Optimization of in-gas laser spectroscopy setup at S^3-LEB

LISA conference - 02/09/2024

Anjali Ajayakumar

LISA
LASER IONISATION AND SPECTROSCOPY OF ACTINIDES

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

Outline

Experimental setup
- S^3-LEB facility

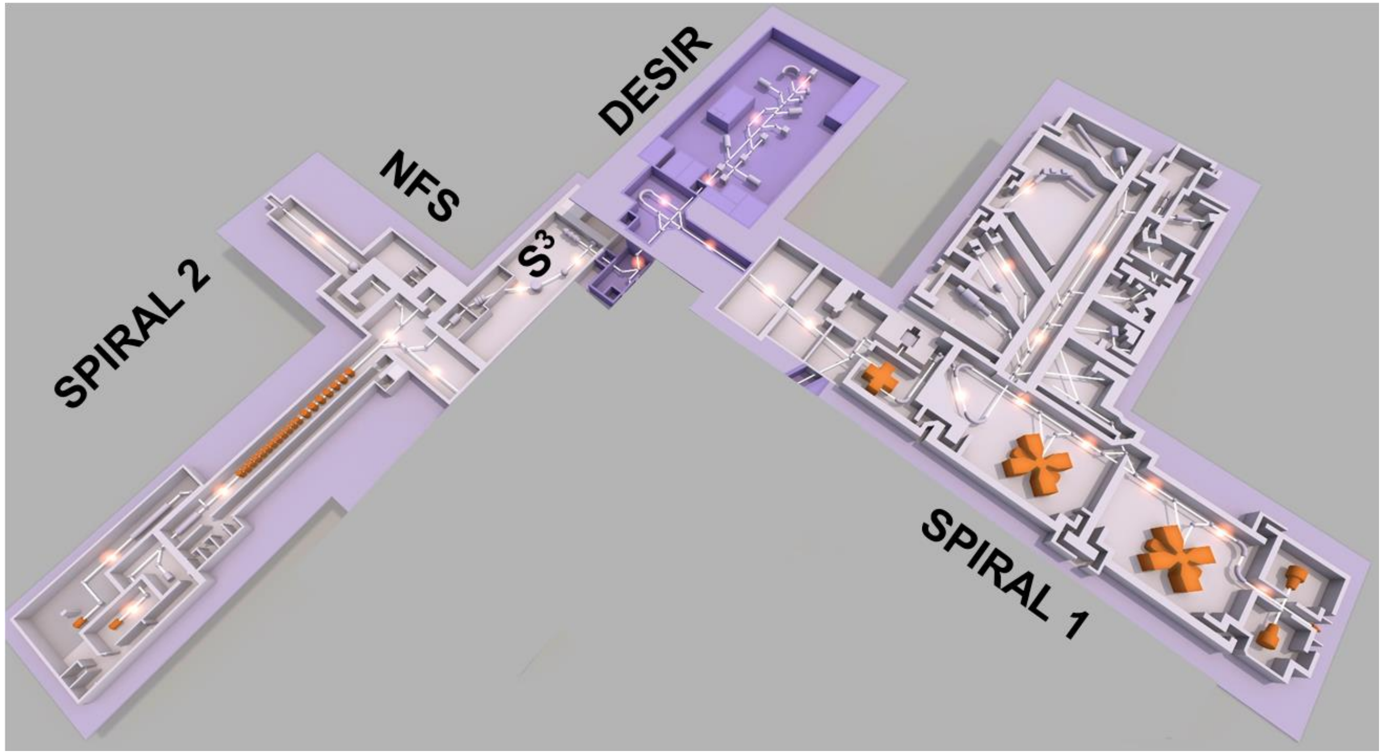
Experimental tests & results
- Offline commissioning tests and results of S^3-LEB

Laser development
- Development of a continuous wave diode pumped Ti: sapphire laser system

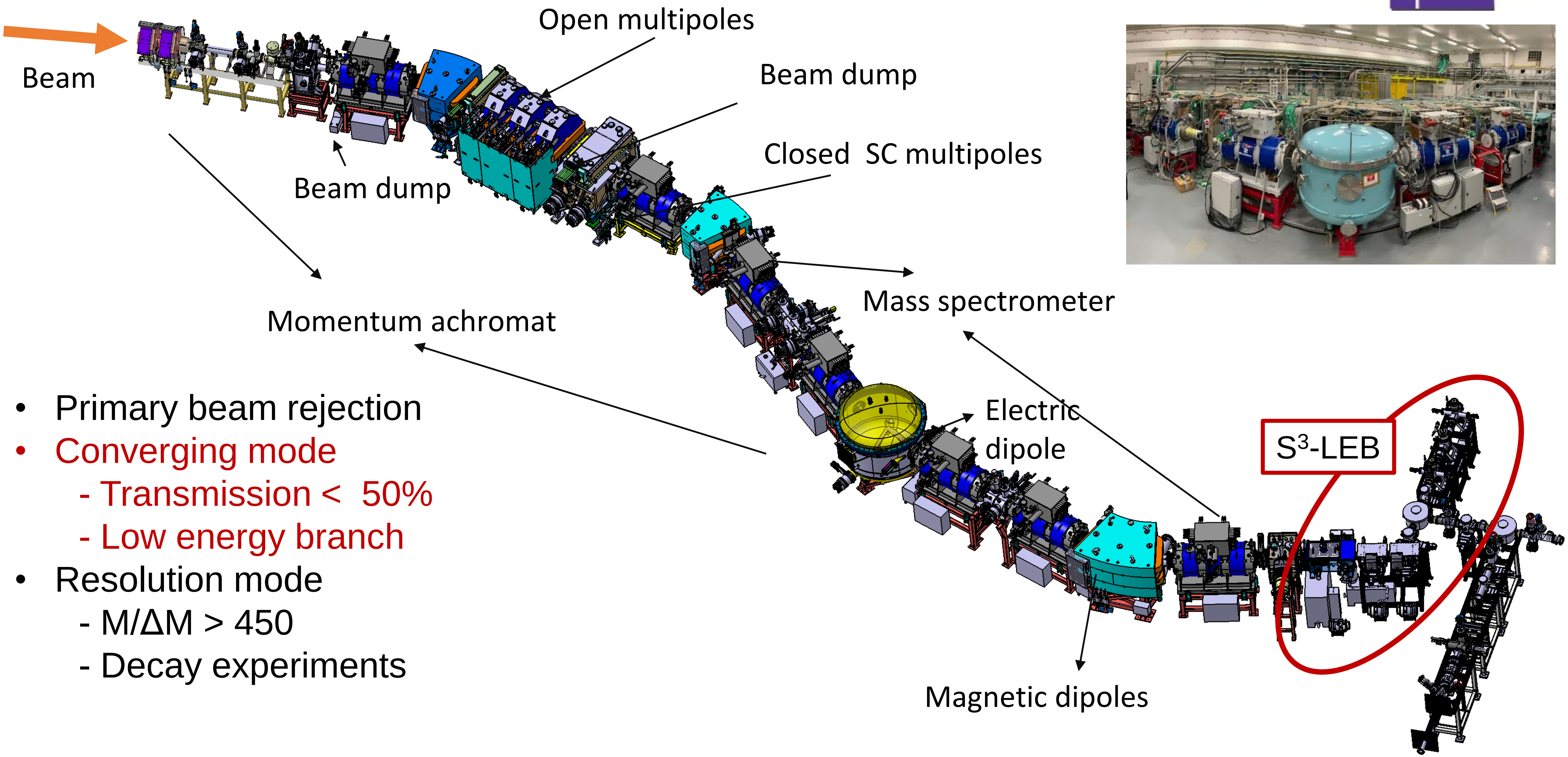
Conclusion
- Summary and outlook

GANIL- SPIRAL2 facility

- Aim to deliver high intensity primary beams from H to U (>1pµA)
- Delivery of beam to NFS in operation
- S3: Nuclear fusion evaporation to produce exotic nuclei



Super Separator Spectrometer (S^3)

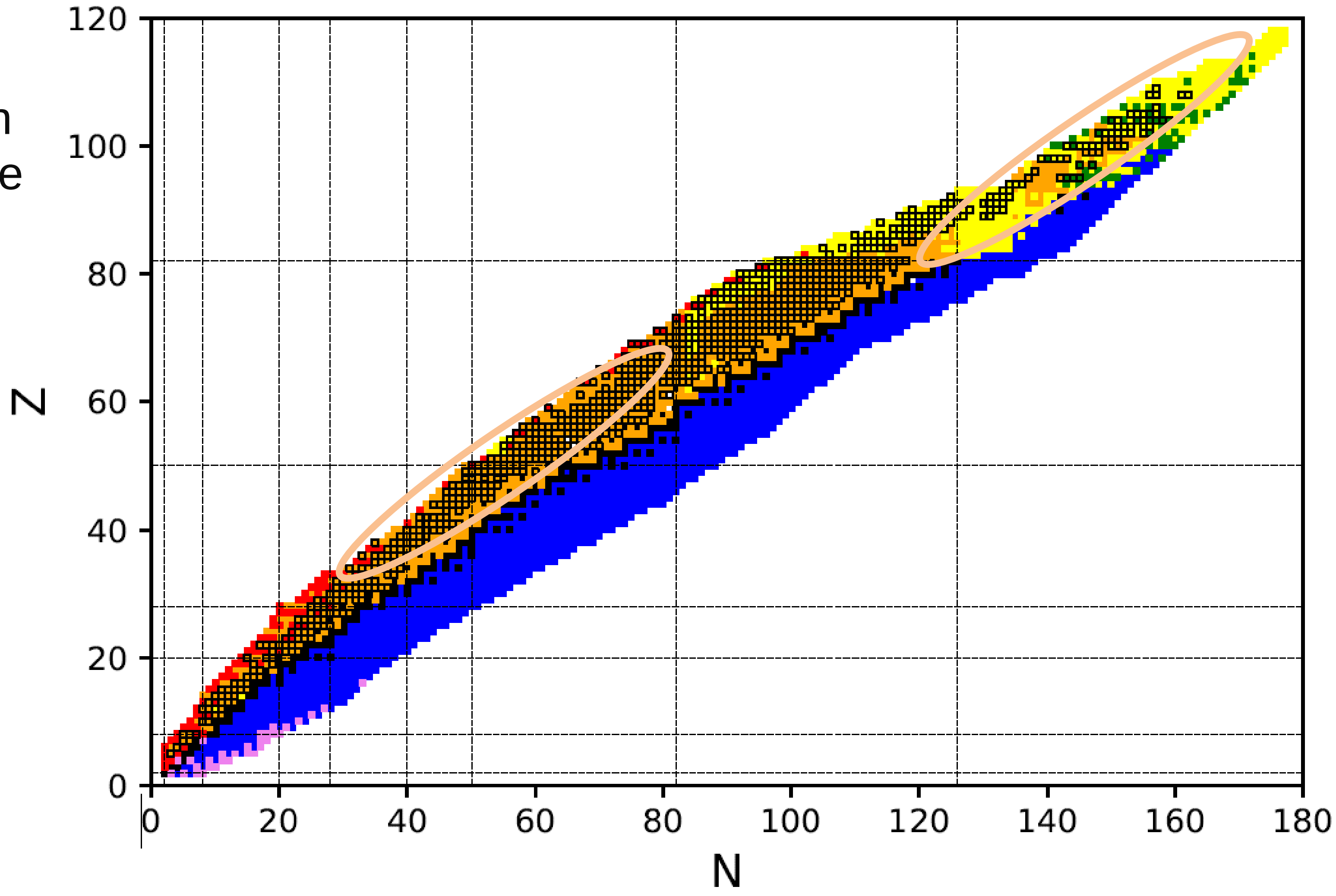


- Primary beam rejection
- Converging mode
  - Transmission < 50%
  - Low energy branch
- Resolution mode
  - M/ΔM > 450
  - Decay experiments

Super Separator Spectrometer (S^3)

laboratoire commun CEA/DRF CNRS/IN2P3

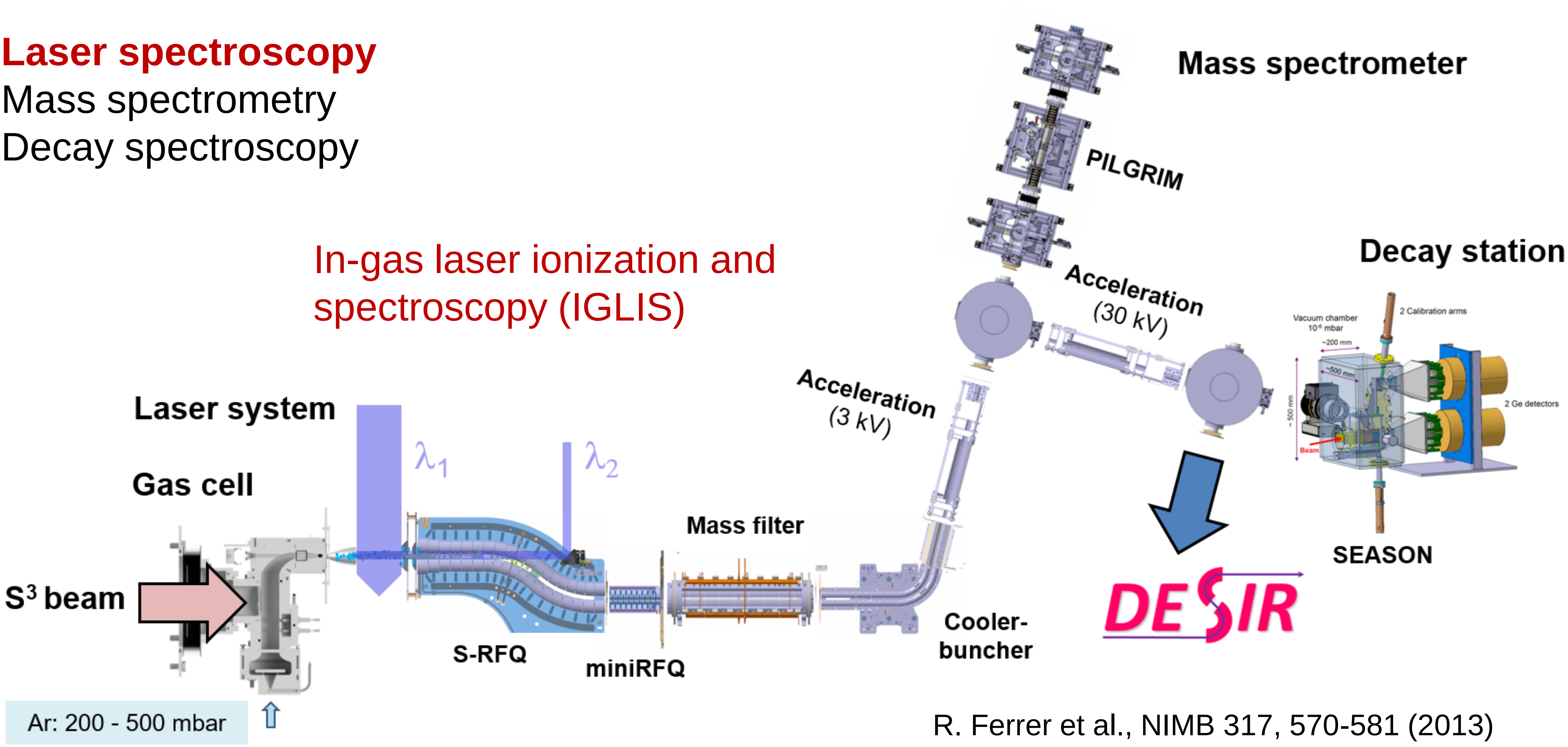
- Laser spectroscopy on the neutron deficient nuclei near the N=Z region and the heavy regions of the nuclide chart
- Mass measurements
- Decay spectroscopy
- Provide exotic beams for high precision measurements at DESIR



S3-LEB

- **Laser spectroscopy**
- Mass spectrometry
- Decay spectroscopy

In-gas laser ionization and spectroscopy (IGLIS)



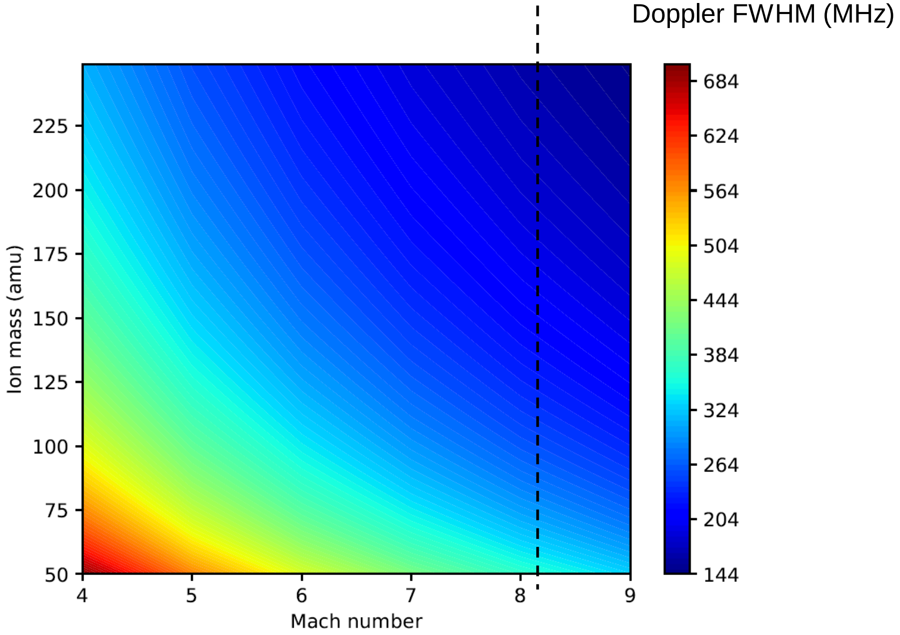
R. Ferrer et al., NIMB 317, 570-581 (2013)
J. Romans et al., Atoms 10, 21 (2022)
A. Ajayakumar et al., NIMB 539, 102-107 (2023)

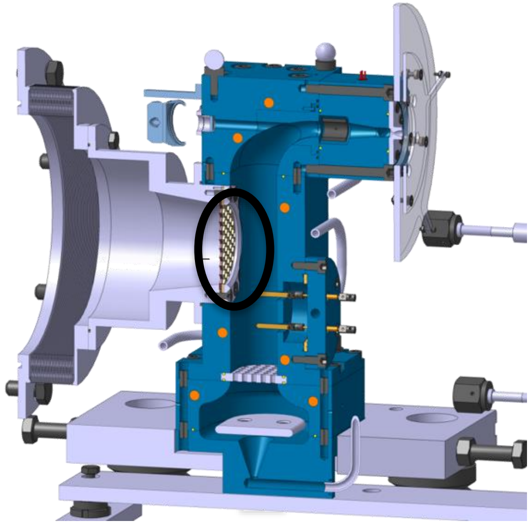
In-gas laser ionization and spectroscopy

Gas cell
- Broadening effects
- Broad band laser (GHz)

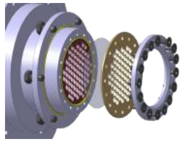
de Laval nozzle
- Hypersonic gas jet:

  ρ ↓ & T ↓
- Narrow band laser (MHz)

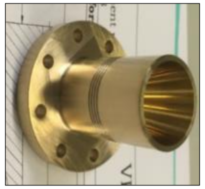




Buffer gas: Ar

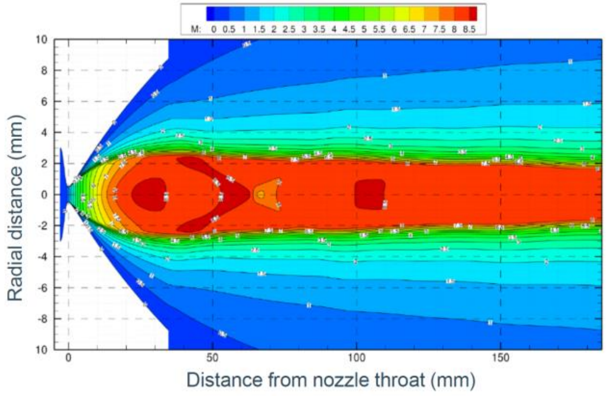


Entrance window Ti, Mylar
- 1-5 µm foils
- Dedicated test bench

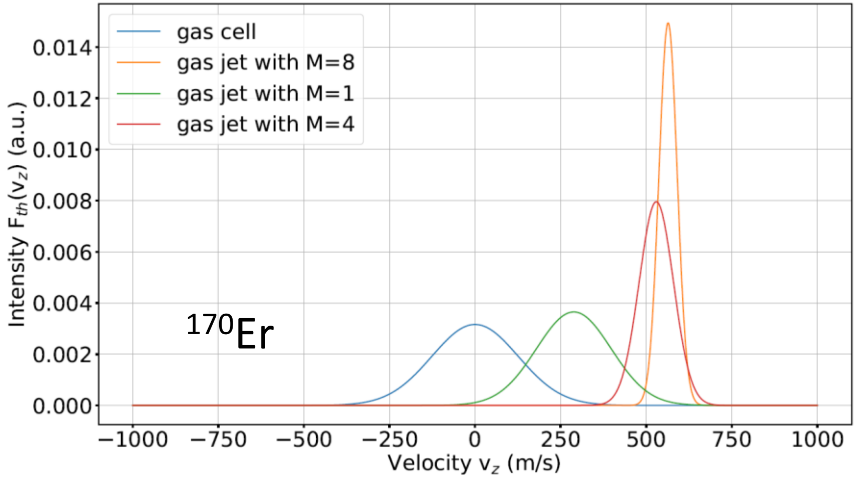


de Laval nozzle

M=8



Mach number: $M = \frac{Jet\ velocity\ (u)}{Speed\ of\ sound\ (a)}$



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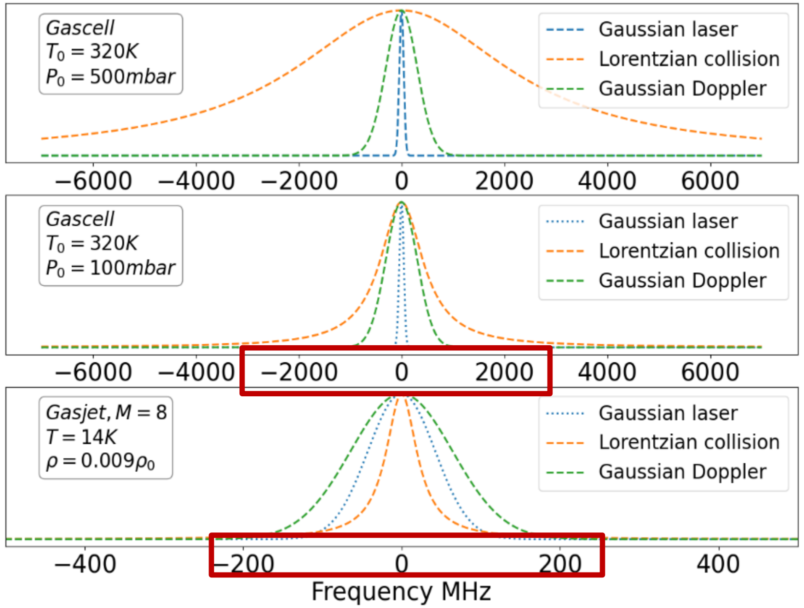

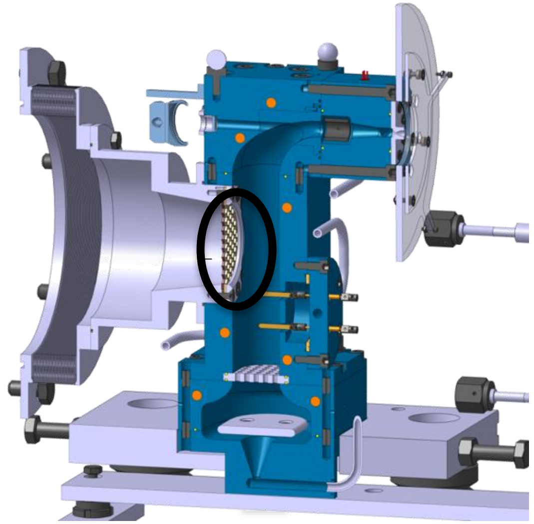

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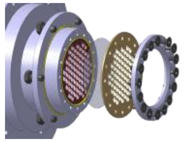

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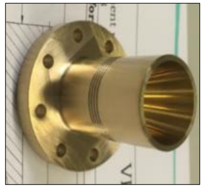

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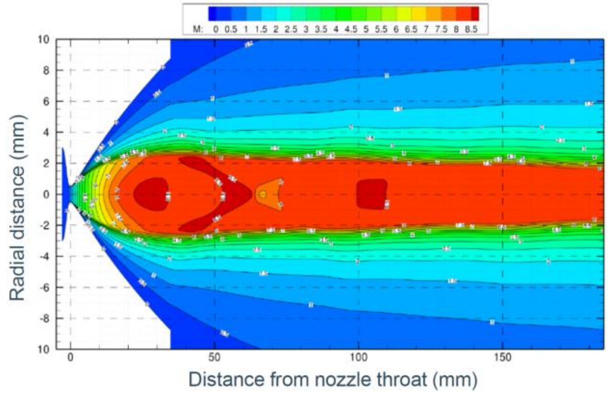

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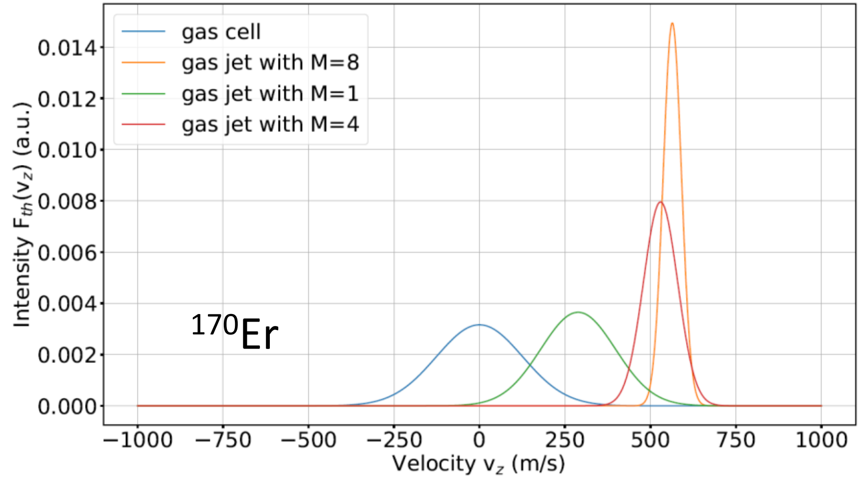

In-gas laser ionization and spectroscopy

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- Hypersonic gas jet:

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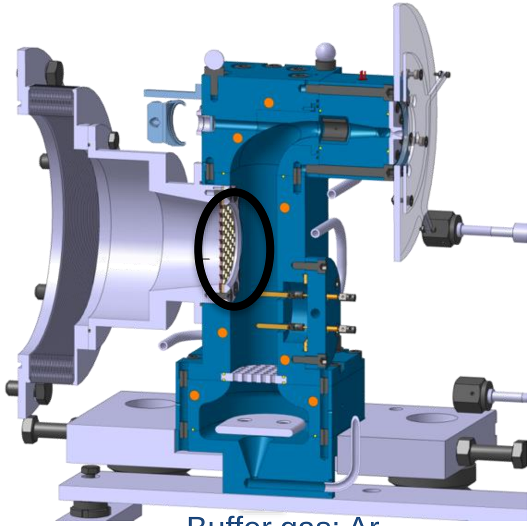
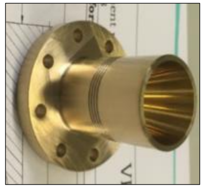
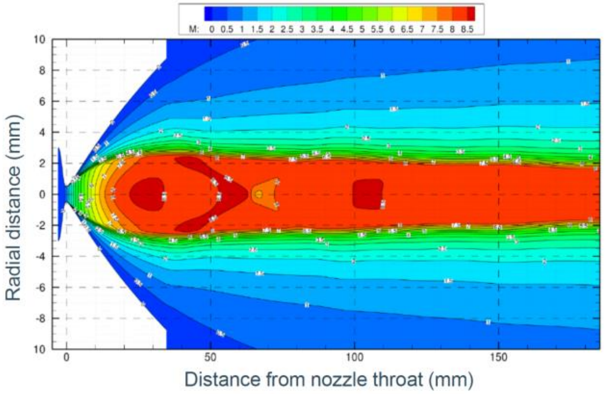
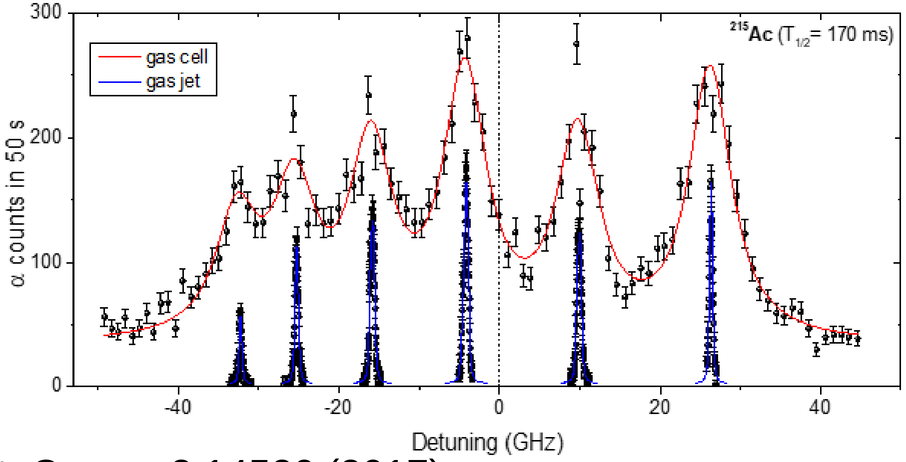
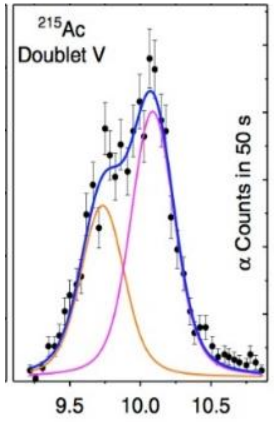










R. Ferrer et al., Nat. Comm. 8.14520 (2017)

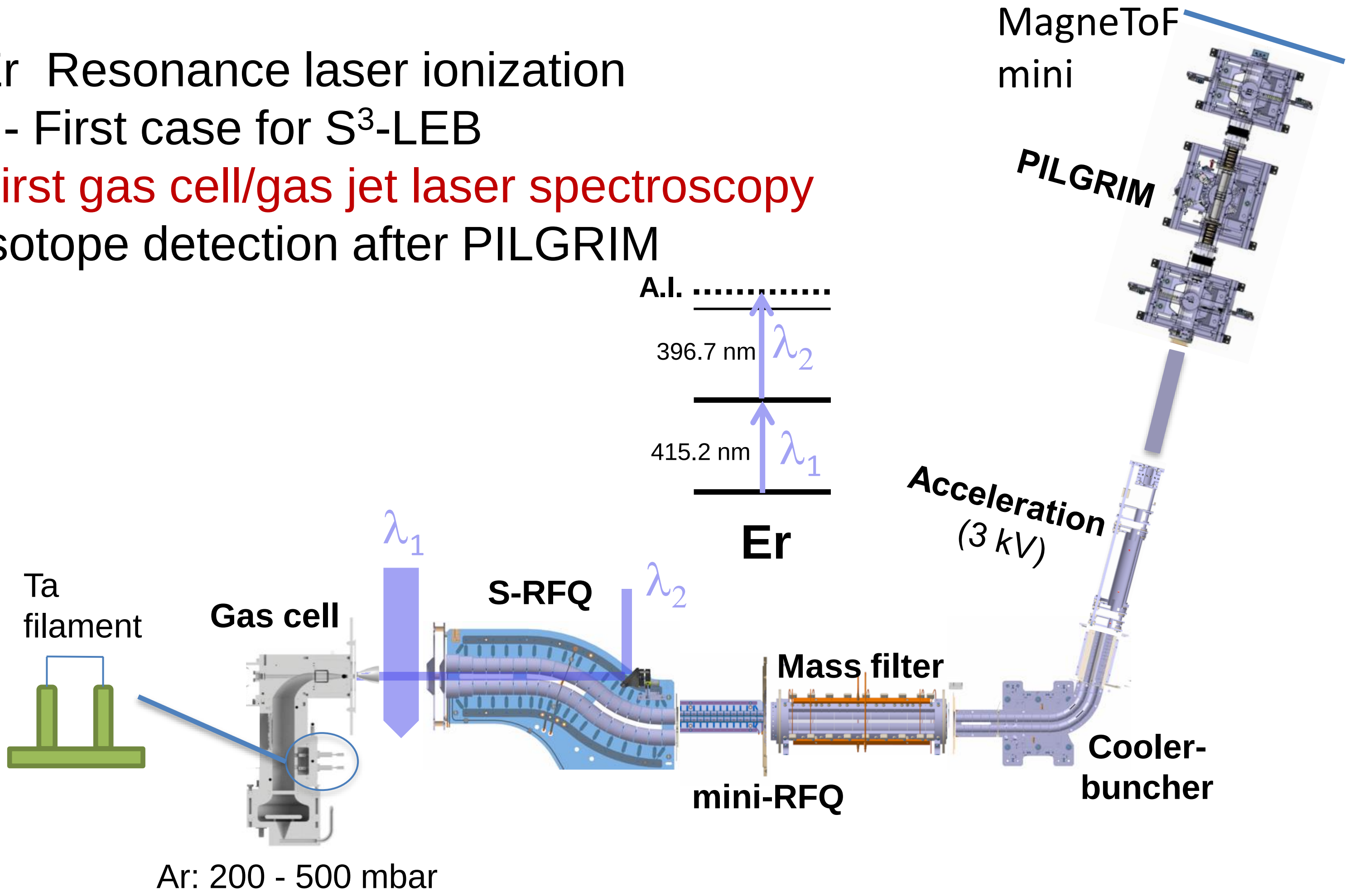
R. Ferrer et al., Phy Rev. Res. 3, 043041 (2021)

OUTLINE

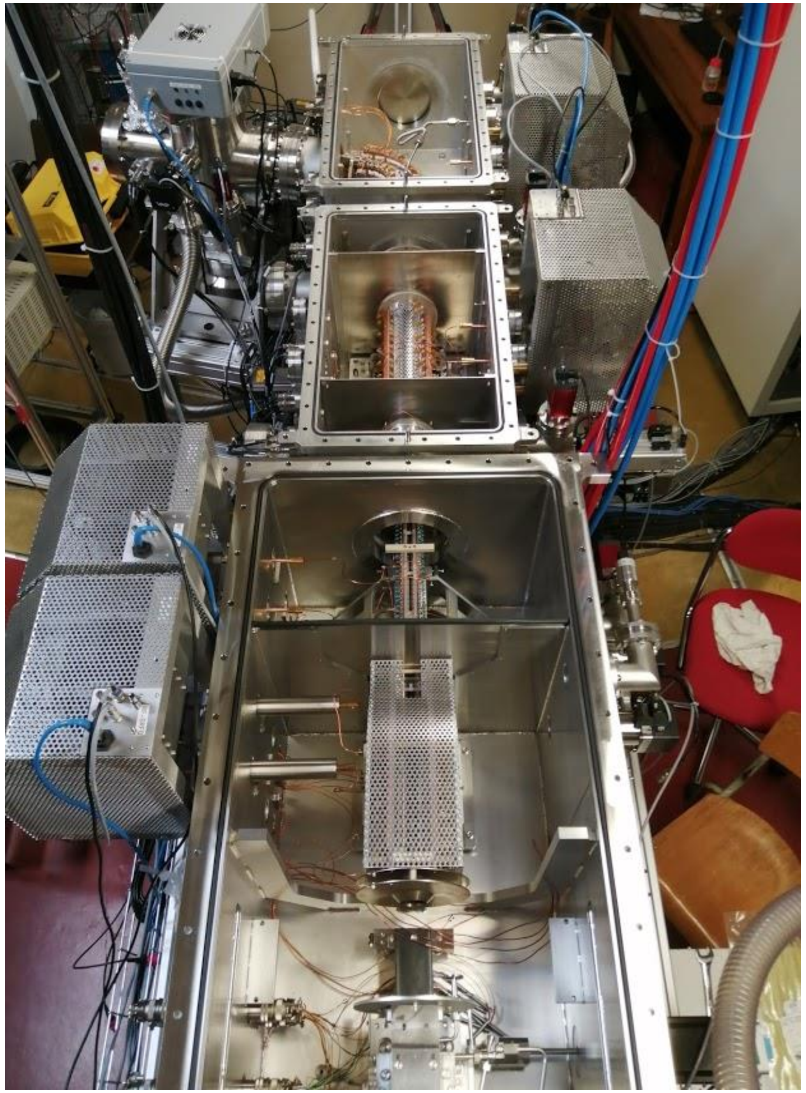
Introduction	• Laser spectroscopy for nuclear physics
Experimental setup	• S^3-LEB facility
Experimental setup	• Offline commissioning tests and results of S^3-LEB
Technical development	• Development of a continuous wave diode pumped Ti: sapphire laser system
Conslusion	• Summary and outlook

OFFLINE commissioning

- Er Resonance laser ionization
  - First case for S^3-LEB
- First gas cell/gas jet laser spectroscopy
- Isotope detection after PILGRIM



J. Romans et al., Atoms 10, 21 (2022)
A. Ajayakumar et al., NIMB 539, 102-107 (2023)



Laser system for S^3-LEB

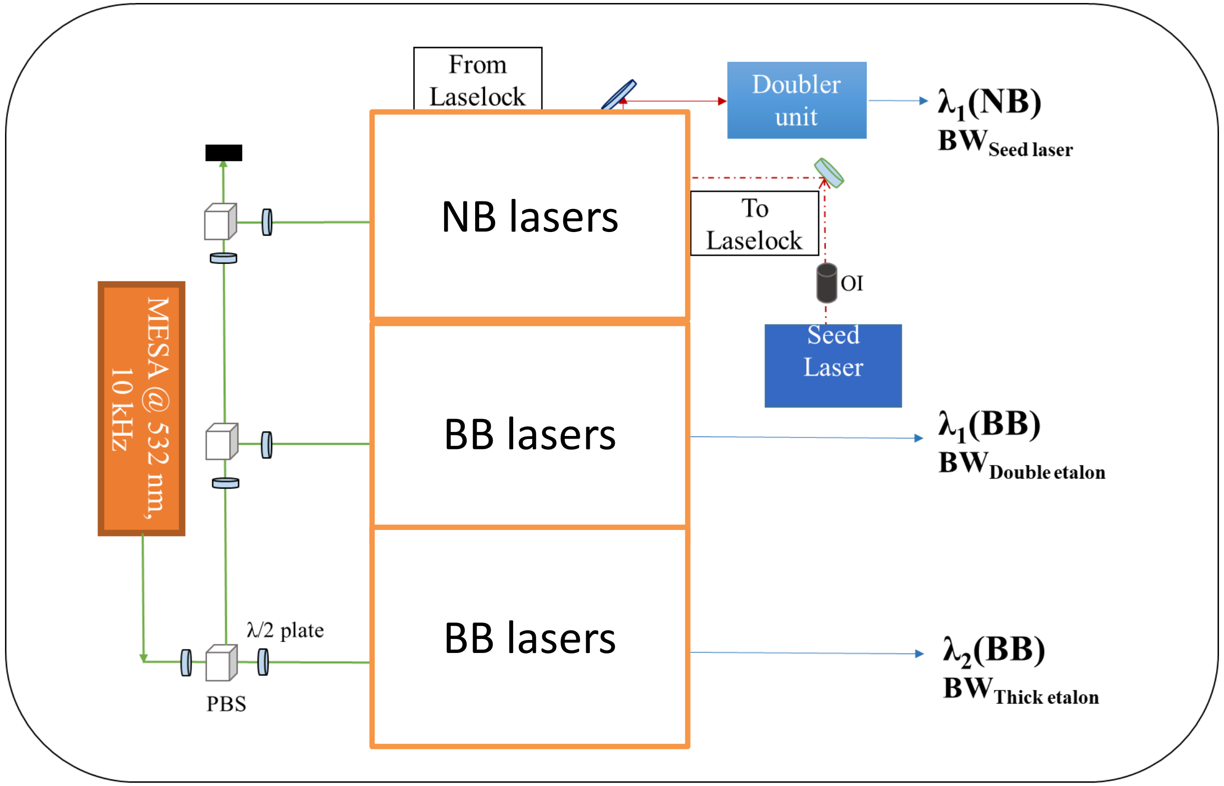
- Laser systems were installed for commissioning

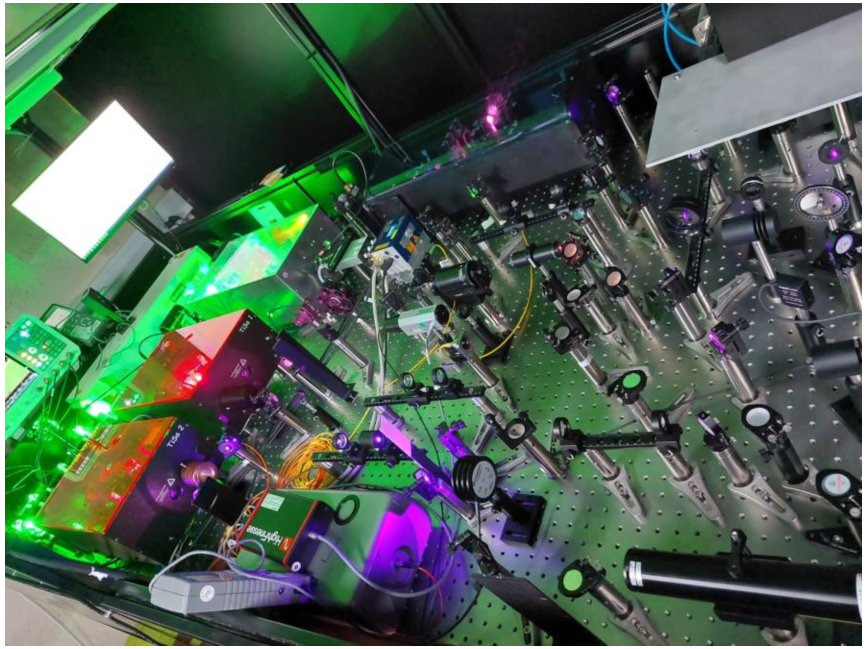
    Gas cell laser ionization:

  - Broadband Ti:sa laser (1.5 - 2 GHz)

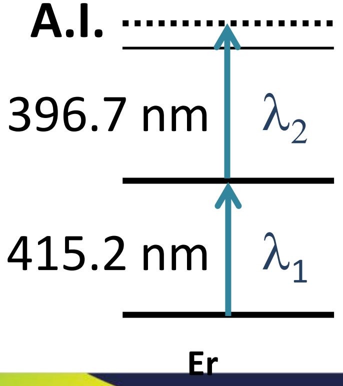
    Gas jet laser ionization:

  - Narrowband Injection locked laser (35 MHz)





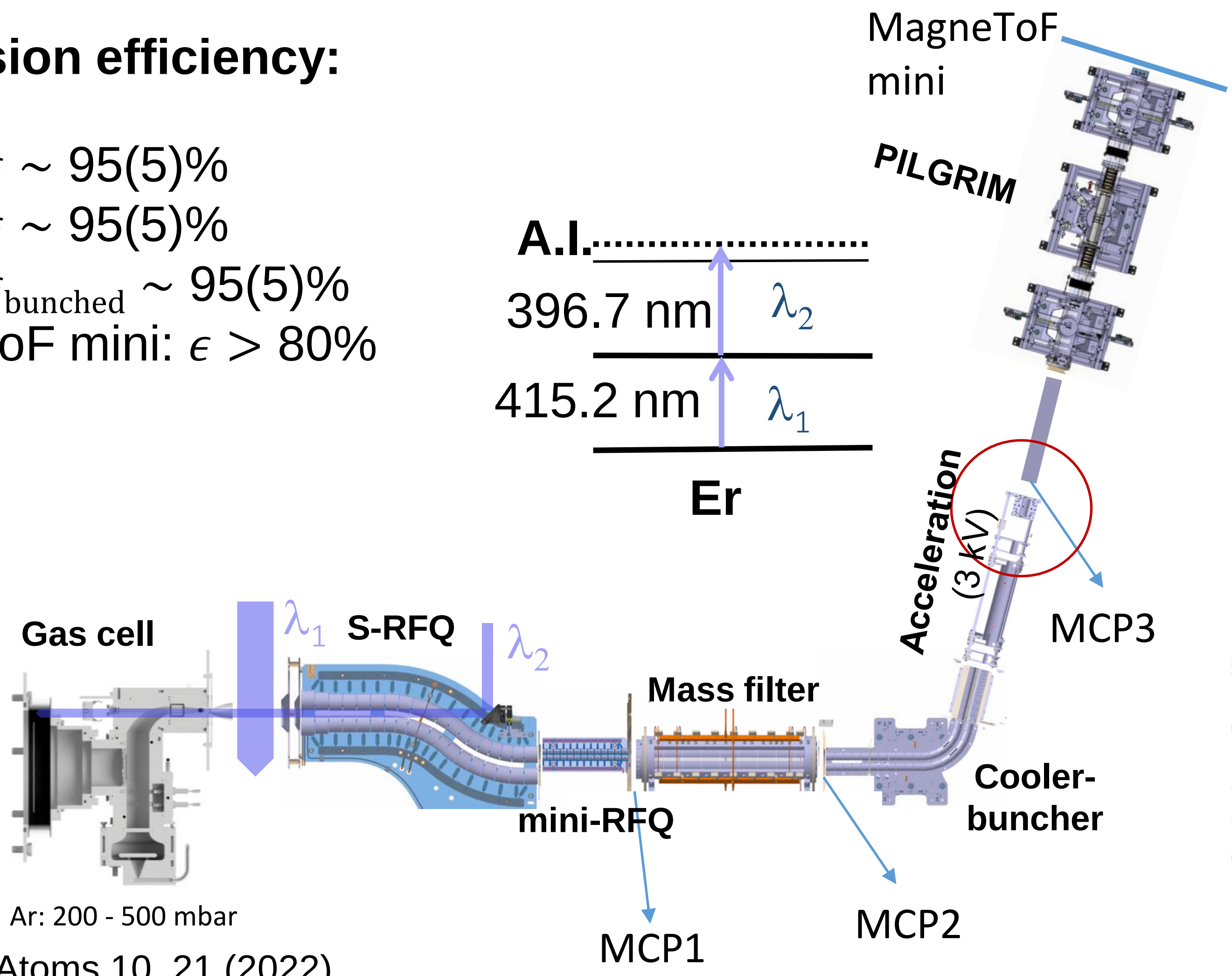
Titanium sapphire lasers installed at LPC

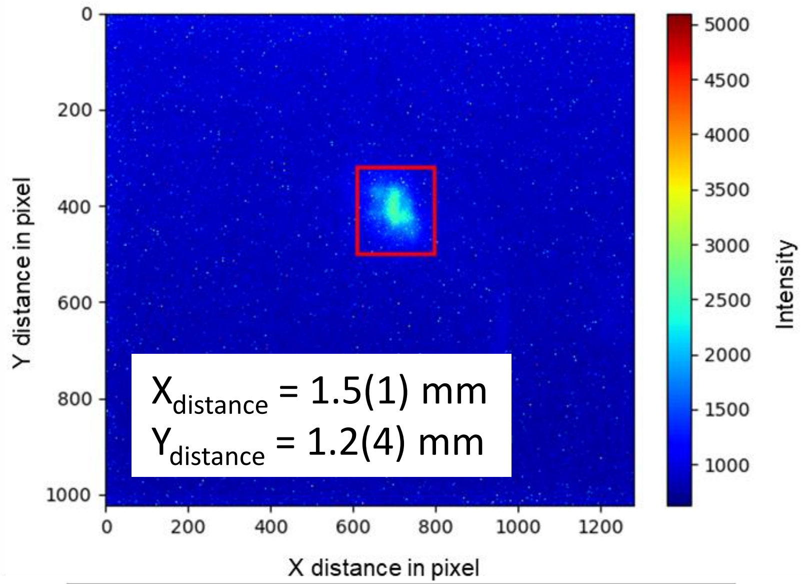


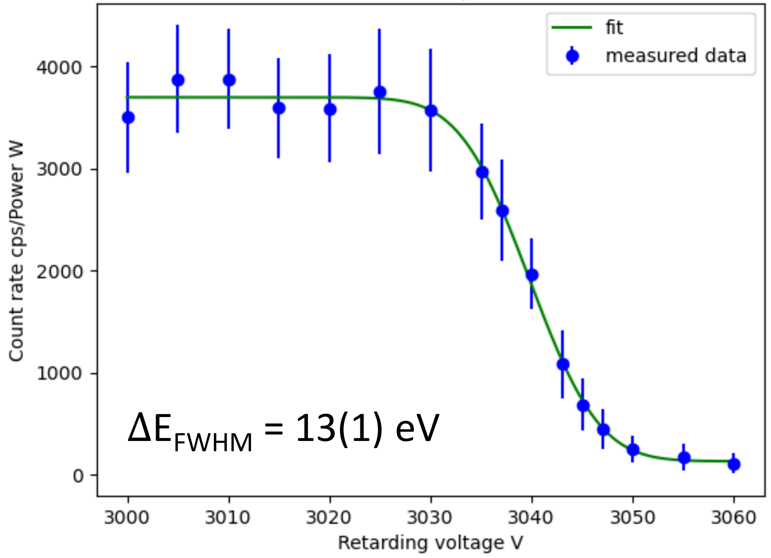
Ion transport towards PILGRIM

Transmission efficiency:

- MCP1: $\epsilon \sim 95(5)\%$
- MCP2: $\epsilon \sim 95(5)\%$
- MCP3: $\epsilon_{\mathrm{bunched}} \sim 95(5)\%$
- MagneToF mini: $\epsilon > 80\%$







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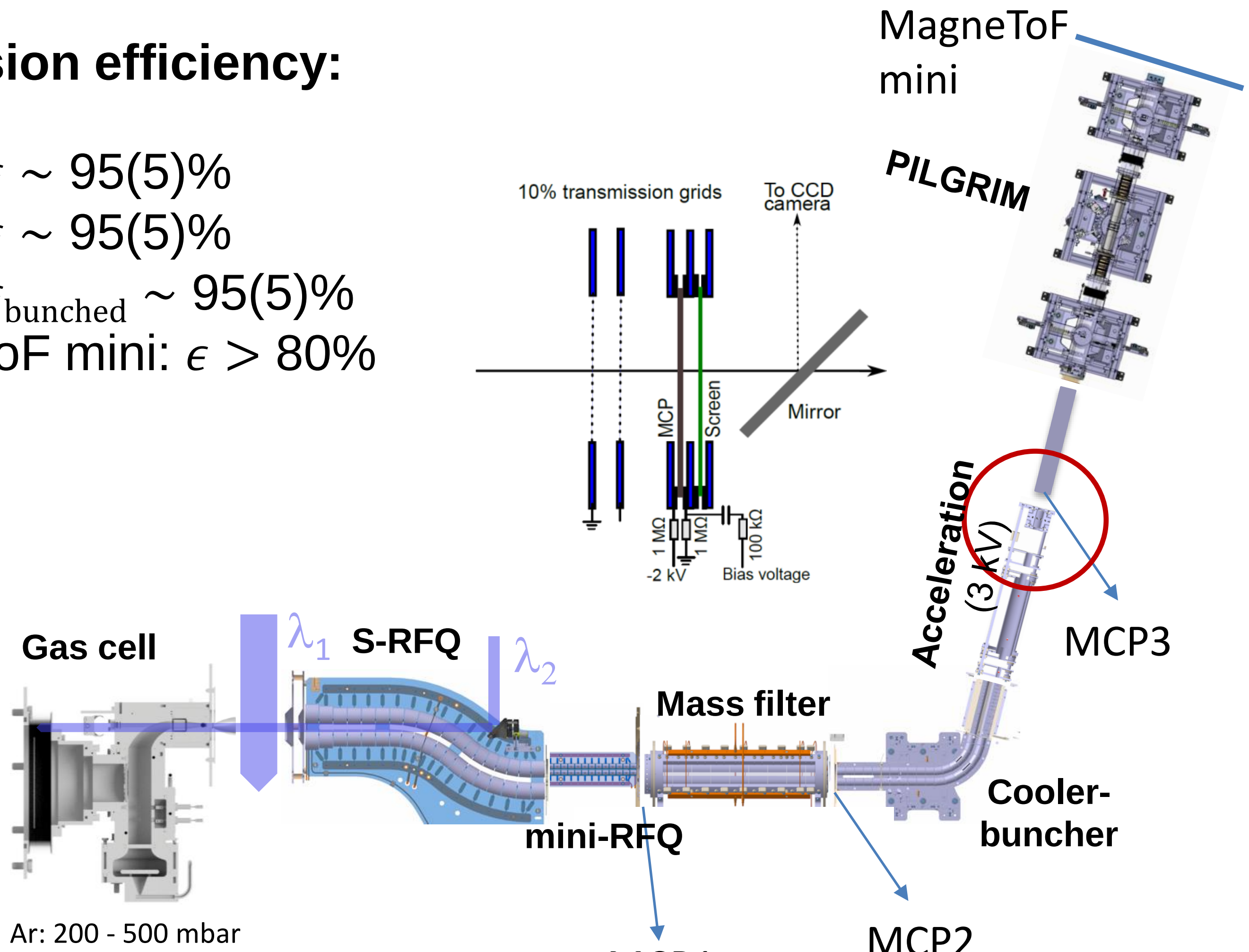

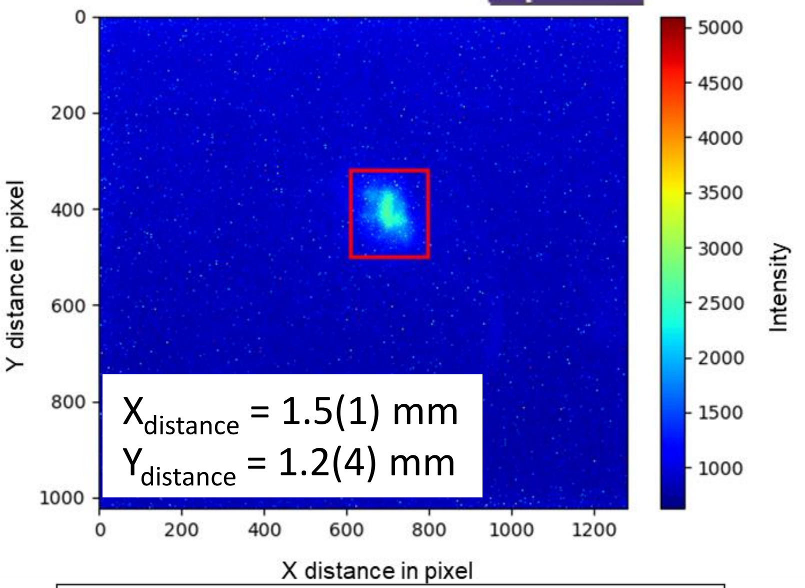

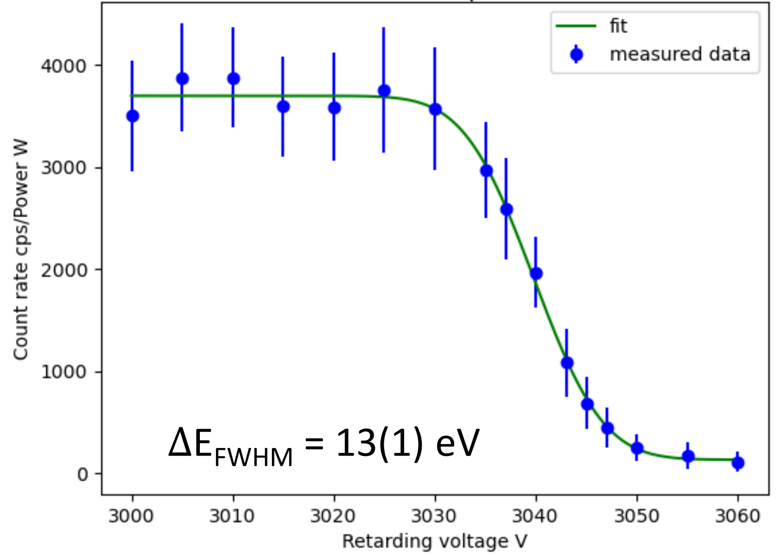

J. Romans, et al., Atoms 10, 21 (2022)
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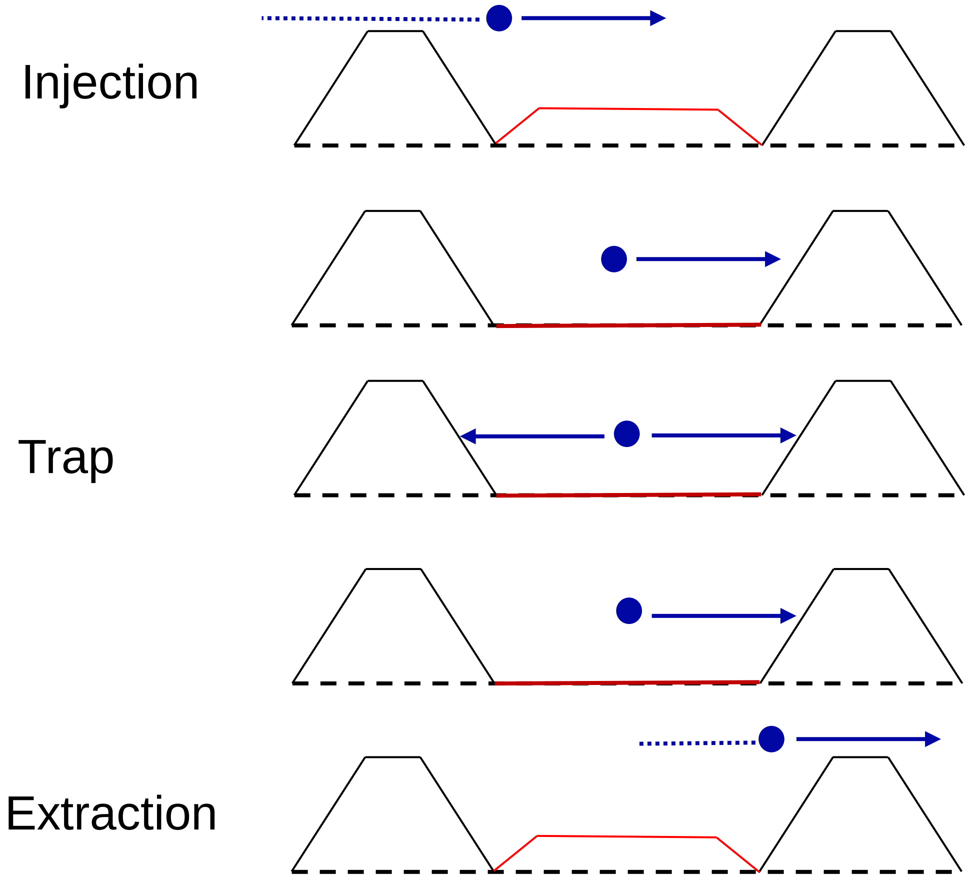
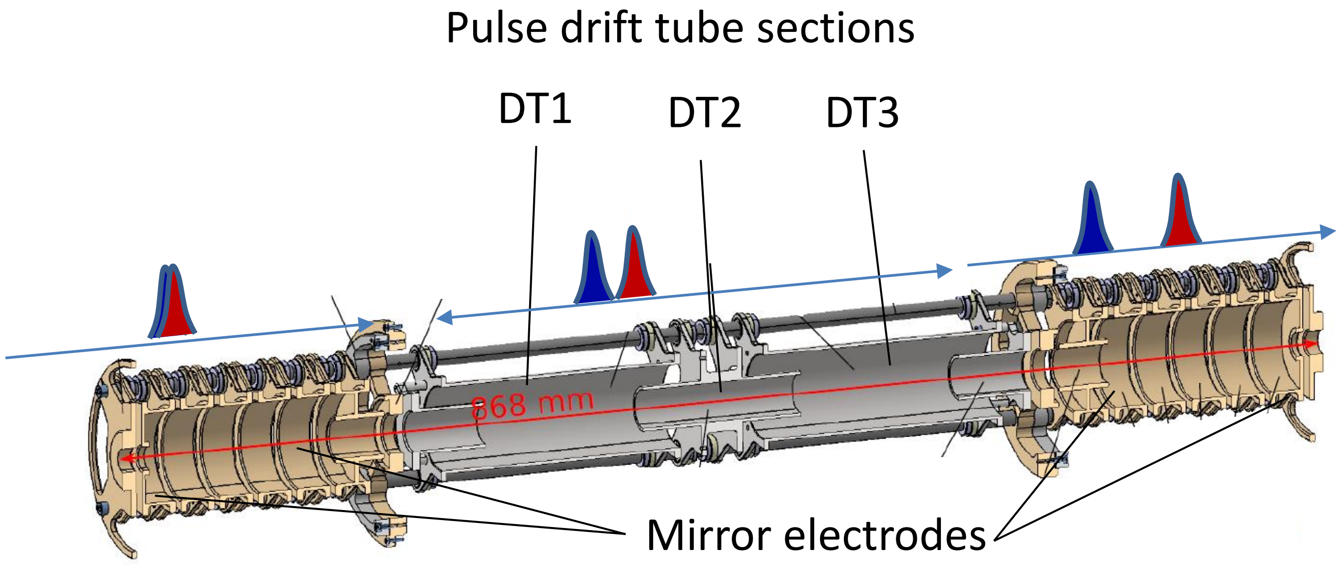
PILGRIM:MR-TOF-MS

Multi reflection time of flight spectrometer

- In trap lift method



P. Chauveau et al., NIMB 376, 211-215 (2016)
B. M. Ratailleau, Ph.D. Thesis (2021)
Y. Balasmeh, Master Thesis (2022)



- M/ΔM >100000 with alkali ion sources with BNG

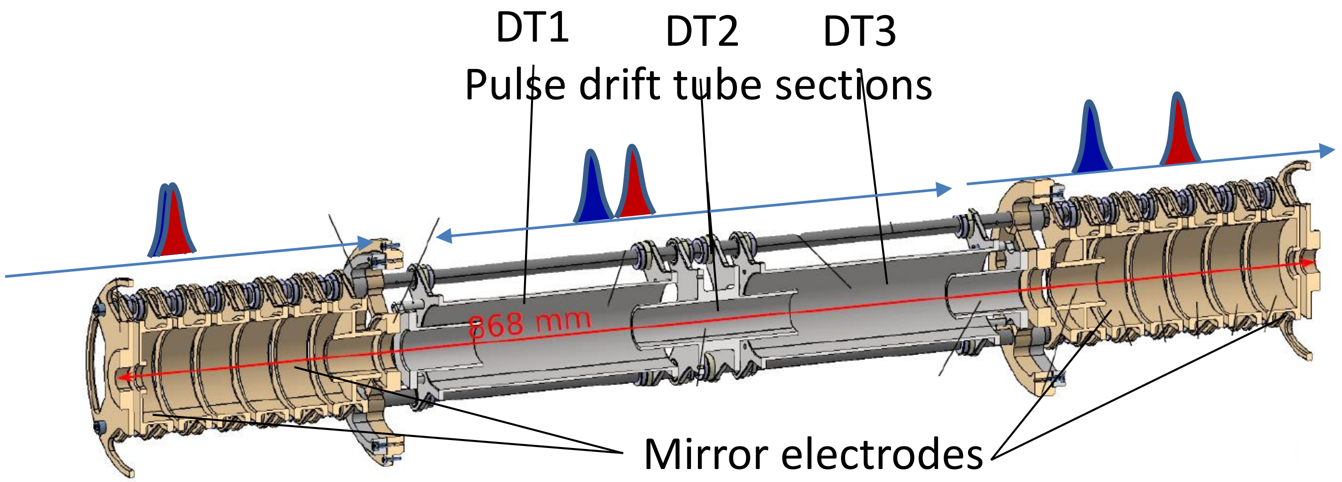
Test with $^{170,166,168}Er$ ions

- M/ΔM ~ 80000
- Future: Active voltage stabilization optimization to reach M/ΔM ~300000
- Buncher /PILGRIM optimization for transmission

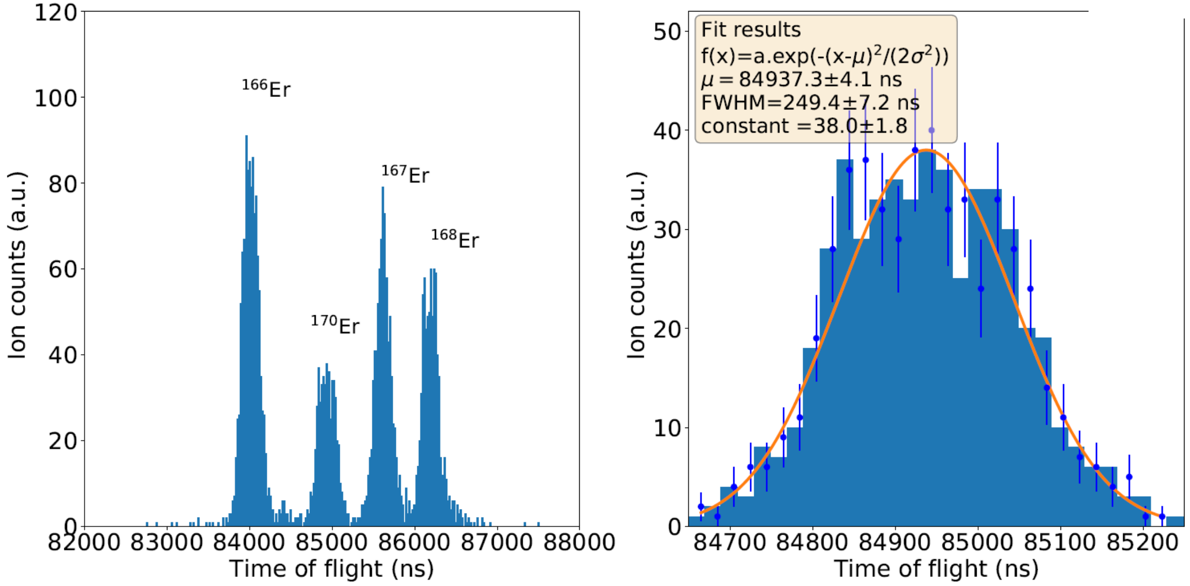
PILGRIM: MR-TOF-MS

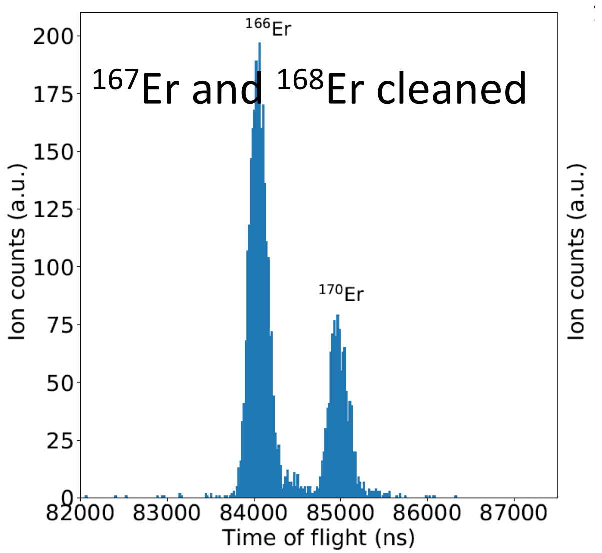
Cleaning of contaminants

- Appropriate number of turns
- Using drift tube sections for extraction at different turns



TOF at 1000 turns for ^{170}Er





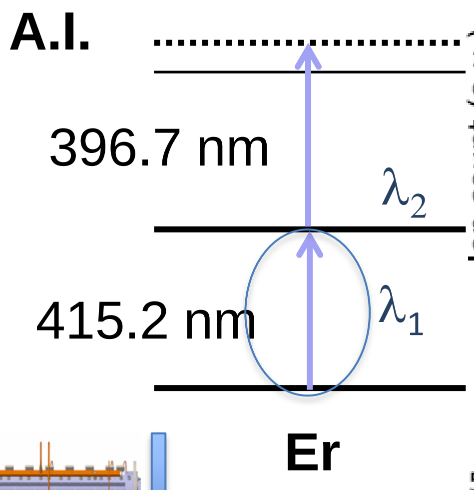
Laser spectroscopy with S^3-LEB

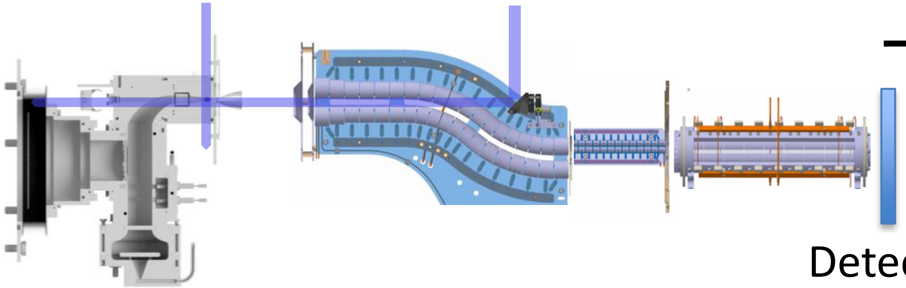
laboratoire commun CEA/DRF CNRS/IN2P3

- In-gas-cell laser spectroscopy
  - ✓ Spectral resolution
  - ✓ Pressure broadening studies
  - ✓ Collision effects
- In-gas-jet laser spectroscopy
  - ✓ Spectral resolution
  - ✓ Isotope shift and hyperfine parameters
  - ✓ Gas jet characterization

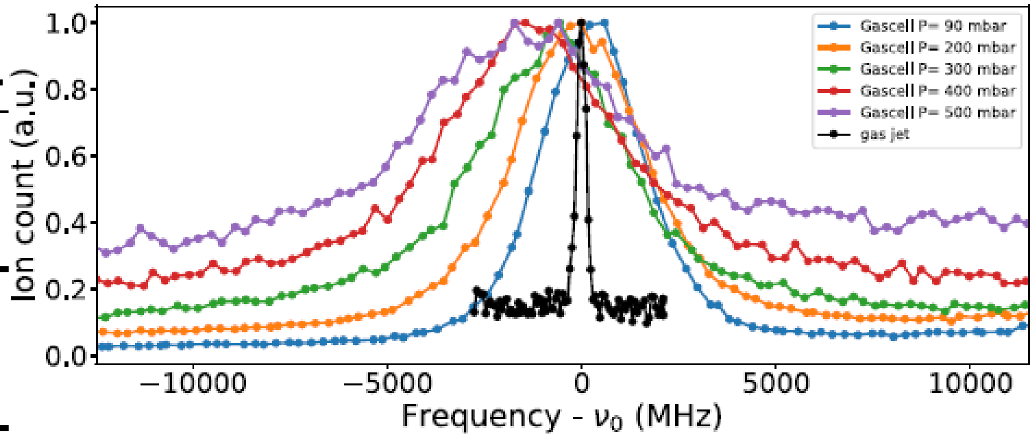
In-gas cell laser spectroscopy

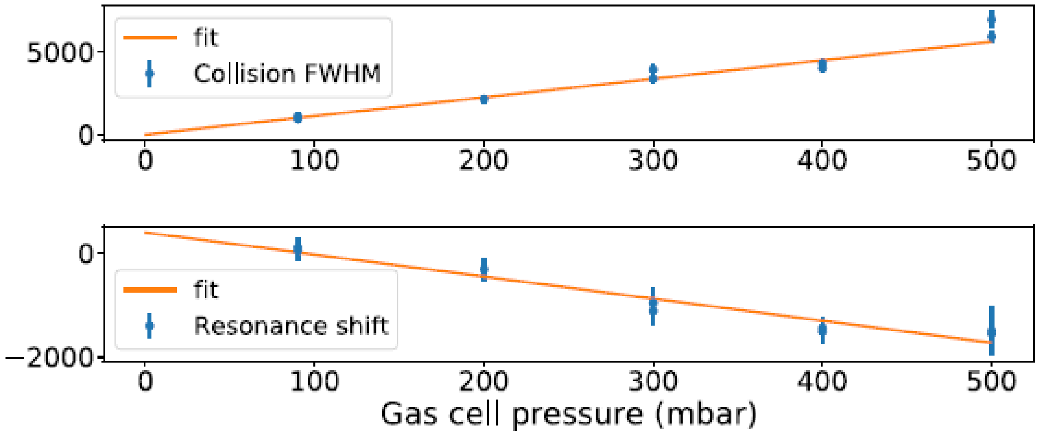
- Er I Resonance laser ionization
- In gas cell laser ionization
  Dual etalon laser
  ~ 1.8 GHZ FWHM
- Pressure broadening studies





Ar: 200 - 500 mbar



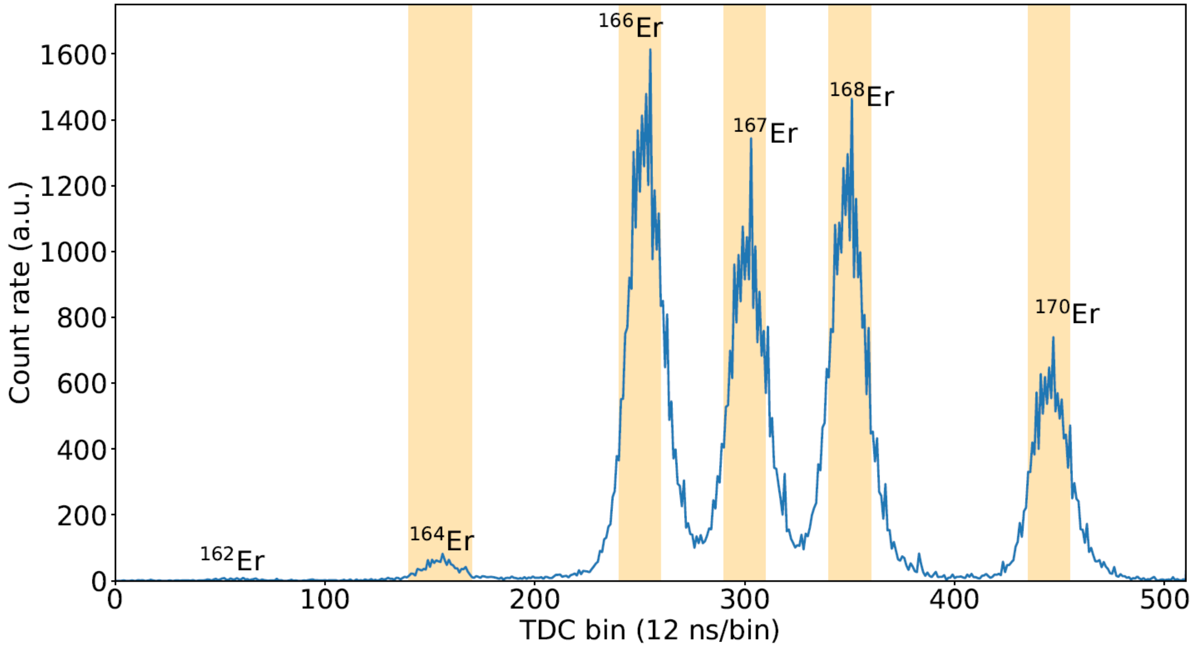


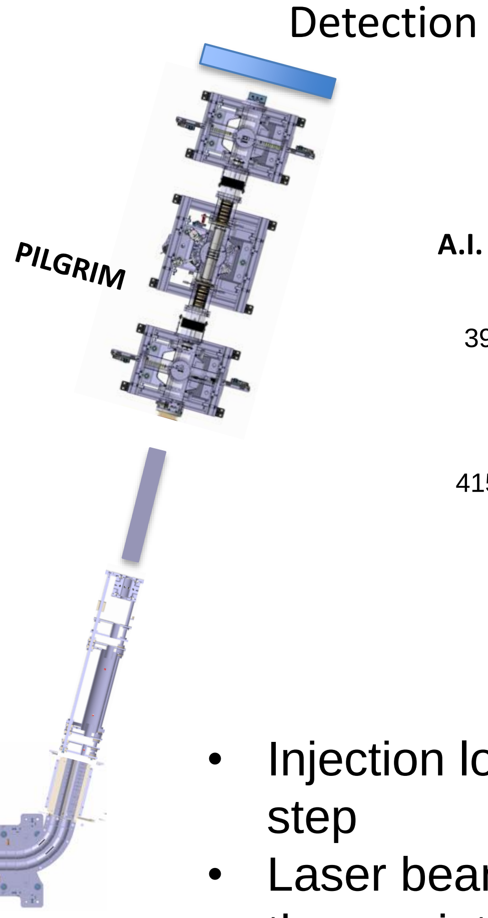
- Resonance peak fitted with Voigt profile

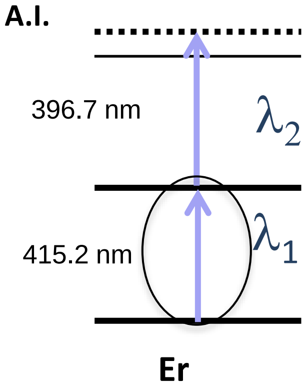
Spectral resolution at 300 mbar, FWHM = 4.5(2) GHz
Resonance peak centroid, Γ_{shift} = - 4(1) MHz/mbar
Resonance peak FWHM, Γ_{coll} = 11(1) MHz/mbar

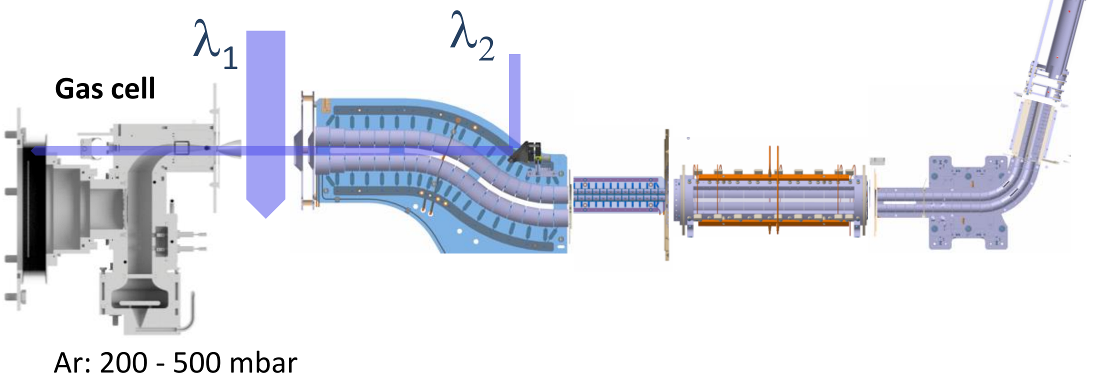
A. Ajayakumar et al., NIMB 539, 102-107 (2023)

In-gas jet laser spectroscopy



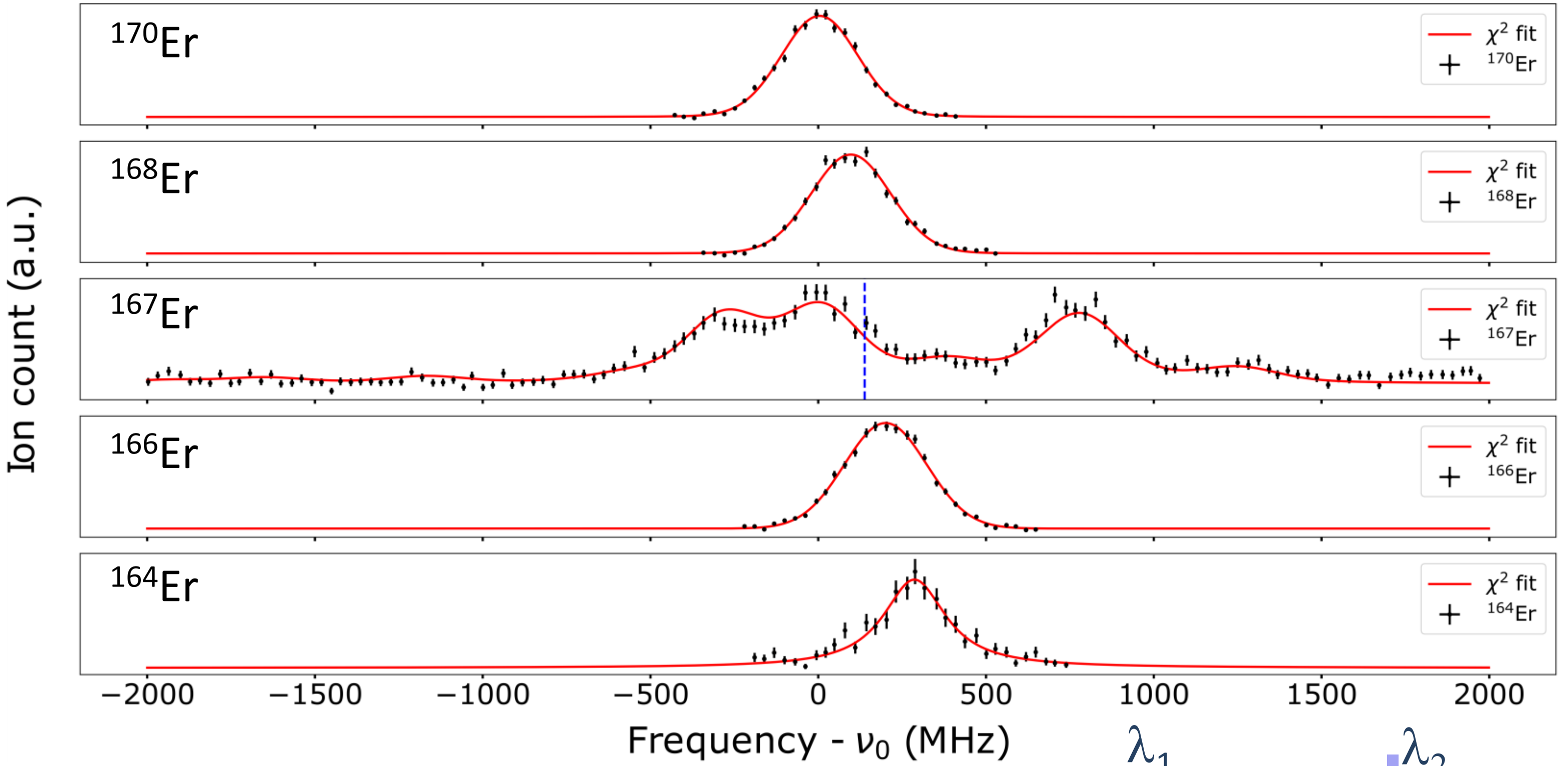


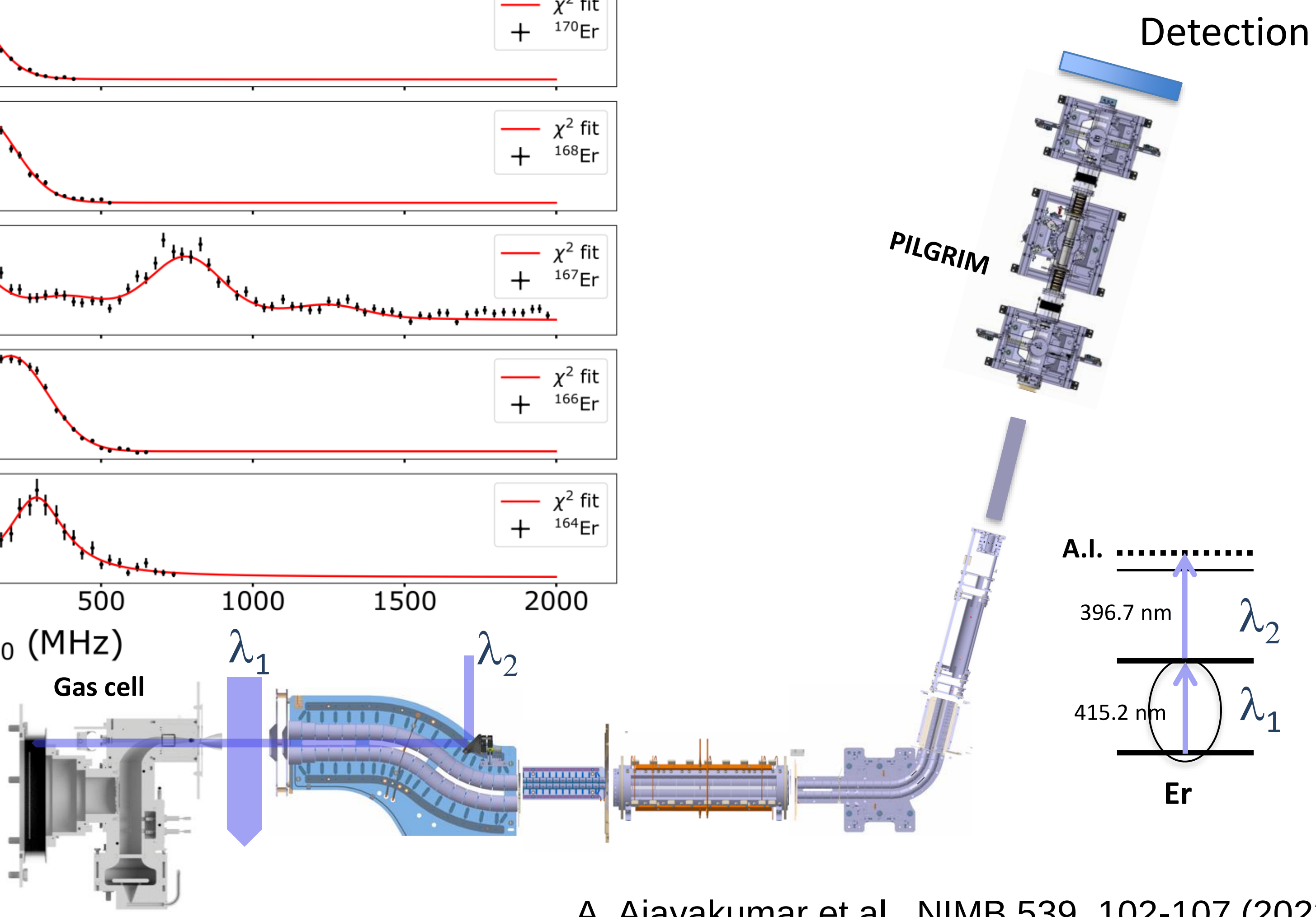




- Injection locked laser as first step
- Laser beam expansion to cover the gas jet region

In-gas jet laser spectroscopy





Laser FWHM linewidth ~ 35 MHz

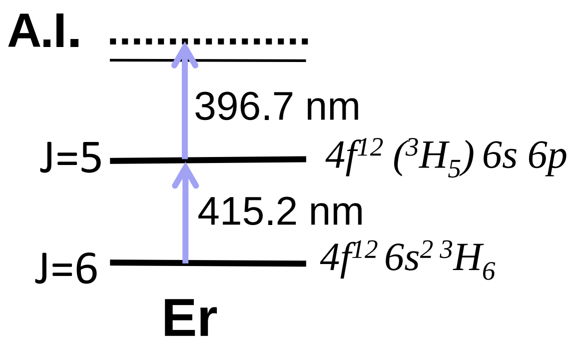
Spectral FWHM ~ 281(5) MHz

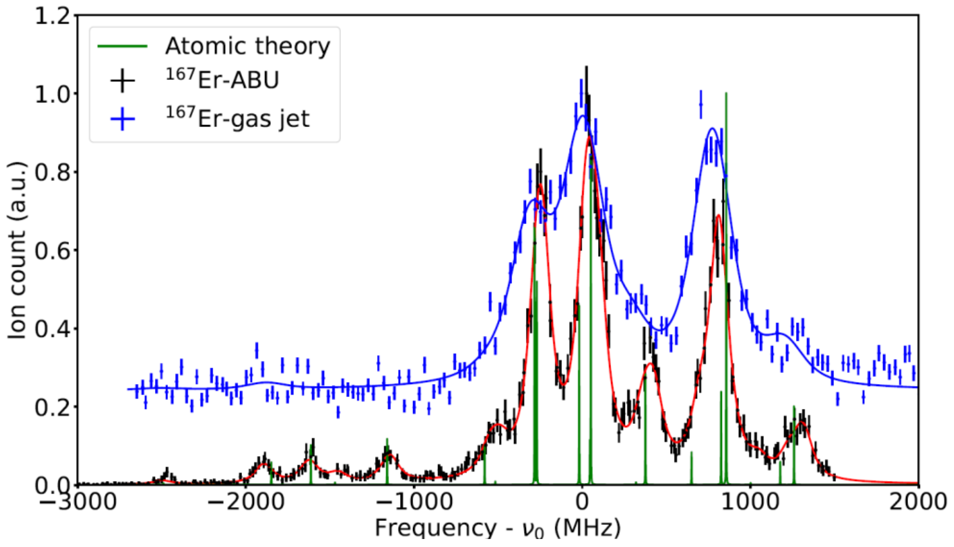
Ar: 200 - 500 mbar

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

In-gas jet laser spectroscopy

- Isotope shift measurement and hyperfine constants
  Agreement with literature





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

Isotope shift, $\Delta\nu^{A',170}$ (MHz)		
Mass number	gas jet	ABU [1]
168	96(6)	97(8)
167	138(8)	132(10)
166	196(7)	193(8)
164	283(7)	298(7)

^{167}Er HFS constants	Ground state		Excited state	
Method	*A* (MHz)	*B* (MHz)	*A* (MHz)	*B* (MHz)
gas jet	-122(3)	-4847(237)	-148(4)	-2230(200)
gas jet	-121.8(fixed)	-4563(fixed)	-147.1(7)	-1936(24)
ABU [1]	-121.80(75)	-4563(53)	-147.66(83)	-1888(58)
[2], [3]	-120.487(1)	-4552.984(10)	-146.6(3)	-1874(16)

[1] J. Romans et al., Nucl. Instrum. Meth. B 536 (2023) 72–81.
[2] W. J. Childs et al., Phys. Rev. A 28 (1983) 3402–3408.
[3] S. Ahmad et al., Proceedings of the “Symposium on Quantum Electronics” (1985).

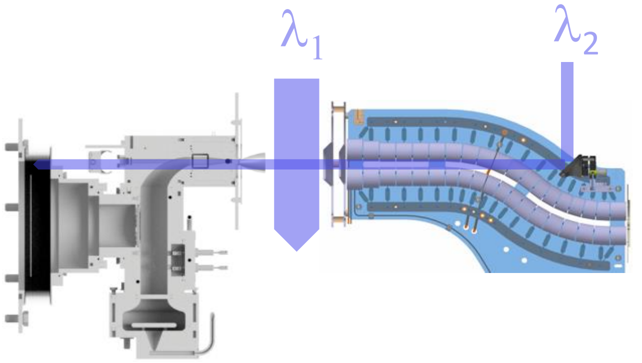
Gas flow characterization

The local temperature of the gas jet:

- Used the transverse first-step laser configuration

$$\Delta\upsilon_{FWHM} = \nu_0\sqrt{\frac{8kbT\ ln2}{mc^2}}$$

- Temperature of the jet T = 46(2) K

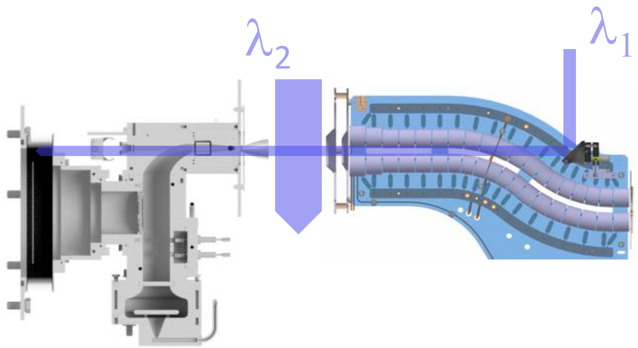


Stream velocity of the jet:

- Measure Doppler shifted centroid

$$\nu = \nu_0\left(1 + \frac{u}{c}\right)$$

Deduced stream velocity of the jet *u* = 565(35) m/s



Mach number:

For a measured spectral resolution: 280 MHz

- *Deduced M* = $\frac{\text{stream velocity } (u)}{\text{speed of sound}} = 4.5(3)$

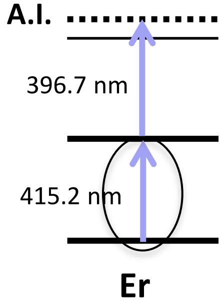
Expected Mach number: 8
Room for improved resolution!

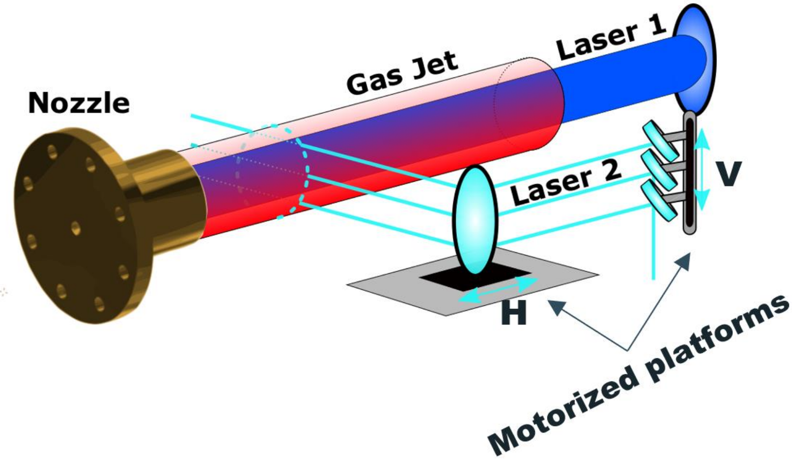
Pressure matching, laser alignment, power broadening

Gas flow characterization

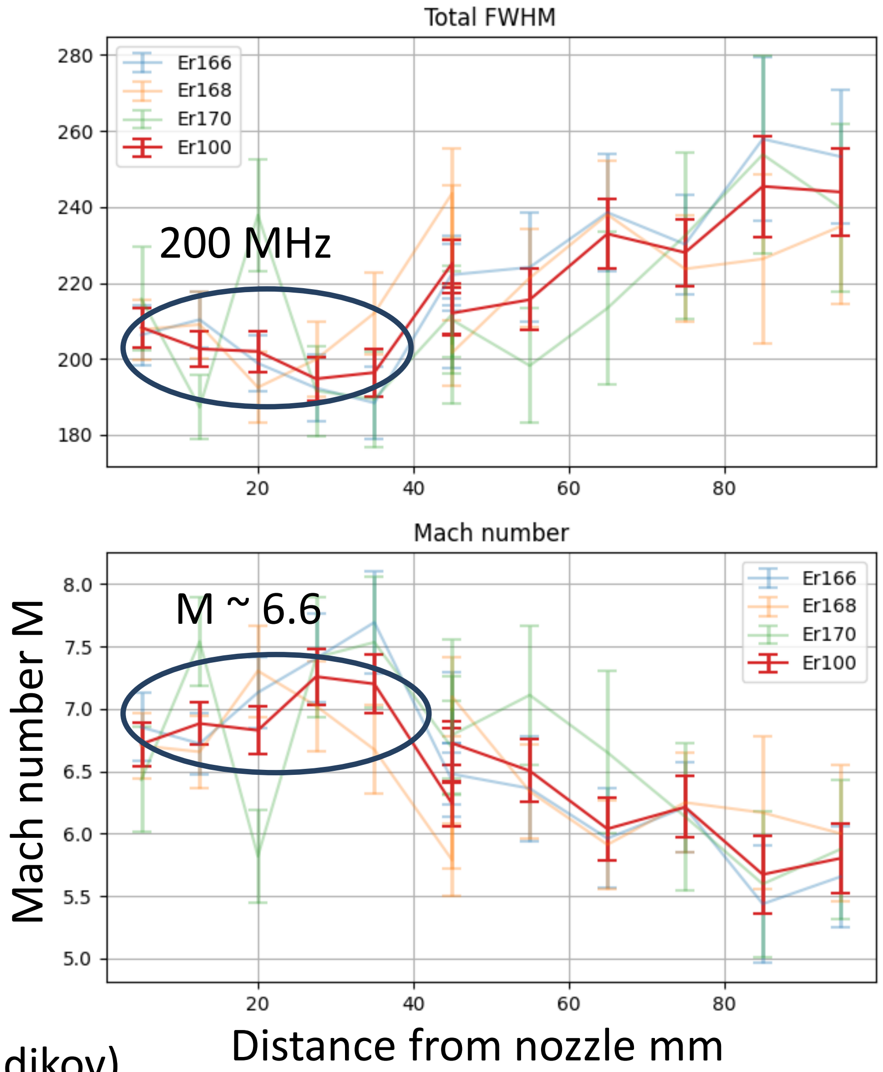
Possible reasons:

- Flow matching : fine control of P_{cell}/P_{bg}
  under/over expansion
- Power broadening:
  Very efficient transition scheme
- Misalignment of laser





Spectral resolution → 200 MHz



Thesis (F. Ivandikov)

Summary

- First in gas cell/gas-jet laser spectroscopy performed
  - ✓ Laser systems implemented
  - ✓ Laser ion production and transmission

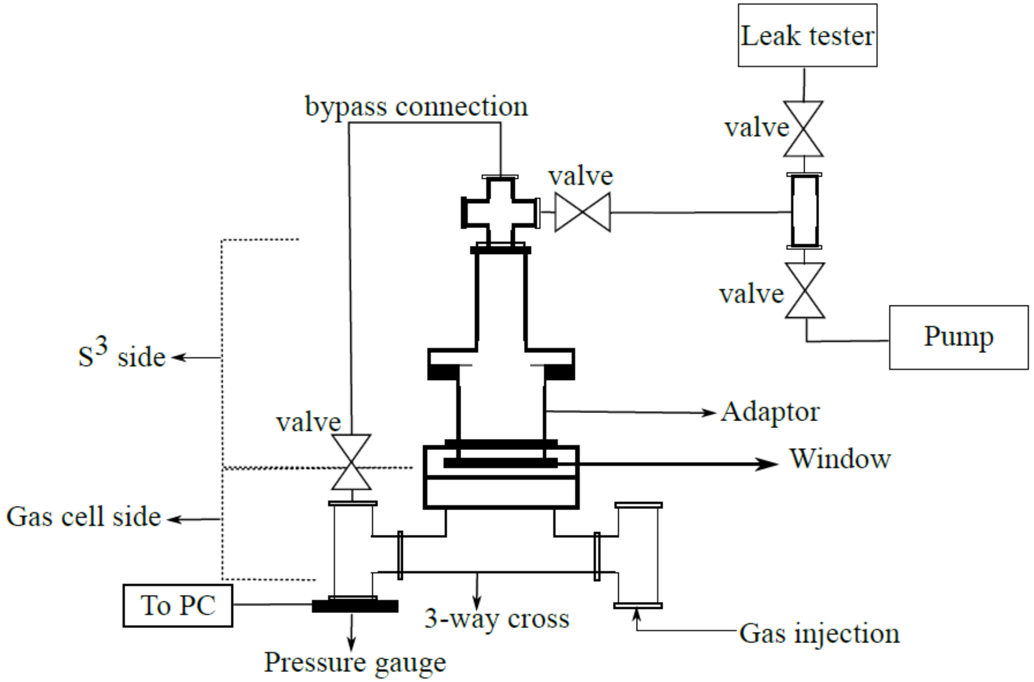
- Characterization of the gas cell, gas jet with laser ions performed
  - ✓ Spectral resolution
  - ✓ Isotope and hyperfine constants measured

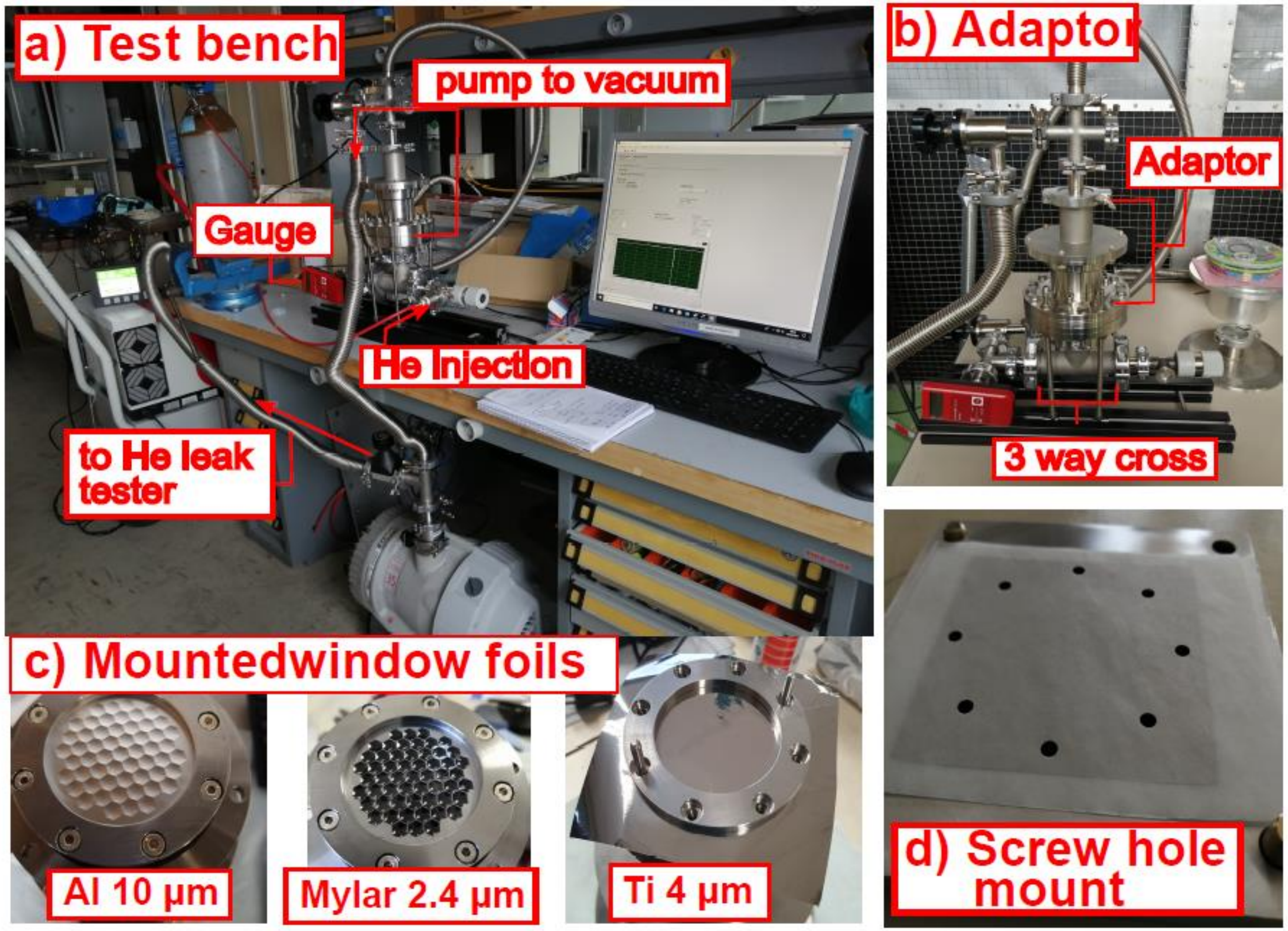
- Entrance window and gas cell optimization tests performed and ready for commissioning cases
  - ✓ Ti and Mylar foils tested in dedicated testbench

- Laser developments:
  - ✓ Seed laser system constructed and lasing
  - ✓ Proof of principle measurements

S^3-LEB is ready for online commissioning with Er!

Entrance Window tests





- Dedicated test bench for window tests
- Resistance and leak tests
- SRIM/TRIM calculation for four reactions covering the kinematics of S^3

Er, Sn, Ac

Summary

- First in gas cell/gas-jet laser spectroscopy performed
  - ✓ Laser systems implemented
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S^3-LEB is ready for online commissioning with Er!


VOIE DE GARAGE
(Super Séparateur Spectromètre)

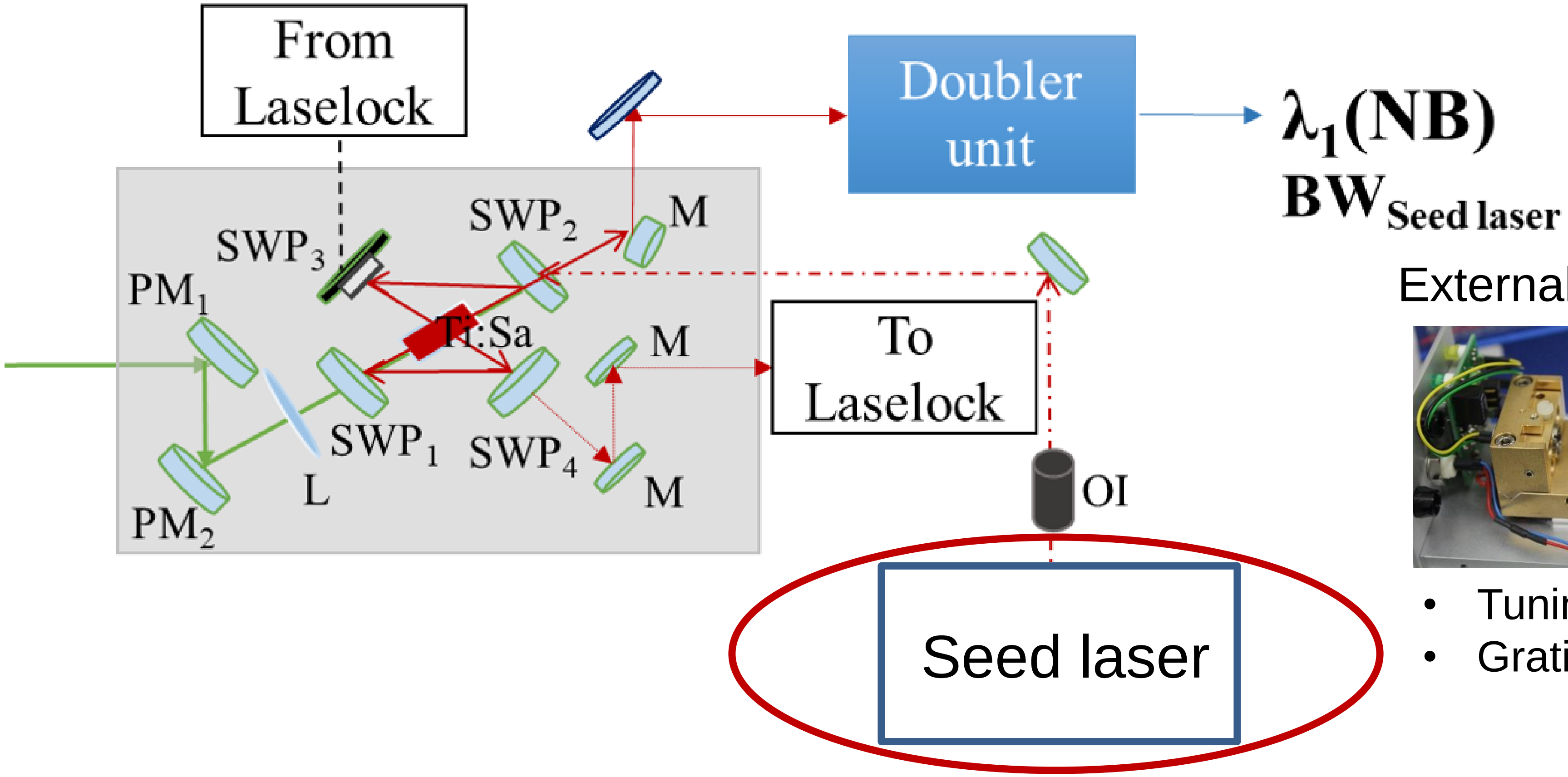
OUTLINE

Introduction	• Laser spectroscopy for nuclear physics
Experimental setup	• S^3-LEB facility
Experimental setup	• Offline commissioning results of S^3-LEB
Technical development	• Development of a continuous wave diode pumped Ti: sapphire laser system
Conslusion	• Summary and outlook

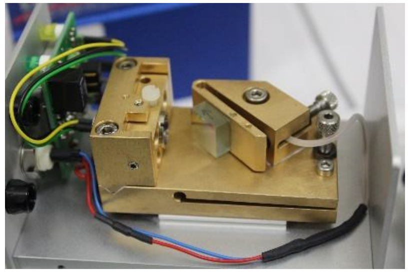
Laser development

High resolution spectroscopy: Injection locked Ti: sapphire lasers

- Laser line width < 100 MHz



External cavity diode laser



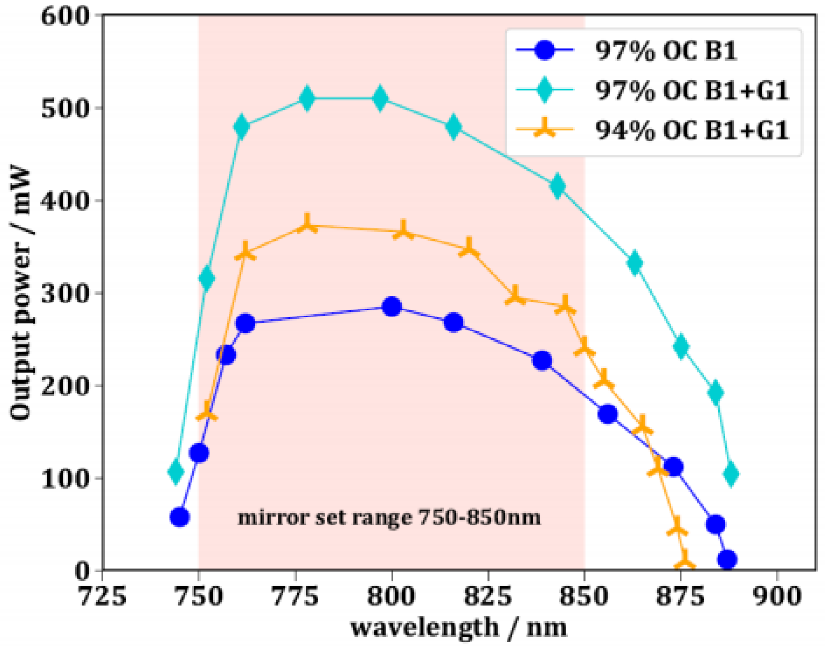
- Tuning range : 10 - 50 nm
- Grating for wavelength tunability

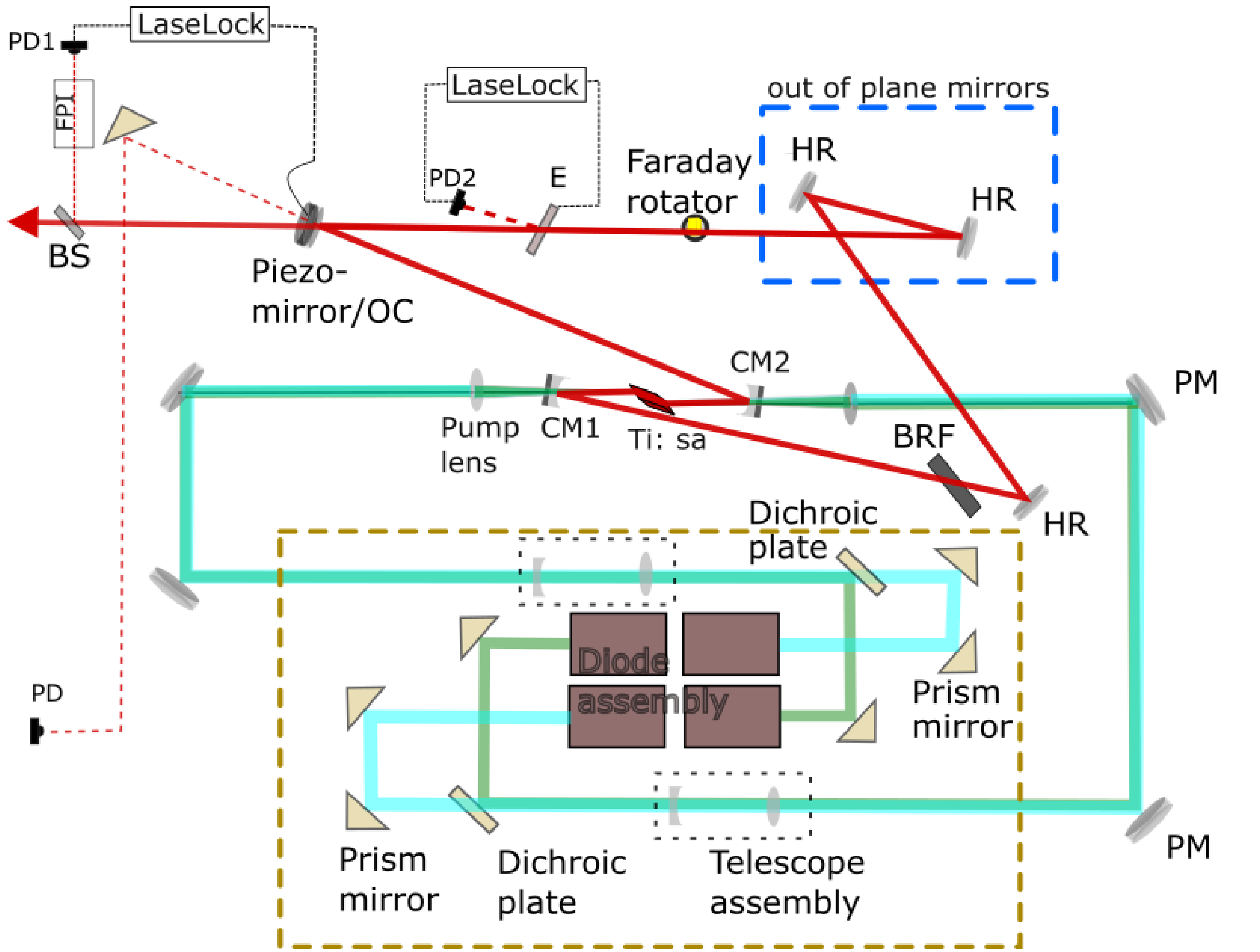
Alternative seed source: CW diode pumped Ti: sapphire laser system

CW diode pumped Ti: sa laser

laboratoire commun CEA/DRF CNRS/IN2P3

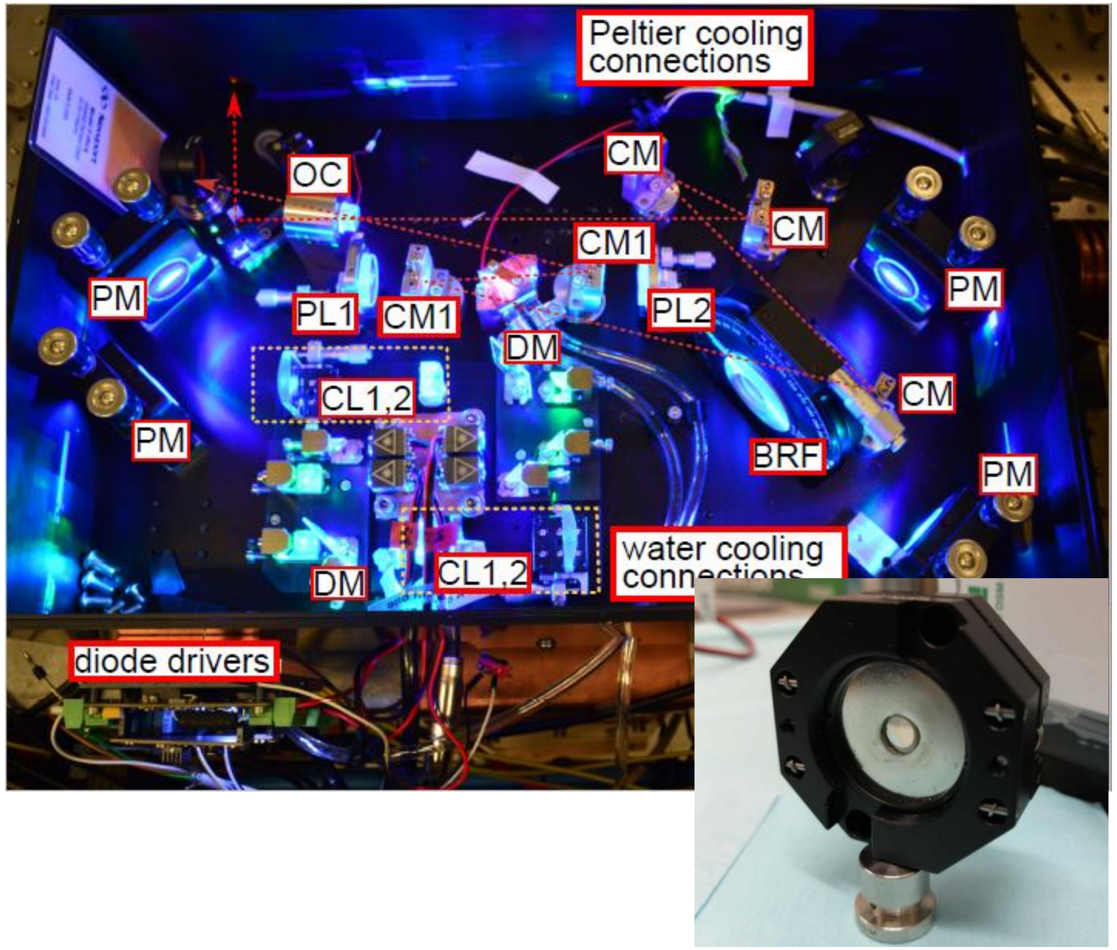
Wavelength tunability : 300 nm
Mode hop free scanning: 10- 50 GHz
Narrow Linewidth: MHz
Power :500 mW



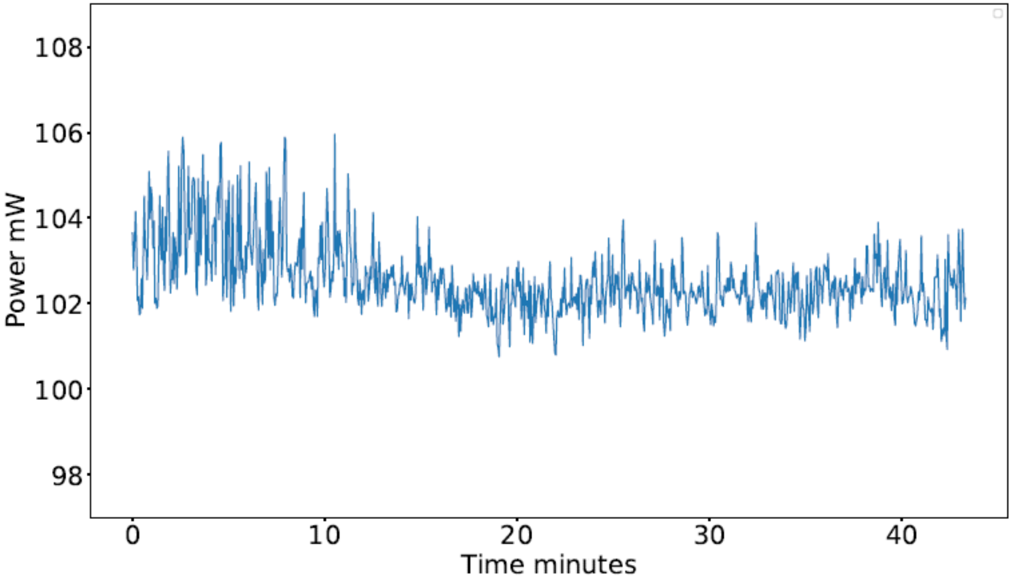


V. Sonnenschein et al., NIMB 463 (2020)

CW diode pumped Ti: sapphire laser



Faraday rotator



Cavity lasing

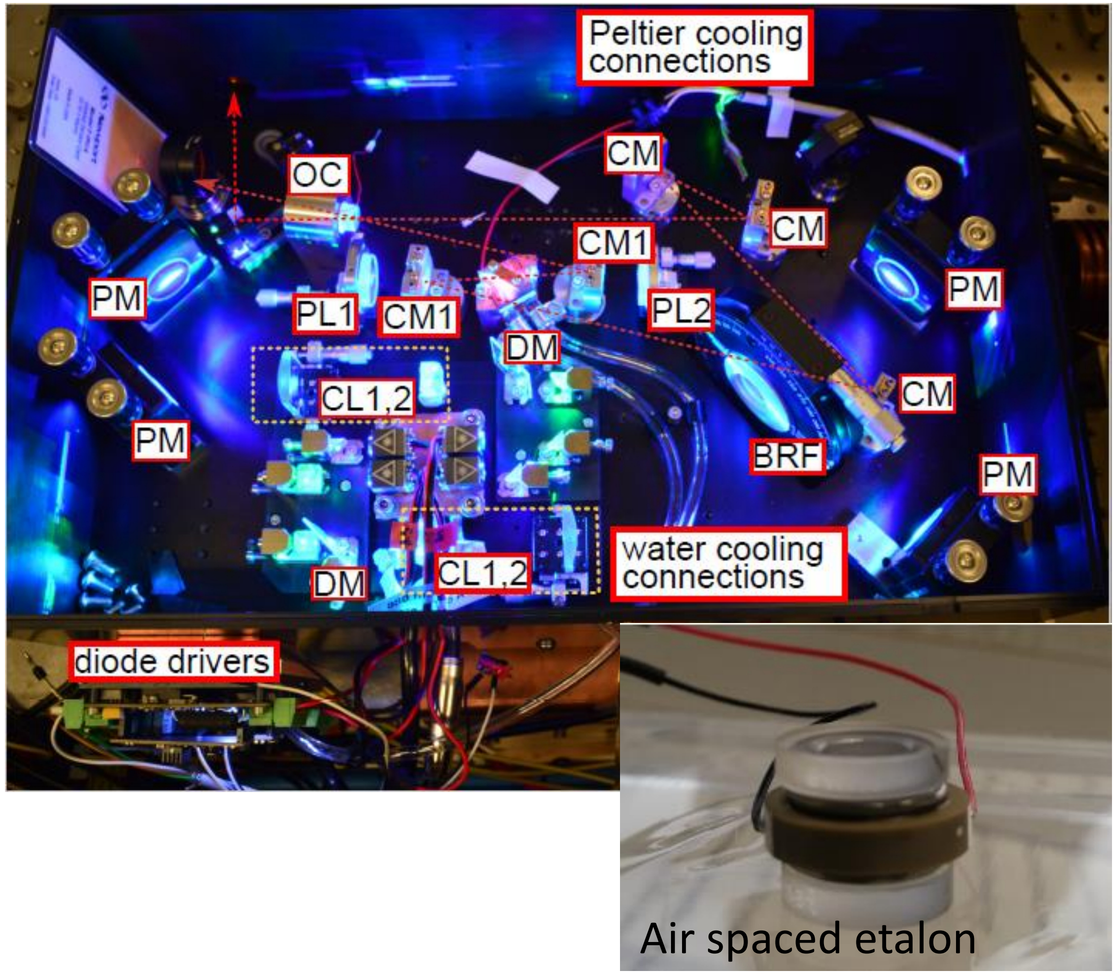
Out of plane geometry

Unidirection operation

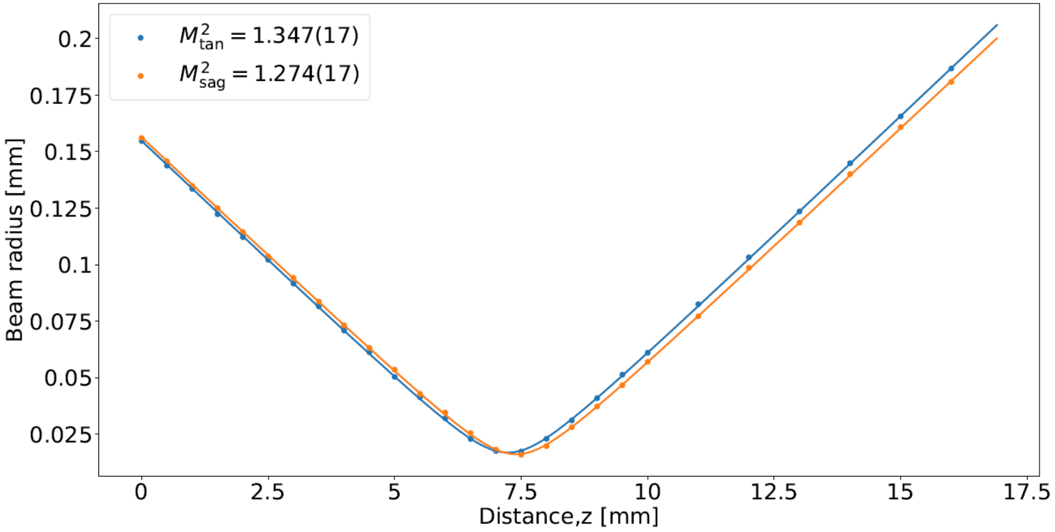
Single mode operation

Active stabilization and tuning

CW diode pumped Ti: sa laser



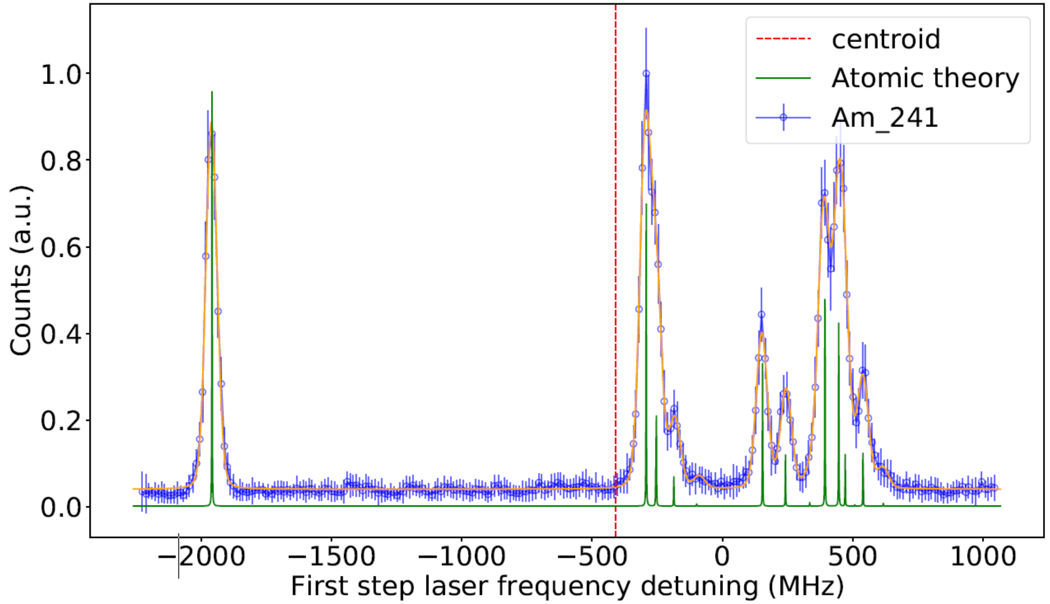
Beam profile measurement

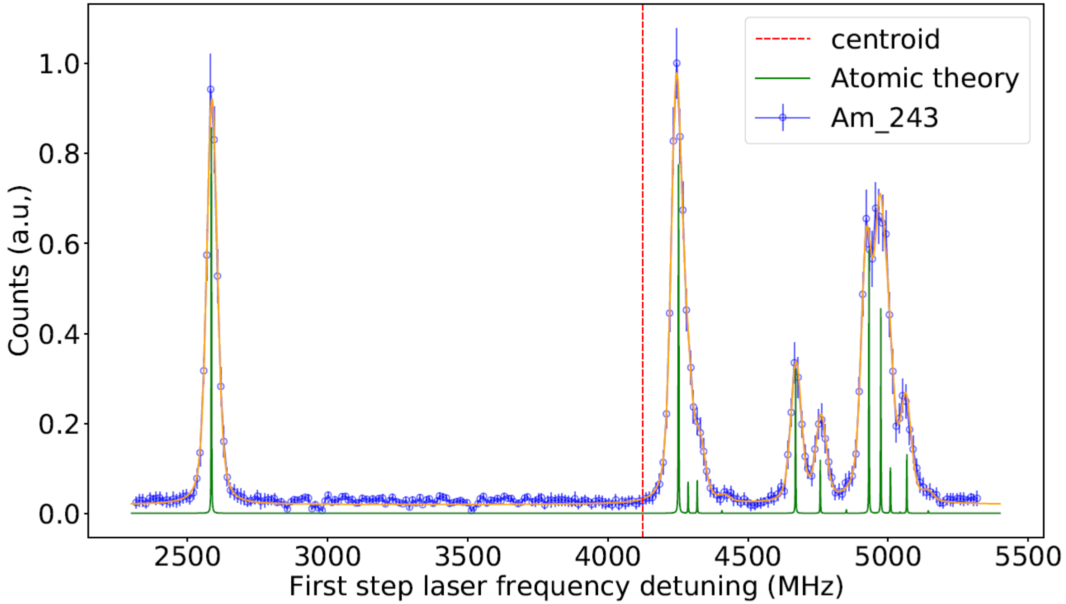


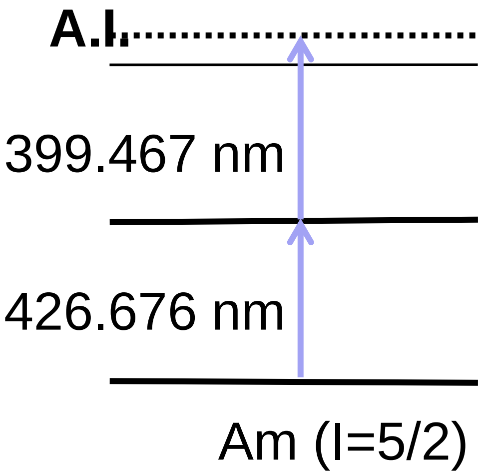
Beam propagation ratio, $M^2 \sim 1$ (ideal Gaussian beam)

- Cavity lasing
- Out of plane geometry
- Unidirection operation
- Single mode operation
- Active stabilization and tuning

Am laser spectroscopy with RISIKO







Am isotopes	A_l (MHz)	A_u (MHz)	B_l (MHz)	B_u (MHz)	FWHM (MHz)
^{241}Am	-16.6(5)	-100.7(4)	136(6)	-2118(7)	49(2)
^{243}Am	-16.6(7)	99.5(6)	121(11)	-2139(10)	46(2)
^{241}Am[1]	-17.144(8)	-	123.82(10)	-	-
^{243}Am[2]	-17.1437(28)	-	123.8477(323)	-	-

M. Stemmler (JGU Mainz)

[1] J. Blaize et al., Tables Internationale de constants(1992)
[2] R Marrus et al., Phy. Rev 120.4 (1960)

Thank you

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and the RESIST network in ENSAR2