

# Status of $S^3$ & possible studies on spontaneous fission

*J.Piot on behalf of the  $S^3$  project & collaboration*

7<sup>th</sup> Workshop on Nuclear Fission and Spectroscopy of Neutron Rich Nuclei



# Superheavy nuclei

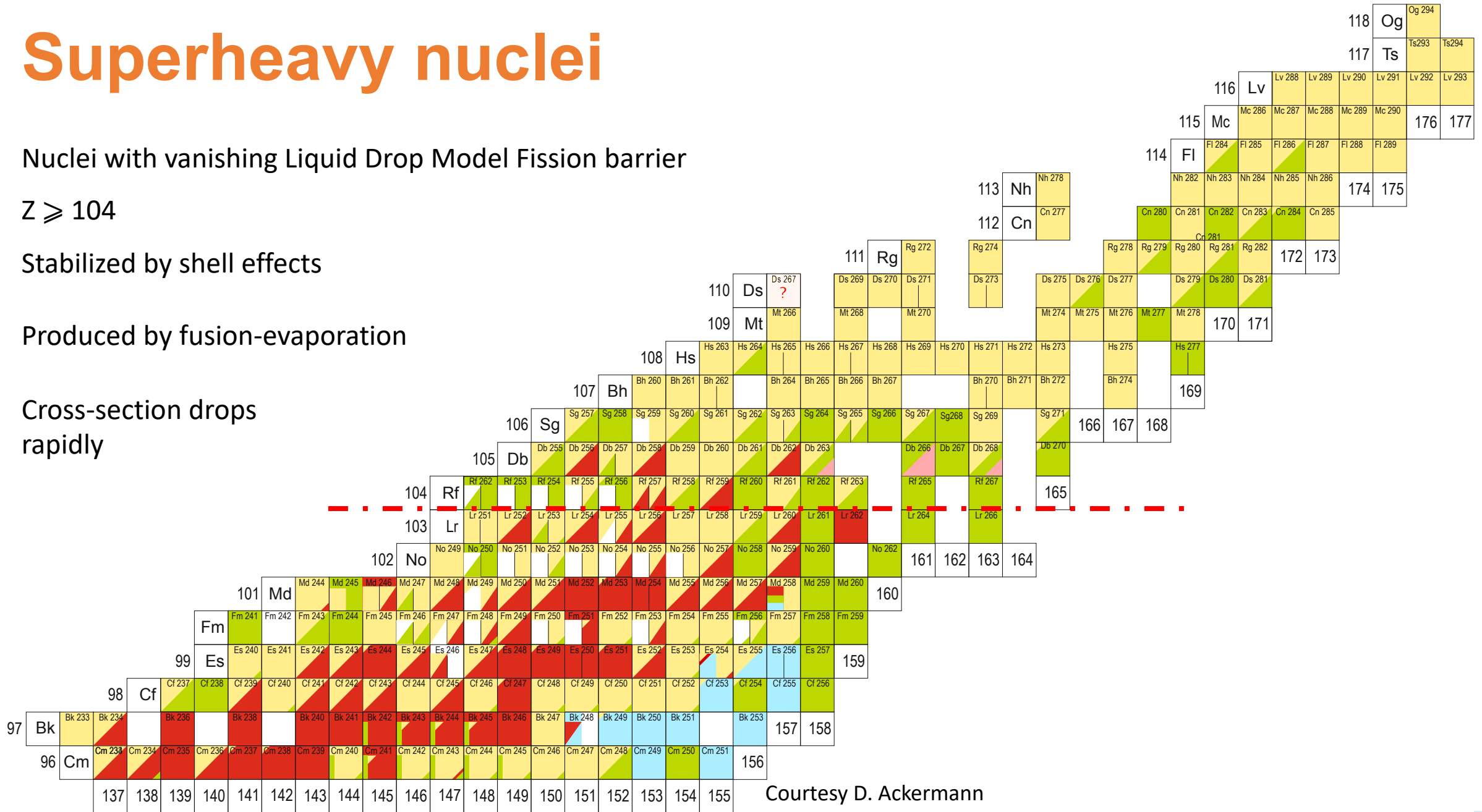
Nuclei with vanishing Liquid Drop Model Fission barrier

$Z \geq 104$

Stabilized by shell effects

Produced by fusion-evaporation

Cross-section drops rapidly



Courtesy D. Ackermann

# Superheavy nuclei

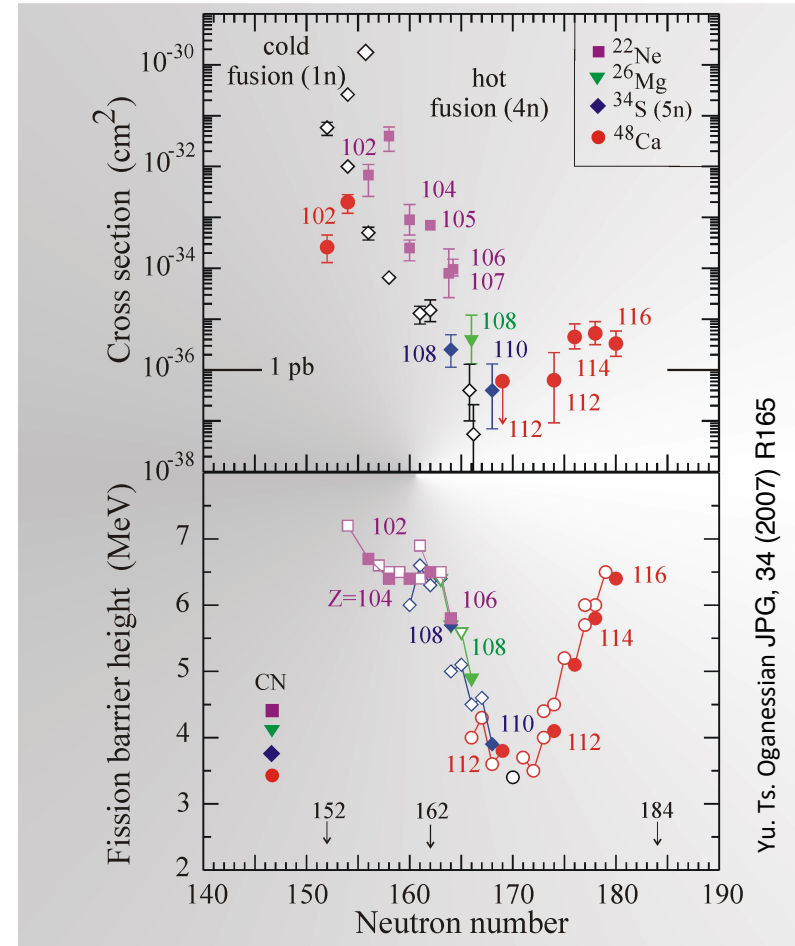
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Yu. Ts. Oganessian JPG, 34 (2007) R165

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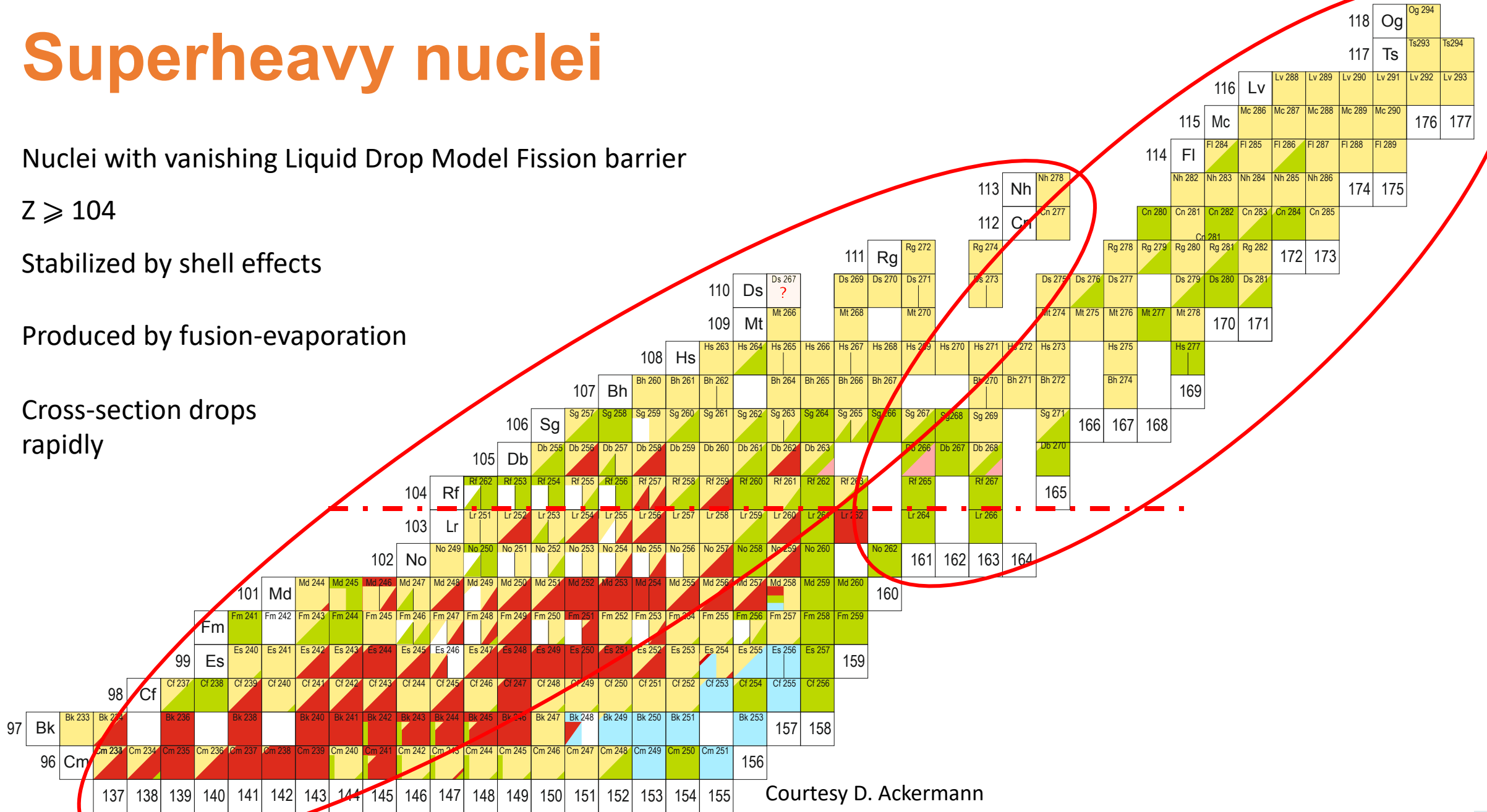
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# S<sup>3</sup> at SPIRAL2



Study Superheavy nuclei

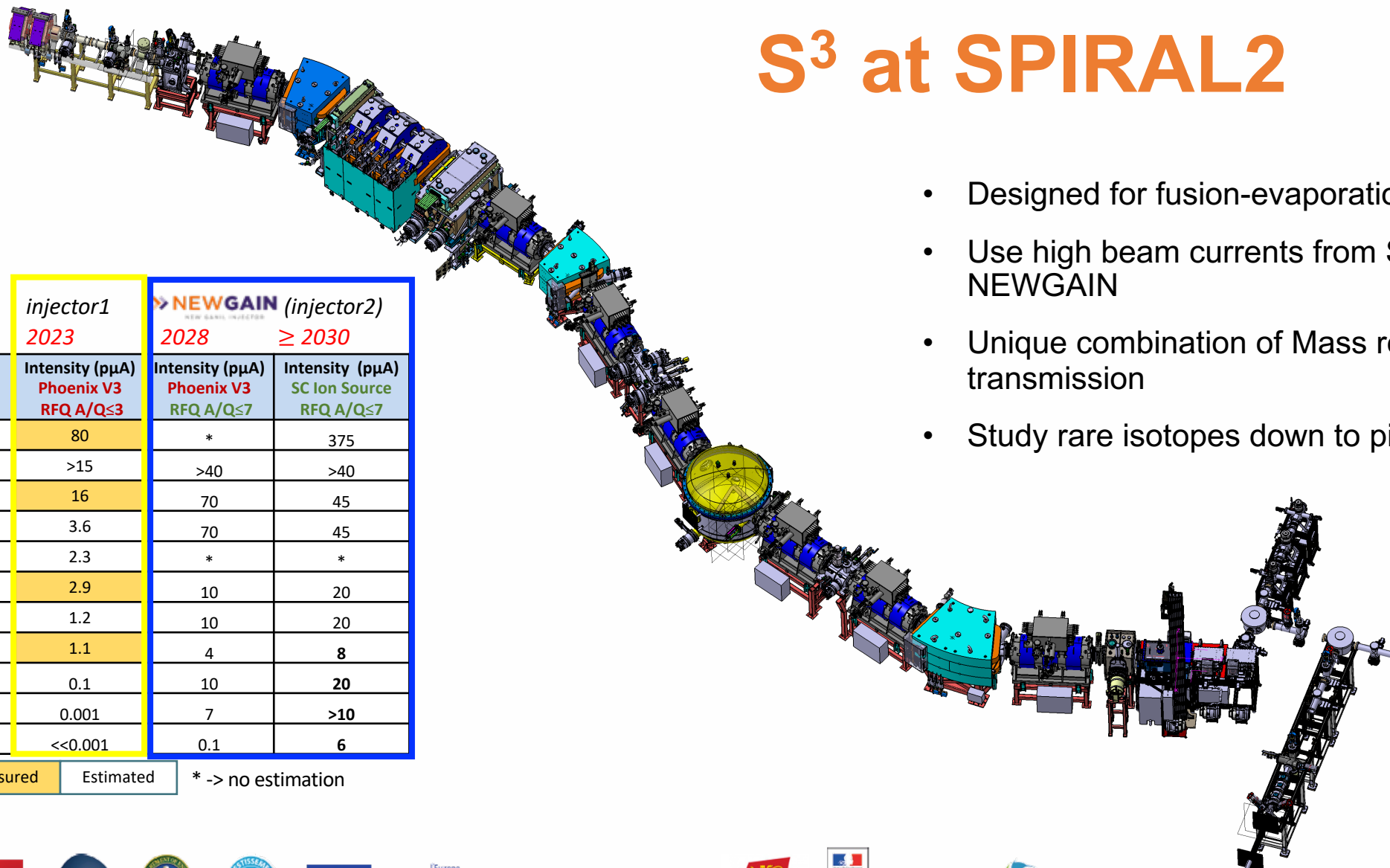
&

N=Z neutron deficient nuclei

- 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



# 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

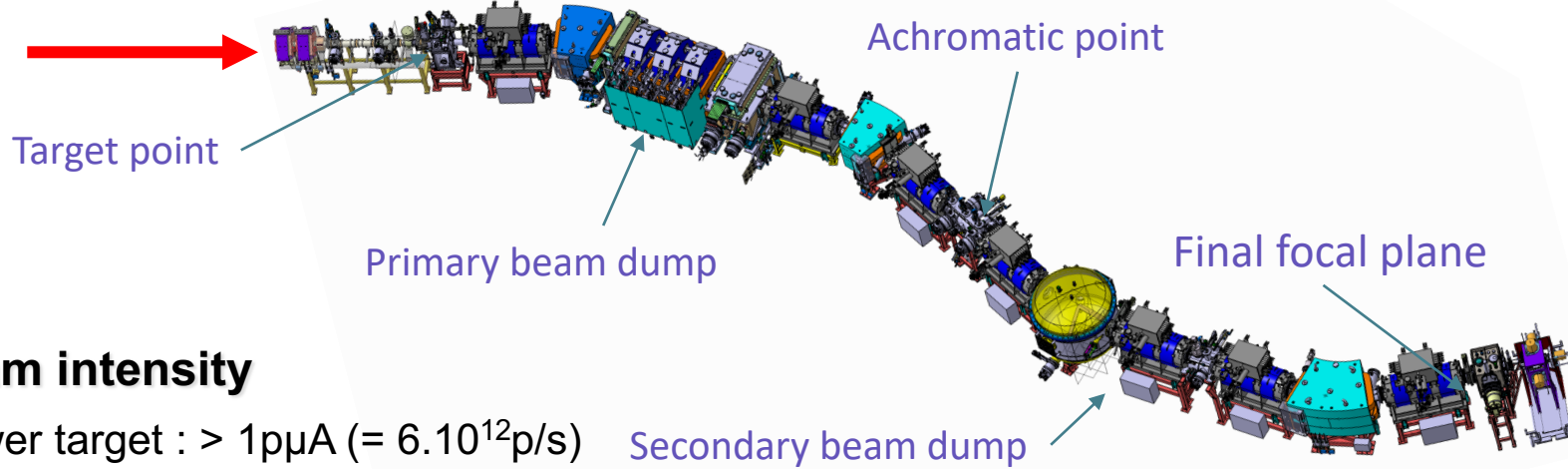
Estimated

\* -> no estimation

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



# Performances



## ✓ High Beam intensity

→ High power target :  $> 1 \mu\text{A}$  ( $= 6 \cdot 10^{12} \text{p/s}$ )

→ High transmission : 50%

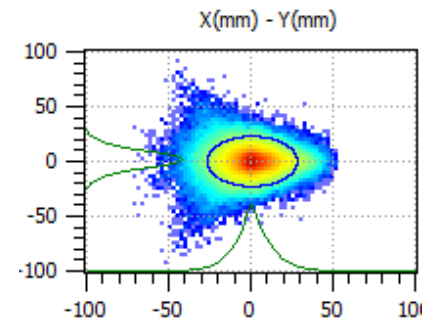
→ High Selectivity :  $> 10^{13}$

## ✓ Versatility

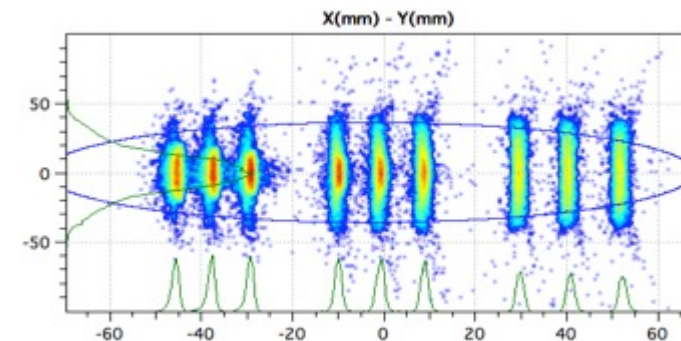
→ 2 extreme optical modes defined

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

*Convergent mode*



*Mass Resolution mode*



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

## Complementary setups to study superheavy nuclei :

- SIRIUS/SHEXI for Identification & Spectroscopy
- S3-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

# Spontaneous Fission

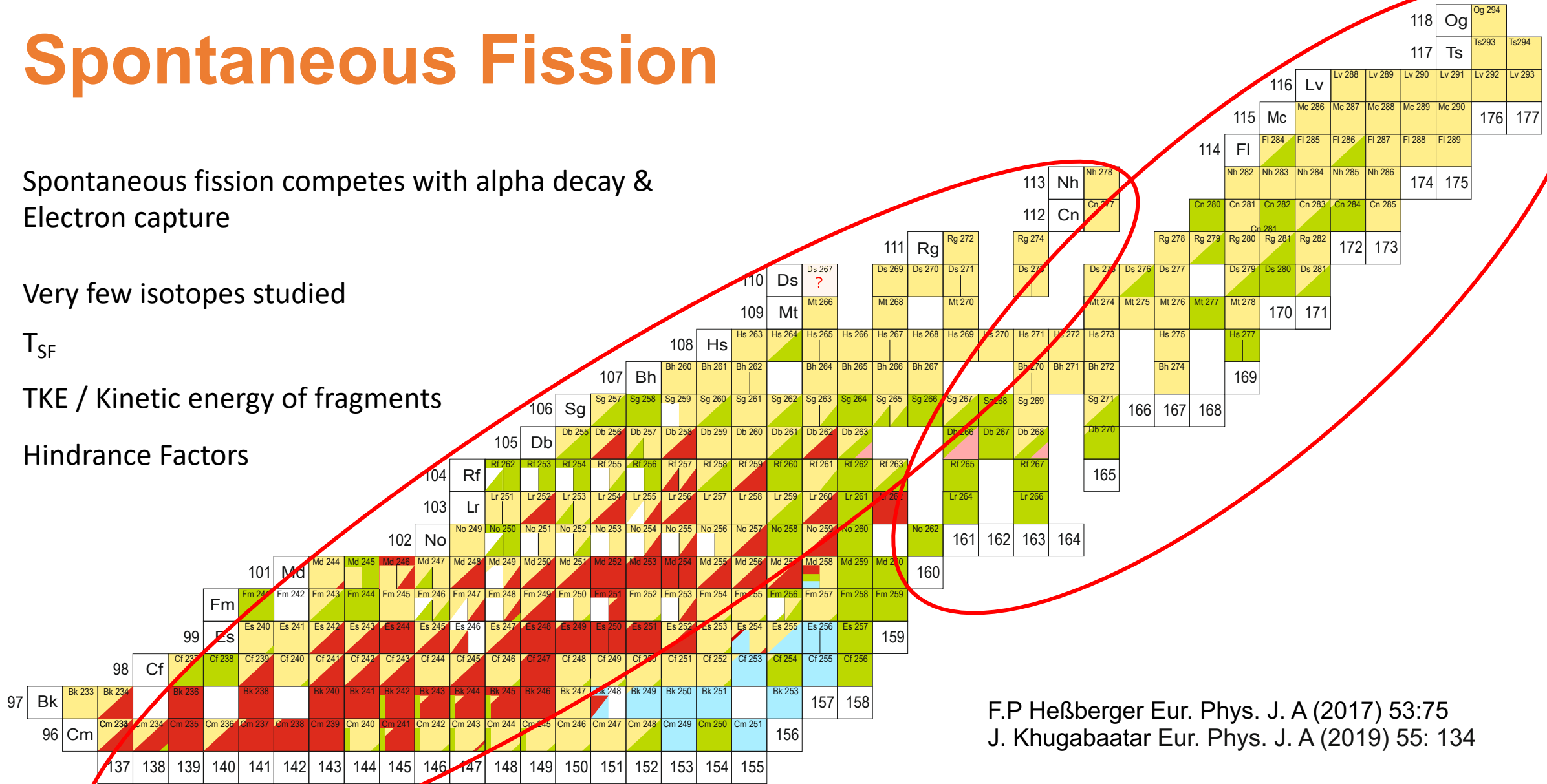
Spontaneous fission competes with alpha decay & Electron capture

Very few isotopes studied

$T_{SF}$

TKE / Kinetic energy of fragments

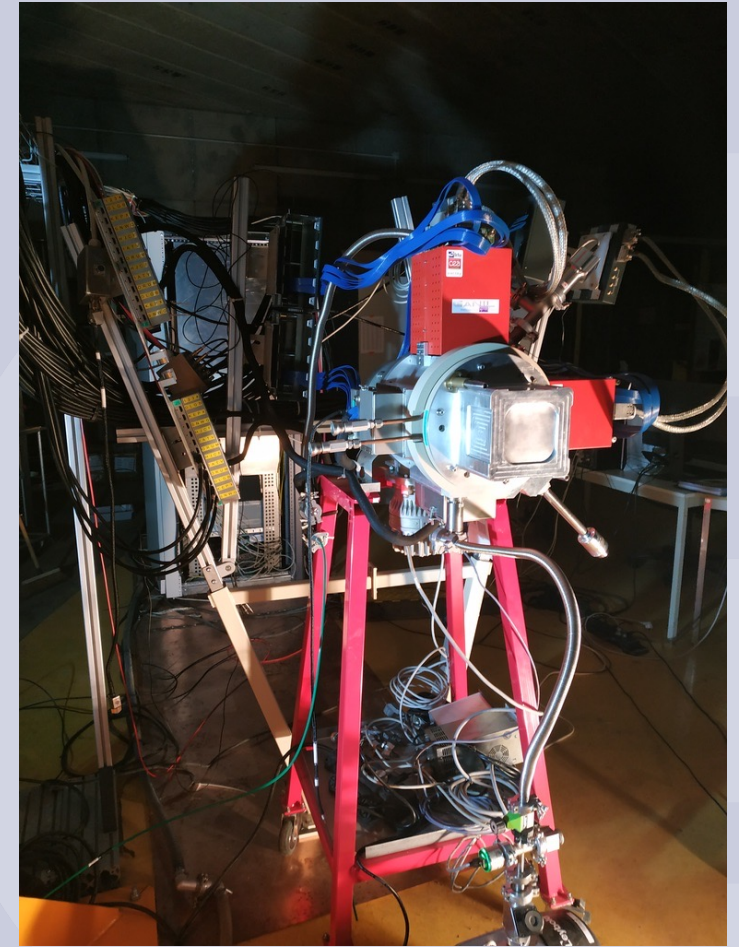
Hindrance Factors



F.P Heßberger Eur. Phys. J. A (2017) 53:75  
 J. Khugabaatar Eur. Phys. J. A (2019) 55: 134

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

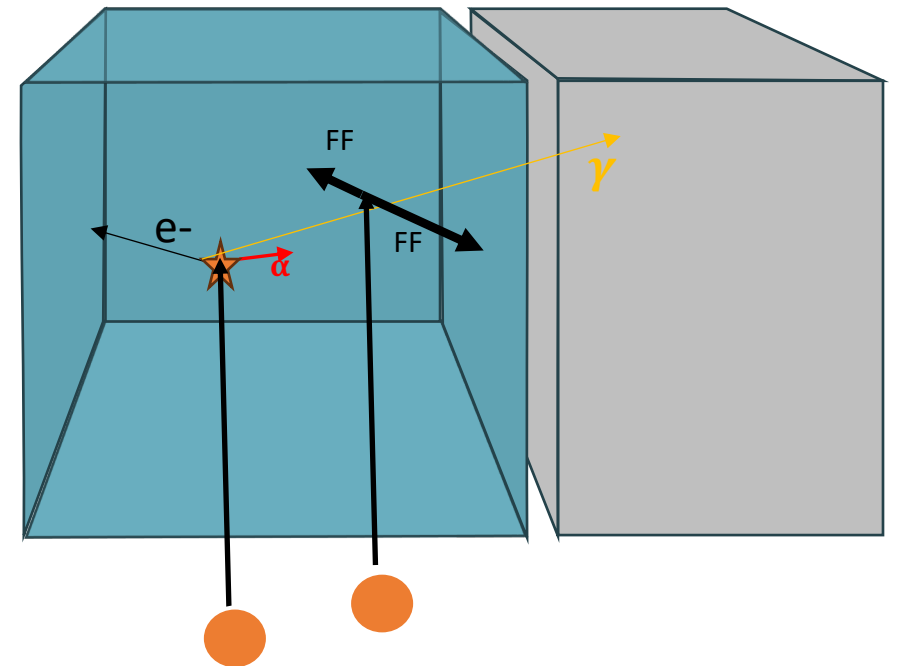
Decay Spectroscopy of Superheavy nuclei with SIRIUS



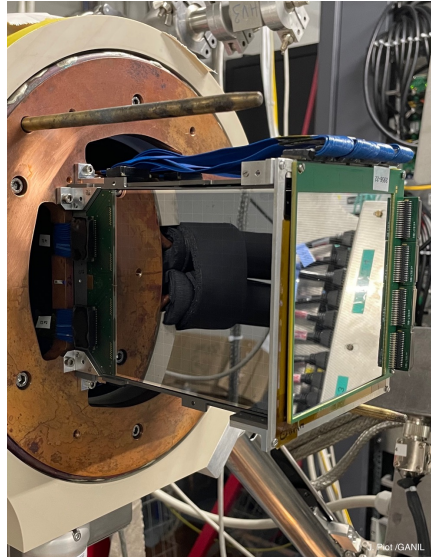
# SIRIUS

## Study the nuclear structure through decay spectroscopy

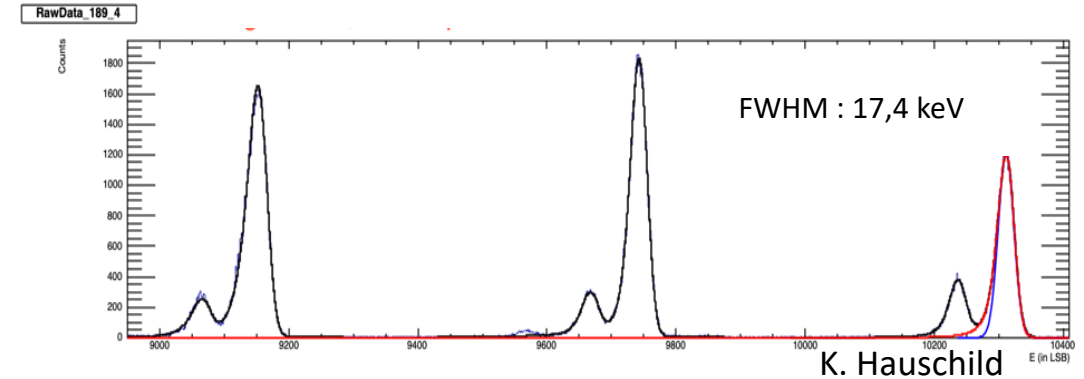
- $\alpha$ -decay measurement for identification and spectroscopy
- Conversion electron spectroscopy
- $\gamma$ -ray and X-ray spectroscopy
- TKE for fission fragments



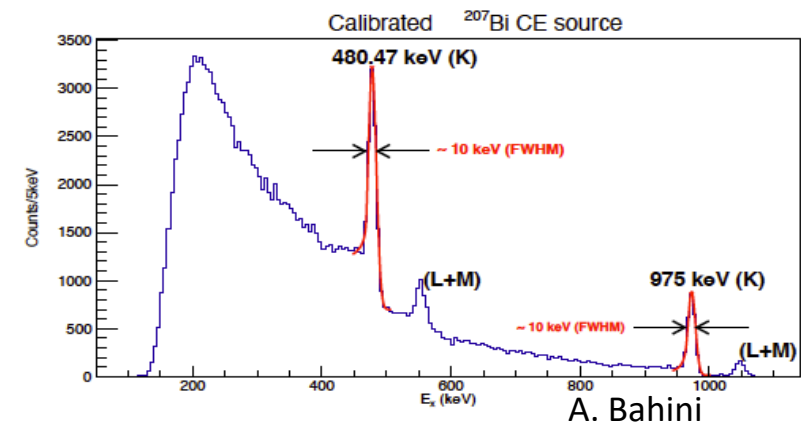
# SIRIUS – Si Box



Alpha energy resolution : 17,4 keV FWHM

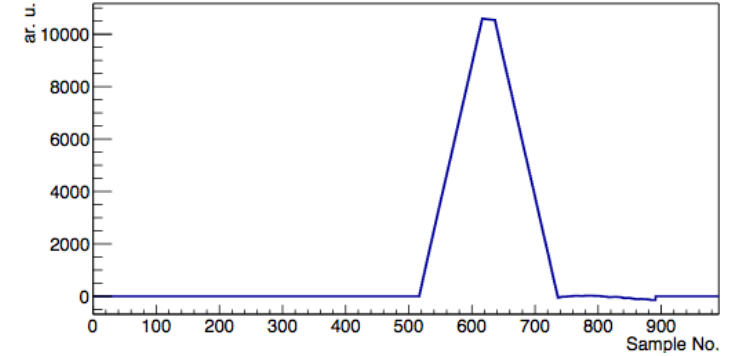
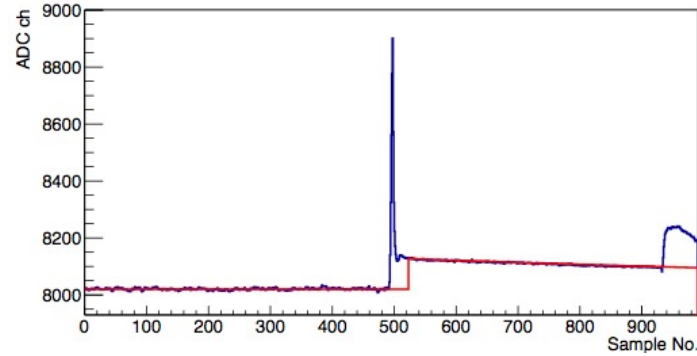
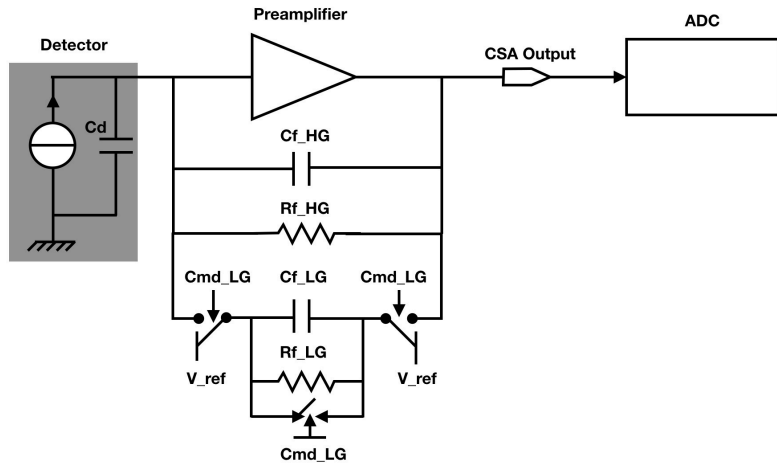


Conversion electron resolution : 11 keV FWHM



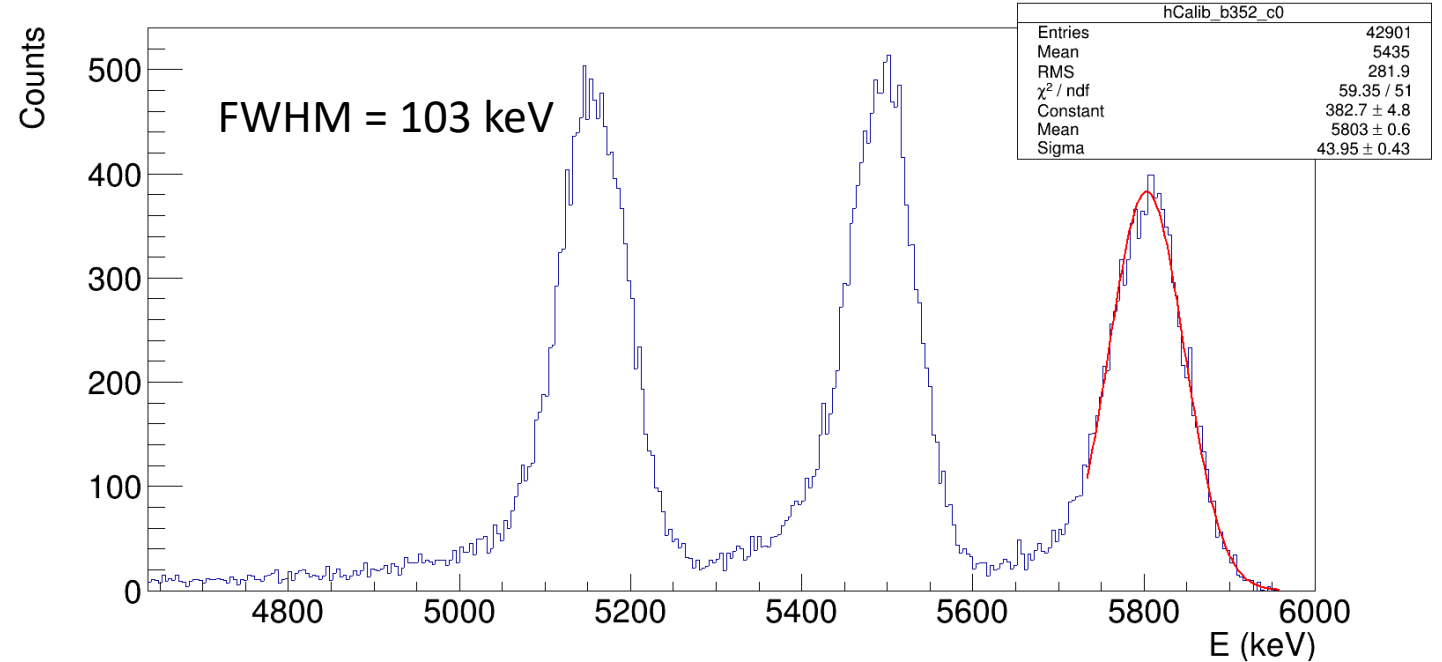
- Gain switching Silicon detectors preamplifiers :
- High gain for Conversion Electrons & Alpha decay
  - Low gain for Implantation & Fission fragments

# Fission fragment detection



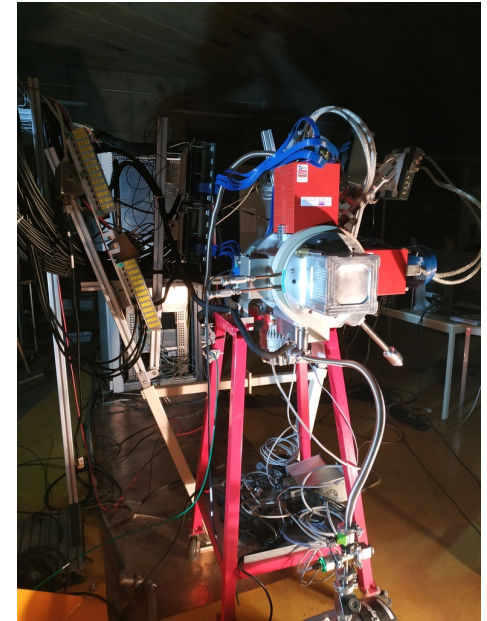
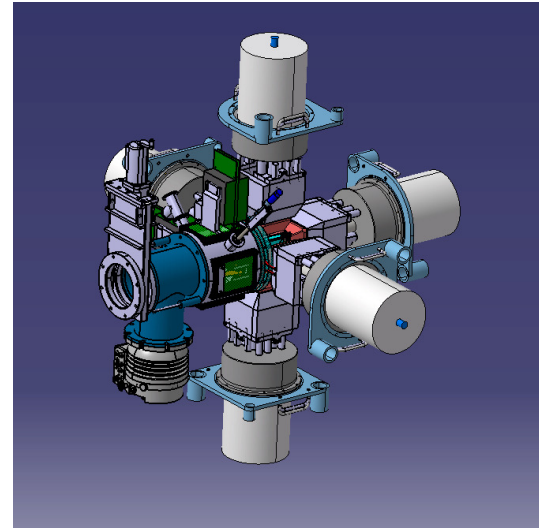
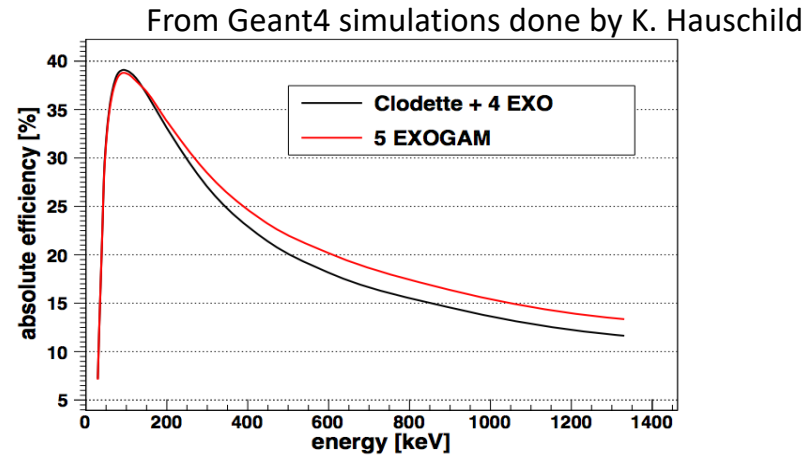
R. Chakma

Switching feedback capacitor to change gain as a function of output signal level



# SIRIUS

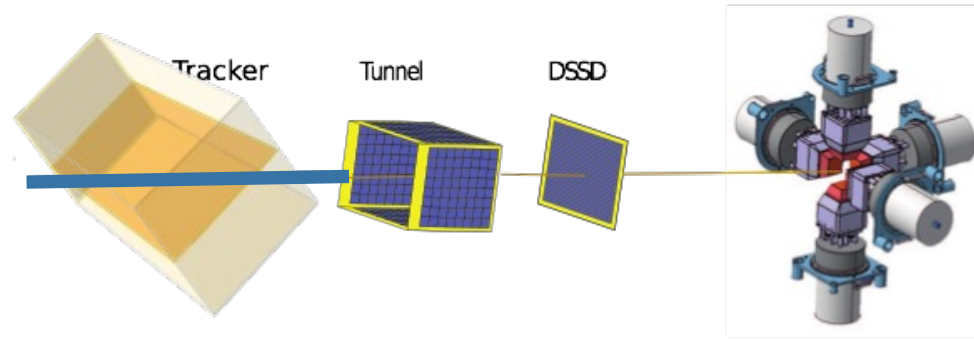
## Very efficient Gamma-ray Detection : 5 EXOGAM



## Full Digital & Triggerless electronics (NUMEXO)

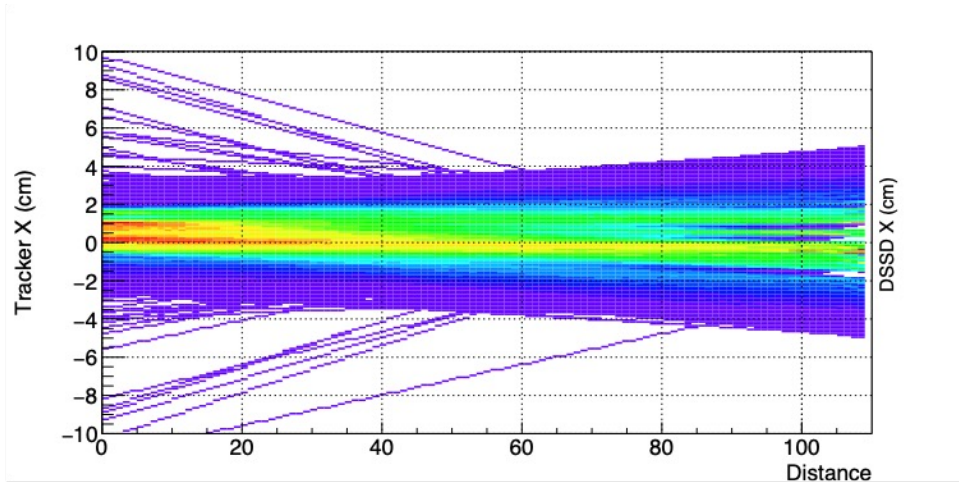


# SIRIUS

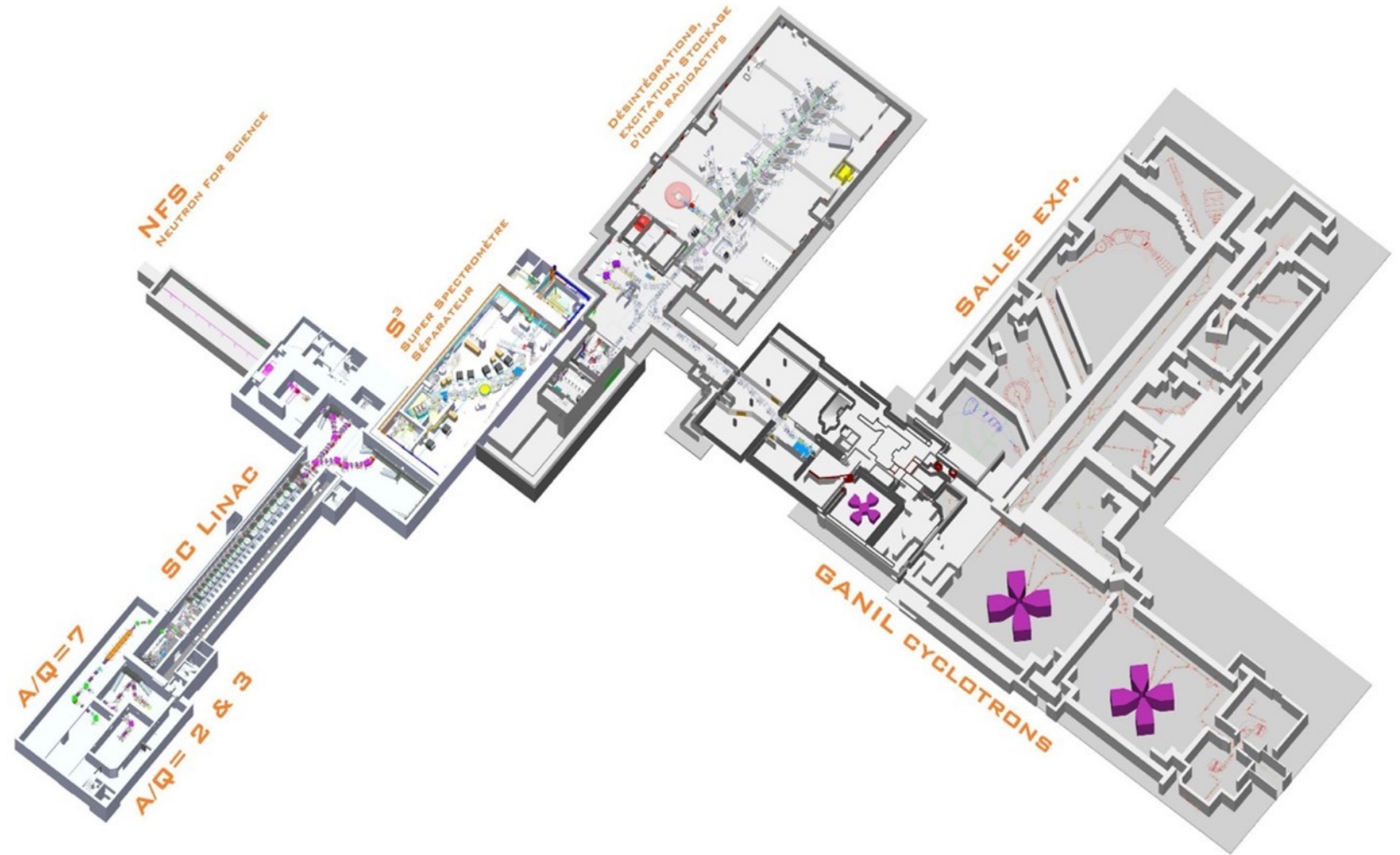


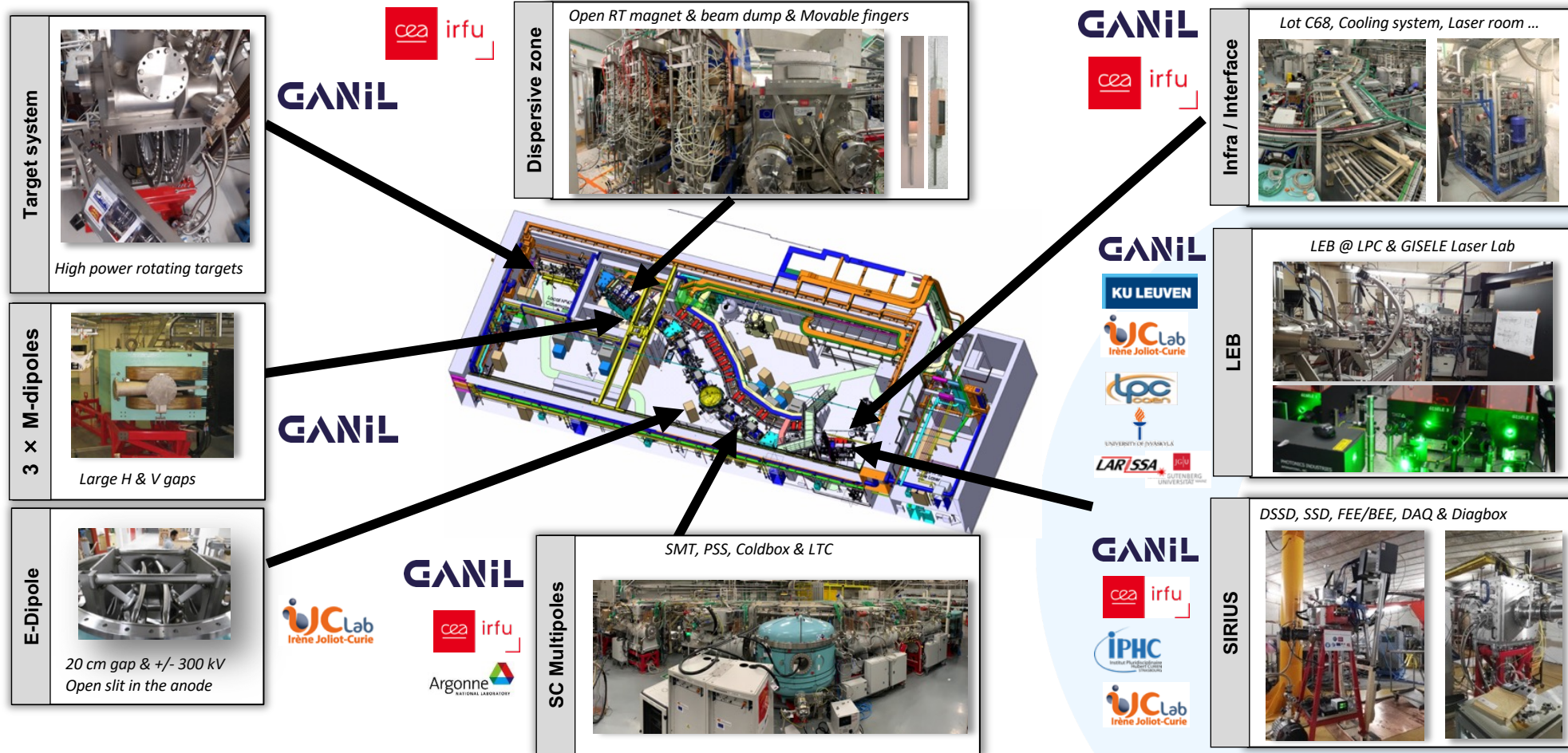
Ion Tracking for mass resolution between Tracker & DSSD  
Sub millimeter resolution

Time Flight resolution : 2.83 ns FWHM



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

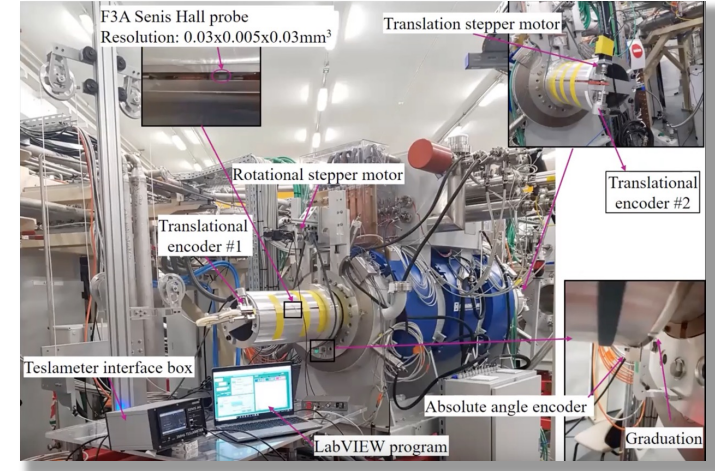




- High selectivity  $> 10^{13}$  - High efficiency 50 % - In flight mass separation = 500
- Versatility & unique instrumentation (SIRIUS – LEB)

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

- All Equipement installed except Beamdump fingers
- Nov 2024 : Control of accelarator by target validated.
- May 25 : Electrical Diode conditioned at +/- 200kV : Voltage sufficient for the Commissioning.
- Vaccuum leak repaired on SMT 5
- New Helium probe installed on SMT6
- HTS Current lead were successfully replaced on SMT 5 and 6
- Field mapping done on 2 SMT - Alignement done



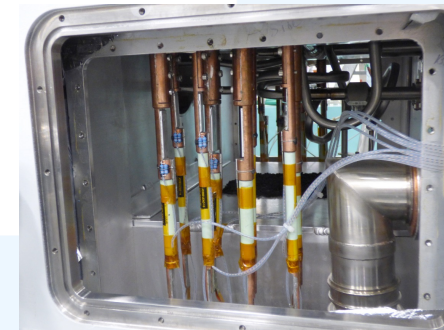
- **All the SMT have been placed at final position**
- SMT P2 : ADI successfully repaired
- Complete Cool down (SMT P1-7) started in august – Stopped because of leaks
- Leaks detected on SMT P1, P2, P4 and P7
  
- **ASNR shutdown of Helium Cold Box end 2025**  
→ Processing ongoing, 1 year delay expected



LTS



HTS



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## In the meantime :

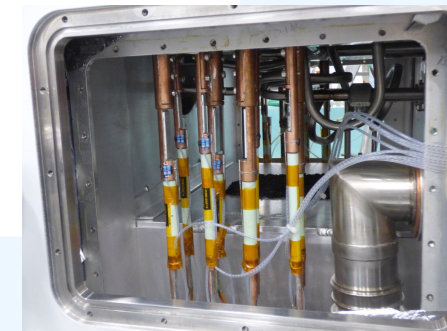
- Solve the leaks on LTS of SMTs P1, P2, P4 and P7
- Install the new Helium probes on all SMTs
- Replace corroded HTS on all SMTs
- Finish construction and installation of Beam Dump fingers



LTS



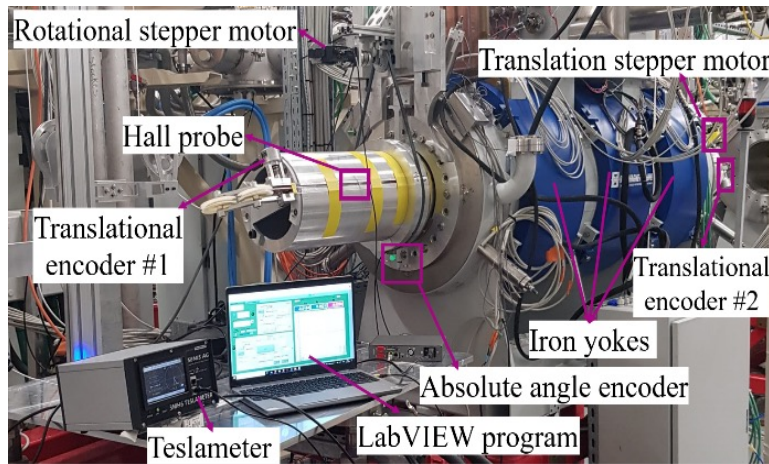
HTS



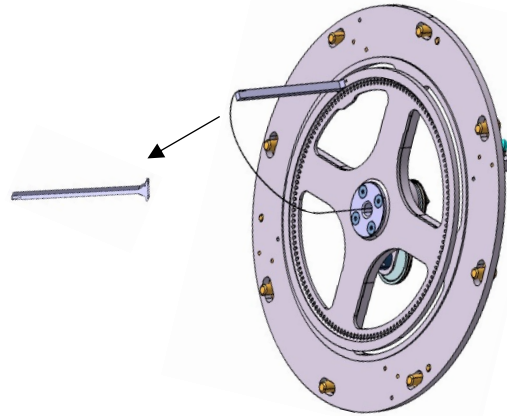
**As soon as the cold box can be used :**

- 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)

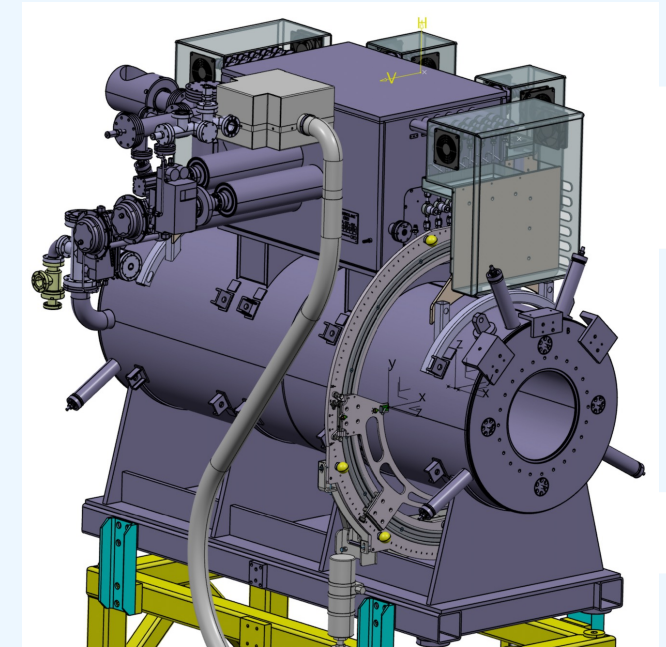
3D mapper



Thin mapper

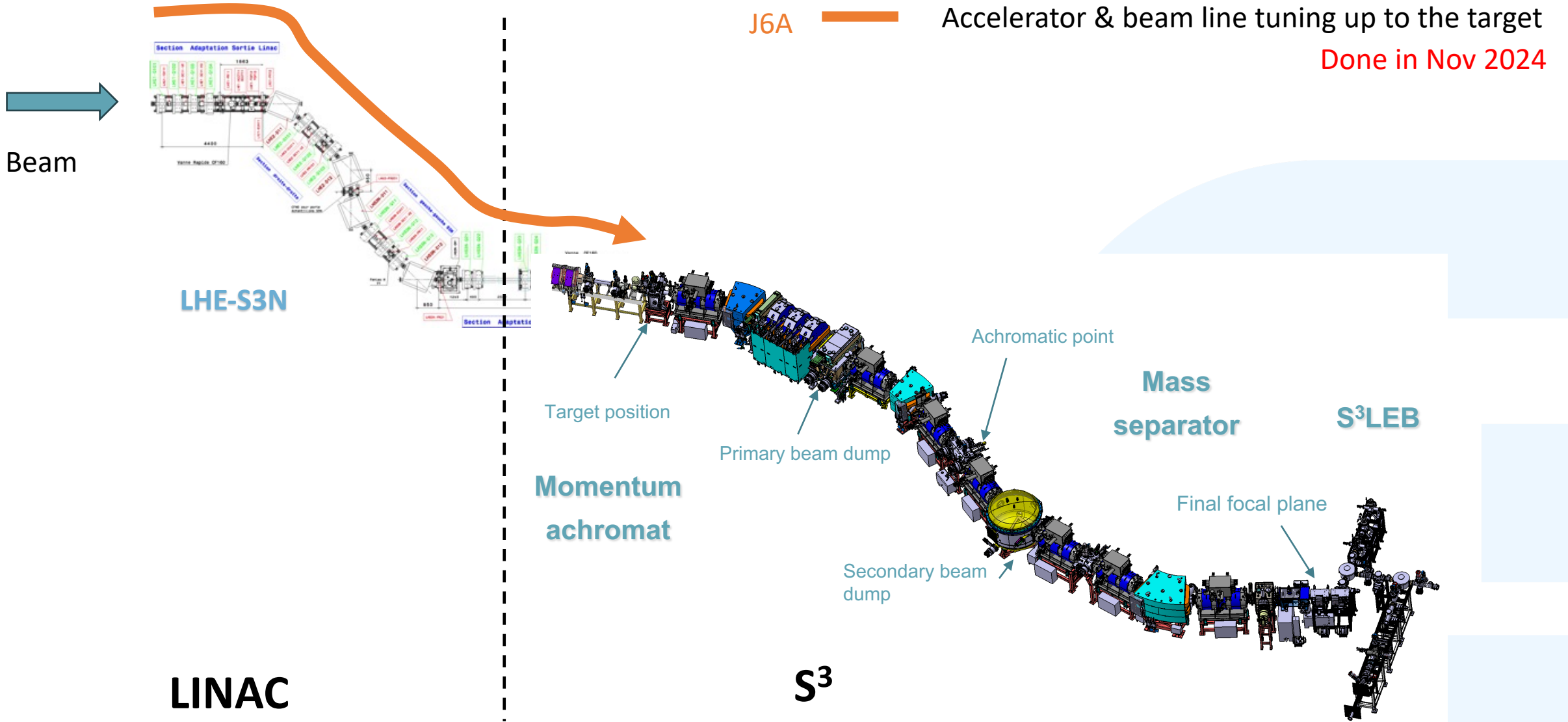


External mapper (GANIL/Irfu)





# J6x : commissioning milestones



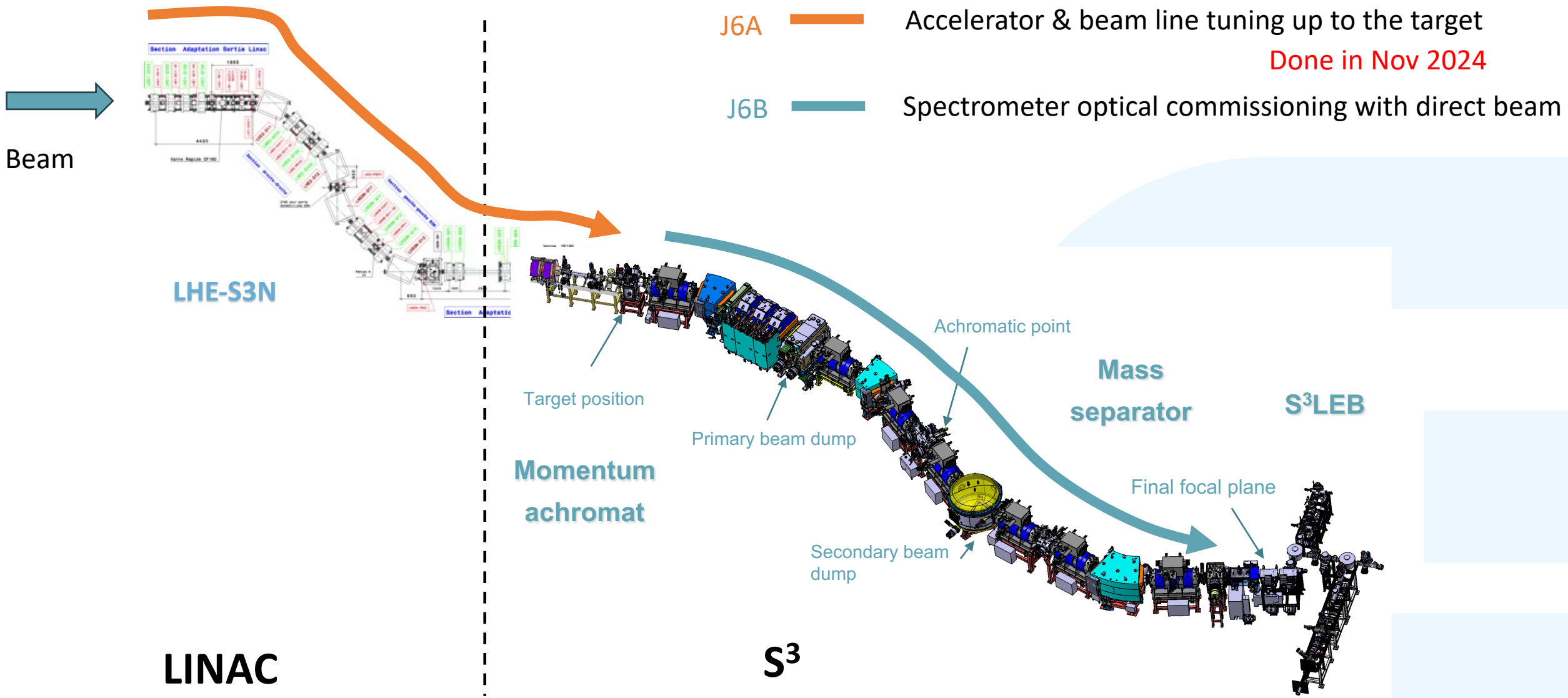
Done in Nov 2024

LINAC

S<sup>3</sup>

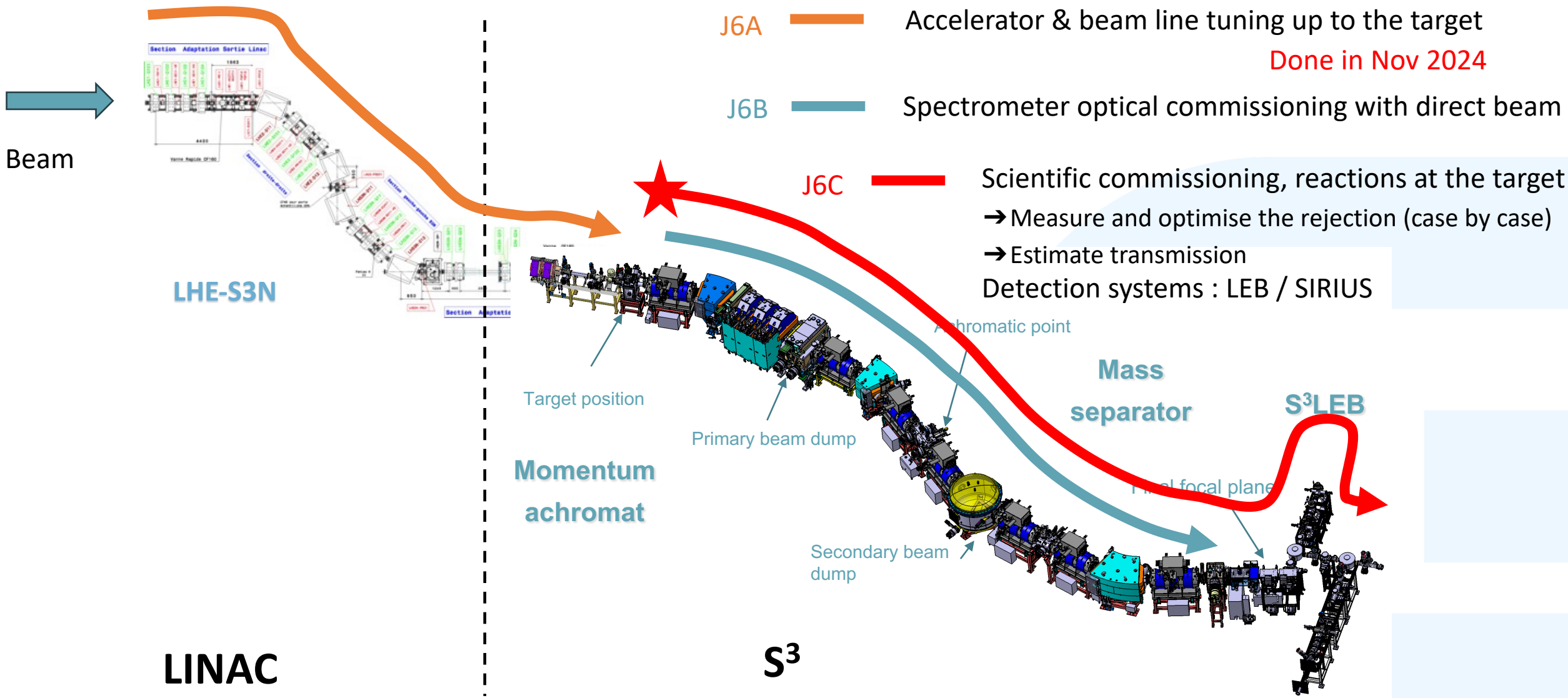


# J6x : commissioning milestones

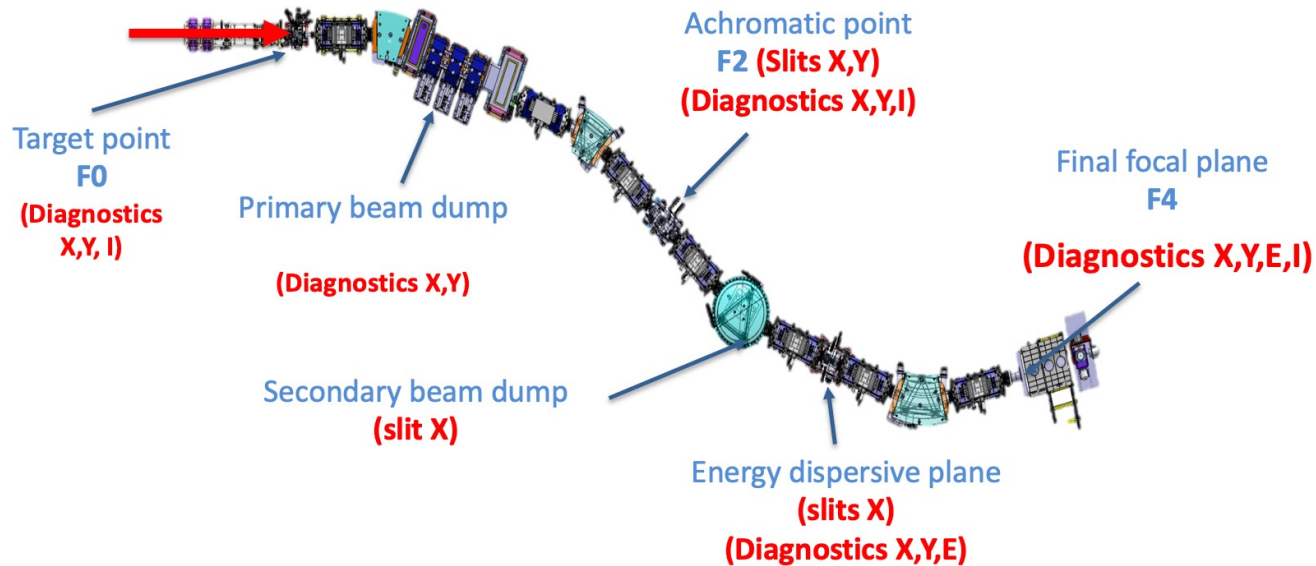
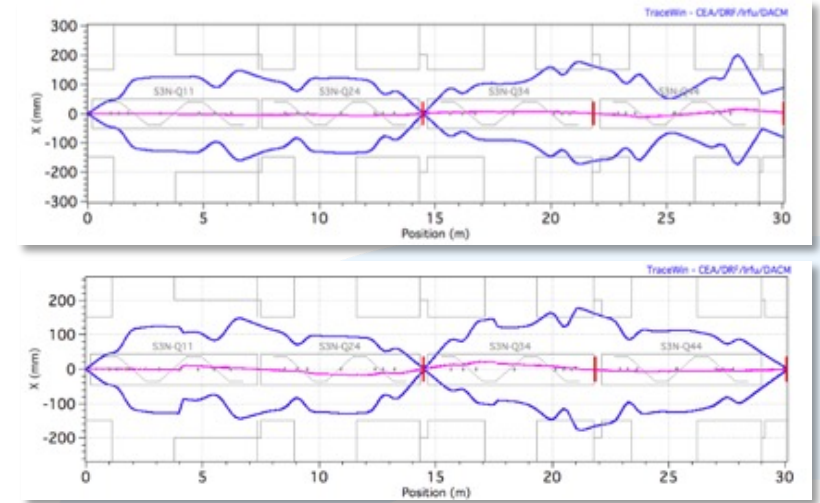




# J6x : commissioning milestones



- 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

# 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*



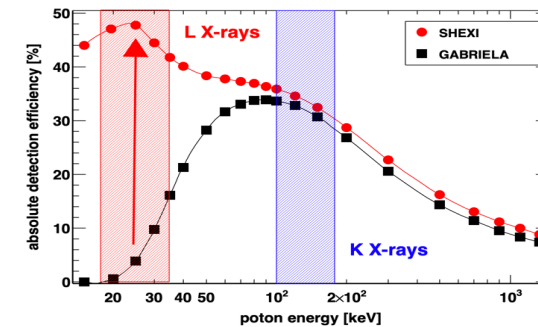
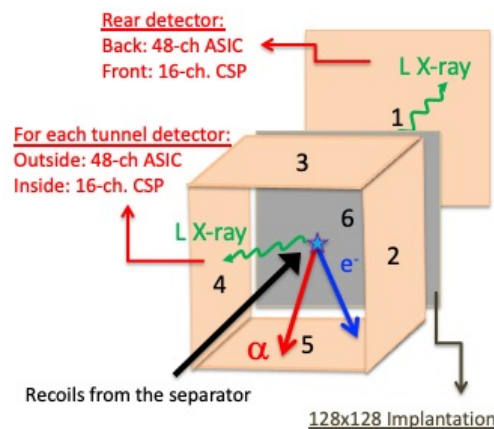
# Next steps

**D-SHEXI** : ANR accepted (PI Karl Hauschild)

Detect L X-ray inside the chamber

Z identification of SHE

Tests for detectors at IJClab

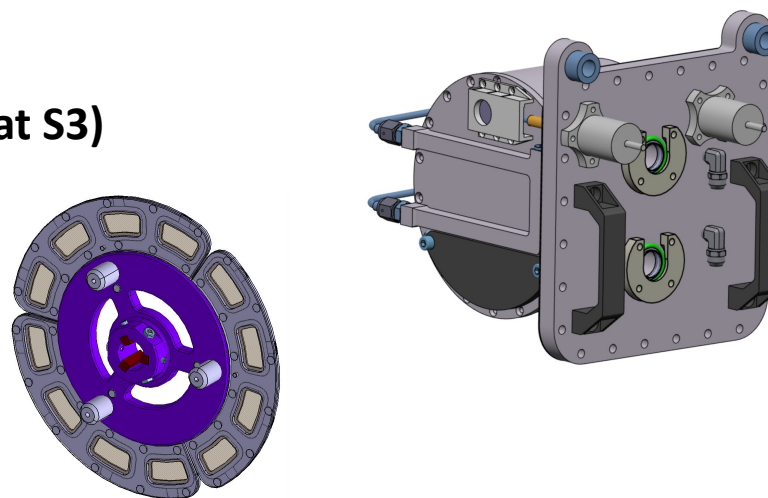


→ L-Xray detection

**TARDIS (TARget for: RaDioactive Isotopes at S3)**

Target station for actinide targets at S3

Preliminary study underway



Elément	Isotopes
Pb	210
Bi	210
Po	208, 209, 210
Ac	227
Ra	226
Pa	231
Th	228, 229, 230, 232
U	232, 233, 234, 235, 236, 238
Np	235, 236, 237
Pu	236, 238, 239, 240, 242, 244
Am	241, 242, 243
Cm	242, 243, 244, 245, 246, 247, 248, 250
Bk	247, 249
Cf	248, 249, 250, 251, 252
Es	252, 254
Fm	257