

# Status of the Super Separator Spectrometer at GANIL

*J.Piot on behalf of the S<sup>3</sup> project & collaboration*



# Superheavy nuclei

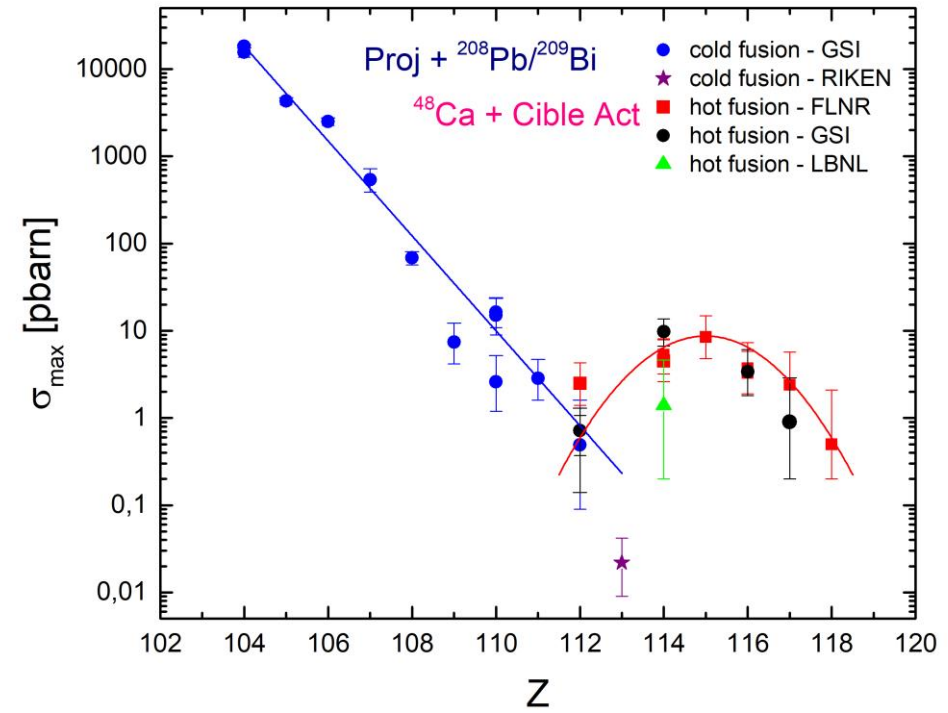
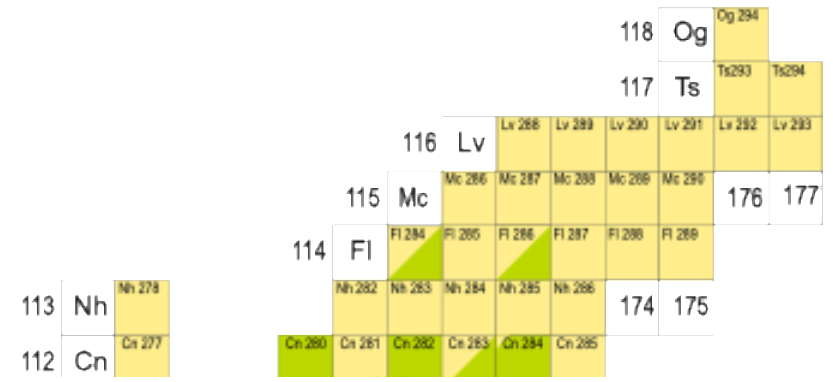
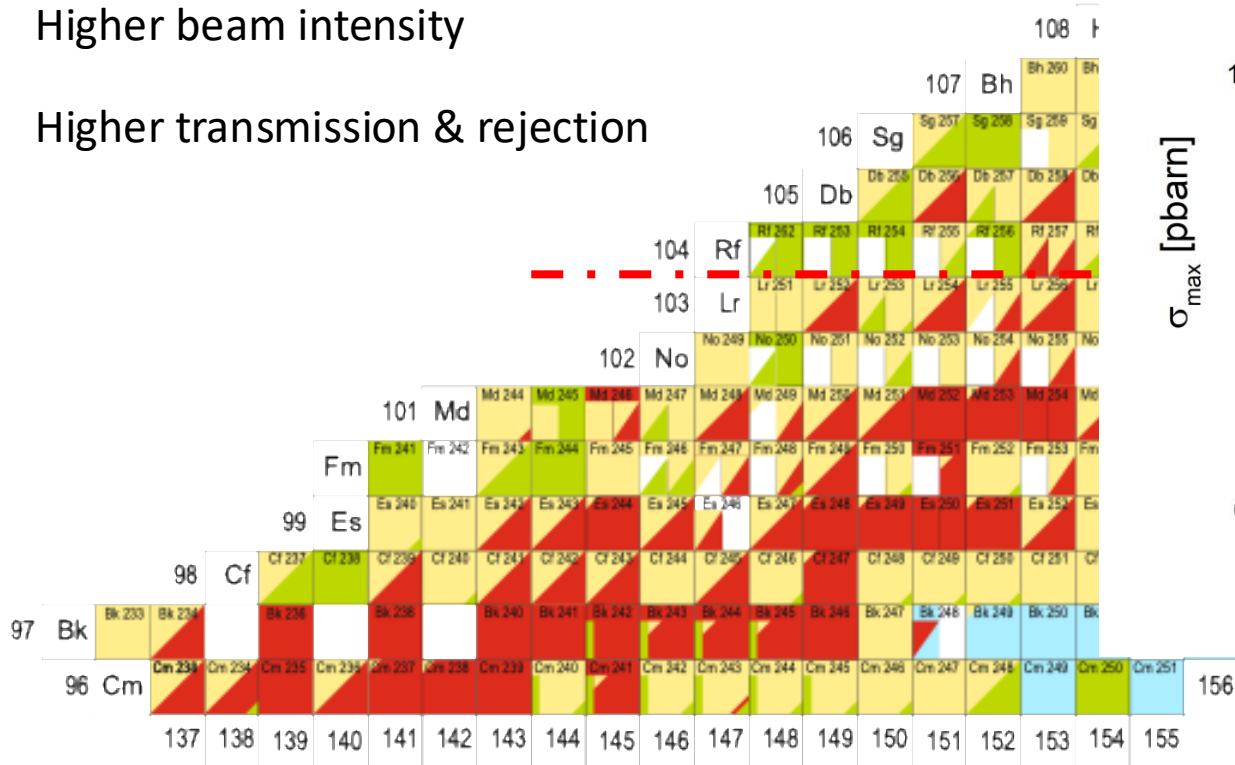
How to study superheavy nuclei in more details?

Increase production yield

Remove background

Higher beam intensity

Higher transmission & rejection



D. Ackermann & Ch. Theisen, Phys. Scr. 92 (2017) 083002

# Grand Accélérateur National d'Ions Lourds

SPIRAL2

Cyclotrons

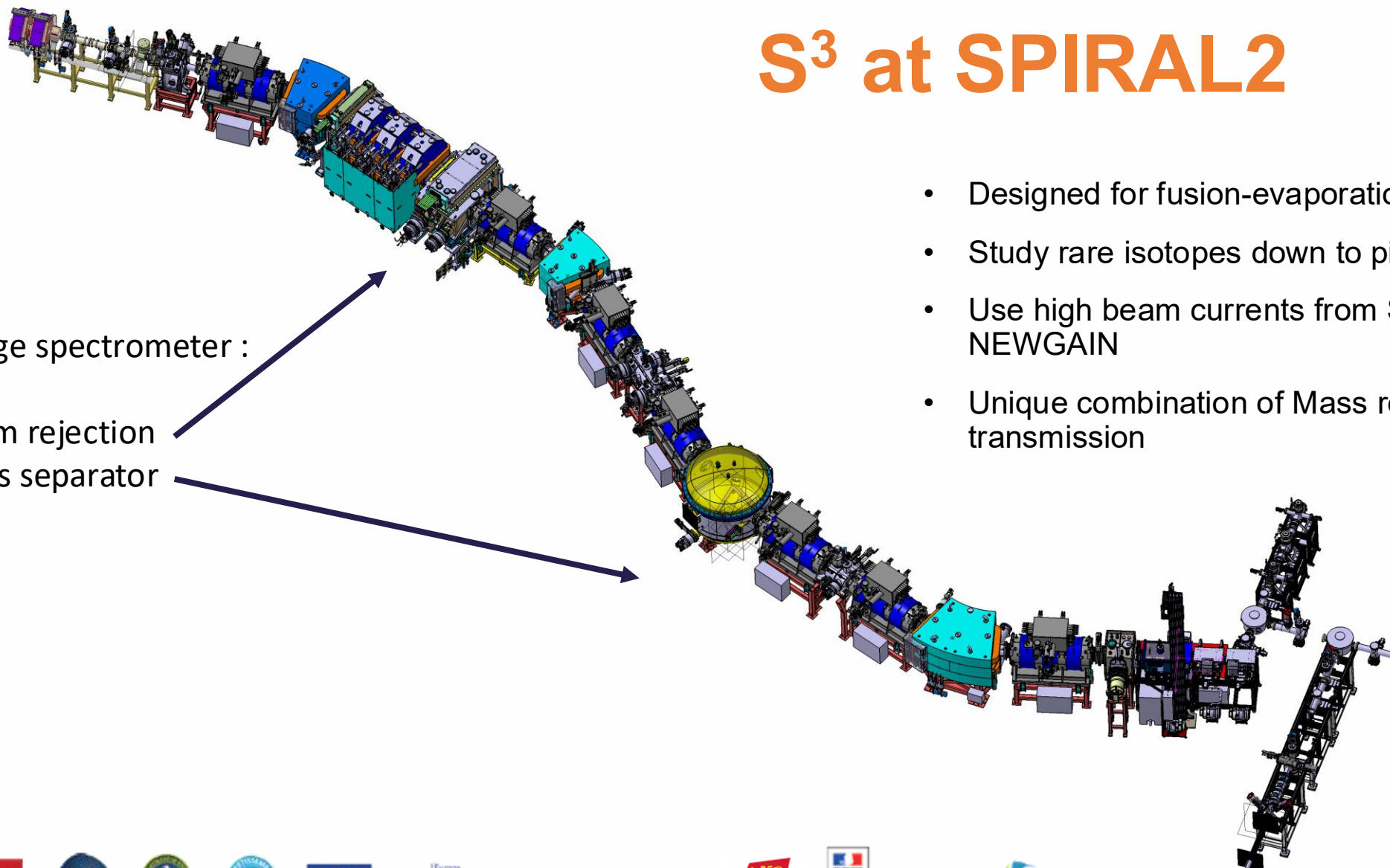
# S<sup>3</sup> at SPIRAL2



Two stage spectrometer :

1. Beam rejection
2. Mass separator

- Designed for fusion-evaporation
- Study rare isotopes down to picobarns
- Use high beam currents from SPIRAL 2 and NEWGAIN
- Unique combination of Mass resolution and high transmission



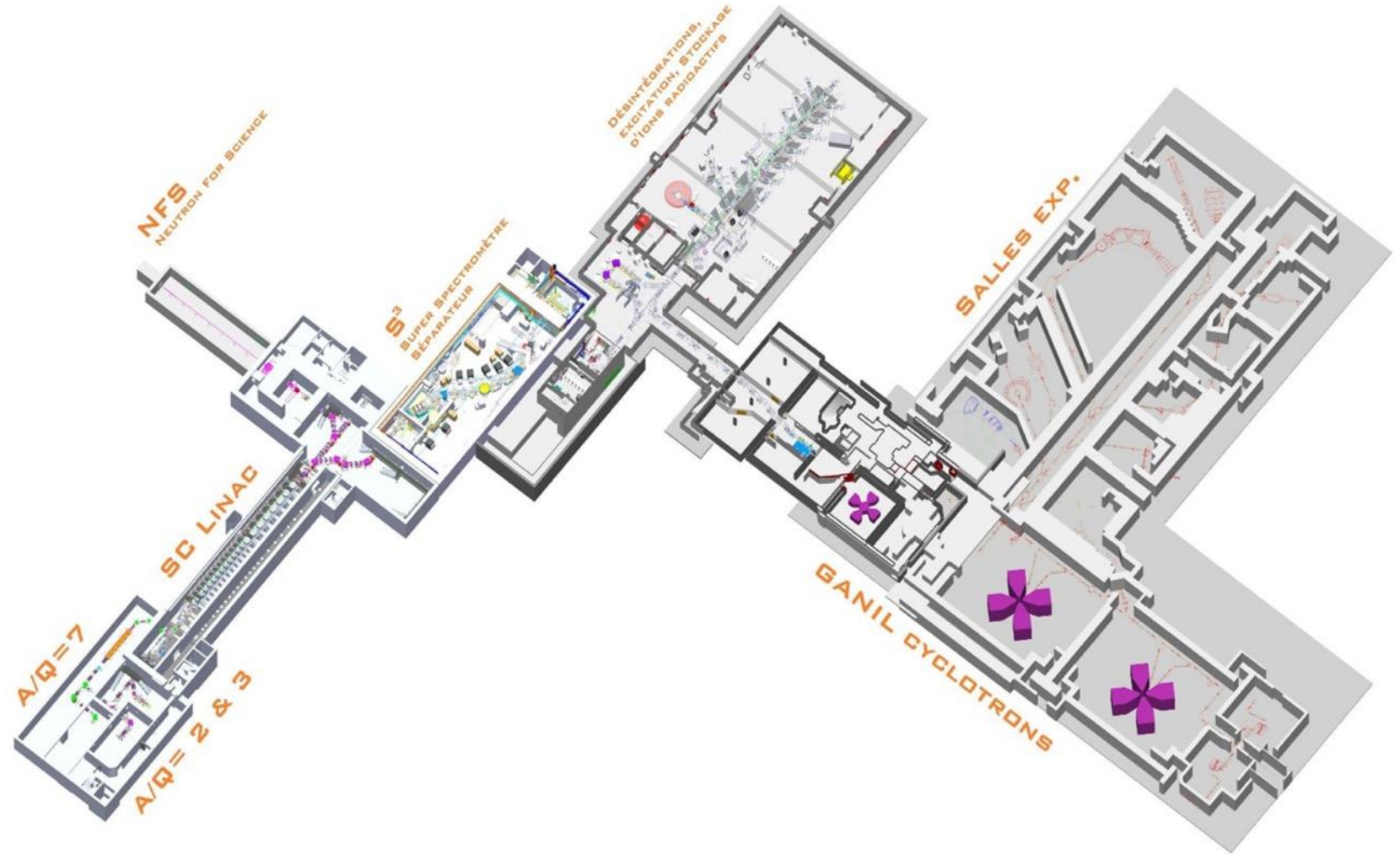
# S<sup>3</sup> at GANIL/SPIRAL2

- SPIRAL2 LINAC :

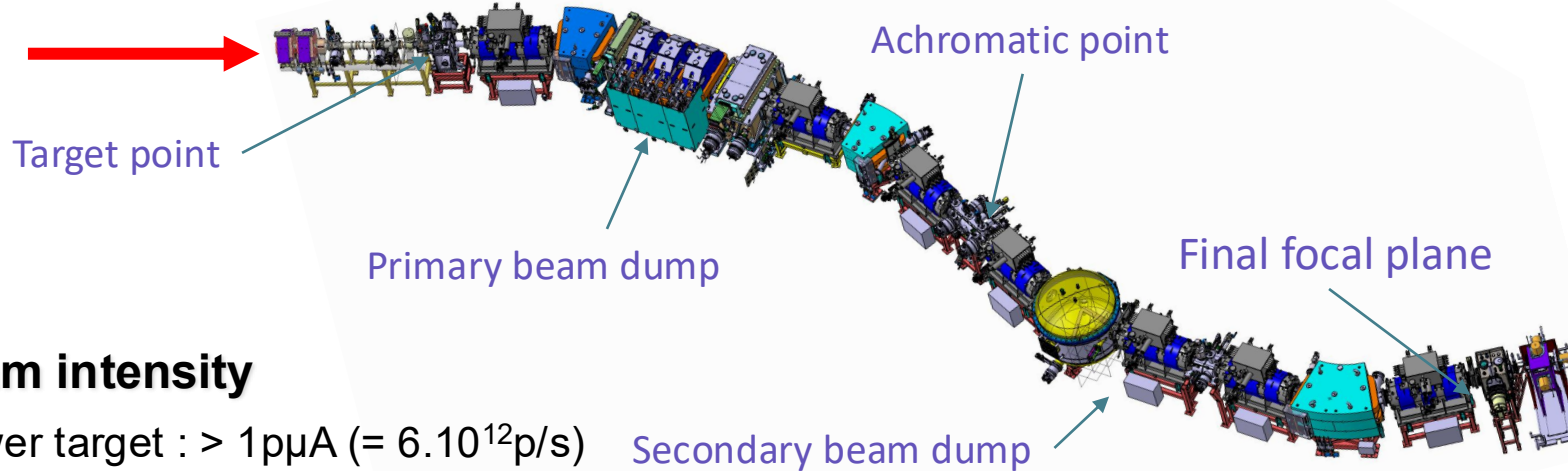
Up to 14.5 MeV/u heavy ions beams

Phenix ECR source

A/Q = 3 RFQ injector



# Super Separator Spectrometer



## ✓ High Beam intensity

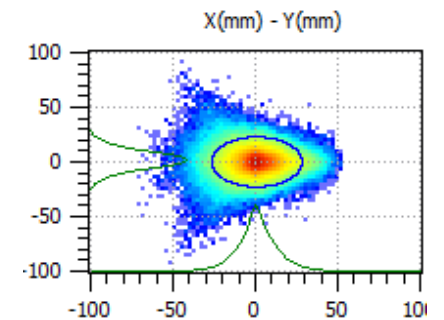
- High power target :  $> 1 \mu\text{A}$  ( $= 6 \cdot 10^{12} \text{p/s}$ )
- High transmission : up to 60% - Multiple charge states in A/Q
- High Selectivity :  $> 10^{13}$  rejection

## ✓ Versatility

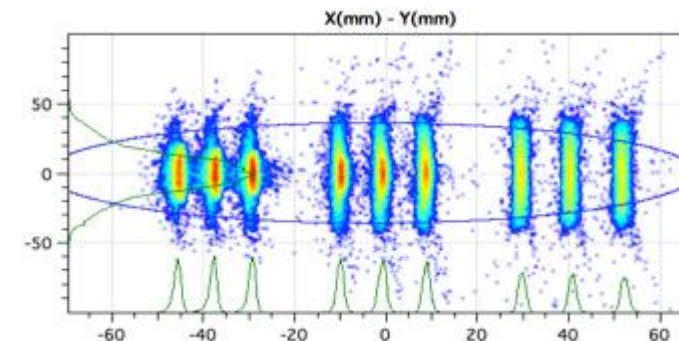
→ 2 extreme optical modes defined

1. Convergent : Simplest mode for 1<sup>st</sup> expt ( $\Delta_{dp/p}=20\%$ ,  $\Delta_p=90\text{mrad}$ ,  $\Delta_\varphi=140\text{mrad}$ )
2. High mass res.:  $M/\Delta M = 505$  ( $\Delta_{dp/p}=16\%$ ,  $\Delta_p=45\text{mrad}$ ,  $\Delta_\varphi=140\text{mrad}$ )

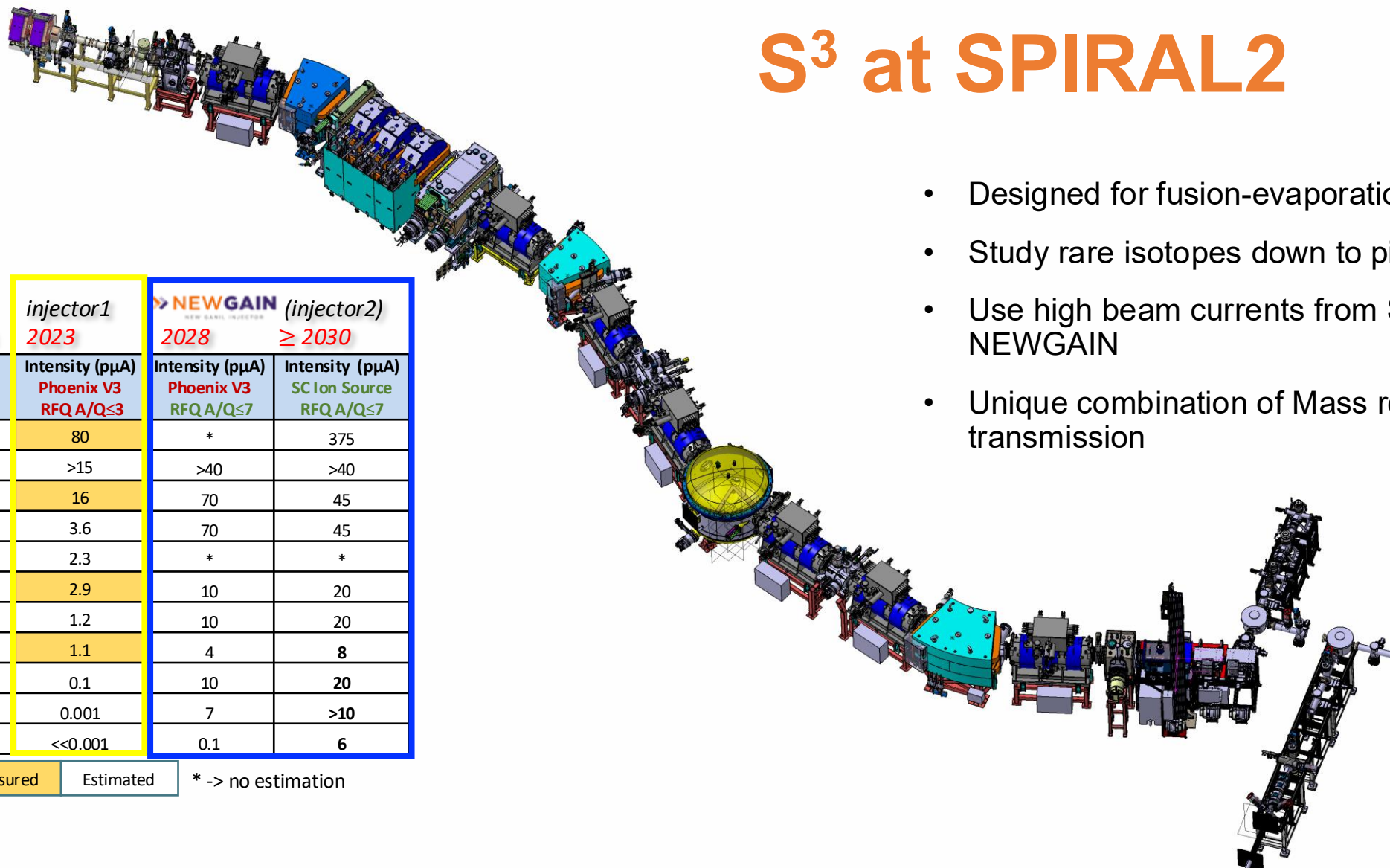
*Convergent mode*



*Mass Resolution mode*



# S<sup>3</sup> at SPIRAL2



beam intensities

Ions	injector1 2023	NEWGAIN (injector2)	
	Intensity (pμA) Phoenix V3 RFQ A/Q≤3	2028 Intensity (pμA) Phoenix V3 RFQ A/Q≤7	≥ 2030 Intensity (pμA) SC Ion Source RFQ A/Q≤7
<sup>18</sup> O	80	*	375
<sup>19</sup> F	>15	>40	>40
<sup>36</sup> Ar	16	70	45
<sup>40</sup> Ar	3.6	70	45
<sup>36</sup> S	2.3	*	*
<sup>40</sup> Ca	2.9	10	20
<sup>48</sup> Ca	1.2	10	20
<sup>58</sup> Ni	1.1	4	8
<sup>84</sup> Kr	0.1	10	20
<sup>139</sup> Xe	0.001	7	>10
<sup>238</sup> U	<<0.001	0.1	6

Measured

Estimated

\* -> no estimation

- Designed for fusion-evaporation
- Study rare isotopes down to picobarns
- Use high beam currents from SPIRAL 2 and NEWGAIN
- Unique combination of Mass resolution and high transmission

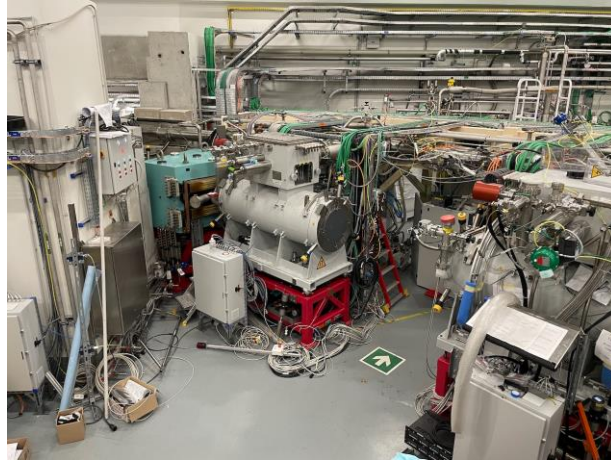
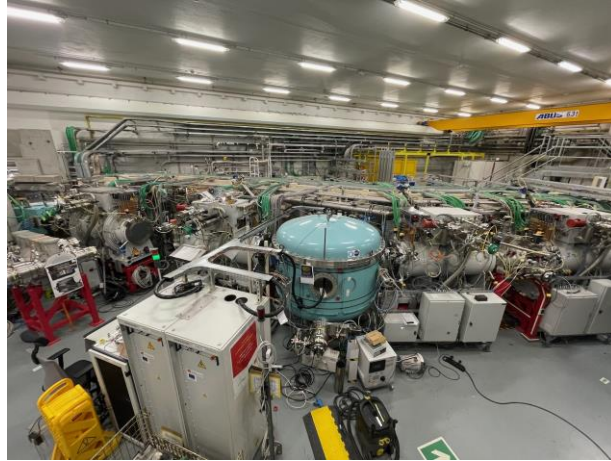
# S<sup>3</sup> for superheavy nuclei

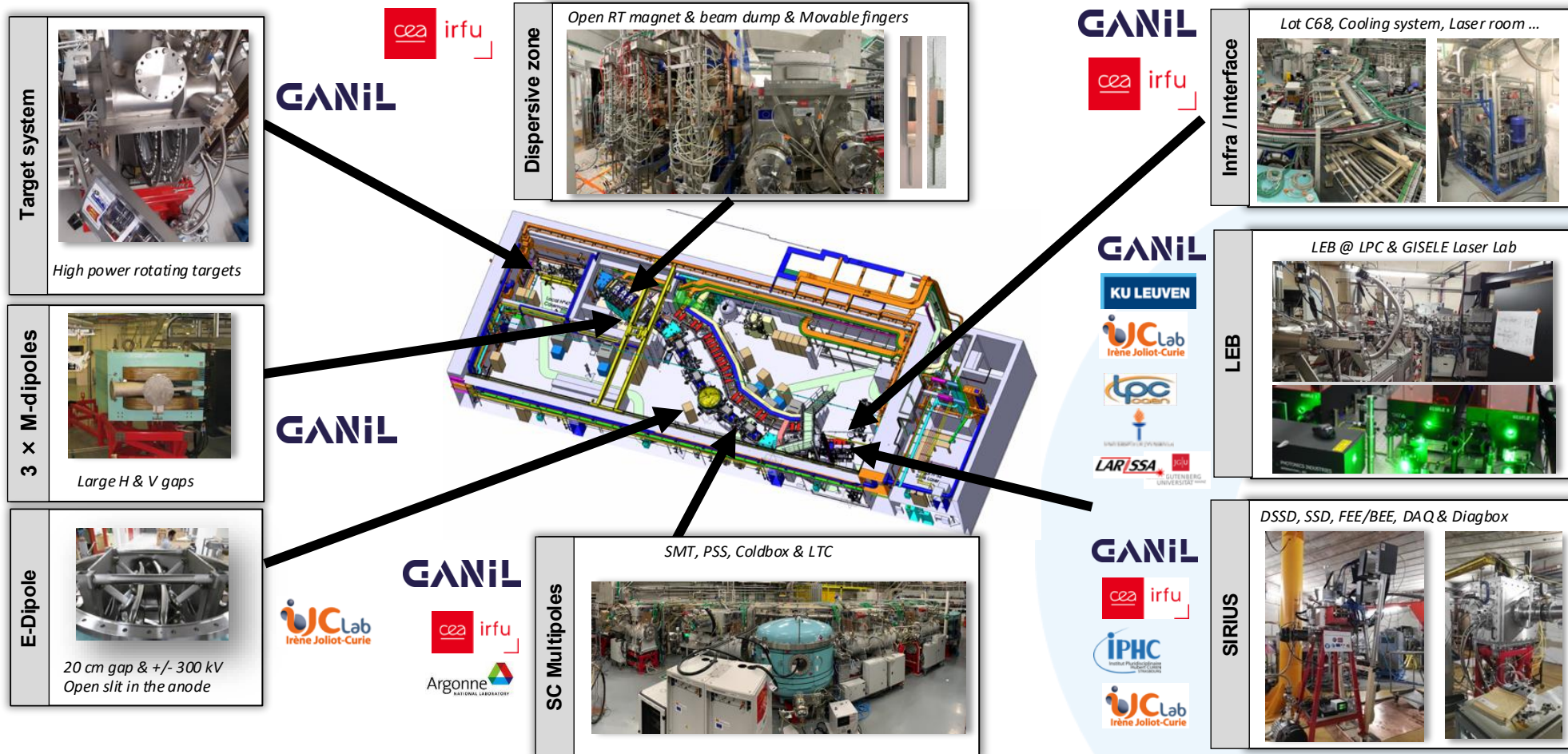
## Complementary setups to study superheavy nuclei :

- SIRIUS/SHEXI for Identification & Spectroscopy
- S<sup>3</sup>-LEB for Mean charge radii, Electric and Magnetic moments PILGRIM for mass measurement & identification
- SEASON for low background spectroscopy & improved electron spectroscopy
- LRC for ion mobility

- Designed for fusion-evaporation
- Use high beam currents from SPIRAL 2 and NEWGAIN
- Unique combination of Mass resolution and high transmission
- Study rare isotopes down to picobarns

# Status of S<sup>3</sup>

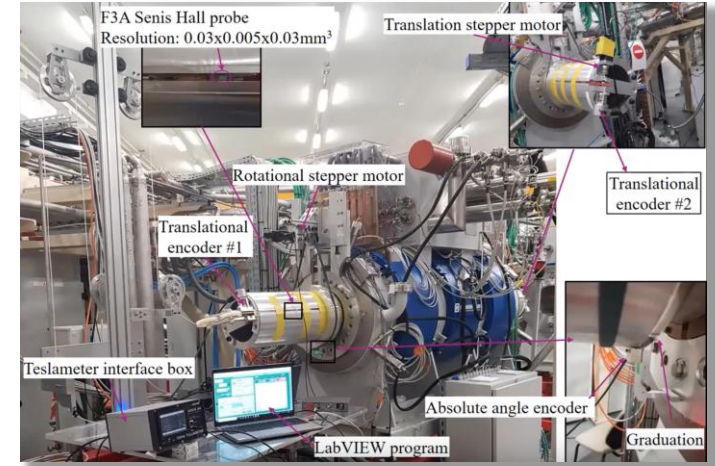




- High selectivity  $> 10^{13}$  - High efficiency 50 % - In flight mass separation = 500
- Versatility & unique instrumentation (SIRIUS – LEB)

# Status of S<sup>3</sup>

- All Equipement installed except Beamdumps
- Nov 2024 : Control of accelerator by target validated.
- May 25 : Electrical Diode conditioned at +/- 200kV : Voltage sufficient for the Commissioning.
- Leak repaired on SMT P2
- New Helium probe installed on SMT P4
- HTS Current lead were successfully replaced on SMT P3 and P4
- Field mapping done on 2 SMT - Alignement of cold mass in the dewar done



- **All the SMT have been placed at final position**
- SMT P2 : ADI successfully repaired
- Complete Cool down (SMT P1-7) started in august – Stopped because of leaks
- Leaks detected on SMT P1, P2, P4 and P7
- **ASNR shutdown of Helium Cold Box end 2025**
  - Processing ongoing, 1 year delay expected
  - Derogation file sent to ASNR end April

## In the meantime :

- Solve the leaks on LTS of SMTs P1, P2, P4 and P7
- Install the new Helium probes on all SMTs
- Replace corroded HTS on all SMTs
- Finish construction and installation of Beam Dump & fingers



LTS



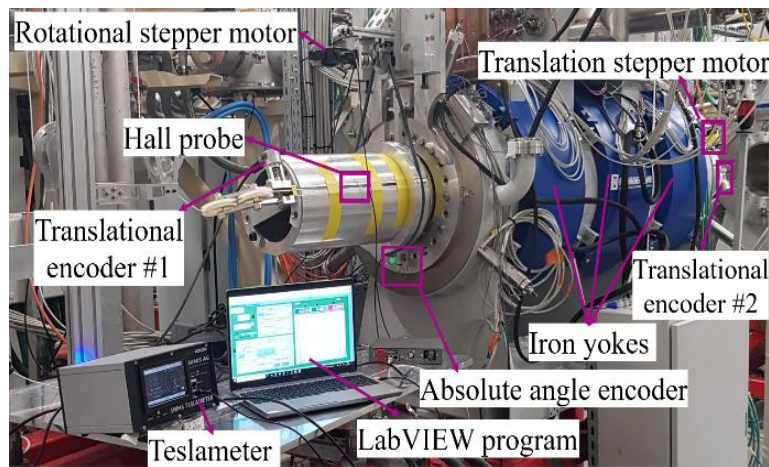
HTS



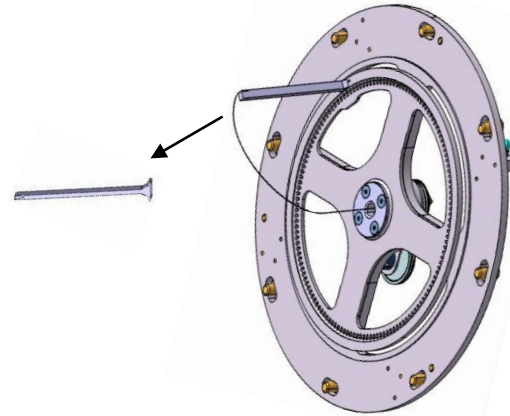
**As soon as the cold box can be used :**

- SMT 2-3-4 to be retested pair with their own PSS (final position in the spectro line – All PSS ready)
- Coil mass alignment of SMT1-2-3-4-6-7 (difficult task as various alignment tools are required)  
(SMT1 aligned in September 2025 with the thin mapper)

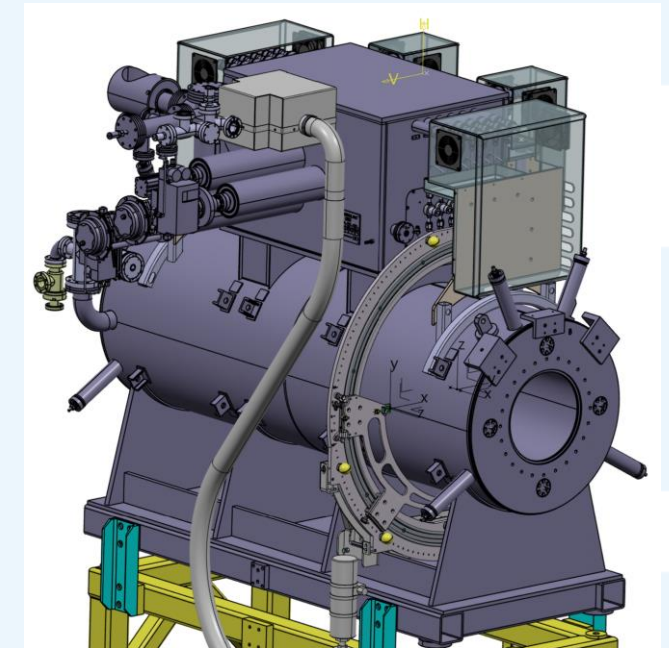
3D mapper



Thin mapper

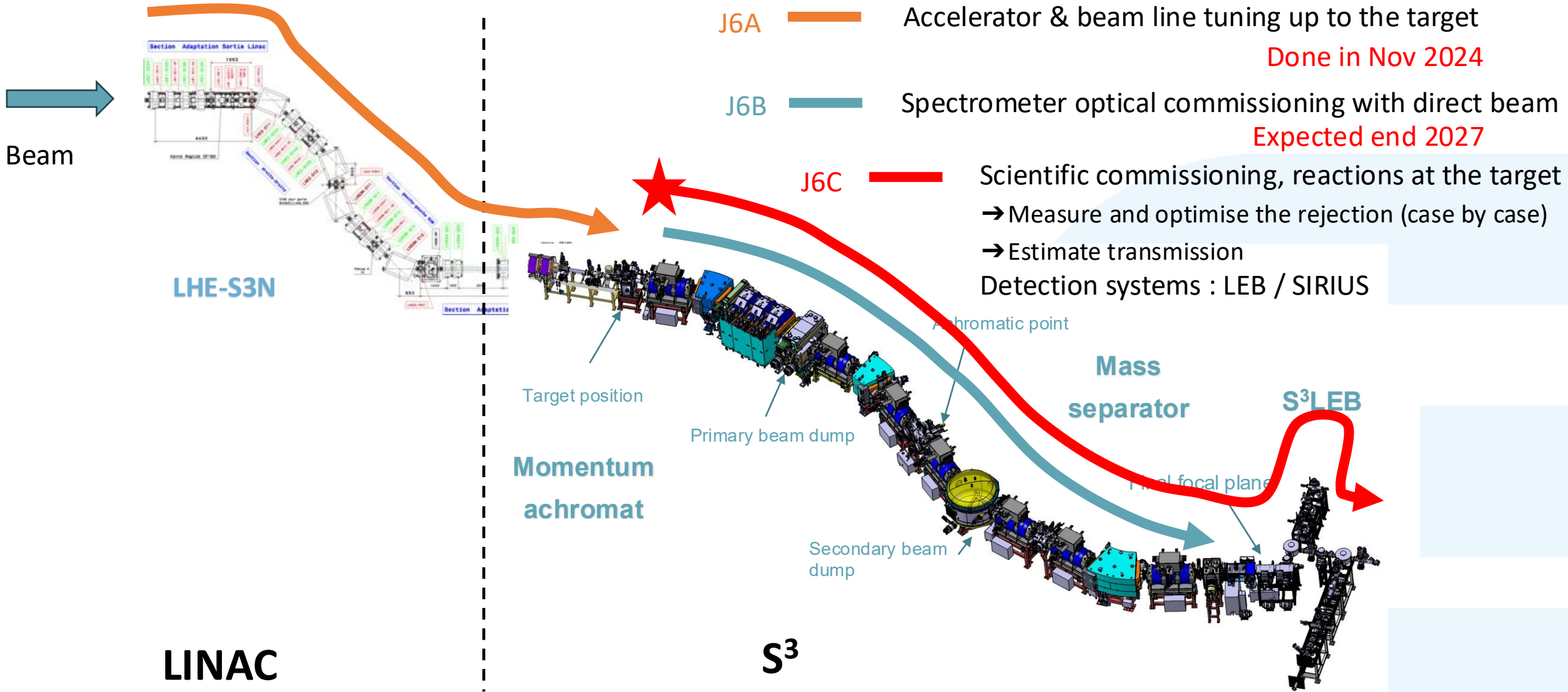


External mapper (GANIL/Irfu)

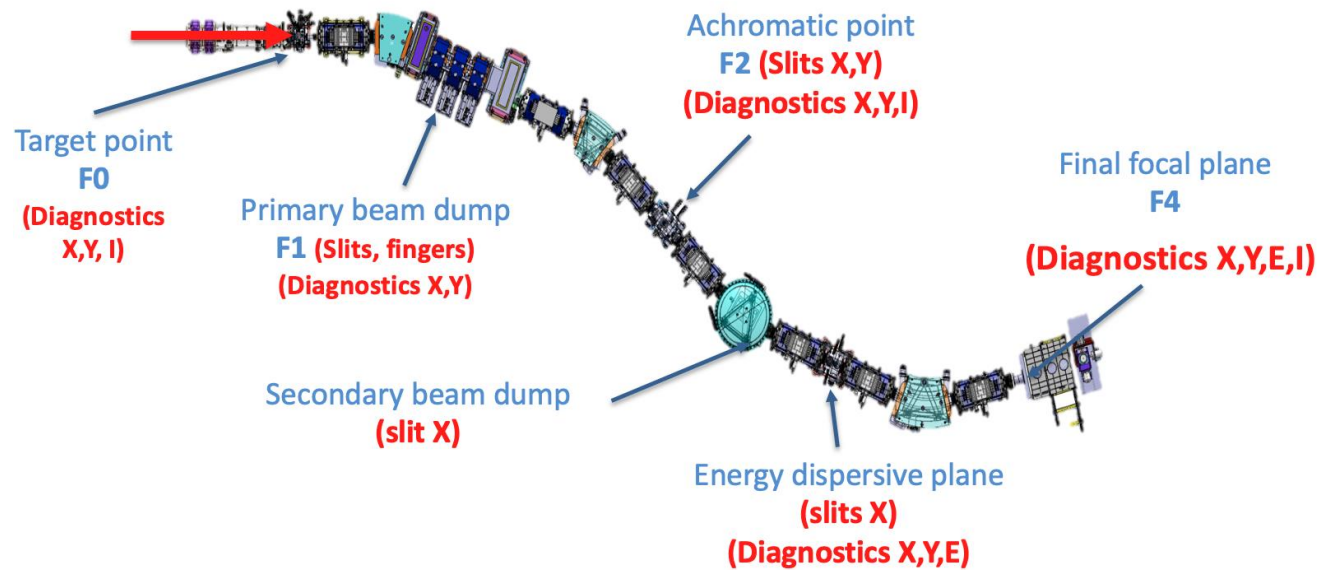
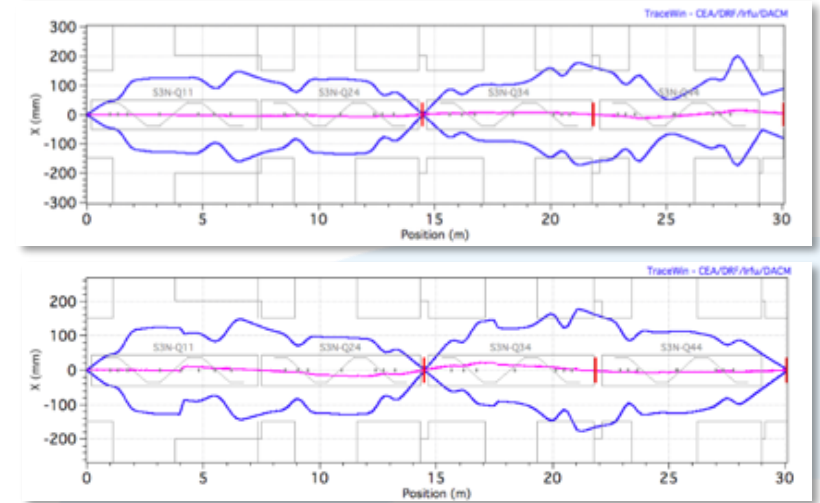




# J6x : commissioning milestones



- Direct and stripped beam up to the focal plane
  - Progressive tuning of the elements (MA+ MS)
  - Tools : diagnostics along the spectrometer + additional diagnostics at the focal plane (SIRIUS & LEB can be connected but not used)
- Beam <sup>40</sup>Ar ; E = 0.73 - 5 MeV/u and intensity of 30 W

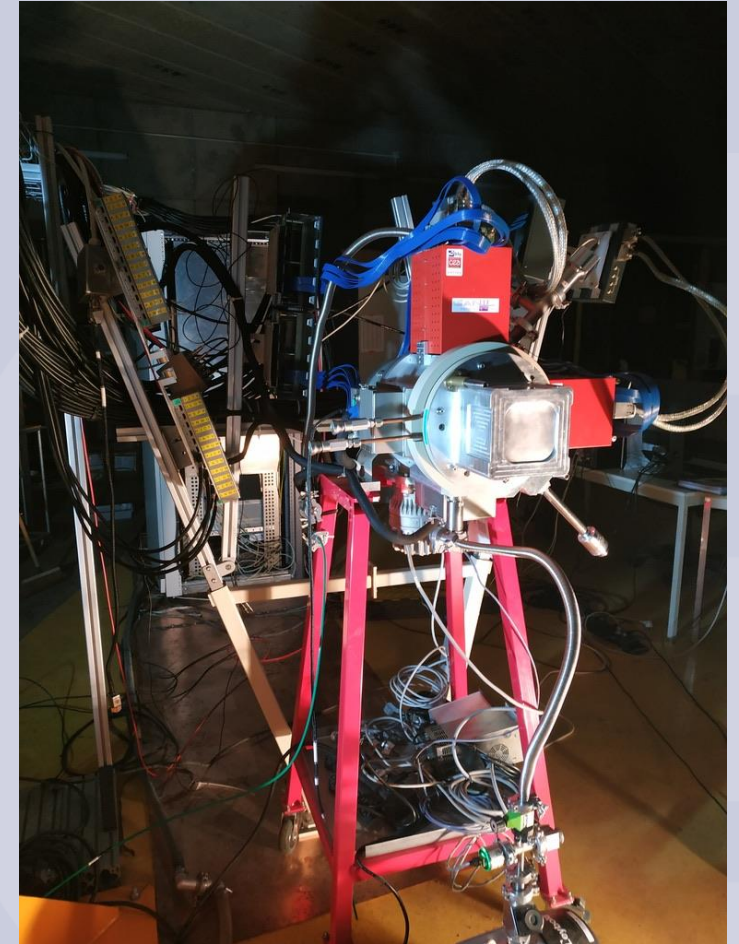


### Prerequisites

- Beam on target : commissioning de of LHE-S<sup>3</sup> with validation of the beam characteristics at the target point (Done J6A)
- Commissioning of individual elements (magnets, power supplies, control-command, diagnostics...)
- Alignments of magnets, slits and diagnostics  
Safety systems must be operational

# Spectroscopy & Identification of Rare Isotopes Using $S^3$

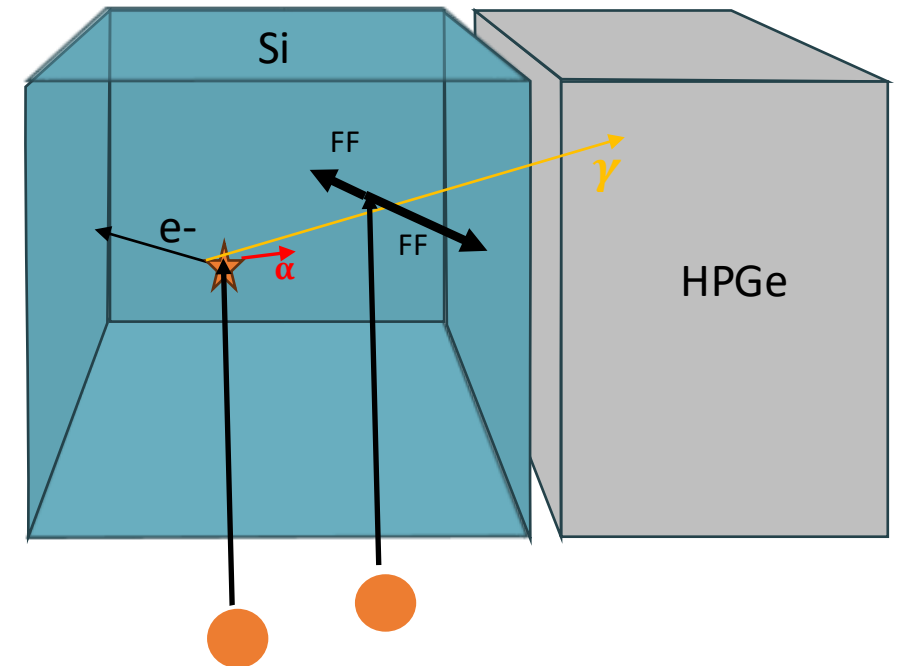
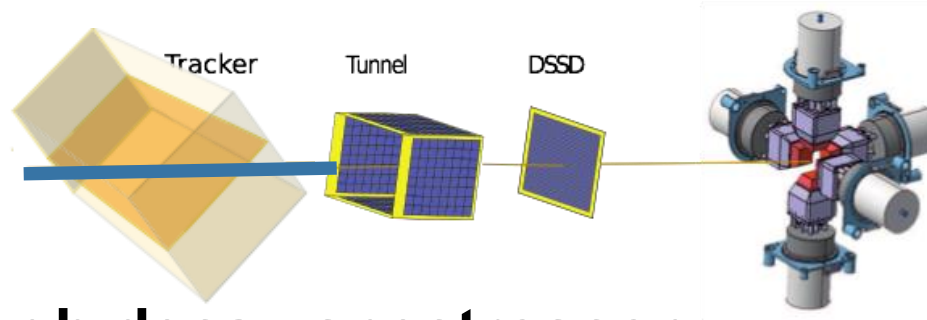
Decay Spectroscopy of Superheavy nuclei with SIRIUS



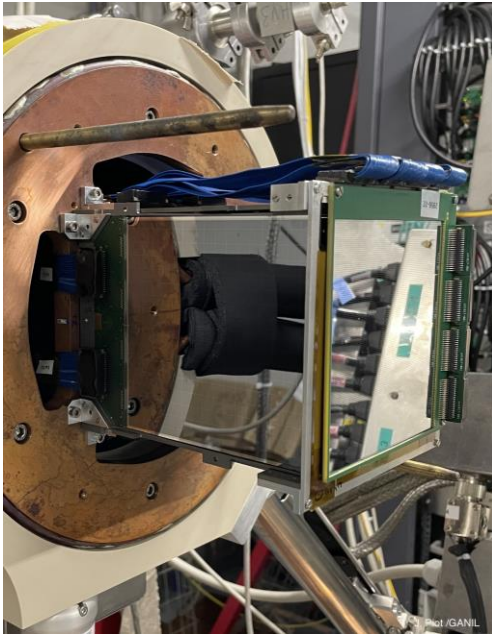
# SIRIUS

## Study the nuclear structure through decay spectroscopy

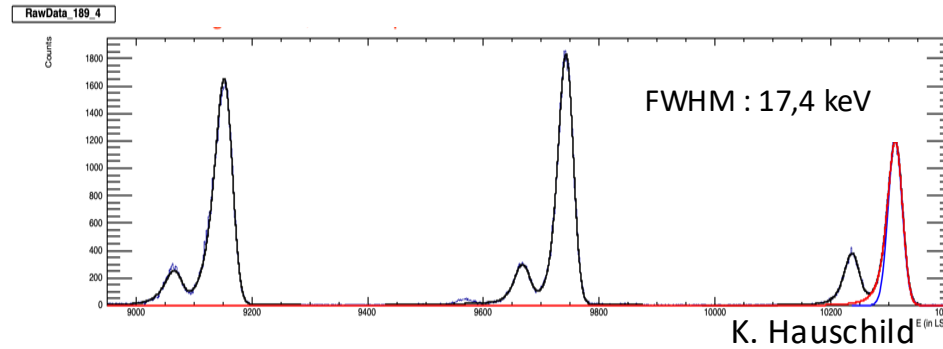
- $\alpha$ -decay measurement for identification and spectroscopy
- Conversion electron spectroscopie
- $\gamma$ -ray and X-ray spectroscopy
- TKE for fission fragments



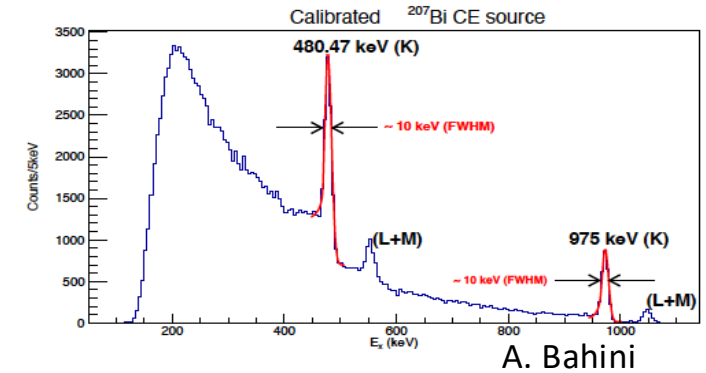
# SIRIUS – Si Box



Alpha energy resolution :  
17,4 keV FWHM



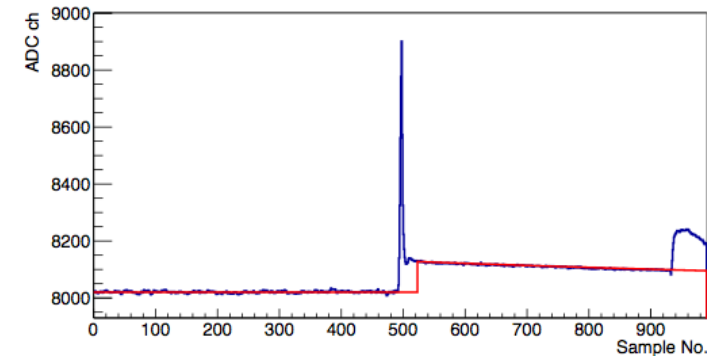
Conversion electron resolution :  
11 keV FWHM



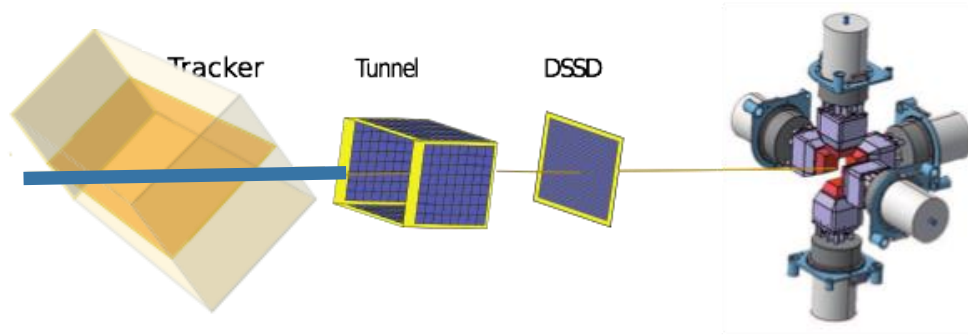
Full trace storage for DSSD

Gain switching Silicon detectors preamplifiers :

- High gain for Conversion Electrons & Alpha decay
- Low gain for Implantation & Fission fragments



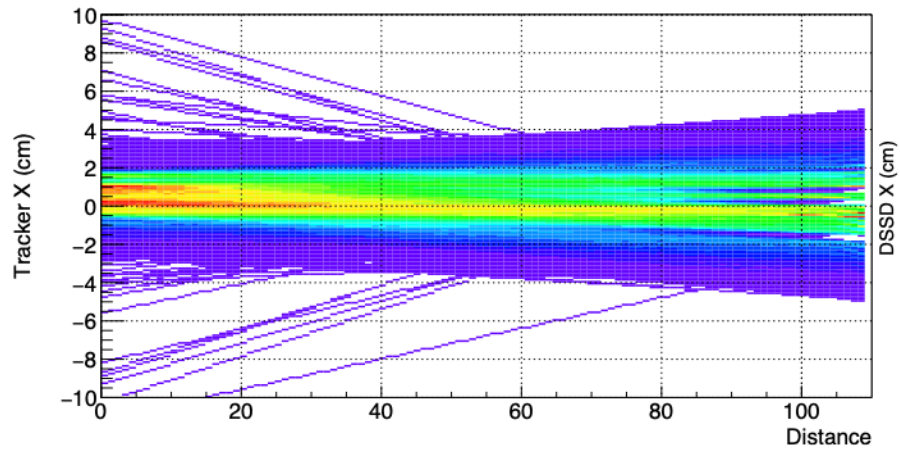
# SIRIUS



Ion Tracking for mass resolution between Tracker & DSSD  
Sub millimeter resolution



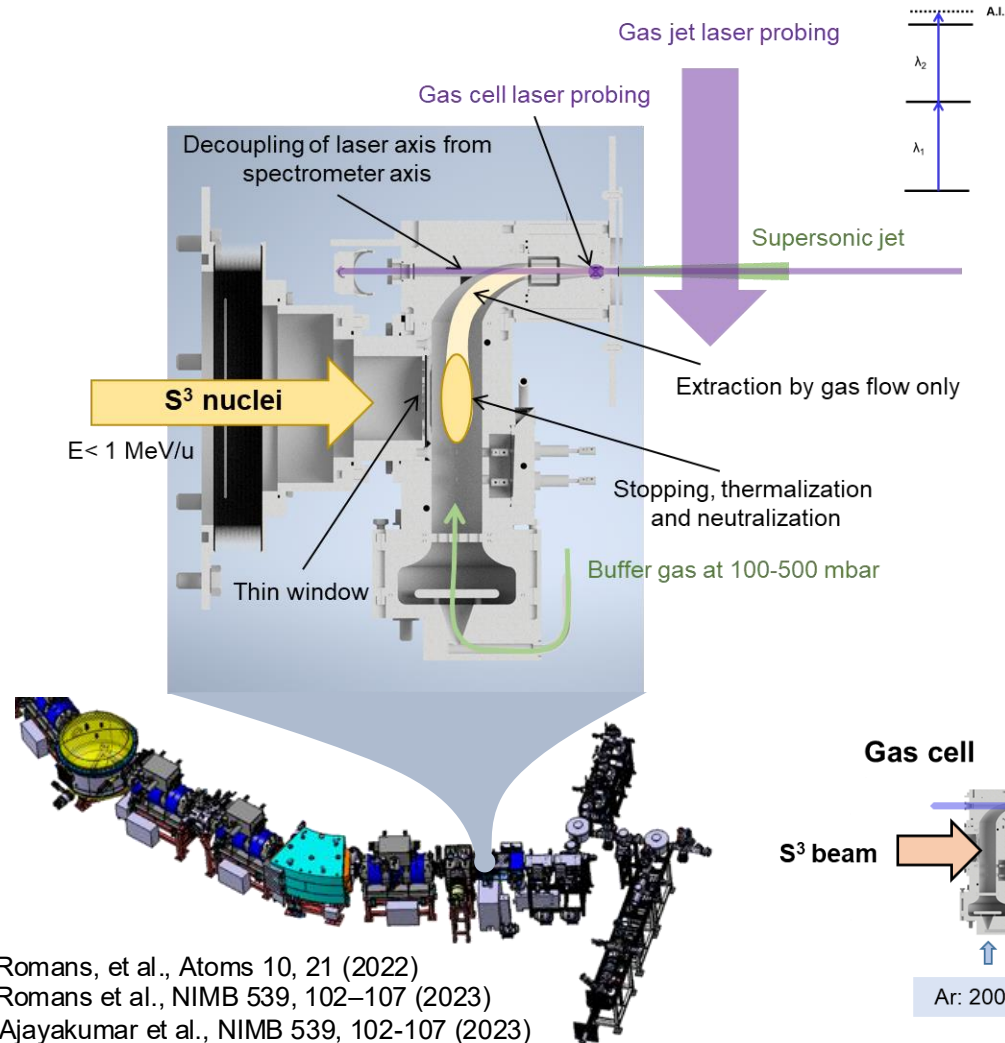
Time Flight resolution : 2.83 ns FWHM



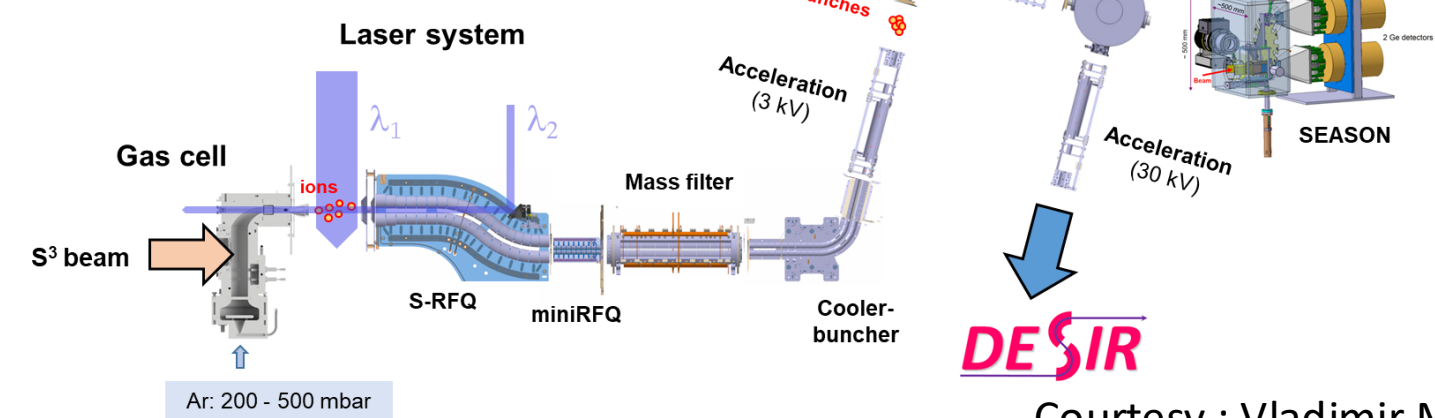
# $S^3$ -Low Energy Branch

Select & study ions through in gas resonance Ionization Laser spectroscopy

# Beam-production and experimental methods of S<sup>3</sup>-LEB



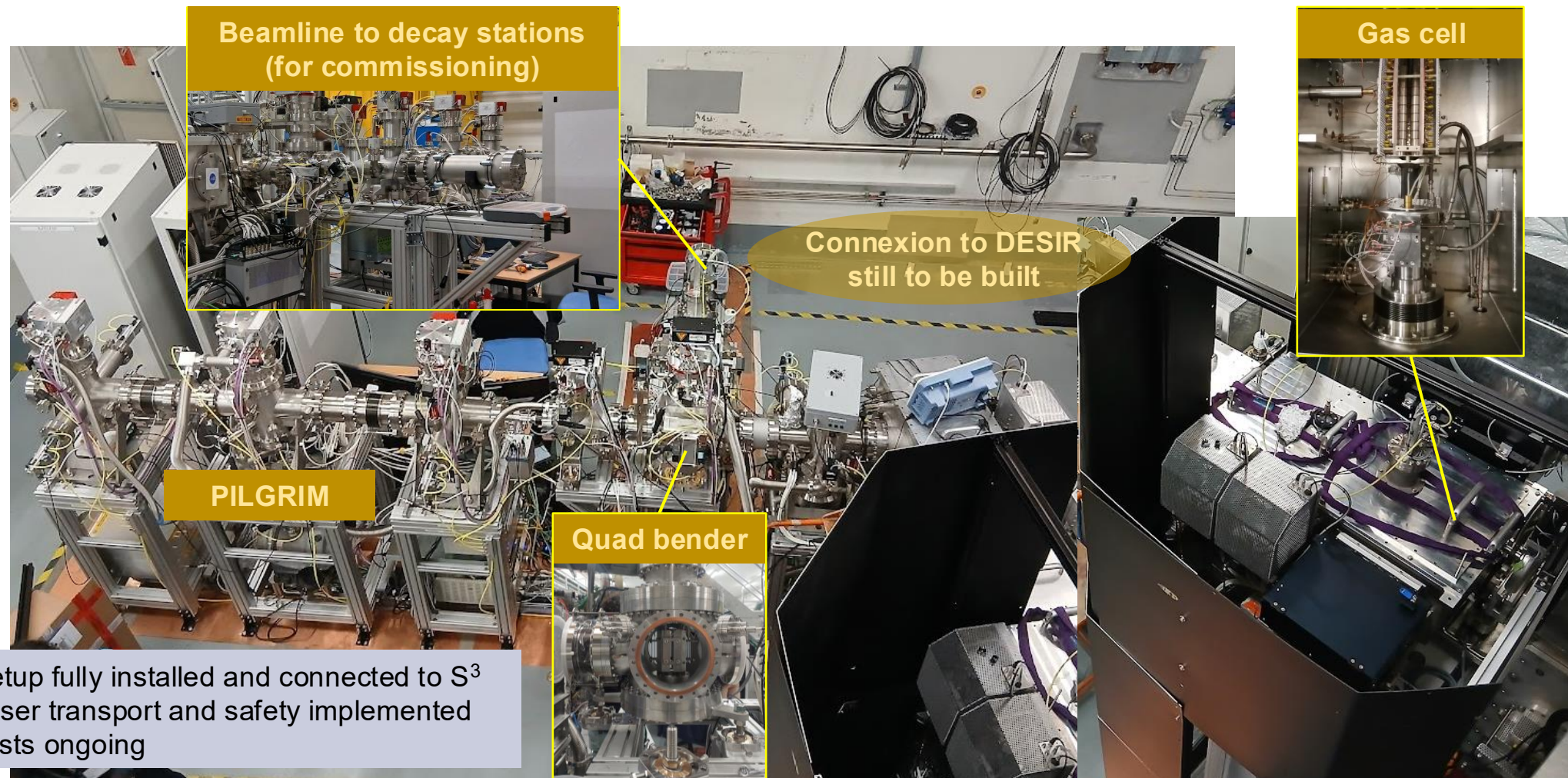
- Laser spectroscopy in a supersonic jet at intermediate resolution (200 MHz)
- Mass and decay spectroscopy measurements
- Possible transport towards DESIR



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)

Courtesy : Vladimir Manea

# Status of the setup: S<sup>3</sup>-LEB



Courtesy : Vladimir Manea

# Status of the setup: S<sup>3</sup>-LEB

- ❑ S<sup>3</sup> Ti:Sa laser room ready for sending beams to S<sup>3</sup>-LEB

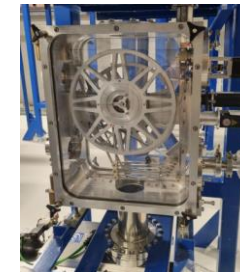


Courtesy : Vladimir Manea

## SEASON



- ❑ Windmill decay station
- ❑  $\alpha$ , FF, CE,  $\gamma$
- ❑ Developed by IRFU
- ❑ Commissioned at IGISOL

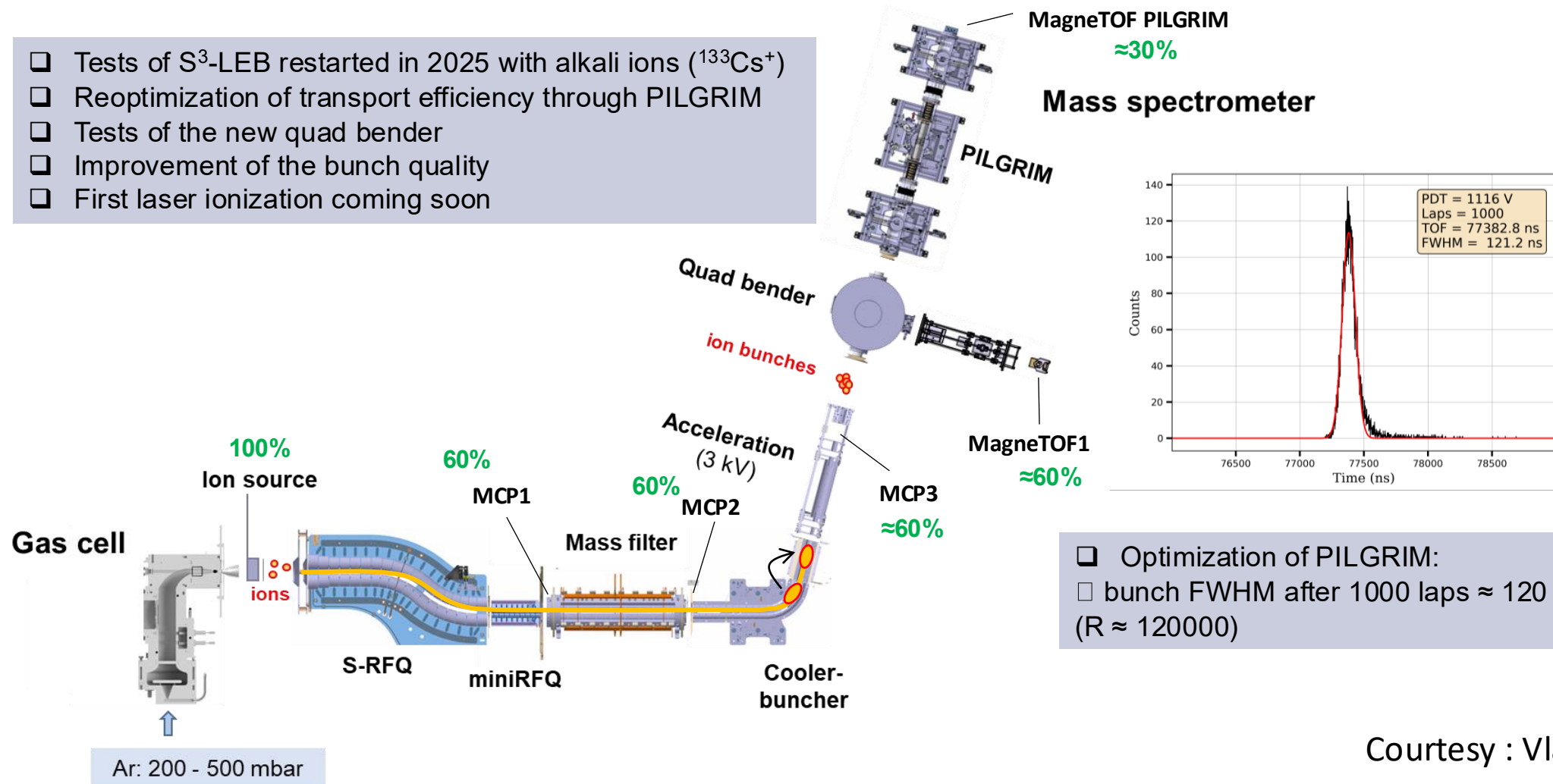


## IDEAS3

- ❑ Tape-based decay station
- ❑ p,  $\beta^+$ , X,  $\gamma$
- ❑ Under construction at IJCLab

# Status of the setup: PILGRIM tuning

- Tests of S<sup>3</sup>-LEB restarted in 2025 with alkali ions (<sup>133</sup>Cs<sup>+</sup>)
- Reoptimization of transport efficiency through PILGRIM
- Tests of the new quad bender
- Improvement of the bunch quality
- First laser ionization coming soon



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

Courtesy : Vladimir Manea

# Laser Resonance Chromatography

## Project goals:

- Explore the atomic structure of SHEs, starting with  $^{254,255}\text{Lr}^+$
- Conduct HFS on neutron-deficient  $^{208-211}\text{Ac}^+$

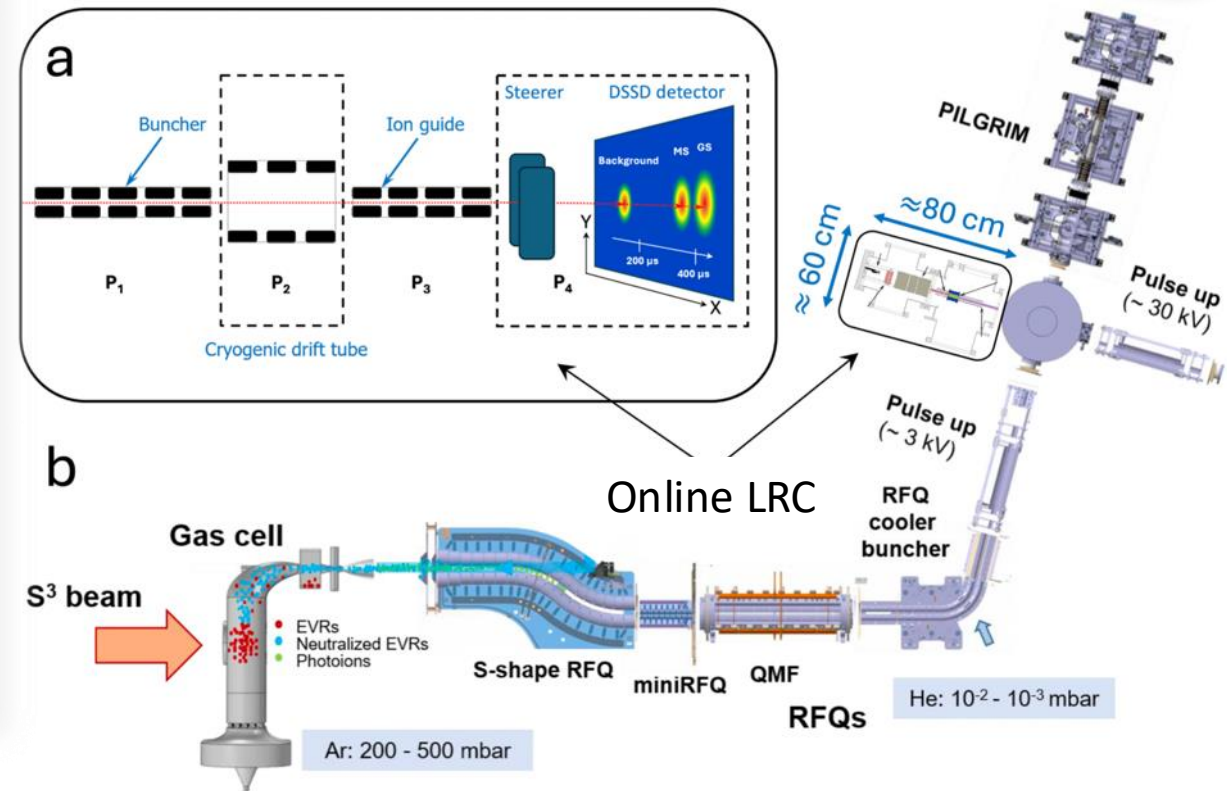
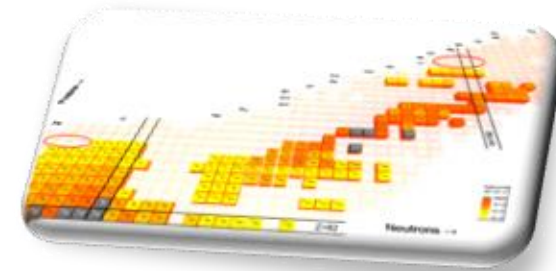
## Project milestones:

- Develop decay-assisted Laser Resonance Chromatography
- Commission LRC behind the S3-LEB deflector
- Operate LRC at the focal plane of S3

## Achievements:

- ✓ Project moved to GANIL & integrated in the S3 collaboration
- ✓ Supported by the GANIL Scientific Council
- ✓ Startup package for the PI
  - 1x PhD student (T. Stefan)
  - 1x Postdoc (H. Dinesan)
  - 150 k€ initial budget
- ✓ ANR proposal (submitted)
- ✓ Drawings for the workshop (ongoing)

PI: *Mustapha LAATIAOUI*  
(CNRS UAR 3266 – GANIL)



# Conclusions

- S<sup>3</sup> designed to study low cross-section isotopes with mass identification
- Construction ongoing : All elements except Beamdump installed
- A lot of experience on Superconducting magnets (hard) earned
- Administrative hurdles to be overcome
- S<sup>3</sup>-LEB commissioning ongoing
- SIRIUS ready for operation
- LRC under construction

# Thank you for your attention

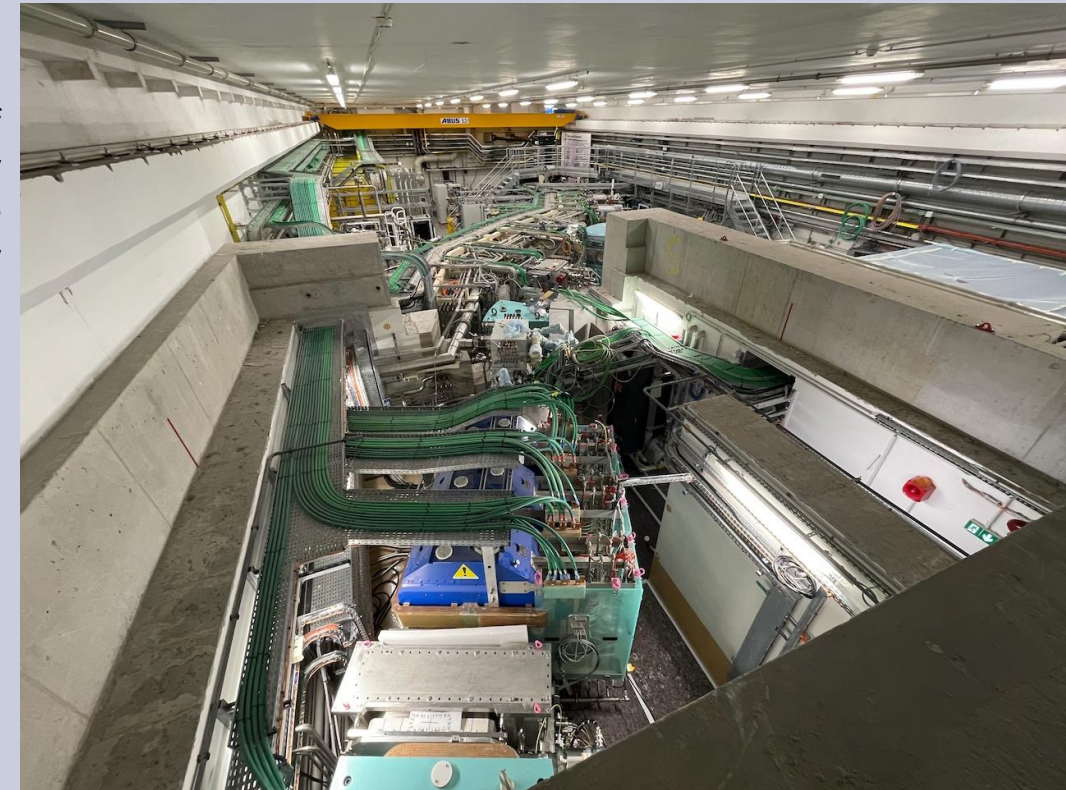


S<sup>3</sup> Collaboration - Letters of intent proposed by 18 laboratories:

ANL (U.S.A.), CENBG, IJCLab, JINR-FLNR, (Russia), GANIL, GSI (Germany), INFN Legnaro (Italy), IPHC, IPNL, Irfu CEA Saclay, JYFL (Finland), K.U. Leuven (Belgium), University of Liverpool (U.K.), LNS (Italy), LPSC, MSU (U.S.A.), LMU (Germany), Nanjing University (China), Northern Illinois University (U.S.A.), SAS Bratislava, (Slovaquia), IFJ PAN Cracovie (Poland), Smoluchowski Institute (Poland), CEA-DAM, SUBATECH, TAMU (U.S.A.), University of Mainz (Germany), University of York (U.K.), Vinca Institute (Serbia)

Construction partners :

GANIL, Irfu, IJCLab, ANL, KU LEUVEN, IPHC, INSP/UPMC, CIMAP, University of Mainz, University of Jyväskylä, University of JENA, GSI



*S3 has been funded by the French Research Ministry, National Research Agency (ANR), through the EQUIPEX (EQUIPMENT of EXcellence) reference ANR-10EQPX- 46, the FEDER (Fonds Européen de Développement Economique et Régional), the CPER (Contrat Plan Etat Région), and supported by the U.S. Department of Energy, Office of Nuclear Physics, under contract No. DE-AC02-06CH11357 and by the E.C.FP7-INFRASTRUCTURES 2007, SPIRAL2 Preparatory Phase, Grant agreement No.: 212692.*

*SIRIUS has been funded by the CPIER "Vallée de Seine", and by the Région Normandie & FEDER through the SoSIRIUS RIN tremplin Grant*

S3LEB has received funding from the French Research Ministry through the National Research Agency under contract number ANR-13-BS05-0013, from the Research Foundation-Flanders (FWO) under the International Research Infrastructure program number I002219N, from the Research Coordination Office – KU Leuven (C14/22/104), from the European Research Council under contract number ERC-2011-AdG-291561-HELIOS, from the FWO and F.R.S.-FNRS under the Excellence of Science (EOS) programme (40007501), from the European Union's Horizon 2020 research and innovation program under grant agreement number 654002–ENSAR2-H2020-INFRAIA-2014-2015 and under grant agreement number 861198–LISA–H20 20-MSCA-ITN-2019 and from IN2P3-DSM/CEA and GSI under the French-German collaboration agreement number PN1064.