GISELE

10-64

Laserspectroscopy of heavy elements and target development

IN2P3 Spokesperson: Nathalie Lecesne

GSI Spokesperson: Sebastian Raeder

GANIL: H. Savajols, J. Piot, *A. Ajayakumar (PhD), A. Ortiz-Cortes (PhD), A. Brizard (PhD)*

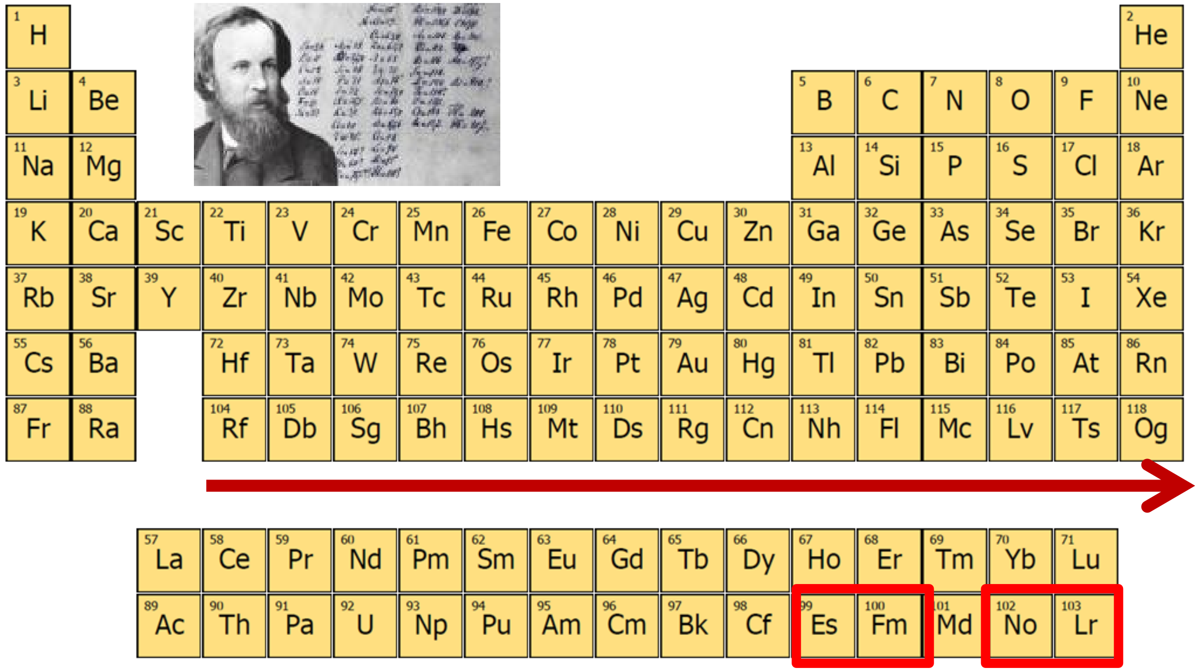
IJCLab: V. Manéa

GSI: M. Block (Prof), J. Lantis, *J. Warbinek (PhD), K. van Beek (PhD),* D. Studer, B. Lommel, B. Kindler

JGU: K. Wendt (Prof), C.E. Düllmann(Prof), *M. Kaja (PhD),* S. Nothhelfer, *M. Stemmler (PhD), D. Münzberg (PhD) , L. Reed (PhD), E. Artes (PhD),* C. Mokry, J. Runke, A. Tzeitel Loria Basto

Properties of the Heaviest Elements

- Understanding of atomic structure & chemical behaviour → Laser spectroscopy
- Nuclear structure: what is their shape and size ?
- How are they produced best in the lab → Target production

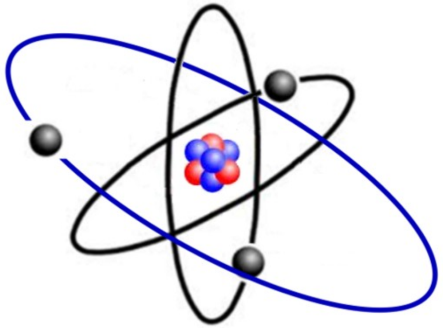


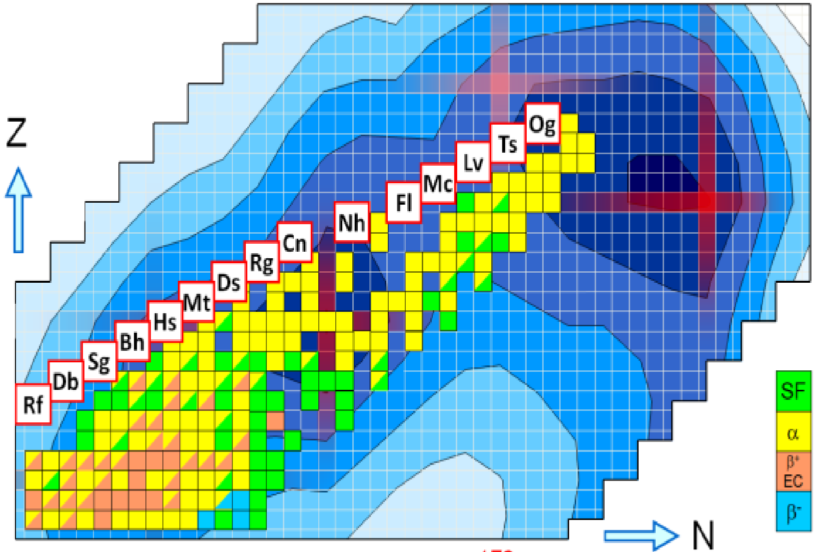
Electron shell

atomic structure

chemical properties

→ defines the element





Courtesy Ch. E. Düllmann

Nucleus

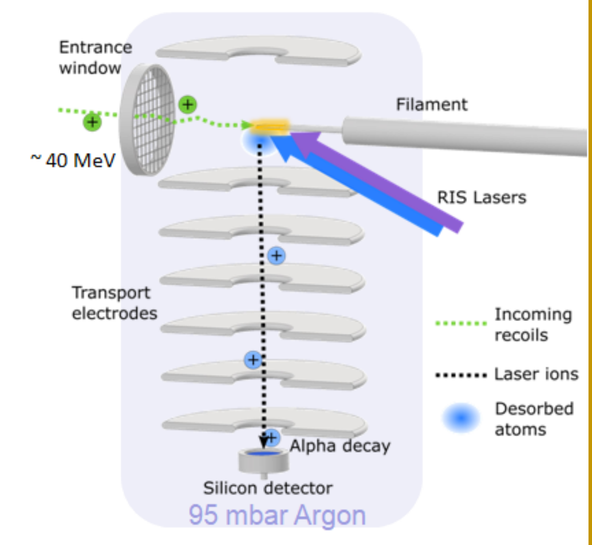
nuclear structure

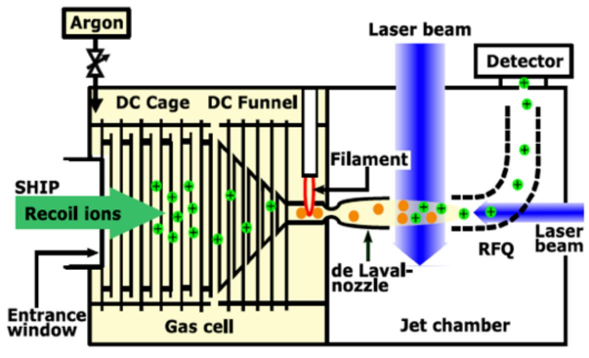
stability of elements

GANIL spiral2 laboratoire commun CEA/DSM CNRS/IN2P3 HIM HELMHOLTZ Helmholtz-Institut Mainz GSI RESEARCH FOR GRAND CHALLENGES JG|U JOHANNES GUTENBERG UNIVERSITÄT MAINZ

Laser spectroscopy of heavy elements

Common interest and synergies in-gas-cell and in-gas-jet developments
and high resolution laser spectroscopy of heavy elements





RADRIS

(Radiation Detected Resonant Ionization Spectroscopy)

H. Backe et al., Eur. Phys. J. D 45, 99 (2007).
F. Lautenschläger et al., NIMB 383, 115 (2016).
M. Laatiaoui et al., Nature 538, 495–498 (2016).
J. Warbinek et al., Atoms 10, 41 (2022).

TETRIS

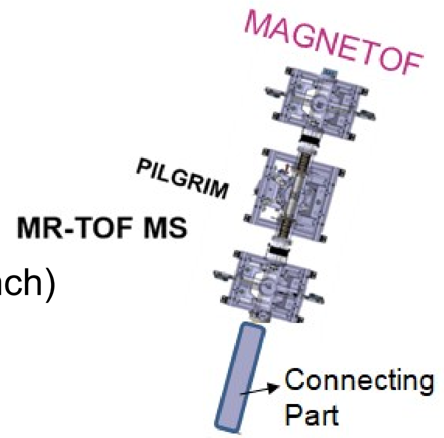
S. Raeder et al., NIMB , 376:382-387 (2016)

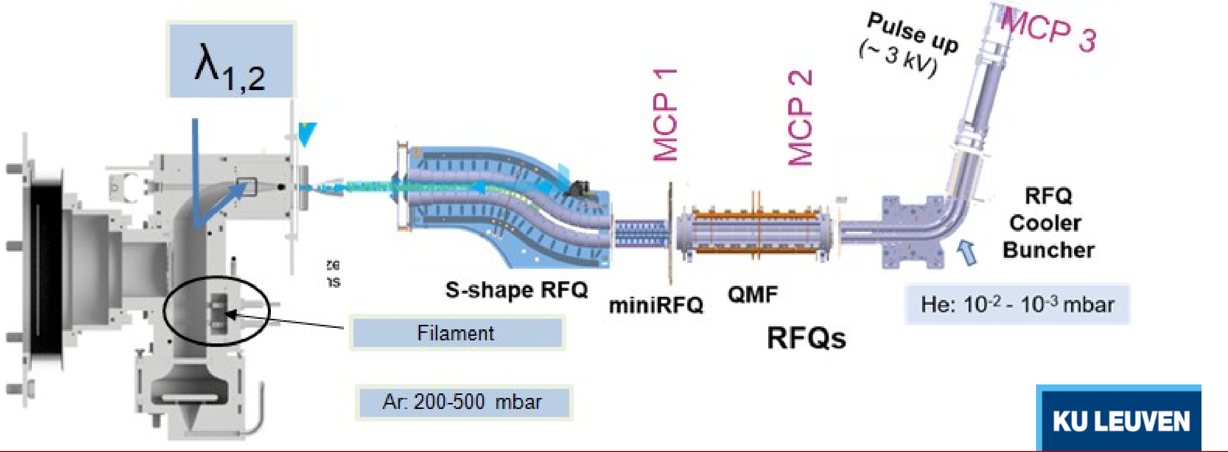
KU LEUVEN

S^{3}LEB

(Super Separator Spectrometer Low Energy Branch)

R. Ferrer et al.,
Nature Communication 8, 14520 (2017)





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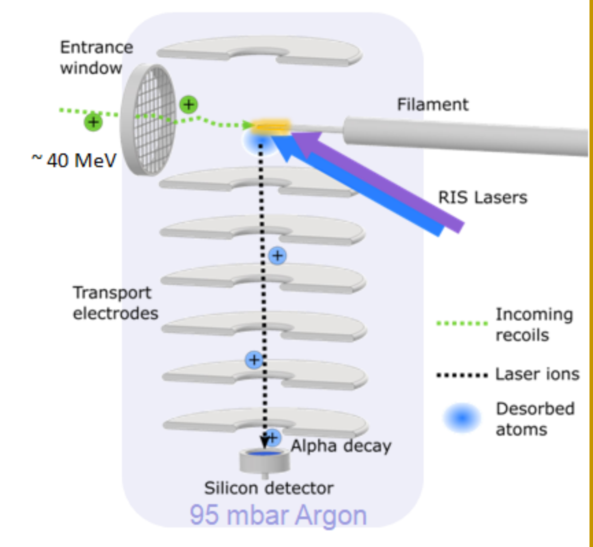
GSI - Beamtime 2022 - RADRIS



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H. Backe et al., Eur. Phys. J. D 45, 99 (2007).
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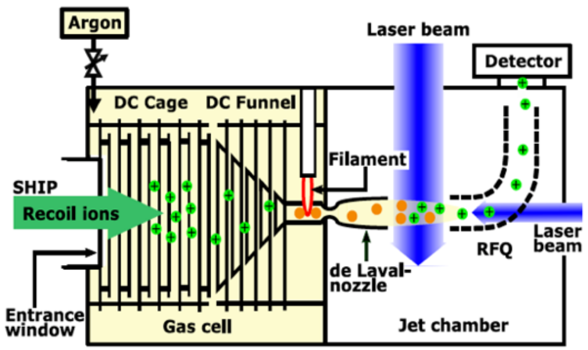


S. Raeder et al., NIMB , 376:382-387 (2016)

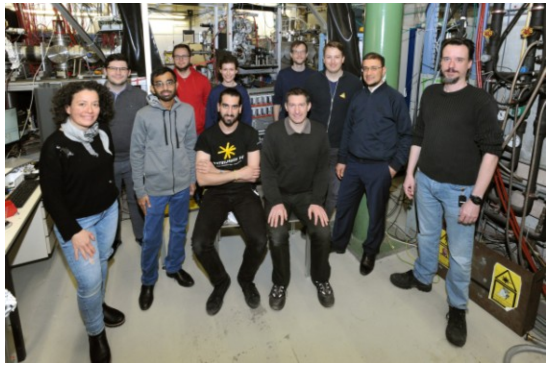
KU LEUVEN

RADRIS

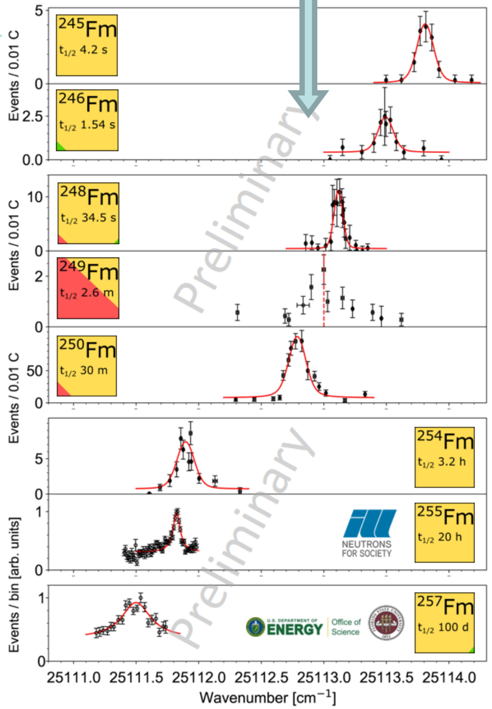
Laser spectroscopy on Fm isotopes

Level search in Lr (Z=103)

Laser spectroscopy in ^{251}No

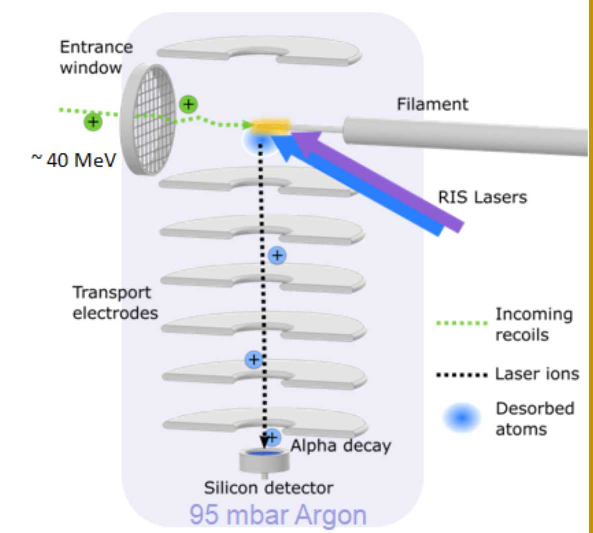


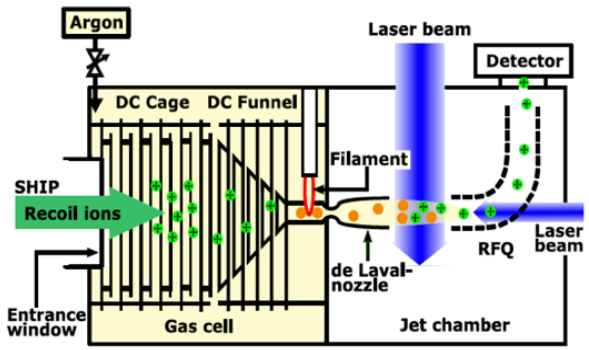
PhD: J. Warbinek



J. Warbinek et al., Results presented at INPC 2022 conference, Cape Towm , South Afrika

GSI - Beamtime 2022 - JetRIS





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F. Lautenschläger et al., NIMB 383, 115 (2016).
M. Laatiaoui et al., Nature 538, 495–498 (2016).
S. Raeder et al., Phy. Rev. Lett, 120, 232503 (2018).
J. Warbinek et al., Atoms 10, 41 (2022).

S. Raeder et al., NIMB , 376:382-387 (2016)
D. Münzberg et al *Atoms* 10.2 (2022): 57.

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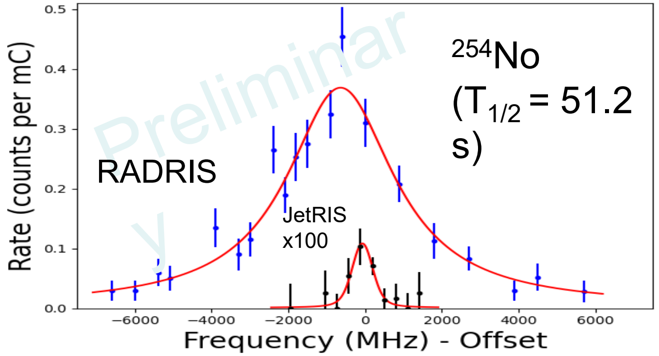
Online commissioning with ^{254}No first narrow band spectrum



PhD: D. Münzberg
PhD: M. Stemmler
PhD: A. Brizard

Alexandre Brizard (GANIL) @ GSI in February 2023

Joined GSI and GANIL

PhD position in nuclear instrumentation

SHELA (Super Heavy Element LAser spectroscopy at GSI and GANIL)

GSI Helmholtz Centre for Heavy Ion Research in Germany, Darmstadt, and GANIL Grand Accélérateur National d'Ions Lourds in France, Caen, have a common interest in developing laser spectroscopic instrumentation to measure nuclear hyperfine interactions of actinide and trans-actinide isotopes.
Laser spectroscopy is a powerful and precise tool to measure atomic levels and their hyperfine structure, revealing atomic and chemical properties, in addition to information on the shape and the size of the atomic nuclei.
Elements above the actinide element fermium (100 protons), known as super-heavy elements, lack such information and therefore their atomic structure information relies on atomic theory calculations. Here, experimental investigations are needed to validate modern atomic theory

M. Stemmler et al., Results presented at EMIS 2022 conference, Daejeon, Korea

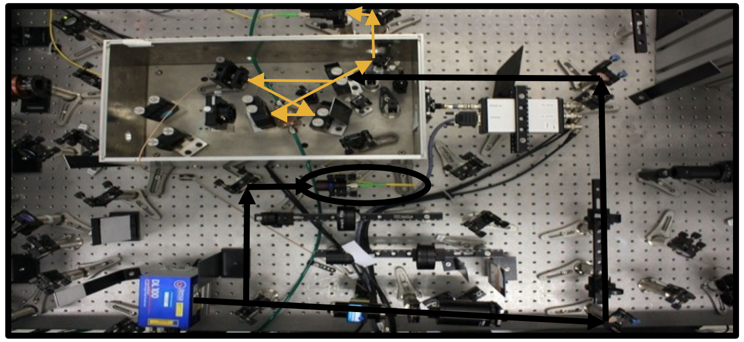
HIM HELMHOLTZ Helmholtz-Institut Mainz
GSI RESEARCH FOR GRAND CHALLENGES
JOHANNES GUTENBERG UNIVERSITÄT MAINZ

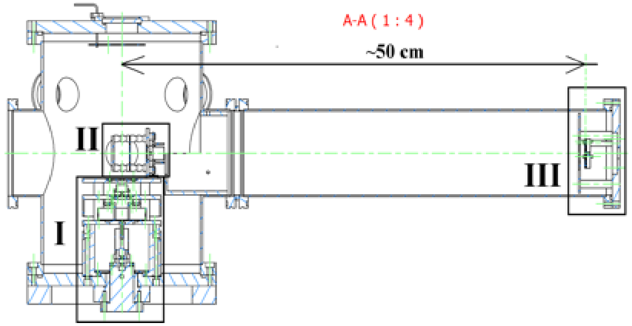
GANIL - GISELE TiSa Laser system

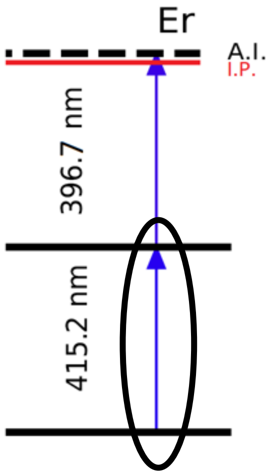
- Broadband tunable TiSa laser system
- New Narrow-bandwidth / Single-mode TiSa laser system (**$\Delta\lambda$ < 50 MHz**)

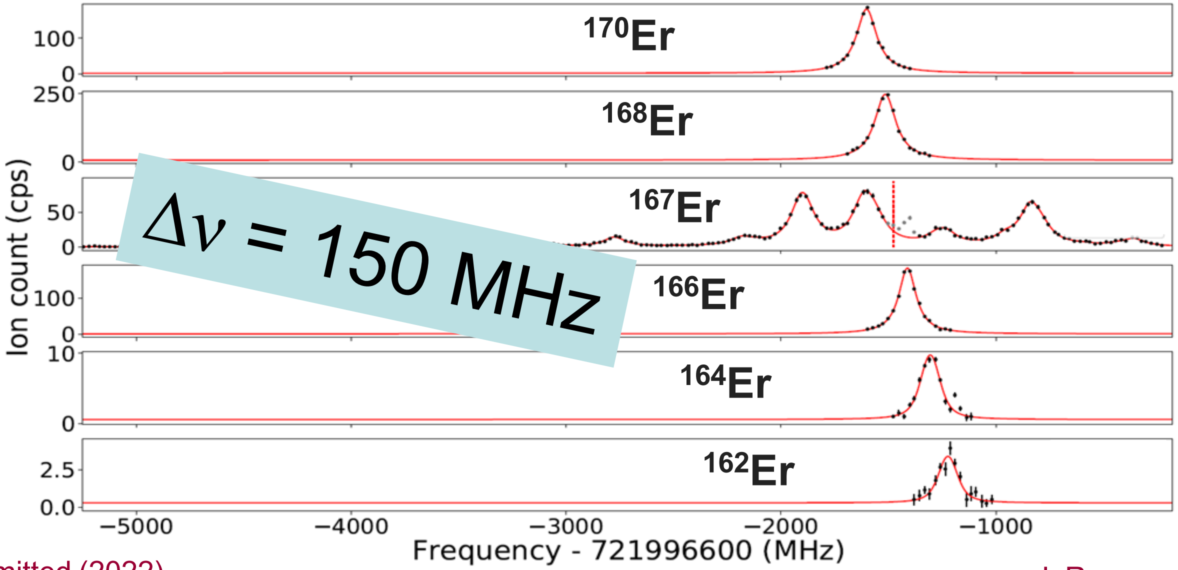
KU LEUVEN

PhD: J. Romans

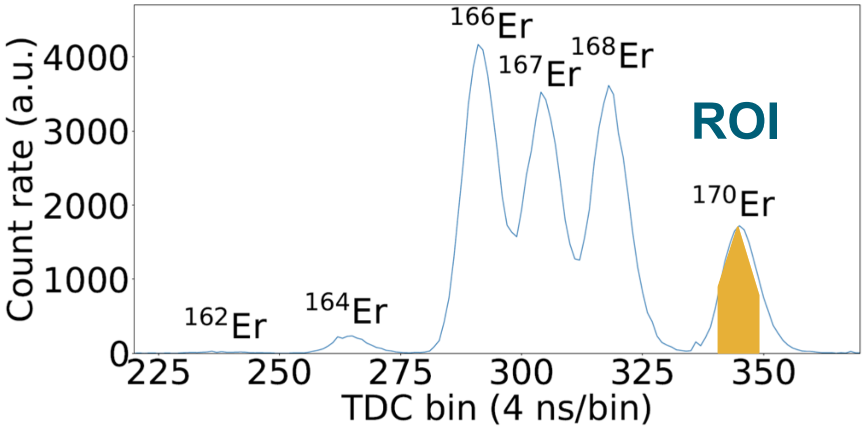








ABU with ToF separation



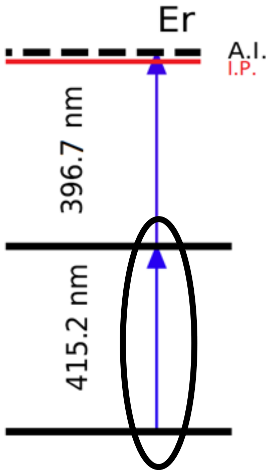
J. Romans et al. NIMB, submitted (2022)

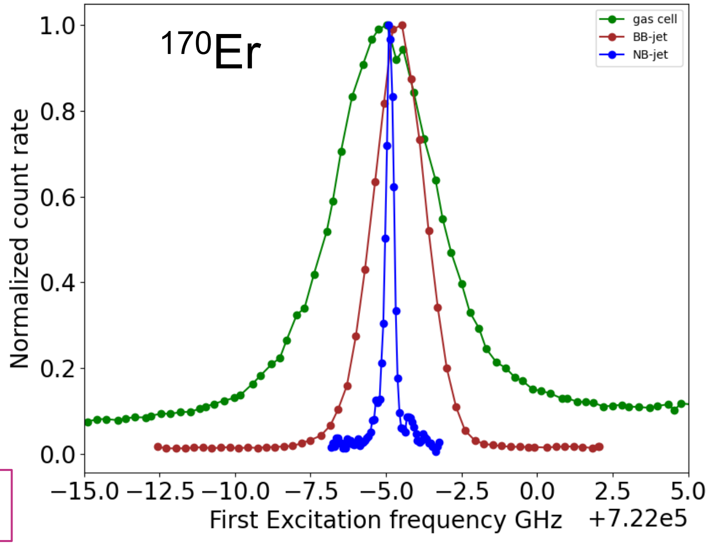
J. Romans et al., Results presented at EMIS 2022 conference, Daejeon, Korea

GANIL spiral2 HIM HELMHOLTZ Helmholtz-Institut Mainz GSI RESEARCH FOR GRAND CHALLENGES JOHANNES GUTENBERG UNIVERSITÄT MAINZ

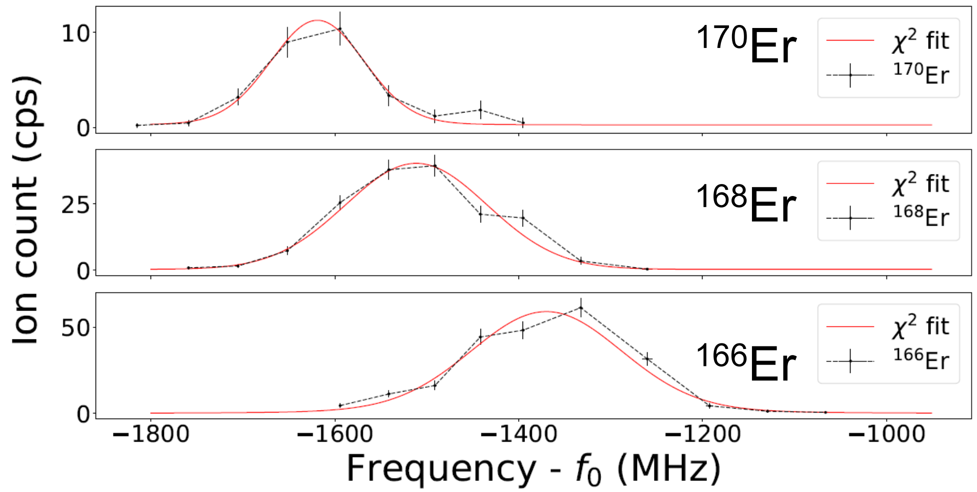
LPC - S^3LEB commissioning

- Narrow bandwidth seeded laser cavity installed at S^3LEB
- In-gas jet spectroscopy and first measured Isotope Shifts in Er





PhD: A. Ajayakumar



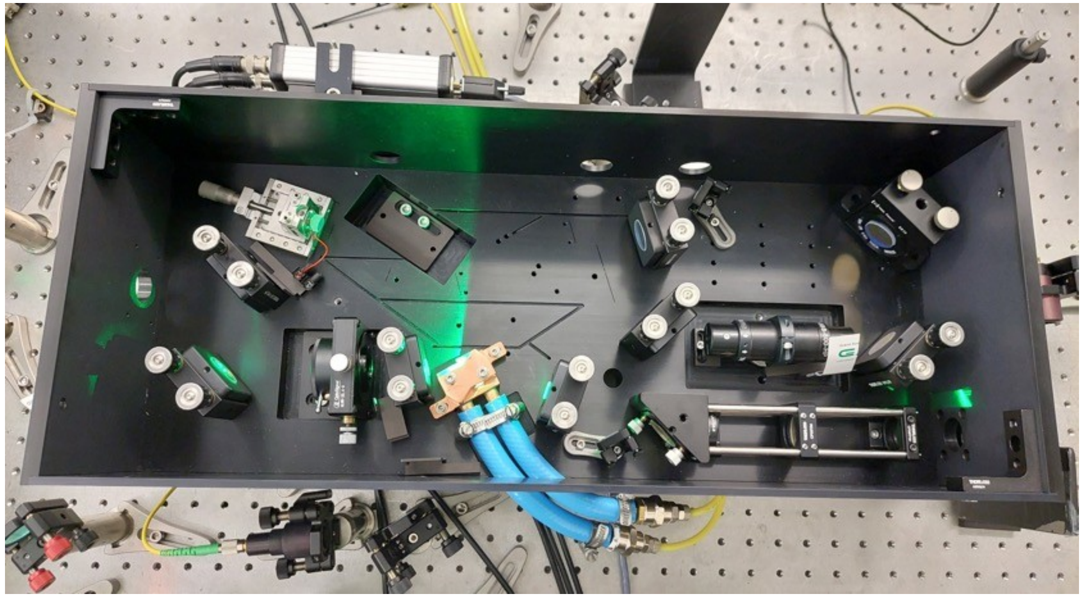
$\Delta f^{170,A^*}$ (MHz) $4f^{12}\,6s^2\ ^3H_6 \rightarrow$ $4f^{12}\,6s\ (^3H_5)\ 6p$	In-Gas jet with BB laser RIS PRELIMINARY	In-Gas jet with NB laser RIS PRELIMINARY	Vacuum (J.Romans et al. article in preparation)
$\Delta f^{170,166}$	181(30)	231(14)	197(5)
$\Delta f^{170,168}$	80(34)	99(7)	97(5)

- Excitation step with Narrow Band Laser < 100 MHz
  - Spectral Linewidth (FWHM): 316(5) MHz
- Ionization step: Broad Band Laser ~ 1.8 GHz
  - Spectral Linewidth (FWHM): 2(1) GHz

A. Ajayakumar et al., Results presented at EMIS 2022 conference, Daejeon, Korea

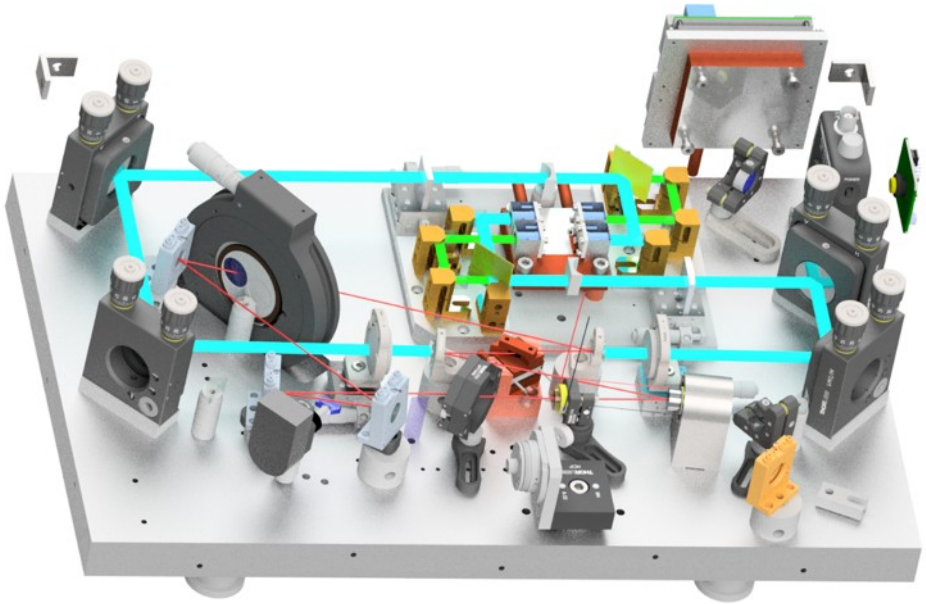
Laser developments @ JGU and GANIL

◎ New injection locked cavity from JGU @ GANIL



PhD: A. Ortiz-Cortes @ GANIL
D. Studer @ JGU

◎ New CW TiSa cavity projects @ JGU and @ GANIL



V. Sonnenschein et al., NIMB 463 (2020) 512–514

PhD: A. Ajayakumar @ GANIL
PhD: M. Stemmler @ JGU

Participation to the LISA school in Normandy

- A. Ajayakumar (GANIL), A. Brizard (GANIL), M. Kaja (JGU), D. Münzberg (JGU), L. Reed (JGU), M. Stemmler (JGU), J. Warbinek (GSI)

This Marie Sklodowska-Curie Action (MSCA) Innovative Training Networks (ITN) receives funding from the European Union's H2020 Framework Programme under grant agreement no. 861198

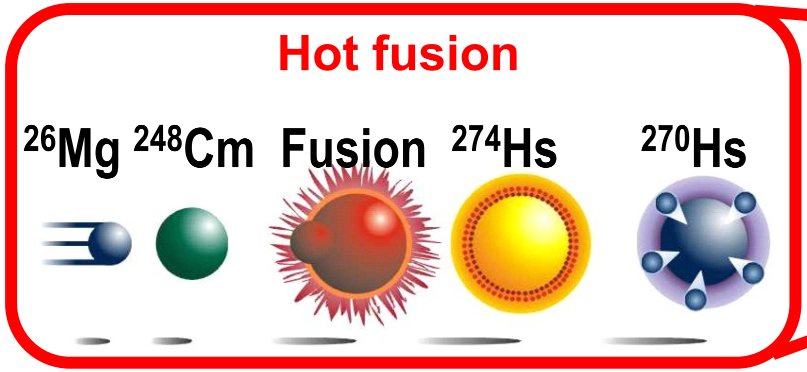
Production of the Heaviest Elements

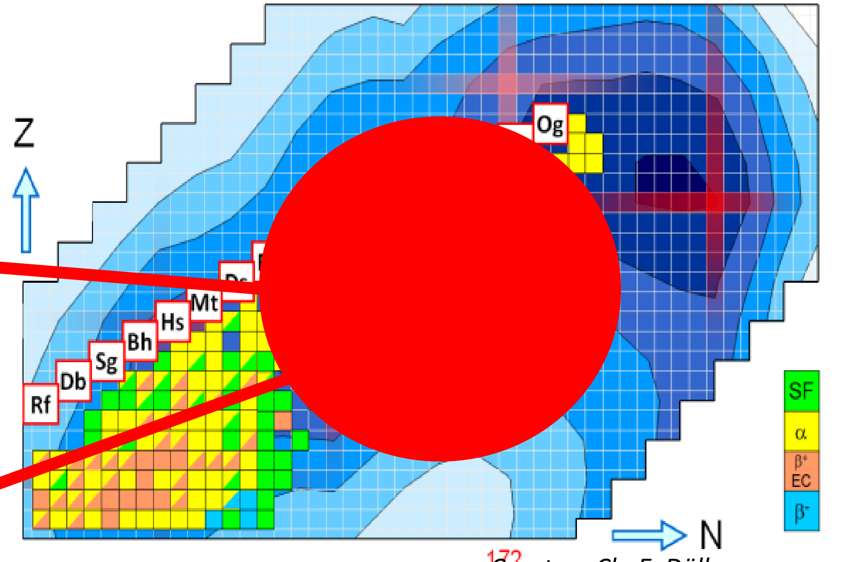
- Understanding of atomic structure & chemical behaviour
- Nuclear structure: what is their shape and size ?
- How are they produced best in the lab

→ Laser spectroscopy

→ Target production

Hot fusion for SHE requires actinide targets





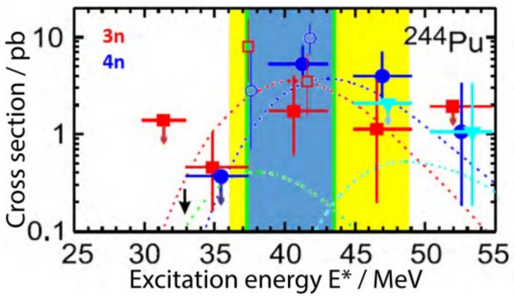
Courtesy Ch. E. Düllmann

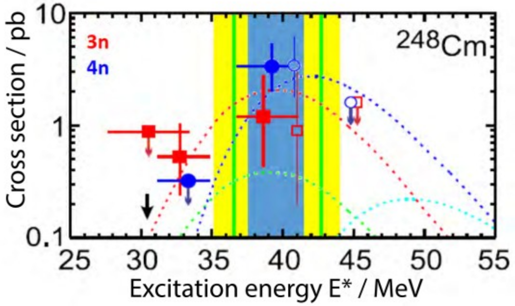
Target development

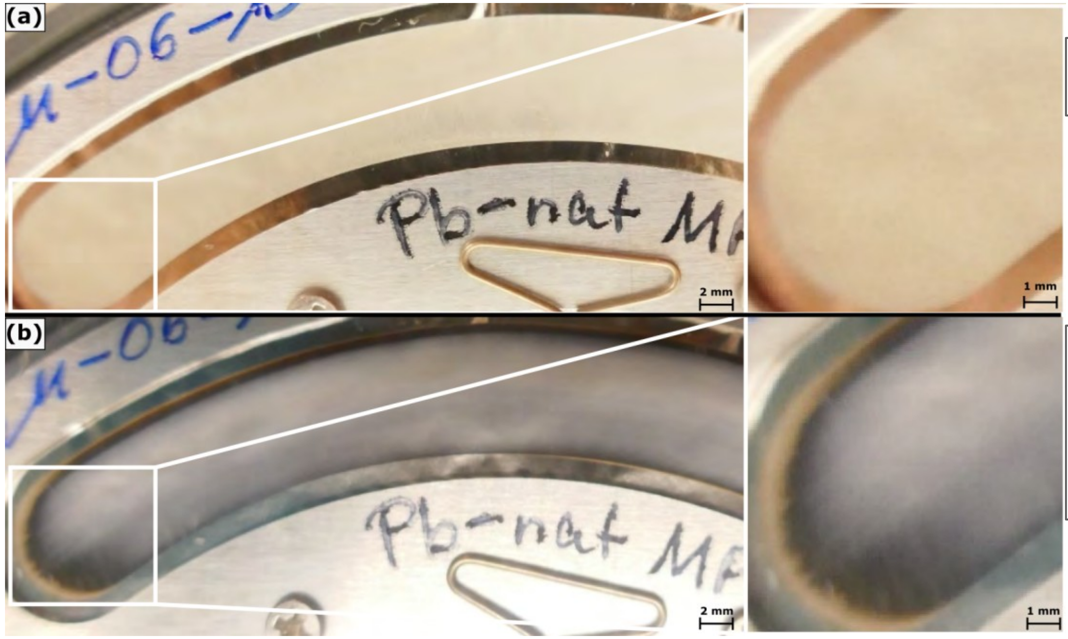
Hot fusion for SHE requires actinide targets

Thicker targets promise a larger yield → limited by production techniques

Behaviour of target at irradtiation is crucial







fresh Pb MP target

after irradiation:
6.5×10^{13} ions/cm^2
with 5.90 MeV/u ^{48}Ca-beam

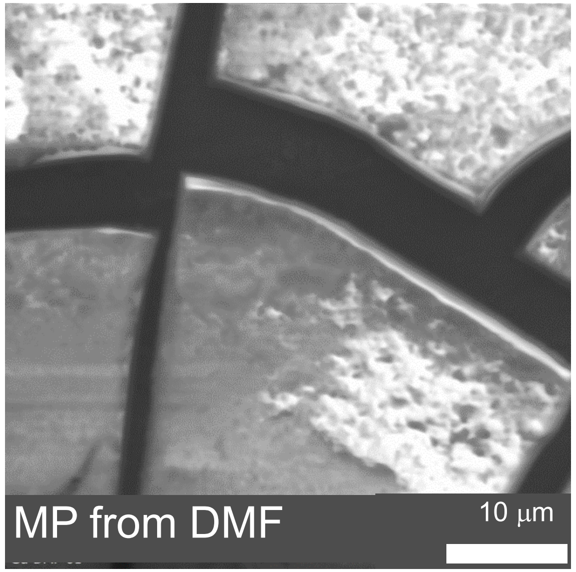
Meyer *et al.*, Nucl. Instrum. Meth. A 1028 (2022) 166365

Oganessian & Utyonkov, Nucl. Phys. A 944 (2015) 62-98
Düllmann *et al.*, Phys. Rev. Lett. 104.25 (2010) 252701
Khuyagbaatar *et al.*, Phys. Rev. Lett. 112.17 (2014) 172501

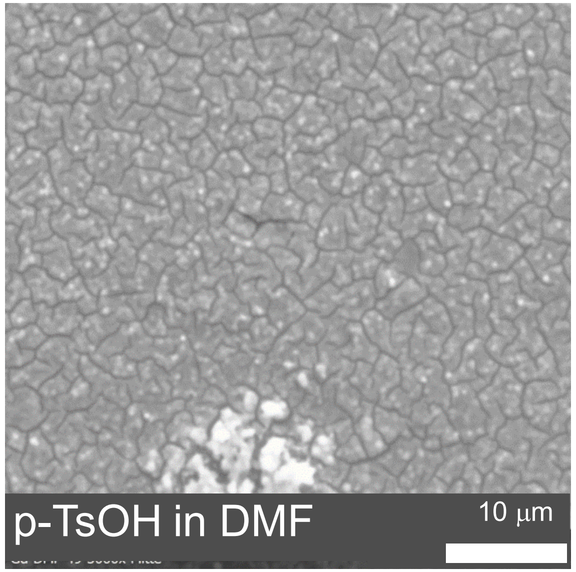
Modern electrochemical approaches for f-elements

1) p-Toluenesulfonic acid (p-TsOH): "Tosylate-method"

$$Gd_2O_{3\,(s)} + 6\ p\text{-TsOH}_{\,(s)} \xrightarrow{DMF} 2\,[Gd(p\text{-TsO})_3]_{\,(solv)} \longrightarrow \text{Plating}$$



Gd-film, 500 μg/cm^2



Gd-film, 2000 μg/cm^2

p-TsOH = 

pK_s = -2.8

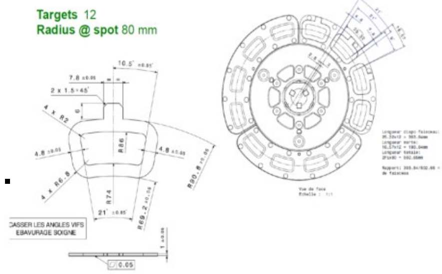
→ no application to actinides reported in literature.

→ in principle: modification to one pot reaction possible!
But: Is *p*-Toluenesulfonic acid strong enough?

P. Liu *et al.*, Electrochim. Acta 45 (2000) 2147
J. Lodermeyer *et al.*, J. Electrochem. Soc 153.4 (2006) C242

Needs to test new target production methods under realistic conditions!

→ Test targets will be mounted on rotating wheel of S3 station installed in the LISE 2000 beamline.



PhD: E. Artes @ JGU
PhD: L. Reed @ JGU

Synergy and knowlegde transfer for target development!

Activities planned for 2023

Laserspectroscopy

JETRIS@GSI/HIM/JGU preparation for beamtime 2024 (60 shifts beamtime granted)

- improving efficiency of the setup and further characterization
- Offline measurements
- Development of MR-ToF for coupling to JETRIS (PhD D. Münzberg, A. Br
- Laser development (PhD M. Stemmler)
- RADRIS preparation (PhD J. Warbinek, K. van Beek)

LEB@LPC/GANIL

- Continuation of off-line commissioning of the S^3-LEB (PhD A. Brizard)
- Laser development (seeded laser, cw-laser) (PhD A. Ajayakumar,)

Well established

Collaborational work

Target development

- JGU/GSI: Development of new techniques for targetproduction
- GANIL: test of targets

Synergy and lively knowlegde transfer in all activies benefit all partners!!