Status of the JetRIS apparatus for laser spectroscopy of the heaviest elements

MATOU STEMMLER FOR THE SHE LASER COLLABORATION

EMIS XIX

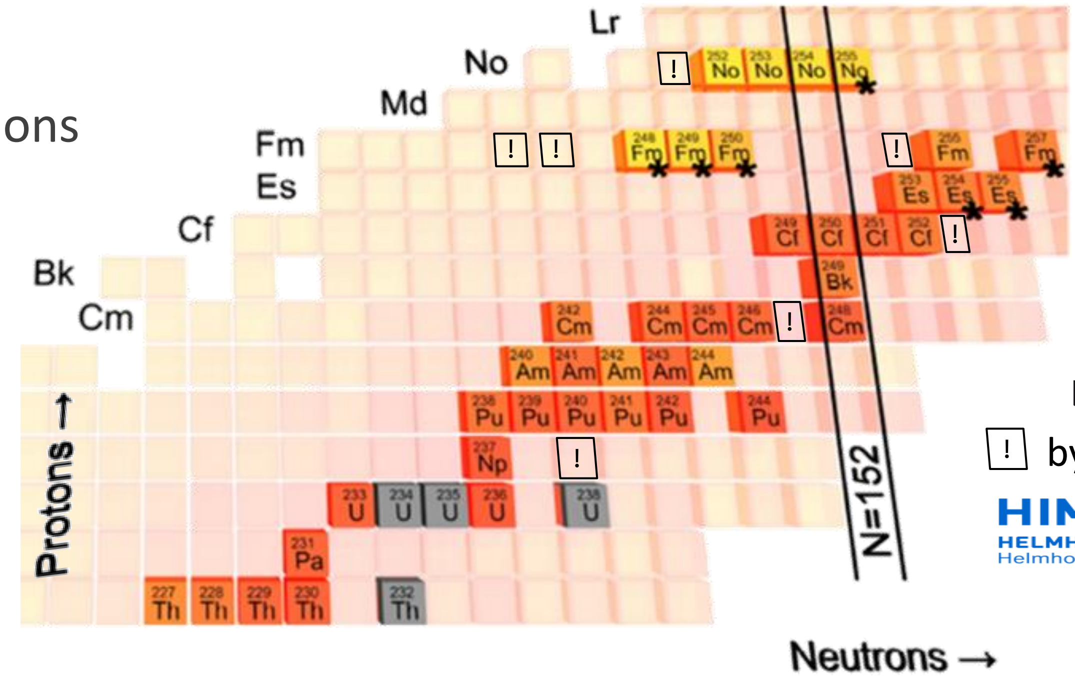
OCTOBER 7, 2022

DAEJEON, KOREA

General Motivation

Atomic physics & chemistry

- Experimental identification of atomic transitions
- Study relativistic effects
- Benchmark atomic models



Astrophysics

- Provide spectroscopic data for the search of superheavy elements in the universe

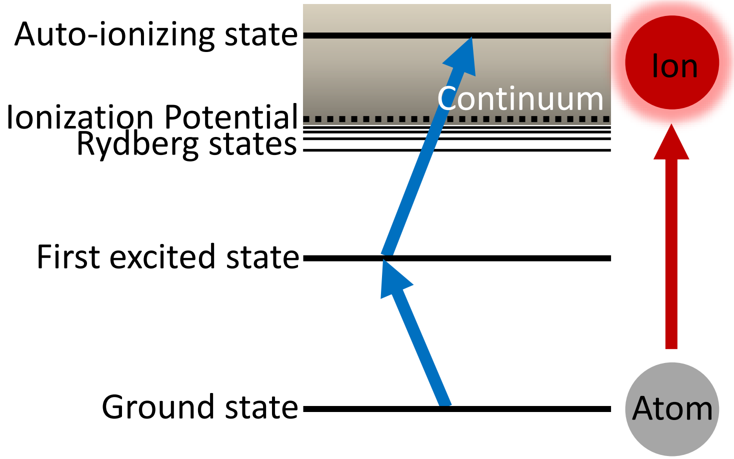
Nuclear physics

- Differential charge radii via isotope shift measurements across multiple isotopes
- Spin coupling and nuclear moments (single-particle and collective properties) via HFS spectroscopy
- Validation of nuclear models

Resonance Ionization Spectroscopy (RIS)

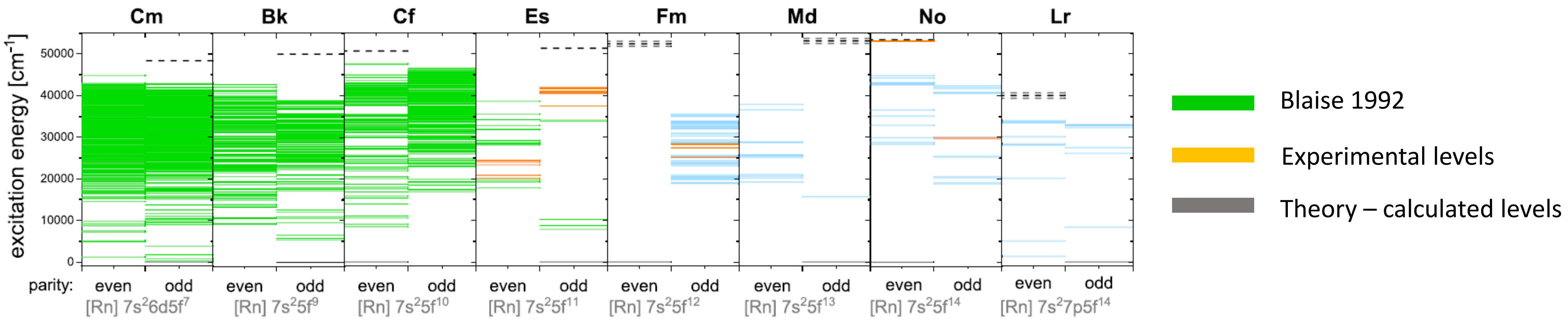
Resonant multi-step excitation via unique series of states of each element

- Element selectivity
- High ionization rates



Principle of laser resonance ionization

Sparse for heavier elements: Z ≥ 100 only calculations available

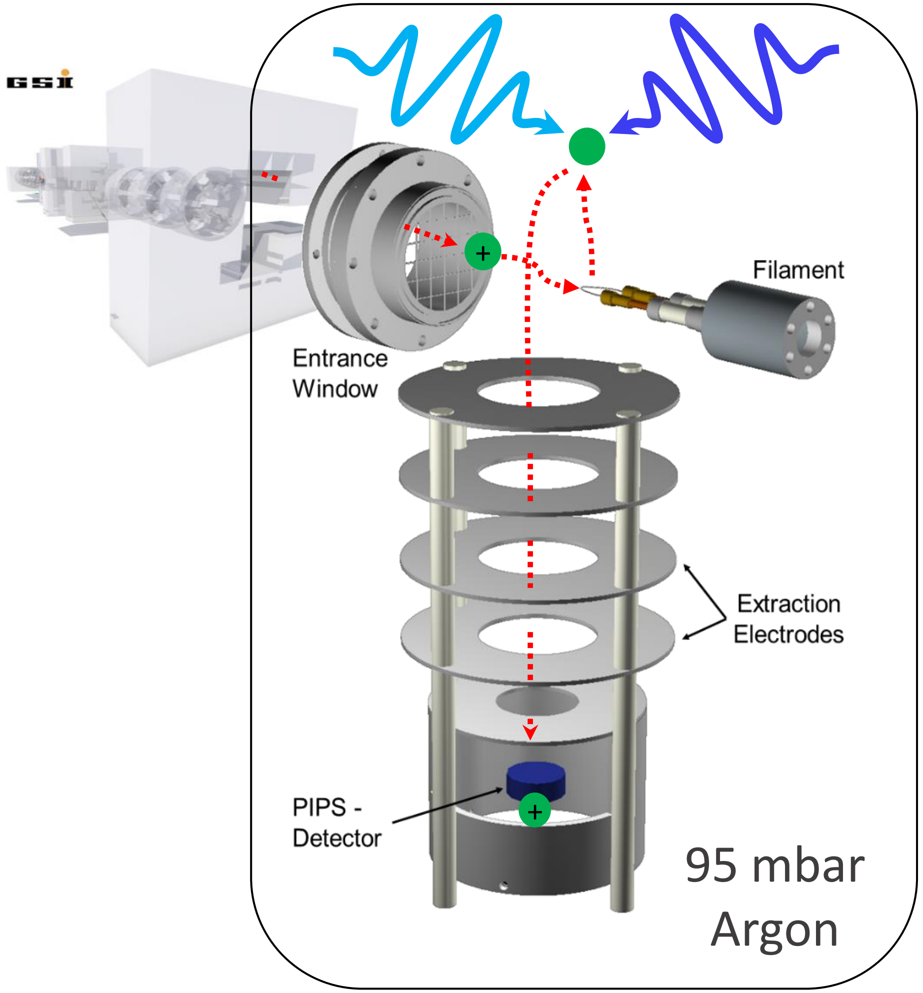


Block, M. et al, *Progress in Particle and Nuclear Physics* (2020): 103834.

RADRIS technique

RAdiation **D**etected **R**esonance **I**onization **S**pectroscopy

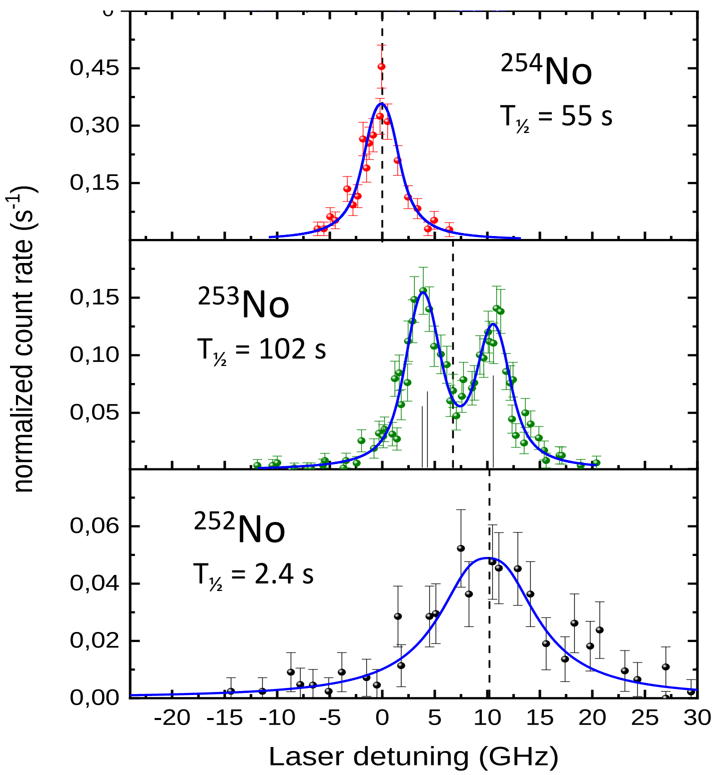
- Thermalizing of incoming fusion products
- Collecting onto thin tantalum / hafnium wire
- Evaporation
- Two-step photoionization process with high power 100 Hz laser system
- Transport to detector and detection of alpha decay



RADRIS technique

RAdiation **D**etected **R**esonance **I**onization **S**pectroscopy

- Thermalizing of incoming fusion products
- Collecting onto thin tantalum / hafnium wire
- Evaporation
- Two-step photoionization process with high power 100 Hz laser system
- Transport to detector and detection of alpha decay



S. Raeder et al., Phys. Rev. Lett. **120** (2018) 232503

Motivation of TETRIS

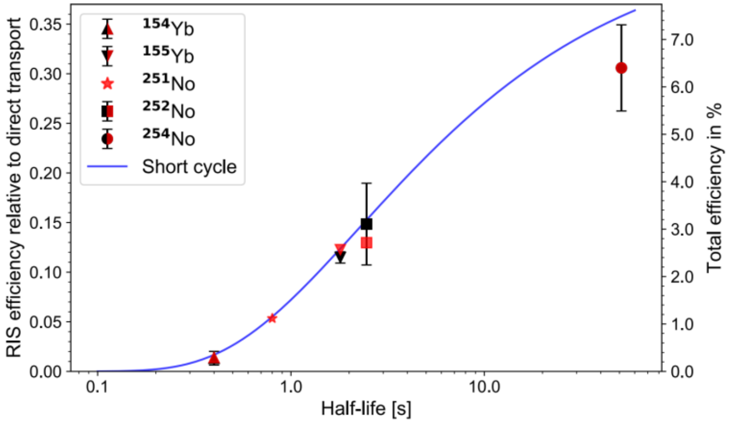
Goal: perform high-resolution laser spectroscopy on heavy actinides and up to superheavy elements

Established measurement method: RADRIS technique

Limited by:

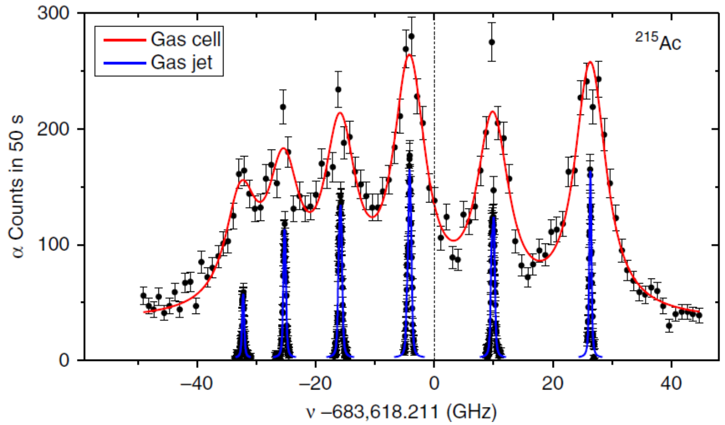
- Achievable spectral resolution
- Half-life dependent decay losses

JetRIS apparatus is developed to overcome those limits [1]



RIS efficiency dependency on half-life

J. Warbinek et al., Atoms 10(2), 41 (2022)



Gas jet results for ^{215}Ac @ LISOL

R. Ferrer, et al., Nature Commun., 8, 2017.

[1] S. Raeder et al., Nucl. Instrum. Methods Phys. Res. B, 463:272-276 (2020)

TETRIS apparatus

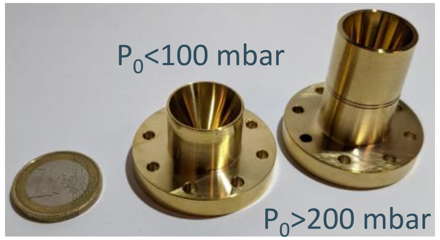
Combination of high efficiency RADRIS with high resolution in-jet methods from KU Leuven

RADRIS technique [1]

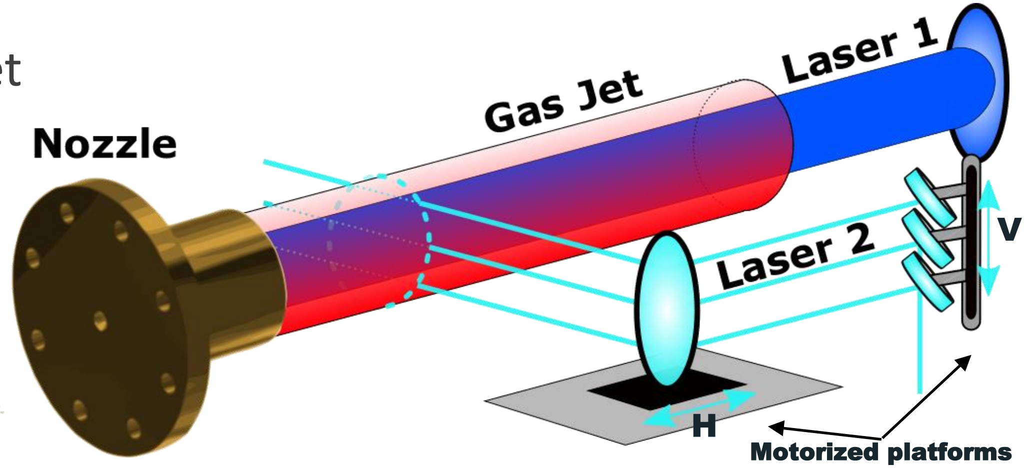
- Stopping charged recoil ions in a gas-filled cell
- Ion collection and neutral desorption from a heated filament

KU Leuven [2]

- High-resolution gas-jet laser ionization
- de Laval nozzle for collimated, supersonic gas jet



de Laval nozzles



Principle of in-jet laser spectroscopy

[1] H. Backe et al., Eur. Phys. J. D, 45(1):99-106 (2007)
[2] Yu. Kudryavtsev et al., Nucl. Instrum. Methods Phys. Res. B, 376:345-352 (2016)

TETRIS apparatus

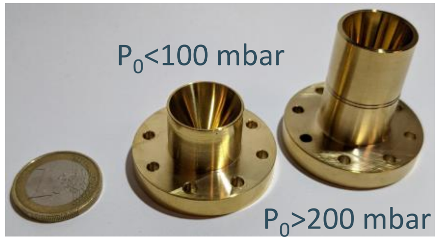
Combination of high efficiency RADRIS with high resolution in-jet methods from KU Leuven

RADRIS technique [1]

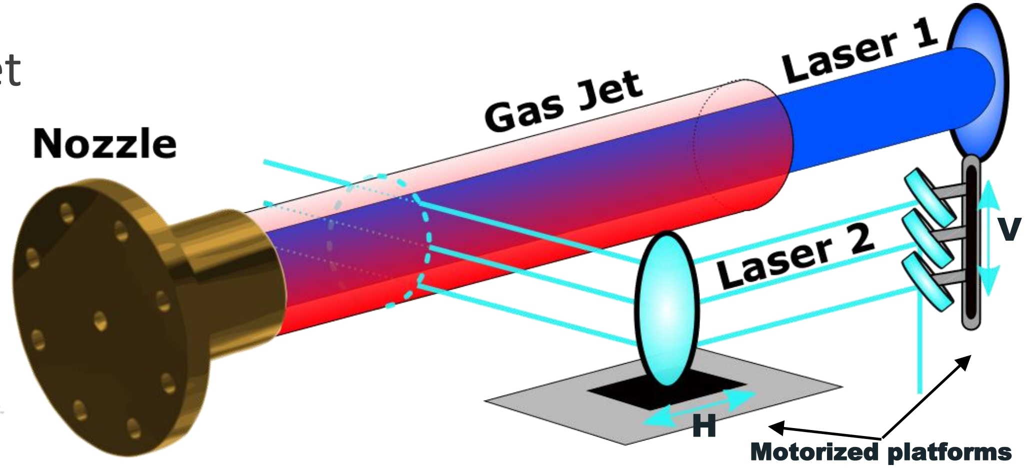
- Stopping charged recoil ions in a gas-filled cell
- Ion collection and neutral desorption from a heated filament

KU Leuven [2] PS-7-4 R. Ferrer

- High-resolution gas-jet laser ionization
- de Laval nozzle for collimated, supersonic gas jet



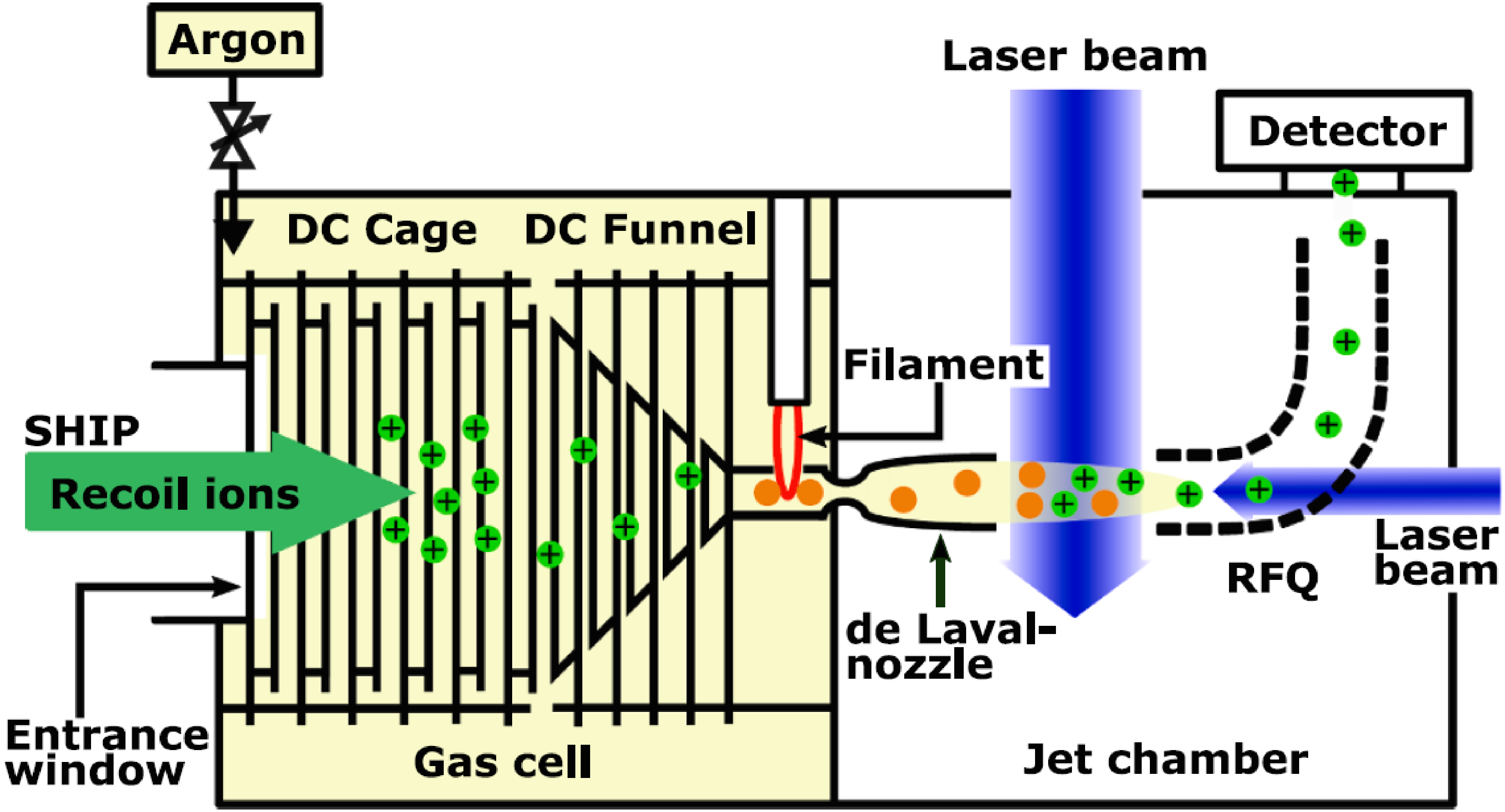
de Laval nozzles



Principle of in-jet laser spectroscopy

[1] H. Backe et al., Eur. Phys. J. D, 45(1):99-106 (2007)
[2] Yu. Kudryavtsev et al., Nucl. Instrum. Methods Phys. Res. B, 376:345-352 (2016)

Conceptual design of TETRIS

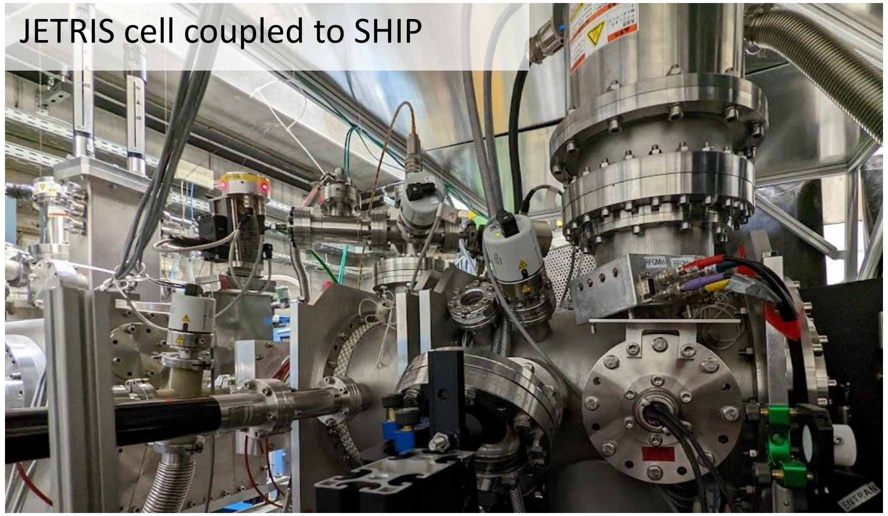


S. Raeder et al., Nucl. Instrum. Methods Phys. Res. B, 376:382-387 (2016)

JETRIS commissioning with ^{254g}No

JetRIS setup - commissioned 2022

- Setup from HIM HELMHOLTZ Helmholtz-Institut Mainz
- Laser system and de Laval nozzle from KU LEUVEN
  - Dye laser system (15 kHz repetition rate)



JETRIS cell coupled to SHIP

High rep rate laser system installed at GSI

TETRIS commissioning with ^{254g}No

JetRIS setup - commissioned 2022

- Setup from HIM HELMHOLTZ Helmholtz-Institut Mainz
- Laser system and de Laval nozzle from KU LEUVEN
  - Dye laser system (15 kHz repetition rate)

Beamtime 2022

- Yb broadband measurements
- First narrowband linewidth of ^{254g}No
- 6 - 7 fold improved resolution

- Lousy efficiency observed

Future prospects

Beamtime 2024 @ GSI, Darmstadt (pending)

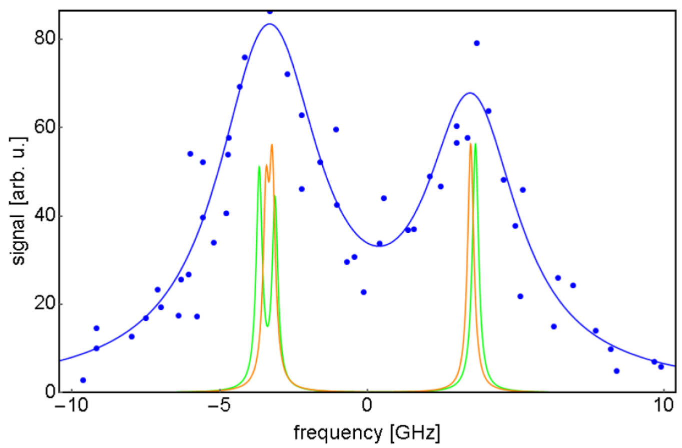
K-isomer in ^{254m}No ($T_{1/2}$ = 266 ms) with JetRIS

- Nuclear configuration of 8^- isomer

HFS of ^{253}No

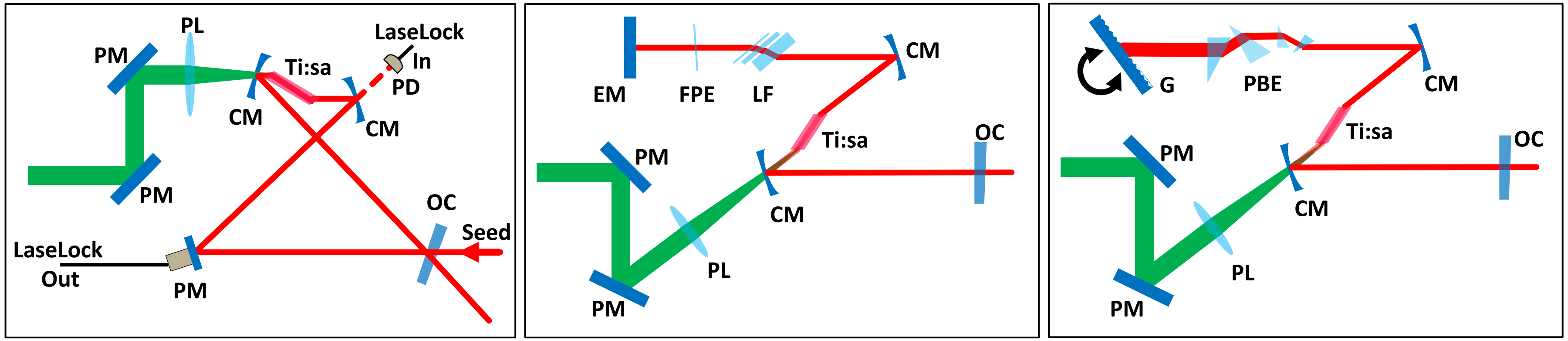
- Improve accuracy in HFS parameters
- Assign Spin and improve precision of quadrupole moment

Remeasure Fermium isotopes with high resolution



Expected HFS of ^{253}No

Ti:sa laser system



Specifications	Injection-locked laser [1]	Standard laser [2]	Grating laser [3,4]
Repetition rate	10 kHz	10 kHz	10kHz
Power fund.	2 W	**3 - 5 W**	1 - 2.5 W
Power SHG	100 mW	**2 W**	1 W
Pulse length	30 - 50 ns	30 - 50 ns	30 - 50 ns
Spectral width	**≈ 10 MHz**	1 - 10 GHz	1 - 2.5 GHz
Tuning range	10 - 20 GHz	100 GHz	**690 - 1000 nm**

[1] V. Sonnenschein et al., Laser Phys. 27.8 (2017)
[2] C. Mattolat, Dissertaton, JGU Mainz (2010)
[3] P. Naubereit, Masterthesis, JGU Mainz (2014)
[4] S. Rothe, Dissertation, JGU Mainz (2012)

CW Ti:sa laser

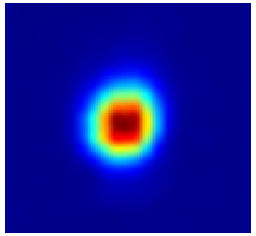
Used as seed laser for injection-locked laser

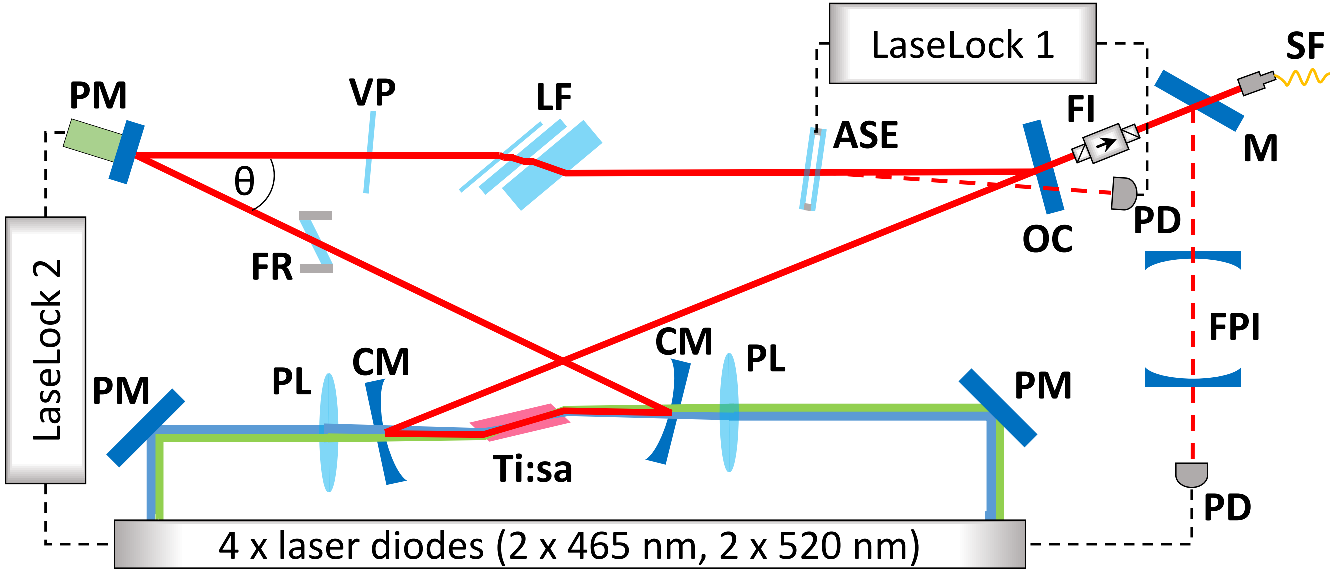
Direct laser diode pumped with approx. 8.5 W

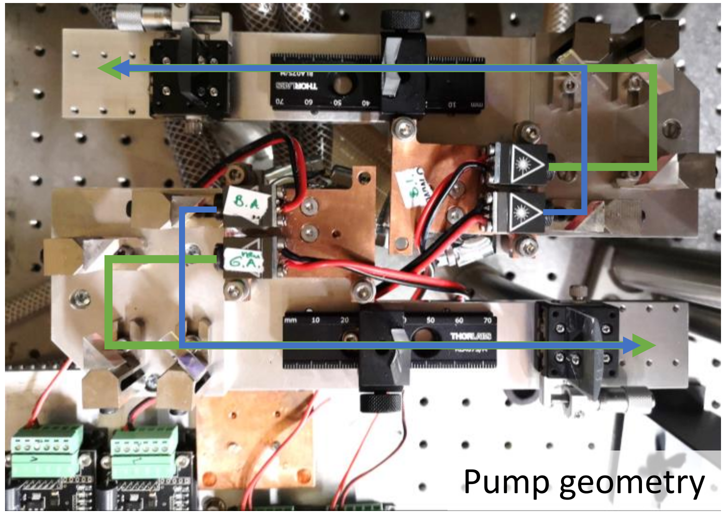
Two-step frequency stabilization

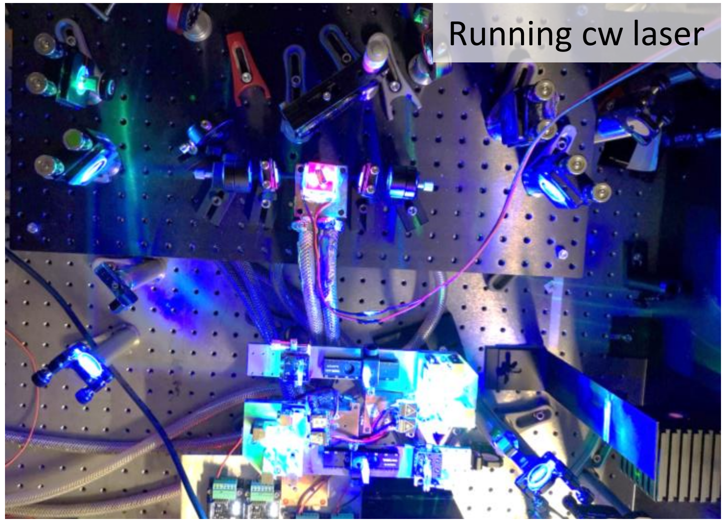
M^2 of 1.16 and 1.27

Linewidth of 3.0(3) MHz







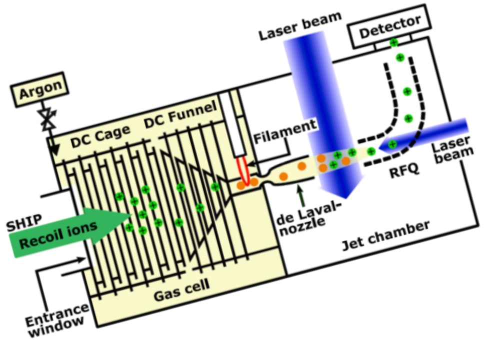


Summary and Outlook

JetRIS to overcome limits of RADRIS technique

Combination of high efficiency RADRIS with high resolution in-jet methods

Proof of principle provided by measurement of ^{254g}No

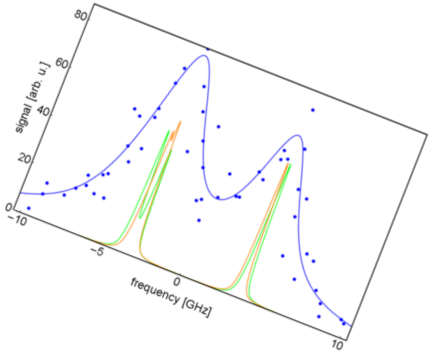


Planned additions to setup:

- Mass selection by MRToF planned for 2023
- Ti:sa laser system to compliment existing dye laser system

Beamtime 2024 at GSI Darmstadt (pending):

- Measuring ^{254m}No and ^{253}No with JetRIS
- Remeasure Fermium isotopes with high resolution



SHE Laser Collaboration

GSI Darmstadt
B. Andelic, M. Block, F. Giacoppo, F.P. Heßberger, O. Kaleja, A. Mistry, S. Raeder, J. Warbinek, A. Yakushev, M. Guiterrez-Torres

KU Leuven
A. Claessens, R. Ferrer, S. Kraemer, J. Romans, P. Chhetri, P. Van Duppen, S. Sels, F. Ivandikov, A. De Roubin

Universität Mainz
M. Laatiaoui, W. Lauth, E. Romero Romeno, E. Kim, Ch. E. Düllmann, J. Auler, M. Stemmler, M. Kaja, N. Kneip, D. Studer, F. Weber, K. Wendt

HIM Mainz
J. Lantis, St. Nothhelfer, D. Münzberger, E. Rickert, T. Kieck, J. Auler

GANIL
P. Chauveau, N. Lescesne, H. Savajols, V. Manea

TRIUMF Vancouver
P. Kunz, T. Mürbock

University of Liverpool
B. Cheal, Ch. Devlin

Jyväskylä
A. Raggio, I. Moore

CEA Saclay
E. Rey-Herme, B. Sulignano, M. Vandebrouck

TU Darmstadt
T. Walther

This Marie Sklodowska-Curie Action (MSCA) Innovative Training Network (ITN) receives funding from the European Union H2020 Framework Programme under grant agreement no. 861198. LISA will run from November 2019 to October 2023.
This research is supported by the U.S. DOE, Office of Science, BES Heavy Element Chemistry program. The isotopes used in this research were supplied by the U.S. DOE Isotope Program, managed by the Office of Science for Nuclear Physics.