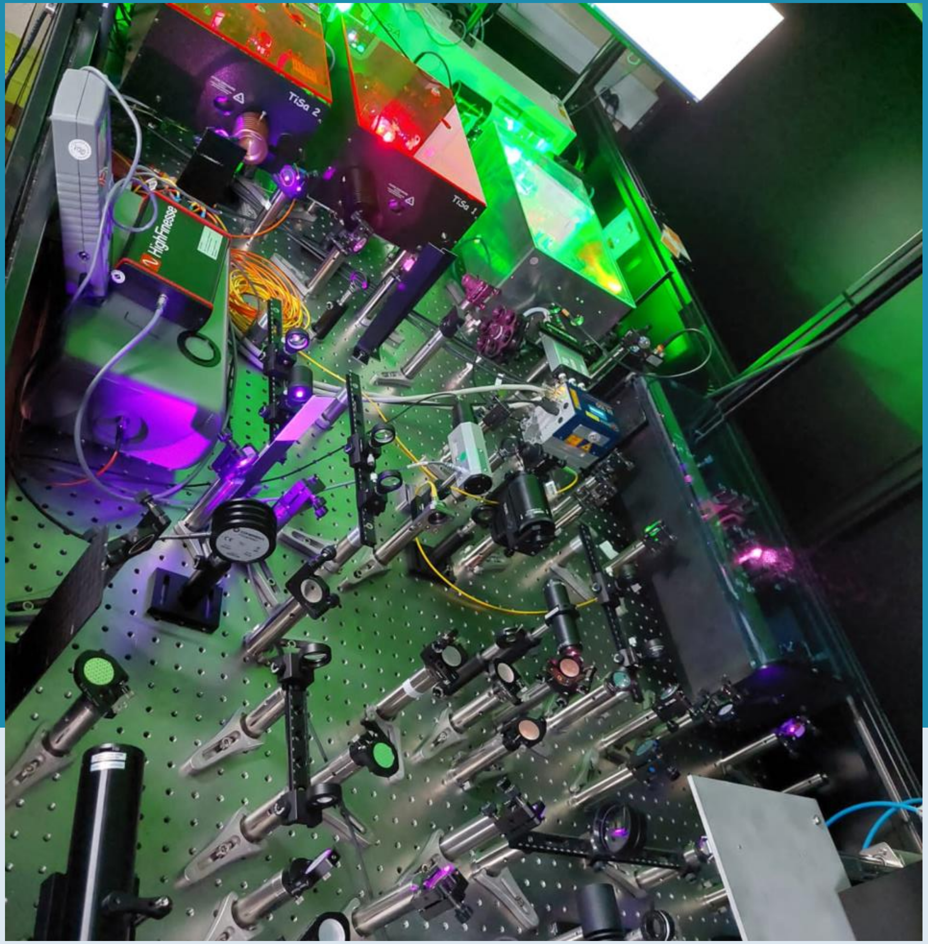
Status of S^3-LEB

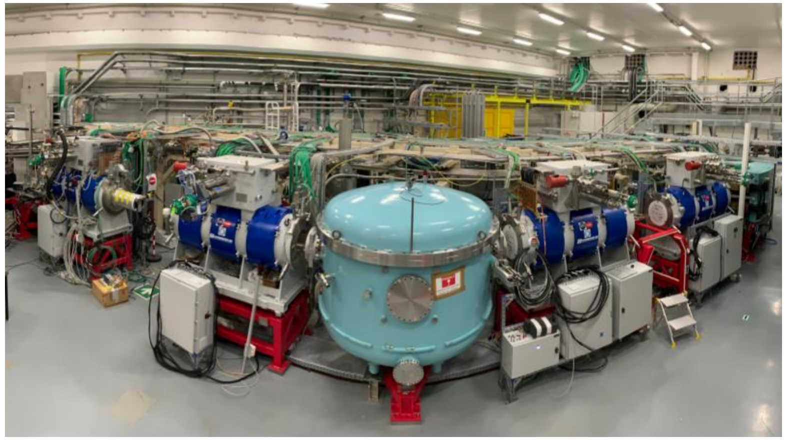


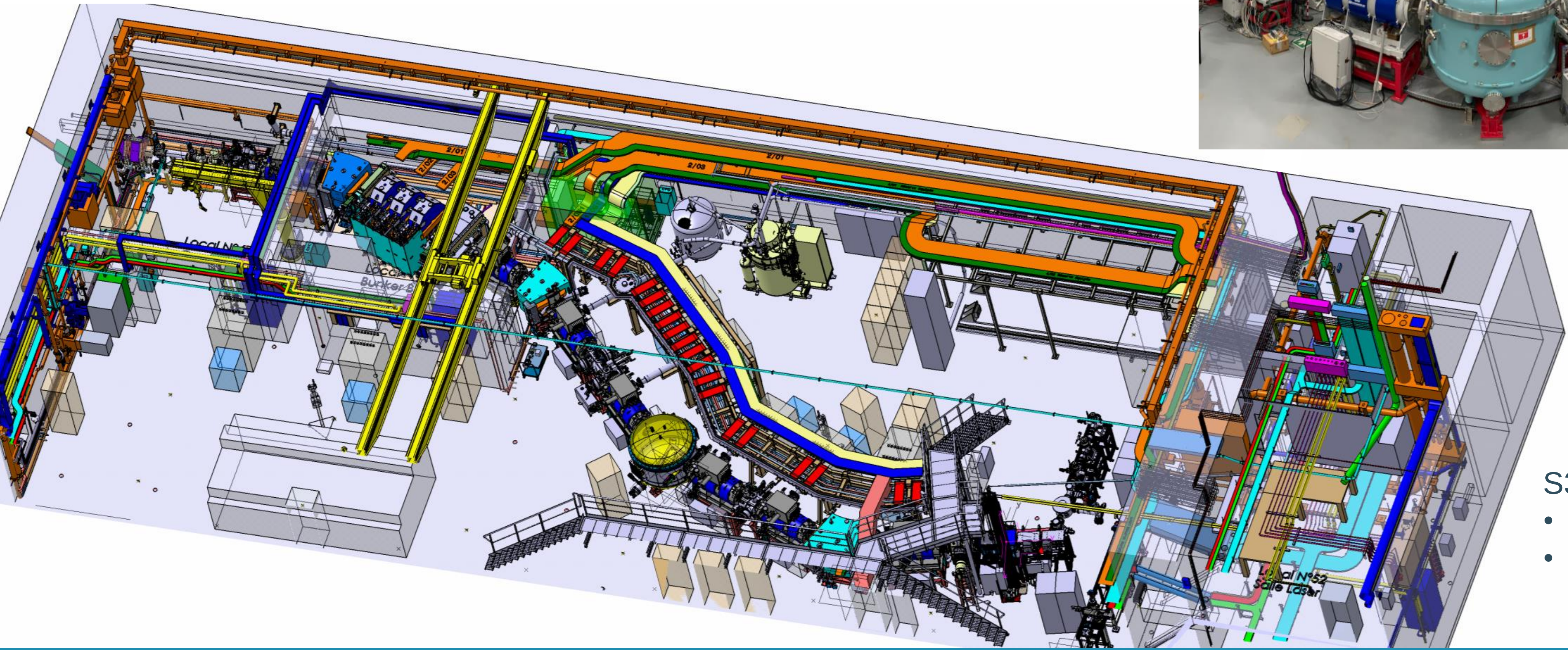
Antoine de Roubin

S^3-LEB collaboration

S3 – Super Separator Spectrometer

- Wide range (H to U) of high intensity primary beams (10 μAmp)
- High primary beam rejection and high acceptance spectrometer

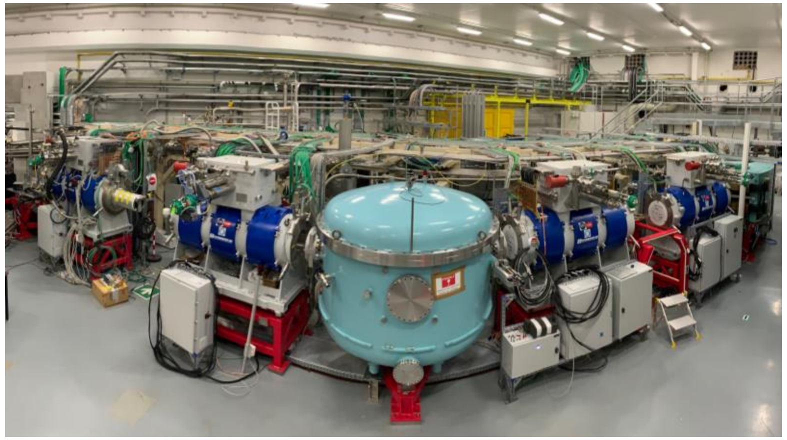


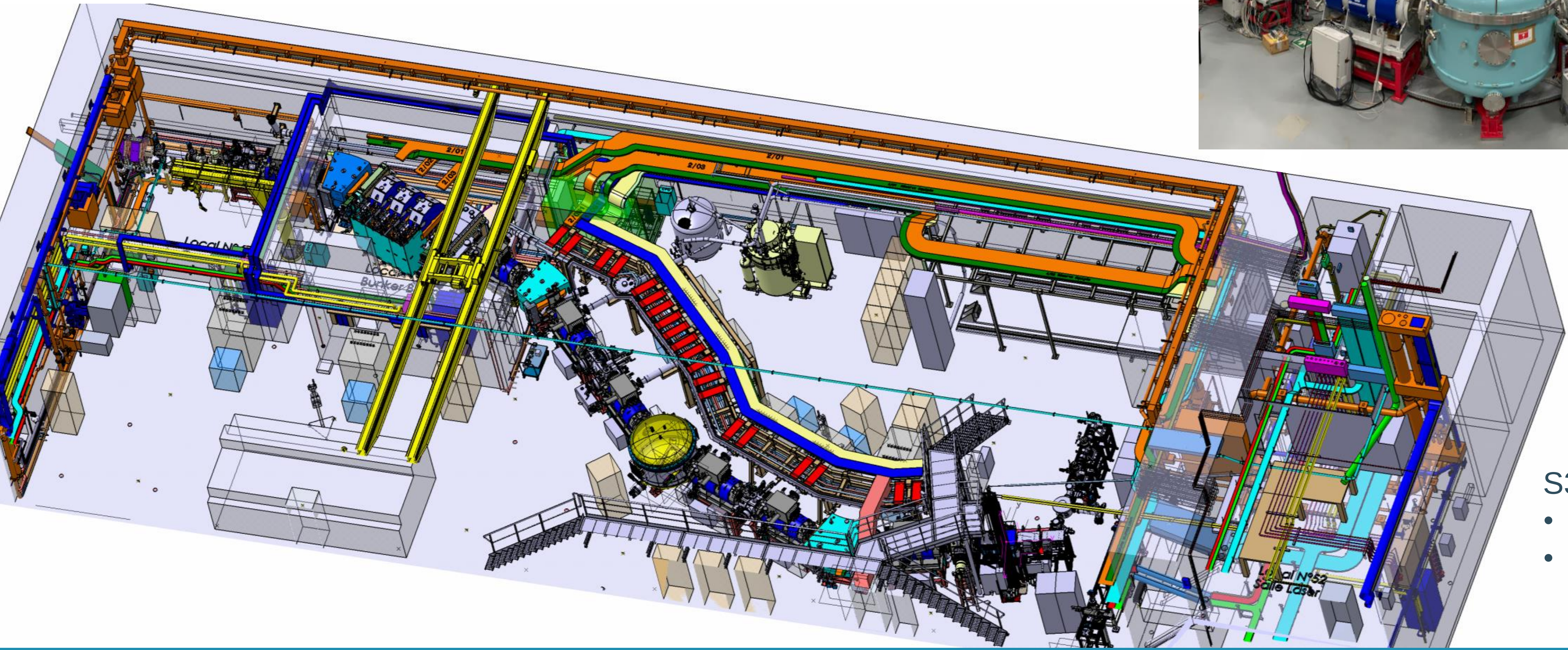


S3 equipex:
- 22 M€
- 400 ETP (12 years)

S3 – Super Separator Spectrometer

- The RIBs are produced by fusion evaporation
- Pre-selected by the in-flight spectrometer S3
- Transported to the gas cell in the converging mode.





S3 equipex:

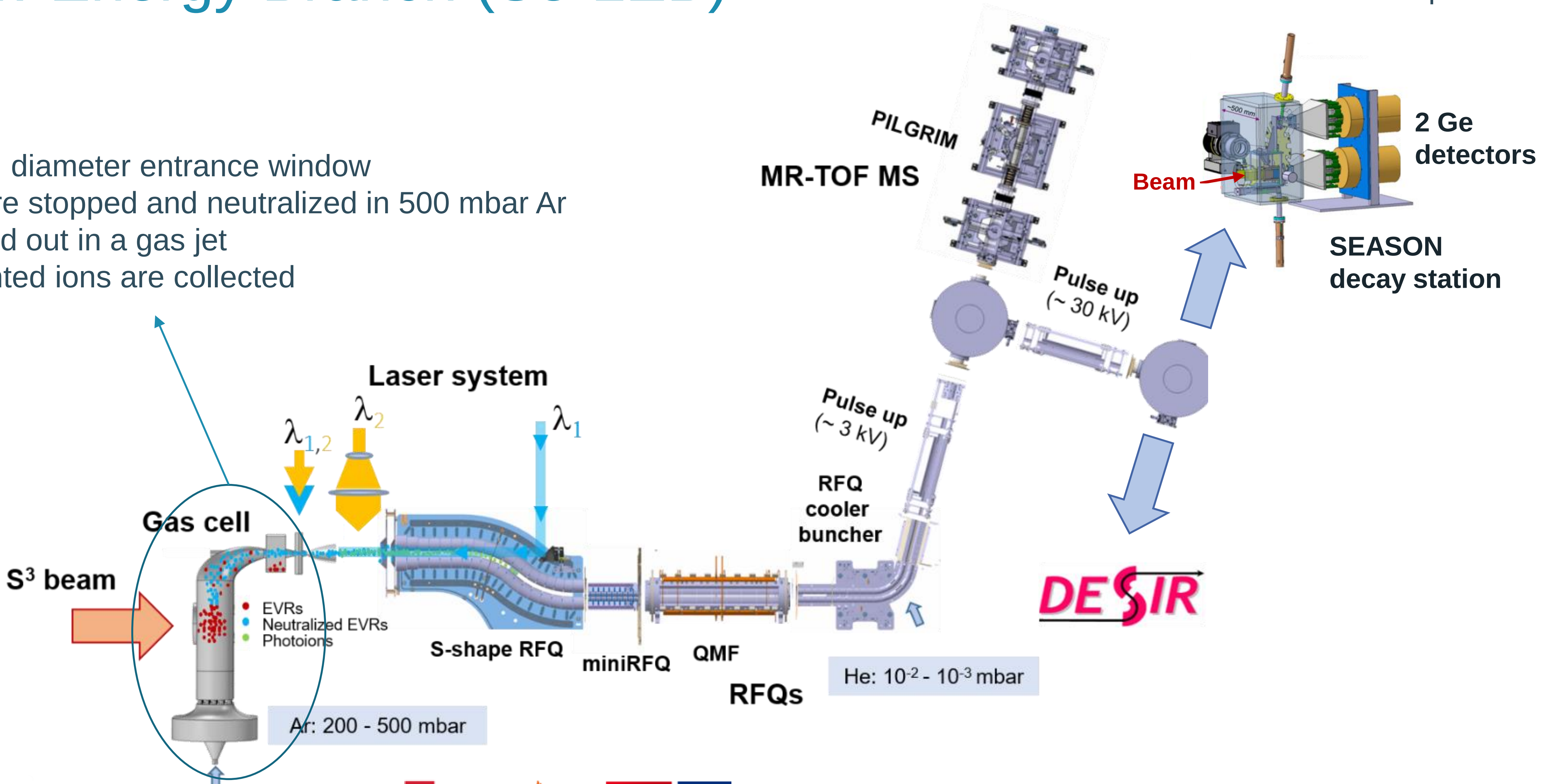
- 22 M€
- 400 ETP (12 years)

S3 Low Energy Branch (S3-LEB)

See Damien Thisse’s presentation

Gas cell:

- 50 mm diameter entrance window
- Ions are stopped and neutralized in 500 mbar Ar
- Flushed out in a gas jet
- Unwanted ions are collected

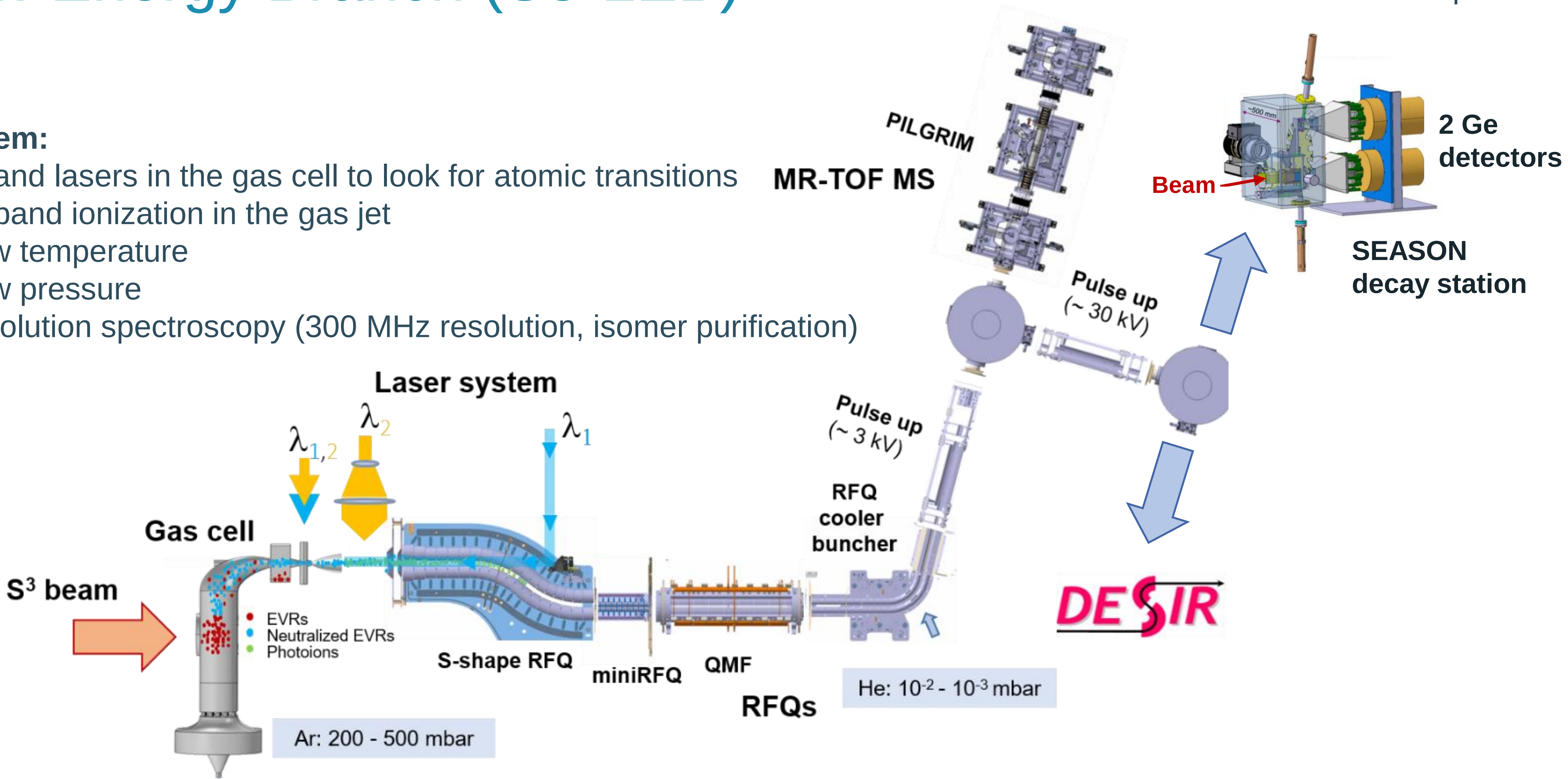


S3 Low Energy Branch (S3-LEB)

See Damien Thisse’s presentation

Laser system:

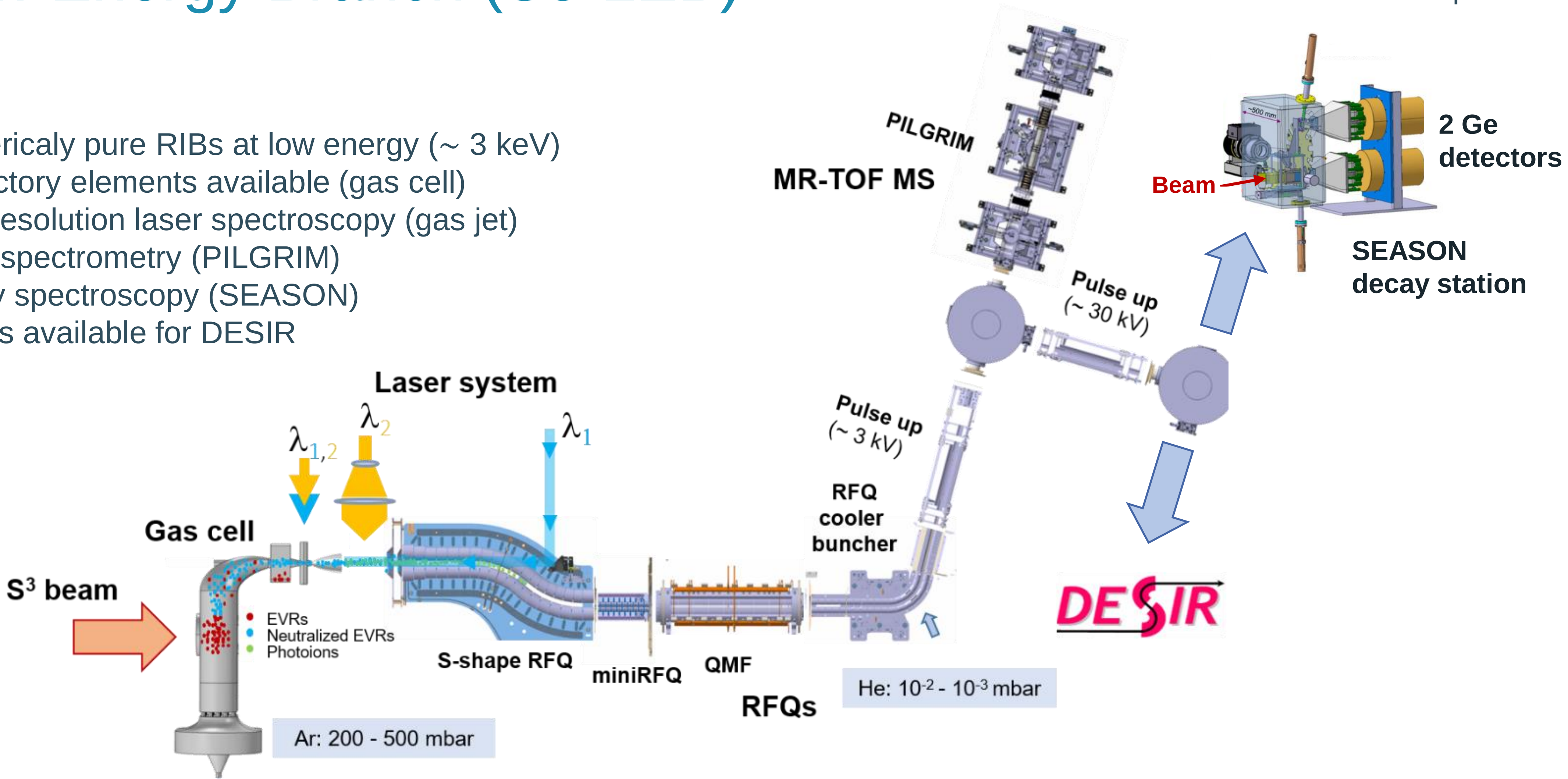
- Broad band lasers in the gas cell to look for atomic transitions
- Narrow band ionization in the gas jet
  - Low temperature
  - Low pressure
- High resolution spectroscopy (300 MHz resolution, isomer purification)



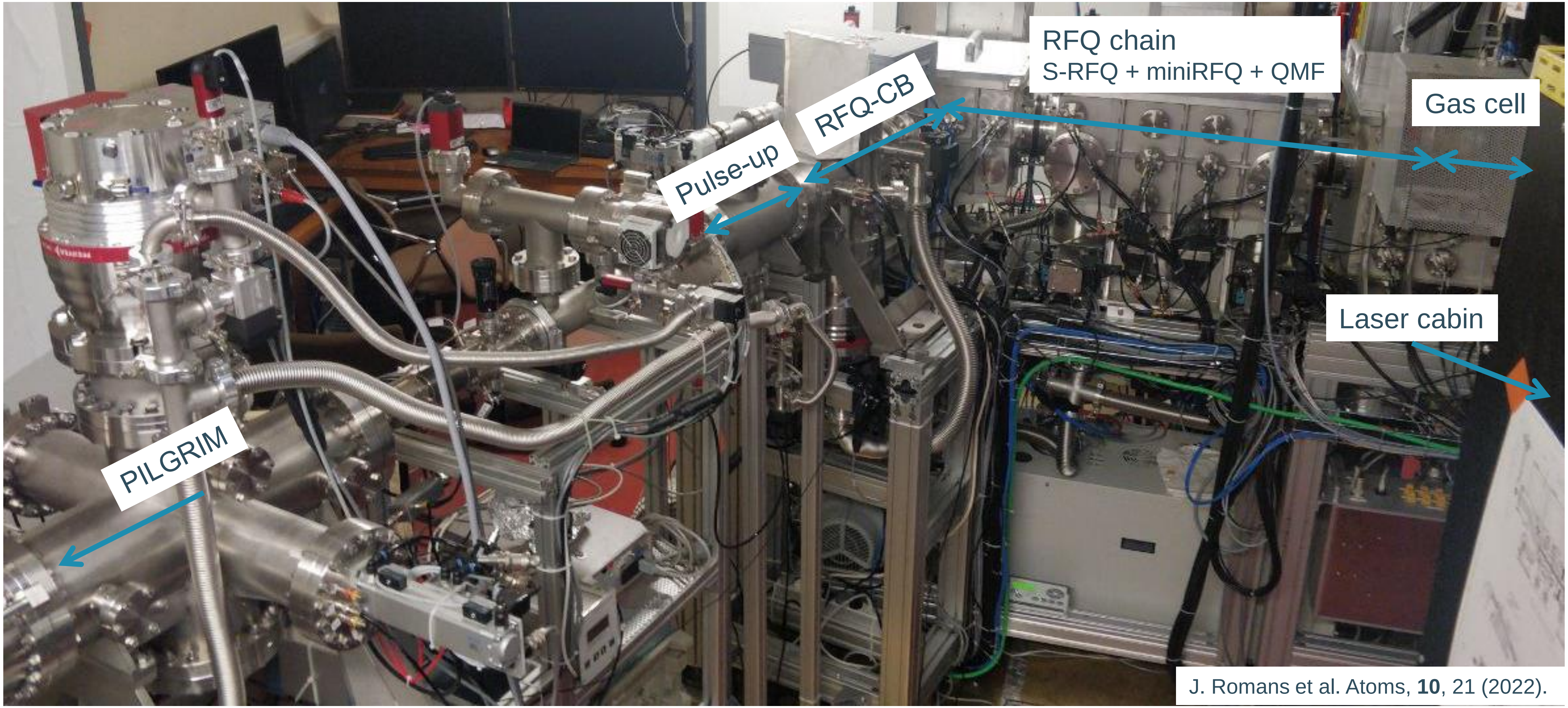
S3 Low Energy Branch (S3-LEB)

See Damien Thisse’s presentation

- Isomericaly pure RIBs at low energy (~ 3 keV)
- Refractory elements available (gas cell)
- High resolution laser spectroscopy (gas jet)
- Mass spectrometry (PILGRIM)
- Decay spectroscopy (SEASON)
- Beams available for DESIR



S3 Low Energy Branch (S3-LEB) at LPC



RFQ chain
S-RFQ + miniRFQ + QMF

Gas cell

RFQ-CB

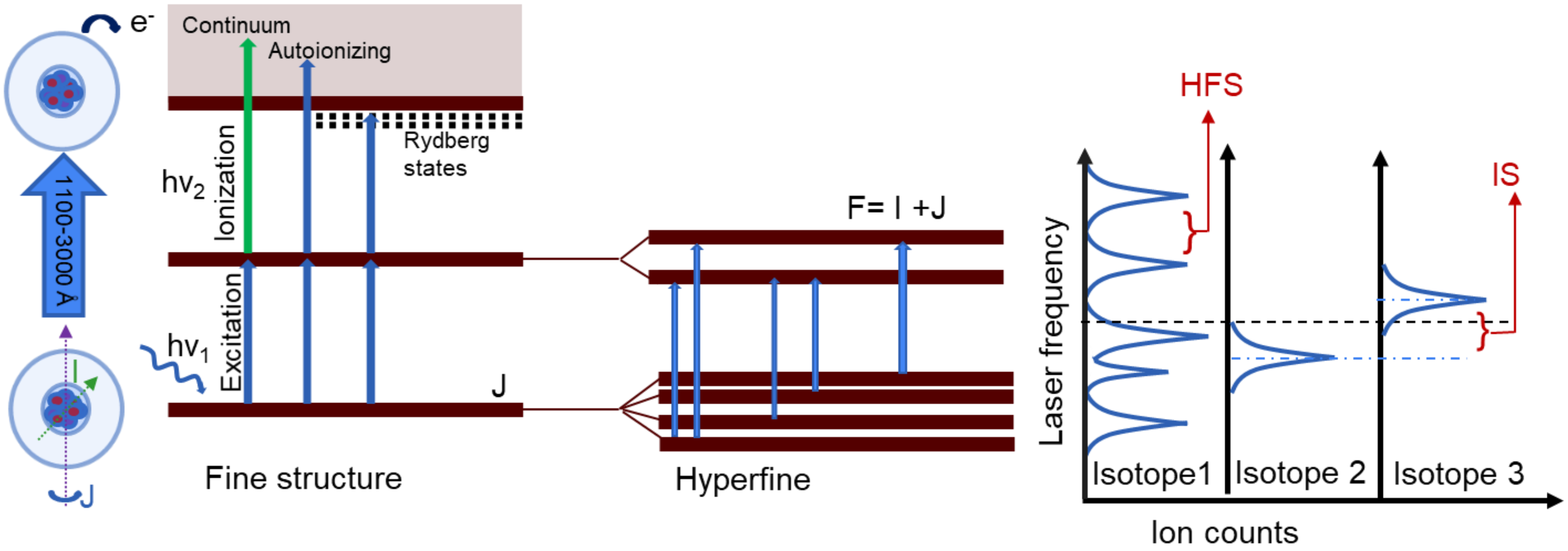
Pulse-up

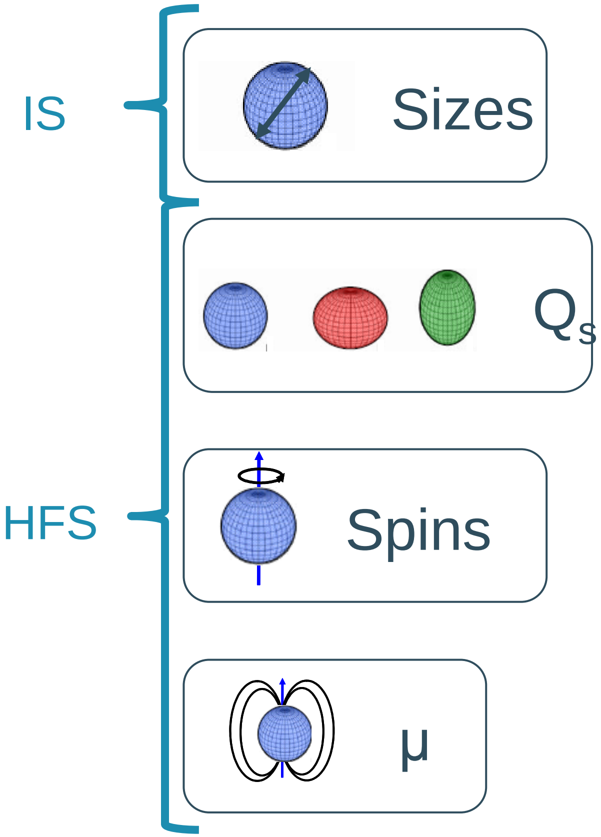
Laser cabin

PILGRIM

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

Resonant laser ionization spectroscopy

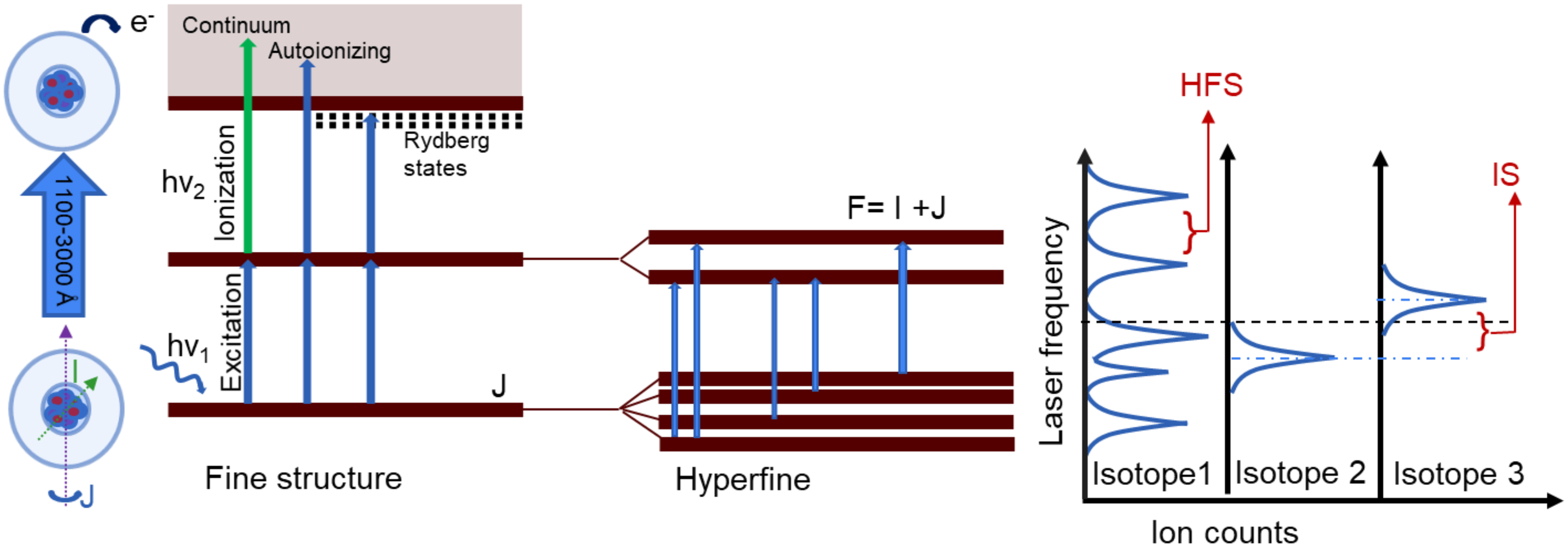


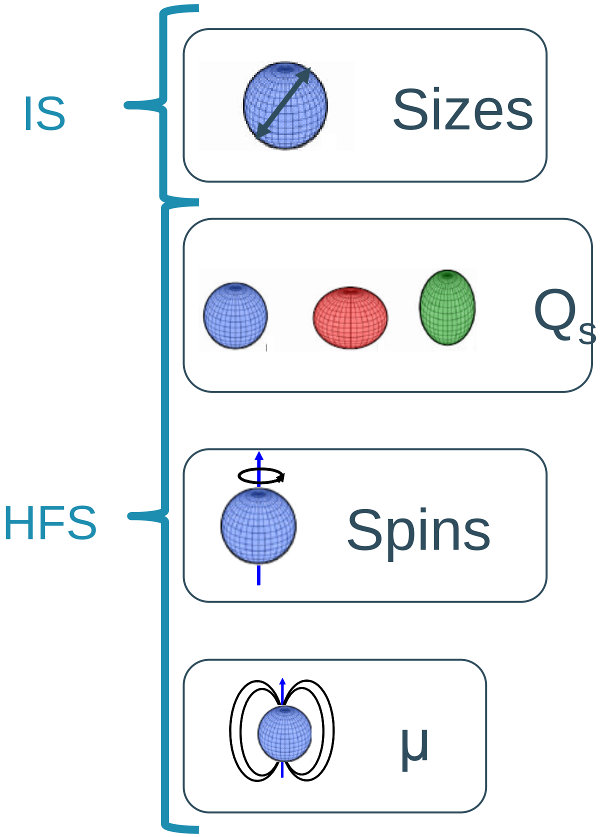


Resonant Laser Ionization method:

- Gives an extra selection in Z to the ions of interest
    - Only one given element (isomer) is ionised with the chosen combination of photons.
- Increasing the resolution of the system can give access to the hyperfine structure
    - Due to the coupling of the nucleus with the electronic orbital

Resonant laser ionization spectroscopy

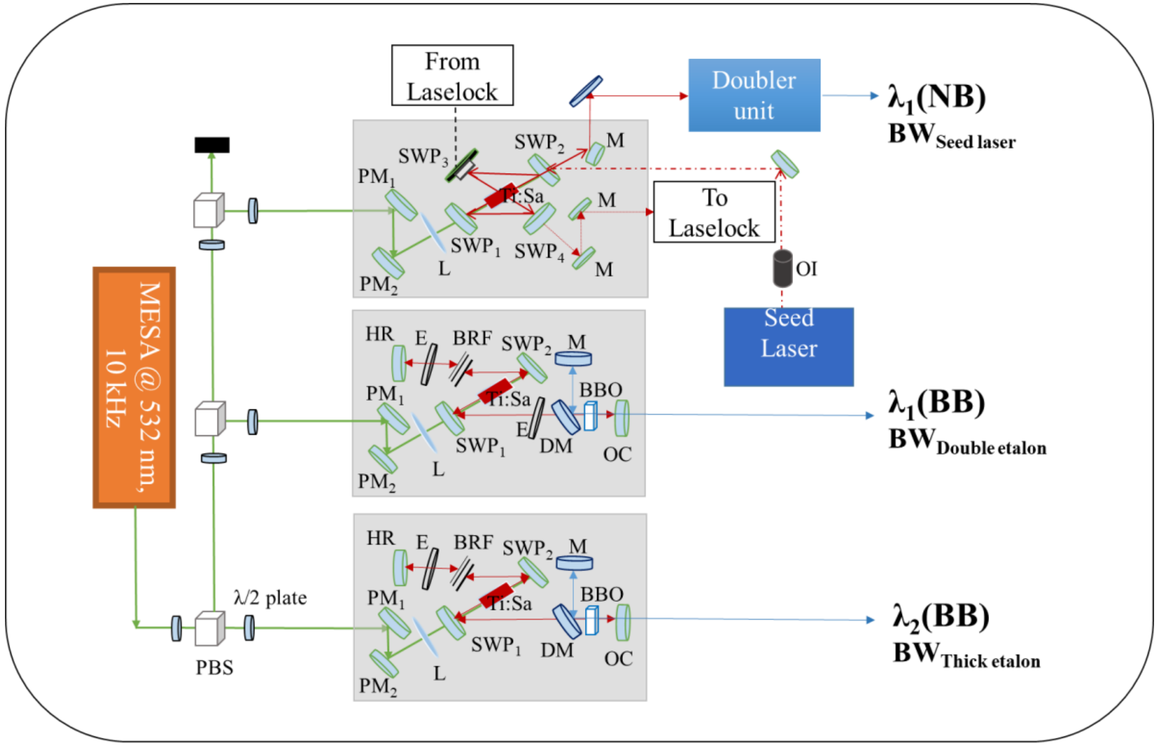


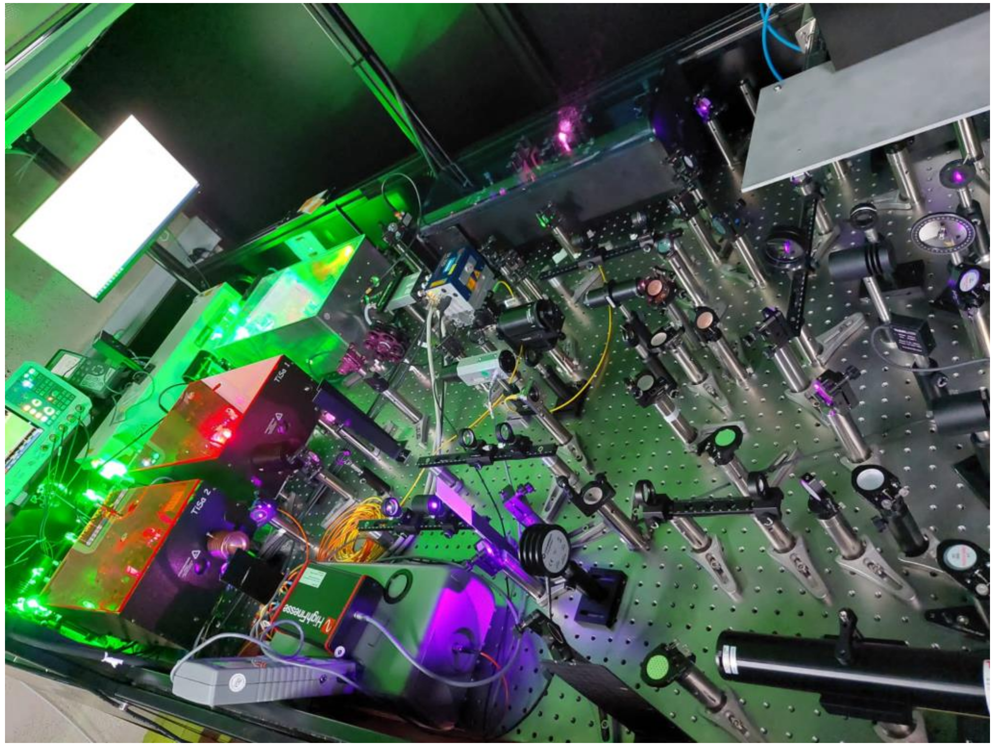


Resonant Laser Ionization method:

- Scan the laser frequency of the transition to measure isotope shifts
  - Information on charge radii
- Hyperfine splitting
  - Give access to deformation, spins and magnetic moments.

Resonant laser ionization spectroscopy



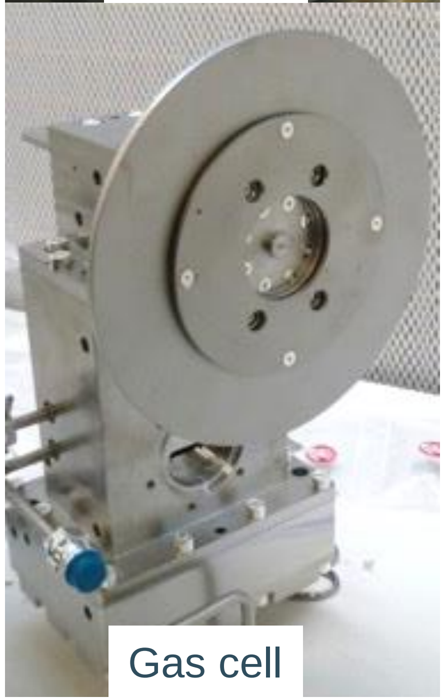


Requirements :

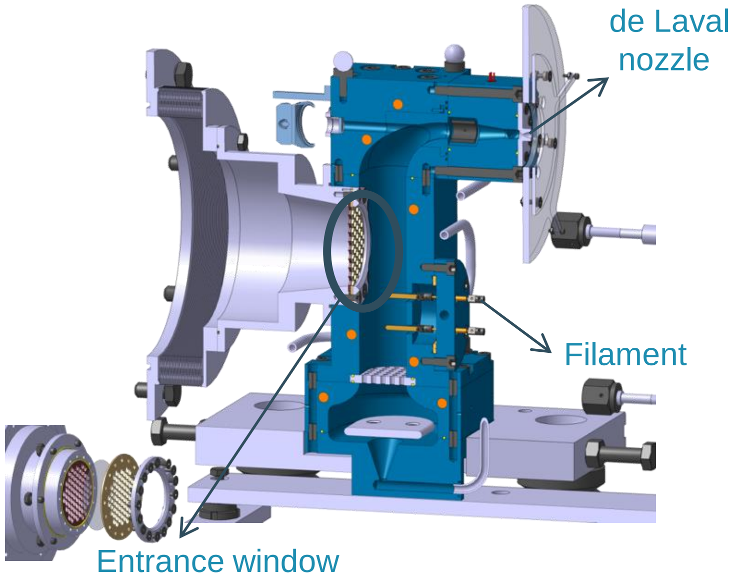
- Pulsed high repetition laser sources
- Laser line width to match the atomic transition line width
- Ti:sa / dye laser used complementarily
- Ti:sa lasers were commissioned and set up for in-gas laser spectroscopy.

In gas cell / in gas jet laser ionization spectroscopy

Filament



Gas cell



Filament

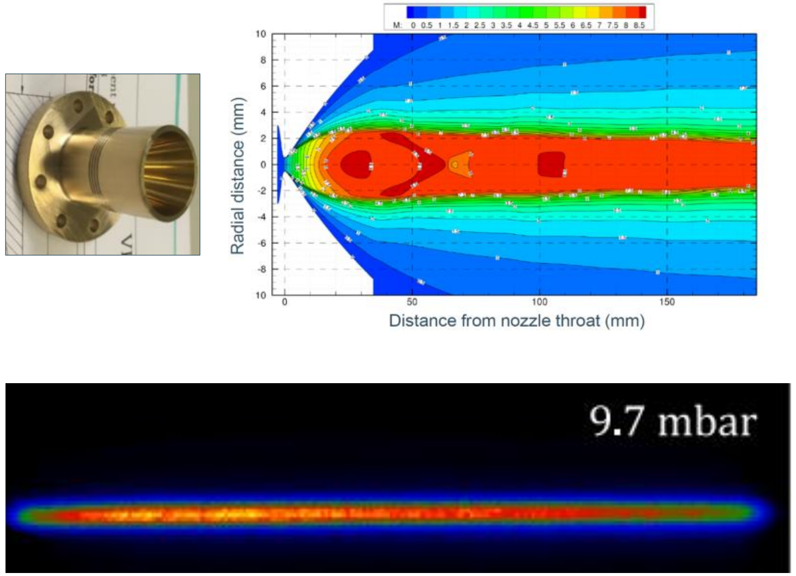
- 30 μL Er_2O_3 in HNO_3 solution
- Resistively heated by 13 A current

Gas cell

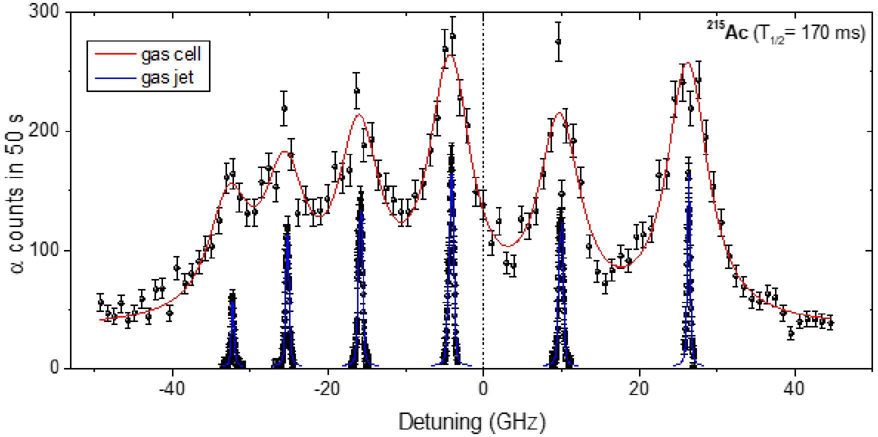
- Broadening effects
- Broad band laser (GHz)

De Laval nozzle

- Hypersonic gas jet: $\rho\downarrow$ & $T\downarrow$
- Narrow band laser (MHz)



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



R.Ferrer et al. Nature Communications.8.14520 (2017)

In-gas cell spectral broadening

The buffer gas causes collisional broadening of the spectrum

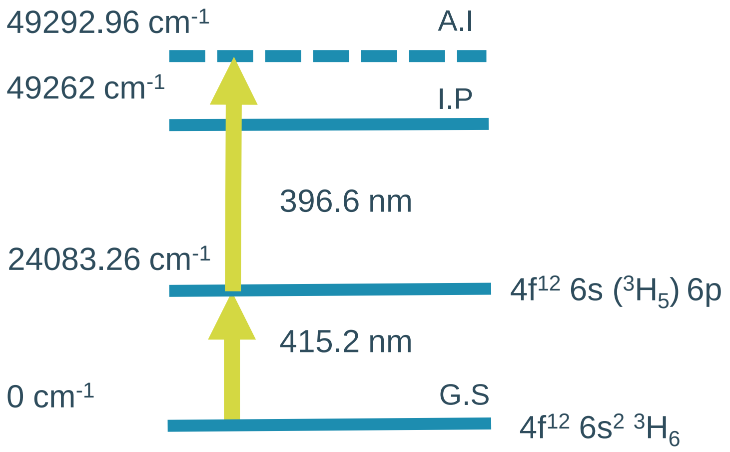
- Can be several GHz wide
- Prohibits precise measurements of atomic isotope shift and hyperfine constants.

The gas might also hamper the ionization efficiency

- Even for strong transition schemes by collisional de-excitation of states.

In-gas cell ionization

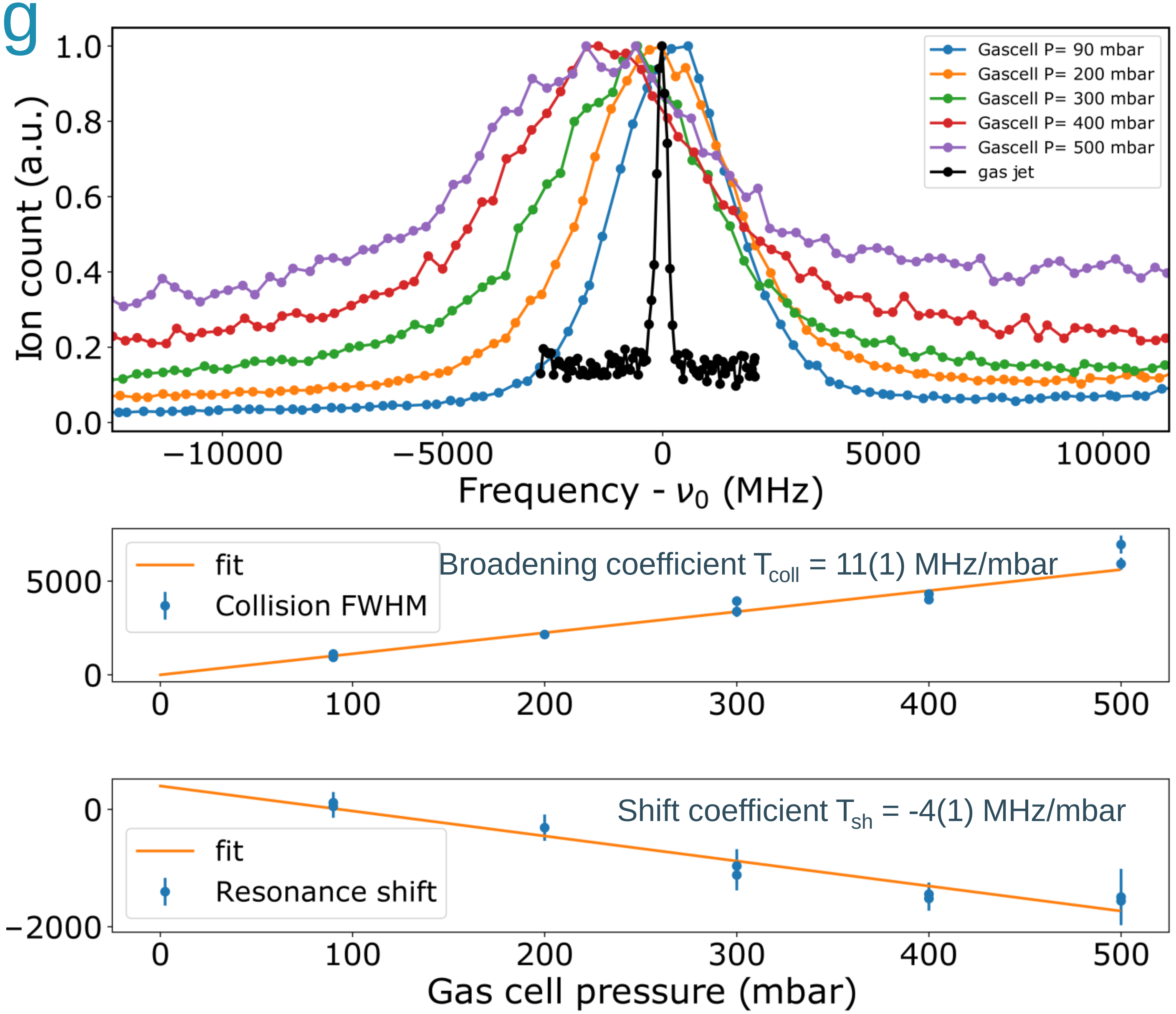
- Frequency-doubled dual-etalon Ti:sapphire laser cavity
- Average fundamental linewidth of 1.8 GHz FWHM



Er RIS Scheme[4]

A. Ajayakumar et al., NIM B accepted for publication

In-gas cell spectral broadening



The in-gas cell spectroscopy:

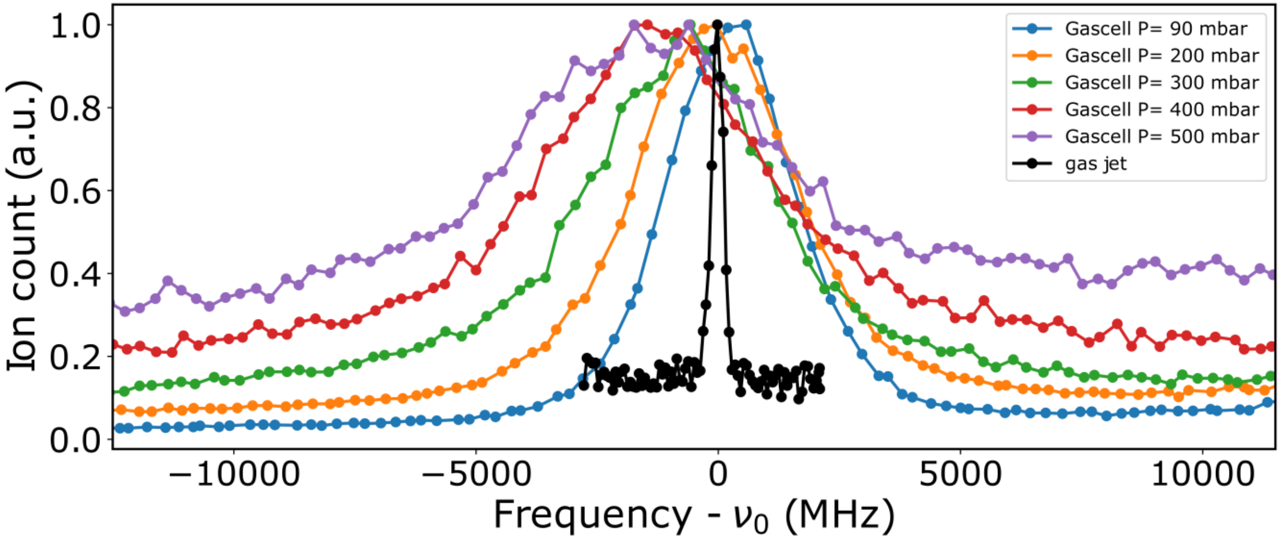
- Spectral linewidth of Δ_{nFWHM} = 2(1) GHz
- Broadening coefficient T_{coll} = 11(1) MHz/mbar
- Shift coefficient T_{sh} = -4(1) MHz/mbar

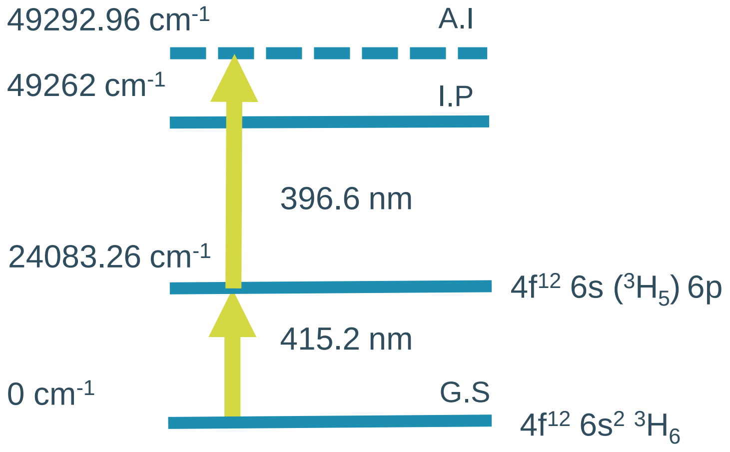
A. Ajayakumar et al., NIM B accepted for publication

In gas jet laser ionization spectroscopy

In-gas jet ionization

- Frequency-doubled injection-locked Ti:sapphire laser seeded by an external cavity diode laser
- A TEM Messtechnik Laselock lock-in amplifier to stabilize the injection-locked cavity to the frequency of the seeding
- Average fundamental linewidth of 35 MHz.





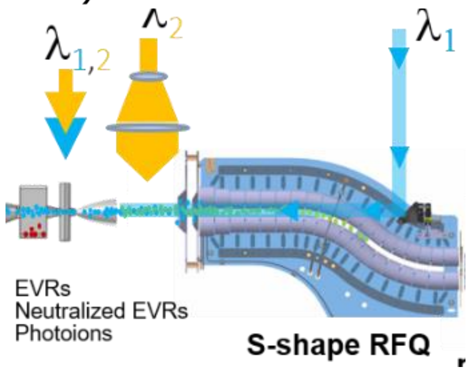
Er RIS Scheme[4]

Measurement preformed with:

- Step one counter-propagating
- Step two transverse to the jet

The in-gas jet spectroscopy:

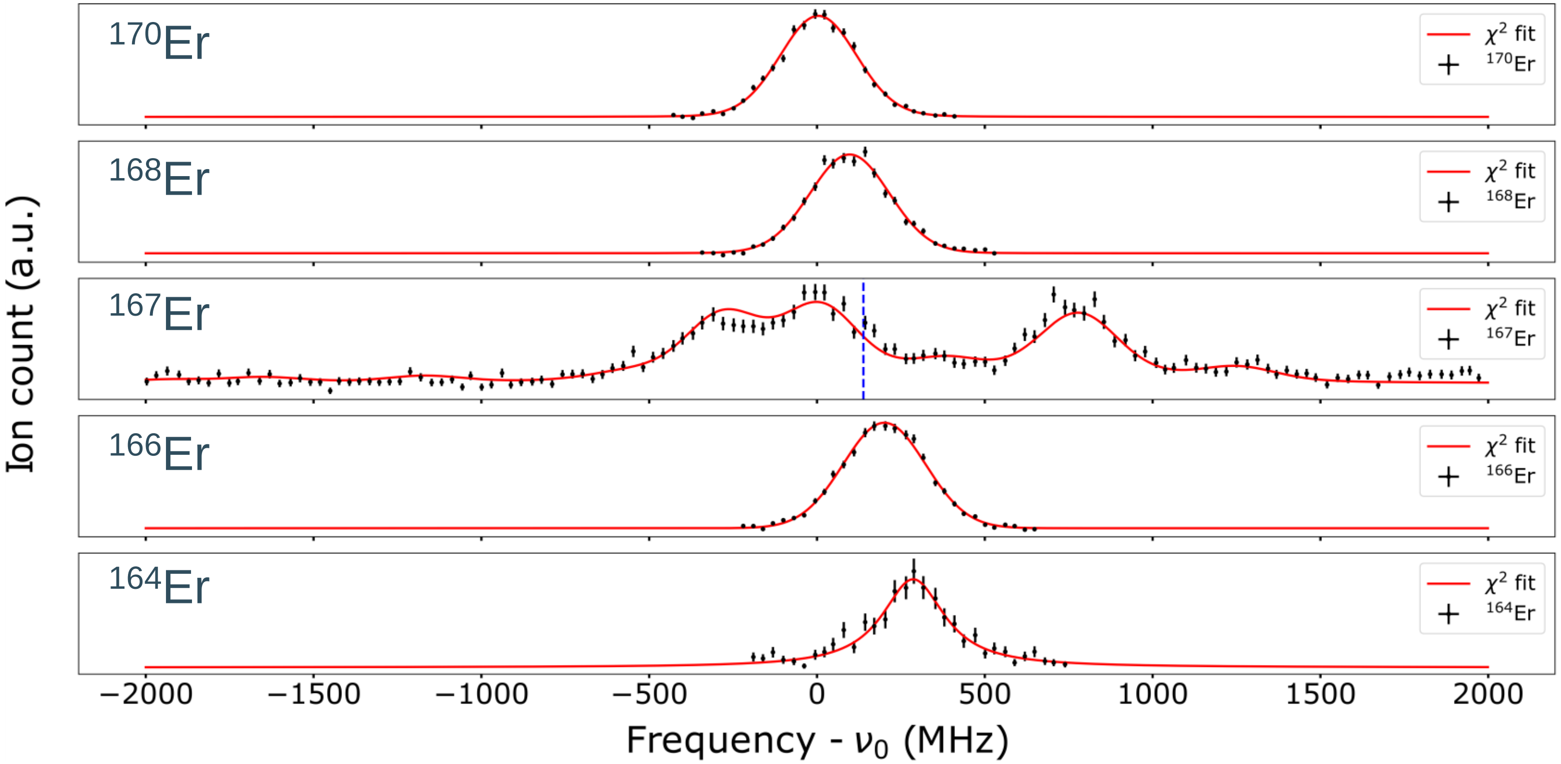
- Spectral linewidth of Δ_{nFWHM} = 281(5) MHz.



A. Ajayakumar et al., NIM B accepted for publication

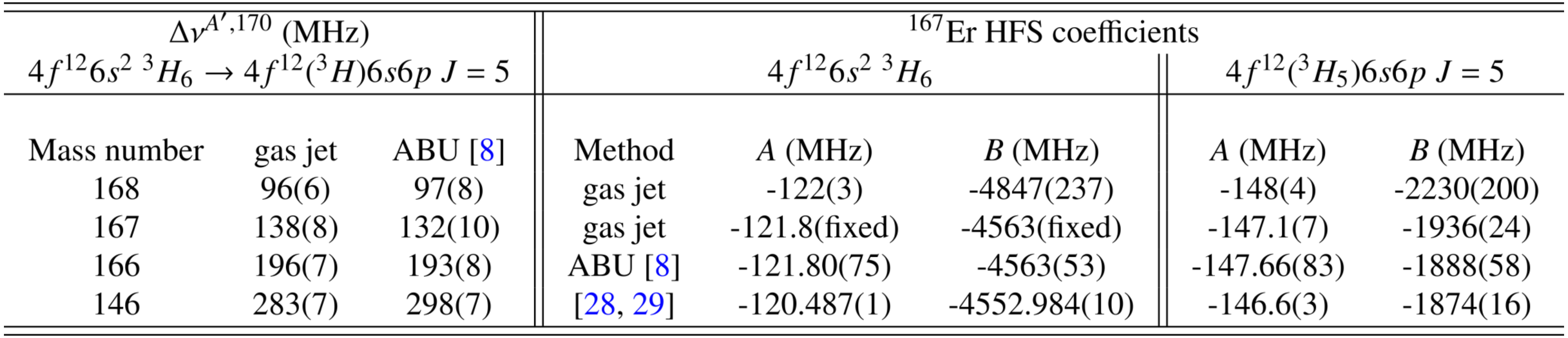
Resonance-ionization laser spectroscopy

- The isotope shifts measured for $^{170-164}$Er with ^{170}Er as the reference isotope
- Bunched ions trapped for 3 revolutions in PILGRIM



Resonance-ionization laser spectroscopy

- The isotope shifts measured for $^{170-164}$Er with ^{170}Er as the reference isotope
- Bunched ions trapped for 3 revolutions in PILGRIM
- Hyperfine A and B constants of the odd isotope ^{167}Er were determined
  - **Results in agreement with the literature !**



$\Delta\nu^{A',170}$ (MHz)			^{167}Er HFS coefficients				
$4f^{12}6s^2\ ^3H_6 \rightarrow 4f^{12}(^3H)6s6p\ J=5$			$4f^{12}6s^2\ ^3H_6$			$4f^{12}(^3H_5)6s6p\ J=5$	
Mass number	gas jet	ABU [8]	Method	A (MHz)	B (MHz)	A (MHz)	B (MHz)
168	96(6)	97(8)	gas jet	-122(3)	-4847(237)	-148(4)	-2230(200)
167	138(8)	132(10)	gas jet	-121.8(fixed)	-4563(fixed)	-147.1(7)	-1936(24)
166	196(7)	193(8)	ABU [8]	-121.80(75)	-4563(53)	-147.66(83)	-1888(58)
146	283(7)	298(7)	[28, 29]	-120.487(1)	-4552.984(10)	-146.6(3)	-1874(16)

A. Ajayakumar et al., NIM B accepted for publication

[8] J. Romans, et al., Nucl. Instrum. Meth. B 536 (2023) 72–81.

[28] W. J. Childs et al., Phys. Rev. A 28 (1983) 3402–3408.

[29] S. Ahmad, et al., Proceedings of the “Symposium on Quantum Electronics” (1985).

Mach number

The local temperature of the gas jet:

- Used the transverse first-step laser configuration
- Determined from the Doppler FWHM and atomic transition frequency ν_{01} of the ^{170}Er resonance
- ν_{01} = 721,995,054(60) MHz
- Temperature of the jet T = 46(2) K

Stream velocity of the jet:

- Used the counter-propagating first-step laser configuration
- Measure the doppler shifted centroid of the ^{170}Er resonance ν_{02}
- ν_{02} = 721,993,693(60) MHz
- Stream velocity of the jet *u* = 565(35) m/s

Mach number:

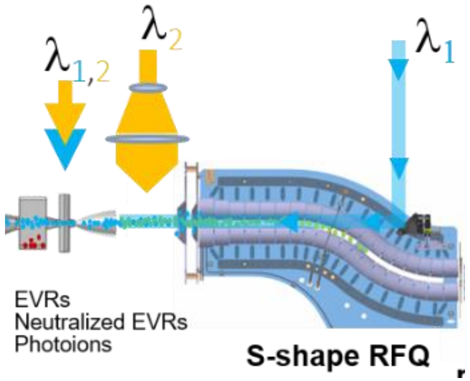
- From the stream velocity (*u*) and speed of sound, derived from the temperature of the gas jet:
- *M* = 4.5(3)

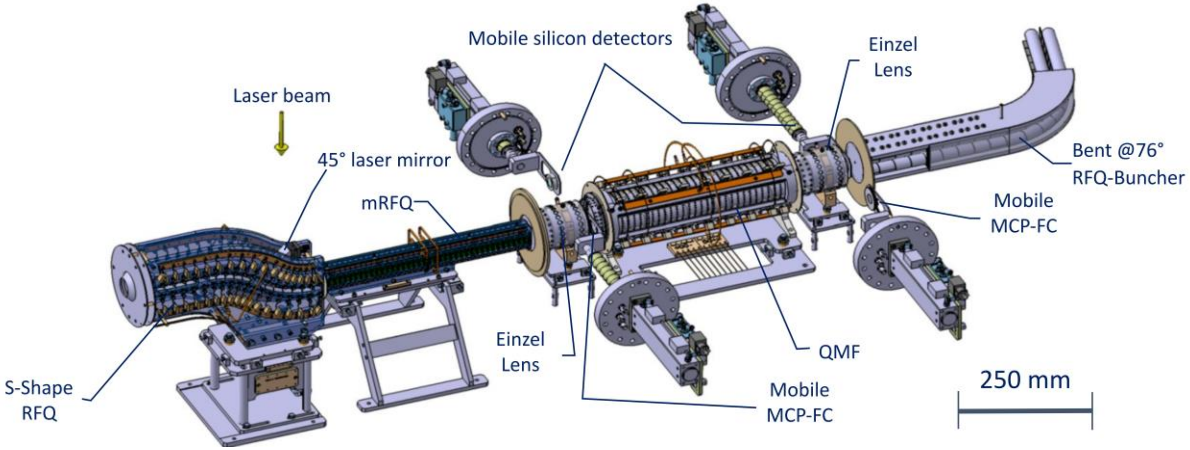
The deduced temperature in the gas cell is T_0 = 353(16) K

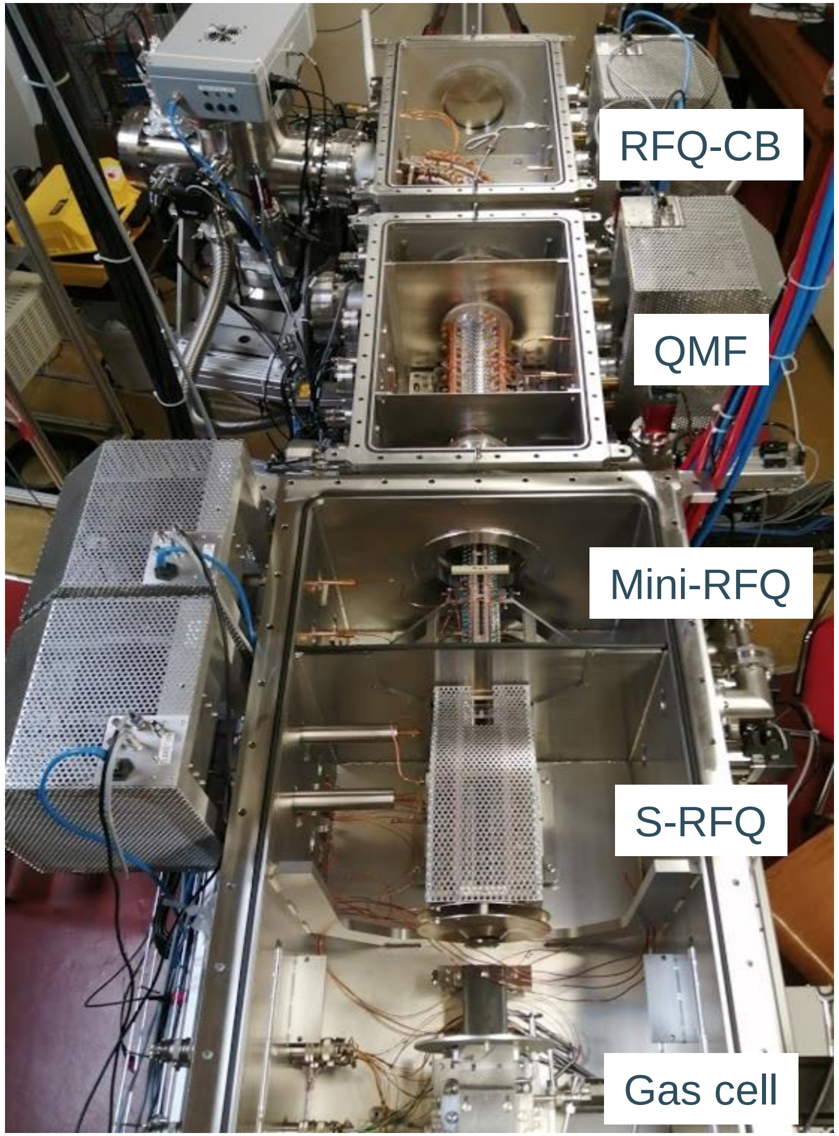
Ion transport towards PILGRIM

The laser ionized beam is:

- Transported through the S-RFQ
  - To be decoupled from the laser beam
- The miniRFQ acts as a pumping barrier
- A first mass separation is achieved via the QMF
  - ($m/\Delta m \sim 50$)
- Cooled and bunched in the RFQ-CB







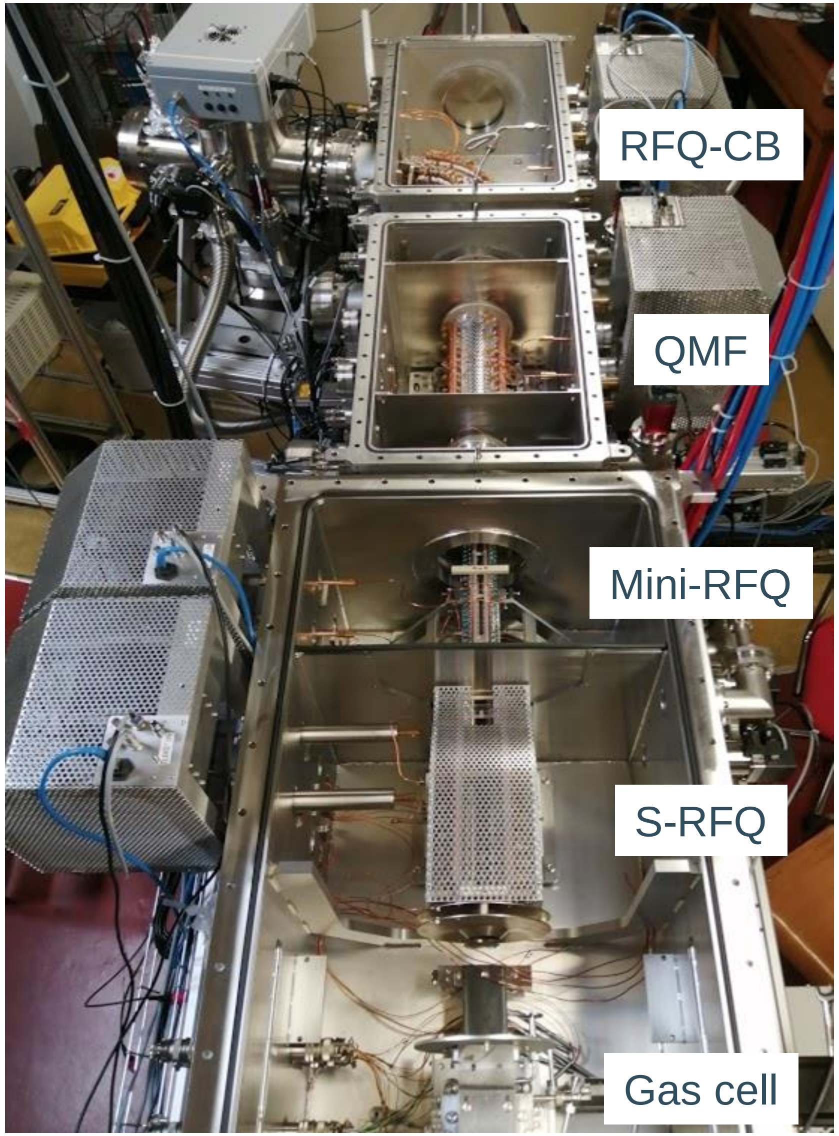
Recent update on the beamline

Control command:

- All control command is now EPICS based for the optics
  - GUI in Python
  - For the laser it is a work in progress
  - For the vacuum it will be done soon

Re-alignment of the buncher:

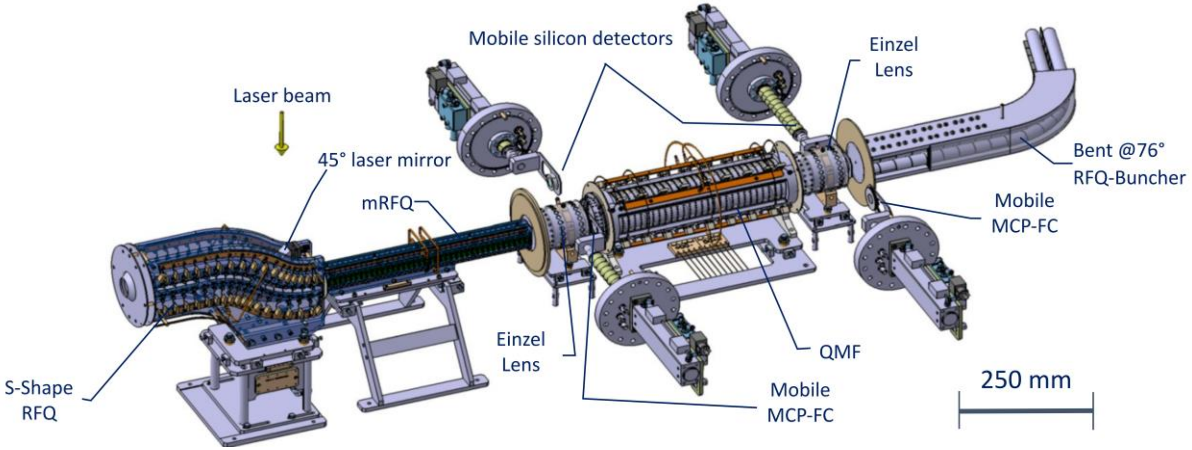
- The buncher was “badly” attached to its support (Tilted by respect to the beam axis)
  - Suspected to be the reason of the poor transmission efficiency of the buncher
  - Opened the chamber to fix the buncher

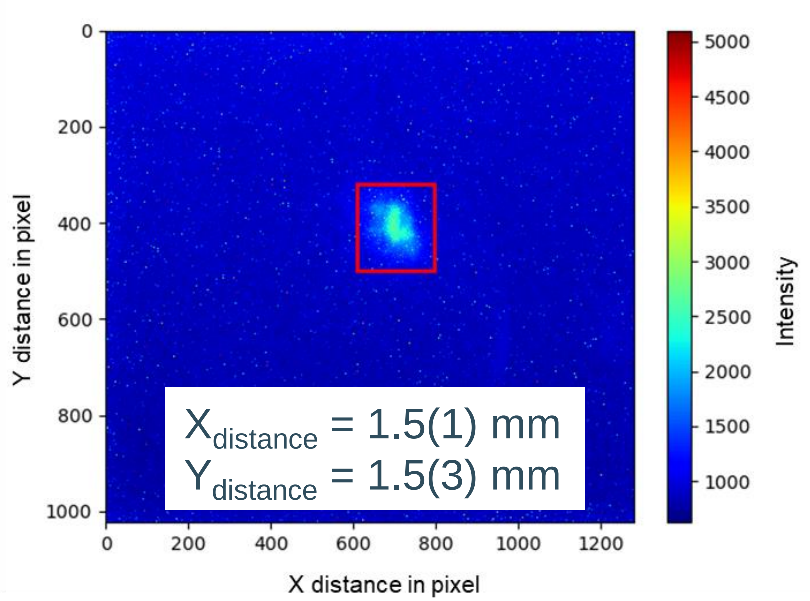


Ion transport towards PILGRIM

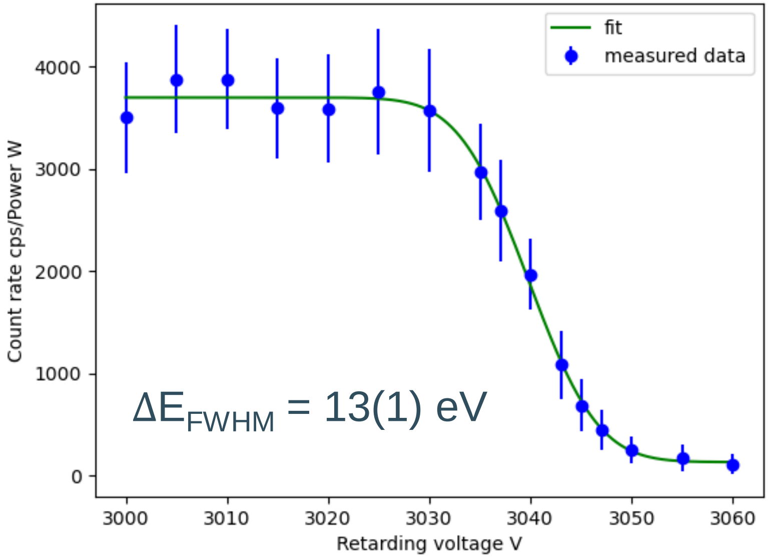
Transmission efficiency:

- S-RFQ + miniRFQ: $\epsilon \sim 95(5)\%$
- QMF: $\epsilon \sim 95(5)\%$ (moderate filtering)
- RFQ-CB: $\epsilon_{\mathrm{bunched}} \sim 95(5)\%$
- RFQ-CB – PILGRIM: $\epsilon > 80\%$

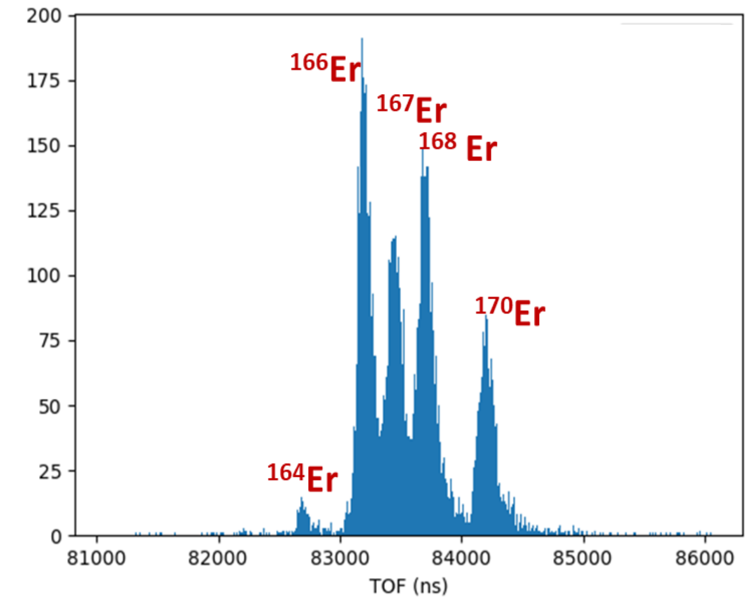




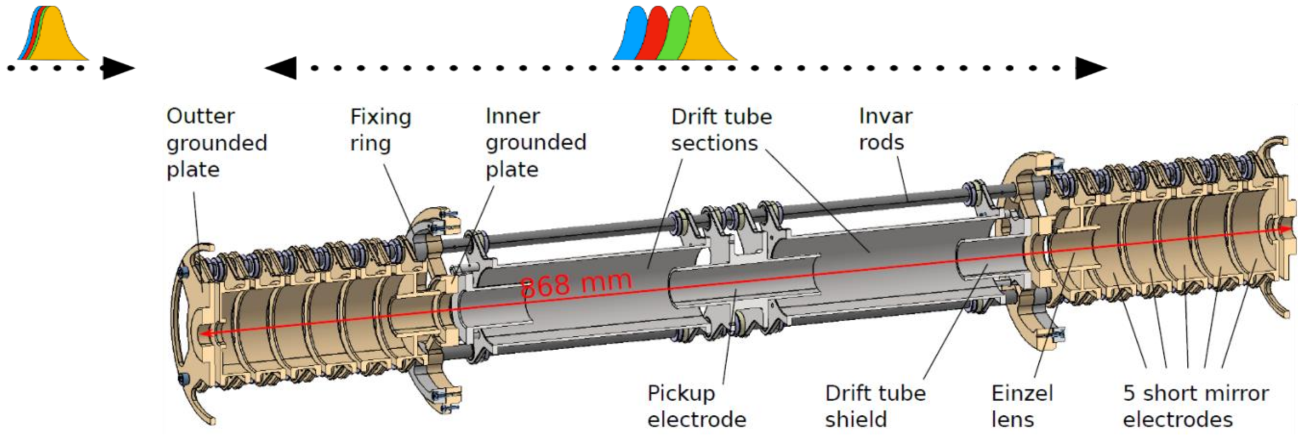
X_{distance} = 1.5(1) mm
Y_{distance} = 1.5(3) mm

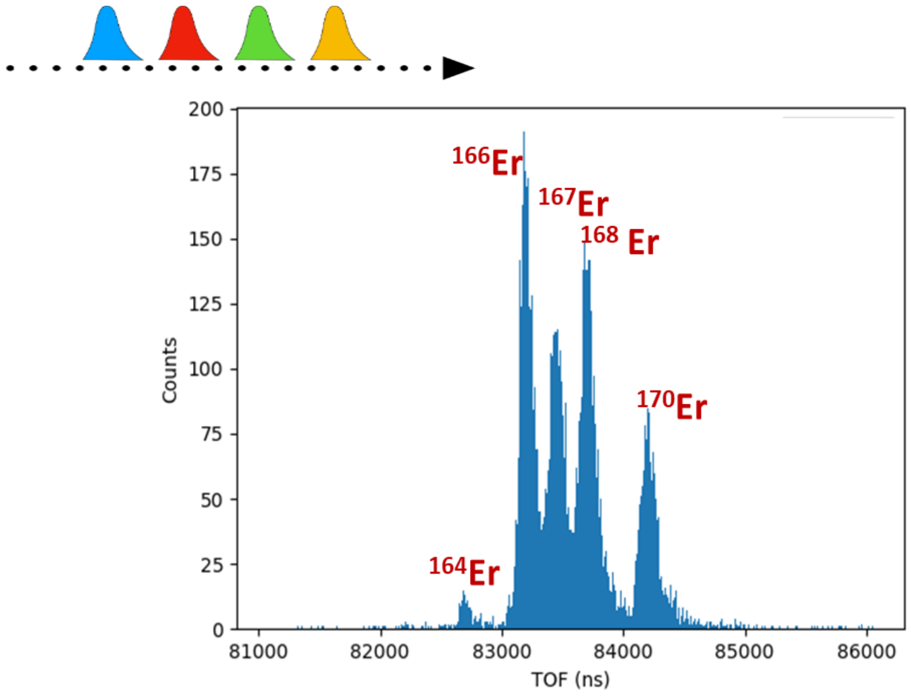


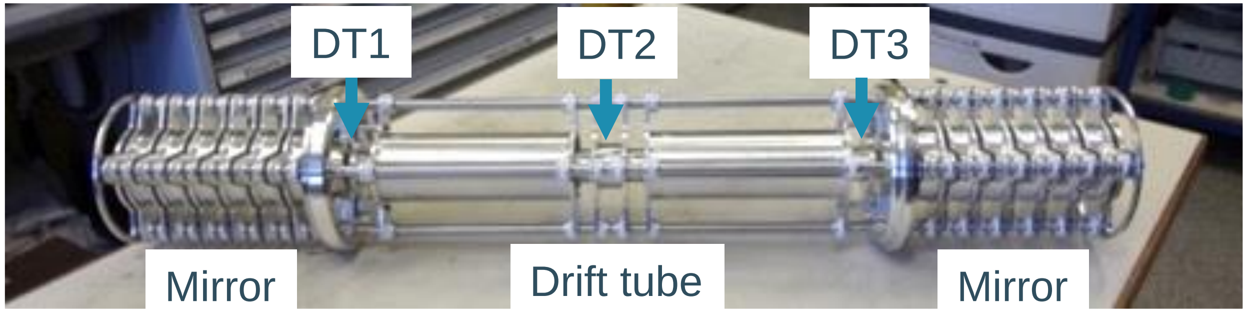
ΔE_{FWHM} = 13(1) eV



PILGRIM (Piège à Ions Linéaire du Ganil pour la Résolution des Isobares et la mesure de Masse)





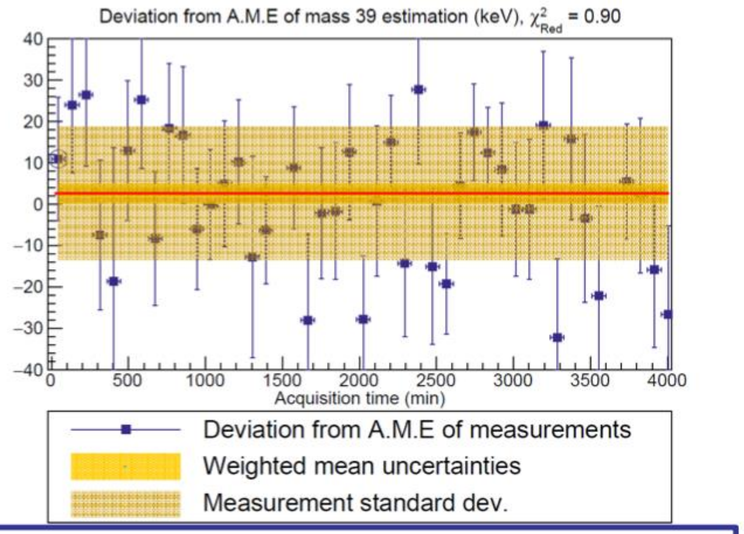


- The MR-TOF MS is an electrostatic ion trap
- Increase the TOF by muyltiple reflections
- Purification and mass measurements

PhD: P. Chauveau, B-M. Retailleau

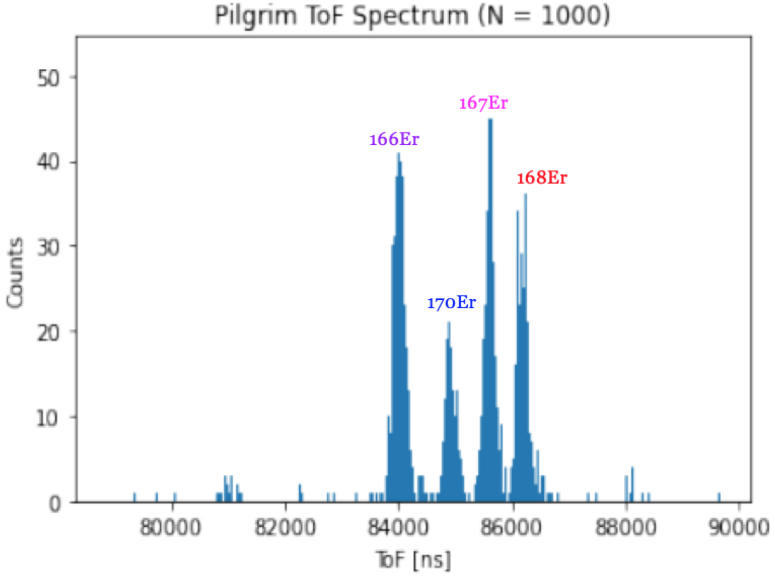
PILGRIM (Piège à Ions Linéaire du Ganil pour la Résolution des Isobares et la mesure de Masse)

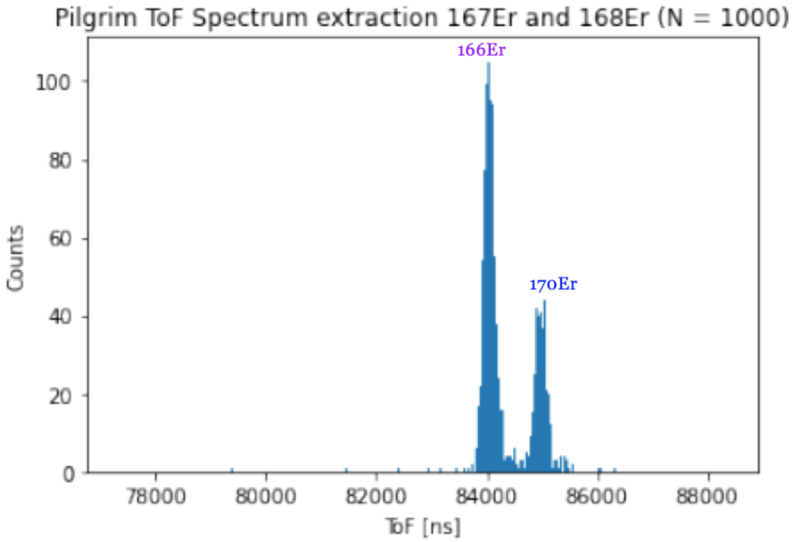
- ^{39}K using ^{23}Na and ^{85}Rb as references



σ_m=2.4 keV, σ_m/m=6.7 10^{-8}

- Bunch from BN Gate
- Tests with ^{23}Na, ^{39,41}K, ^{85,87}Rb and ^{133}Cs
- R = ~ 130 000
- δm/m ~ 10^{-8}





- Ion bunch from the RFQ-CB
- Tests with ^{162,164,166,167,168,170}Er
- R ~ 80 000
- δm/m ~ 10^{-7}
- Efficient suppression of contaminants

Master: Y. Balasmeh

Conclusion and outlook

Conclusion

- TiSa laser system ready for High Resolution Laser Spectroscopy
- First in-jet laser spectroscopy of Er @ S3LEB
- Characterization of the gas cell, gas jet, PILGRIM @ S3LEB ongoing

Outlook

- New CW cavity for continuous wavelength scanning (PhD A. Ajayakumar)
- New Frequency mixing cavity development for extended wavelength range
- Fast gas cell development: ANR FRIENDS3 (IJCLab) (PhD W. Dong)
- Test of Day 1 experiment elements of interest (Sn, In, Ag, Zr, U…)

Installation at S^3

- S^3 Laser room end of 2022
- Installation of S^3-LEB @ S^3 end 2023

Thanks to S^3 LEB TEAM

GANIL:

Anjali Ajayakumar; **Alexandre Brizard**; Lucia Caceres; Pierre Delahaye; Sarina Geldhof; Nathalie Lecesne; Renan Leroy; Franck Lutton; **Alejandro Ortiz-Cortes**; Benoit Osmond; Julien Piot; Hervé Savajols

LPC:

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

IJC Lab:

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

KU Leuven:

Arno Claessens; Rafael Ferrer; Ruben de Groote; **Sandro Kraemer** ; **Jekabs Romans**; Antoine de Roubin; Simon Sels; Paul Van Denbergh; Piet Van Duppen;

JGU:

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JYU:

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IRFU:

Martial Authier; Olivier Cloue; Antoine Drouard; **Emmanuel Rey-Herme**; Marine Vandebrouck

PhD students