In-gas-jet laser spectroscopy with S^3-LEB, status and perspectives

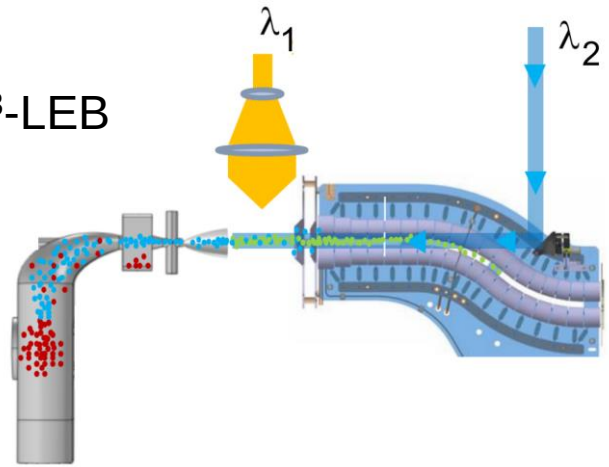
Wenling Dong

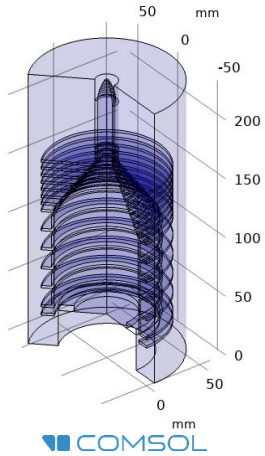
IJCLab, Orsay, France
November 29, 2023

for the S^3-LEB collaboration

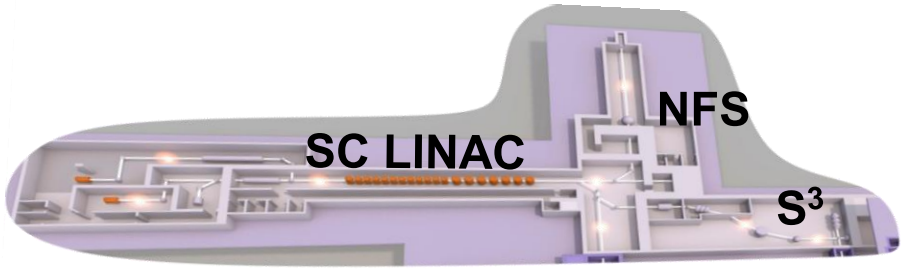
Outline

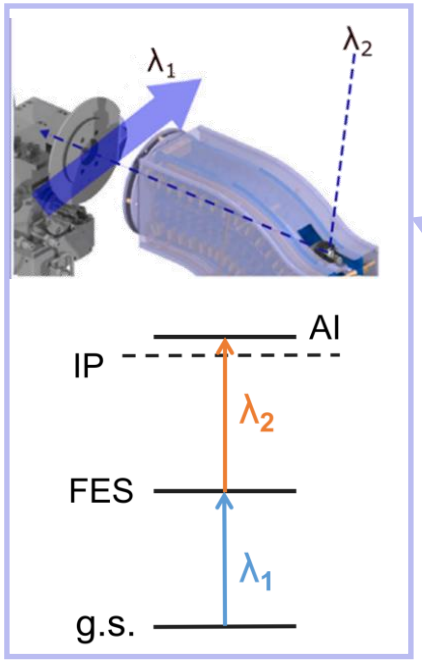
- Off-line laser spectroscopy measurements with S^3-LEB
- Design of the FRIENDS^3 prototype
  - Preliminary simulation study
  - Test-bench study
- Conclusion and outlook

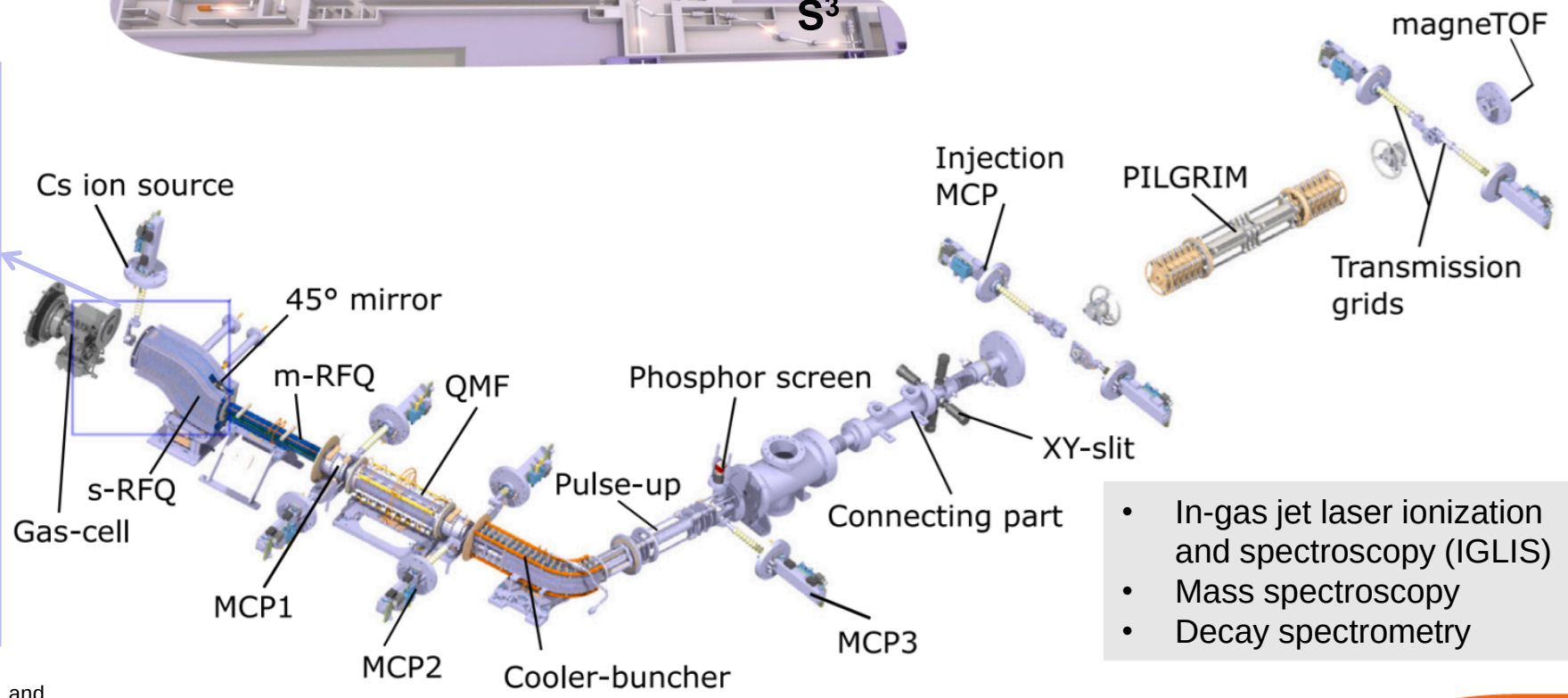




S³-LEB setup





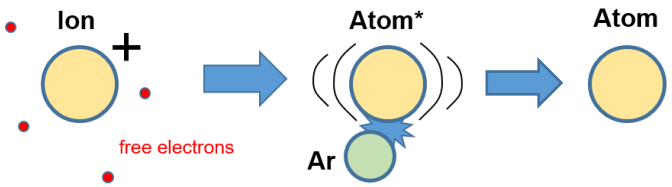


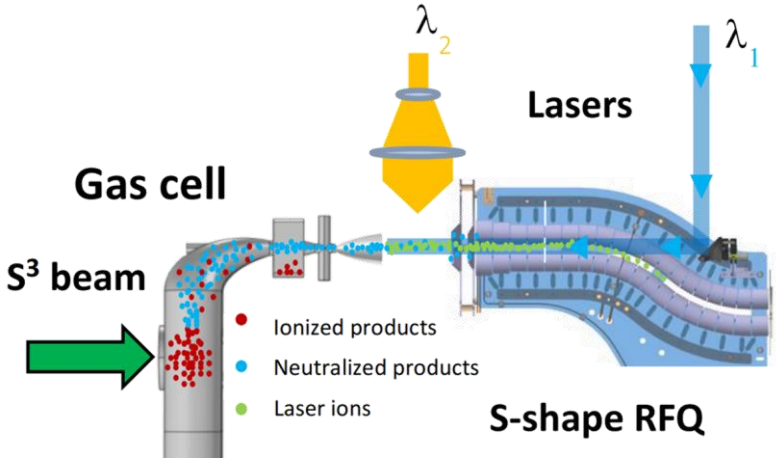
- In-gas jet laser ionization and spectroscopy (IGLIS)
- Mass spectroscopy
- Decay spectrometry

[1] A. Ajayakumar et al. Nuclear Inst. and Methods in Physics Research, B 539 (2023)

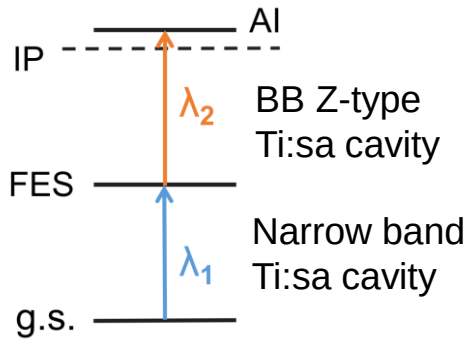
S³-LEB laser spectroscopy technique

Stop, neutralizae in the gas cell and extract the atoms



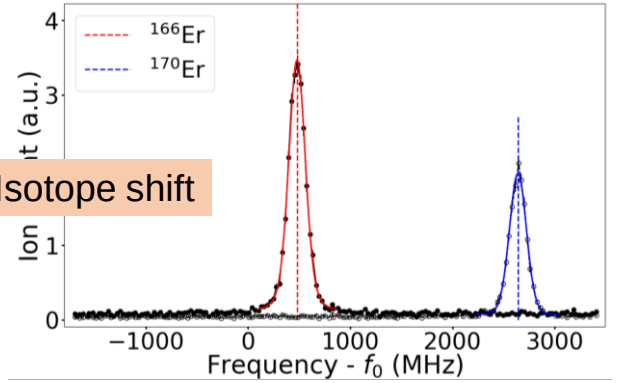


In-Gas Laser Ionization and Spectroscopy (IGLIS) technique with NB Ti:sa system

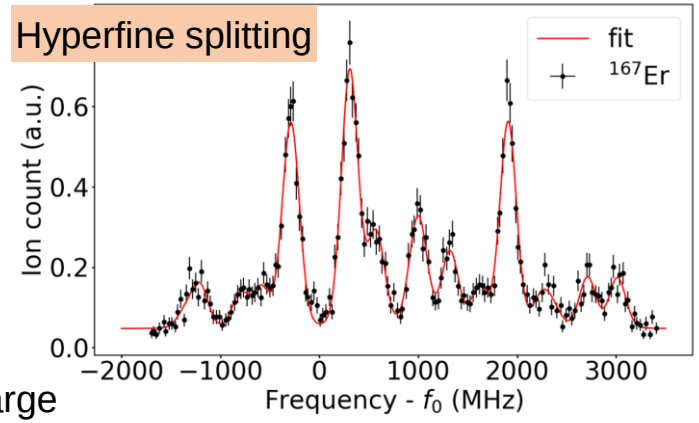


High-resolution in-gas-jet laser spectroscopy FWHM ~ 200 MHz

Isotope shift



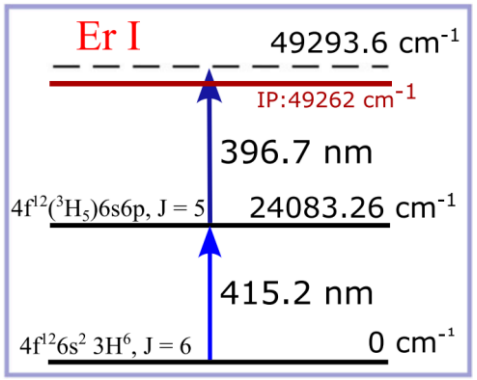
Hyperfine splitting



Nuclear properties

Differences in mean-square charge radii, moments and nuclear spins...

Status of the S³-LEB experiments



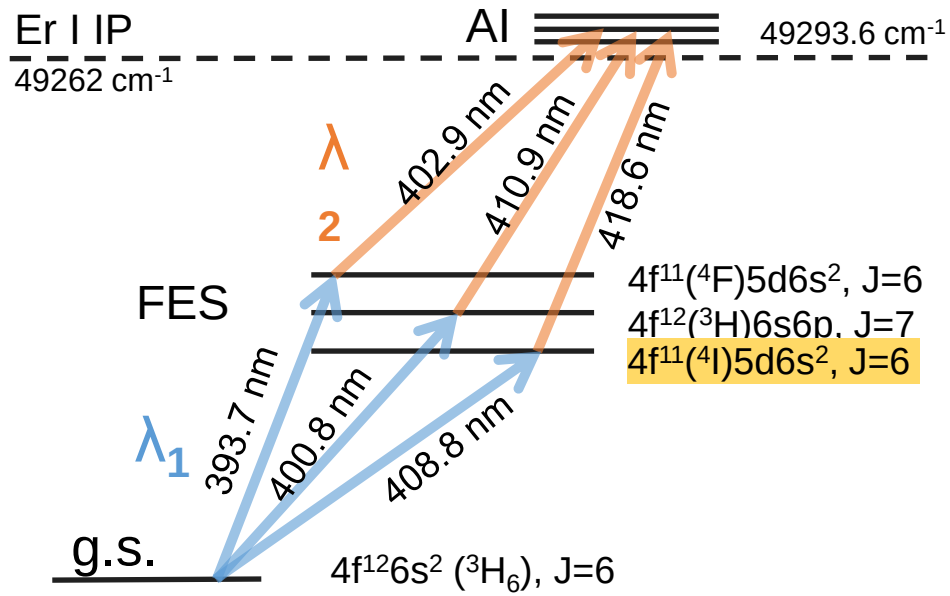
First off-line measurement, studied by J. Romans and A. Ajayakumar.

What has been achieved:

- The in-gas-jet resonance laser ionization were explored in detail for Er (S^3 first physics case).
- The transmission across the whole setup was preliminarily optimized to 80-100%.

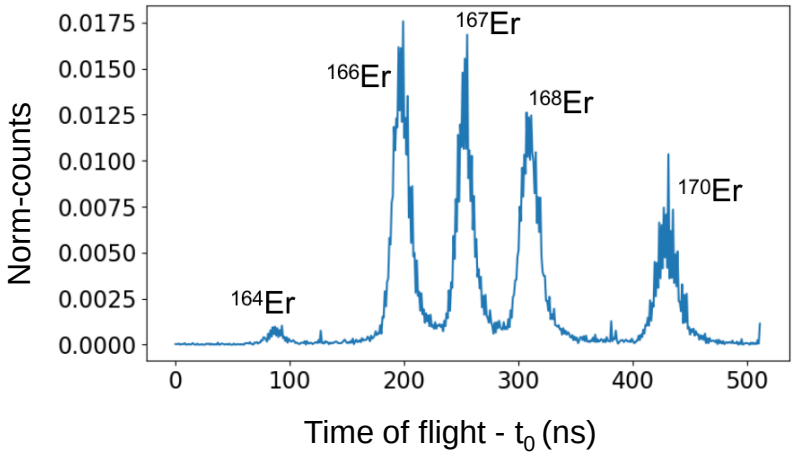
Recent work:

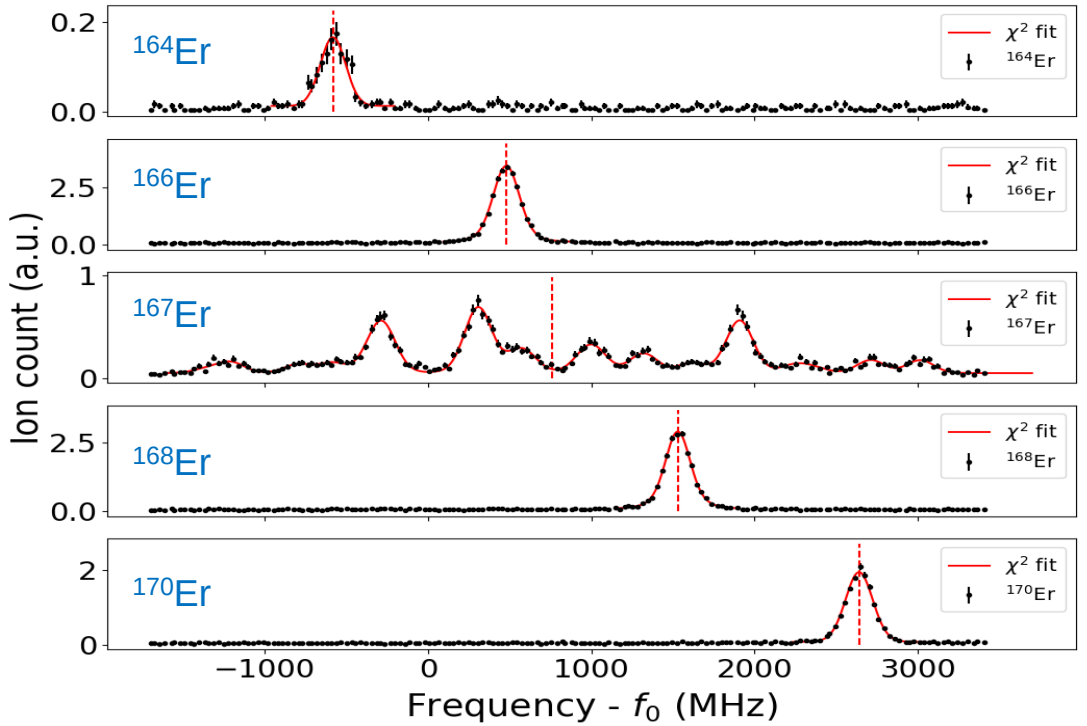
- check the other sensitive schemes that are efficient and sensitive to nuclear properties.

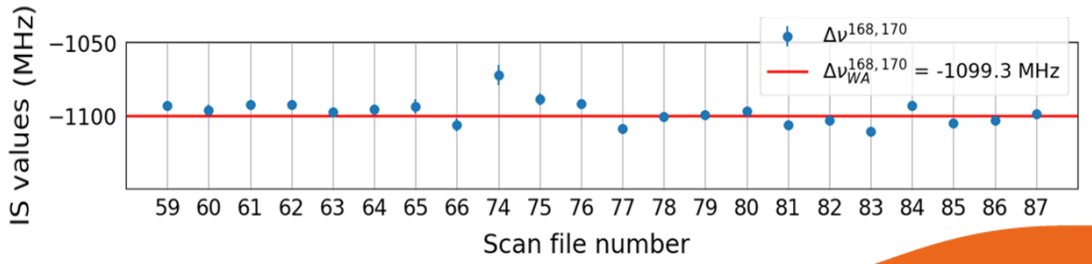


High-resolution in-gas-jet laser spectroscopy

TOF spectrum of stable Er behind PILGRIM



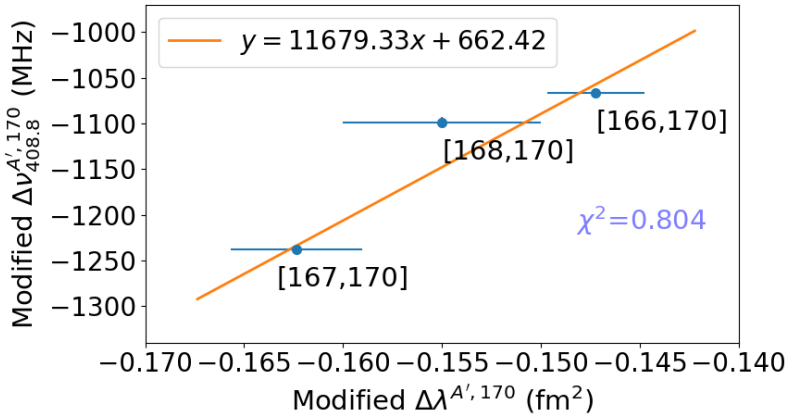




Isotope Shift and Hyperfine values

King plot analysis for IS factors

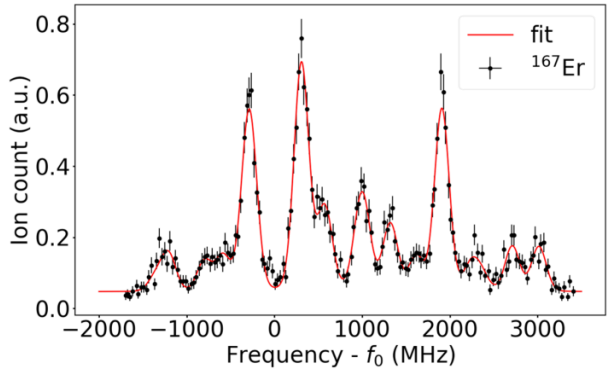
$$\delta\nu_{409}^{A',A} = F_{409}\,\mathcal{M}^{AA'} + M_{409}\,\frac{A'-A}{A'A}$$



F_{409} = 11679(2943) MHz fm^{-2}

M_{409} = -9459 (6435) GHz*u

Hyperfine structure constants A and B for different FES of ^{167}Er



Atomic states	excitation step	Method	A(MHz)	B(MHz)
$4f^{11}(^4I)5d6s^2$, J=6	408.8 nm	gas jet	-123.9(0.4)	213.4(22.6)
$4f^{12}(^3H_5)6s6p$, J=5	415.2 nm	gas jet [1]	−147.1(7)	−1936(24)
		ABU [2]	−147.66(83)	−1888(58)
		ref [3]	−146.6(3)	−1874(16)
g.s.	-	ref [2]	−121.80(75)	−4563(53)

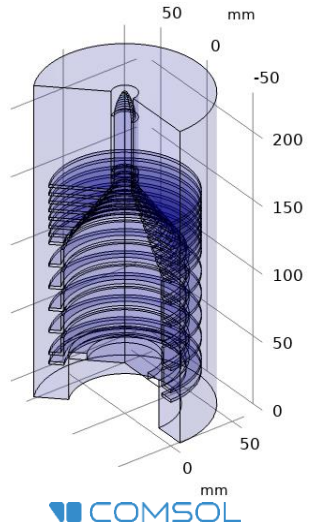
[1] A. Ajayakumar et al.Nuclear Inst. and Methods in Physics Research, B 539 (2023)
[2] J. Romans et al. Nucl. Instrum. Meth. B 536 (2023)
[3] W.J. Childs et al., Phys. Rev. A 28 (1983)

Outline

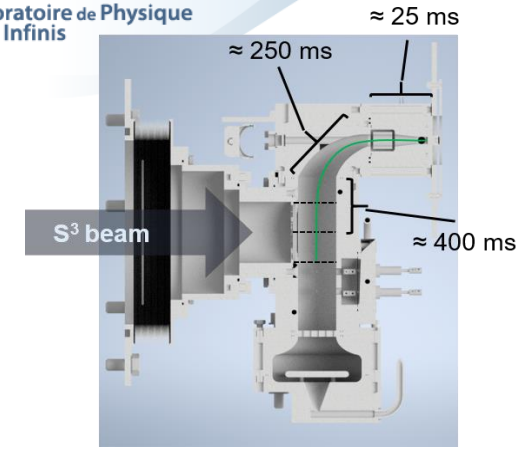
- Off-line laser spectroscopy measurements with S^3-LEB

- Design of the FRIENDS^3 prototype
  - Preliminary simulation study
  - Test-bench study

- Conclusion and outlook



FRIENDS^3 project objectives and guiding idea

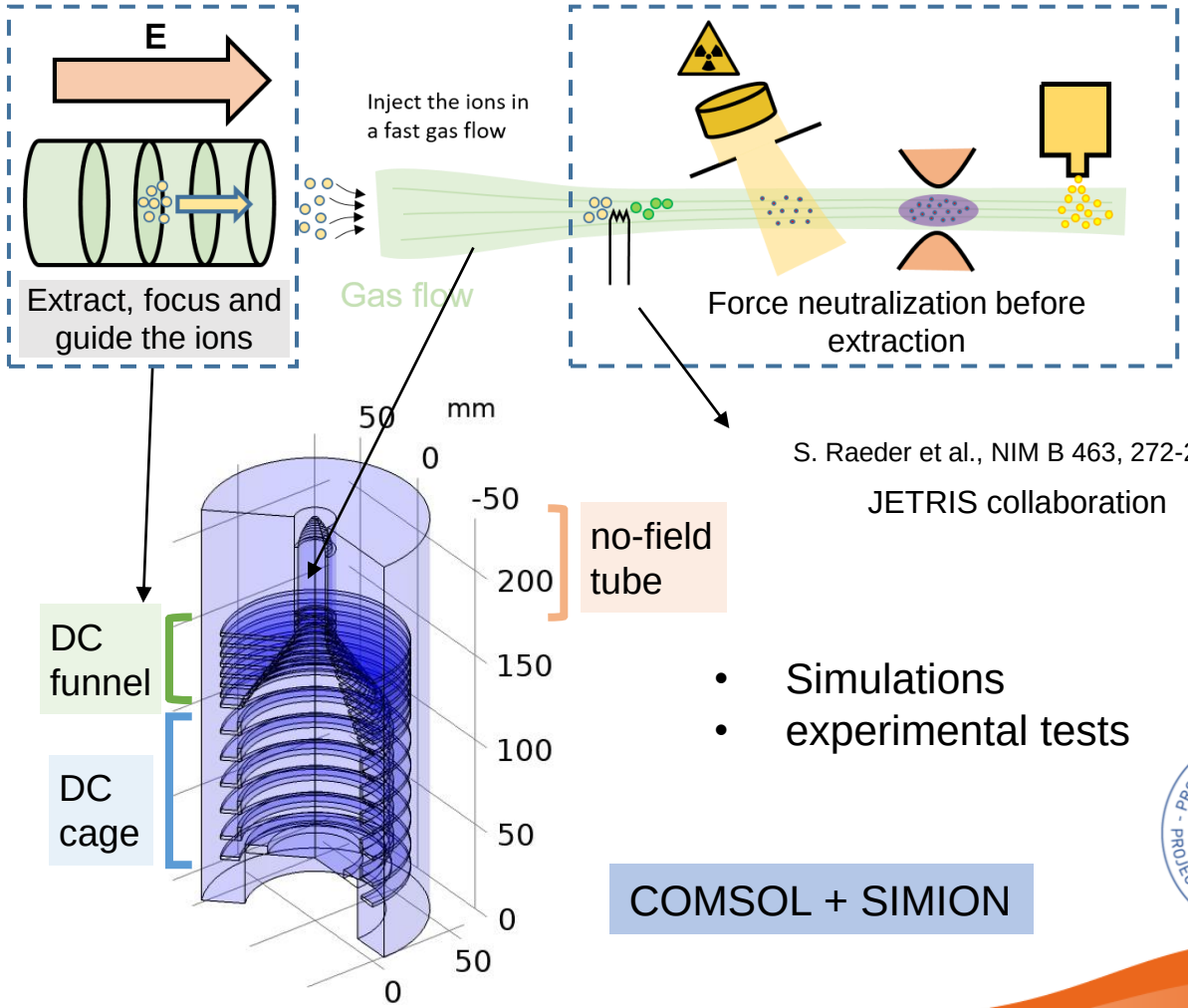


Limitations of current gas cell:

- Extraction time too long for short-lived S^3 products
- Neutralization efficiency depends on the beam intensity

Objectives of FRIENDS^3 project:

- Reduce extraction time ~ 100 ms.
- Improve neutralization efficiency
- Ideally both at the same time



S. Raeder et al., NIM B 463, 272-276 (2020)

JETRIS collaboration

- Simulations
- experimental tests

COMSOL + SIMION

Preliminary simulation study: multiphysics

Study of simulation tools and methods: COMSOL + SIMION

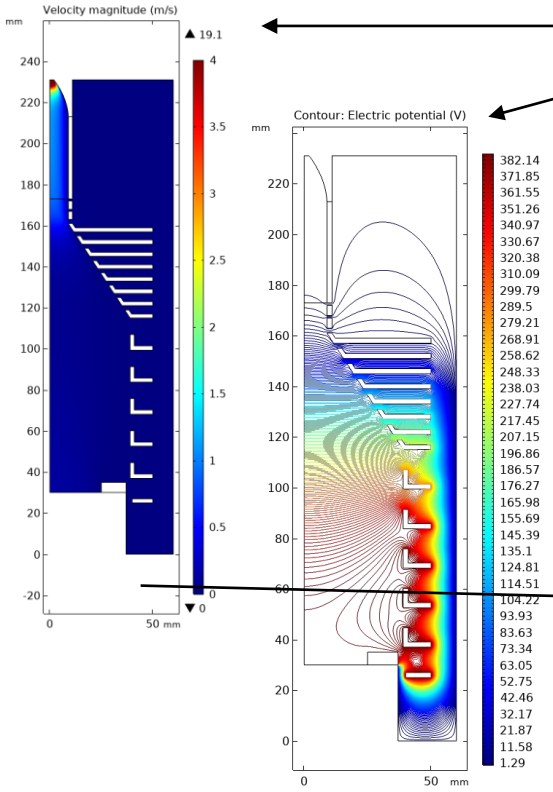
COMSOL

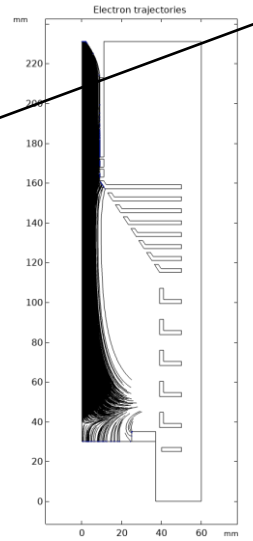
Multiphysics problem: COMSOL

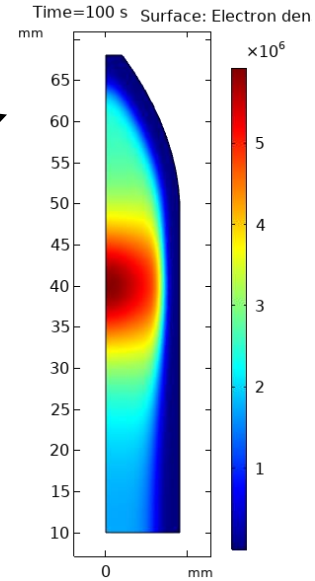
- Laminar gas flow through the cell
- Calculation of static and dynamic electrical fields
- Particle tracing under the action of gas flow (drag) and electrical field (drift)
- Plasma processes (ion recombination)

Statistical Diffusion Simulation (SDS): SIMION

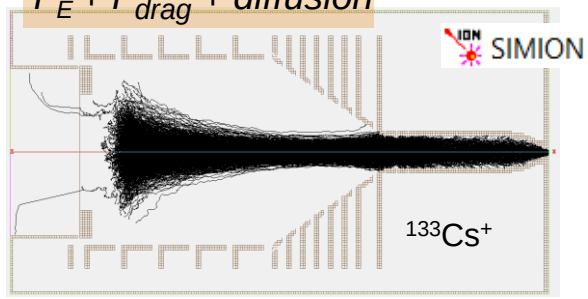
- Diffusion effect in high pressures







$F_E + F_{drag} + diffusion$



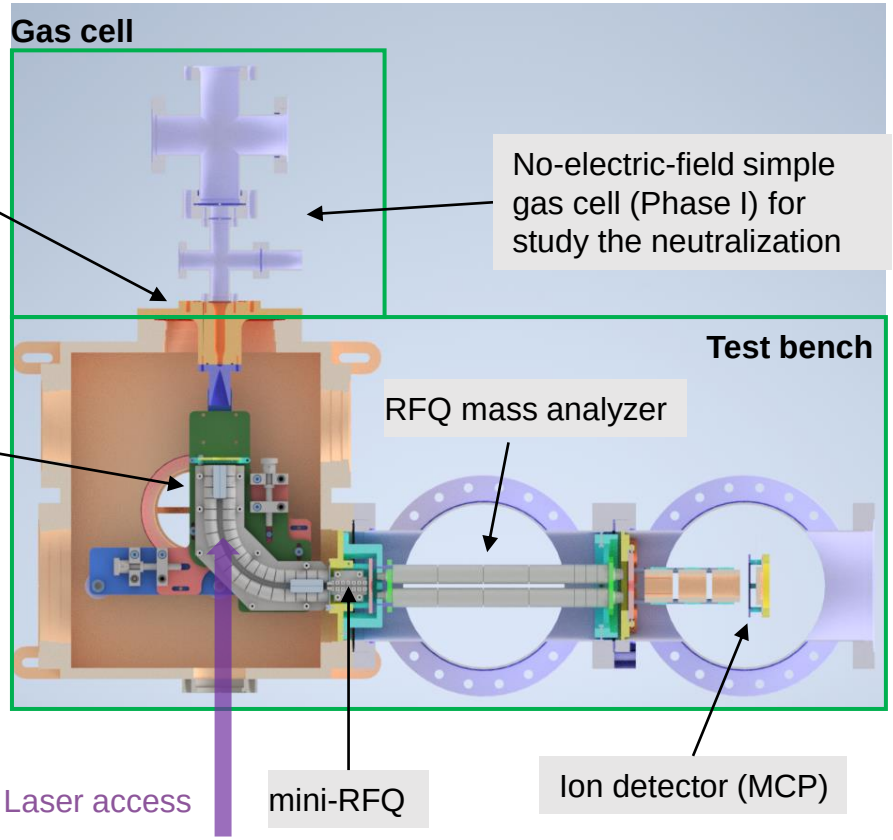
➢ Flow simulated by COMSOL, ion transport simulated by SIMION.

Simulated performance:

- extraction efficiency ~ 30%.
- extraction time ~ 120 ms.
- time available for neutralization ~ 55 ms.

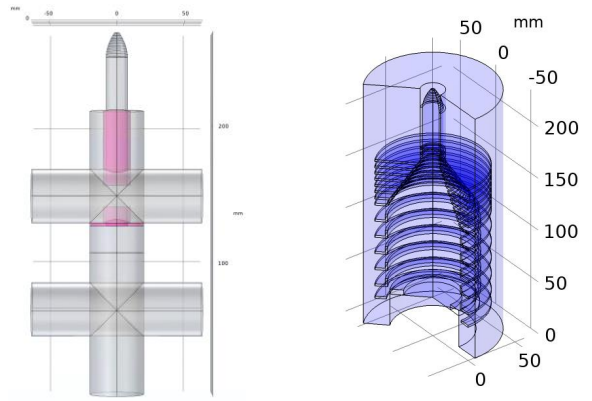
Test-bench study: demonstrator design

The mechanical study of the test bench is almost completed.



- Study ion extraction times and neutralization efficiencies.
- Mass filtering and identification.
- Perform in-jet laser spectroscopy.

no-electric-field simple gas cell → electrical prototype



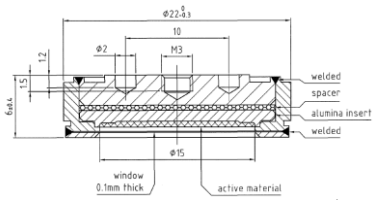
Phase I **Phase II**

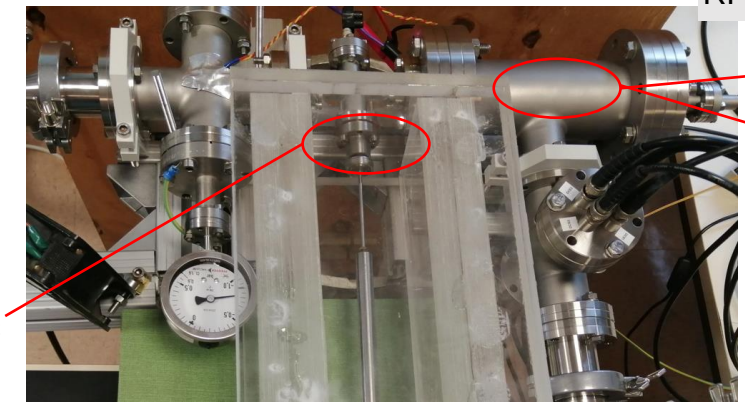
Bent RFQ et mini-RFQ: contribution of KU Leuven (Kudryavtsev et al., NIMB 297, 2013)

Test-bench study: tests of the beta source

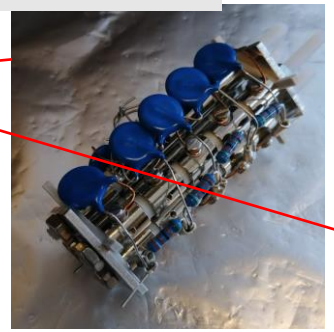
^{90}Sr source installation, Cu window 100 um

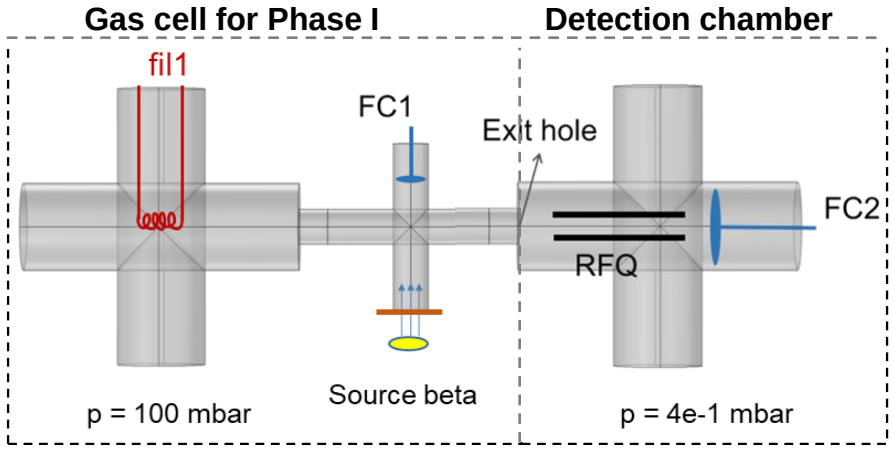
^{90}Sr, 37 MBq

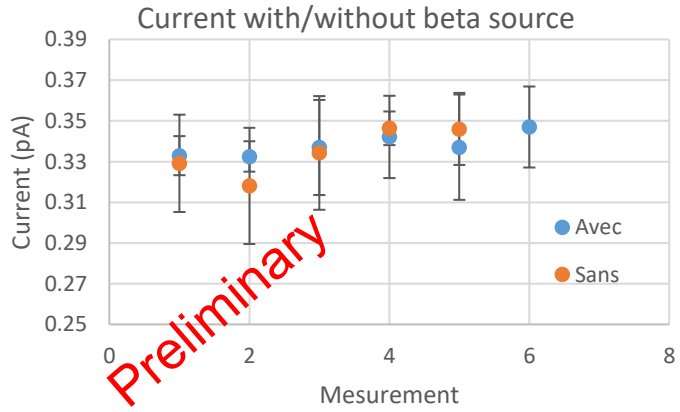




RFQ for ion extraction







Conclusion and outlook

The first off-line results for Er(415.2 nm to FES) are in good agreement with the literature values:

- the laser system and technique is capable of the intended first physics cases at the SPIRAL2-GANIL S^3 facility.
- the systematic uncertainties are under control.

A more sensitive scheme (408.8 nm to FES) for Er was mearsured in the scope of S^3 first physics cases:

- IS and HFS constants have been found for this transition.

The results from the in-gas-jet RIS show the potential of the S^3-LEB to perform high-resolution laser spectroscopy for on-line studies.

In the future,

- the connecting part to PILGRIM will be replaced by a 90◦ bender to couple to SEASON.
- S^3-LEB will be put at S^3 after the commissioning, first experiments with S^3-LEB are forseen for 2025.
- FRIENDS^3 test bench will be moved to GANIL at 2024.

The S^3-LEB collaboration

GANIL:

Anjali Ajayakumar; Dieter Ackermann; Lucia Caceres; Samuel Damoy; Pierre Delahaye; Patrice Gangnant; Nathalie Lecesne; Thierry Lefrou; Renan Leroy; Franck Lutton; Alejandro Ortiz; Benoit Osmond; Julien Piot; Blaise-Maël Retailleau; Hervé Savajols; Gilles Sénécal

LPC:

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

IJCLab:

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

KU Leuven:

Arno Claessens; 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:

Ruben de Groote; Iain David Moore; Michael Reponen; Juha Uusitalo

IPHC:

Emil Traykov

IRFU:

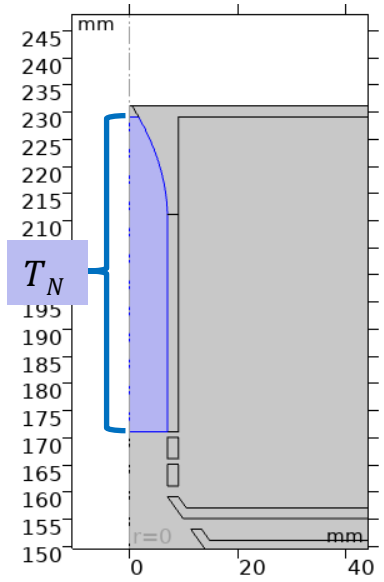
Martial Authier; Olivier Cloue; Antoine Drouard; Thomas Goigoux; Emmanuel Rey-Herme; Damien Thisse; Marine Vandebrouck

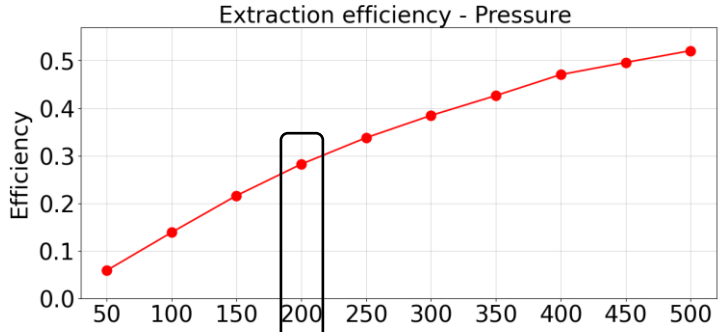
and the RESIST network in ENSAR2

Preliminary simulation study: extraction

Simulated performance:

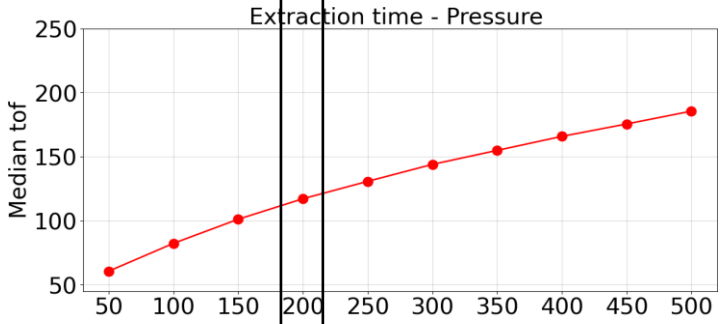
- extraction efficiency~ 30%
- extraction time ~ 120 ms
- time available for neutralization ~ 55 ms



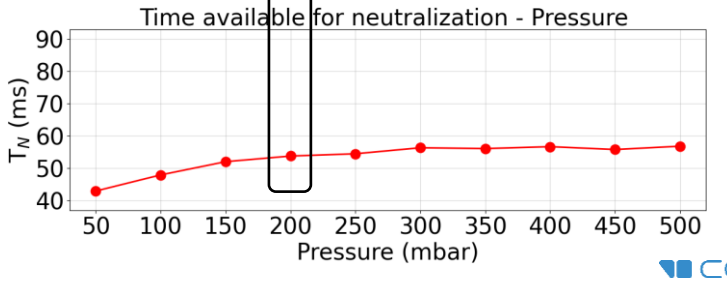


200 mbar

~ 30%



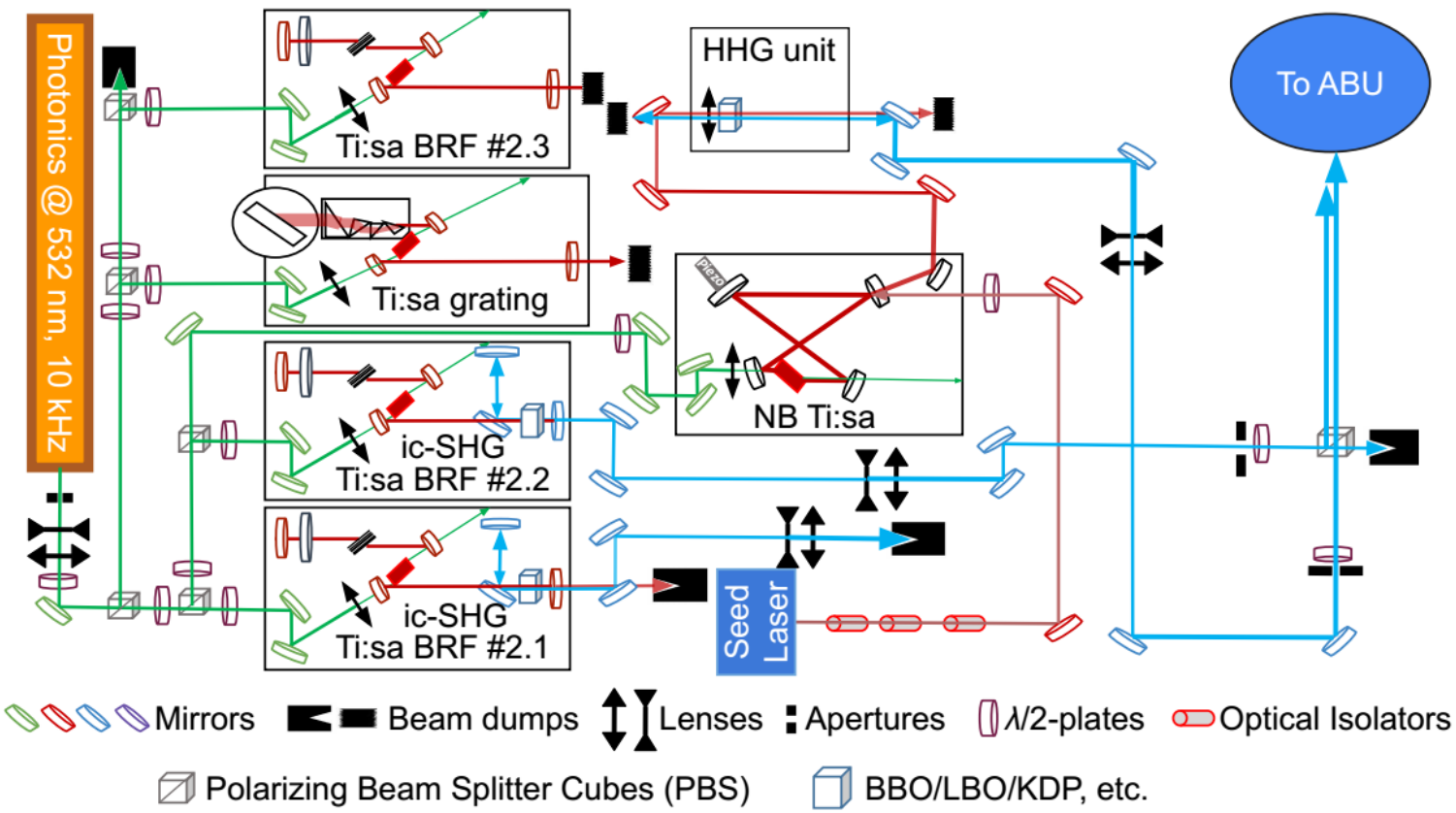
~ 120 ms



~ 55 ms

COMSOL ION SIMION

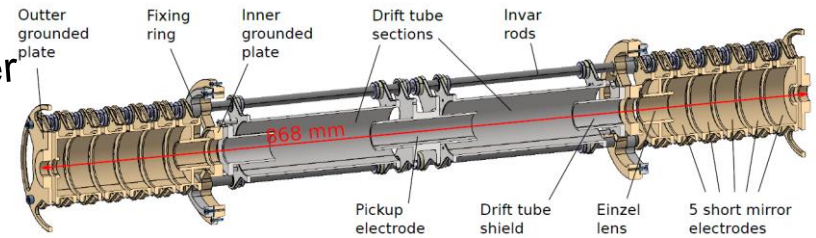
Ti:sa cavities



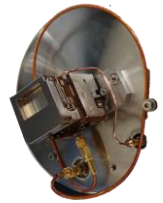
S^3-LEB off-line results: PILGRIM

Designed in collaboration with Uni. Greifswald

3-keV beam from S^3-LEB cooler-buncher



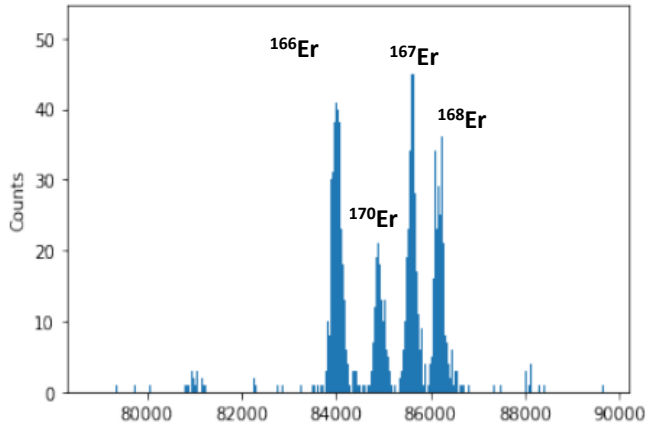
MagneTOF



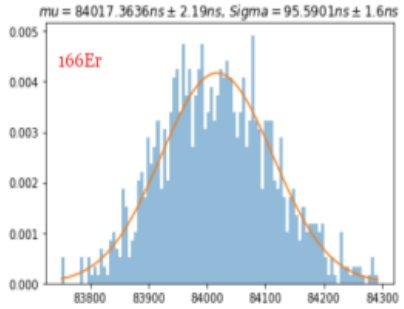
Pierre Chauveau, PhD thesis, Université de Caen Normandie (2016)
Pierre Chauveau et al., Nucl. Instrum. Meth. B **376**, 211-215 (2016)

- Mass separation and measurements tested with bunches from the S^3-LEB cooler-buncher
- Resolving power ≈ 100 000
- Mass accuracy tested on a few cases to a few ≈ 10^{-7}

^{170}Er at 1000 turns (other isotopes on different numbers of turns)



TOF – acquisition offset (ns)

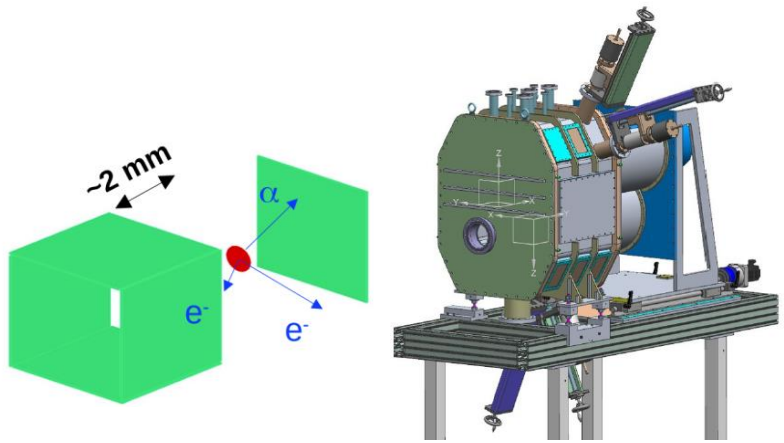


TOF – acquisition offset (ns)

Y. Balasmeh, master thesis, LPC Caen 2022

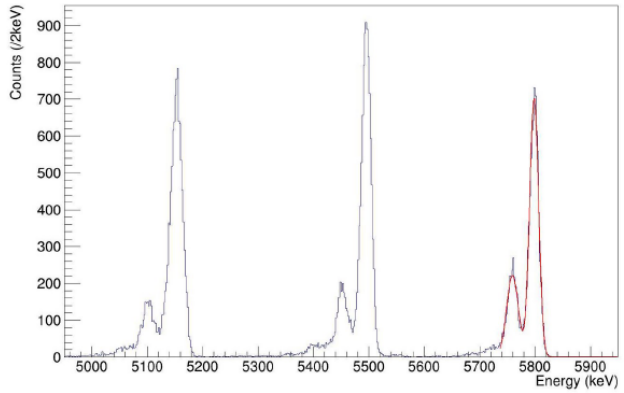
S^3-LEB off-line results: SEASON

- Developed at CEA Saclay
- « Windmill » of implantation foils
- Silicon box detector (DSSSD) for alphas and electrons
- Germanium detectors



- Mechanical design finished, construction foreseen for end of 2023
- First DSSSD tested, target resolution achieved with radioactive sources:
  - 17.2 keV FWHM for alpha at 5.8 MeV
  - 10.2 keV FWHM for electrons at 320 keV

3-α calibration source (^{239}Pu, ^{241}Am, ^{244}Cm)



Marine Vandebrouck, Thomas Goigoux, Emmanuel Rey-Herme, Damien Thisse et al.