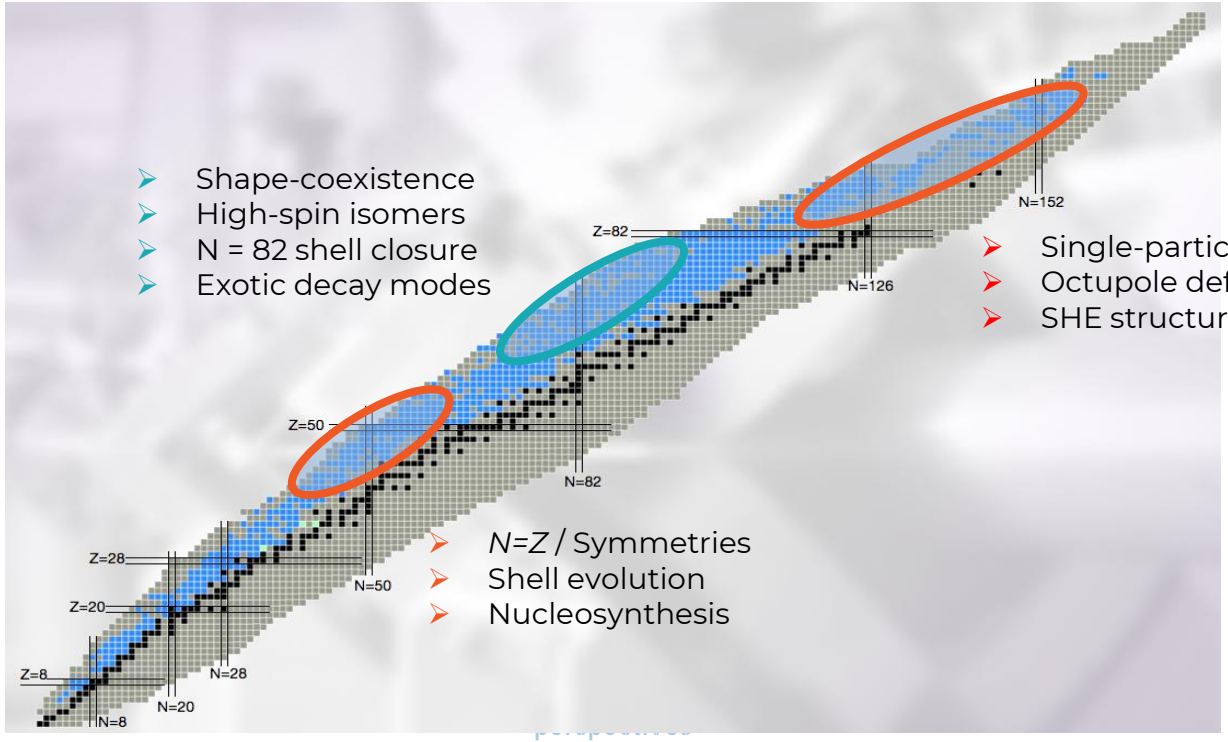


# Perspective for online commissioning

After online commissioning, start of scientific programme:

- 11 pre-proposals/Letters of Intent prepared for workshop back in 2018, re-discussed in 2022
- Additional abstracts on neutron-deficient (heavy-)medium mass nuclei (Z = 50 to Z = 82) in 2022

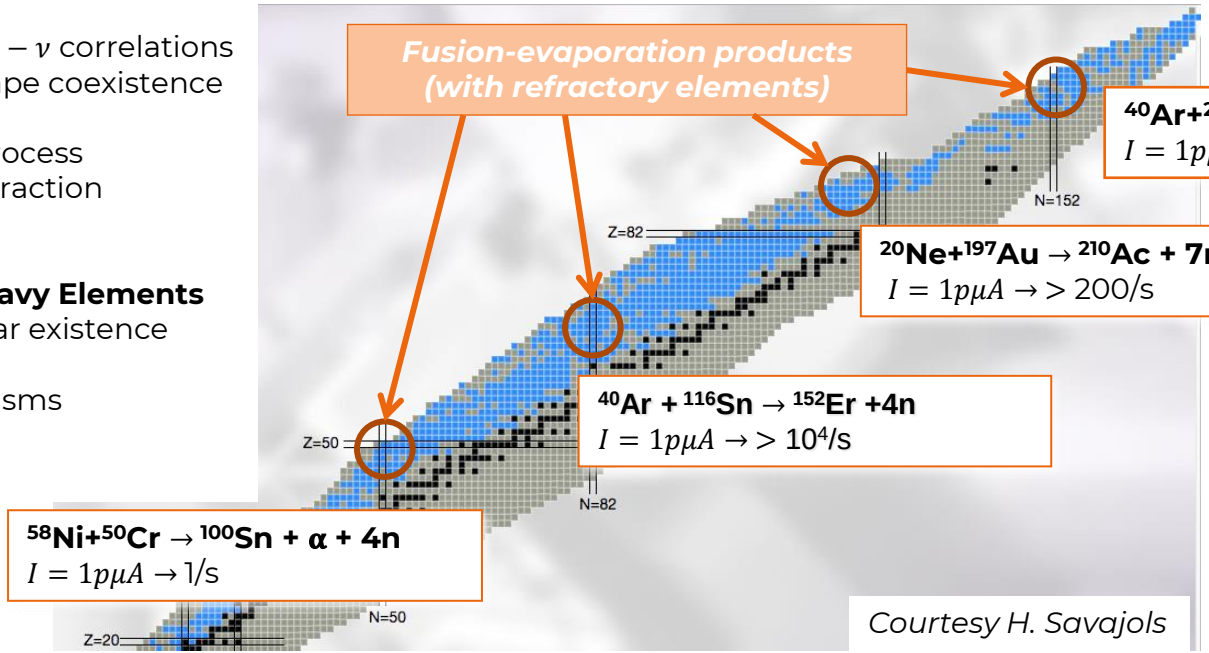
Main focus:



# S³ – Super Separator Spectrometer

**Proton dripline & $N = Z$ nuclei**
- Nuclear structure
- Study the role of $\pi - \nu$ correlations
- Deformation – shape coexistence
- Exotic decay
- Astrophysics rp-process
- Fundamental interaction

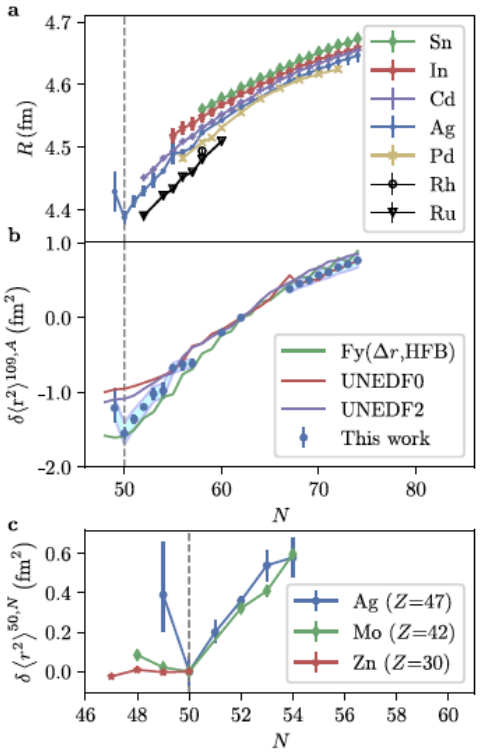
**Heavy and Superheavy Elements**
- Limit of the nuclear existence
- Nuclear structure
- Reaction mechanisms
- Atomic properties



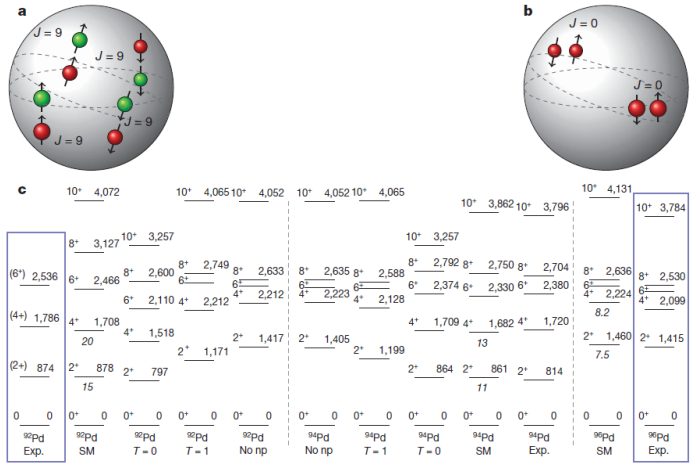

http://u.ganil-spiral2.eu/chartbeams/

# $N = Z$ region

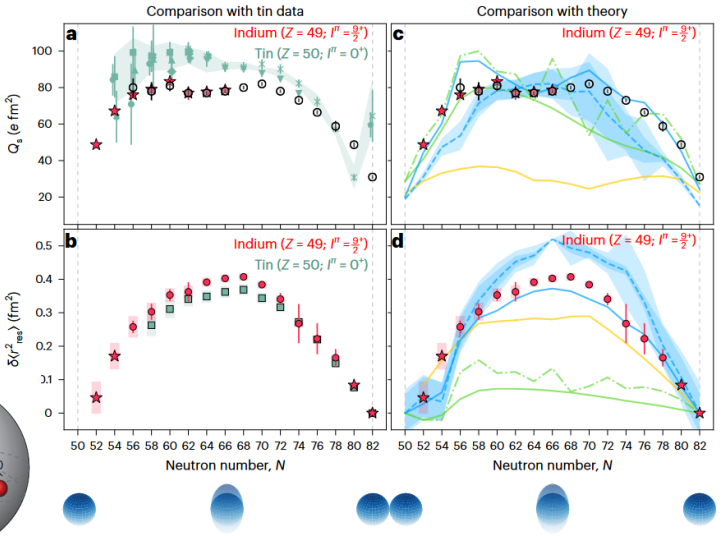
*M. Reponen et al., Nat. Comm. 12 (2021)*



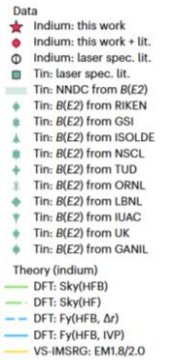

- Electromagnetic moments & mean squared charge radii:
  - Shell structure around N=Z=50 and evolution of N=50 shell closure
  - Role of T=0 neutron-proton pairs
  - Evolution of deformation




*B. Cederwall et al., Nature 469 (2011)*




*J. Karthein et al., Nat. Phys. 20 (2024)*

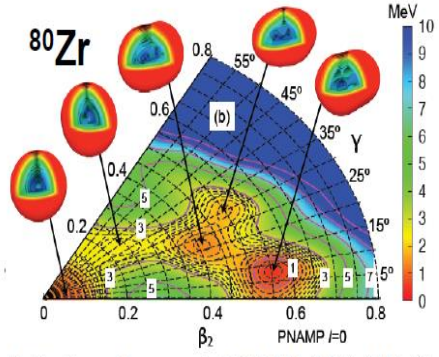



*(courtesy S. Geldhof)*

# $N = Z$ region

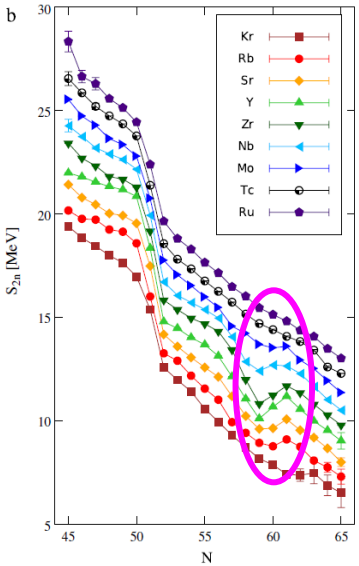
*(courtesy S. Geldhof)*

- Evolution of deformation and shape coexistence around $^{80}$Zr (N=Z=40)
- Odd-odd vs even-even staggering effect

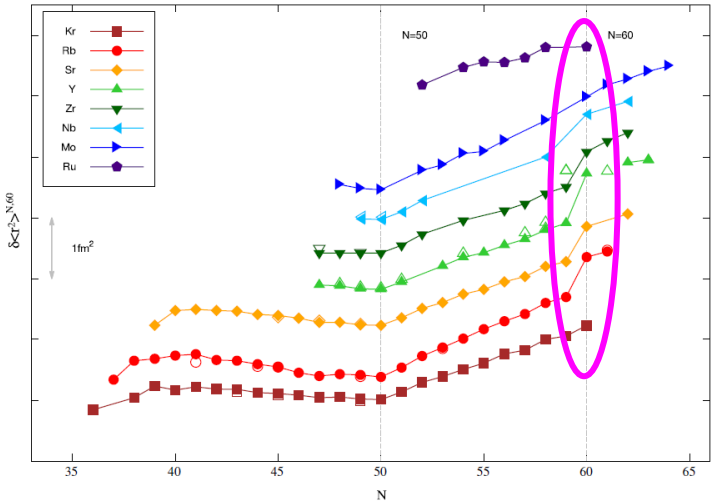


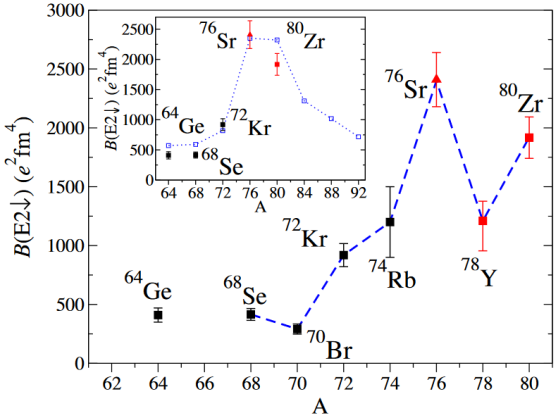

*T.R. Rodriguez et al., Phys. Lett. B 705 (2011)*

Two neutron separation energy




Mean square charge radii




*R.D.O. Llewellyn et al., PRL 124 (2020)*

Deformation effect in $S_{2n}$ and $d\langle r^2\rangle$ systematics around N=60, region around N=40 poorly known

# $N = Z$ region

Pre-proposals

Known masses

Current injector and gas cell (A/Q = 3 & 500 ms)

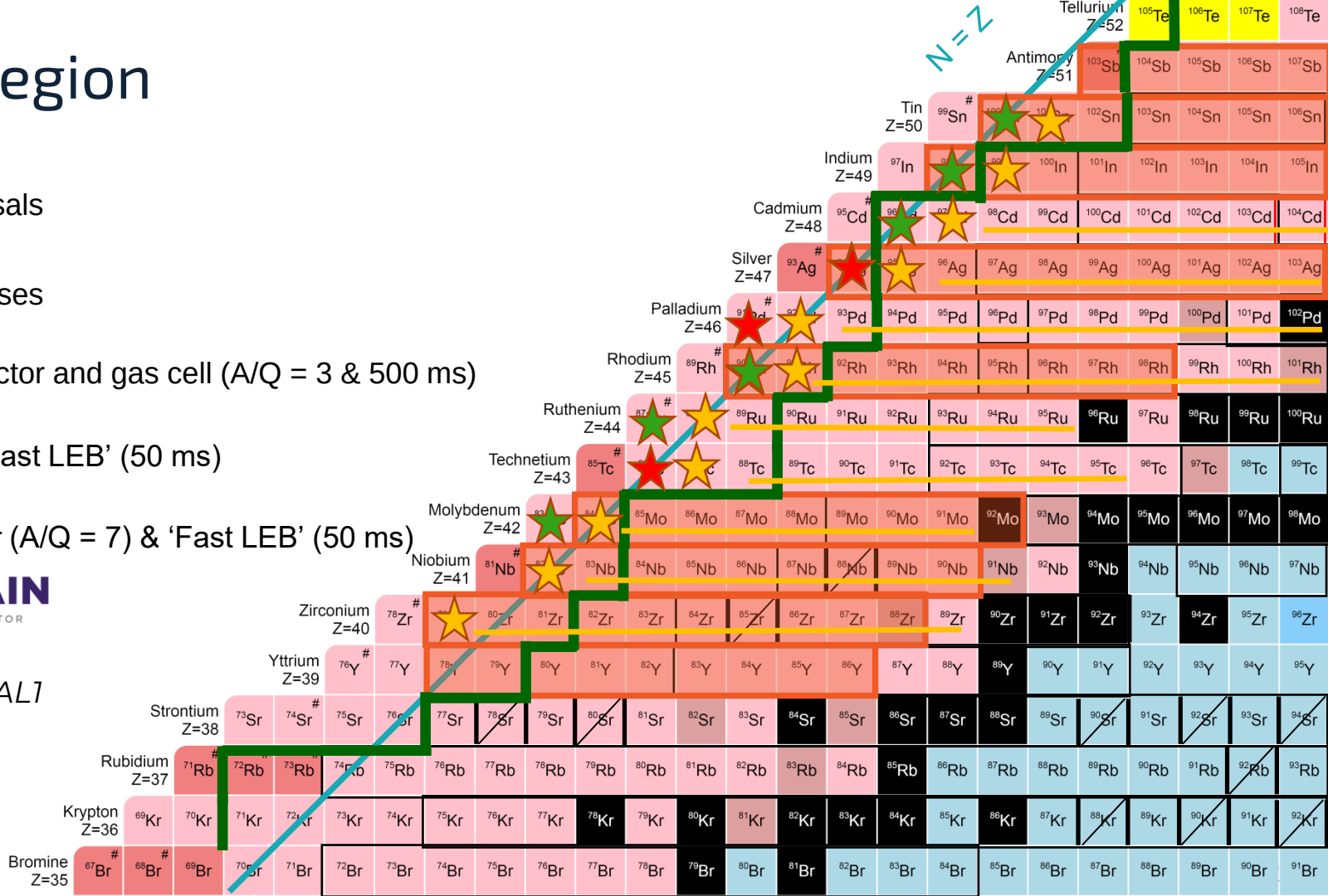
A/Q = 3 & ‘Fast LEB’ (50 ms)

New injector (A/Q = 7) & ‘Fast LEB’ (50 ms)

NEWGAIN
NEW GANIL INJECTOR

*$A < 80$ → SPIRAL1 better suited*

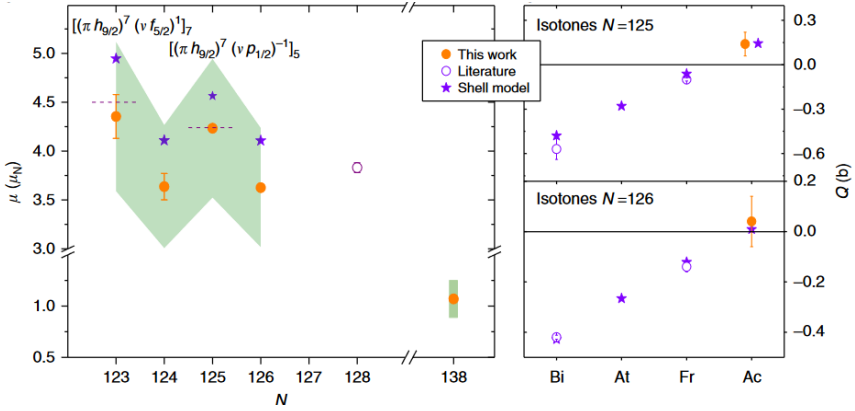
LPC CAEN



# (Super) heavy region

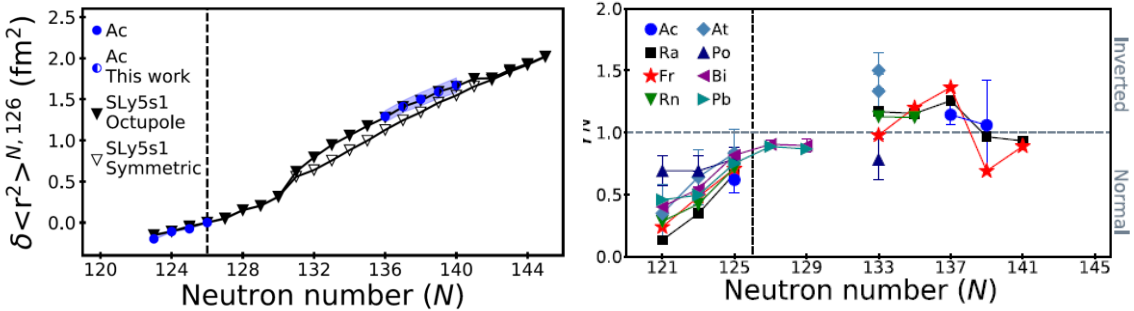

Evolution of nuclear structure near and beyond N=126
→ insight in nuclear forces close to spherical shell closure and proton dripline

Low resolution (in-gas cell) data on $^{212,213}$Ac: tentative spin and no quadrupole moments




*R. Ferrer et al., Nat. Comm. 8 (2017)*

- Search for octupole deformation in U region
  - Deviation in electric quadrupole moments?
  - Change in the charge radii odd-even staggering?
- Density functional theory predictions: Octupole deformation in ground state not only in Ra (Z = 88) but also in heavier isotopes like U (Z = 92, N = 134 - 140)



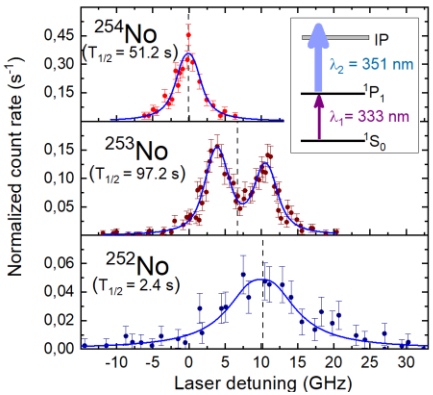

*E. Verstraelen et al. , Phys. Rev. C 100 (2019)*

*(courtesy S. Geldhof)*

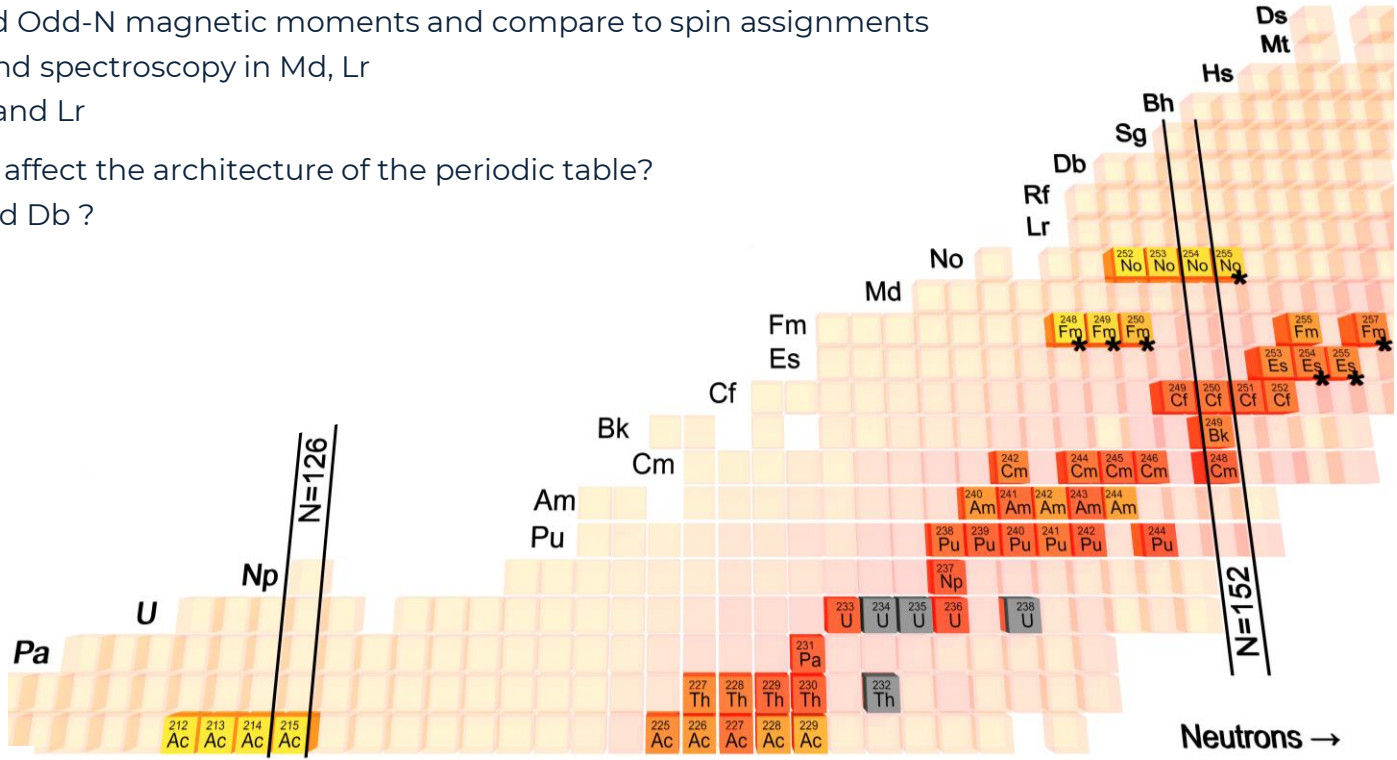
*(courtesy S. Geldhof)*

# (Super) heavy region

- Complete ground state information of SHE
  - Measure Odd-Z and Odd-N magnetic moments and compare to spin assignments
  - Transition search and spectroscopy in Md, Lr
  - K-isomers in $^{254}$No and Lr
- How do relativistic effects affect the architecture of the periodic table?
  - Measure IP in Rf and Db ?



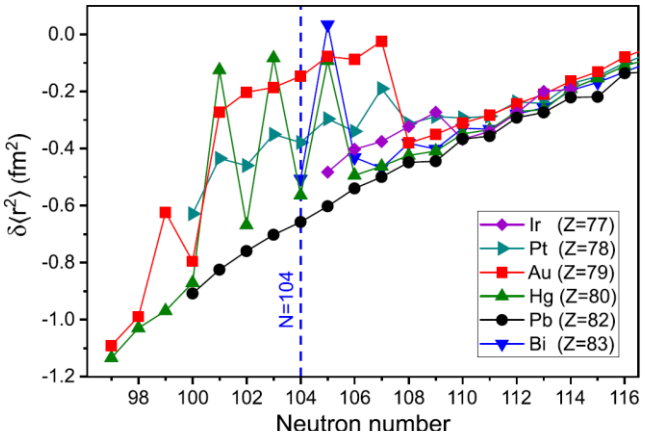

*S. Raeder et al, Phys. Rev. Lett. 120 (2018)*



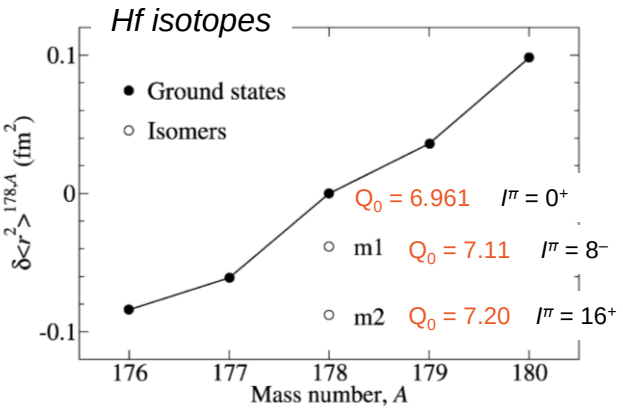

*M. Block, M. Laatiaoui, S. Raeder, PPNP 116 (2021)*

# The region between $Z = 50$ and $Z = 82$

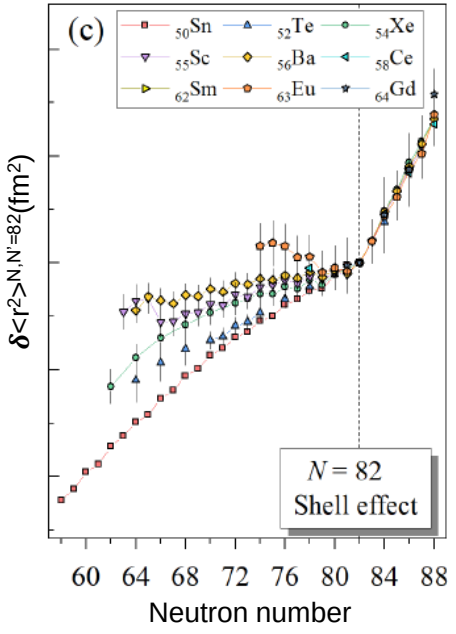
- Shape staggering in Hg region:
  - General return to sphericity towards the proton dripline?
  - Evolution of deformation towards the proton midshell
- High-spin multi quasiparticle isomers
  - $Q_0^m > Q_0^g$ but $\langle r^2 \rangle_m < \langle r^2 \rangle_g$
- N=82 shell closure




*J. Cubiss et al., Phys. Rev. Lett. 131 (2023)*




*M.L. Bissell et al., Phys. Lett. B 645(4) (2007)*



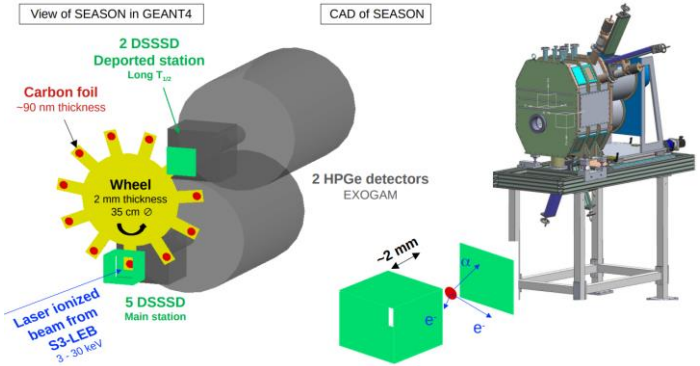

*X. F. Yang, S.J. Wang, S.G. Wilkins, R.F. Garcia Ruiz, PPNP 129 (2023)*

# Ongoing projects

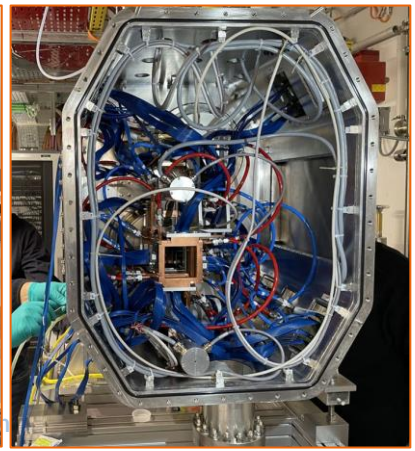
# Ongoing projects: SEASON

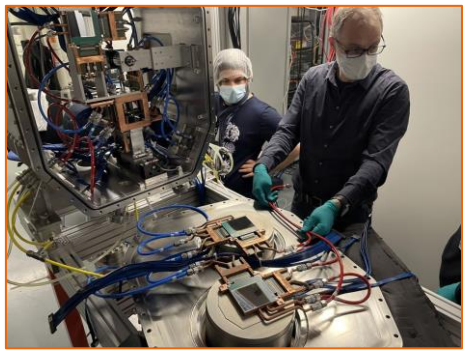
**Offline commissioning at GANIL:**
- Detectors under vacuum (expected < $1e^{-5}$ mbar)
- Red + blue pipes = Cryocooling (glycol @ -20°C)
- 4 radioactive sources (3-$\alpha$ (3kBq) + $e^-$ (37 kBq) per station) mounted on calibration arms

**Planning:**
- Was tested @ GANIL up to spring 2025
- moved to JYFL for online commissioning
- Few months of experimental campaign at JYFL




Developed at CEA Saclay
- « Windmill » of implementation foils
- Silicon box detector (DSSSD) for $\alpha$ and $e^-$
- Germanium detectors





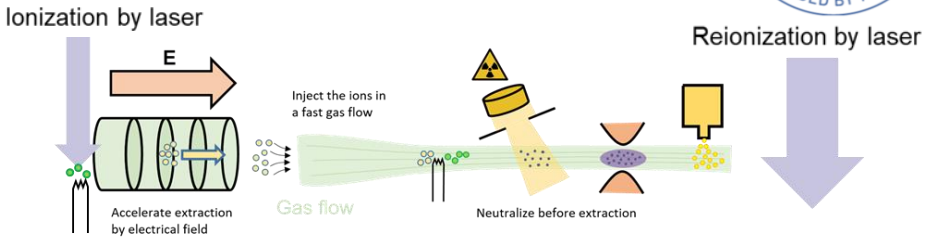
*Courtesy D. Thisse*

# Ongoing projects: FRIENDS$^3$ *(Fast Radioactive Ion Extraction and Neutralization Device for S$^3$)*

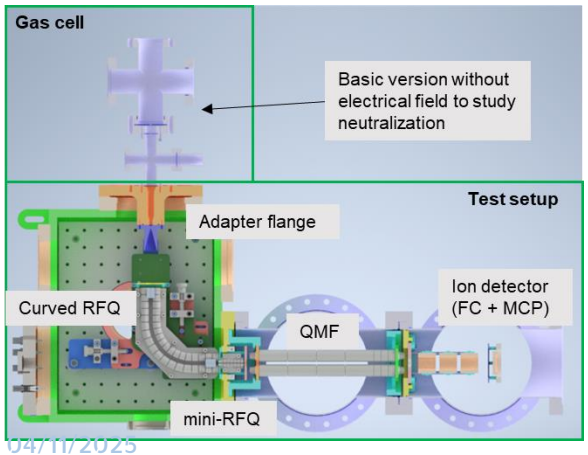
**ANR JC project FRIENDS$^3$** aimed at improving the gas cell:

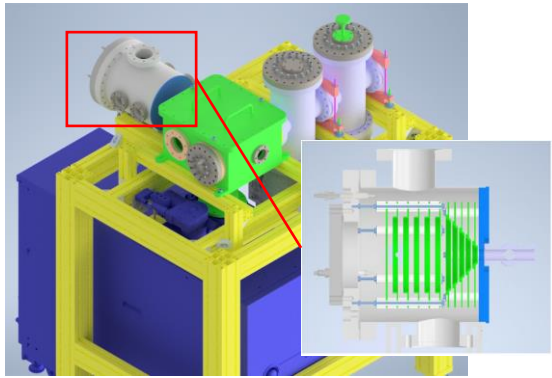
- Reduce extraction time
- Improve neutralisation efficiency

→ Ideally both at the same time




- Fast gas-cell designed, extraction efficiency objectives reached with simulations
- Ongoing neutralization tests, promising results with W filament e-production
- Test bench ready, operational transport line

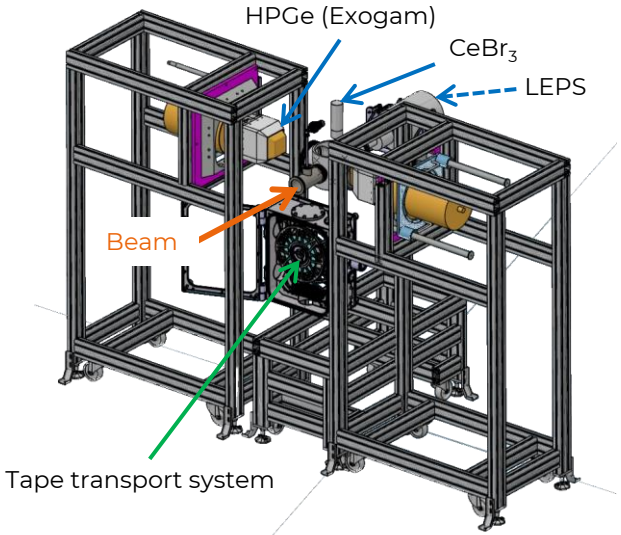


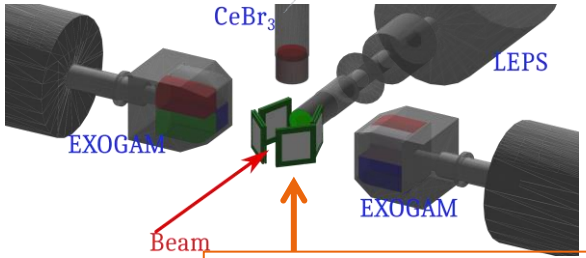



*Courtesy V. Manea, E. Morin*

# Ongoing projects: IDEAS$^3$ (Identification and DEcay Assisted by S$^3$)

**Current mechanical design:**




Tape coming from below (not present)

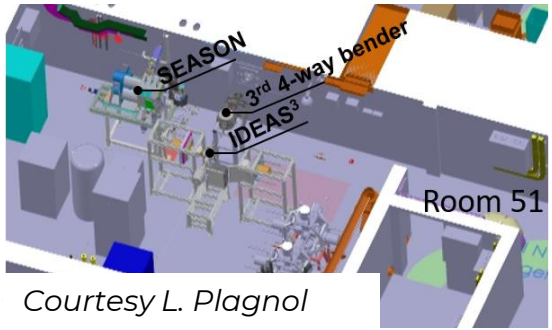
**Multidetection:**

- Gamma-rays:
  - 2 face-to-face HPGe
  - 1 $CeBr_3$ scintillator → (HE γ-rays)
  - 1 planar Germanium → (LE γ-rays & X-ray tagging)
- Charged particles (protons & $\beta^+$)
  - 4 Silicon telescopes

**Simulations and analysis with** nptool

**Preliminary room layout:**

- In room 51 (after PILGRIM)
- 0° after 4$^{th}$-way bender




*Courtesy L. Plagnol*

# Ongoing projects: IDEAS$^3$ (Identification and DEcay Assisted by S$^3$)

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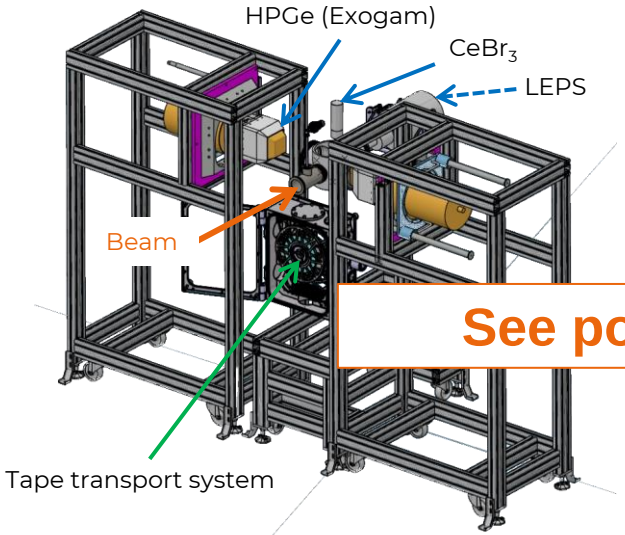


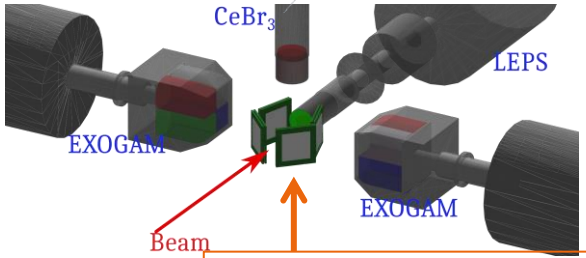


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  - 4 Silicon telescopes

**See poster from Léo Plagnol**

**alysis with**

nptool

**Preliminary room layout:**

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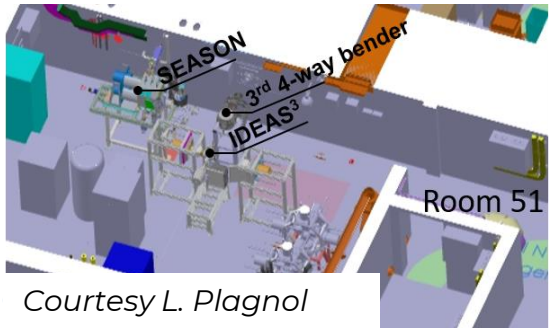
- 0° after 4$^{th}$-way bender



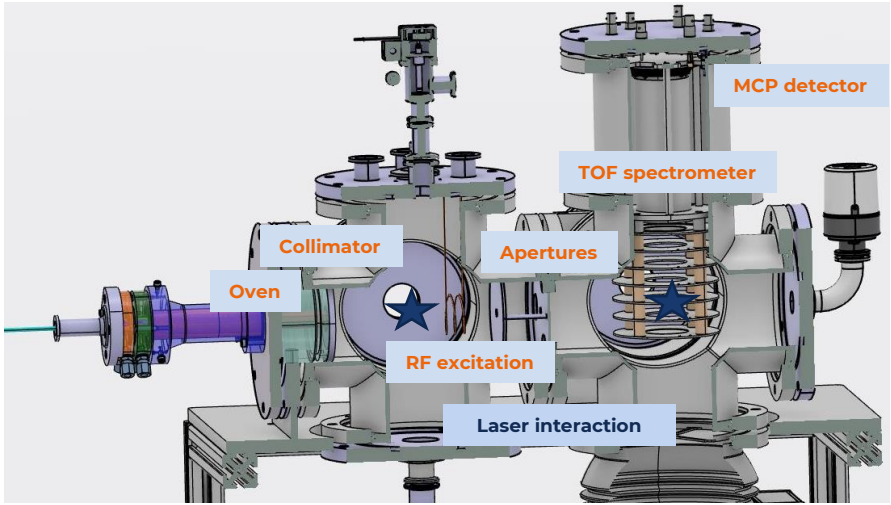

*Courtesy L. Plagnol*

# Ongoing projects: S³ABU

**S³ABU:** Design of the new S³ laser room Atomic Beam Unit

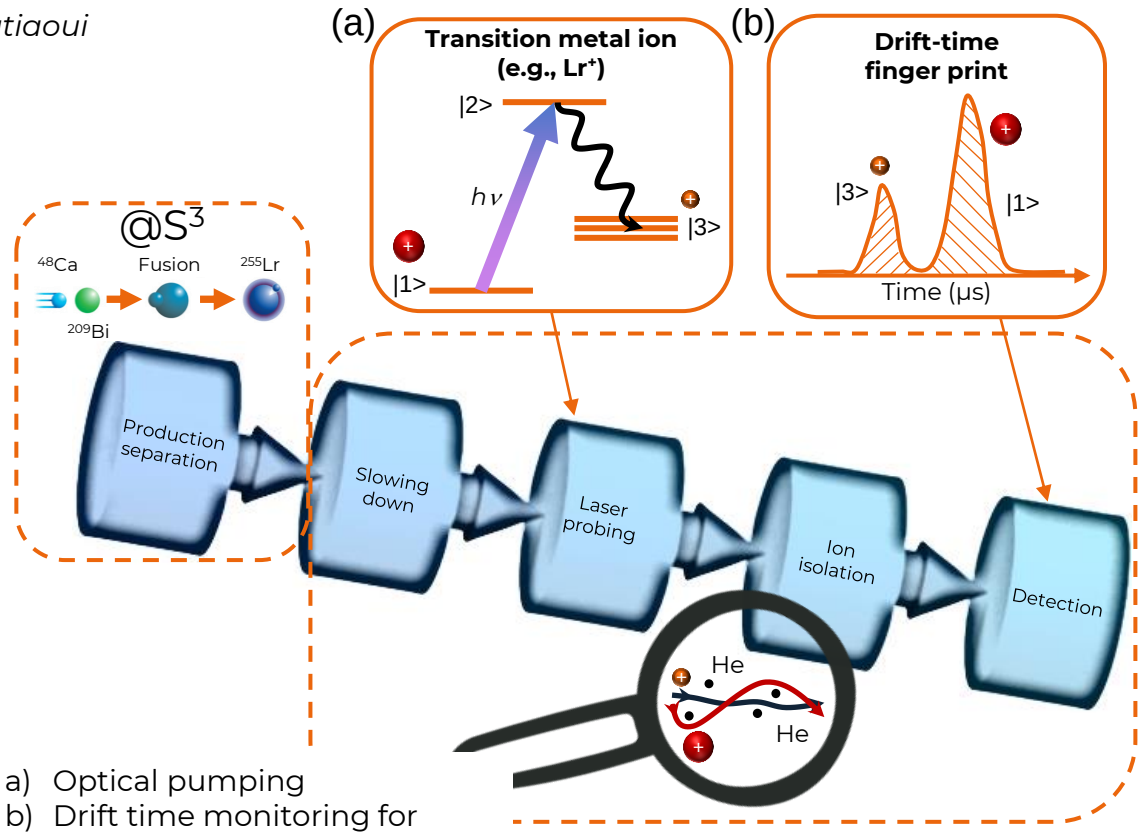
- Will include the possibility to implement the new RF spectroscopy method
- First phase before studying implementation of technique in gas jet

Double resonance spectroscopy at S³LEB
- Project submitted to ANR this year (JCJC)



# Ongoing projects: LRC (Laser Resonance Chromatography)

*Courtesy M. Laatiaoui*



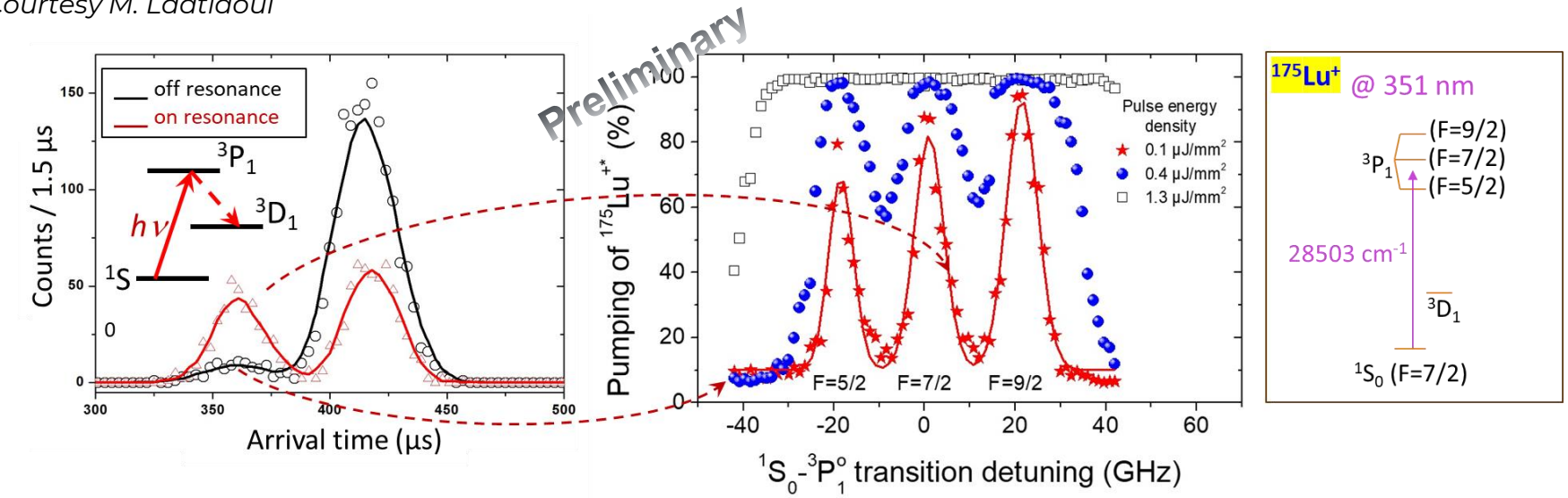

a) Optical pumping
b) Drift time monitoring for resonance identification



Laatiaoui *et al.*, **PRL 125** (2020) 023002
Laatiaoui *et al.*, **PRA 102** (2020) 013106

# Ongoing projects: LRC (Laser Resonance Chromatography)

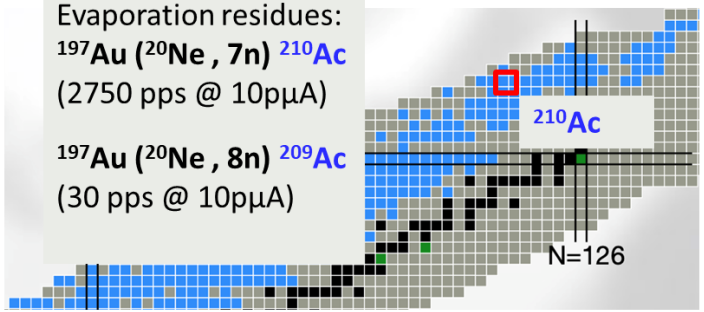
*Courtesy M. Laatiaoui*



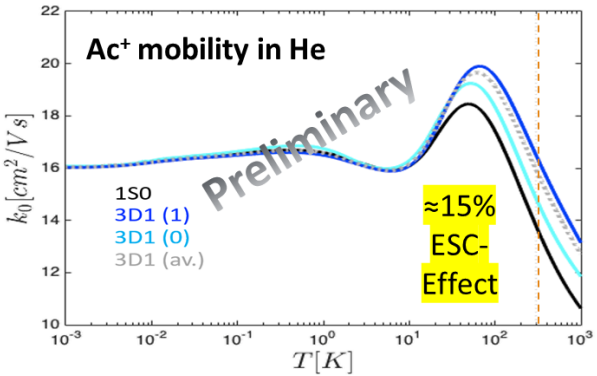

- Hyperfine structure studies possible at low laser power
- Power broadening beneficial for faster level search
- Measured overall-efficiency for ion transport: 0.6%

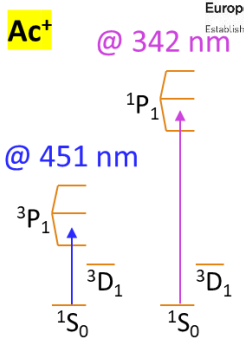

E. Kahl et al., **PRA 100** (2019) 062505
Laatiaoui *et al.*, **PRL 125** (2020) 023002
Laatiaoui *et al.*, **PRA 102** (2020) 013106
Ramanantoanina *et al.*, **PRA 104** (2021) 022813
Ramanantoanina *et al.*, **Atoms 10** (2022) 48
Romero-Romero *et al.*, **Atoms 10** (2022) 87
Ramanantoanina *et al.*, **PRA 108** (2023) 012802
Visentin *et al.*, **PRA 110** (2024) 012805
Kim *et al.*, **NIMB 555** (2024) 165461

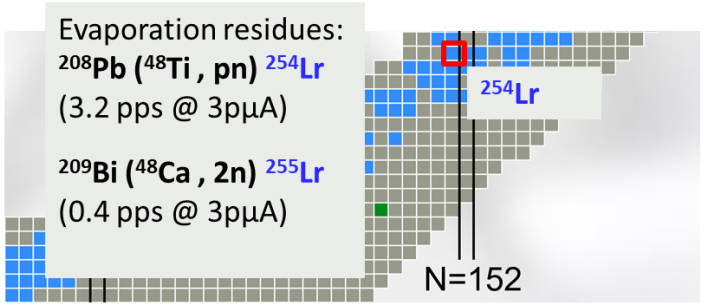
# Ongoing projects: LRC (Laser Resonance Chromatography)




https://u.ganil-spiral2.eu/chartbeams/

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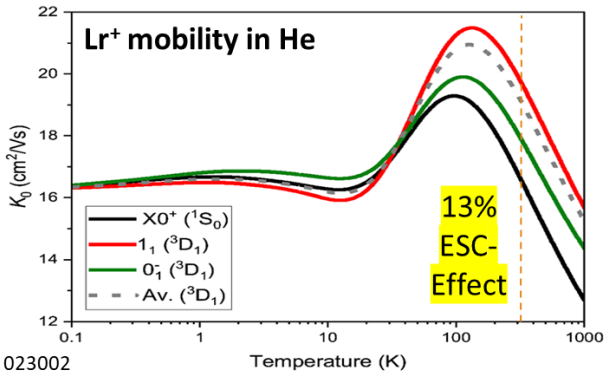
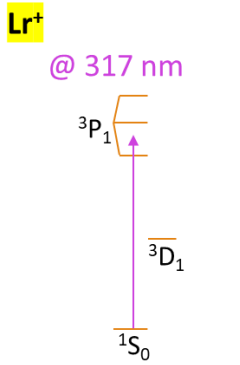


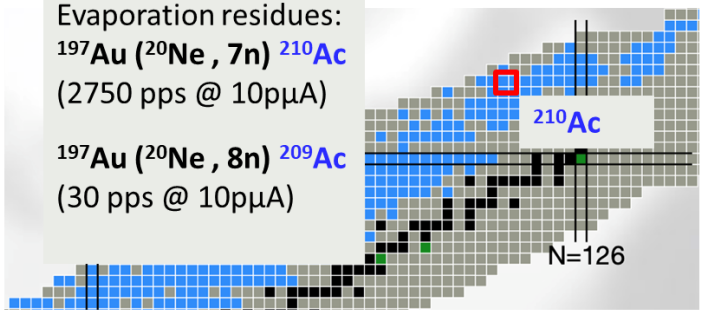



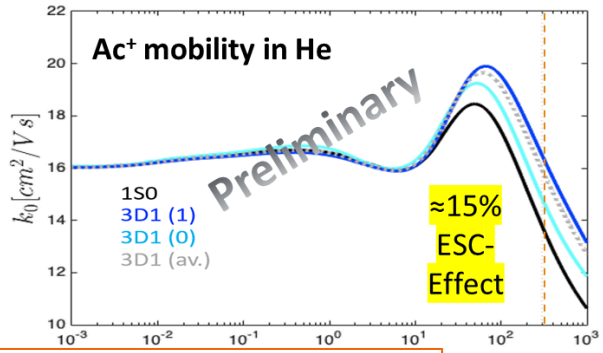

E. Kahl et al., **PRA 100** (2019) 062505
Ramanantoanina *et al.*, **Atoms 10** (2022) 48

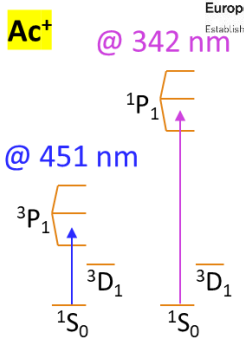
Laatiaoui *et al.*, **PRL 125** (2020) 023002
Ramanantoanina *et al.*, **PRA 108** (2023) 012802

*Courtesy M. Laatiaoui*

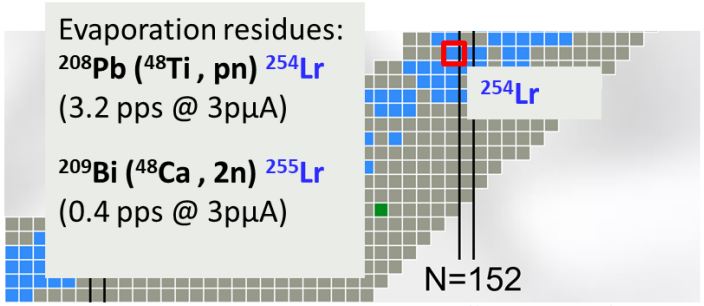
# Ongoing projects: LRC (Laser Resonance Chromatography)

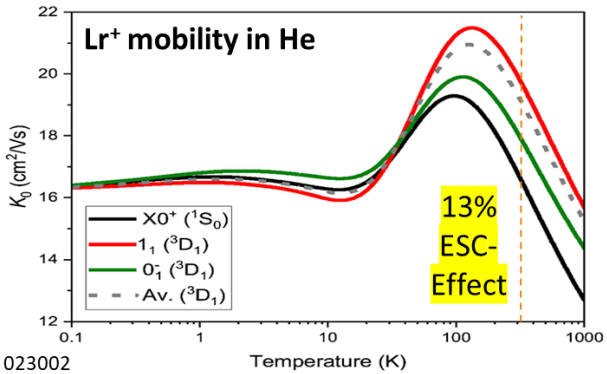


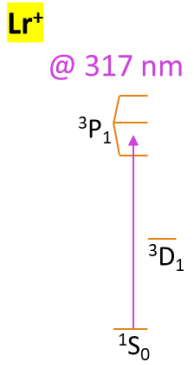




**See poster from Tudor Stefan**



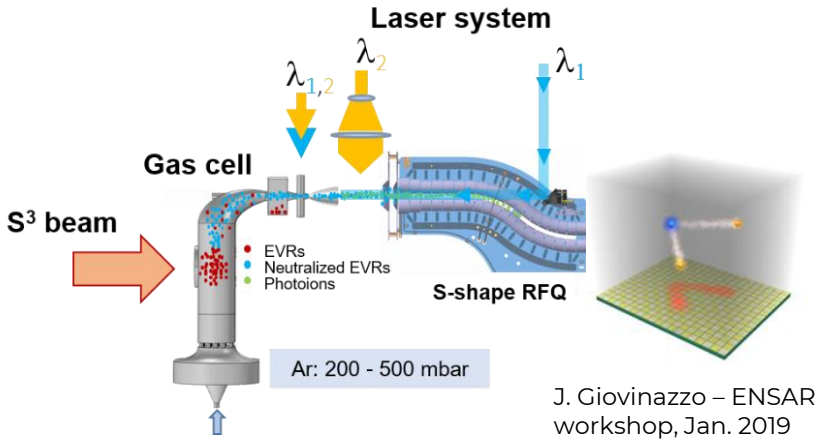

E. Kahl et al., **PRA 100** (2019) 062505
Ramanantoanina *et al.*, **Atoms 10** (2022) 48
Laatiaoui *et al.*, **PRL 125** (2020) 023002
Ramanantoanina *et al.*, **PRA 108** (2023) 012802

*Courtesy M. Laatiaoui*

# Ongoing project: P-box – the search for new p-emitting nuclei

**Investigation of the dripline:**
- High precision Q-values measurements at the dripline
- Finer identification of new proton emitting nuclei
- Observation of the emitted proton
  - Clear definition of the dripline

**P-box:**
- TPC-like detector after the S-shape RFQ
  - Benefit from the laser selection → pure beam
  - TPC is not sensitive to $\beta^+$ → no contaminated spectra
- Gas ionization to see the proton
- No need for the full trace → detector walls made of Si detectors → proton energy measurement




J. Giovinazzo – ENSAR GDS workshop, Jan. 2019

# Conclusion and outlook

- Offline commissioning completed at LPC
  - First in-gas-jet spectroscopy and mass measurements demonstrated
  - Characterisation of many aspects of setup performed
- Installation at focal plane of $S^3$ ongoing, gradual restart to prepare for online commissioning
- $S^3$ laser room ready, installation of Ti:sapphire cavities and transport optics ongoing
- GISELE continues as testing/development/training lab for $S^3$LEB
- Several ongoing projects for improvement of the setup

# Thank you for your attention!


**GANIL:**
A. Ajayakumar, A. Bouriel, A. Brizard, S.K. Chinthakayala, S. Damoy, P. Delahaye, C. Dugueperoux, P. Gangnant, J. Goupil, M. Laatiaoui, N. Lecesne, R. Leroy, A.F. Lopez, F. Lutton, A. Ortiz-Cortes, B. Osmond, J. Piot, H. Savajols, T. Stefan

**LPC:**
M. Brun, J.-F. Cam, X. Fléchard, C. Gautier, J. Lory , Y. Merrer, S. Pineda, H. de Préaumont, A. de Roubin, C. Vandamme

**KU Leuven:**
A. Claessens, T.E. Cocolios, R. Ferrer, R. de Groote, F. Ivandikov, J. Romans, P. Van den Bergh, P. Van Duppen

**IPHC:**
E. Traykov

**IJCLab:**
W. Dong, P. Duchesne, S. Franchoo, L. Lalanne, V. Manea, V. Marchand, E. Morin, L. Plagnol, O. Pochon

**JGU/GSI:**
S. Raeder, D. Studer

**JYU:**
I. D. Moore, M. Reponen

**IRFU:**
M. Authier, O. Cloué, A. Drouart, M. Ragot, E. Rey-Herme, D. Thisse, M. Vandebrouck

Courtesy D. Ackermann (GANIL)

# $S^3$ – Science program "day 1" and beyond

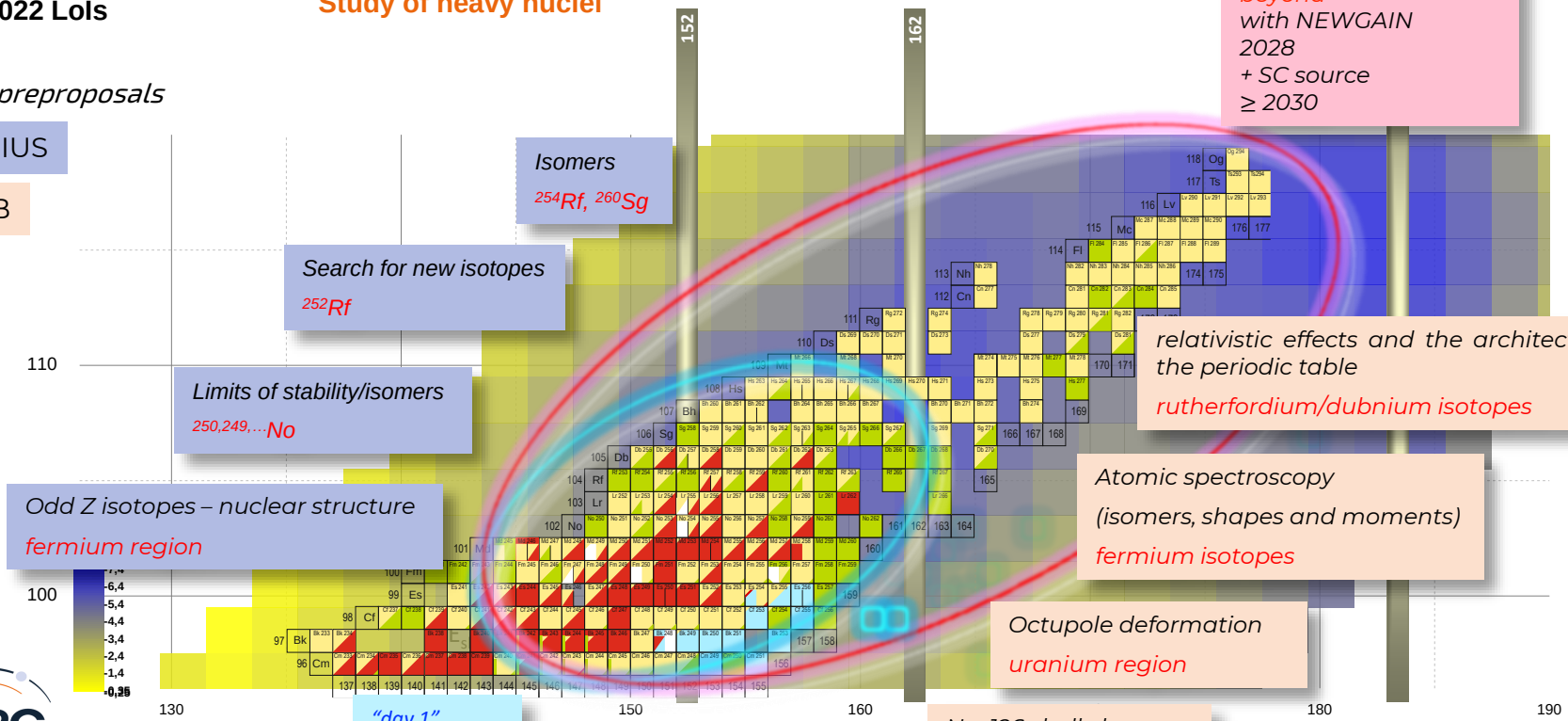
**2018/2022 LoIs**

Study of heavy nuclei

*"day1" - preproposals*

$S^3$SIRIUS

$S^3$LEB




*Isomers*
$^{254}Rf$, $^{260}Sg$

*Search for new isotopes*
$^{252}Rf$

*Limits of stability/isomers*
$^{250,249,...}No$

*Odd Z isotopes – nuclear structure*
*fermium region*

*"day 1"*
*with injector1*

*beyond*
*with NEWGAIN*
*2028*
*+ SC source*
*≥ 2030*

*relativistic effects and the architecture of the periodic table*
*rutherfordium/dubnium isotopes*

*Atomic spectroscopy*
*(isomers, shapes and moments)*
*fermium isotopes*

*Octupole deformation*
*uranium region*

*N = 126 shell closure*
*Ac - Th region*

*Calc.: A. Sobiszewski*

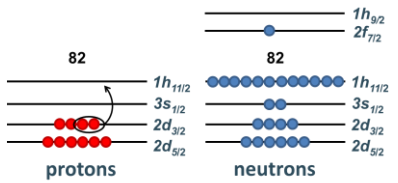
# Perspective for online commissioning

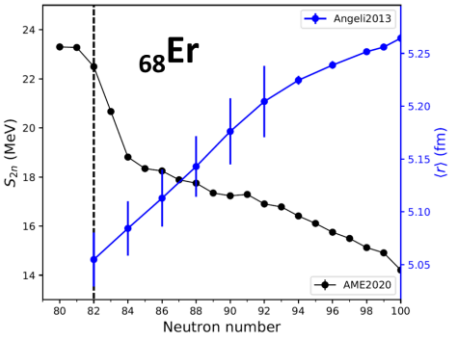
**2026:** Start physics commissioning of S$^3$ with reaction $^{116}$Sn($^{40}$Ar, 4n)$^{151}$Er:

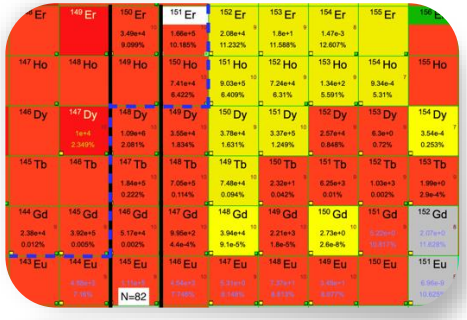
- Opportunity to study the single-particle states and high-spin isomers around the *N = 82* shell closure

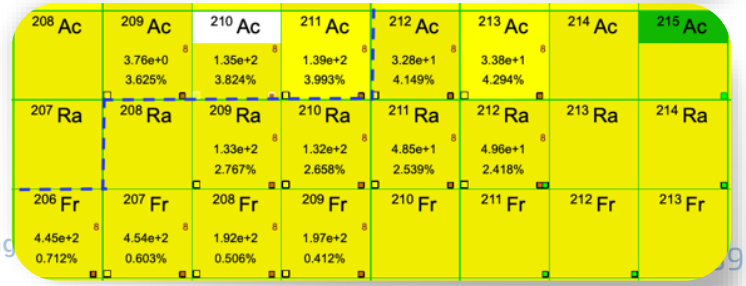
**> 2026:**

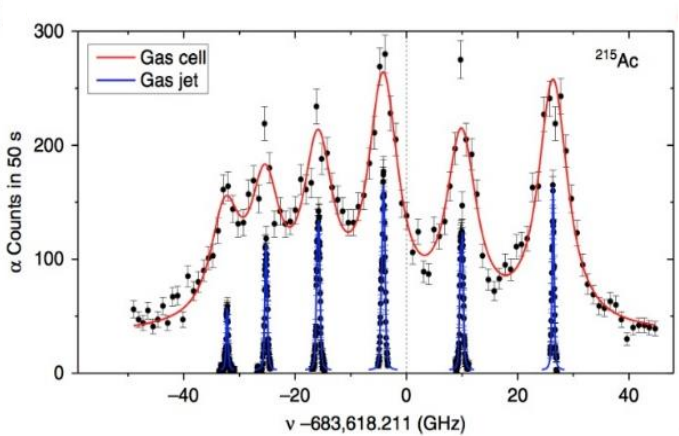
- Production of actinium by asymmetric reactions ($^{40}$Ar + $^{175}$Lu and $^{20}$Ne + $^{197}$Au)
- Production of *N = Z* nuclei ($^{50}$Cr + $^{58}$Ni)




*R. Ferrer, Nature Comm. 8 14520 (2017)*

*Courtesy H. Savajols*

# $S^3$ – Commissioning plan

- Milestone J6a : LINAC beam delivery up to the $S^3$ target end 2024
  - Beam spot optimisation on the target (S3N-CF12) and beam synchronisation

| | 2025 | | | 2026 | | | | | | | | | | | | | 2027 | | | | | | | | | | | | Weeks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | O | N | D | J | F | M | A | M | J | J | A | S | O | N | D | J | F | M | A | M | J | J | A | S | O | N | D | | |
| **Scenario 3 (LEB/LEB & SIRIUS)** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Spectro optical commissioning (α source) | | | | | | α | α | α | α | | | | | | | | | | | | | | | | | | | | 8 |
| Spectro optical commissioning (J6b) | | | 1 | | | | | | 1 | 1 | | | | | | | | | | | | | | | | | | | 6 |
| Scpectro & LEB commissioning (J6c) | | | | | | | | | | 2 | 2 | 2 | 2 | | | | | | | 4 | 4 | 4 | 4 | 4 | 4 | 4 | | | 22 |
| LEB installation/dismounting | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| SIRIUS installation/dismounting | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Spectro & SIRIUS commissioning (J6c) | | | | | | | | | | | | 3 | 3 | 3 | 3 | 3 | | | | | | | | 5 | 5 | 5 | 5 | 5 | 5 | 24 |
| | **Spectro optical commissioning α with source 8 weeks** | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | ***To be shared with NFS*** | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | **Spectro optical commissioning with beam 6 weeks** | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | **Spectro & LEB commissioning 22 weeks** | | | | | | | | | | | **Converging mode** | | | | | | | | **Converging mode** | | | | | | | | | |
| | **Spectro & SIRIUS commissioning 24 weeks** | | | | | | | | | | | | | | | | | | | | | | | **High resolution mode** | | | | | | |

- **Block 1 : Spectrometer optical commissioning**

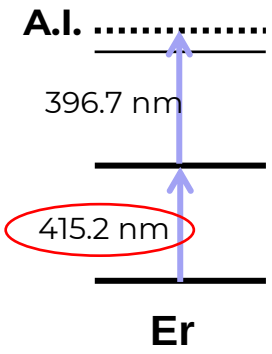
- **Block 2 (Converging Mode) : LEB**
  **Reaction 1**: asymmetric reaction $^{40}$**Ar** + $^{116}$**Sn** to produce erbium (N=82)

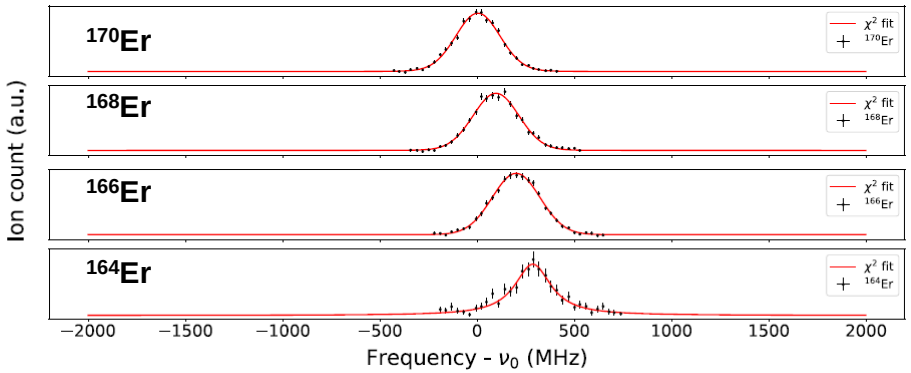
- **Block 3 (Converging mode) : SIRIUS**
  **Reaction 2**: asymmetric reaction $^{40}$**Ar** + $^{174}$**Yb** to produce known actinides
  **Reaction 3**: asymmetric reaction $^{40}$**Ar** + $^{180}$**Hf** to produce thorium (N=126)

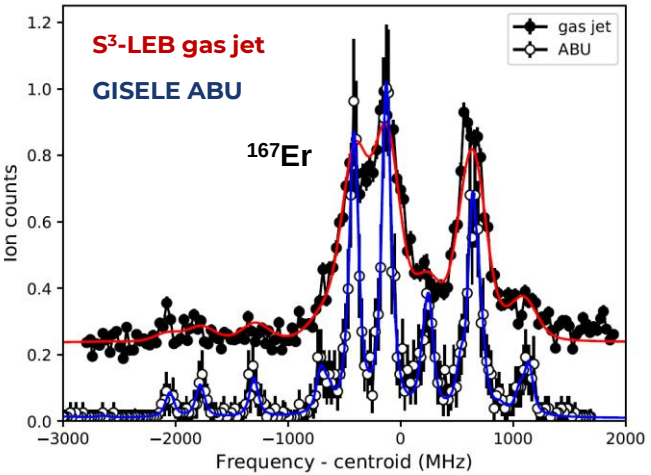
- **Block 4 (Converging mode): LEB**
  **Reaction 4**: asymmetric reaction $^{40}$**Ar** + $^{175}$**Lu** to produce actinium (N=126)
  **Reaction 5:** symmetric reaction $^{50}$**Cr** + $^{58}$**Ni** to produce N = Z nuclei
  **Reaction 6:** very asymmetric reaction $^{20}$**Ne** + $^{197}$**Au** to produce actinium (N=126)

- **Block 5 (Converging / High Resolution modes): SIRIUS**
  **Reaction 7**: very asymmetric reaction $^{22}$**Ne** + $^{206}$**Pb** to produce thorium
  **Reaction 8**: repeat asymmetric reaction $^{40}$**Ar** + $^{116}$**Sn** to produce $^{151\text{-}152}$Er
  **Reaction 9**: repeat asymmetric reaction $^{40}$**Ar** + $^{174}$**Yb**
  **Reaction 10**: $^{40}$**Ar** + $^{209}$**Bi** to populate mendelevium isotopes $^{244\text{-}247}$**Md**

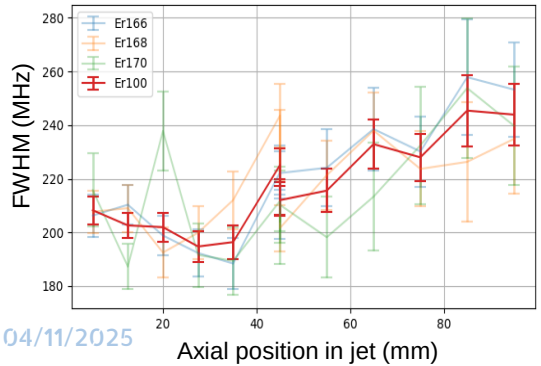
# S³LEB – Offline commissioning at LPC Caen




*A. Ajayakumar et al., NIMB 539 (2023)*




**First in-gas-jet spectroscopy**, resolution of 280 MHz obtained
= apparent Mach number 4.5, nozzle made for Mach 8

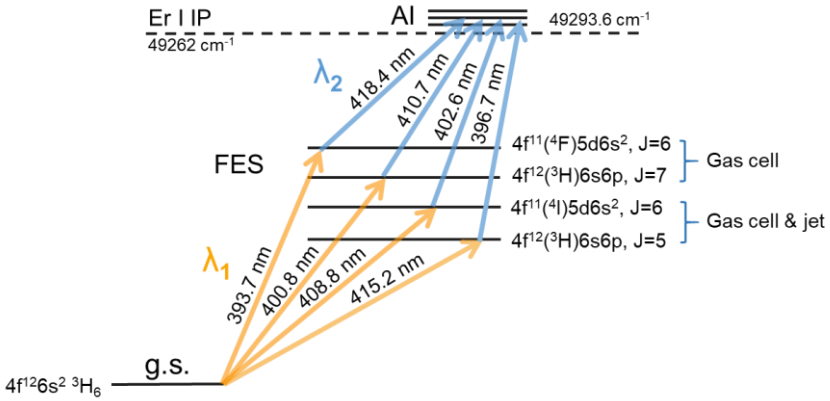
Good agreement with literature data on determined IS and HFS coefficients

**Systematic work** to improve resolution by studying influence of:
- Laser power and alignment
- Background pressure
- Gas cell position and temperature

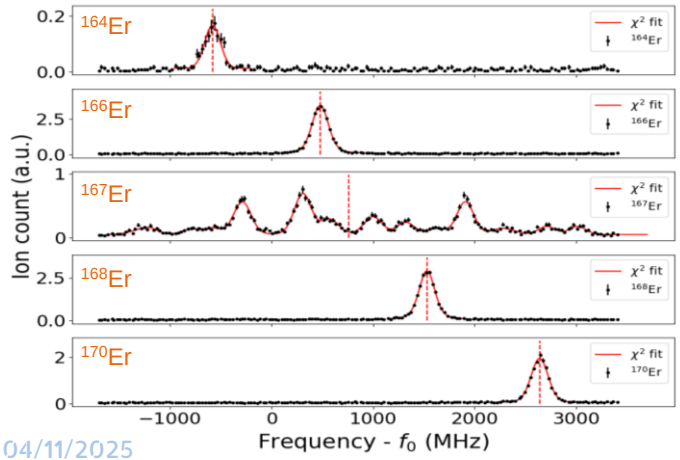
Reached **Mach 6-6.5** (~200 MHz FWHM), to be continued

# S³LEB – Offline commissioning at LPC Caen

- The scheme used for commissioning has no sensitivity to charge radii (tiny field shift factor)
- Verify other transitions with known large isotope shifts (based on old spectroscopy work)

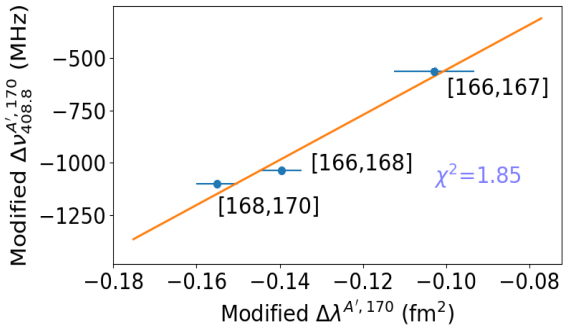



*PhD work of W. Dong*




$$\delta\nu_{A'A} = F\delta\Lambda_{A'A} + M\frac{A'-A}{A'A}$$

| λ (nm) | F (GHz fm$^{-2}$) |
|---|---|
| 415.2 | 0.5 (0.3) |
| 408.8 | 10.7(3.2) |
| 400.8 | −4.3(1.7) |
| 393.7 | 10.8(2.8) |

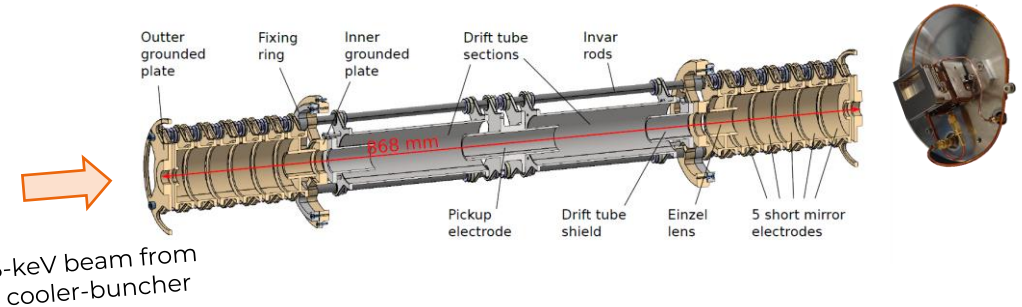


# S³LEB – Offline commissioning at LPC Caen

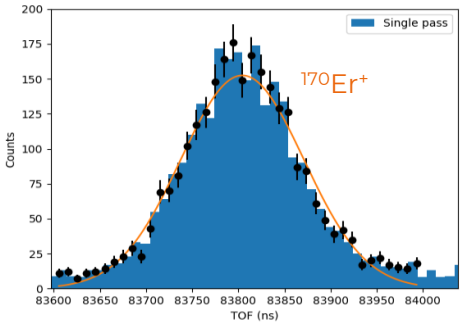
**PILGRIM:** Multi-reflection time-of-flight mass spectrometer designed in collaboration with Uni. Greifswald

- Mass separation and measurements tested with bunches from the S³LEB cooler-buncher
- Resolving power > 100 000

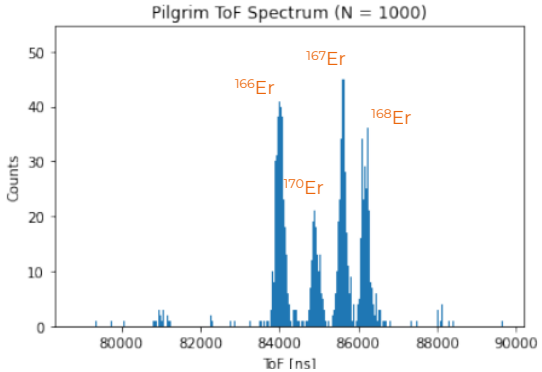
MagneTOF mini




$^{170}$Er at 1000 laps

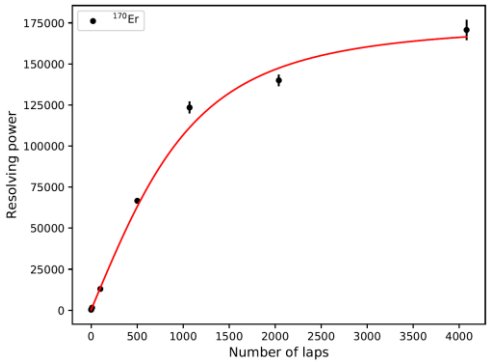



$\Delta TOF_{FWHM}$ = 160 ns



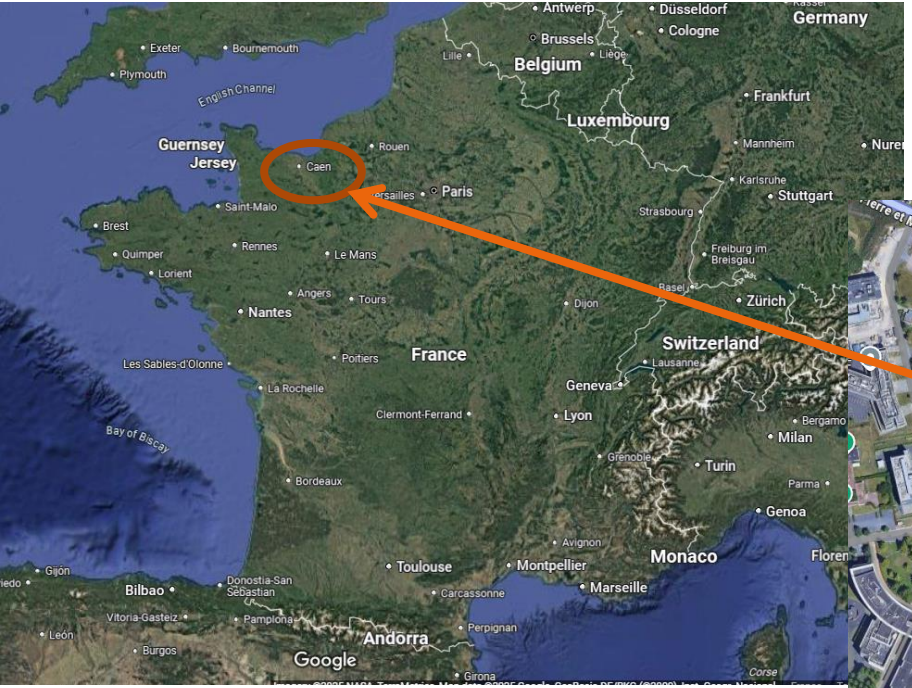

TOF – acquisition offset (ns)

R as a function of $N_{laps}$



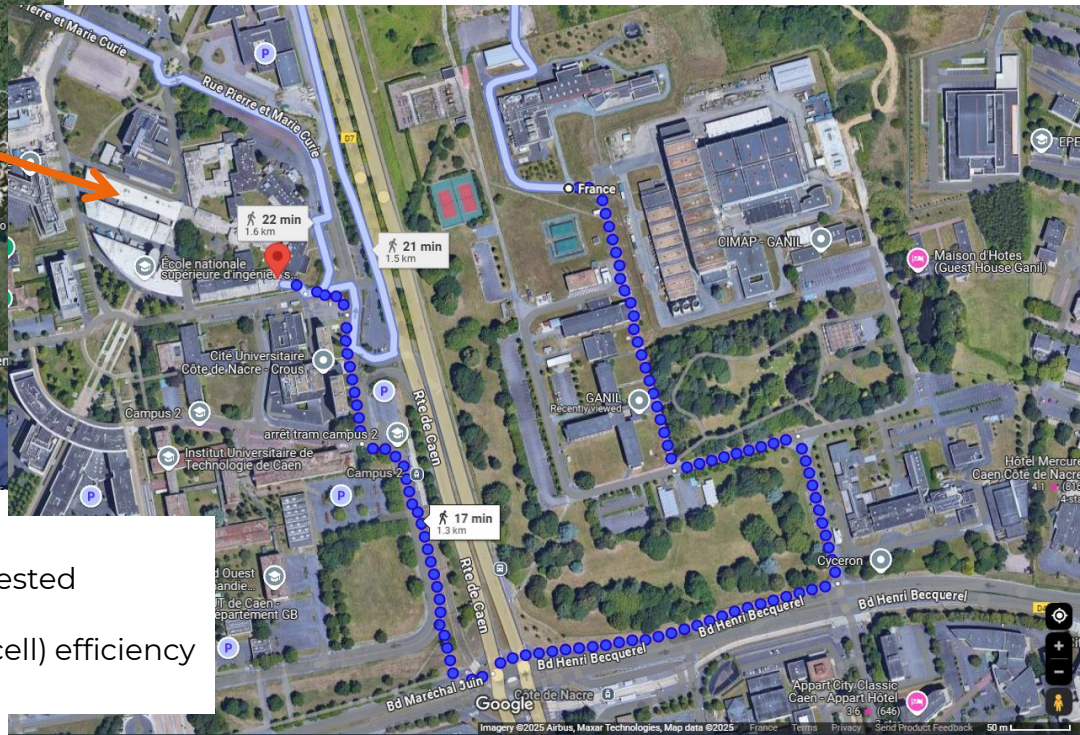

*Courtesy P. Delahaye*
*PhD thesis P. Chauveau, GANIL*
*PhD thesis B.-M. Retailleau, GANIL*
*Master thesis Y. Balasmeh, LPC*

# S³LEB at GANIL




**Offline commissioning of S3-LEB was done at LPC Caen**

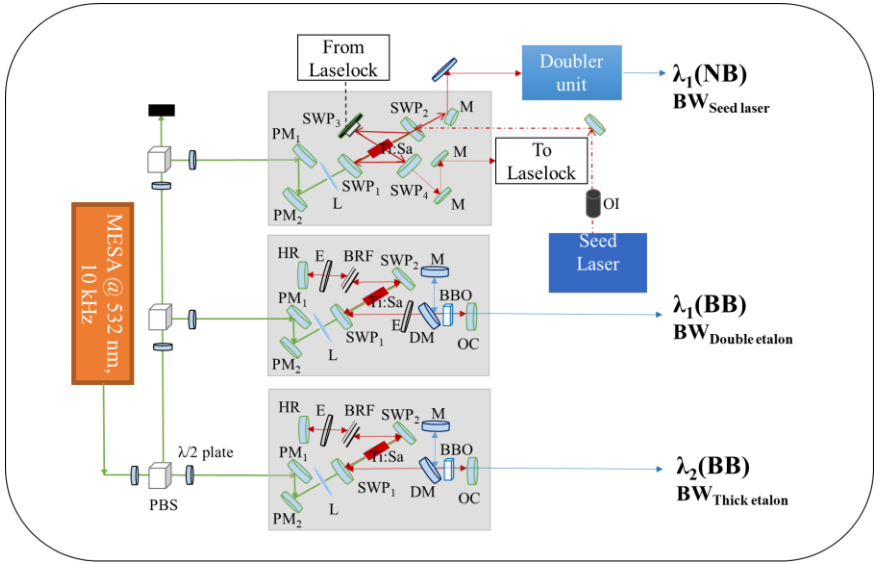
- After 10 years of construction and commissioning at LPC, S³LEB moved to GANIL in March

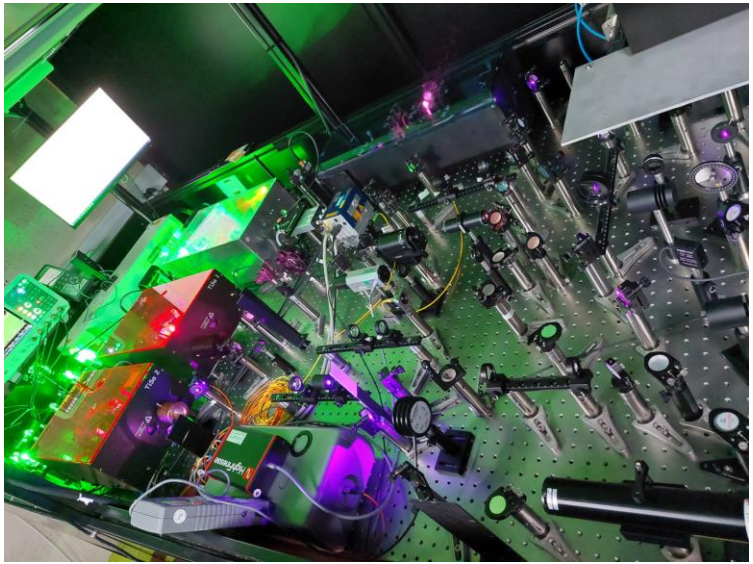



**Installation at S³:**

- Vacuum and related equipment reconnected and tested
- HV and RF cabling and final alignments ongoing
- Recommissioning to start soon, with e.g. total (gas cell) efficiency tests using a Ra recoil source foreseen

# Resonant laser ionization spectroscopy



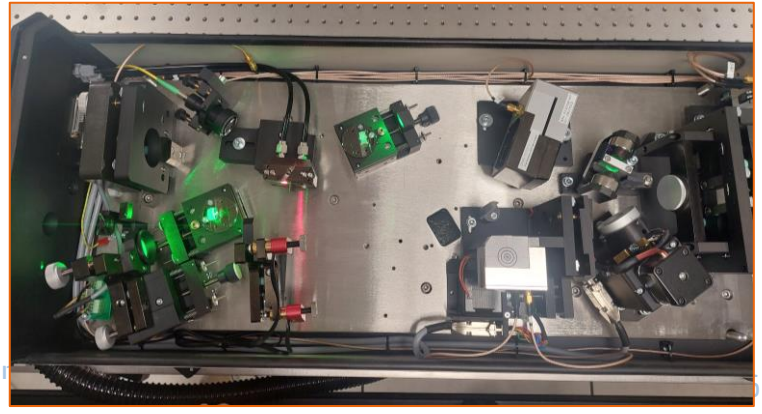



**Requirements :**

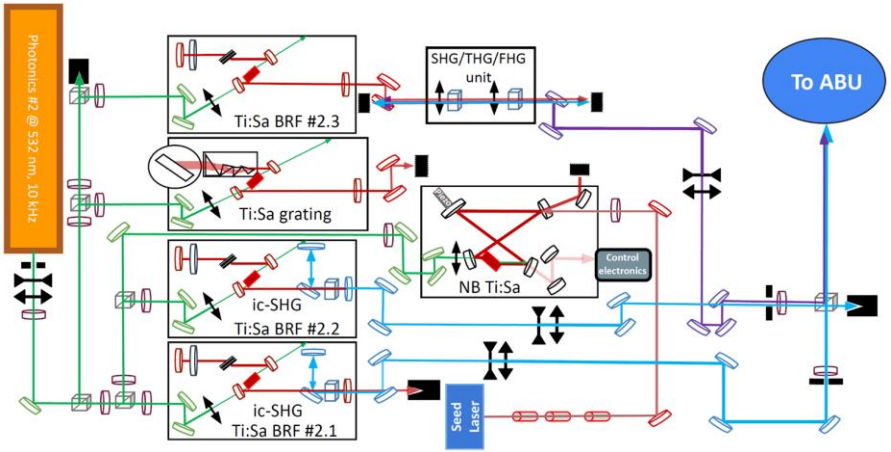
- Pulsed high repetition laser sources
- Laser line width to match the atomic transition line width
- Ti:sa / dye laser used complementarily
- Ti:sa lasers were commissioned and set up for in-gas laser spectroscopy.

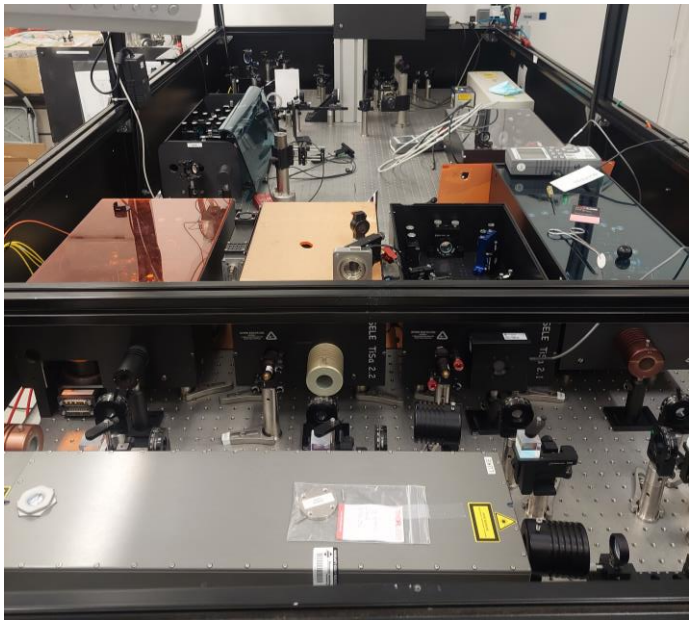
# S³LEB laser room: Altisa

- New laser lab taking shape:
  - 3 pump lasers installed (1 old, 1 new dual-head)
  - 1 new cw Ti:sapphire laser installed
  - Installation of pulsed Ti:sapphire cavities starting soon



# GISELE laser lab



- Complete overhaul of lase table to accommodate a Millenia laser (on loan from IJClab) and optimize layout
- Ongoing developments and tests:
  - Finish construction and characterization of the cw cavity
  - Test intra-cavity tripling, temperature-controlled ic doubling,...
- Dy/Ho/Gd... scheme testing/development started for 'Day 0' experiment