

Status of the Low Energy Branch at SPIRAL2-S³

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GANIL, Caen, France

for the S³-LEB collaboration

- ❑ SPIRAL2, S³ and S³-LEB
- ❑ S³-LEB off-line results
 - Laser developments in the GISELE laboratory
 - In-gas-cell/jet laser spectroscopy
- ❑ Ongoing work and outlook

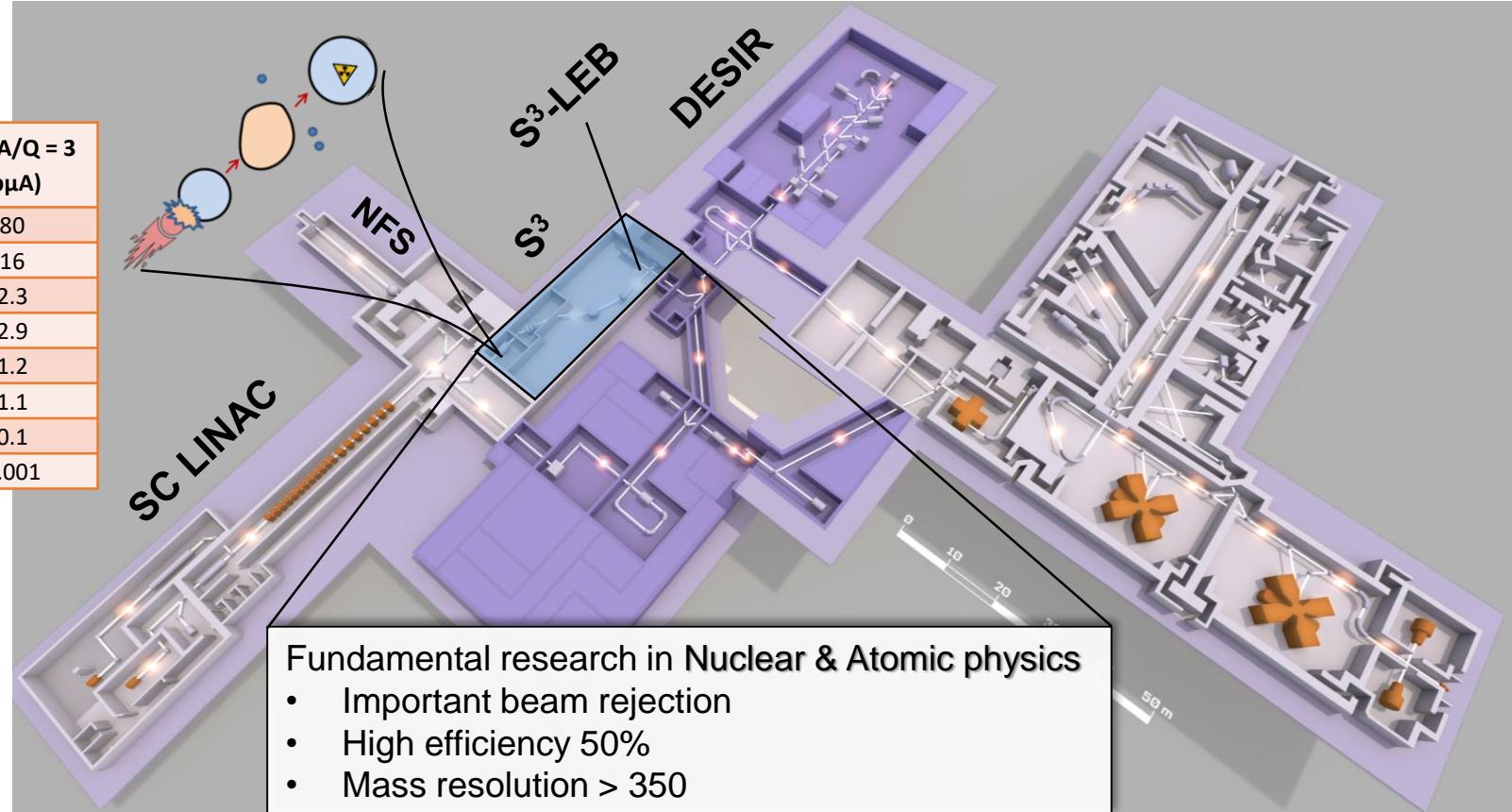
	I for A/Q = 3 (pμA)
^{18}O	80
^{40}Ar	16
^{36}S	2.3
^{40}Ca	2.9
^{48}Ca	1.2
^{58}Ni	1.1
^{86}Kr	0.1
^{136}Xe	0.001



NEWGAIN
NEW GANIL INJECTOR

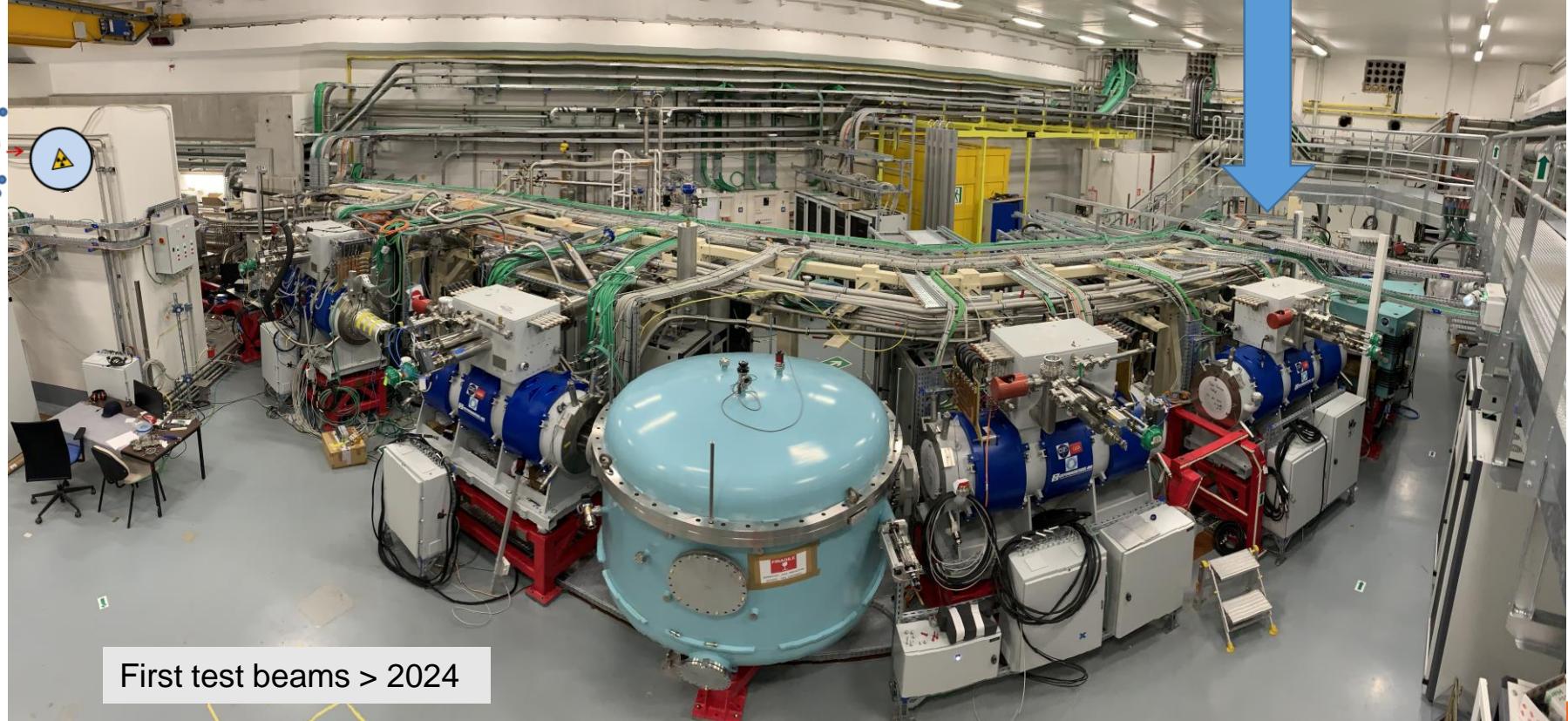
X 5 up to ^{58}Ni

X 10^x for A > 58



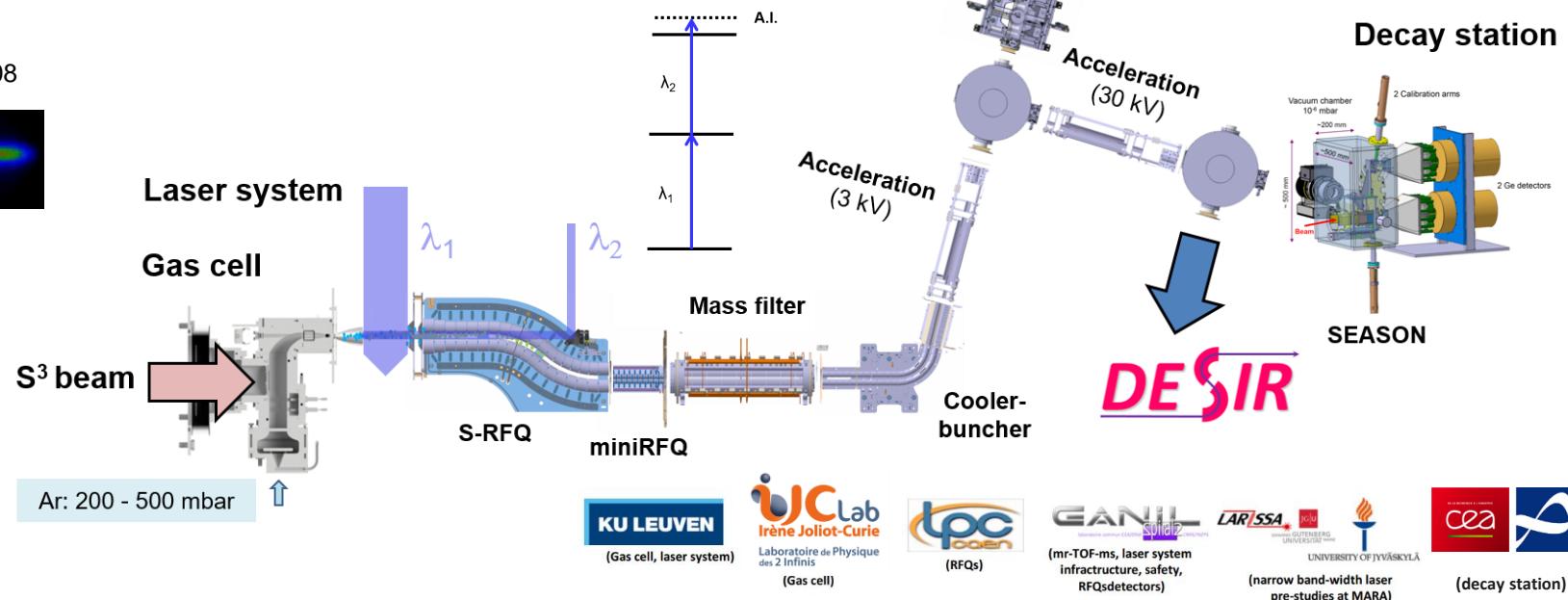
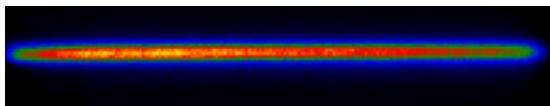
Super Separator Spectrometer (S^3)

Experimental setups and detectors here



- Laser spectroscopy on S³ products in a supersonic jet
- Mass and decay spectroscopy measurements
- Possible transport towards DESIR

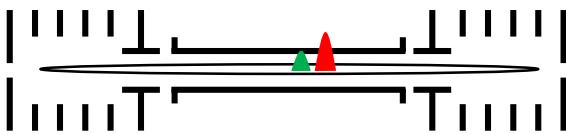
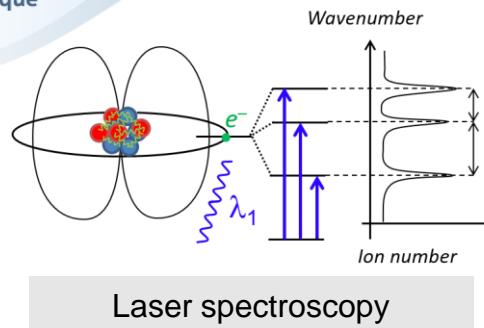
A. Zadvornaya et al., PRX 8 (2018) 041008



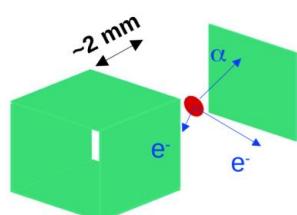
R. Ferrer et al., Nucl. Instr. Meth. B 317, 570-581 (2013)

J. Romans, et al., Atoms 10, 21 (2022)

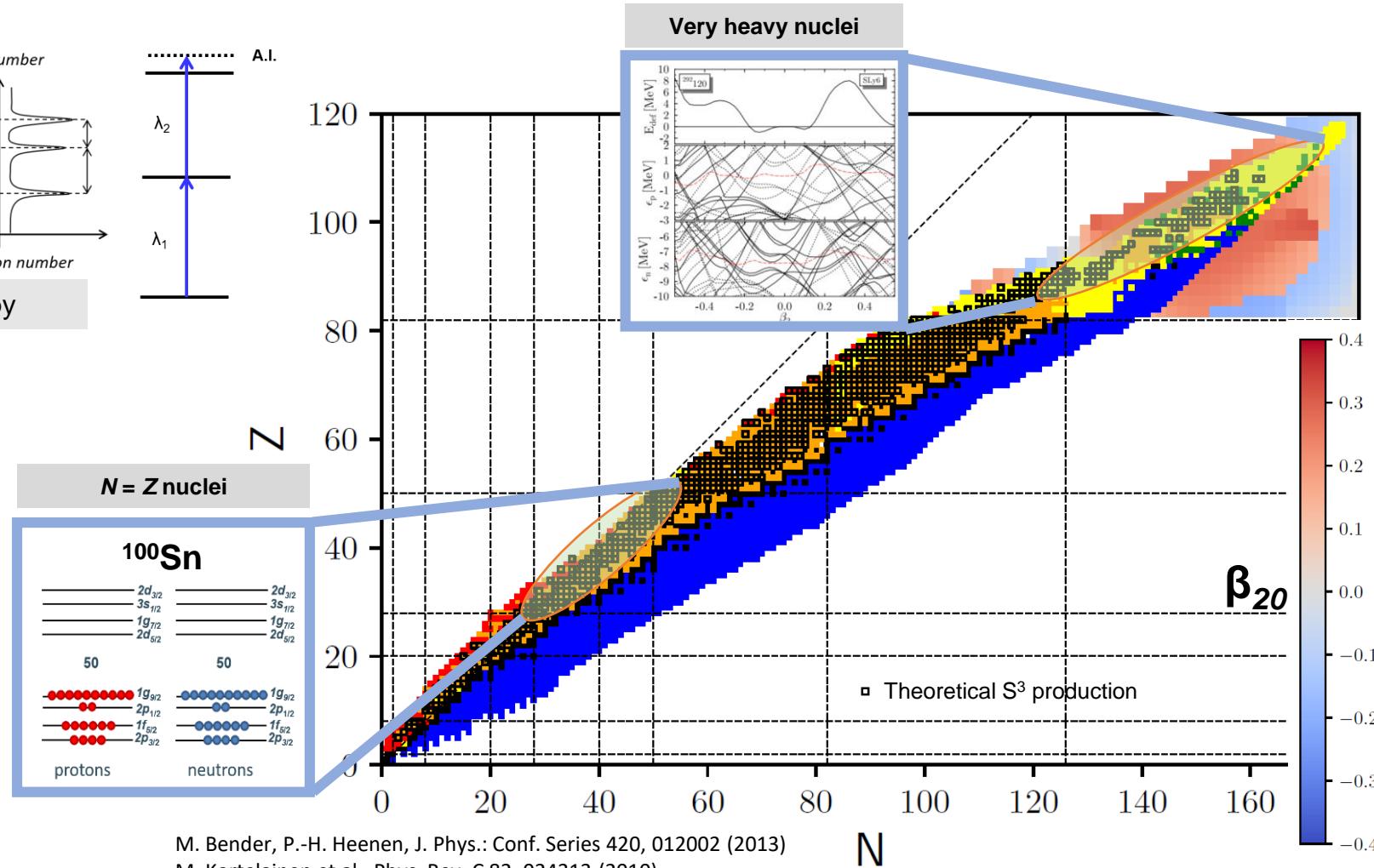
A. Ajayakumar et al., NIMB 539, 102-107 (2023)



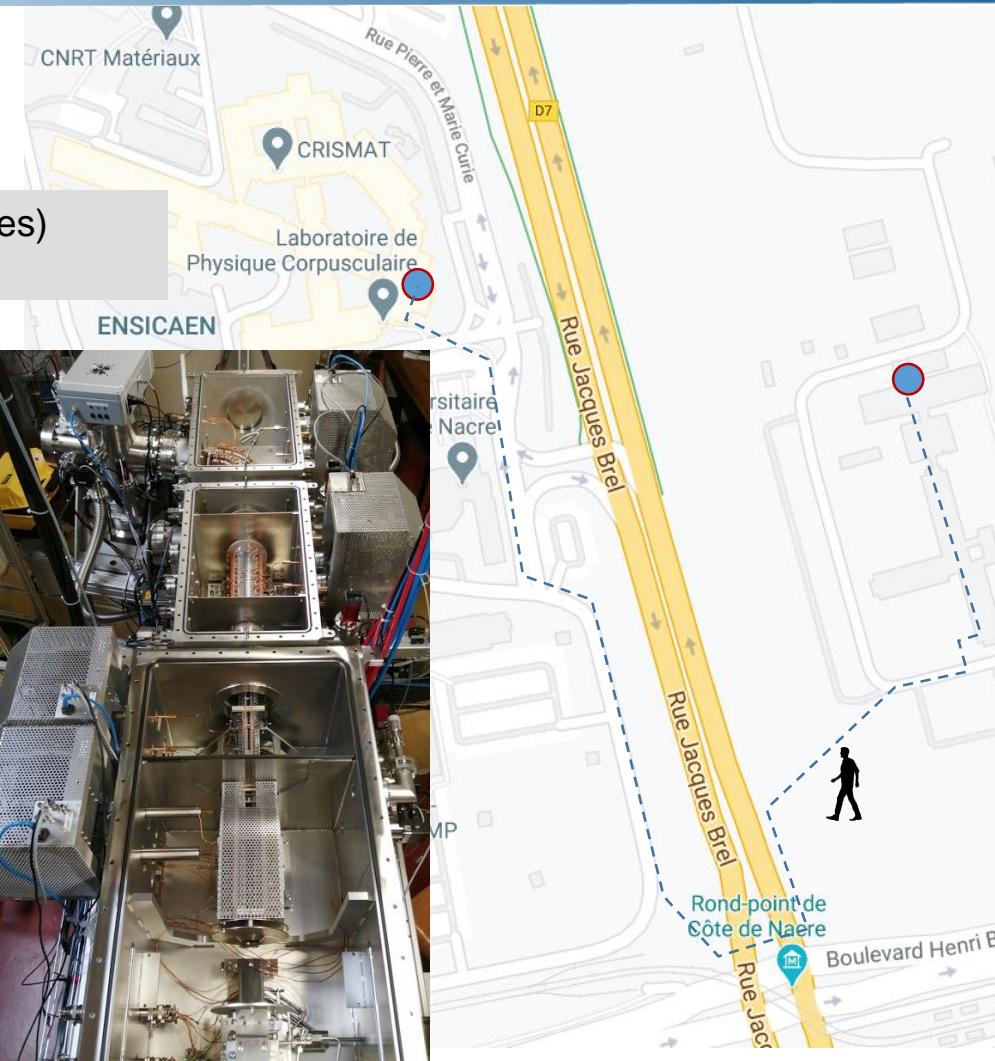
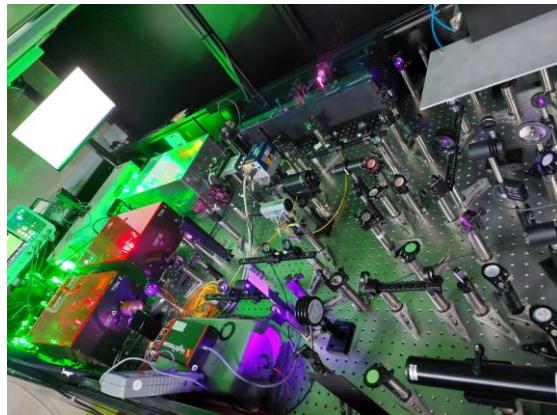
Ion-trap mass spectrometry



Decay spectroscopy



S³-LEB (lasers + beam lines) @ LPC Caen

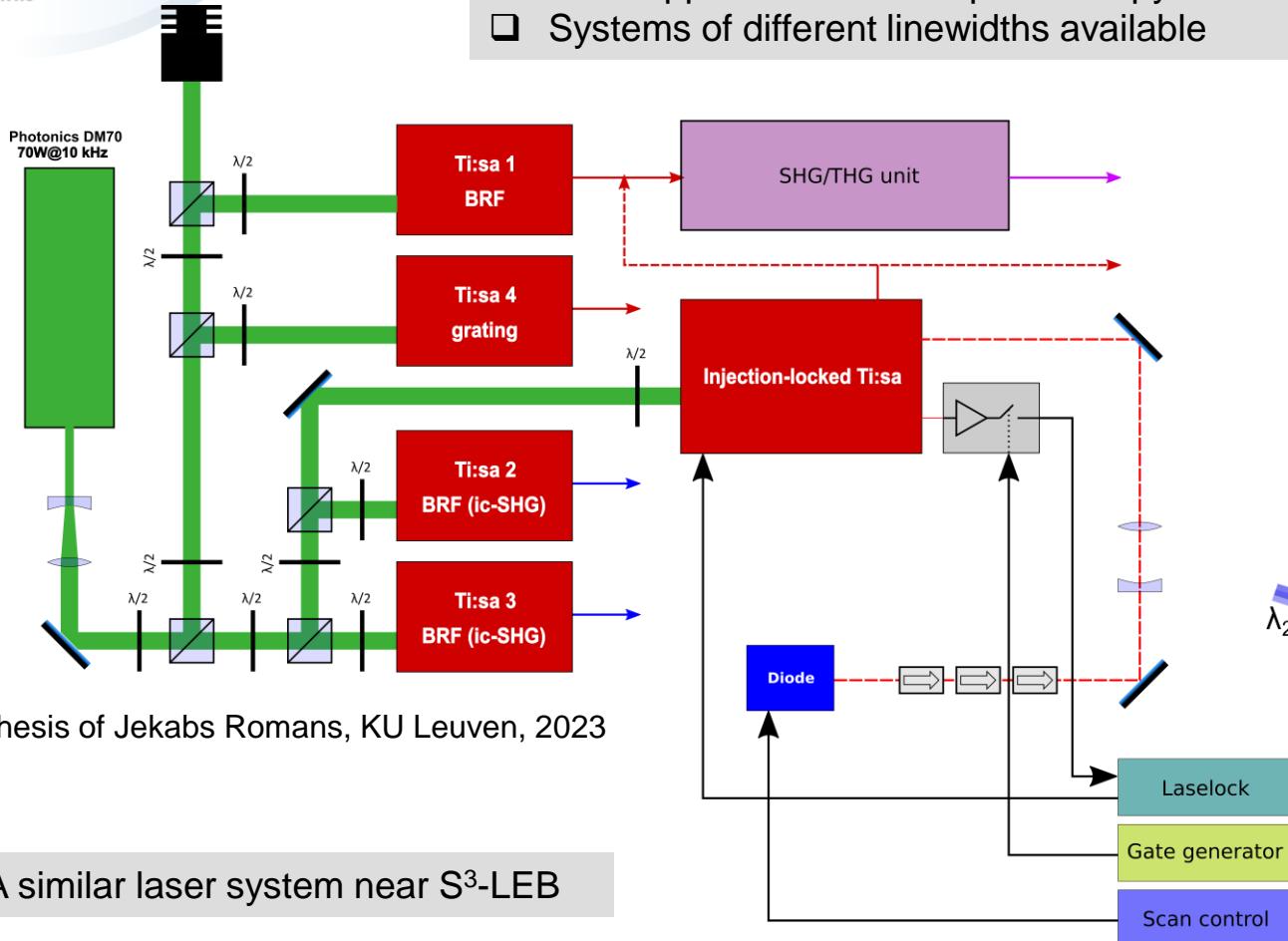


GISELE laser lab @ GANIL

Installation finished 2021

Laser system at GANIL: developments

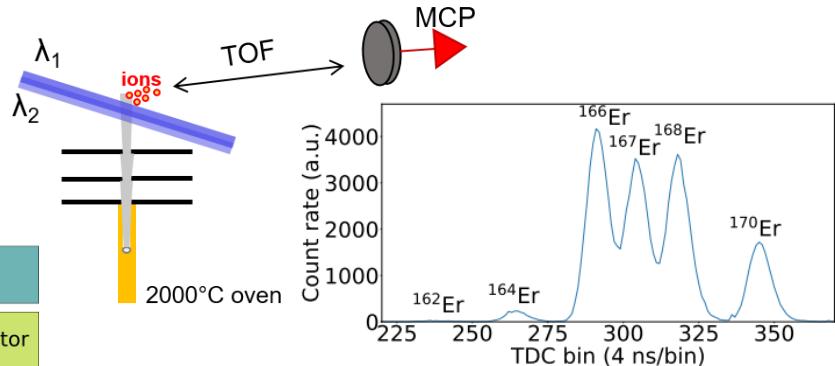
- Developpement of laser spectroscopy methods
- Systems of different linewidths available

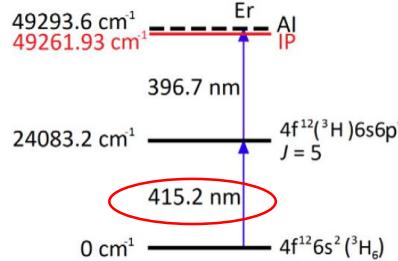


PhD thesis of Jekabs Romans, KU Leuven, 2023

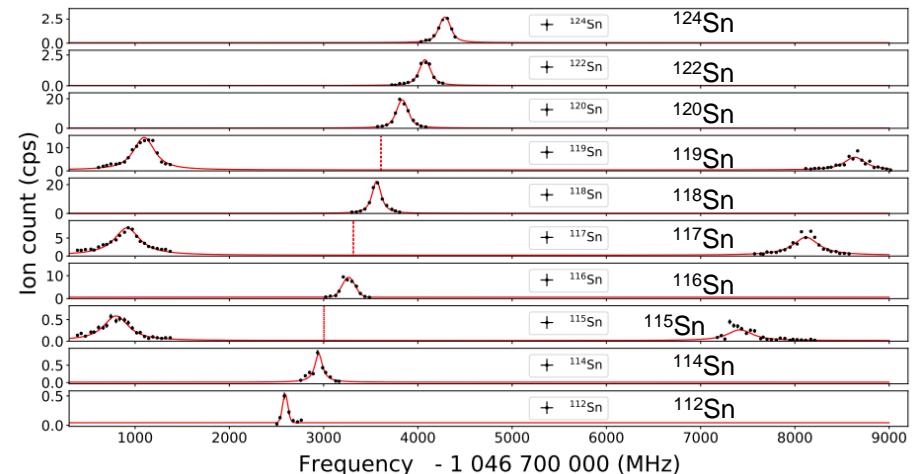
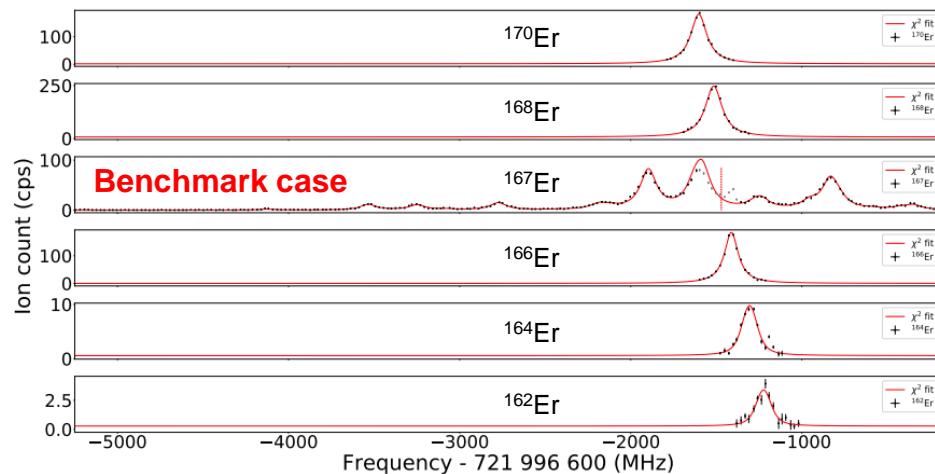
- A similar laser system near S³-LEB

- Atomic beam unit for scheme development





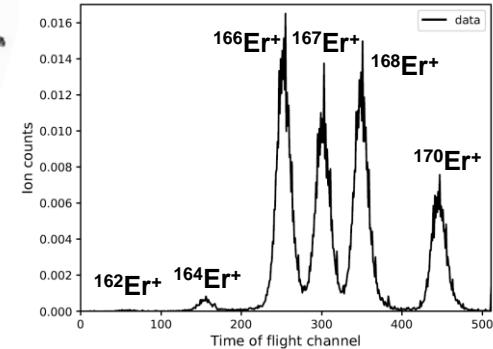
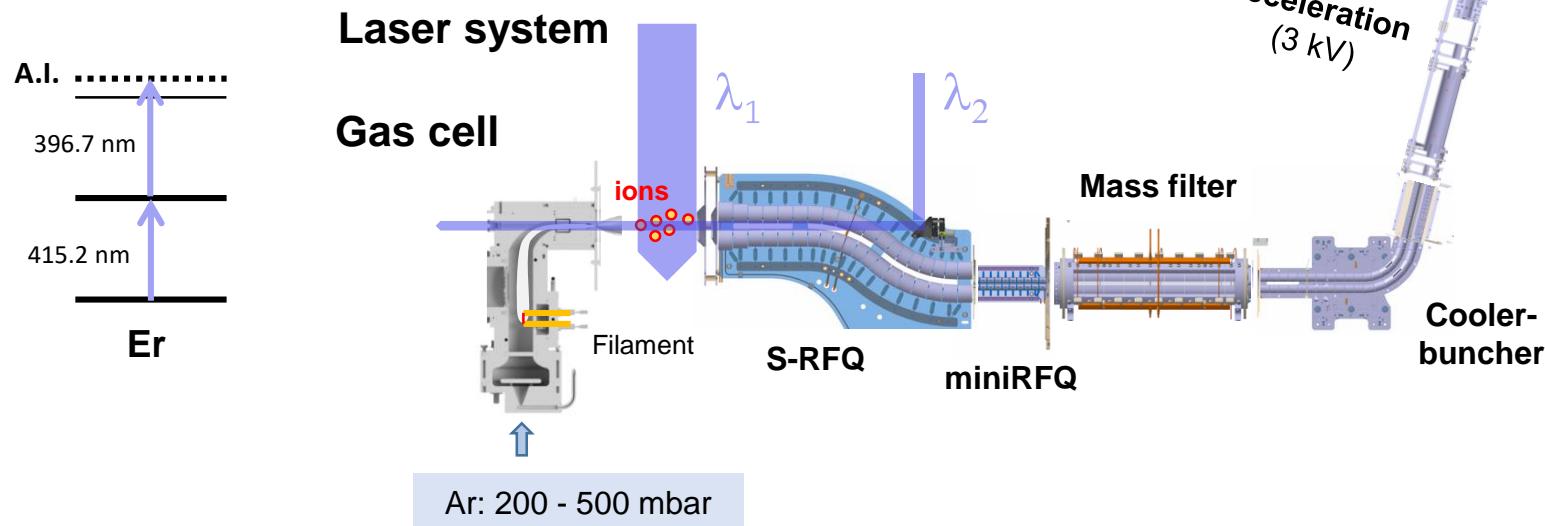
- Narrowband resonance-ionization laser spectroscopy of Er (415.2 nm) and Sn (286.4 nm and 811.6 nm).
- Good agreement to literature for known values of IS and HFS coefficients.



Er will be first case study at S³

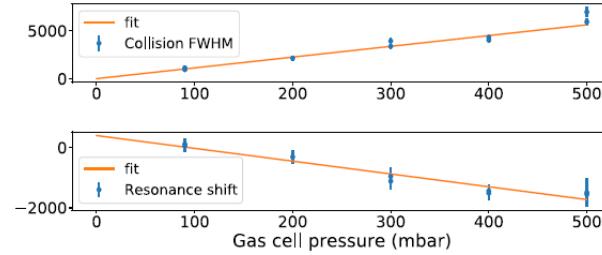
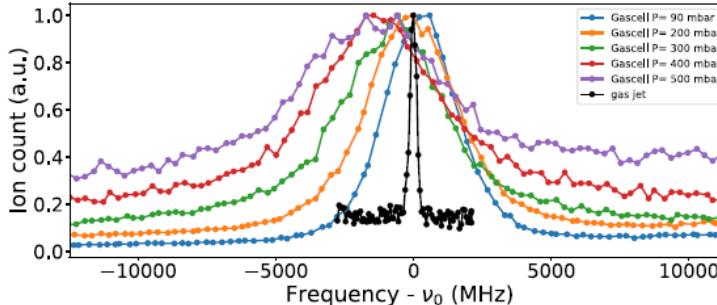
→ Ionization of Er in the gas cell/jet (BB/NB)

→ Measurements with the MR-TOF MS of the Er isotopes

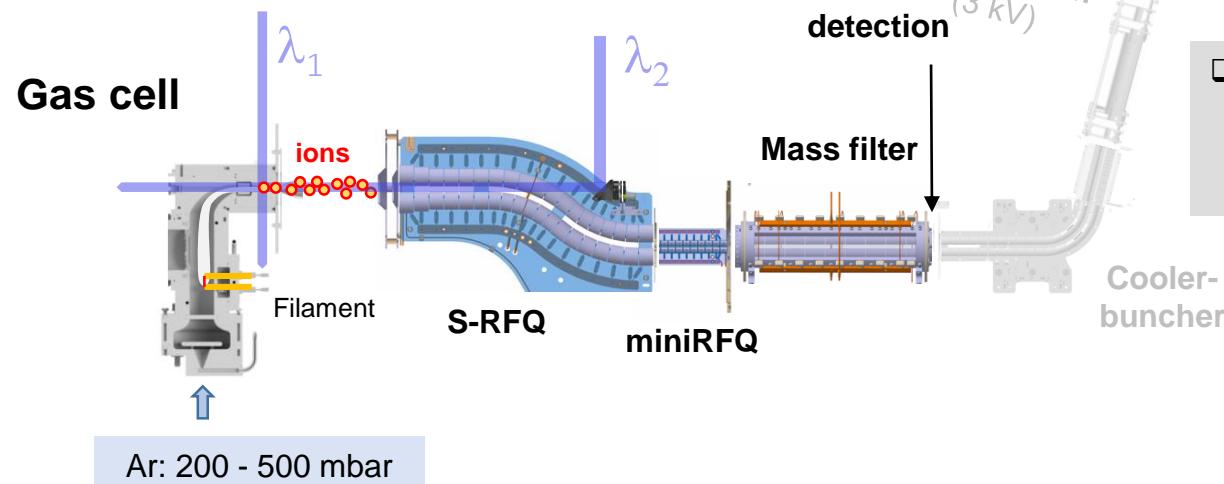
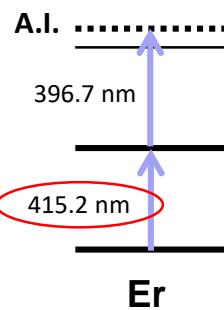


PhD thesis of A. Ajayakumar, GANIL

- In-gas-cell ionization of erbium with double-etalon Ti:Sa laser (≈ 1.8 GHz FWHM)
- Ion detection after mass filter

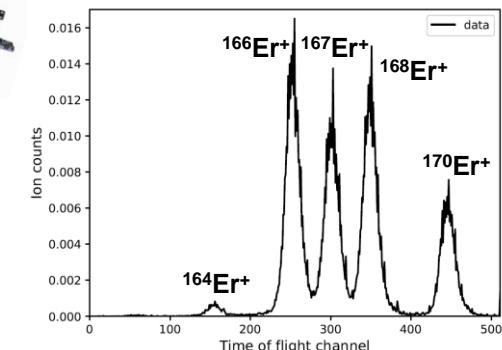
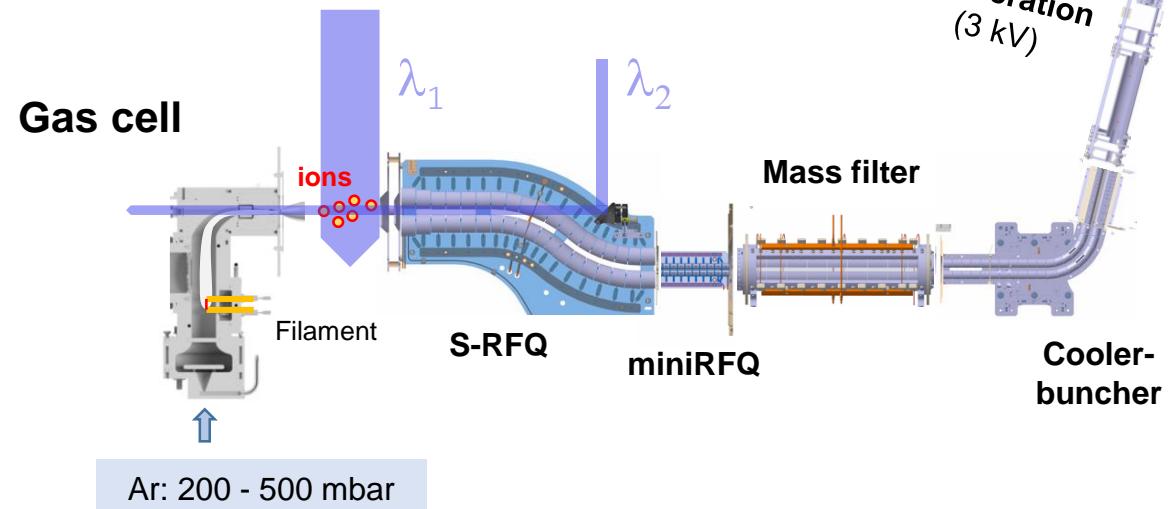
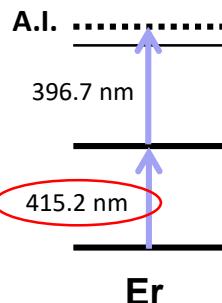
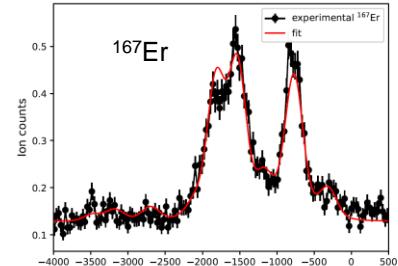
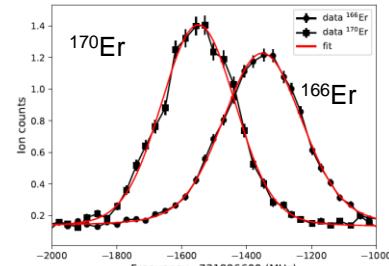


Mass spectrometer



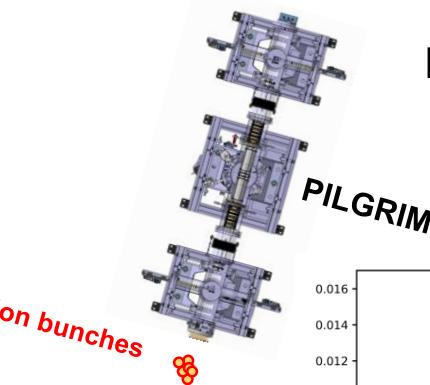
- Studied pressure broadening and shift in gas cell for 415 nm transition:
 - $\Gamma_{\text{shift}} = -4(1)$ MHz/mbar
 - $\Gamma_{\text{coll}} = 11(1)$ MHz/mbar

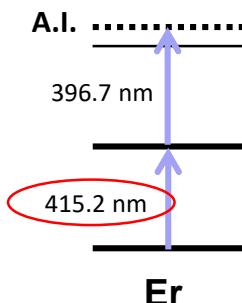
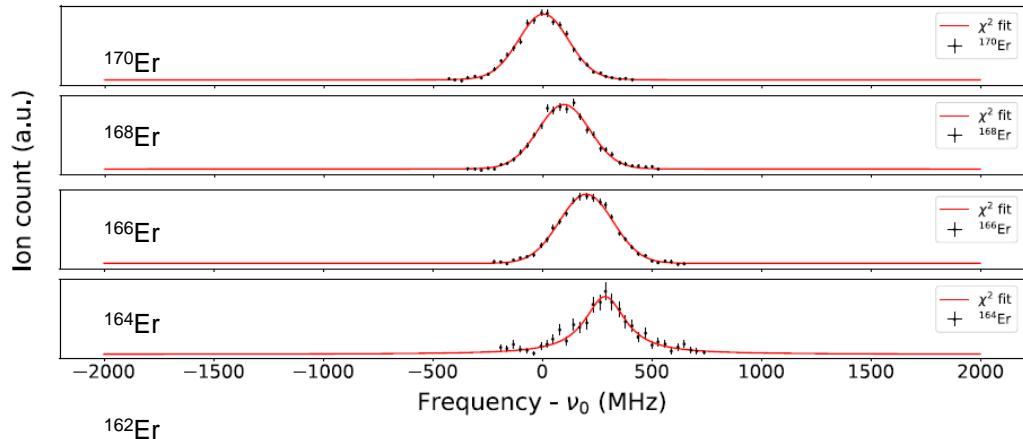
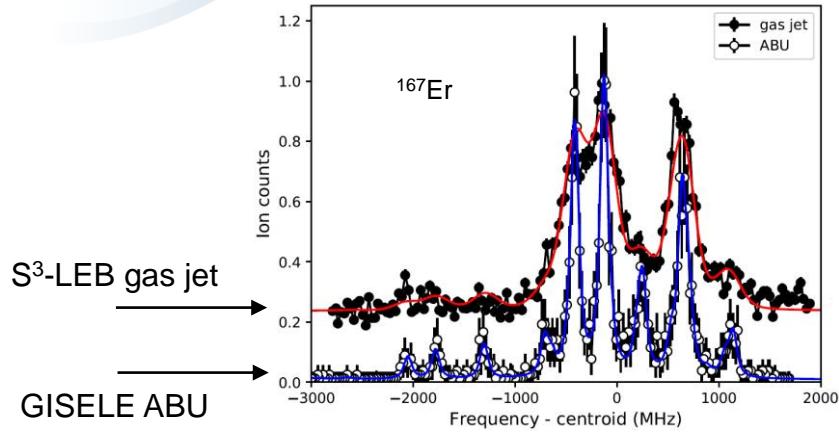
- In-gas-jet spectroscopy of erbium with narrowband laser
- 300 MHz resolution FWHM (Doppler limited)



- Ion detection after MR-TOF MS (isotope selectivity)

Mass spectrometer

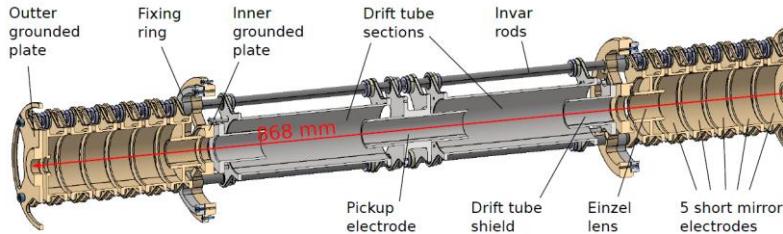
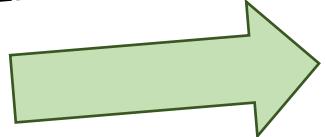




$\Delta\nu_{A,170}$ (MHz)		
A	Gas jet	ABU
168	96(6)	97(8)
167	138(8)	132(10)
166	196(7)	193(8)
164	283(7)	298(7)

- Designed in collaboration with Uni. Greifswald

3-keV beam from
S³-LEB cooler-buncher



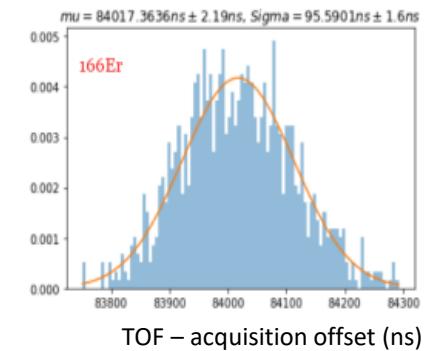
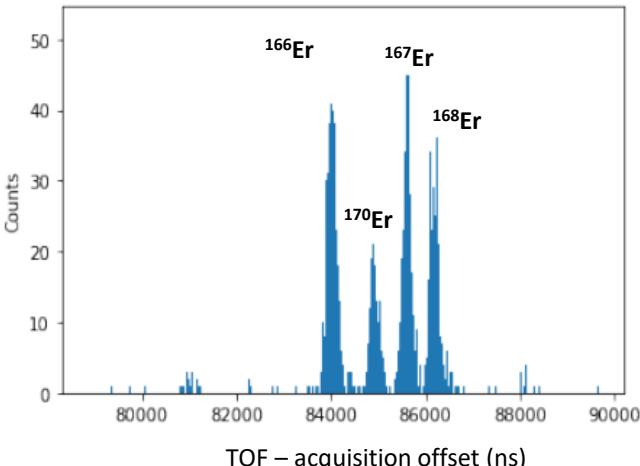
MagneTOF



Pierre Chauveau, PhD thesis, Université de Caen Normandie (2016)
Pierre Chauveau et al., Nucl. Instrum. Meth. B **376**, 211-215 (2016)

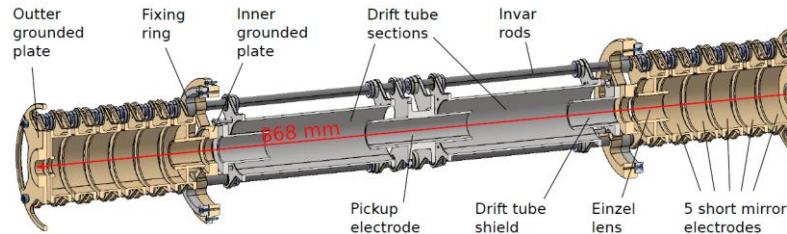
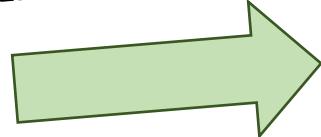
- Mass separation and measurements tested with bunches from the S³-LEB cooler-buncher
- Resolving power $\approx 100\,000$
- Mass accuracy tested on a few cases to a few $\approx 10^{-7}$

¹⁷⁰Er at 1000 turns (other isotopes on different numbers of turns)

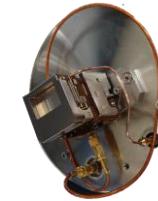


- Designed in collaboration with Uni. Greifswald

3-keV beam from
S³-LEB cooler-buncher

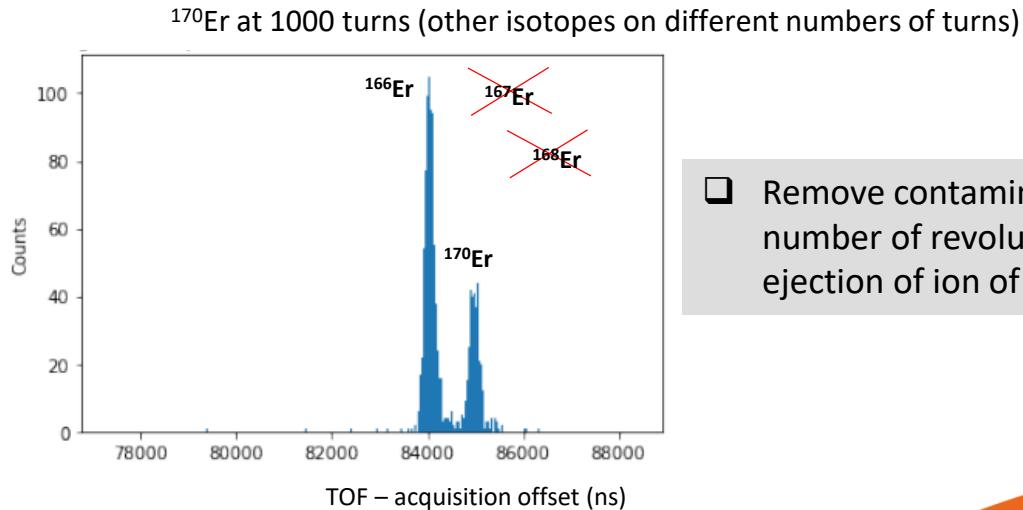


MagneTOF



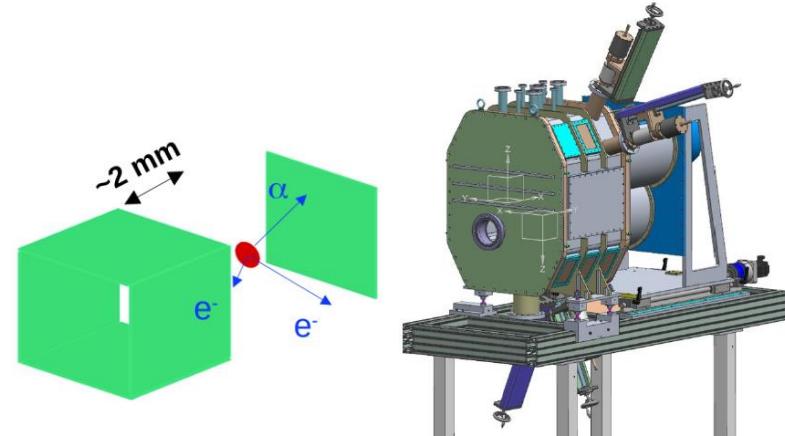
Pierre Chauveau, PhD thesis, Université de Caen Normandie (2016)
Pierre Chauveau et al., Nucl. Instrum. Meth. B **376**, 211-215 (2016)

- Mass separation and measurements tested with bunches from the S³-LEB cooler-buncher
- Resolving power $\approx 100\,000$
- Mass accuracy tested on a few cases to a few $\approx 10^{-7}$



- Remove contaminants at lower number of revolutions than ejection of ion of interest.

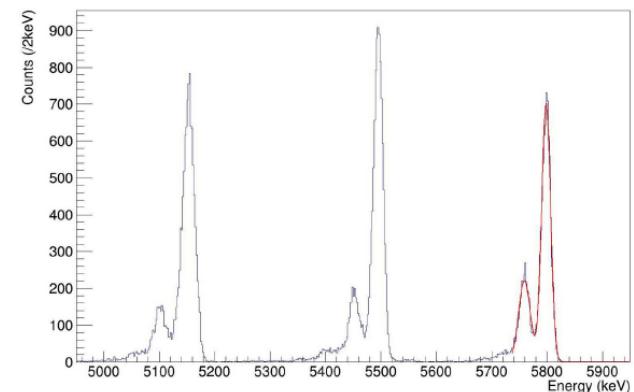
- Developed at CEA Saclay
- « Windmill » of implantation foils
- Silicon box detector (DSSSD) for alphas and electrons
- Germanium detectors



- Mechanical design finished, construction foreseen for end of 2023
- First DSSSD tested, target resolution achieved with radioactive sources:
 - 17.2 keV FWHM for alpha at 5.8 MeV
 - 10.2 keV FWHM for electrons at 320 keV

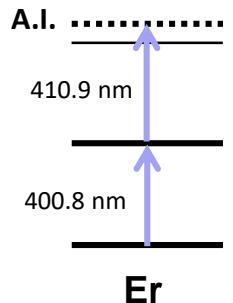
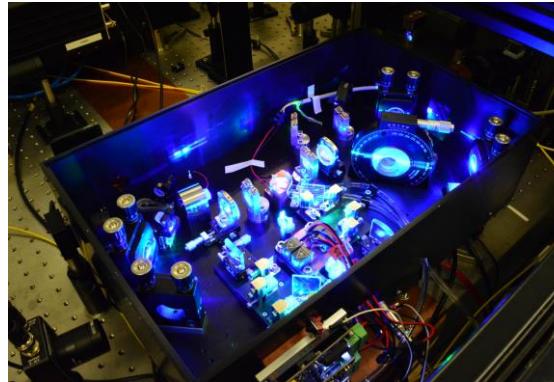
Marine Vandebrouck, Thomas Goigoux, Emmanuel Rey-Herme, Damien Thisse et al.

3- α calibration source (²³⁹Pu, ²⁴¹Am, ²⁴⁴Cm)

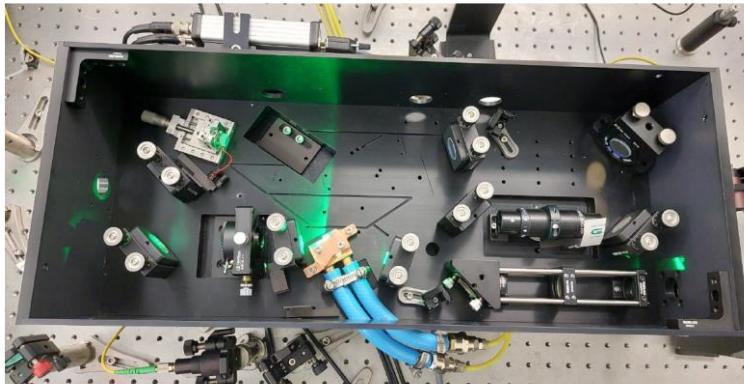


- ❑ So far narrowband spectroscopy used diodes as seed lasers: limited wavelength coverage:
 - Implementation of a diode-pumped CW Ti:Sa (design by Volker Sonnenschein et al.)
 - Cavity mounted and lasing (work of Anjali Ajayakumar)
 - First case study: 400 nm Er I transition

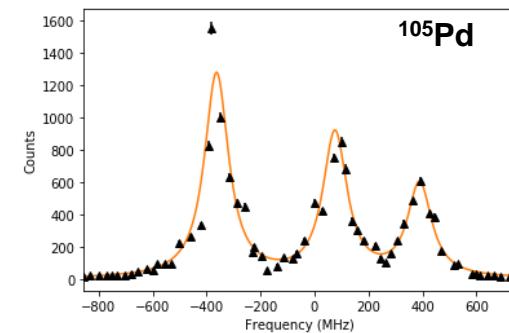
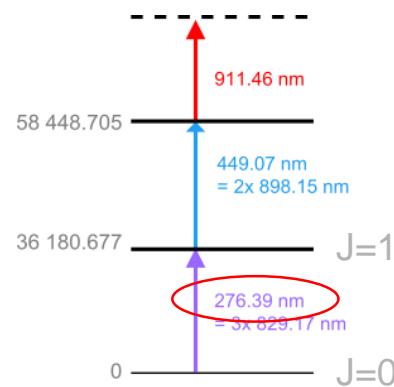
PhD thesis A.Ajayakumar



- ❑ Implementing new-generation injection-locked cavity developed in Mainz (D. Studer et al.)

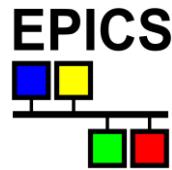


- ❑ Search for Pd scheme to perform resonance-ionization spectroscopy (collaboration with JYFL).



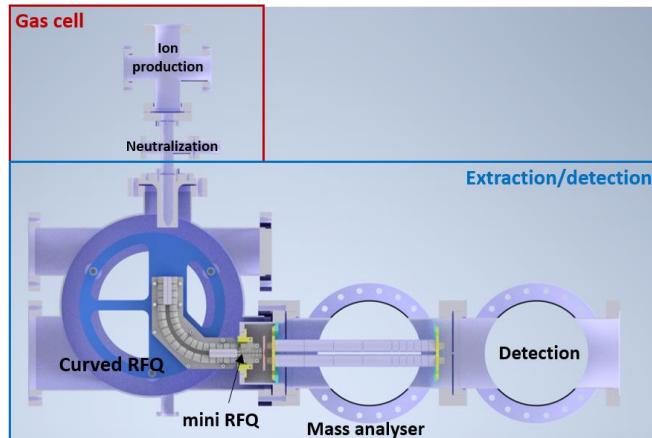
PhD thesis A. Ortiz-Cortes, GANIL, 2023

- Preparation of entrance windows for Day-1 experiments:
 - Dedicated test bench
 - Foils down to 4 µm Ti validated
 - New mesh for thinner foils



- EPICS control system being implemented (deadline end of 2023)

- FRIENDS³ project:
 - Dedicated setup for studying in-gas-cell neutralization and faster ion extraction
 - First tests at GANIL 2024



- ❑ In-gas-jet spectroscopy performed, working on improvements:
 - Gas-jet properties
 - New narrowband lasers
- ❑ PILGRIM ready for beam, SEASON approaching construction
- ❑ S³-LEB on track for first experiments at S³
 - Installation at S³ in 2024
 - 2 years of commission of S³ with S³-LEB and SIRIUS
 - Some first experiments as part of commissioning: Er, Ac, A ≈ 100

The S³-LEB collaboration

GANIL:

Anjali Ajayakumar; Dieter Ackermann; Lucia Caceres; Samuel Damoy; Pierre Delahaye;
Patrice Gangnant; Nathalie Lecesne; Thierry Lefrou; Renan Leroy; Franck Lutton; Alejandro Ortiz;
Benoit Osmond; Julien Piot; Blaise-Maël Retailleau; Hervé Savajols; Gilles Sénécal

LPC:

Frédéric Boumard; Jean-François Cam; Philippe Desrues; Xavier Fléchard;
Julien Lory ; Yvan Merrer ; Christophe Vandamme

IJCLab:

Wenling Dong; Patricia Duchesne; Serge Franchoo; Vladimir Manea; Olivier Pochon

KU Leuven:

Arno Claessens; Rafael Ferrer; Mark Huyse; Fedor Ivandikov; Sandro Kraemer ; Yuri Kudriavtsev;
Jekabs Romans; Simon Sels; Paul Van den Bergh; Piet Van Duppen; Matthias Verlinde ; Elise Verstraelen



JGU:

Sebastian Raeder; Dominik Studer; Klaus Wendt

JYU:

Ruben de Groote; Iain David Moore; Michael Reponen; Juha Uusitalo

IPHC:

Emil Traykov

IRFU:

Martial Authier; Olivier Cloue; Antoine Drouard; Thomas Goigoux;
Emmanuel Rey-Herme; Damien Thisse; Marine Vandebrouck



and the RESIST network in ENSAR2