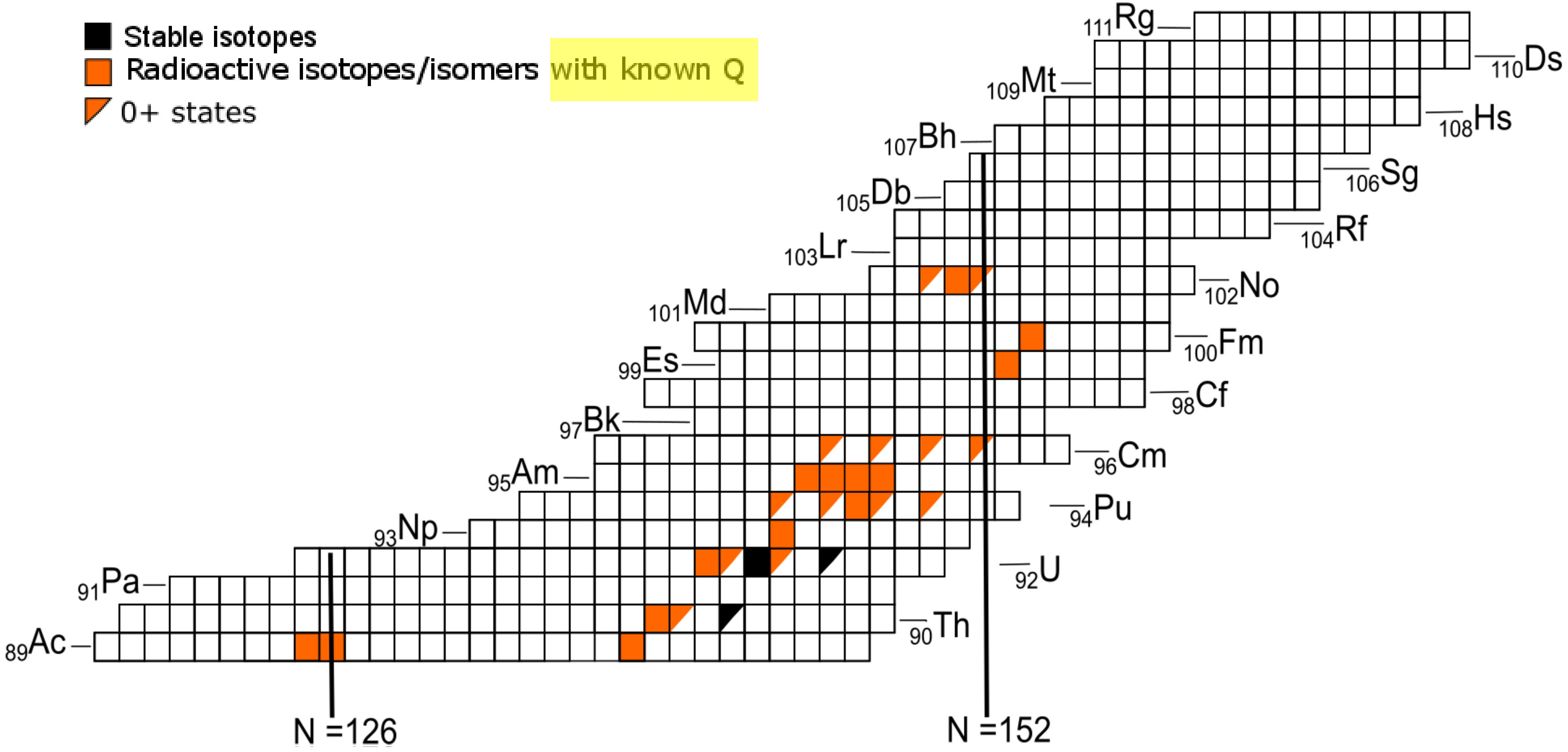
Supersonic Gas Jets for Laser Ionization Spectroscopy of Heavy Elements at the S3-LEB

Rafael Ferrer
KU Leuven, Instituut voor Kern- en Stralingsfysica
Belgium

Outline

- Motivation for Laser Spectroscopy of Heavy Elements
- The In-Gas Laser Ionization and Spectroscopy (IGLIS) technique
  - ➢ Off-line characterization studies
- IGLIS studies of exotic nuclei at S3-LEB (GANIL)
- Summary & Outlook

Optical Spectroscopy Actinides: Status



Important nuclear ground- and isomeric-state properties to understand underlying nuclear structure and improve predictive power of nuclear theories

P. Campbell, I.D. Moore, M.R. Pearson, Prog. Part. Nucl. Phys. 86 (2015) 127-180

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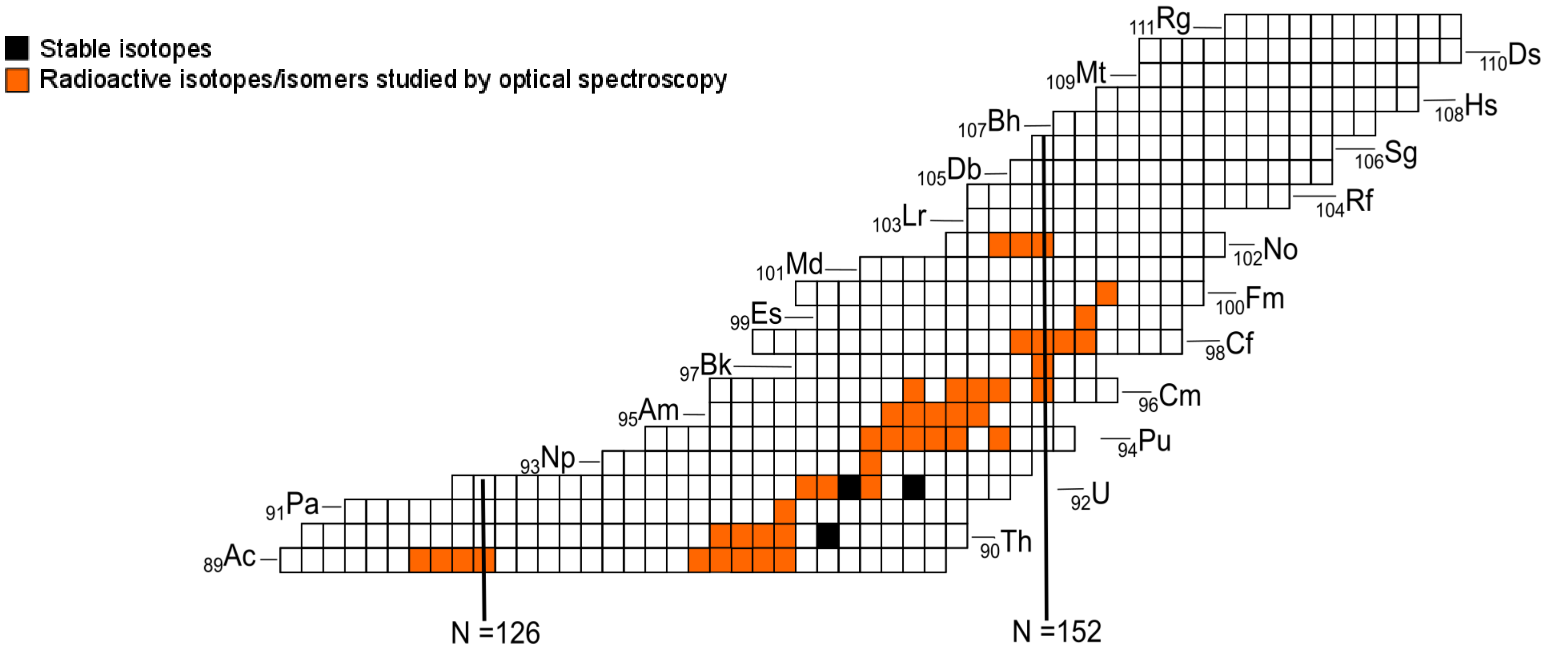
Optical Spectroscopy Actinides: Challenges



- ➢ Laser spectroscopy after fusion evaporation reactions
- ➢ Low production rates of actinides impose highly sensitive and efficient laser spectroscopy technique

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- ➢ High spectral resolution to resolve hyperfine structure

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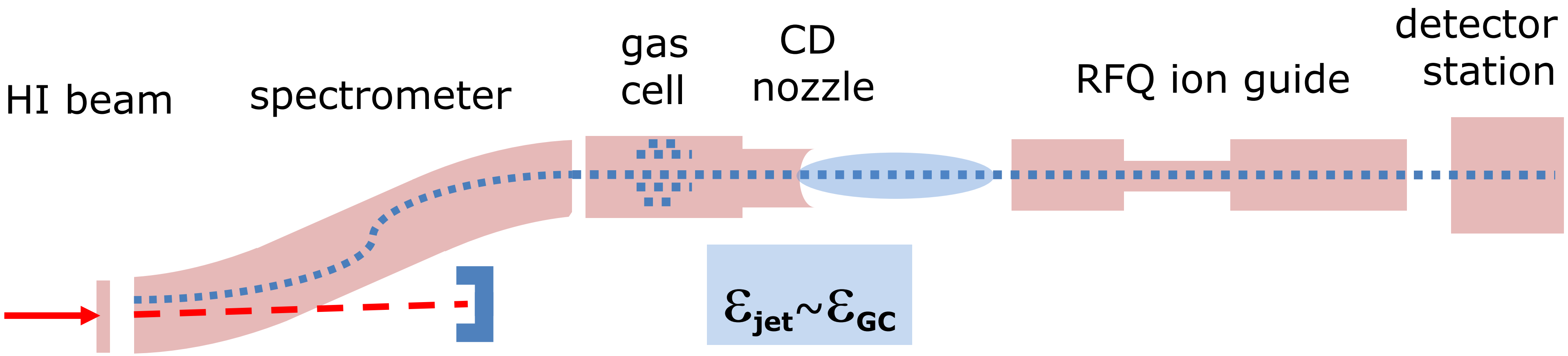
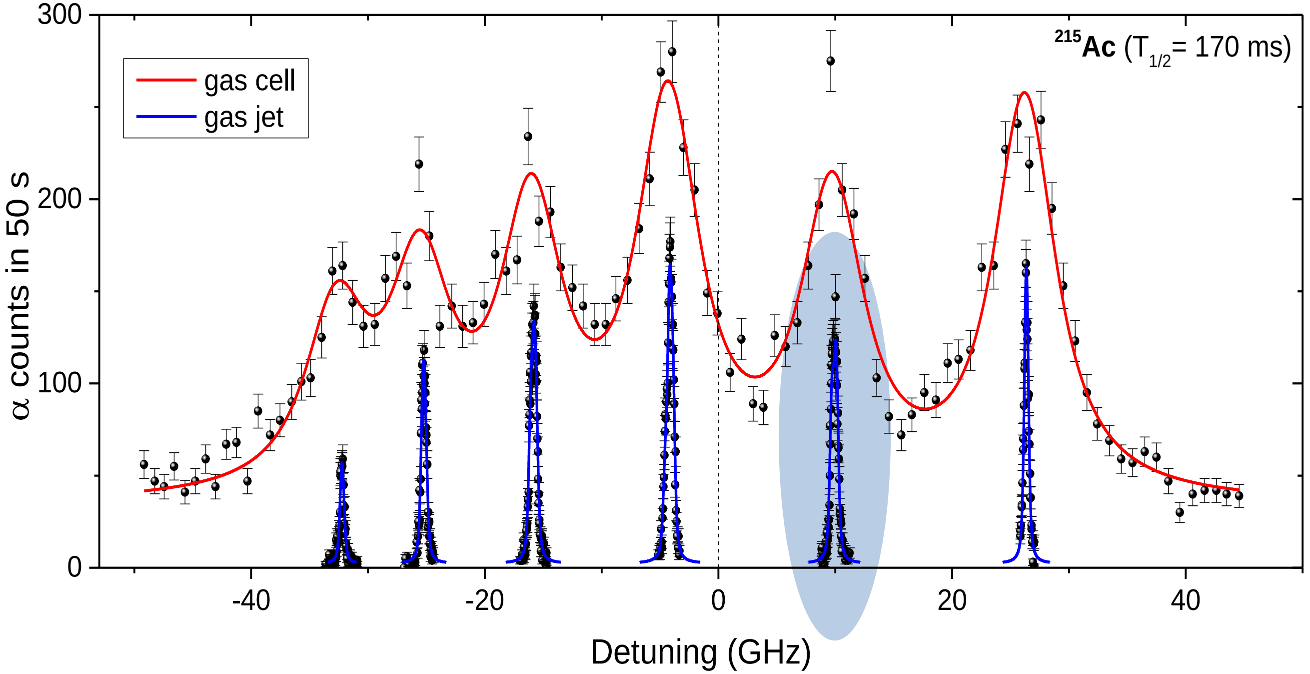
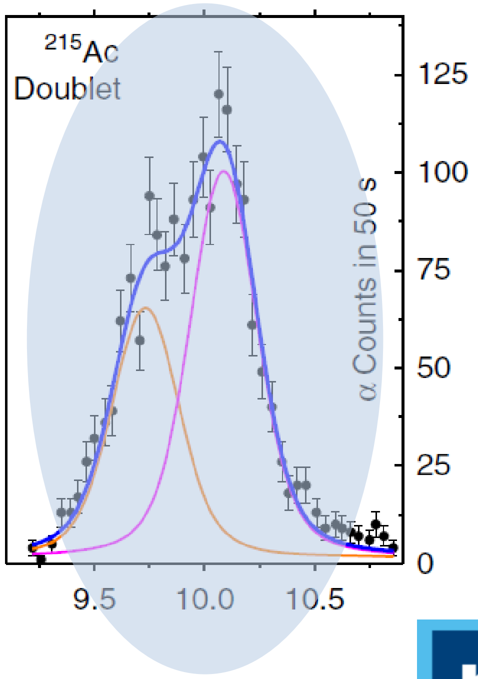
P. Campbell, I.D. Moore, M.R. Pearson, Prog. Part. Nucl. Phys. 86 (2015) 127-180

In Gas Laser Ionization and Spectroscopy (IGLIS)
In-Cell vs In-Jet Spectroscopy







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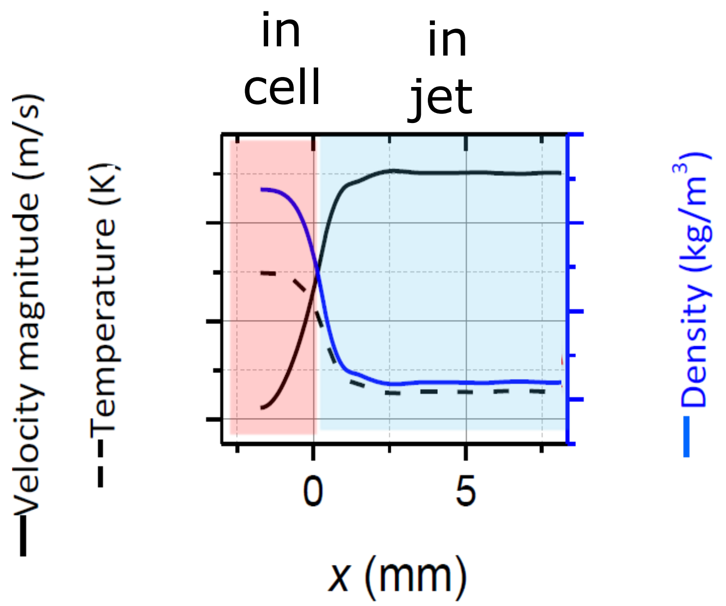
R. F. et al., Nat. Commun. 8 (2017) 14520

Performance of IGLIS on Actinides

Actual and expected performance of IGLIS on ^{215}Ac.		
	Gas cell	**Gas jet (this work)**
Linewidth (FWHM)		
Total (MHz)	5,800 (300)	394 (18)
Lorentz‡ (MHz)	4,000 (400)	42 (6)
Gauss§ (MHz)	1,400 (100)	280 (30)

Characterization/optimization
@ offline IGLIS laboratory

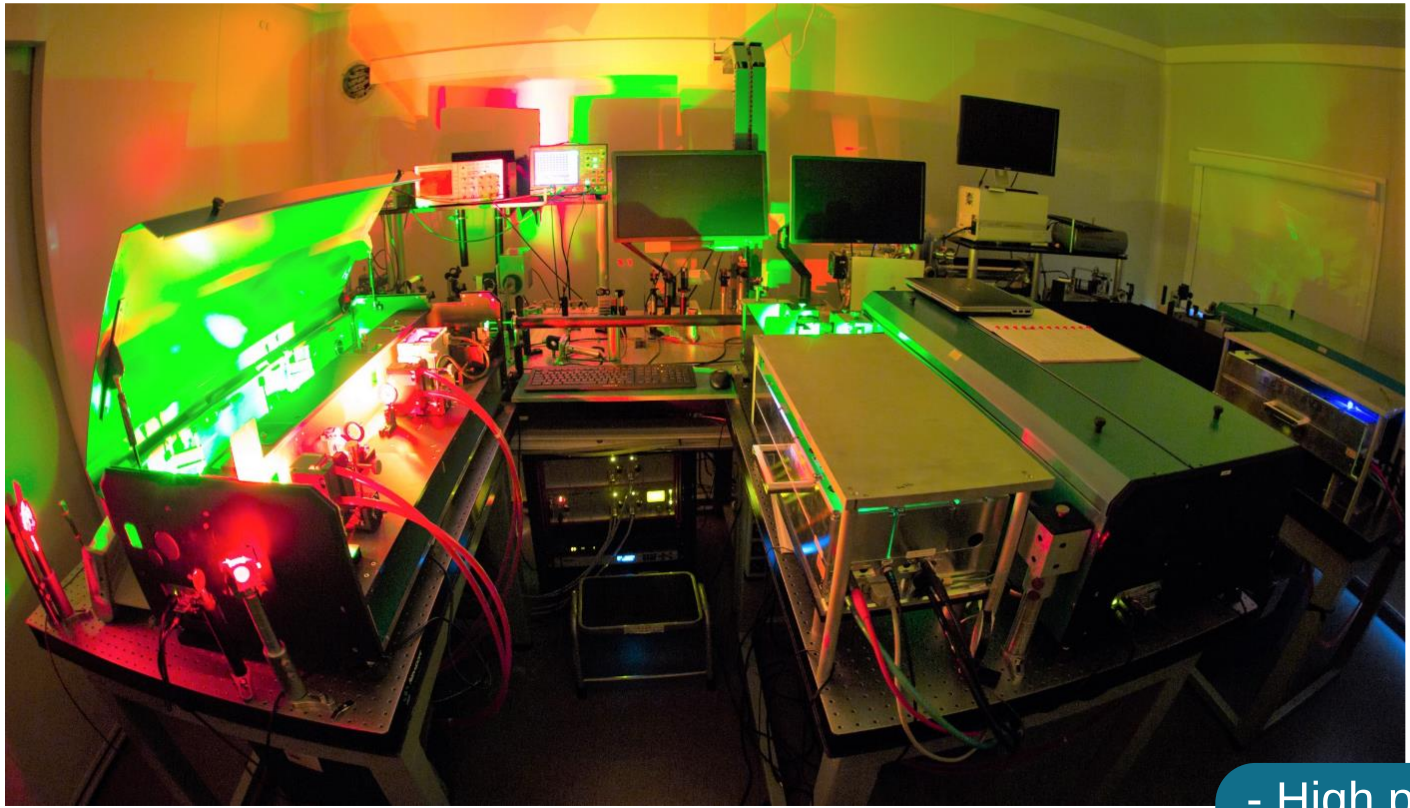


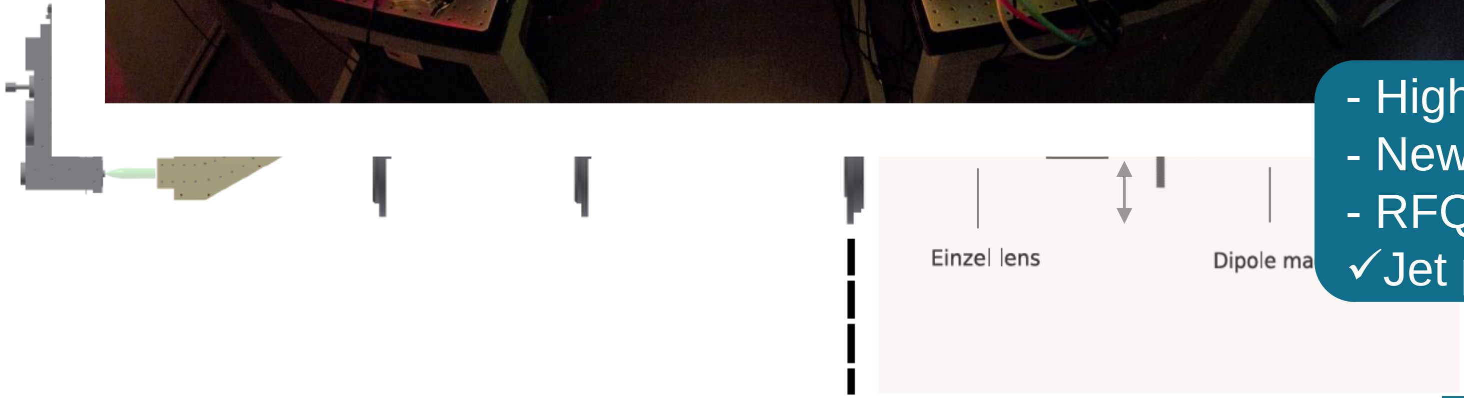
- collisions $\Delta\vartheta_\rho \sim \left(\frac{T_{jet}}{T_{293K}}\right)^{0.3} * \rho_{jet}$

- temperature $\Delta\vartheta_{Doppler} \sim \vartheta_0 \sqrt{T_{jet}/A}$

$$T_{jet} = \frac{T_0}{\left(1 + \frac{\gamma-1}{2} M^2\right)}$$

IGLIS laboratory @ KU Leuven (off-line studies)





- High power high rep. laser system
- New gas cell design
- RFQ Ion Guides
✓Jet properties with CD nozzles

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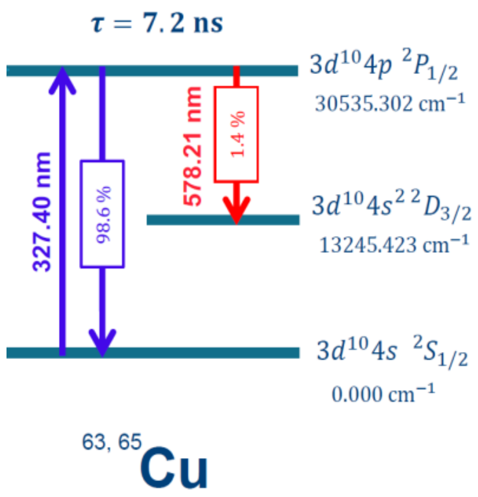
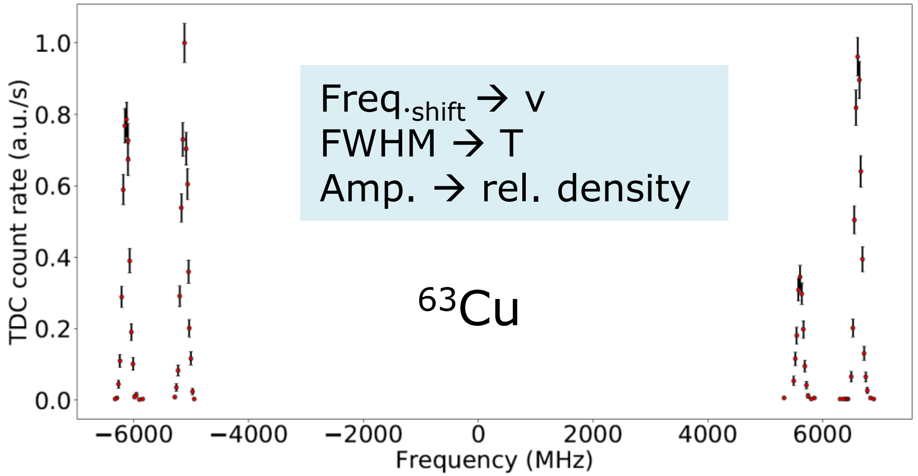
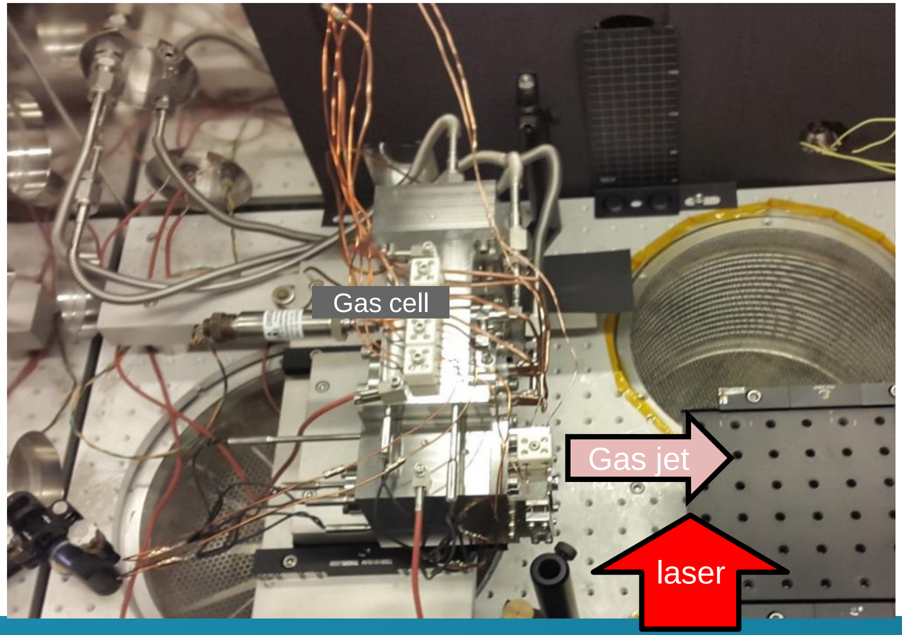
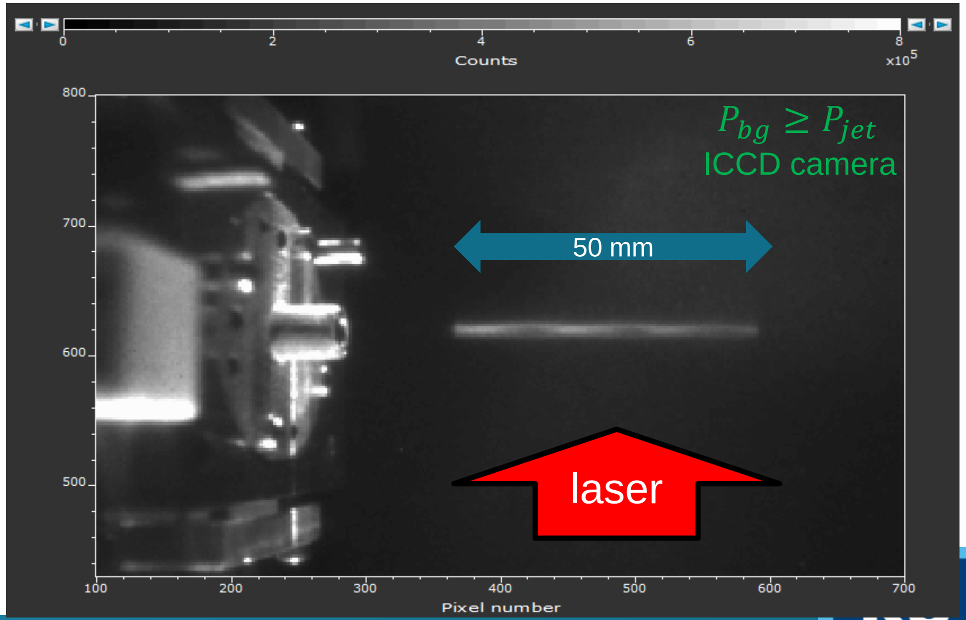
Jet visualization: the PLIF technique

- Information on velocity, temperature and density distributions in the gas jet







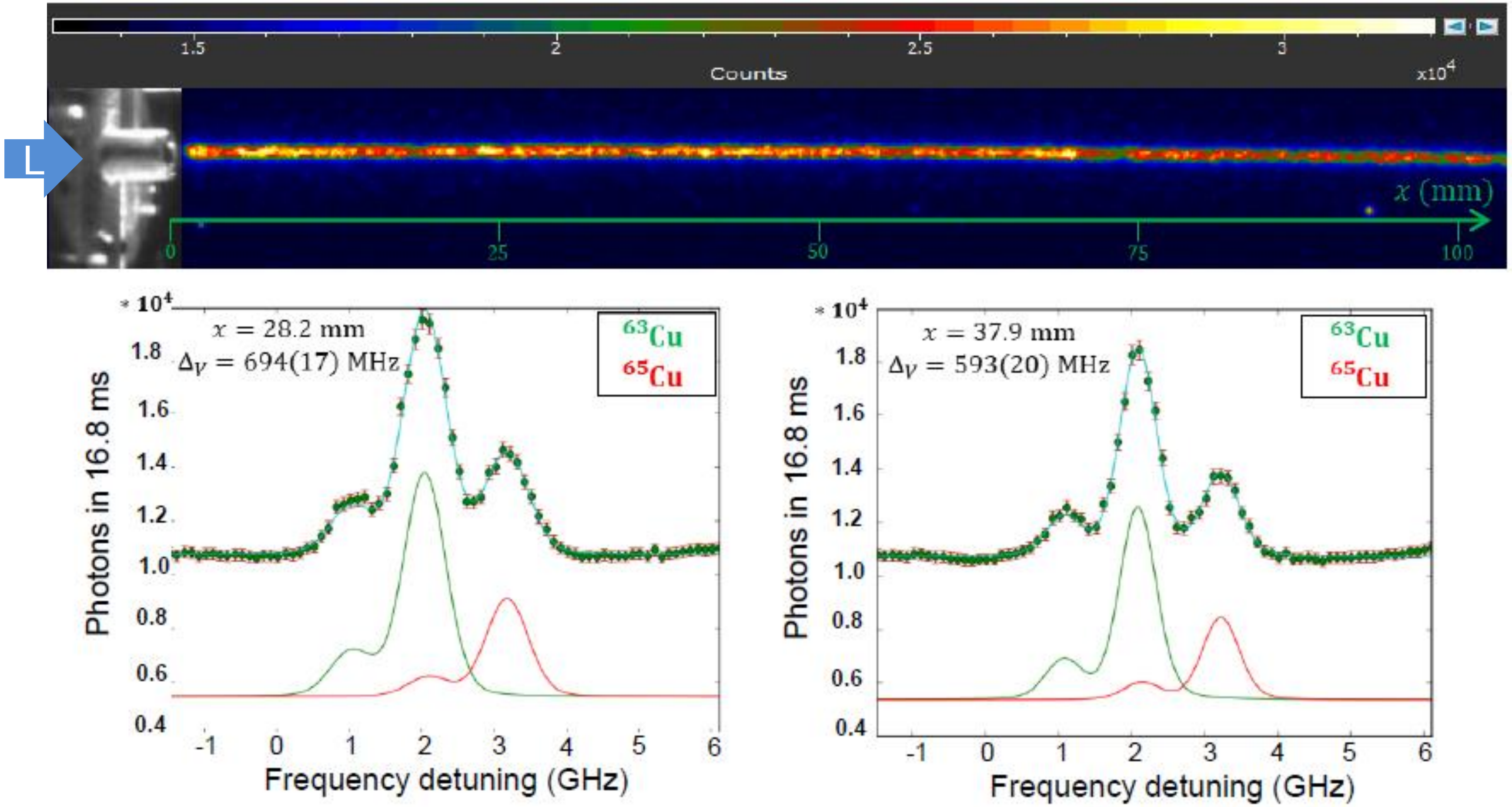


Characterization of jets formed by de Laval nozzles

Quasi-uniform jet

Central jet line @ $P_{bg} \approx P_{opt}$

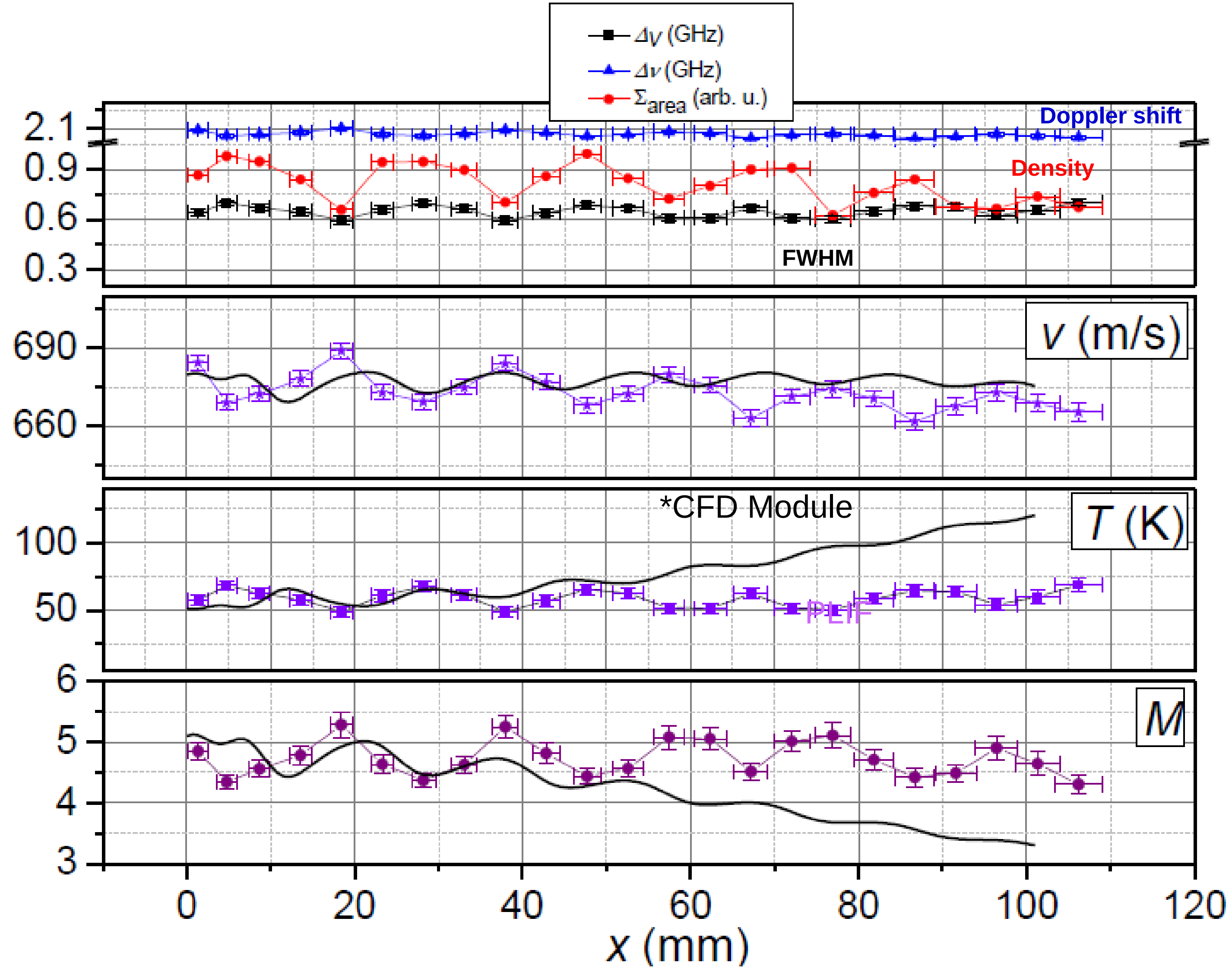
P_0 = 380 mbar, P_{bg} = 1.5 mbar



A. Zadvornaya et al. Phys. Rev. X 8, 041008 (2018)

Characterization of jets formed by de Laval nozzles II

Quasi-uniform jet



*T_0 = 500 K, P_0 = 379 mbar, P_{bg} = 1.46 mbar

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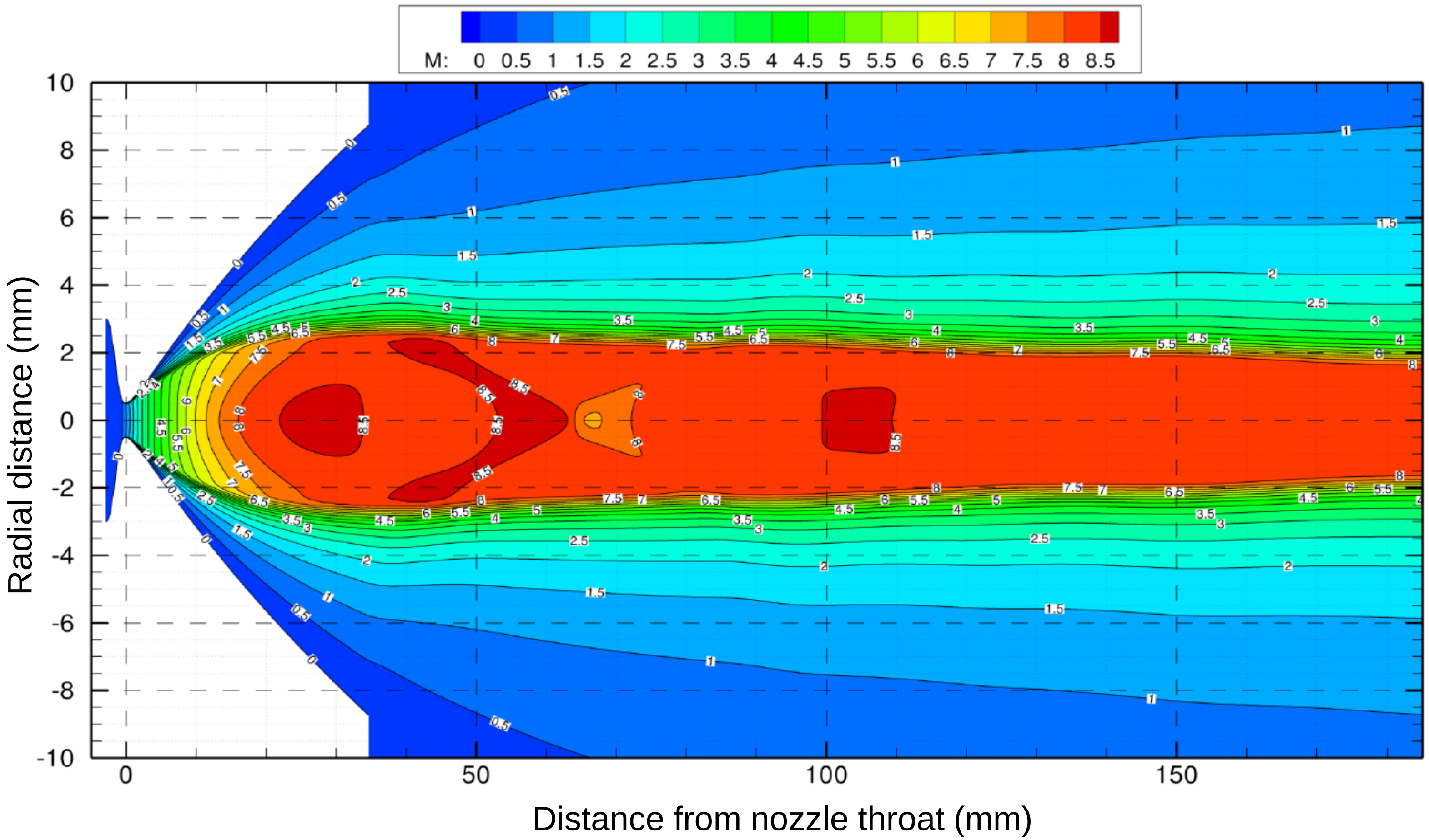
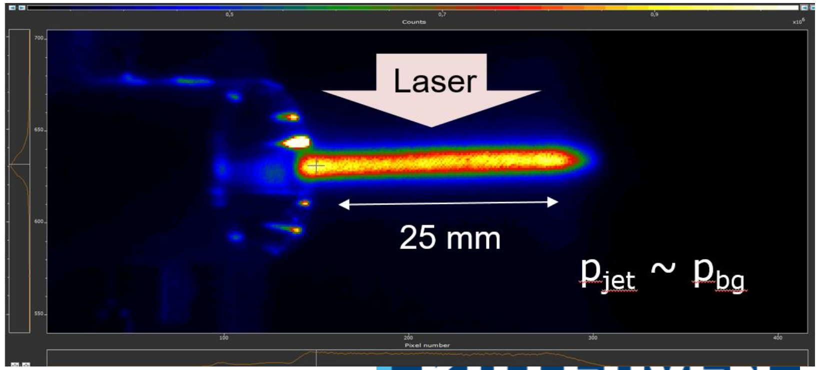
A. Zadvornaya et al. Phys. Rev. X 8, 041008 (2018)

Nozzle (M> 5)

New nozzle contour using advanced simulation code from Aeronautics and Aerospace Department (*von Karman Institute for Fluid Dynamics)*

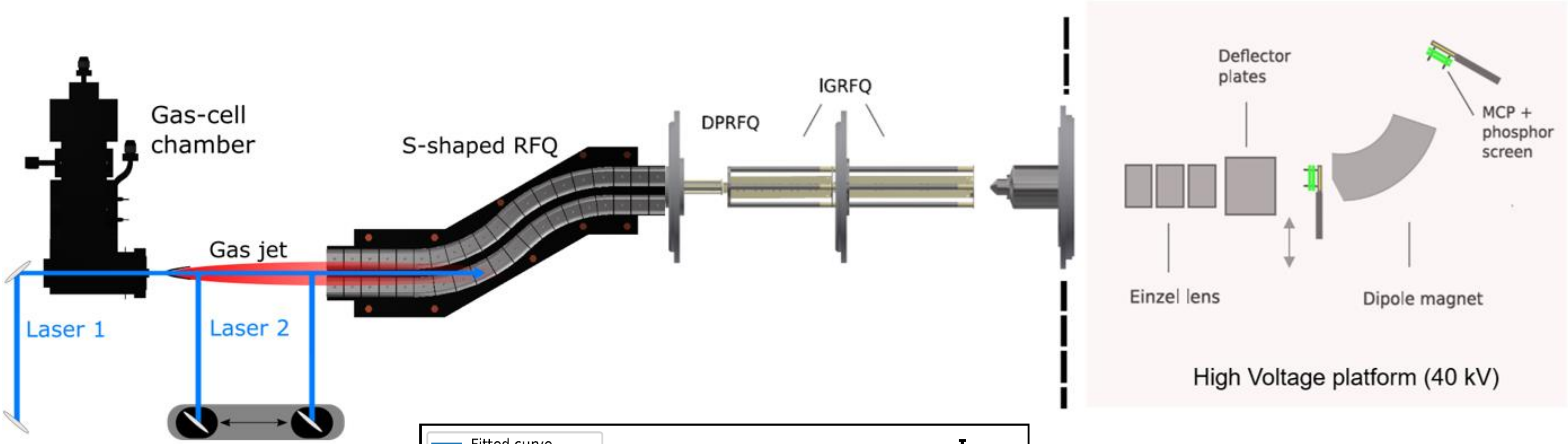


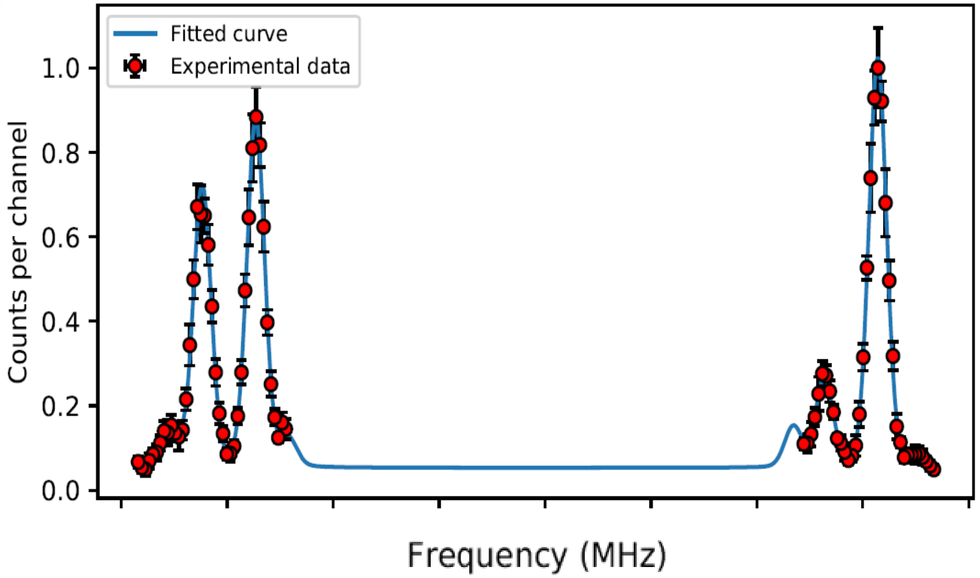
- precision inner contour ~ 5 μm
- surface finishing Ra=0.1 μm



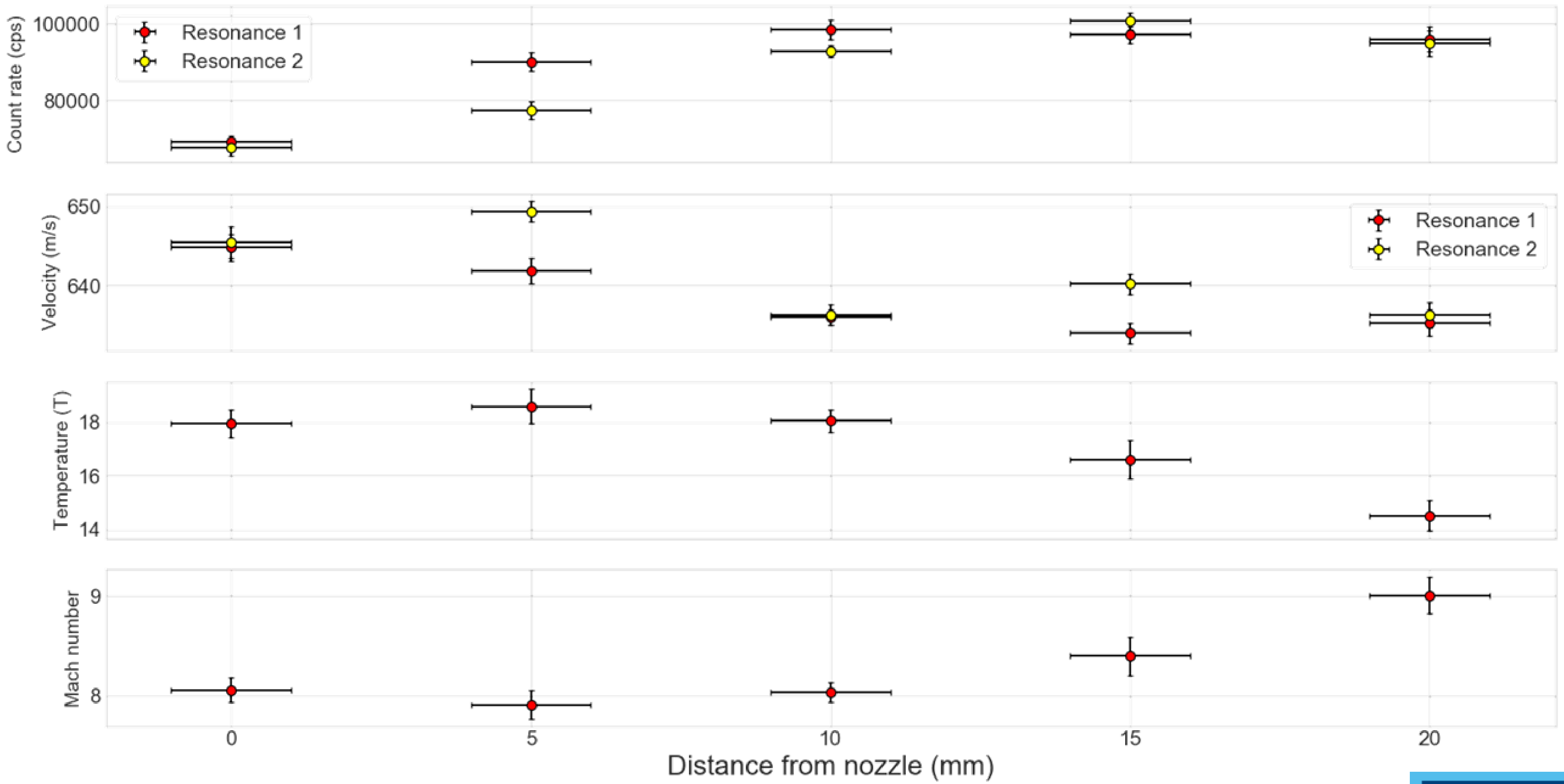
Characterization of the flow parameters by PLIFS and RIS and comparison with results from simulations

Characterization of jets by RIS





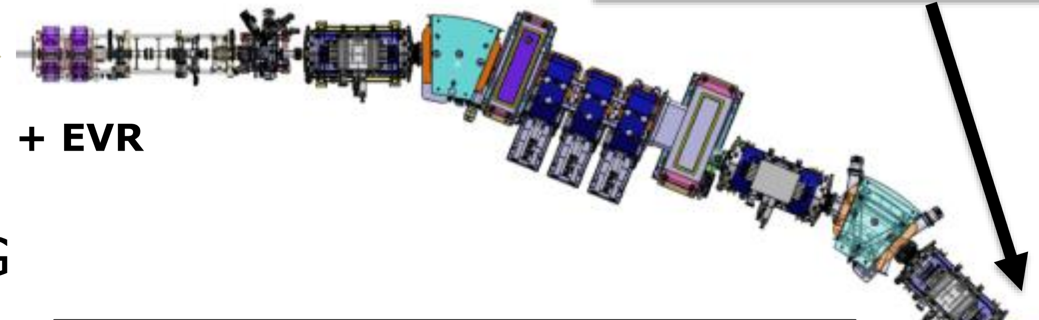
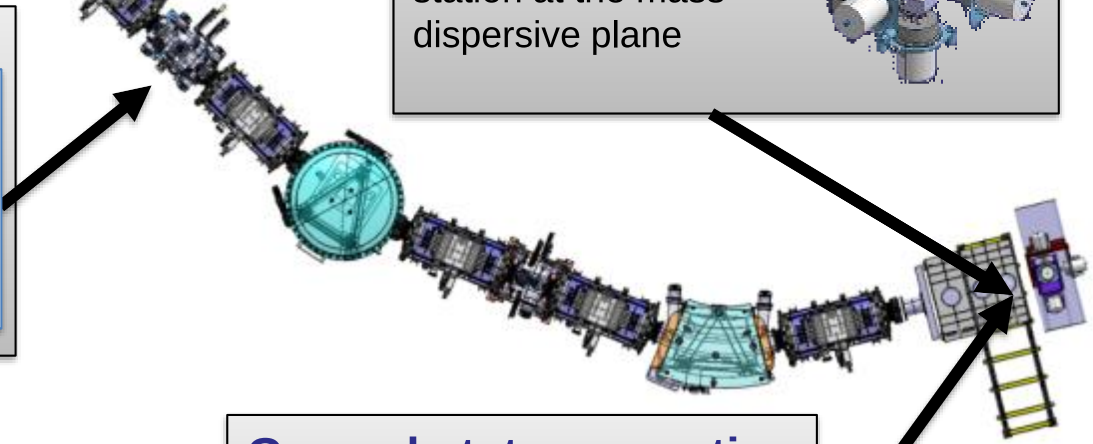
Results of flow parameters using RIS



S^3 Experimental Techniques

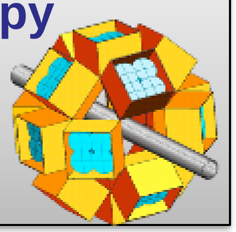
SPIRAL2 Phase1
- Increase the intensity of stable beams
- High intense neutron source
  (HI≤ 10^{15} pps, p-Ni)

  ^{48}Ca @ 2,5 pμA

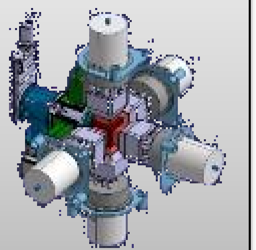
Primary beam + EVR
from
LINAG

In-beam spectroscopy
Two step reactions
EXOGAM2/AGATA
PARIS
MUST2/GASPARD



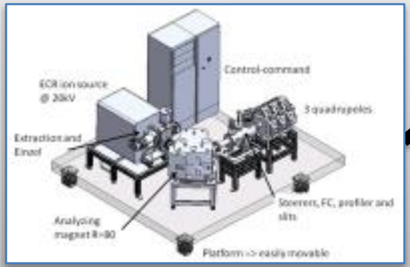
Delayed spectroscopy

SIRIUS setup
Implantation-decay
station at the mass
dispersive plane



Atomic physics

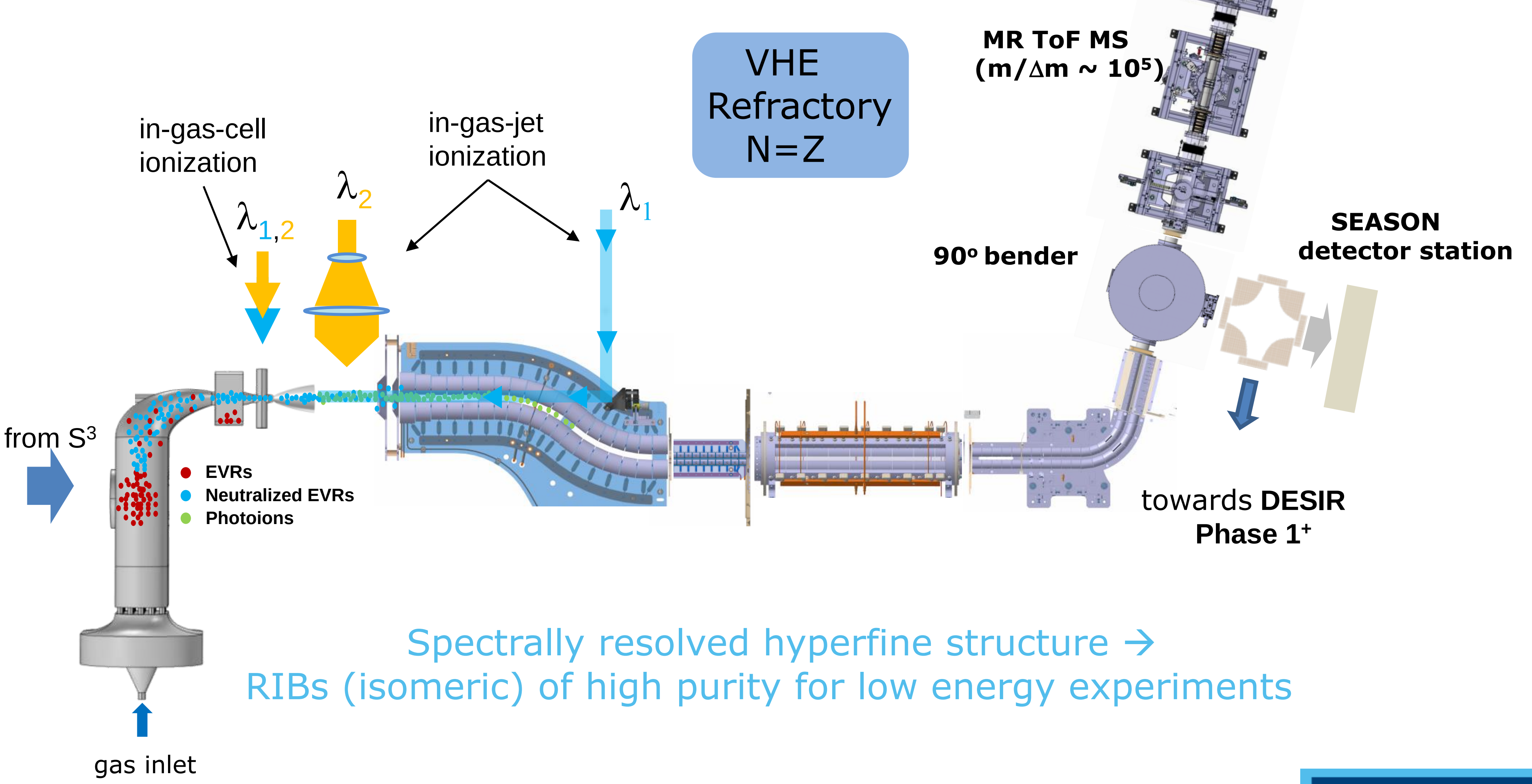
FISIC setup
Fast Ion Slow
Ion Collisions
Electron exchange



Ground state properties
(mass, size, moments, spins)

REGLIS^3 setup
Low Energy
Branch

S³- LEB Layout



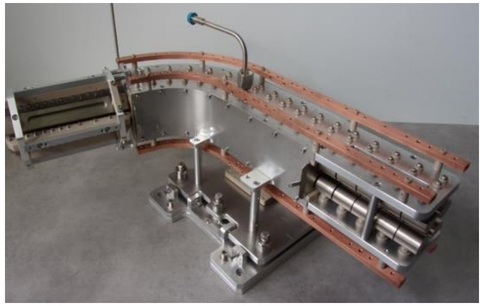
Spectrally resolved hyperfine structure → RIBs (isomeric) of high purity for low energy experiments

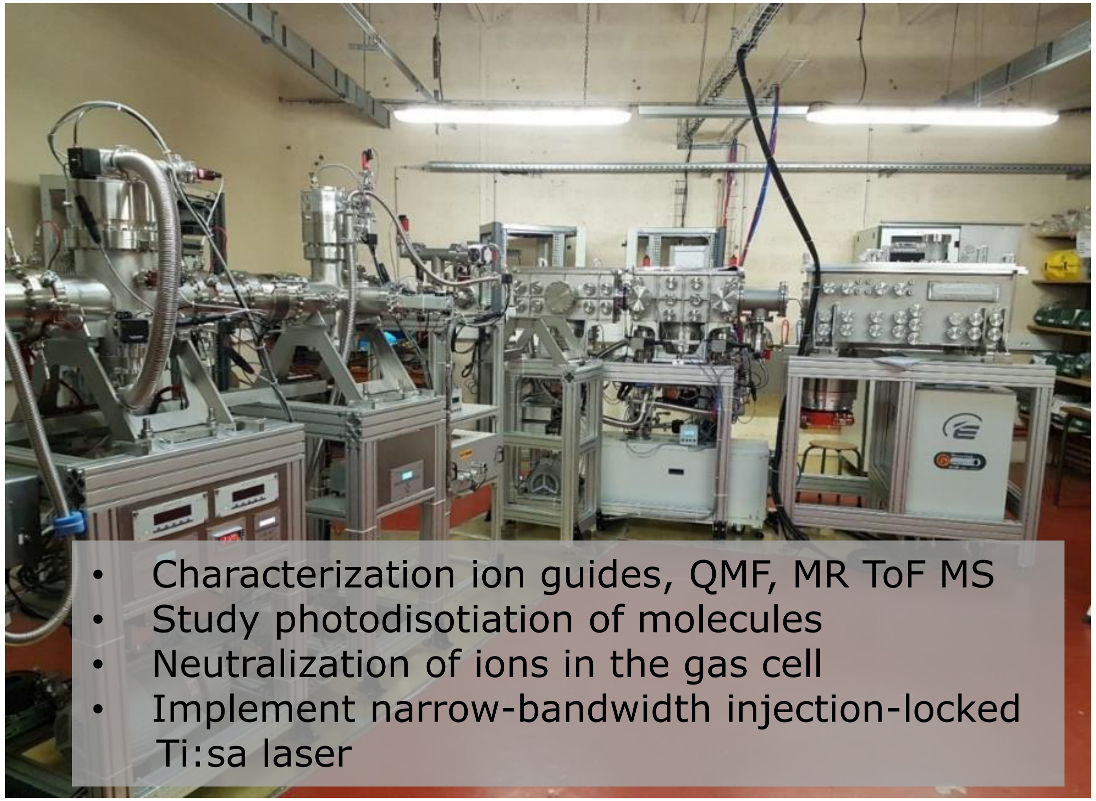
R. F. et al., NIM B 317 (2013) 570

Y. Kudryavtsev et al., NIM B297 (2013) 7

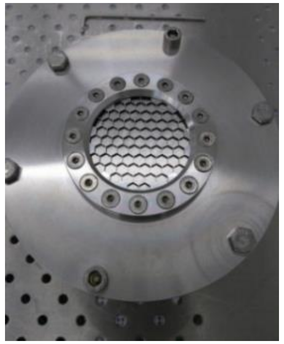
P. Chauveau et al. NIM B 376 (2016) 211

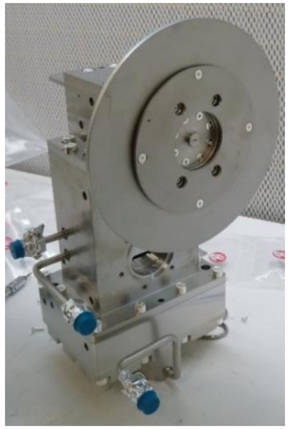
Offline commissioning at LPC

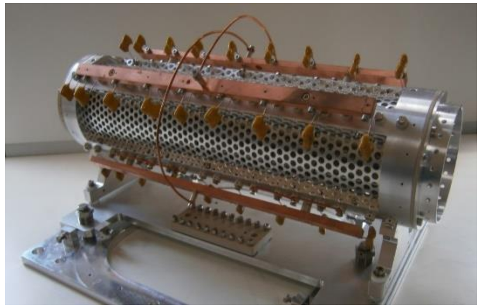


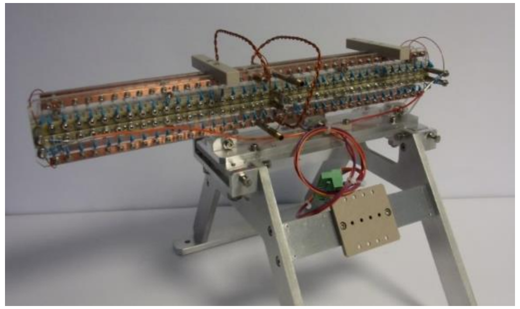


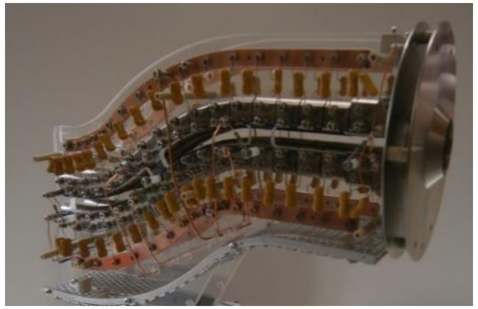
- Characterization ion guides, QMF, MR ToF MS
- Study photodisotiation of molecules
- Neutralization of ions in the gas cell
- Implement narrow-bandwidth injection-locked Ti:sa laser





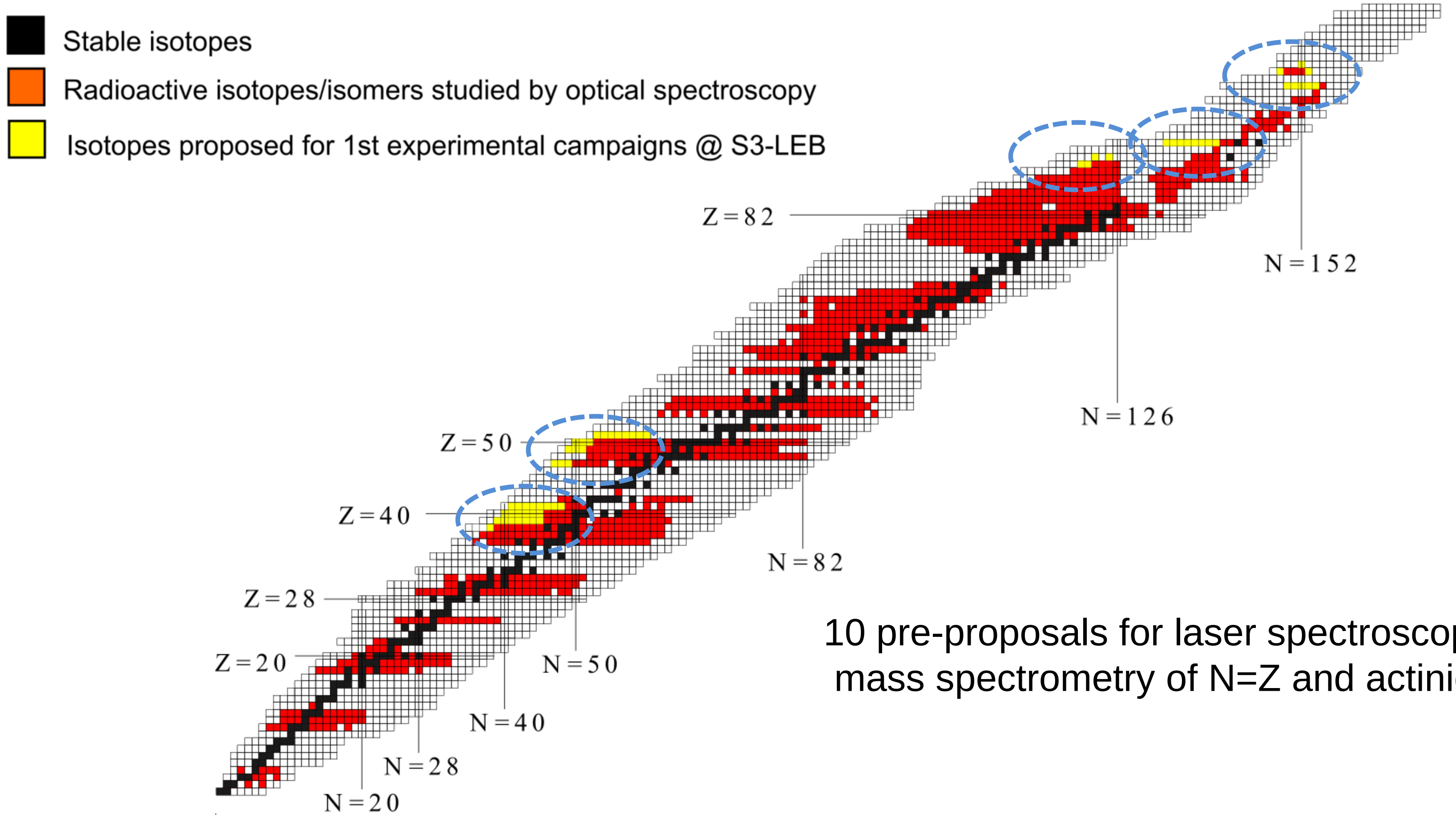






Courtesy N. Lecesne

First experimental campaigns S3-LEB



10 pre-proposals for laser spectroscopy and MR-ToF mass spectrometry of N=Z and actinide nuclei

First experimental campaigns S3-LEB (Actinides)

$^{209}Bi(^{48}Ca, xn)^{255}$**Lr**

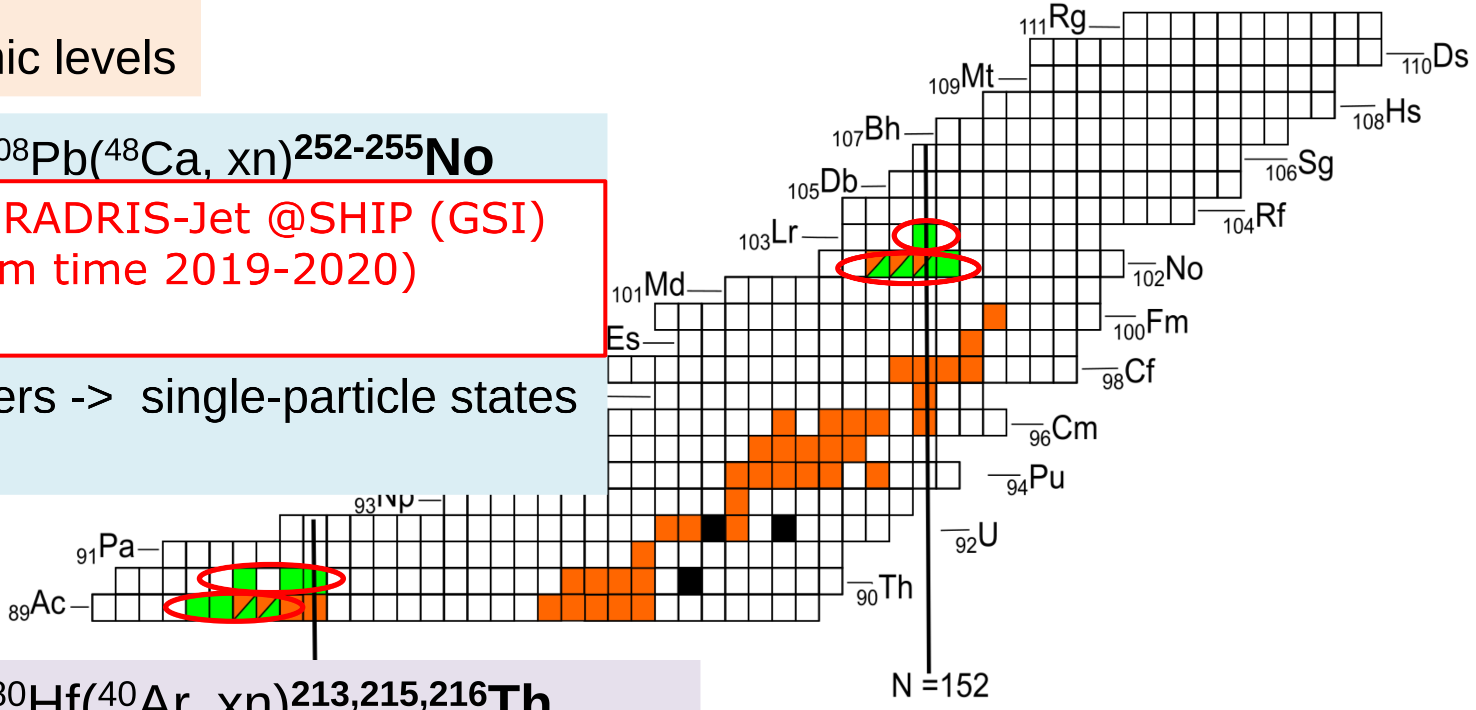
- Look for atomic levels

$^{206,208}Pb(^{48}Ca, xn)^{252-255}$**No**

In the meantime : RADRIS-Jet @SHIP (GSI)
(approved beam time 2019-2020)

- IGLIS on K isomers -> single-particle states

First REGLIS^3 experiments (**1 puA**)



$^{178,180}Hf(^{40}Ar, xn)^{213,215,216}$**Th**

- Check magicity of N=126 shell closure, observed to vanish in the uranium isotopes
- Probe nuclear structure near the proton drip line

$^{197}Au(^{20}Ne, xn)^{210-213}$**Ac**

- Extend high-resolution laser spectroscopy studies
- Refine atomic and nuclear structure predictions

Summary

- The In-Gas-Jet method is being optimized to study fusion evaporation reaction products

- IGLIS combines good efficiency and spectral resolution and is well suited for the study of heavy elements

- PLIF has been implemented and can be used to characterize local flow parameters → find the best nozzles for IGLIS studies

- Considering RIS as an alternative method to characterize flow parameters → (higher efficiency)

- Commissioning of REGLIS3 at LPC Caen is ongoing. A full off-line characterization of the setup along with a further optimization of the IGLIS technique are planned

Acknowledgments

KU Leuven

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Collaborators

S3-LEB:

M. Authier[2], F. Boumard[3], L. Caceres[1], J-F. Cam[3], S. Damoy[1], P. Delahaye[1], P. Desrue[3], A. Drouart[2], P. Duchesne[5], X. Fléchard[3], S. Franchoo[5], P. Gangnant[1], R. de Groote[7], N. Lecesne[1], R. Leroy[1], J. Lory[3], F. Lutton[1], Y. Merrer[3], I. Moore[7], B. Osmond[1], J. Piot[1], O. Pochon[5], B-M. Retailleau[1], H. Savajols[1], E. Traykov[8], J. Uusitalo[7], C. Vandamme[3], M. Vandebrouck[2] and K. Wendt[6]

[1]GANIL, CEA/DRF-CNRS/IN2P3, B.P. 55027, 14076 Caen, France, [2]IRFU, CEA-Saclay, 91191 Gif-sur-Yvette, France, [3]LPC Caen, Normandie Univ, ENSICAEN, UNICAEN, CNRS/IN2P3, 14000 Caen, France, [5]IPNO, Université Paris-Sud 11, CNRS/IN2P3 91406 Orsay, France, [6]Institut für Physik, Johannes Gutenberg-Universität Mainz, 55128 Mainz, Germany, [7]Department of Physics, University of Jyväskylä, PO Box 35 (YFL), Jyväskylä FI-40014, Finland, [8]IPHC, Université de Strasbourg, 67037 Strasbourg, France

GSI: H. Grawe, S. Raeder

JoGu and Helmholtz-Institut Mainz:
M. Block, P. Chhetri, R. Heinke, M. Laatiaoui, T. Murböck, P. Naubereit, S. Nothhelfer, F. Schneider, K. Wendt

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