Radioactive beams from S^3 Low Energy Branch

Vladimir Manea
IJCLab, Orsay, France
GANIL, Caen, France

Outline

- Beam-production and experimental methods of S^3-LEB
- Status of the setup
- Planning and on-line commissioning at S^3
- Considerations for beams from S^3-LEB (to DESIR)

Beam-production and experimental methods of S³-LEB

LINAC beams for S³: He to U
E< 14,5 MeV/A (A/Q=3)
E< 7,5 MeV/A (A/Q=7)

	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

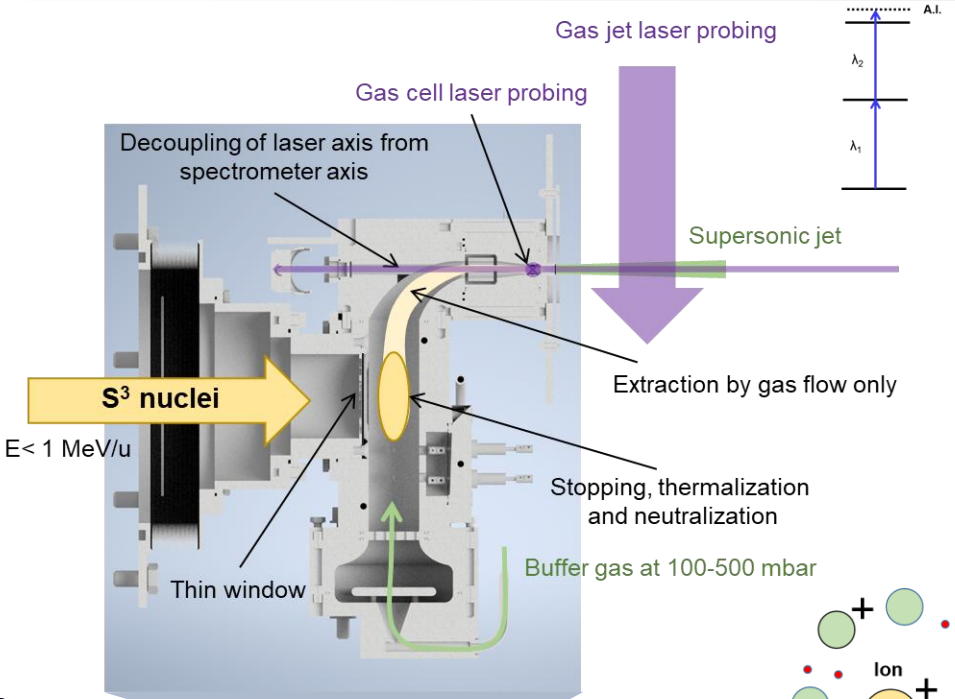
X 5 up to ^{58}Ni
X 10^{x} for A > 58

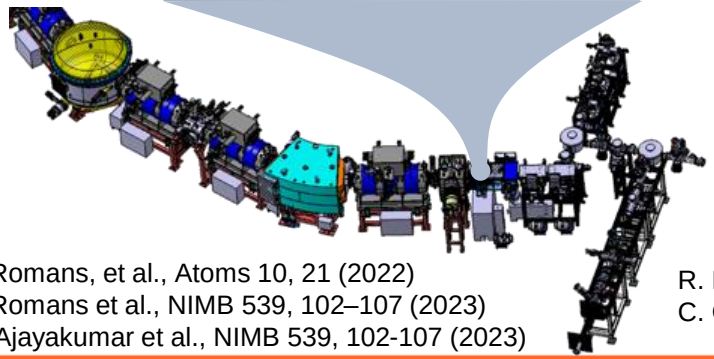
Super Separator Spectrometer

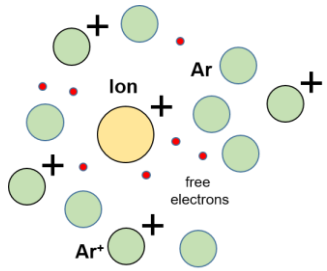
S³ scientific collaboration :

- 27 Laboratoires
- 12 countries : Belgium, France, Finland, Germany, Hungary, Italy, Poland, Slovakia, Spain, Sweden, U.K., USA

Beam-production and experimental methods of S³-LEB



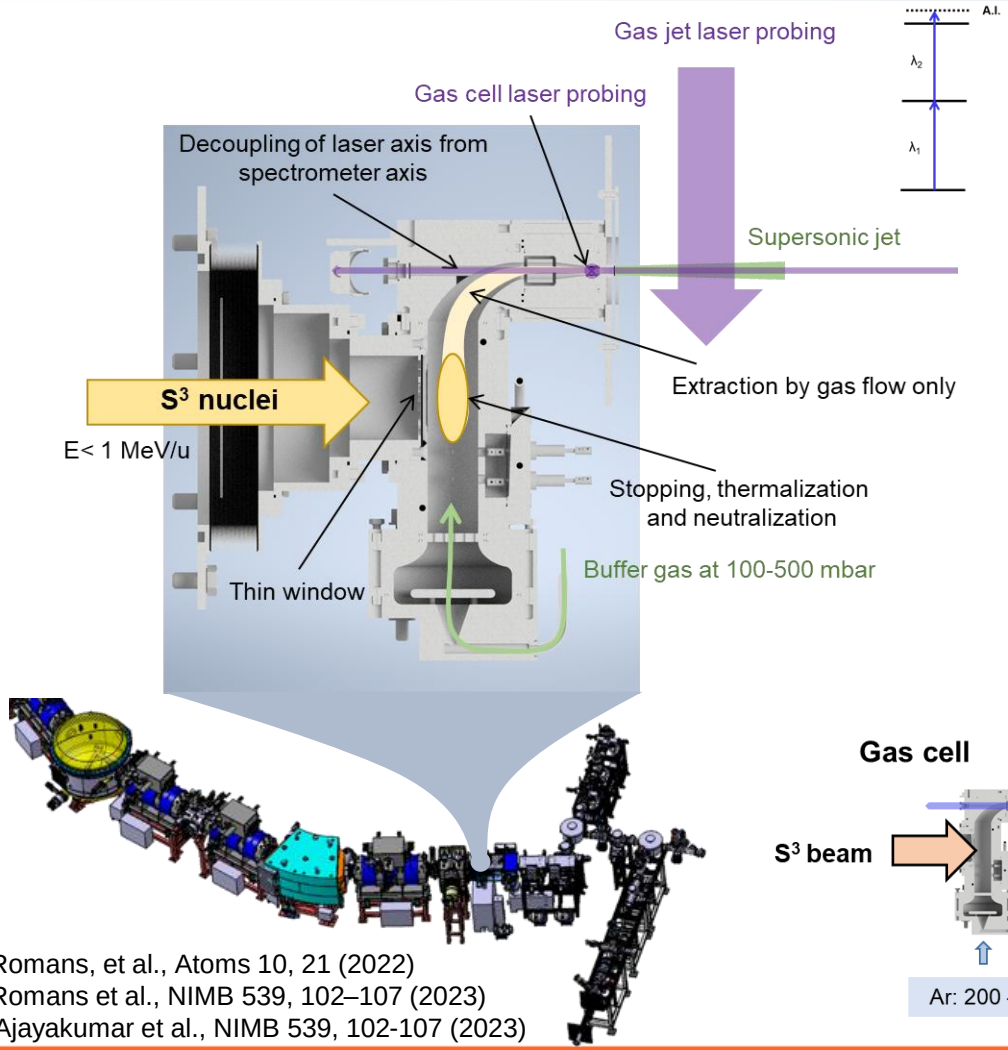




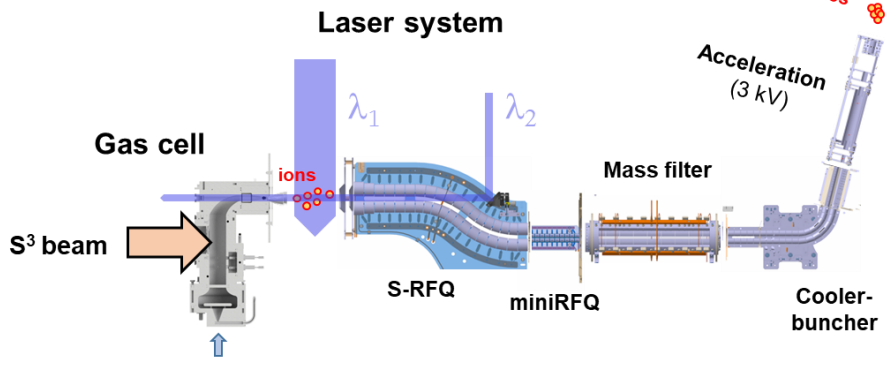
J. Romans, et al., Atoms 10, 21 (2022)
J. Romans et al., NIMB 539, 102–107 (2023)
A. Ajayakumar et al., NIMB 539, 102-107 (2023)

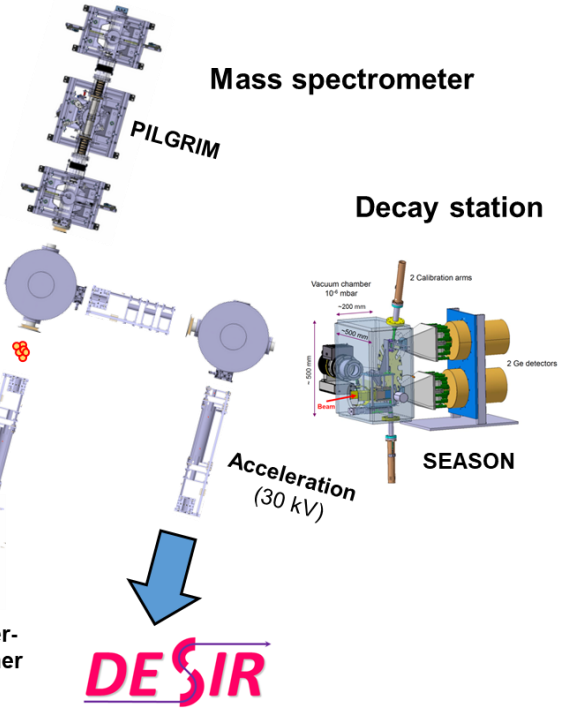
R. Ferrer, Nature Comm. 8 14520 (2017)
C. Granados et al., Phys. Rev. C 96, 054331 (2017)

Beam-production and experimental methods of S³-LEB



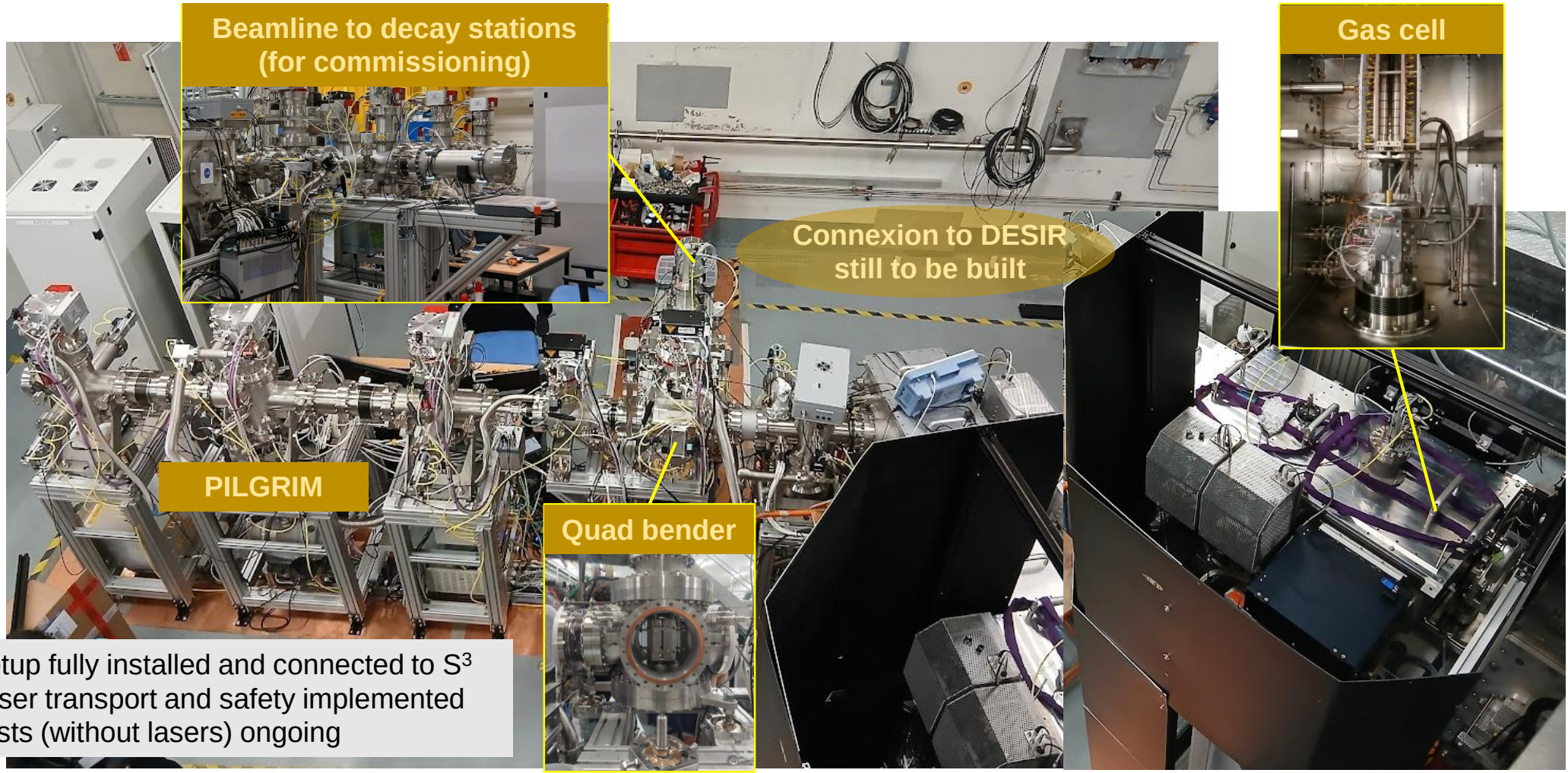
- Laser spectroscopy in a supersonic jet at intermediate resolution (200 MHz)
- Mass and decay spectroscopy measurements
- Possible transport towards DESIR





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

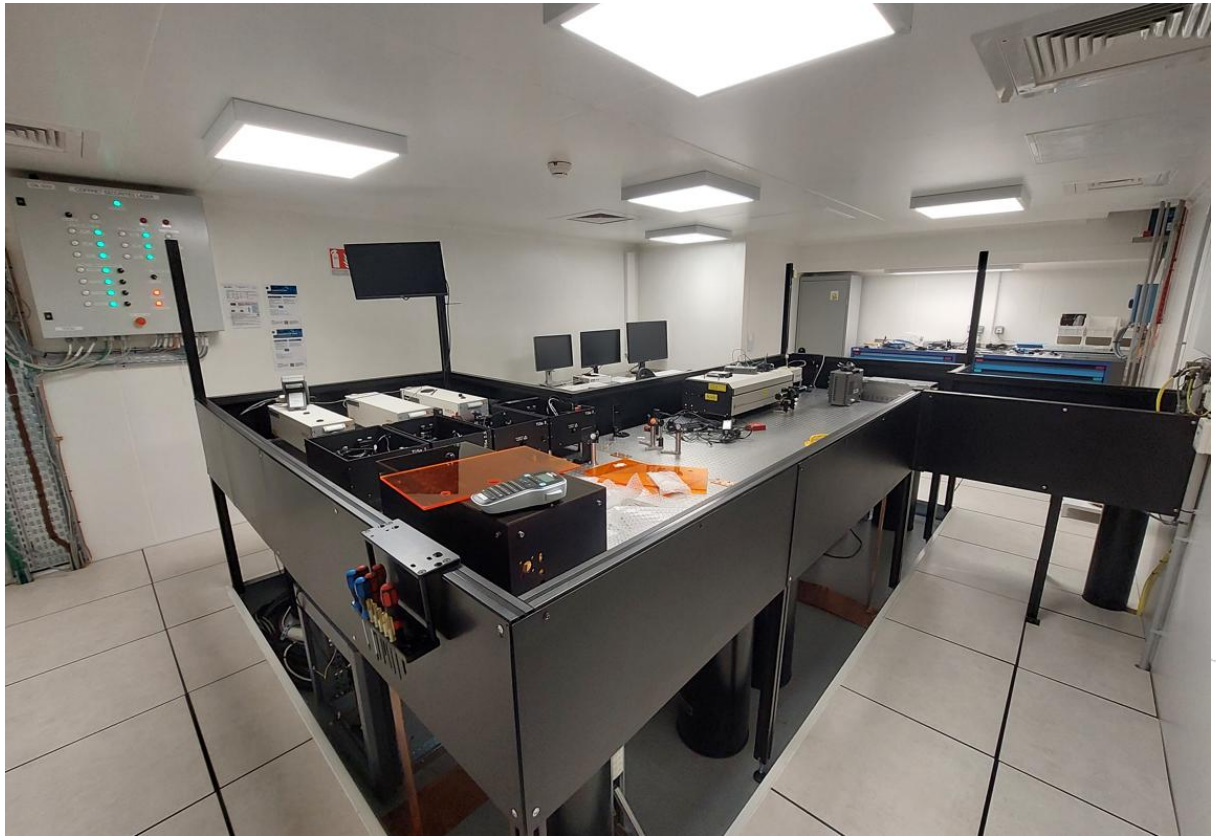
Status of the setup: S³-LEB



- ❑ Setup fully installed and connected to S³
- ❑ Laser transport and safety implemented
- ❑ Tests (without lasers) ongoing

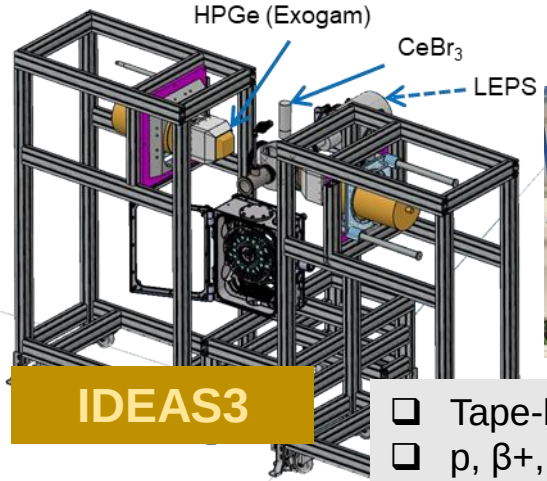
Status of the setup: S³-LEB

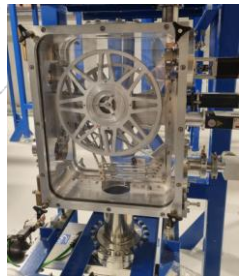
- Ti:Sa laser room ready for sending beams to S³



SEASON

- Windmill decay station
- α, FF, CE, γ
- Developed by IRFU
- Commisioned at IGISOL





IDEAS3

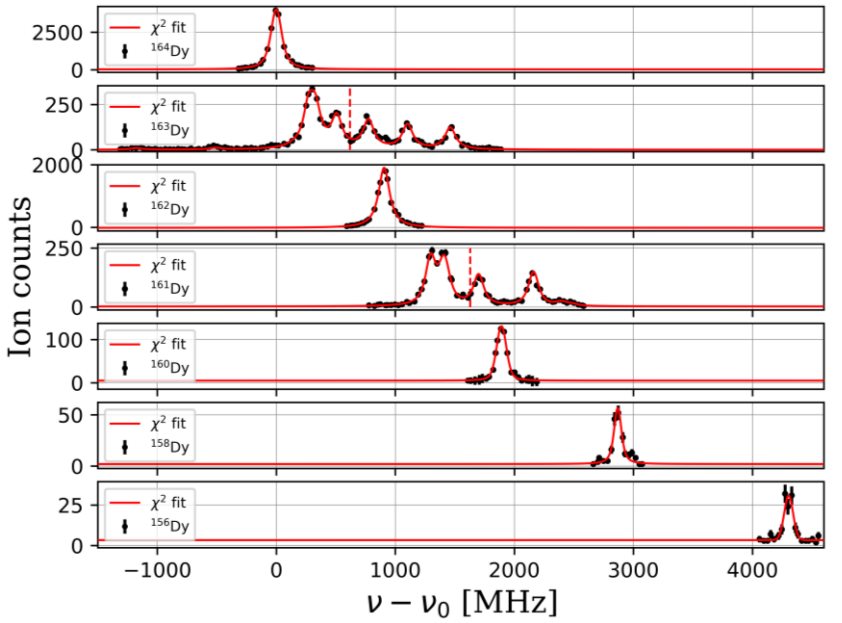
- Tape-based decay station
- p, β+, X, γ
- Under construction at IJCLab

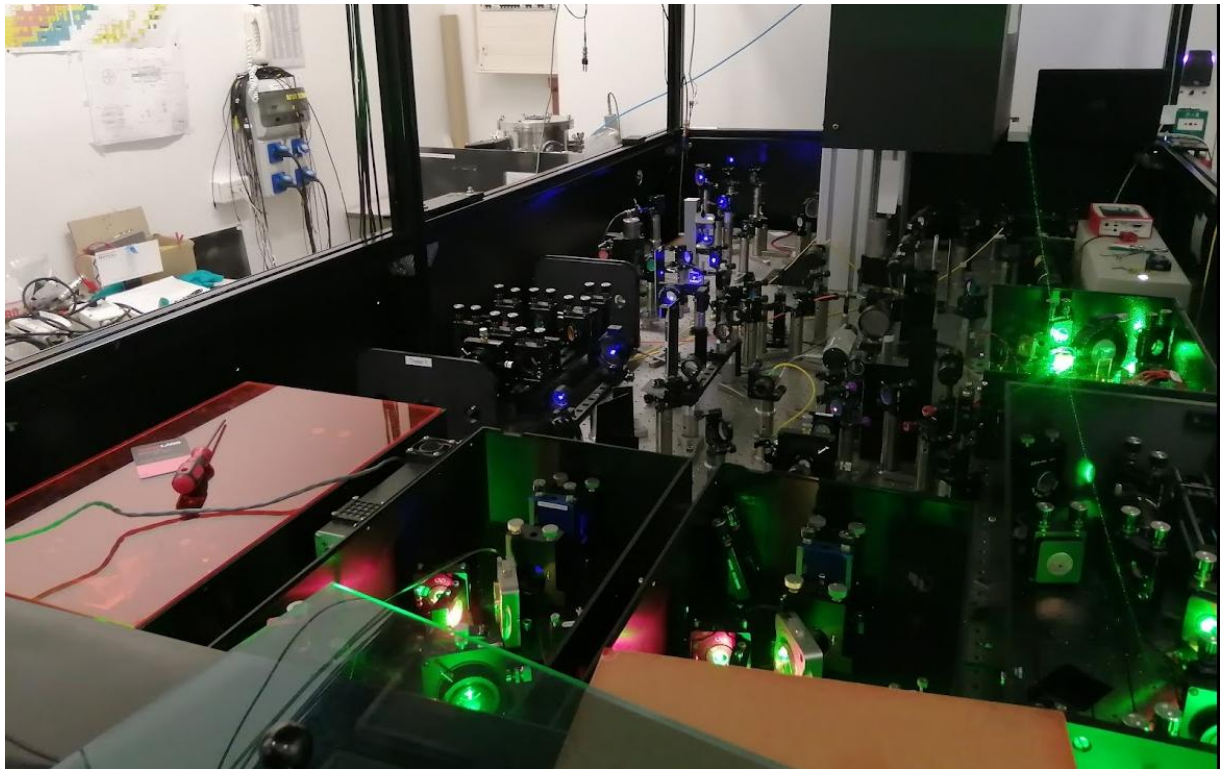
Status of the setup: GISELE

Er | Dy | Gd *ongoing*

Sn | Pd

Talks Andrés Lopez, Valentin Marchand



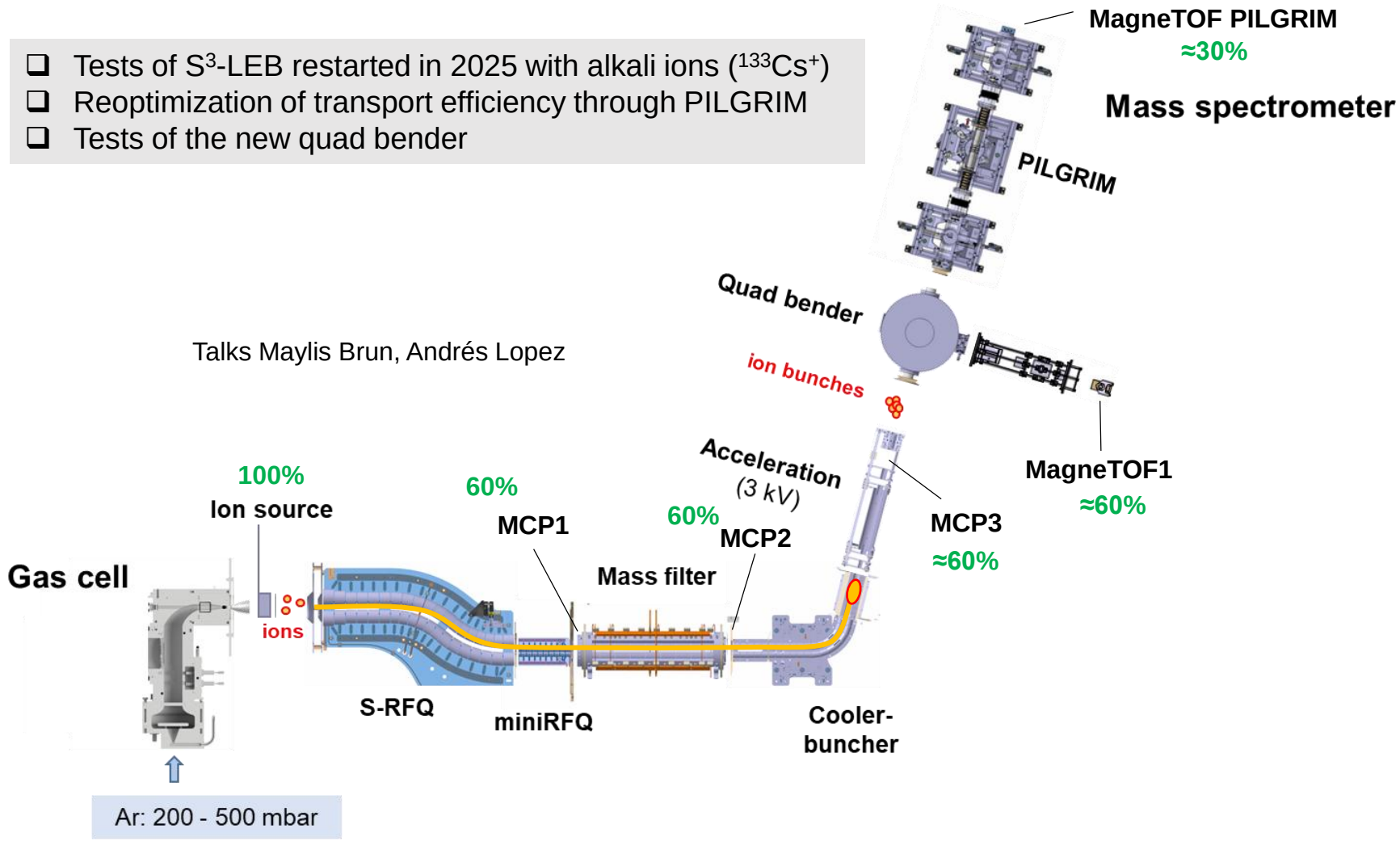


- Off-line Ti:Sa for scheme development and laser R&D.
- Continuously operated.

Status of the setup: transport optimizations

- ❑ Tests of S^3-LEB restarted in 2025 with alkali ions ($^{133}Cs^+$)
- ❑ Reoptimization of transport efficiency through PILGRIM
- ❑ Tests of the new quad bender

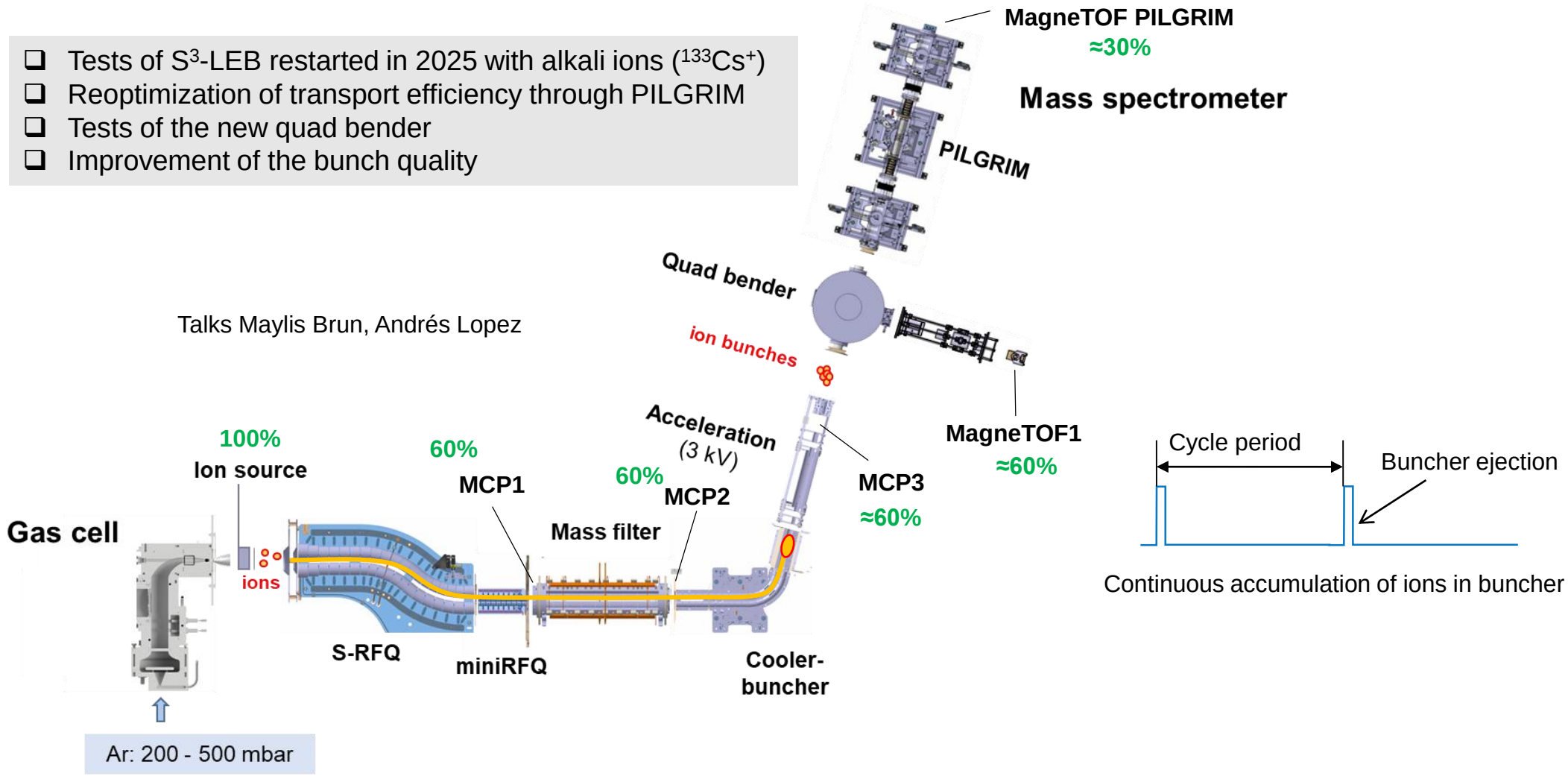
Talks Maylis Brun, Andrés Lopez



Status of the setup: bunch optimizations

- ❑ Tests of S^3-LEB restarted in 2025 with alkali ions ($^{133}Cs^+$)
- ❑ Reoptimization of transport efficiency through PILGRIM
- ❑ Tests of the new quad bender
- ❑ Improvement of the bunch quality

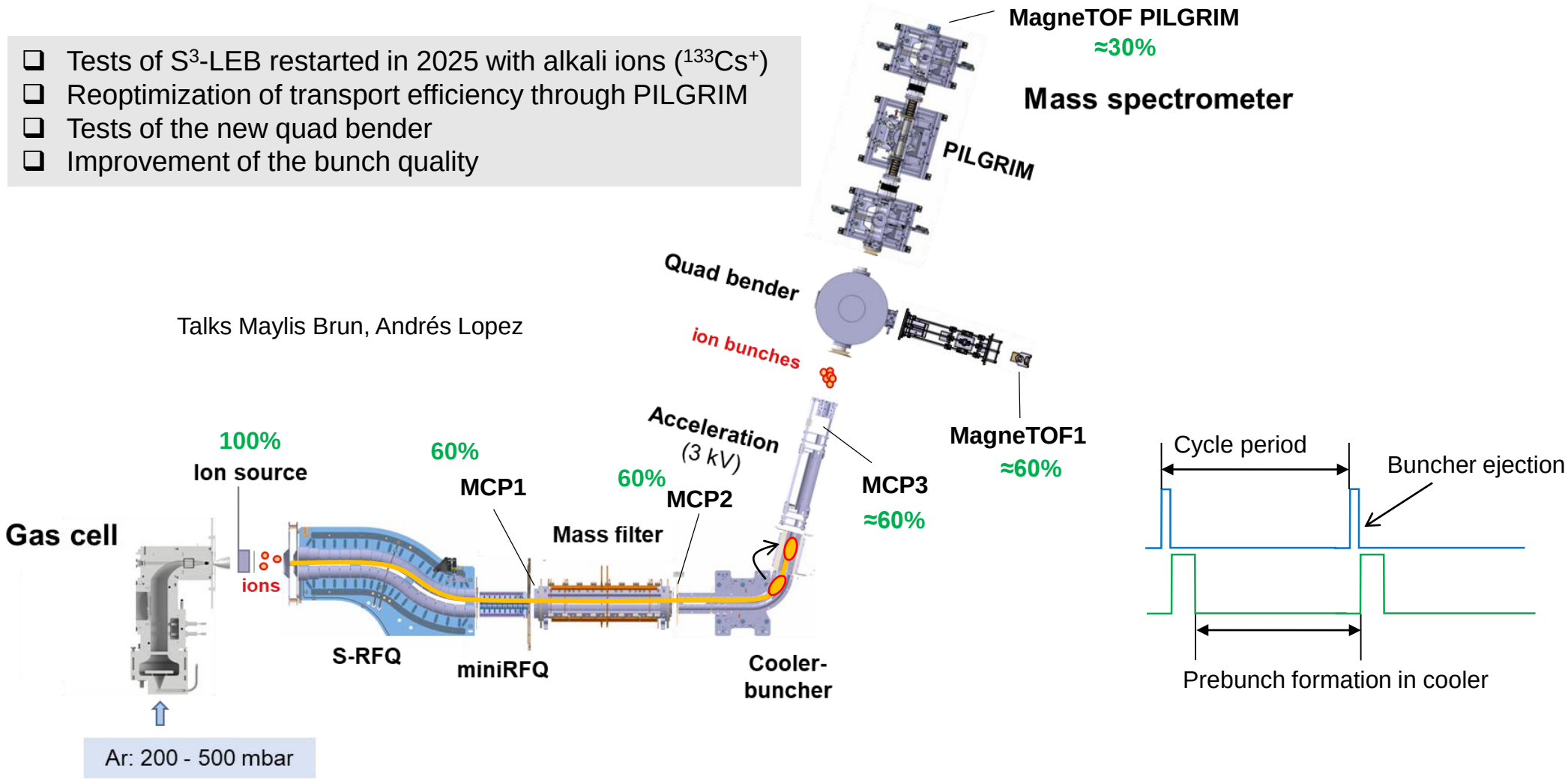
Talks Maylis Brun, Andrés Lopez



Status of the setup: bunch optimizations

- Tests of S^3-LEB restarted in 2025 with alkali ions ($^{133}Cs^+$)
- Reoptimization of transport efficiency through PILGRIM
- Tests of the new quad bender
- Improvement of the bunch quality

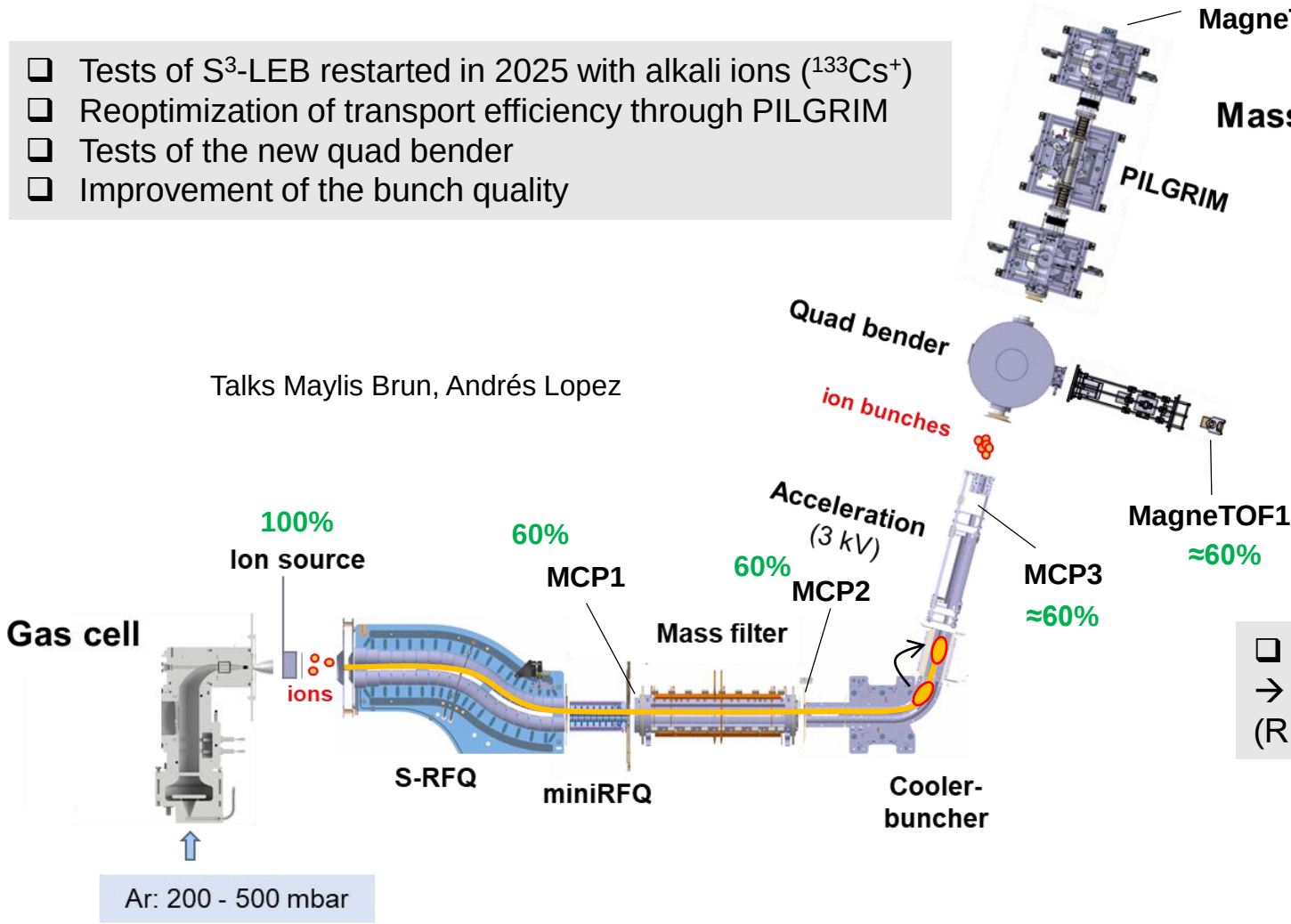
Talks Maylis Brun, Andrés Lopez

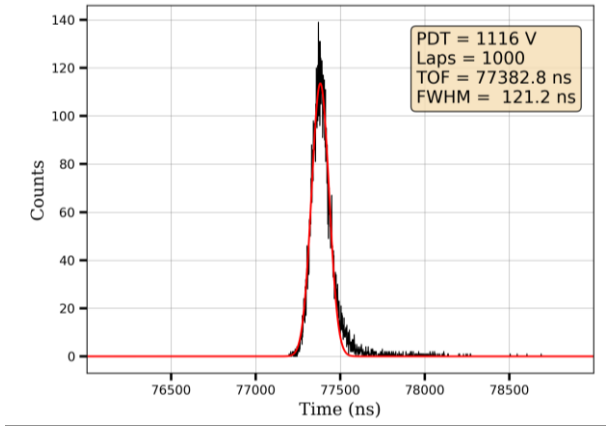


Status of the setup: PILGRIM tuning

- ❑ Tests of S^3-LEB restarted in 2025 with alkali ions ($^{133}Cs^+$)
- ❑ Reoptimization of transport efficiency through PILGRIM
- ❑ Tests of the new quad bender
- ❑ Improvement of the bunch quality

Talks Maylis Brun, Andrés Lopez

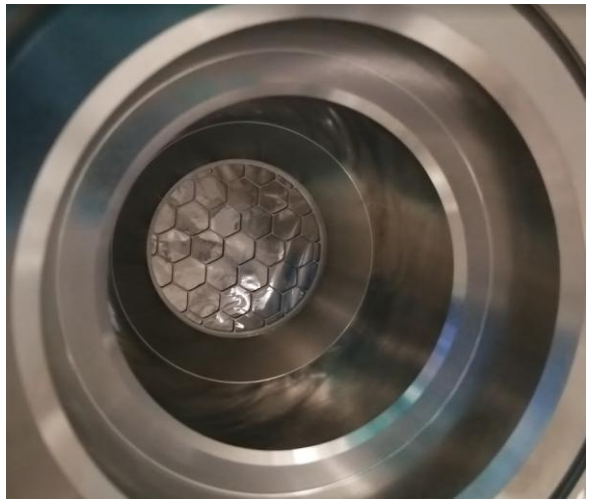


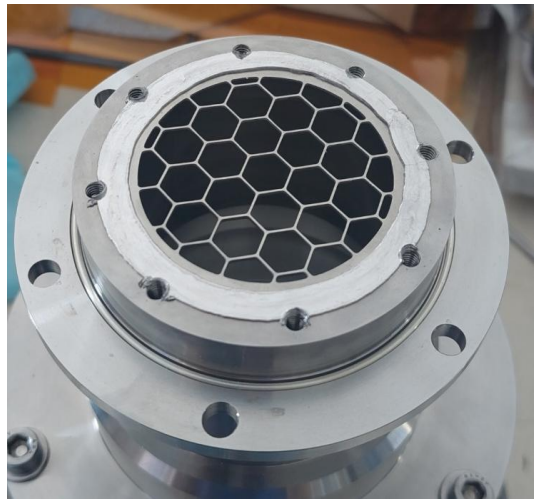


- ❑ Optimization of PILGRIM:
→ bunch FWHM after 1000 laps ≈ 120 ns (R ≈ 120000)

Status of the setup: entrance window tests

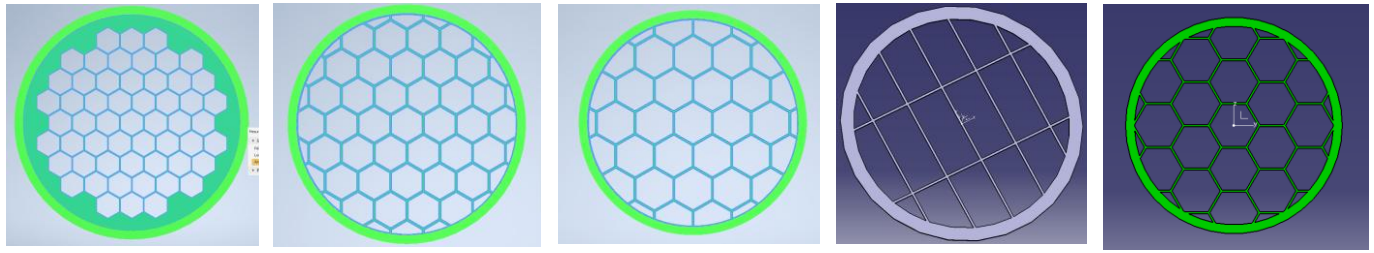
- Window mount and identical copy for off-line tests and plug-and-play installation.



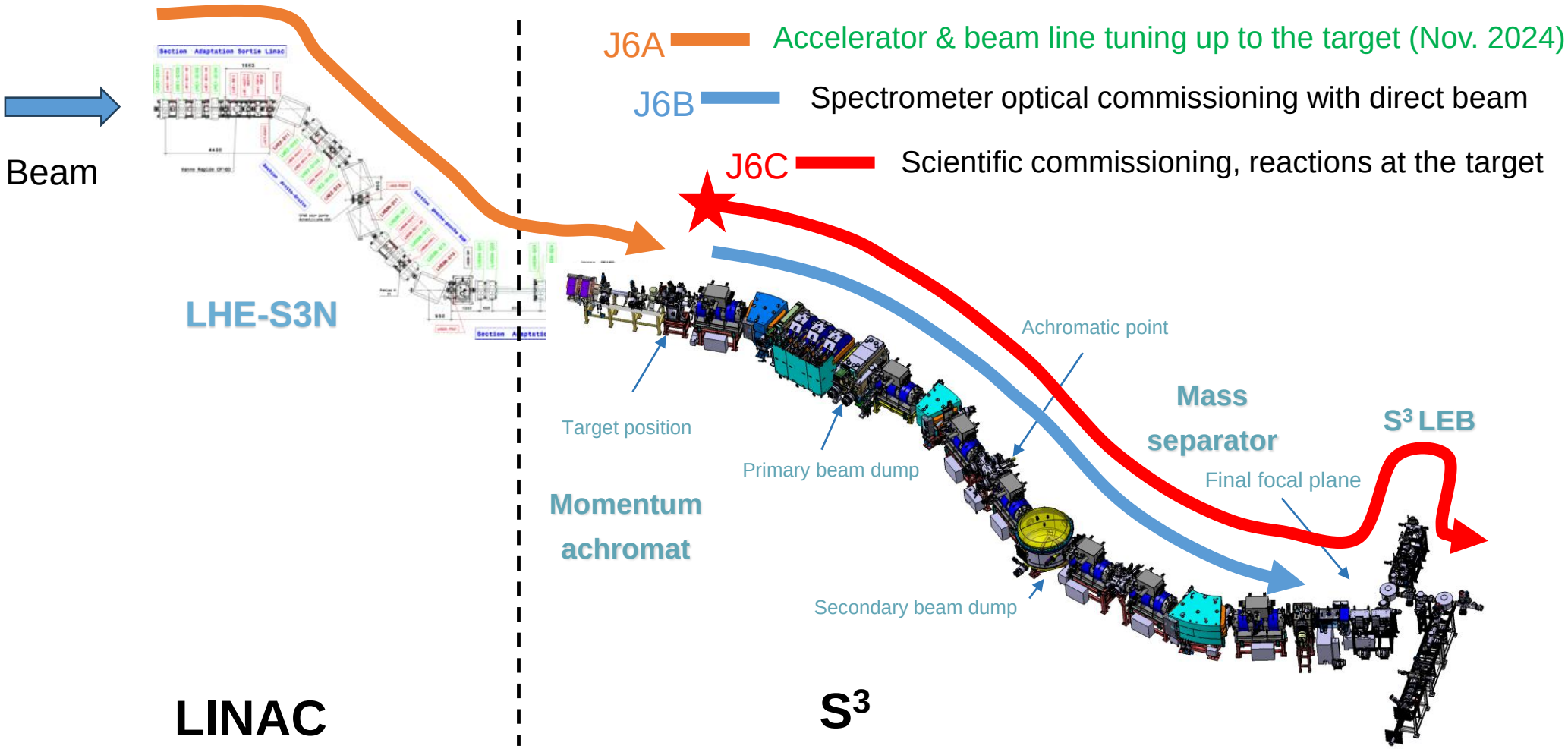


- Different window thickness, material and support mesh tested.
- Focus on commissioning cases.
- Leak rate below acceptable limit.

Work of Ananbelle Bouriel, Johan Goupil



Planning and on-line commissioning at S³: Status of S³



Planning and on-line commissioning at S^3: Status of S^3

- Difficulties operating the SMTs: four require repairs

  - **Re-welding of SMT P2 following repair of broken wire**
  - **Exchange of corroded current feedthroughs** on SMTs P1, P4 and P7



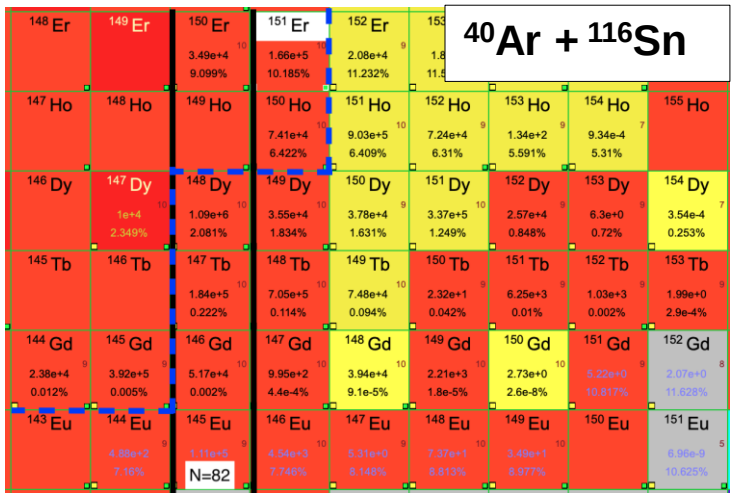
- ASNR inspection revealed **non-conformity in component of cold box**, which imposed a suspension of the cold-box operation → No testing of the SMTs possible until the piece is either exchanged (manufacturing delay) or a derogation is approved (administrative delay).

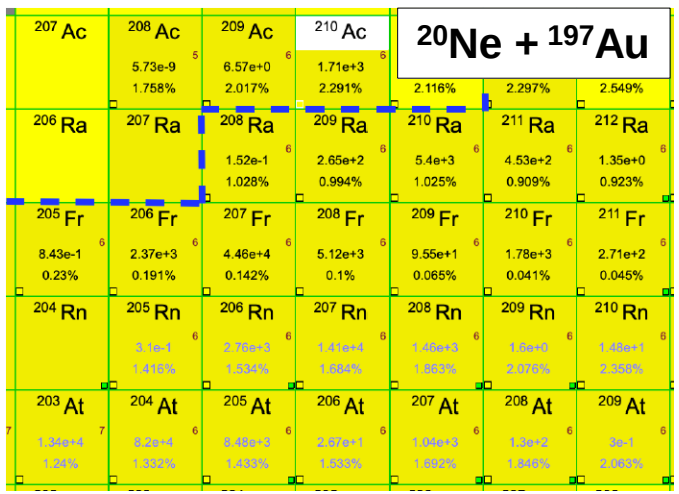
- Preliminary estimates: No possibility to begin optical commissioning before second half of 2027

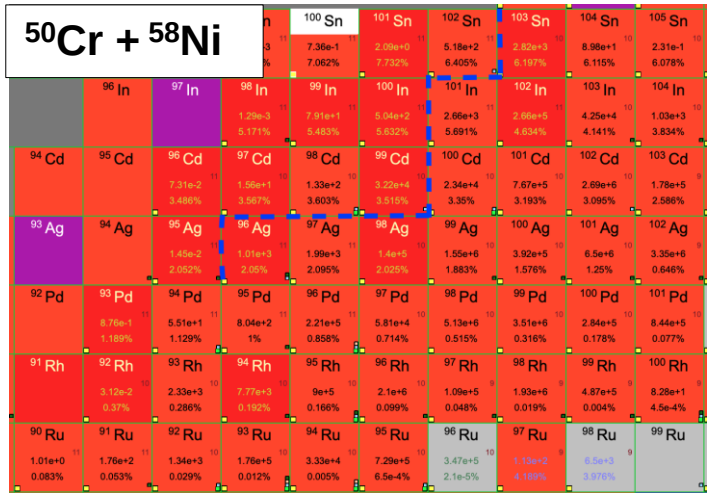
Planning and on-line commissioning at S³: S³-LEB

- S³-LEB will be the first setup to be used for the scientific commissioning of S³
- 3 steps: which could fit in a year of operation:
  - $^{40}Ar + ^{116}Sn$ (test case erbium)
  - $^{40}Ar + ^{175}Lu$ and $^{20}Ne + ^{197}Au$ (test case actinium)
  - $^{50}Cr + ^{58}Ni$ (test case tin)

LISE++ simulations (courtesy Hervé Savajols)







Considerations for RIBs from S^3-LEB (to DESIR): reaction

- ✓ Primary beam:
  - Primary beams will become gradually available with a development plan
  - Initial intensities limited to 1-2 puA
  - Current authorization only for ^{12}C and heavier (special approval for lighter beams)

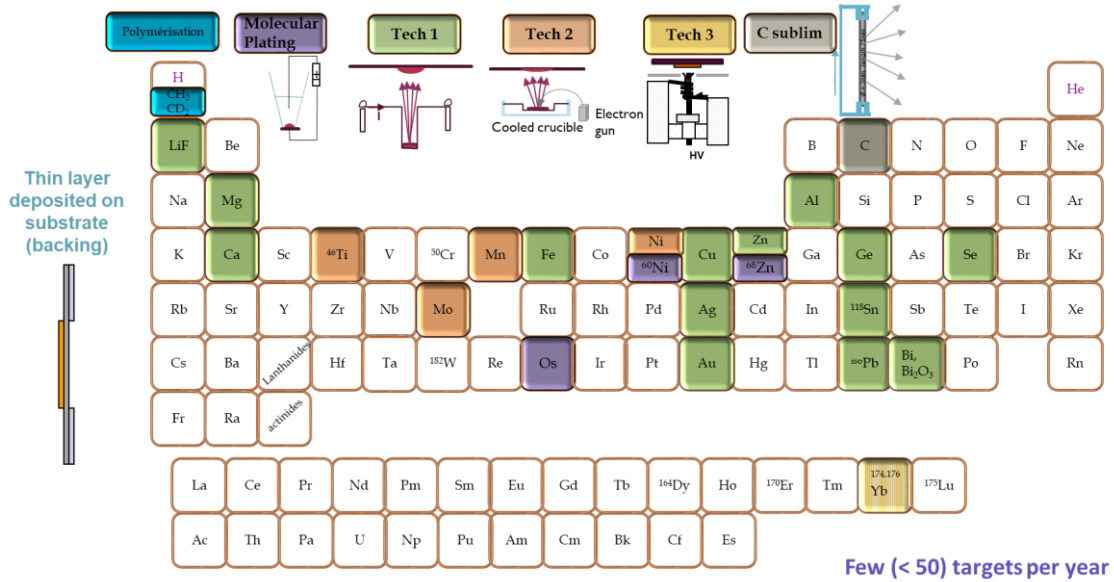
- ✓ Target:
  - Development required for the production of certain targets

- ✓ Fusion-evaporation recoil energy (very asymmetric reactions → slow recoil → very thin entrance window)

Primary beams so far accelerated at SPIRAL2

Parameter	$^{18}O^{6+}$	$^{18}O^{7+}$	$^{40}Ar^{14+}$
Max E (MeV/A)	14.5	7	7
Max I (μA)	50	78	80
Transmission (%)	99	98	99
Beam power (kW)	2	0.6	1.6

Targets produced so far in GANIL target lab



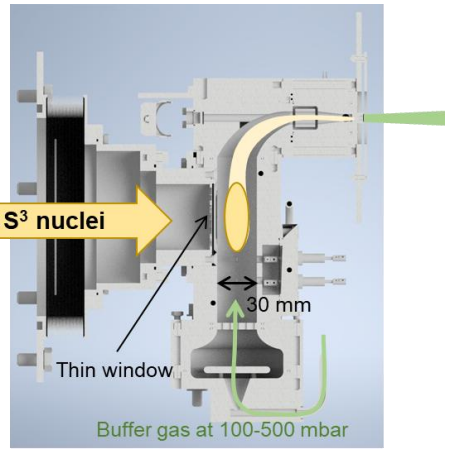
Considerations for RIBs from S^3-LEB (to DESIR): gas-cell extraction

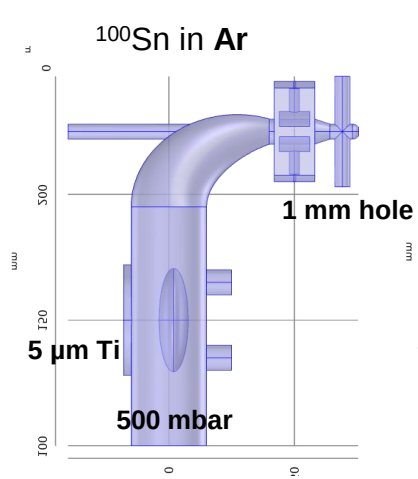
- Possibilities:
  - use argon (lower ion survival)
  - use helium (higher ion survival):
    - limited stopping power
    - much higher diffusion rate

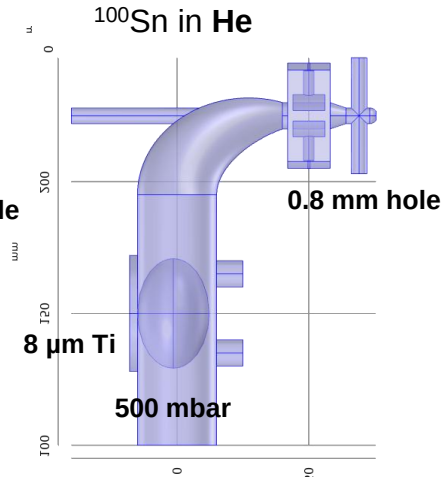
F. Lautenschläger et al., Nucl. Instr. Meth. B 383 115–122 (2016)

- Neutralization:
  - ≈ 10% during thermalization
  - x% Recombination in plasma (depends on total beam intensity)

SRIM + COMSOL



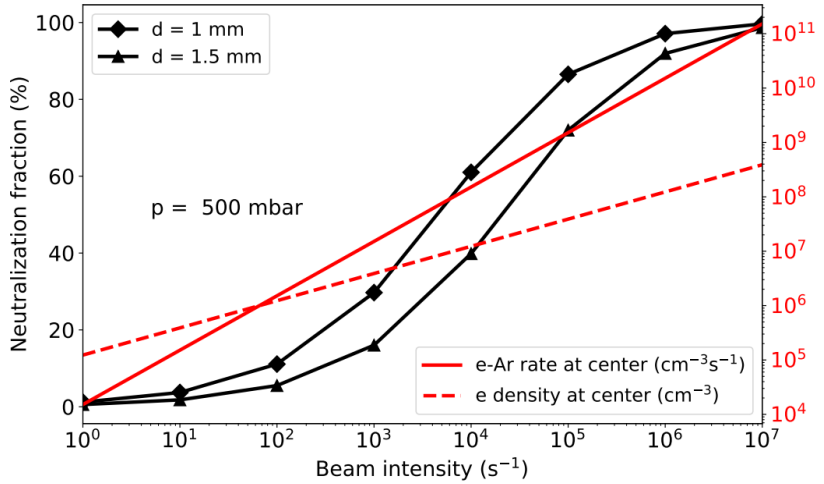




≈100% stopping efficiency
≈ 65% extraction efficiency
≈ 580 ms extraction time

≈ 280 ms with 1.5 mm hole

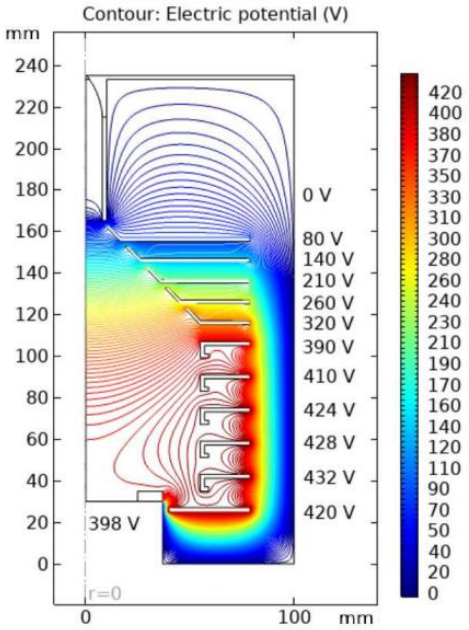
≈ 70% stopping efficiency
≈ 25% extraction efficiency
≈ 300 ms extraction time

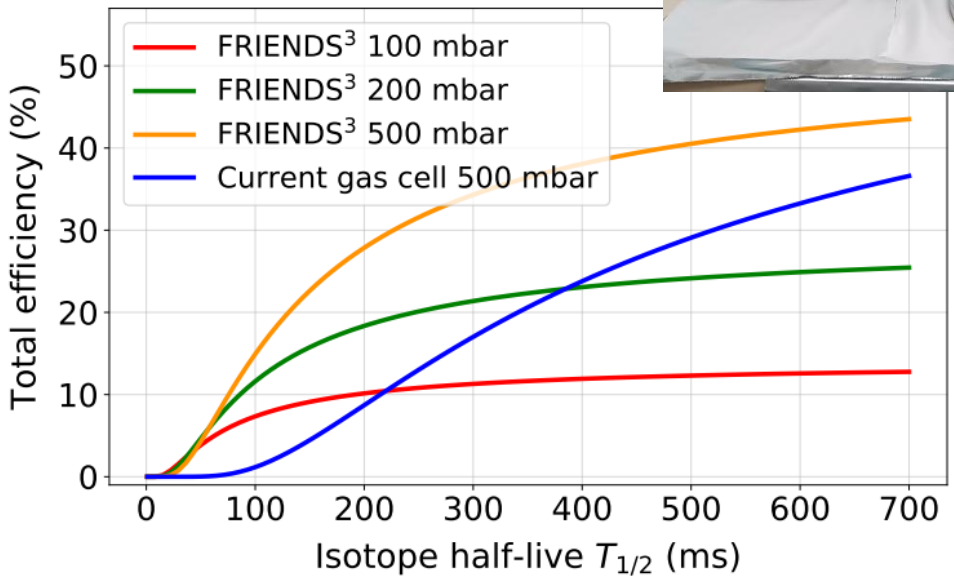


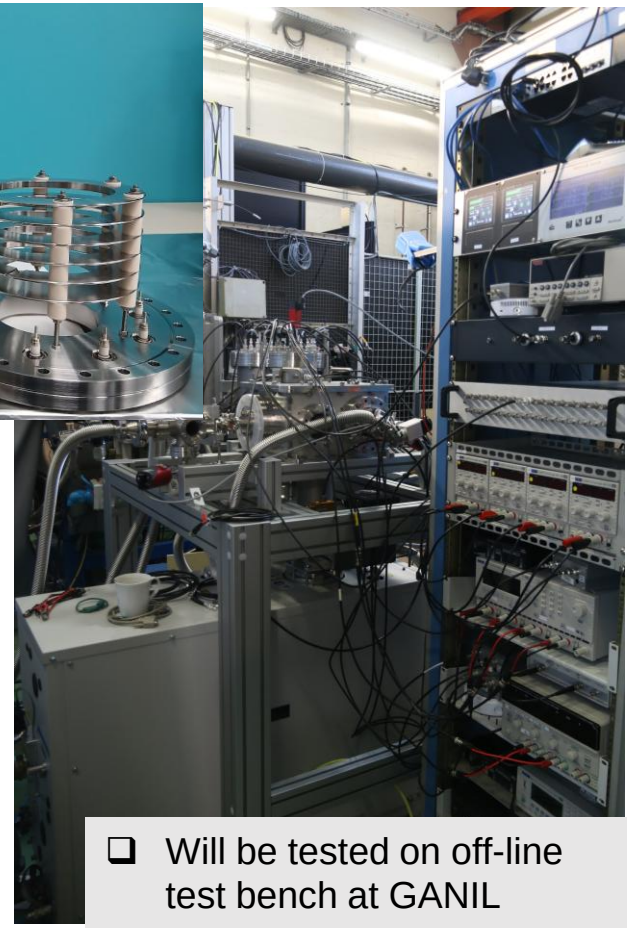
W. Dong et al., arXiv:2601.12009 (2026)

Considerations for RIBs from S^3-LEB (to DESIR): gas-cell extraction

- Gas-cell with electrical-field extraction built within the FRIENDS^3 project.
- Designed to operate with argon
- Typical simulated extraction efficiency (200 mbar, 1 mm) ≈ 30 %
- Typical extraction time (200 mbar, 1 mm) ≈ 100-130 ms





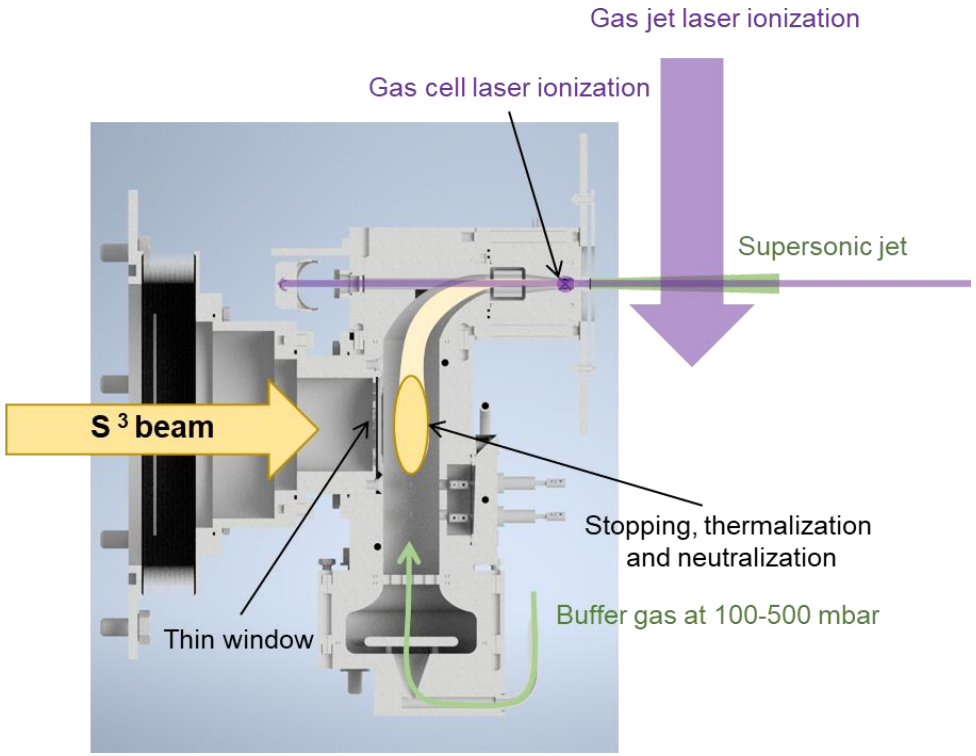


- Will be tested on off-line test bench at GANIL

W. Dong et al., arXiv:2601.12009 (2026)
E. Morin et al., Nucl. Instrum. Meth. B 573, 166027 (2026)

- M. Laatiaoui – new project to develop He, cryo gas cell

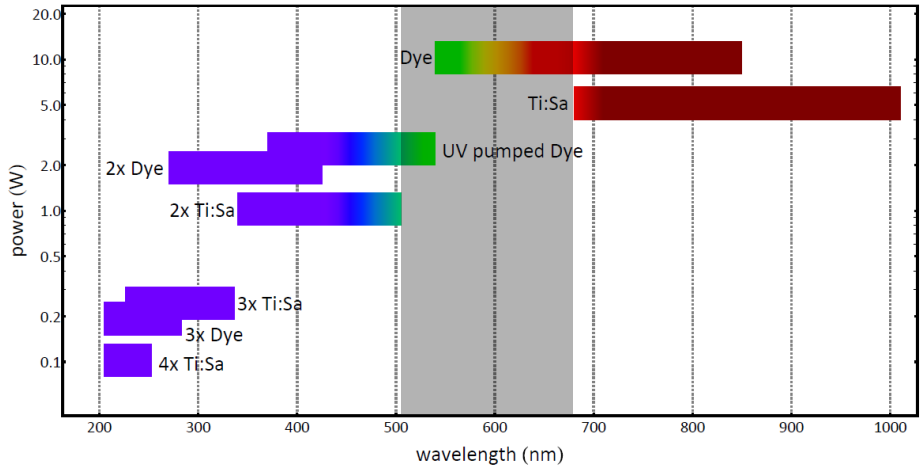
Considerations for RIBs from S^3-LEB (to DESIR): laser ionization



K. Chrysalidis PhD thesis (2019)

- Gas-cell ionization: typical broadband RILIS
- Gas-jet ionization: isomeric selectivity

- Only Ti:Sa schemes possible



S Rothe et al., J. Phys.: Conf. Ser. 312 052020 (2011)

- « Difficult » schemes: 3-step, non-resonant last step, wavelength at the edge of possibilities
- Efficiencies vary between 1% - tens of % (but depend on power of ionization step)

Global view of efficiency

- Efficiency for RIB from S^3-LEB with current gas cell (laser ion source):

$$\varepsilon_{total} = \varepsilon_{stop} \times \varepsilon_{extr} \times \varepsilon_{decay} \times \varepsilon_{chem} \times \varepsilon_{neutr} \times \varepsilon_{ion} \times \varepsilon_{trans}$$

stopping: 70-100%

extraction: 50-100%

decay: $2^{-t_{ex}/(600\ ms)}$

Chemical survival

Neutralisation: 10 – 100 %

Laser ion source: 1 – 30 %

Transport: 50%

Direct ion extraction, replace with: $\times (1 - \varepsilon_{neutr})$

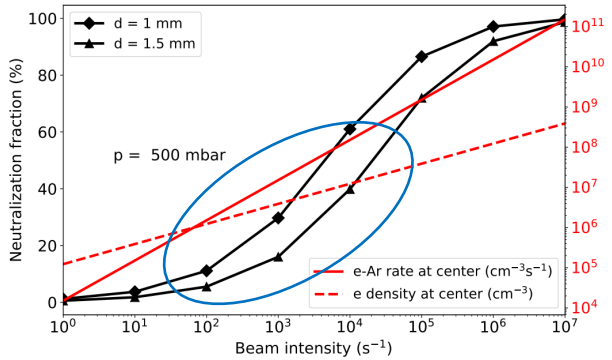
$$\varepsilon_{total}^{laser} = \varepsilon_{chem}^{atom} \times 2^{-t_{ex}/(600\ ms)} \times (0{,}02 - 15)\%$$

$$\varepsilon_{total}^{direct\ ion} = \varepsilon_{chem}^{ion} \times 2^{-t_{ex}/(600\ ms)} \times (0 - 40)\%$$

no selectivity

heavily depending on beam intensity

Disclaimer: needs on-line confirmation!



Conclusions

- S^3-LEB is installed at the S^3 focal plane and working again, but with S^3 uncertainties it is not clear when it will take first beams.
- Once commissioning begins, there will be a learning curve until the optimal efficiency of the setup is reached (it started already).
- The S^3-LEB first commissioning experiments contribute to preparing beams for >1/3 of the LOIs (especially the $^{50}Cr + ^{58}Ni$ reaction).
- Of the remaining, one can remark:
  - a few are in the extended interest list (e.g. N ≈ Z ≈ 40)
  - a few others do not pose particular concerns
  - ❖ a few cases require primary beams < C (at least based on chartbeams): preference for TULIP?
- More and more cases suitable for ionization with Ti:Sa laser
- Direct ion extraction should be possible with existing gas cell (but needs to be tested)

The S^3-LEB collaboration

GANIL:

Anjali Ajayakumar; Dieter Ackermann; Alexandre Brizard; Lucia Caceres; Samuel Damoy; Pierre Delahaye; Hemanth Dinesan; Sai Kumar Chinthakayala; Patrice Gangnant; Sarina Geldhof; Johan Goupil; Nathalie Lecesne; Andrés Lopez; Thierry Lefrou; Renan Leroy; Franck Lutton; Alejandro Ortiz; Benoit Osmond; Julien Piot; Blaise-Maël Retailleau; Hervé Savajols; Gilles Sénécal; Tudor Stefan

LPC:

Frédéric Boumard; Maylis Brun; Jean-François Cam; Hugues de Préaumont; Antoine de Roubin; Philippe Desrues; Xavier Fléchard; Clément Gautier; Pierre Lassegues Julien Lory ; Yvan Merrer; Skyy Pineda; Christophe Vandamme

IJCLab:

Wenling Dong; Patricia Duchesne; Serge Franchoo; Vladimir Manea; Valentin Marchand; Elodie Morin; Olivier Pochon; Afonso Vicente

KU Leuven:

Arno Claessens; Ruben de Groote; 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:

Iain Moore; Michael Reponen; Juha Uusitalo

IPHC:

Emil Traykov

IRFU:

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

and the RESIST network in ENSAR2