Radioactive ion beams from SPIRAL1 and future developments

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for Target Ion Sources Group
Operations and Developments Division

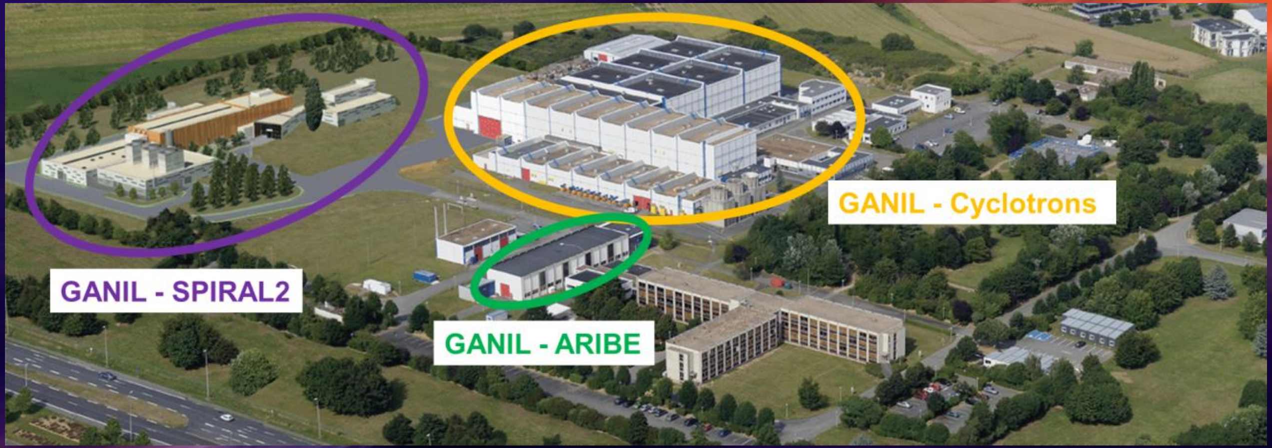
OUTLINE

GANIL facilities, Ion sources

SPIRAL 1
- Beam production
- Charge Breeding, Acceleration
- R&D on SPIRAL1

Stable Beam production
- Challenge for S^3 beams
- R&D for Newgain

Conclusions



GANIL – Cyclotron & SPIRAL1 Facilities

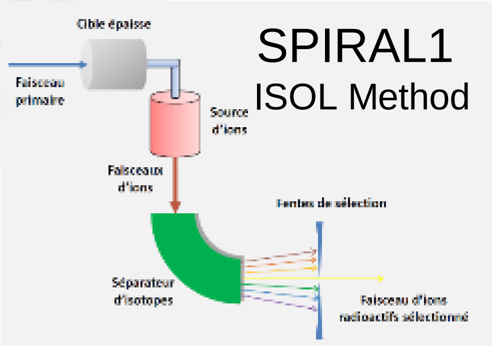
Cyclotrons (1983)

Stable beams :

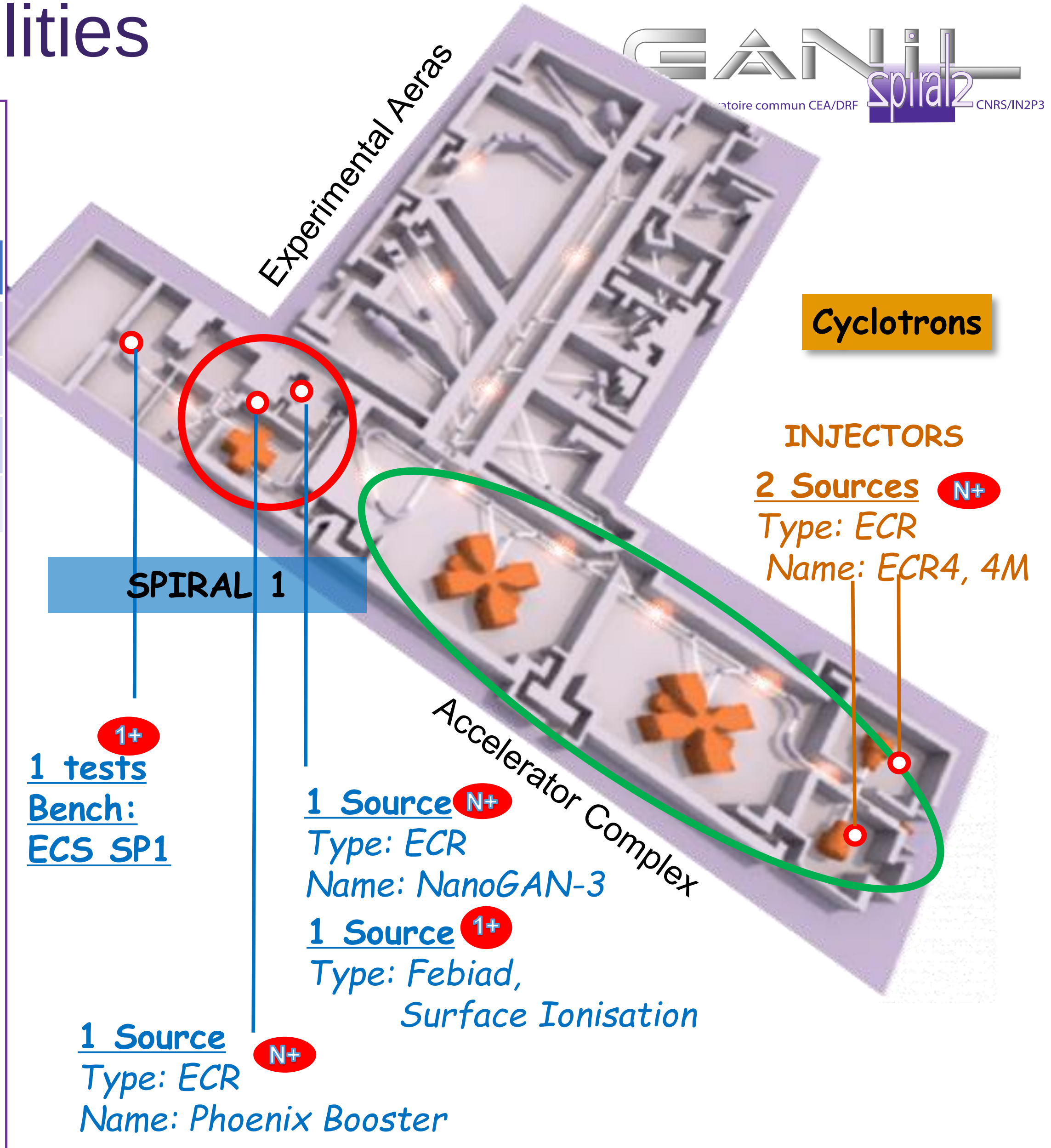
2 injectors CO (2MeV/A)
2 CSS (13MeV/A + 95 MeV/A)
α spectrometer

Heavy ion	
Ions	C - U
Intensity	< 2.10^{13}pps
Energy	3,8<E< 95MeV/A
Power	< 6kW

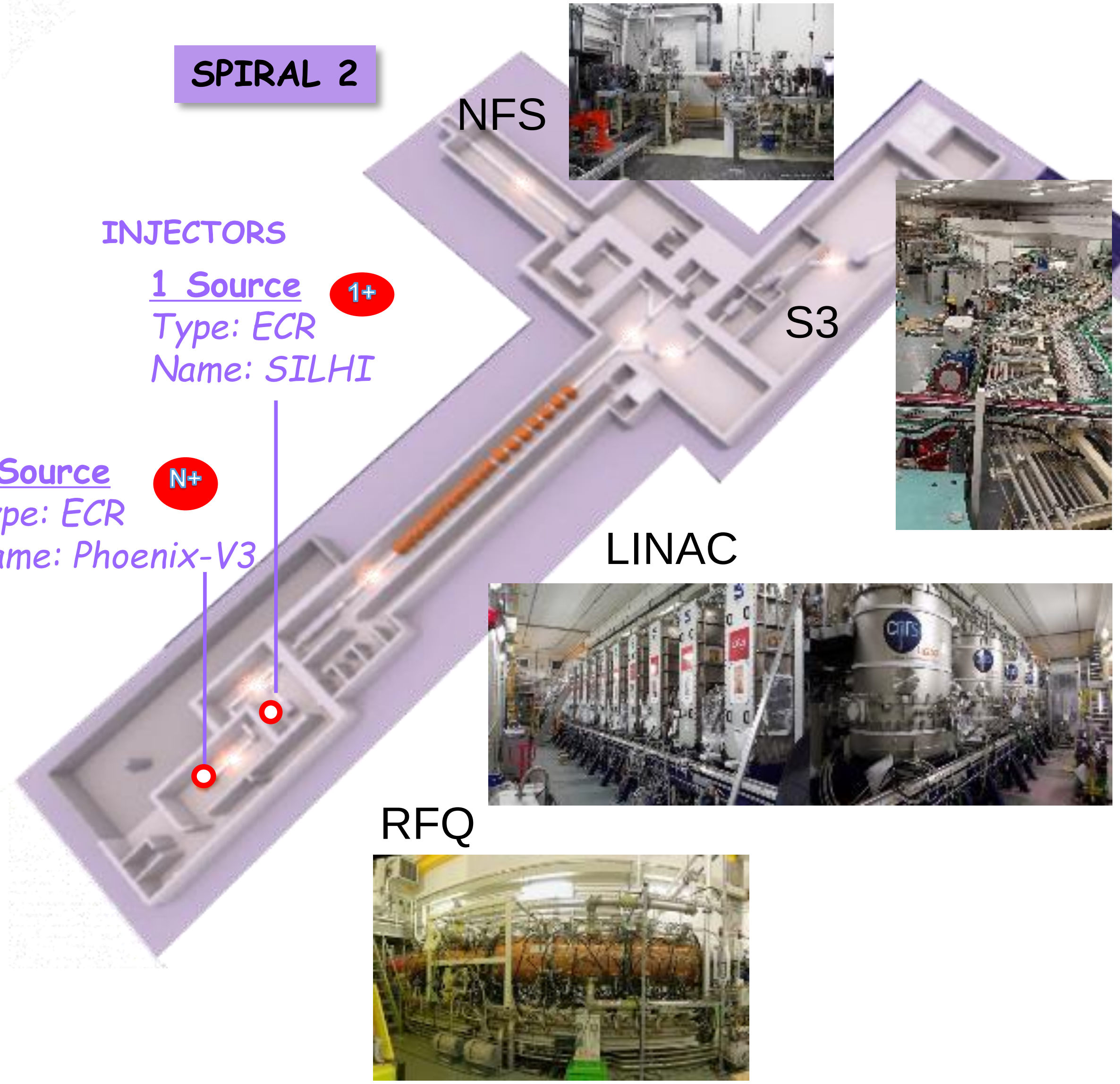
ISOL Radioactive beams :



Intensity : 10^3-10^9pps
Energy : < 20MeV/A
$T_{1/2}$ ≈ 100ms (^{8}He)



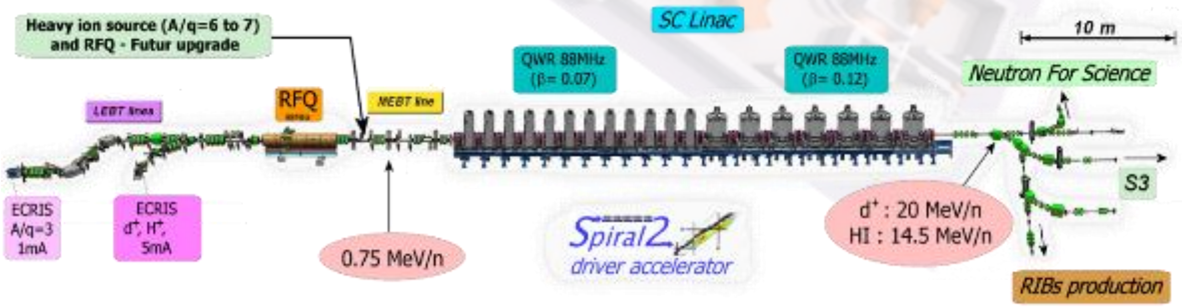
GANIL – SPIRAL2



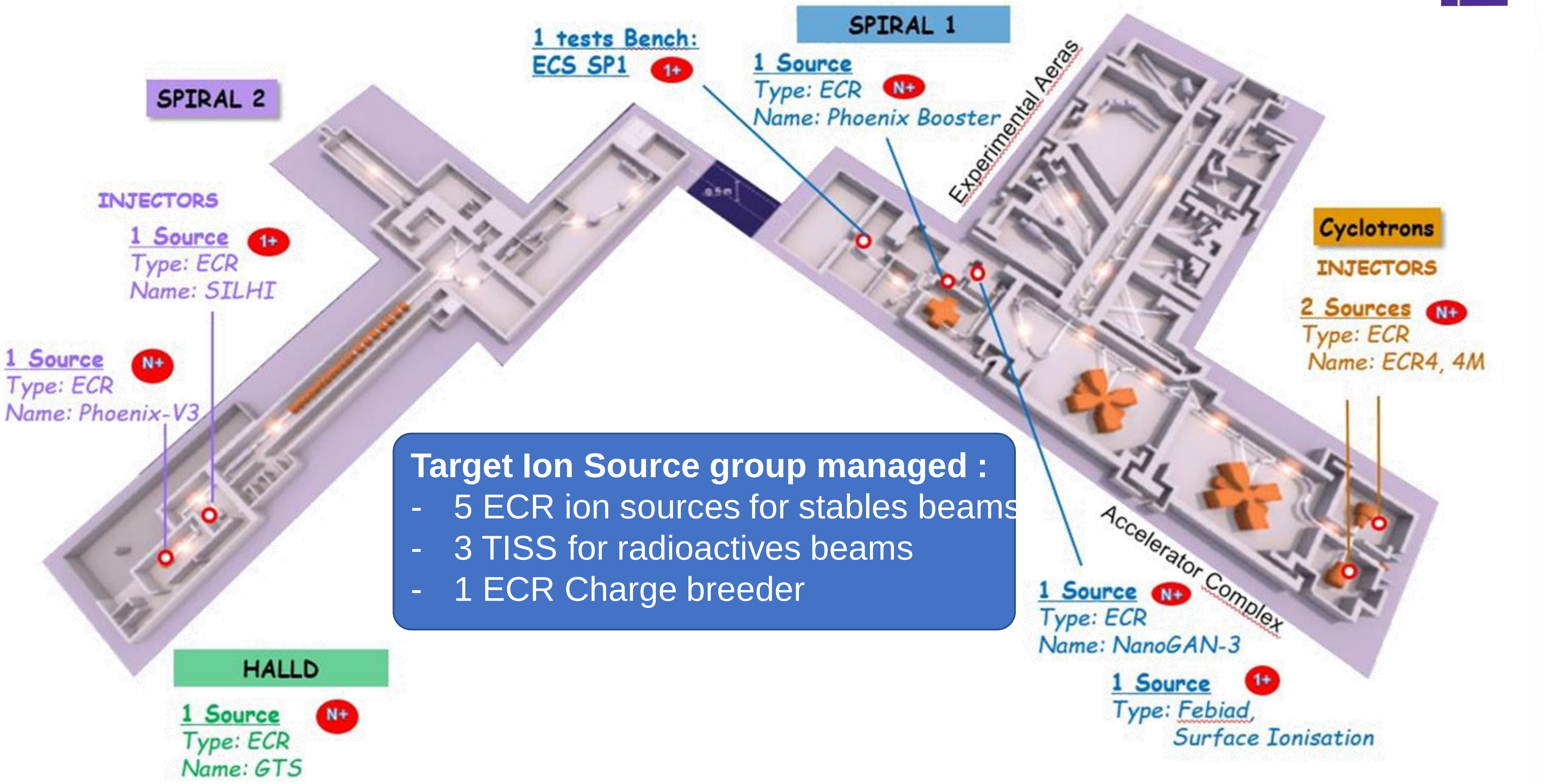
LINAC (2019)

Stable beams :

	Proton	Deuton	Heavy ion
A/Q	1	2	3
Particles	H+	D+	He - U
I max (mA)	< 5	< 5	<1
Max Energy (Mev/A)	33	20	<14.5
Max beam Power (kW)	165	200	44



GANIL-SPIRAL2 Target - Ions Sources



Target Ion Source group managed :

- 5 ECR ion sources for stables beams
- 3 TISS for radioactives beams
- 1 ECR Charge breeder

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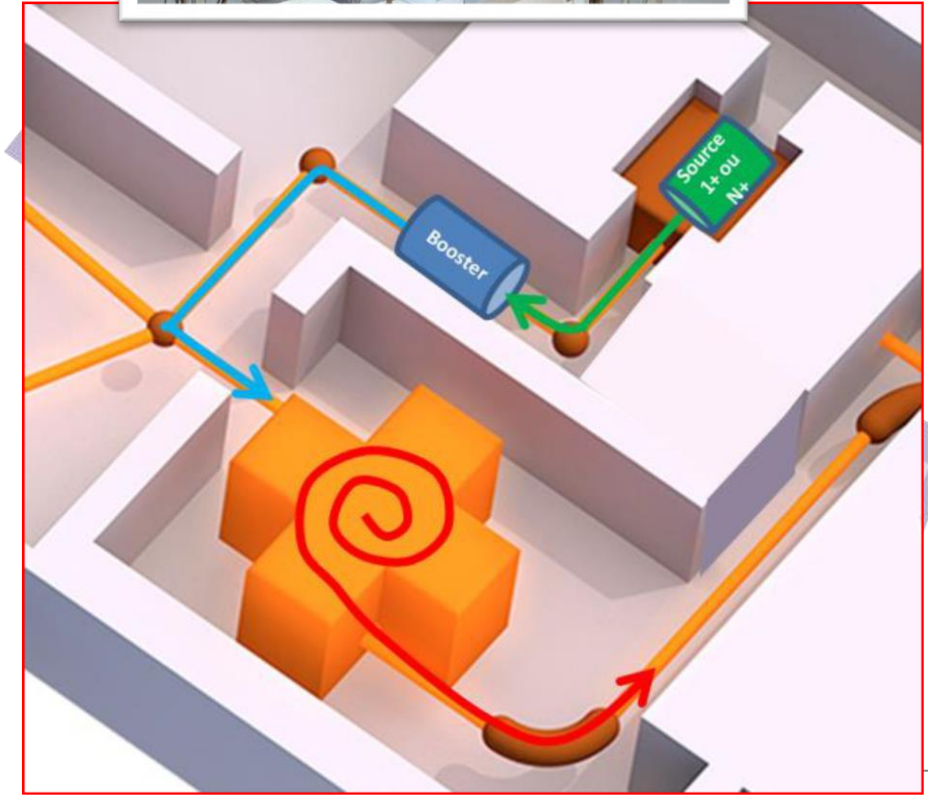
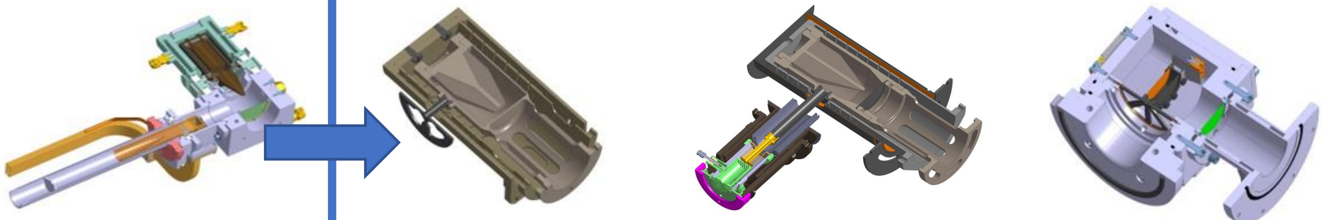
Introduction – SPIRAL1



SPIRAL1

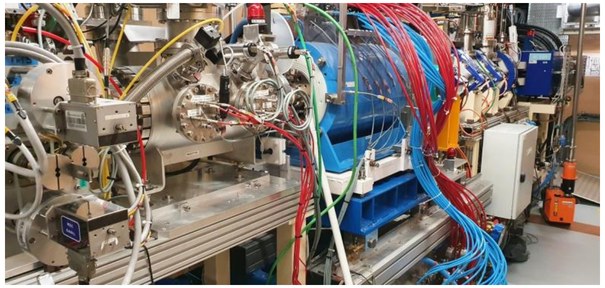
- Target Ion Source Systems

New 1+ sources since 2018



Nanogan	**MonoNaKe**	**FEBIAD**	**TULIP**
For gaz	For alkaline	For condensable	For proton rich isotopes

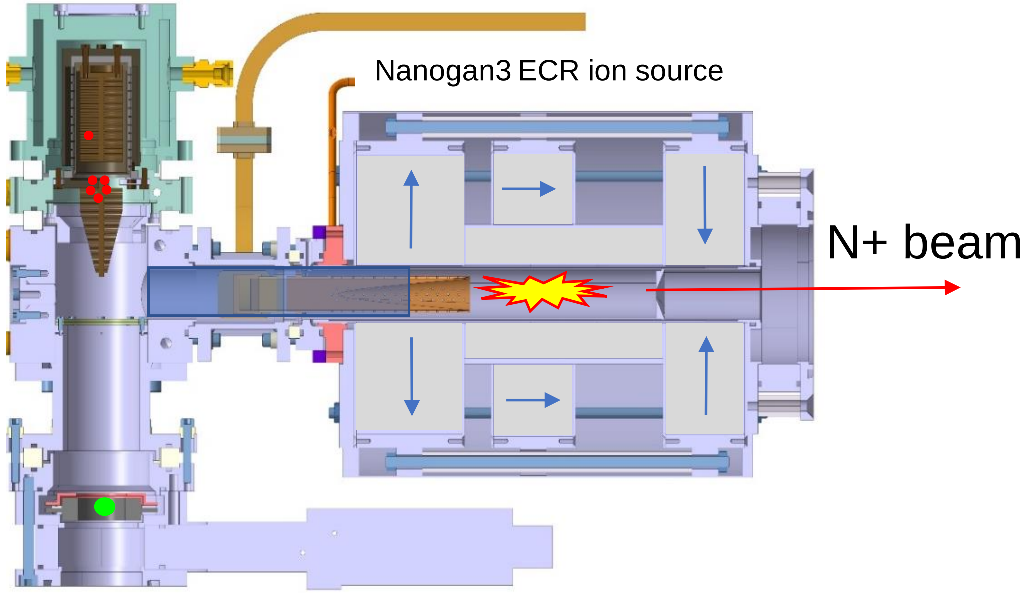
- The charge breeder

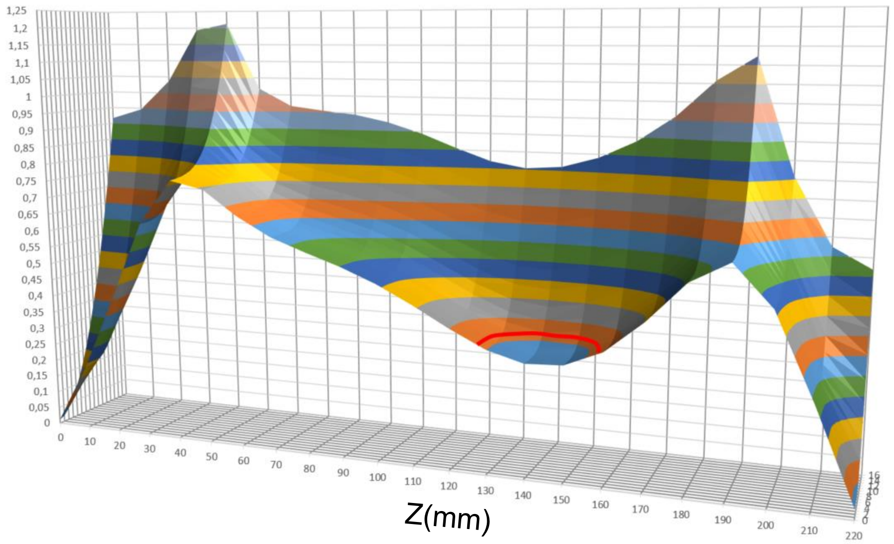


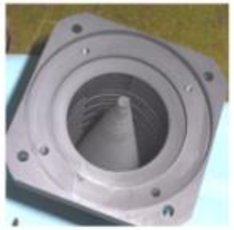
- CIME

Nanogan III

Objective: production of radioactive gaseous ions (since 2001)






4 kW

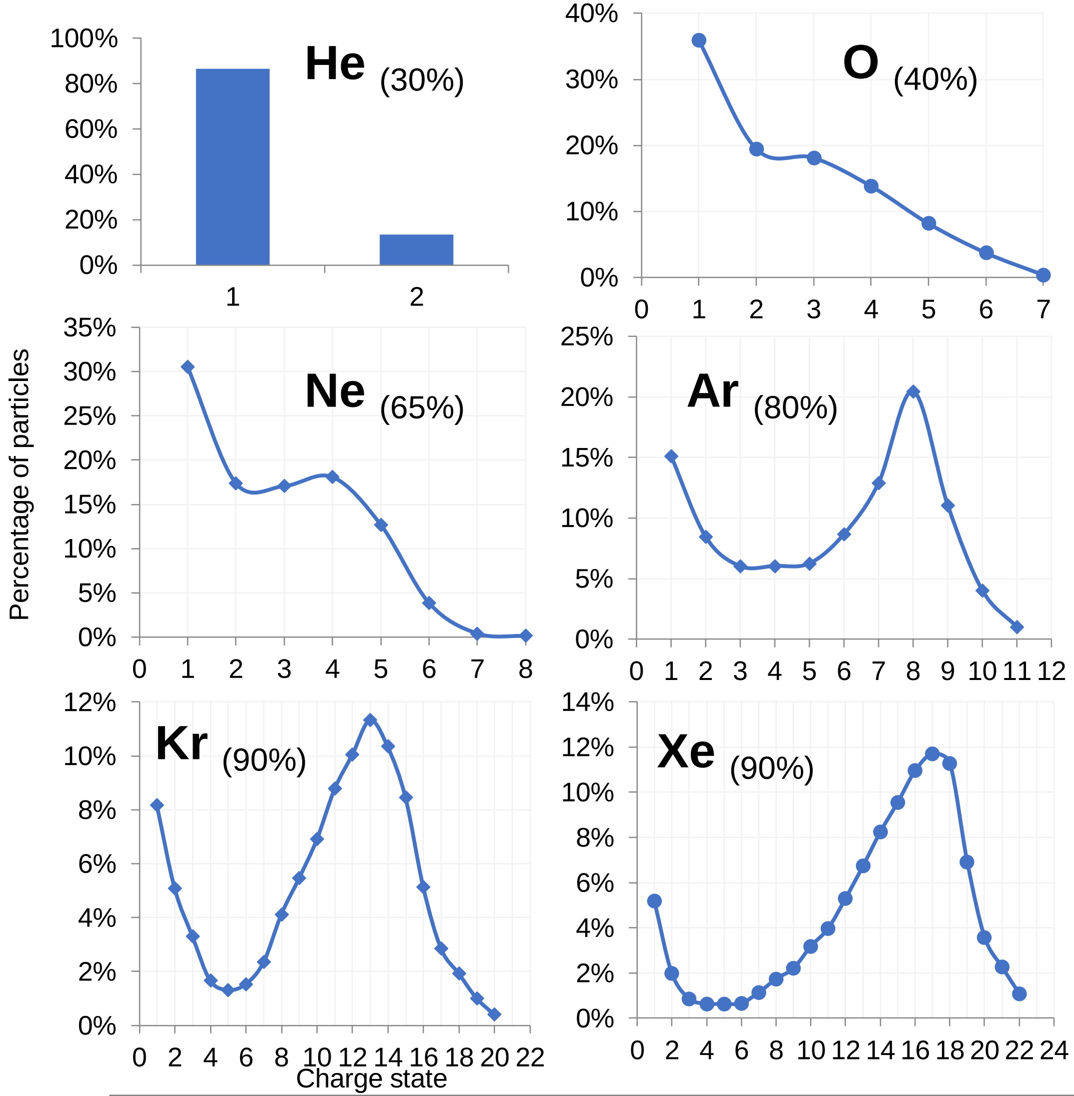

3 kW ^{12}C bear

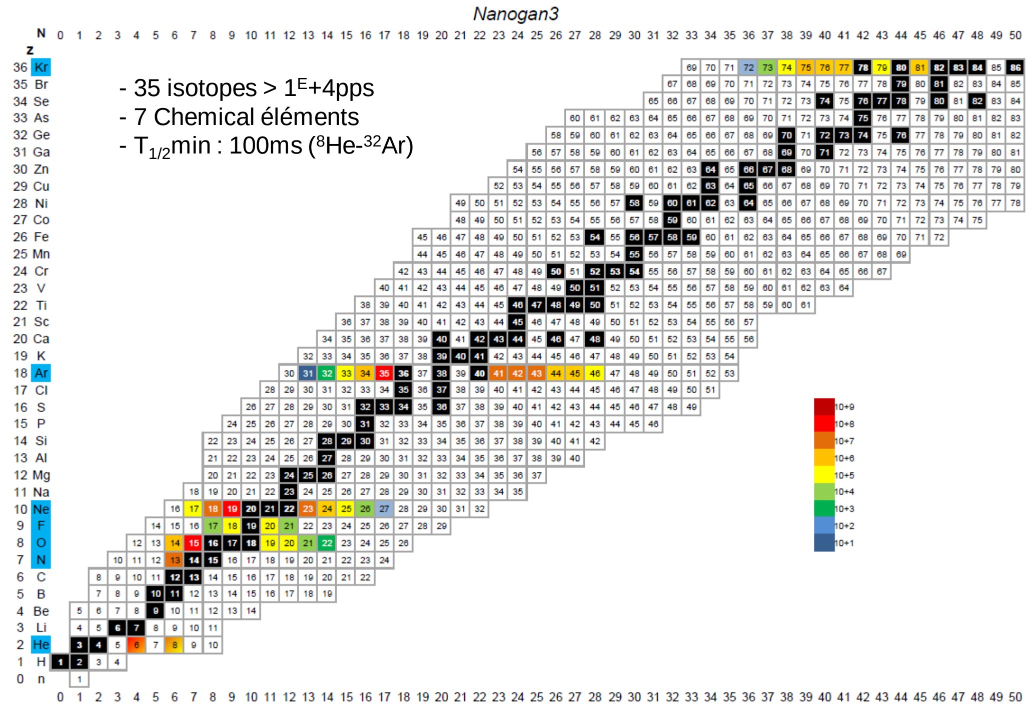
Nanogan 3 ECR ion source	
Frequency	10GHz
Power	<250W
Type	Direct injection
HV plateform	34kV
Magnetic fields	NdFeB

advantage	inconvenient
Reliability	High emittance
Stable	Cost
Efficient	

Nanogan III

Objective: production of radioactive gaseous ions

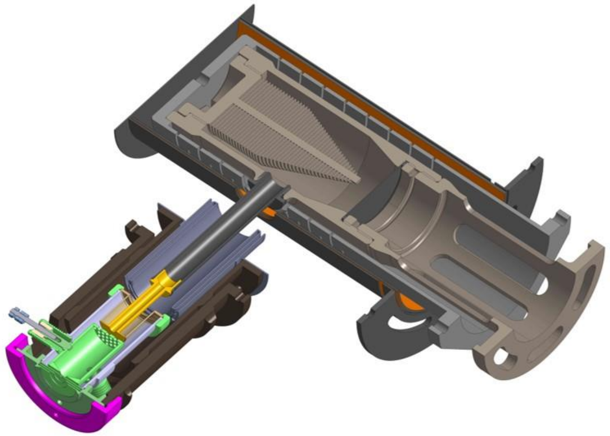




- 87 tests/experiments with radioactive beams since 2001
- Beams of $^{(6,8)}$He, $^{(14,15,19\text{-}21)}$O, $^{(17,18,20,21)}$F, $^{(17\text{-}19,23\text{-}27)}$Ne, $^{(31\text{-}35,41,43\text{-}46)}$Ar, $^{(72\text{-}77,79,81m)}$Kr.
- No R&D

FEBIAD (slide credit P. Chauveau)

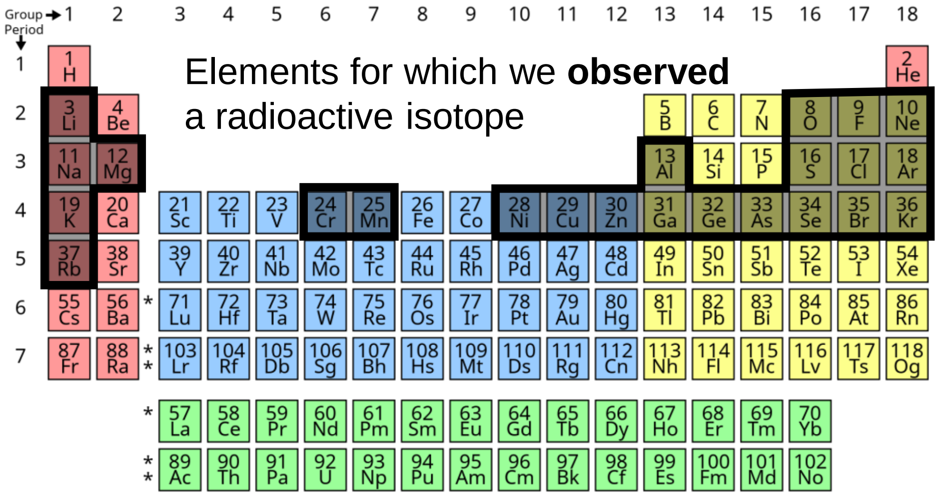
Objective: production of radioactive metallic ions (2018)



- 11 tests/experiments with radioactive beams
- FEBIAD TISSes have received ^{36}Ar (2013,2019,2022), ^{20}Ne (2018), ^{40}Ca (2018,2019), ^{48}Ca (2021), ^{84}Kr (2022) and ^{50}Cr (2023)
- **2 post accelerated beams : ^{38m}K (2019), ^{47}K (2021)**
- 90+ radioactive isotopes/isomers **seen**, including around 60 at post-accelerable intensities (>1E5pps).

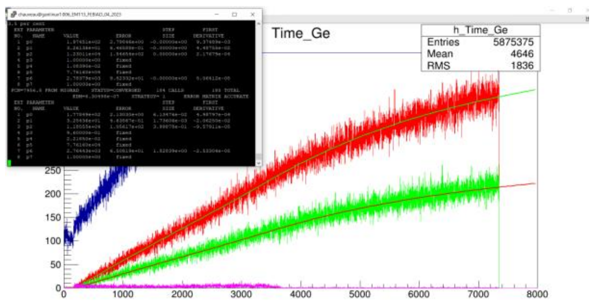
Features

- Efficient: routinely ≈ 20% on Ar
- Resilient : a 15 days endurance test showed no loss in performance
- Repeatable: comparable results and source behavior between 2 TISS



Latest test (^{50}Cr beam)

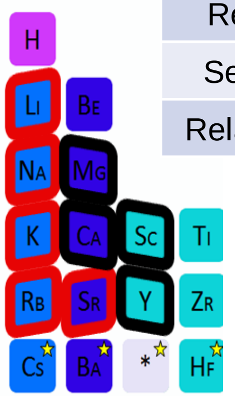
^{48}Cr rate ok (1.2E4pps/W) but very slow release (46min) at low beam power (30W)



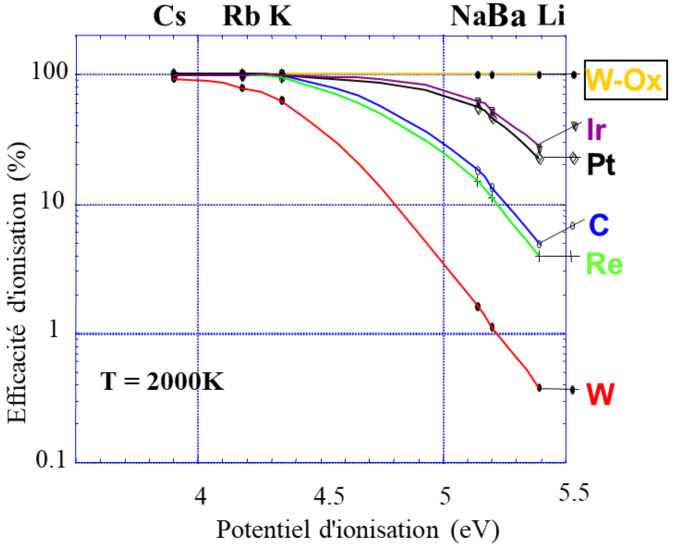
advantage	inconvenient
Resilient	Release time
Many isotopes	Purity

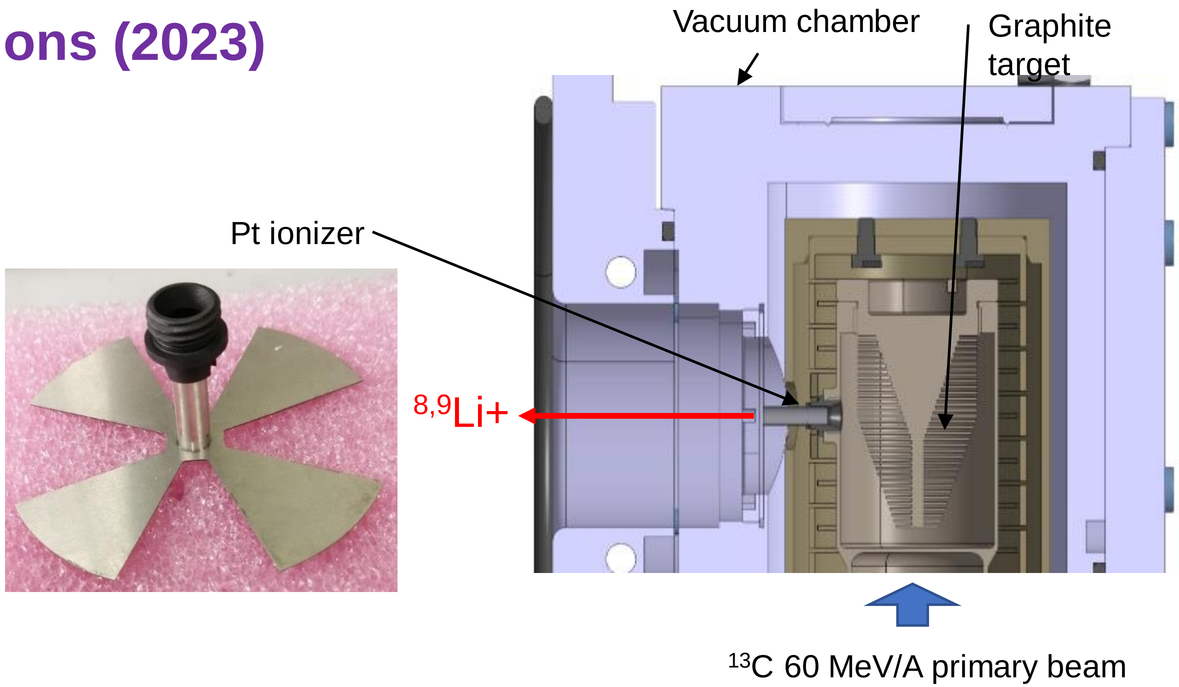
MonoNaKe (slide credit P. Jardin)

Objective: production of radioactive alkali ions (2023)



advantage
Resilient
Selective
Relase time





First on-line test with a Pt ionizer :

$^{8}Li^{+}$ rate = 2,2.10^{4} pps (or AIT efficiency~10^{-5} for 830 W of primary beam), to be compared to AIT efficiency of 0,05 obtained in 2007 with a carbon ionizer.

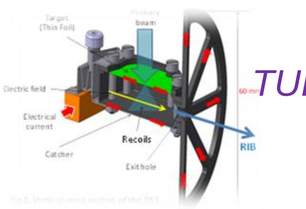
Two points to analyse :

- *Transport in the beam line (results obtained in 20 minutes after the first ion was observed)*
- *Condensation of Li? at the exit of the tube observed during the off-line test*

=> Pt and C ionizer will be compared during an off-line test planned in February and March 2024.

=> On-line test before production in April 2024

Université de Caen Basse-Normandie



AAPG ANR 2018

CES 31: Physique Subatomique ***(PRC)***

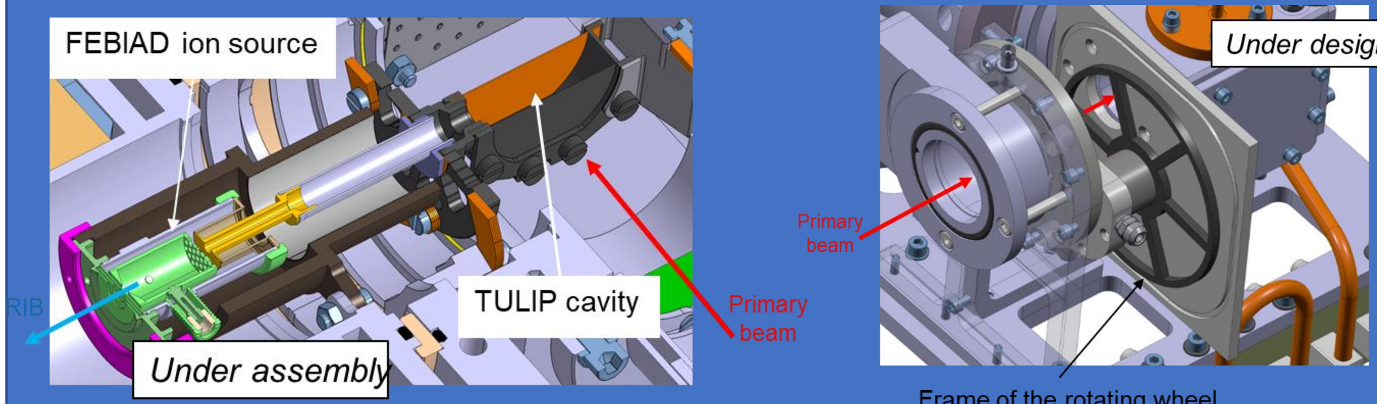
(P. Jardin, M. MacCormick and the TULIP collaborators)

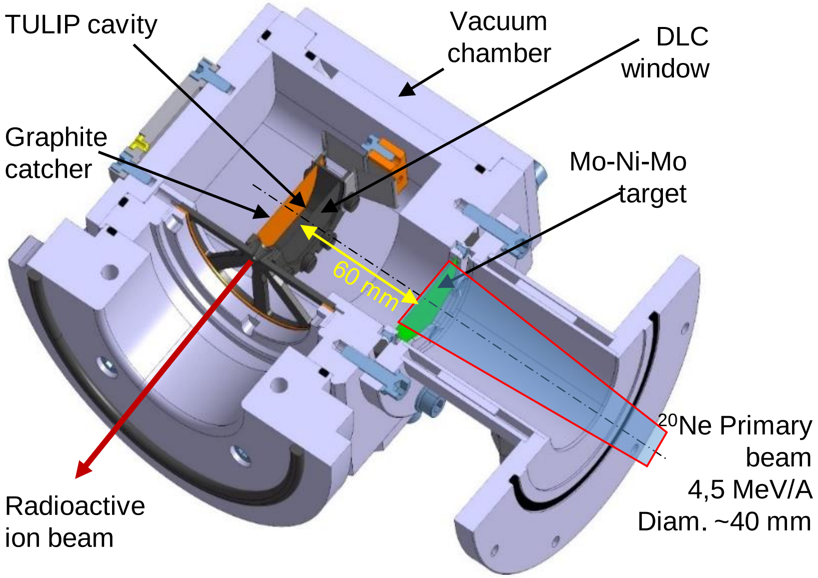
laboratoire commun CEA/DRF CNRS/IN2P3

Objective of the TULIP project

- Production of short-lived neutron-deficient isotopes.
- Production by fusion evaporation
- Two main steps
  - ✓ Proof of principle with $^{74-78}Rb^{+}$ in 2023
  - ✓ Extension to metallic isotopes

Next step



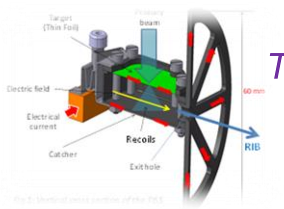


Full carbon cavity (wall in graphite, catcher in Papyex (>125 µm), window in Diamond Like Carbon (2 µm)

- So far used on-line at 1200-1300°C.
- Primary beam power : ~100W
- Irradiation time : 3 days.

=> TISS still operating

- $^{74}Rb^{+}$ production lower than expected. Under analysis



TULIP

AAPG ANR 2018

*CES 31: Physique Subatomique **(PRC)***

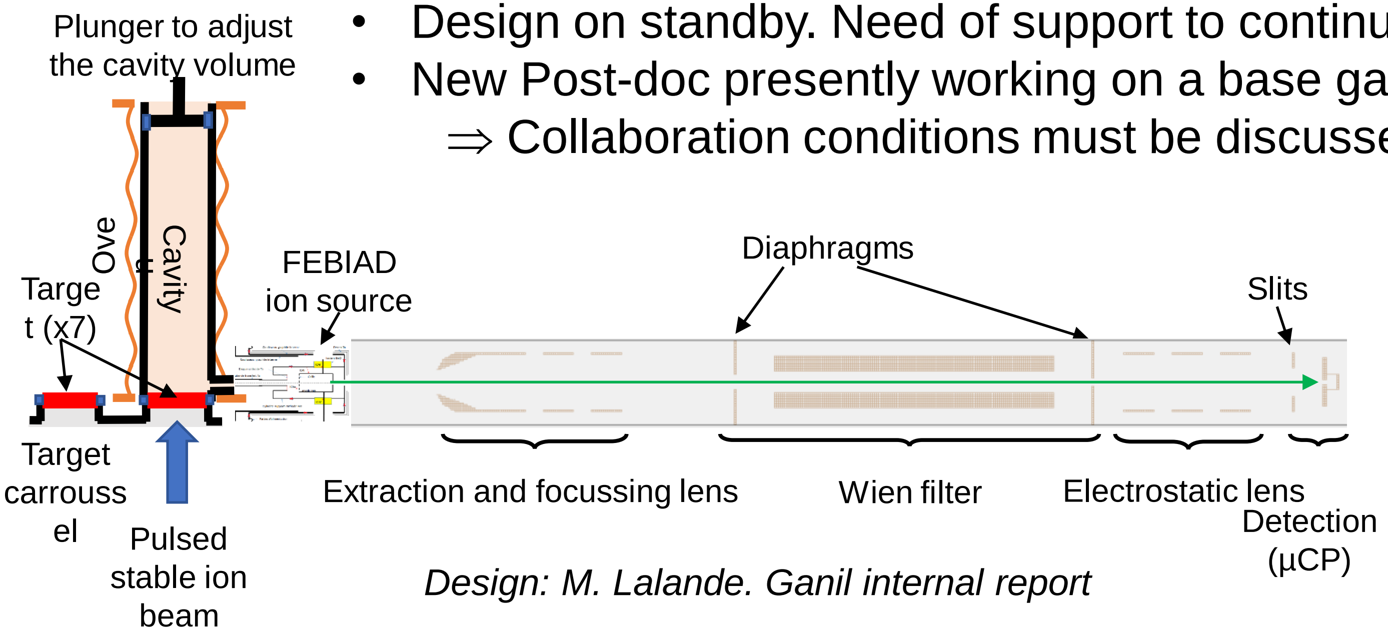
(P. Jardin, M. MacCormick and the TULIP collaborators)

MELODICA *(MEsure en Ligne de cOefficients de Diffusion et de temps de Collage Atomique)*

- Objective : to measure the diffusion coefficients of atoms out of different target of catcher materials in a “standardized” way (same experimental conditions) to make them easily comparable.
  - Use of stable ion beams at “low” energy (< Coulomb energy) to minimize nuclear safety constraints
  - Use of a pulsed beam to directly extract the diffusion coefficient from the release time measurement

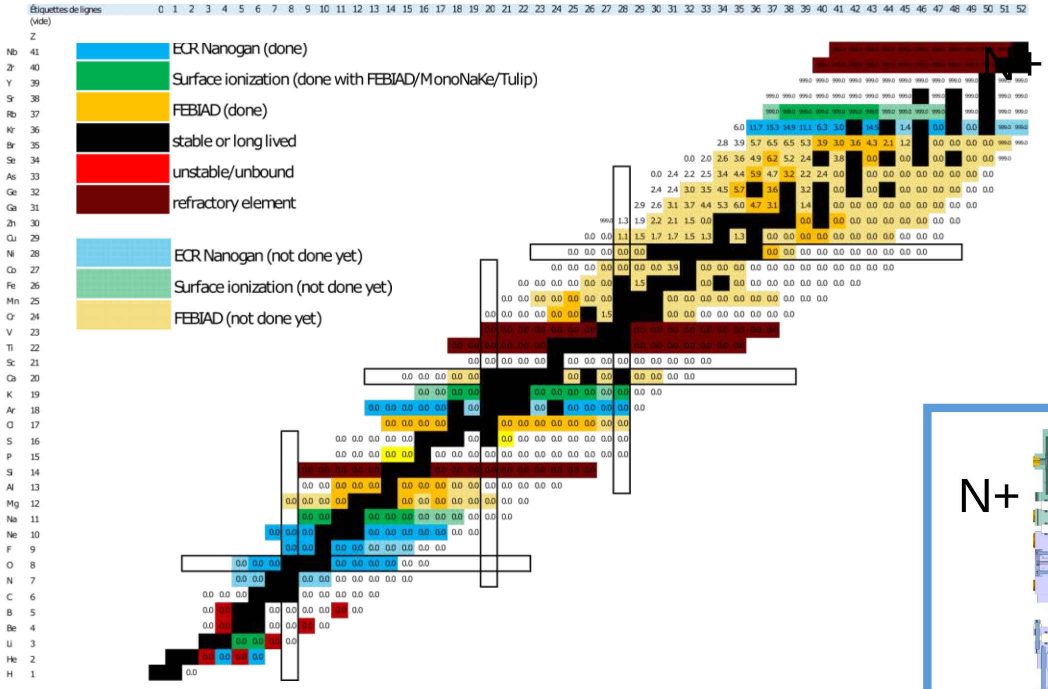
- Design on standby. Need of support to continue
- New Post-doc presently working on a base gathering diffusion coefficient data

  ⇒ Collaboration conditions must be discussed.

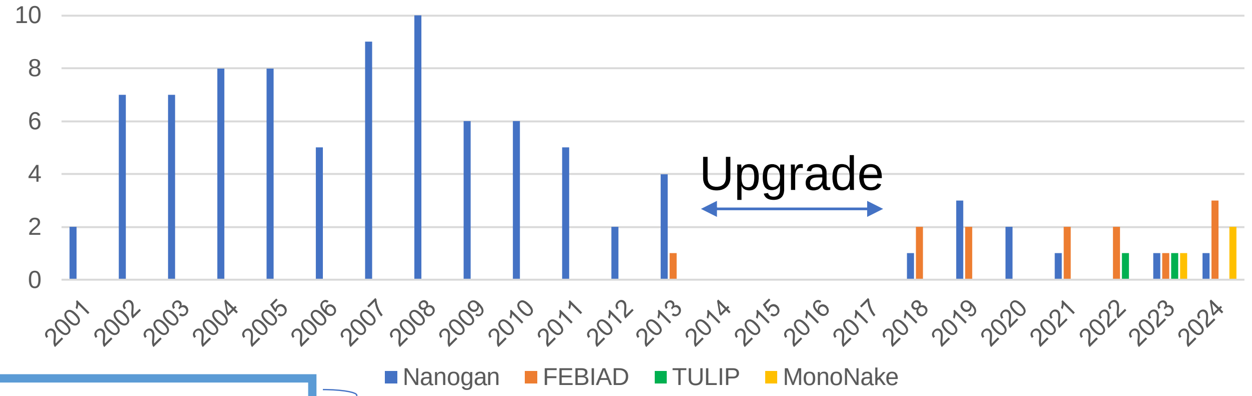


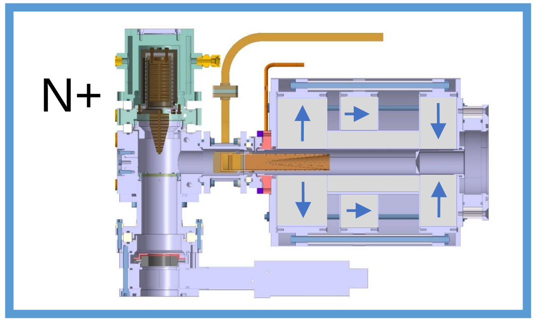
Design: M. Lalande. Ganil internal report

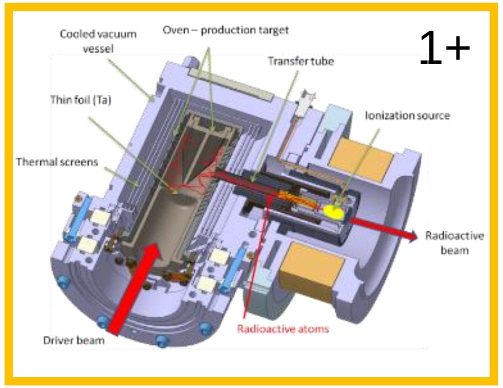
Beam production (status)

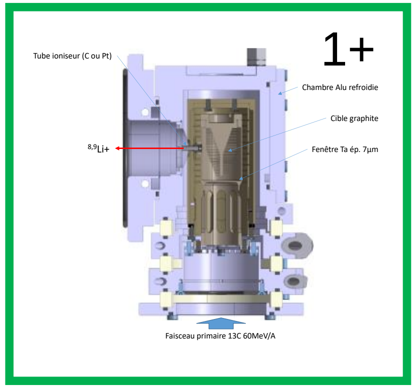


Experiences/Tests radioactifs at SPIRAL









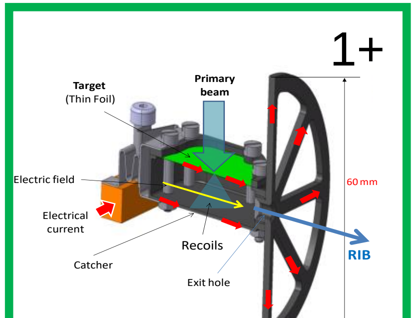
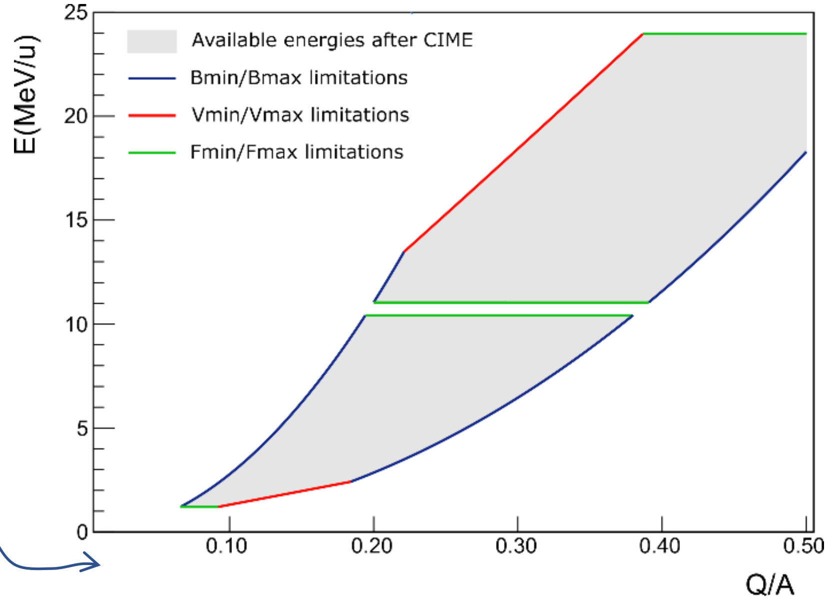
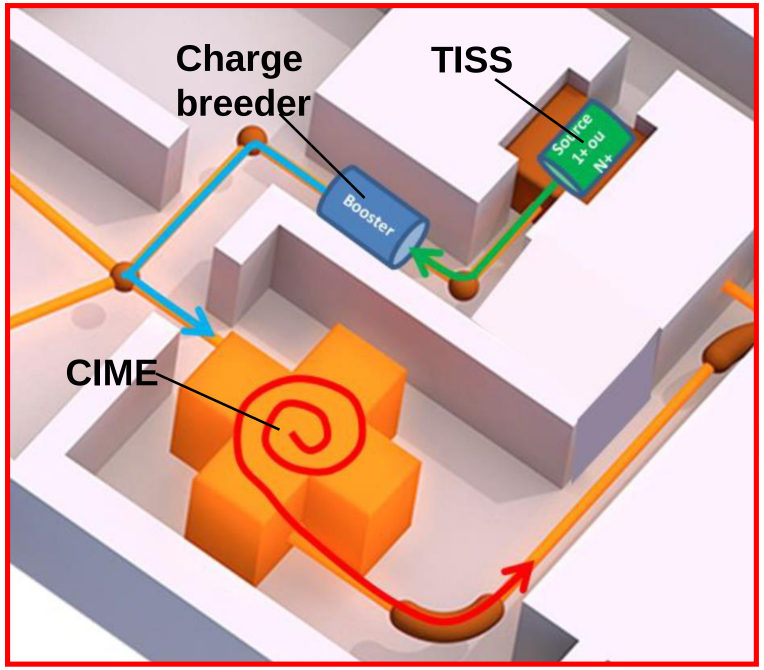
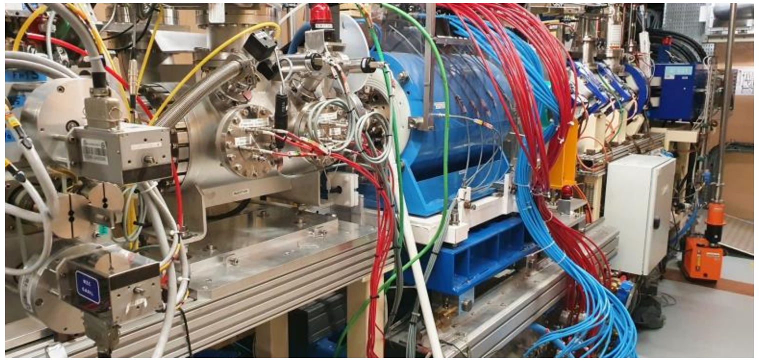


Fig 1: Vertical cross section of the TISS

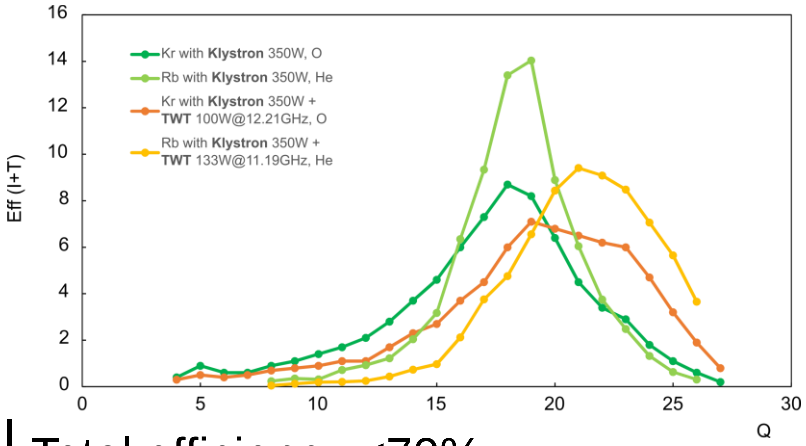


Charge breeding status

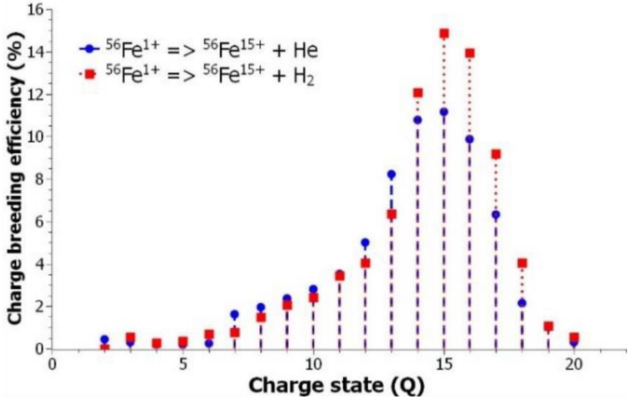




Gaz & Alkali ions

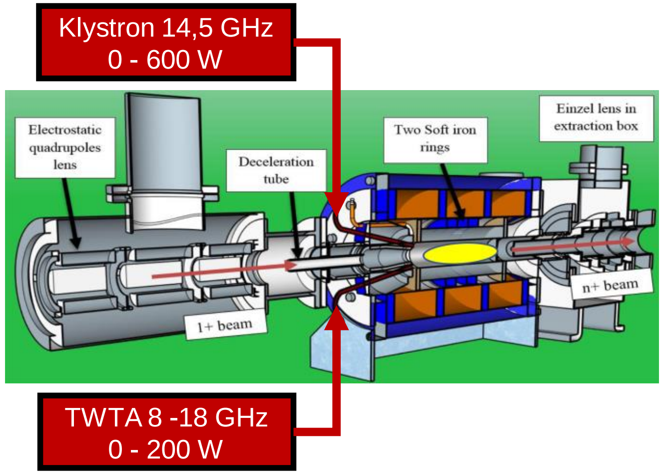


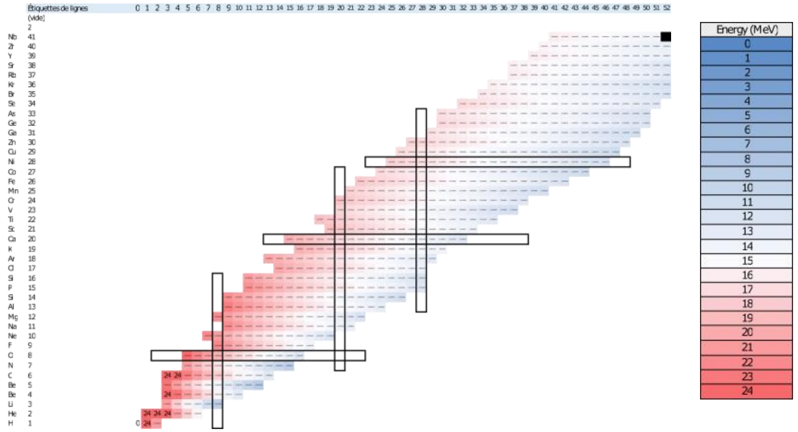
Metallic ions



L. Maunoury et al, Journal of Physics: Conference Series 2244 (2022) 012066

Total efficiency <70%
Charge state efficiency 5-20% depending on Z





OUTLINE

GANIL facilities, Ion sources

SPIRAL 1 :

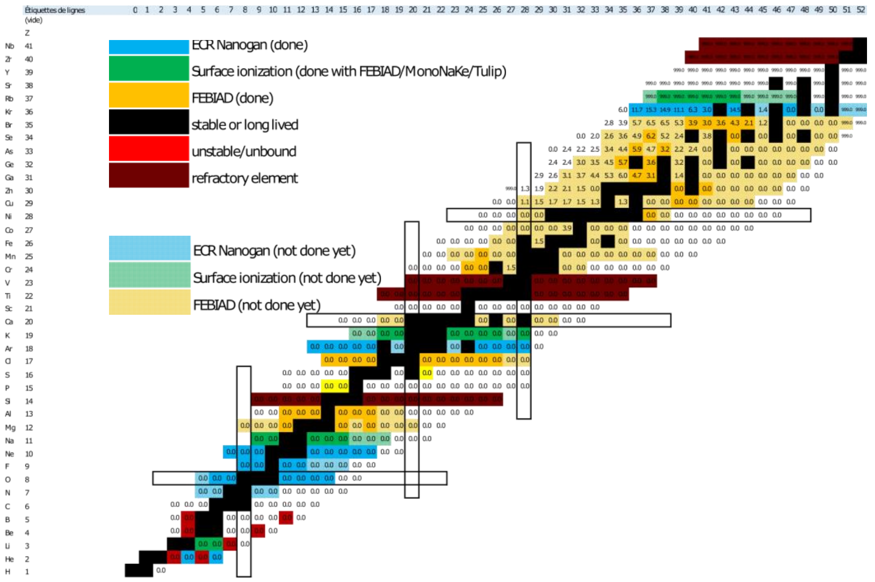
- Beam production
- Charge Breeding , Acceleration
- R&D on SPIRAL1

Stable Beam production

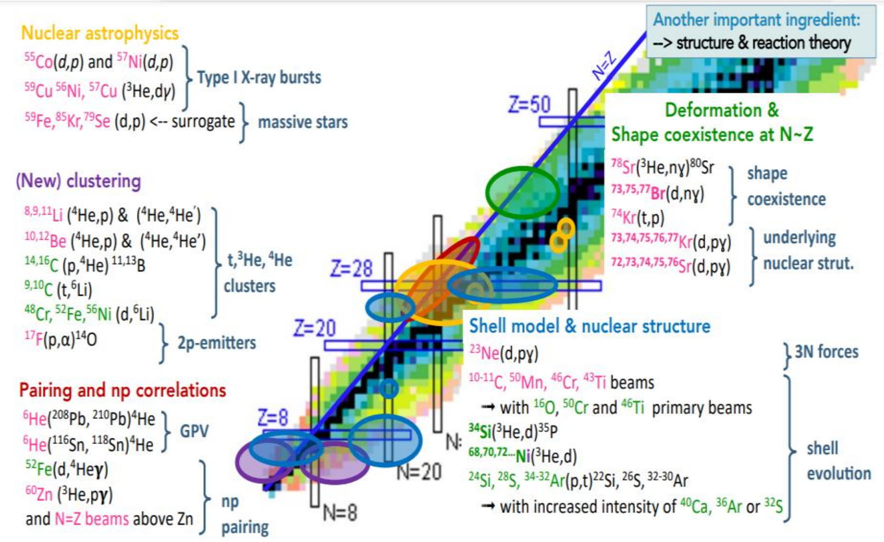
- Technical aspects
- Challenge for S3 beams
- R&D for Newgain

Conclusions

R&D on SPIRAL1



Beams measured and potentially available at SPIRAL1



Physic cases with accelerated radioactives ions beams
M. Assié : Workshop Target Ion Source, Sept. 2023

Logic of beams development:

- Accepted proposal/Endorsed LoI ➡ Specific beam development
- Probing the community (LoI WS 2016 / WS 2023 / discussions with physicists / <u>what we know we can do</u>) ➡ Broadband beam development

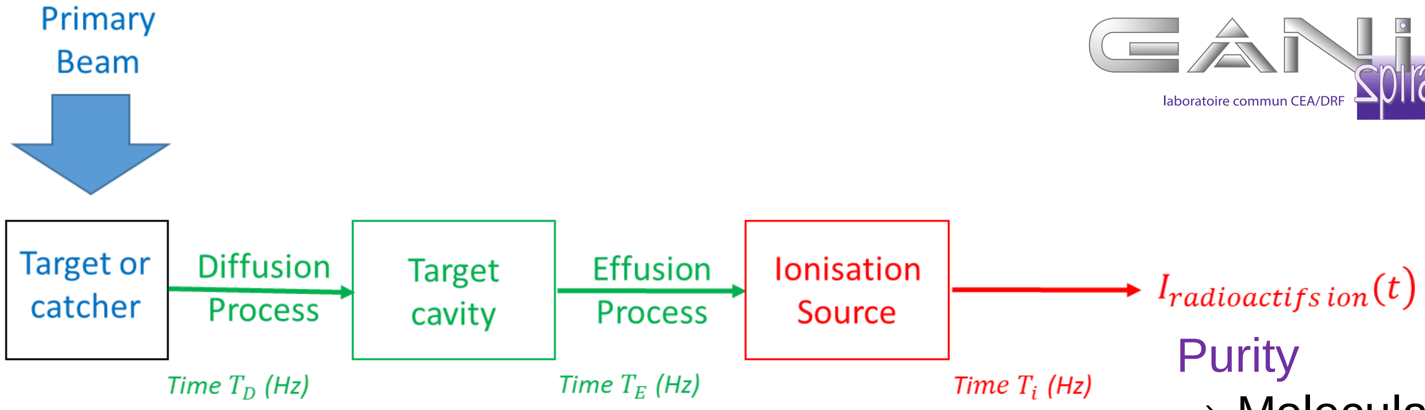
- Access to primary beam limitation : Should we work on Batch Mode Ion Source ?

R&D on SPIRAL1

Limits and improvements

- Primary beam power
- Fragmentation cross-section

$\Rightarrow$ ^{12}C on new target(s)



Purity

$\Rightarrow$ Molecular extraction

Diffusion/effusion time
(refractory materials/short half-lives)

$\Rightarrow$ Target heating,

$\Rightarrow$ TULIP,

$\Rightarrow$ Molecular extraction

Ionization efficiency

$\Rightarrow$ MonoNaKe-Pt,

$\Rightarrow$ FEBIAD heating

Technical developments	Objectives
New Target + 12C beam	Increase in target intensities (postdoc position)
MonoNaKe-Pt	$^{8/9}Li$ beam experiment
FEBIAD	Fe-Co-Ni Beams (hot target)
Molecular Beam with FEBIAD	Ca beam, selectivity
TULIP + FEBIAD	Metallic shot lived isotopes

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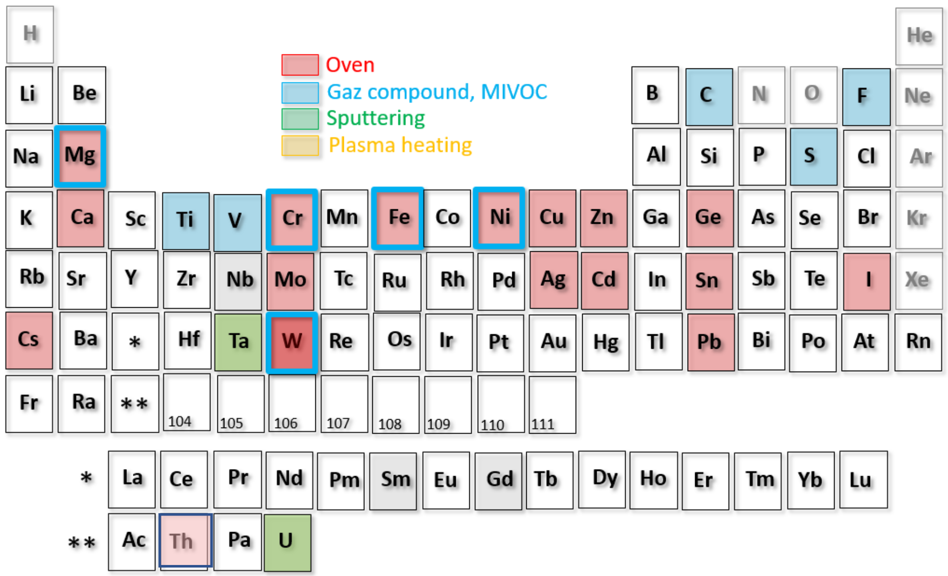
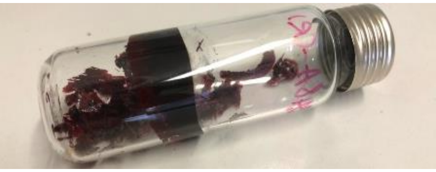
Stable beam production @ GANIL cyclotrons



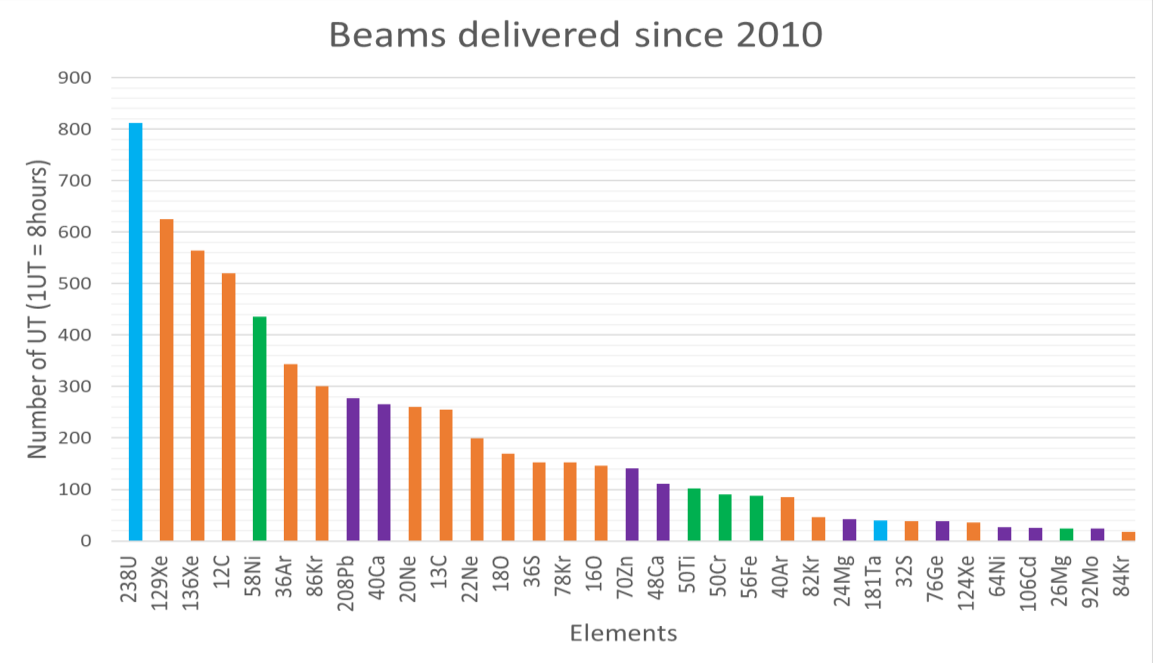
Techniques used for atome injection


Gaz


MIVOC


Oven

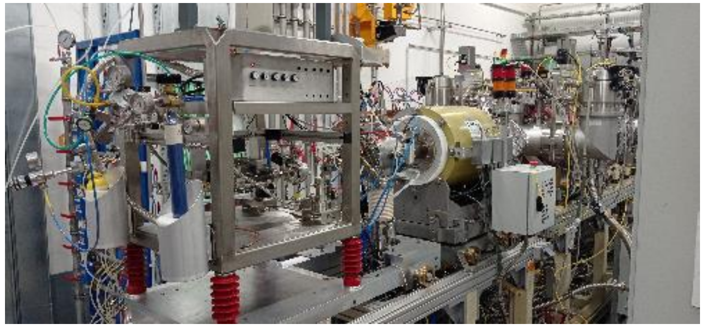

Sputtering



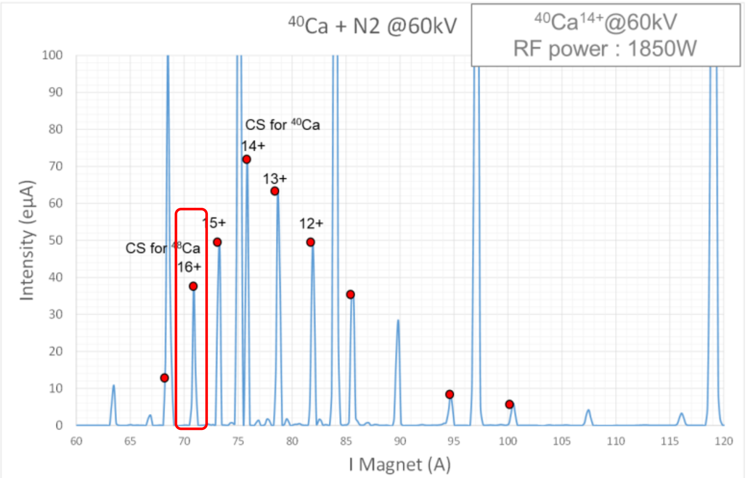
Long experience in the production of metallic beams
⇒ Sharing technical knowledge to improve beams at GANIL and FRIB

S^3 primary beams challenge

A/Q < 3 injectors : high charge state



Phoenix V3 ECR	A/Q<3
High Voltage extraction	60kV
RF (18GHz)	2kW
Plasma Volume	1.4l

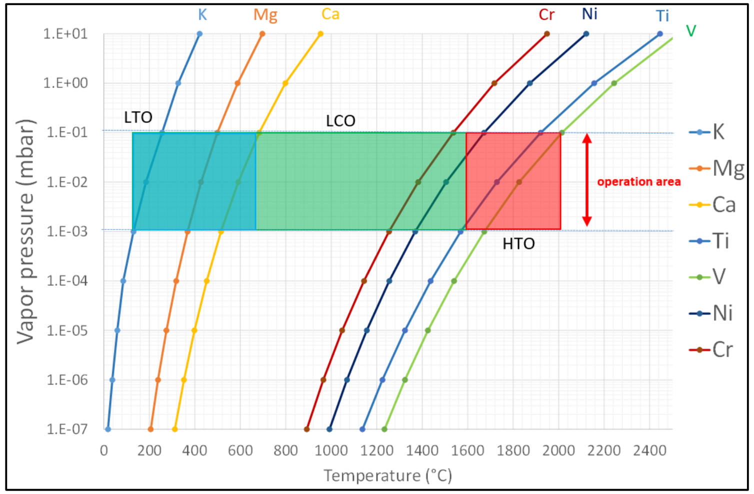


All parameters at limits (Magnetic field, HV, RF power)

- Control impurities into ion source
  - Isotope very pure

Sample expensive (1g : ^{70}Zn: 22k€, ^{64}Ni: 49k€) or not available ^{48}Ca

⇒ **Development of chemical preparation & recycling techniques**



  - Oven technique

High Temperature Oven

Inductive

Resistive

Under development

Large Capacity Oven

Low Temperature Oven

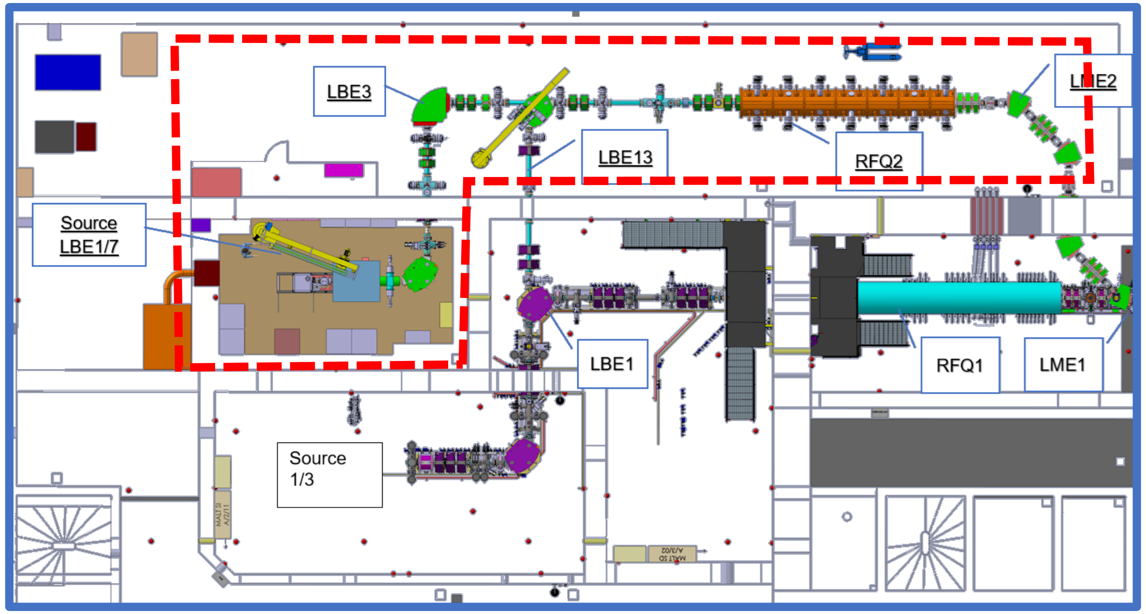
SPIRAL2 : NEWGAIN

NEW GANIL INJECTOR

Project to design and build a second injector at SPIRAL2 with A/Q=7

Budget obtained by ANR/France in 2021

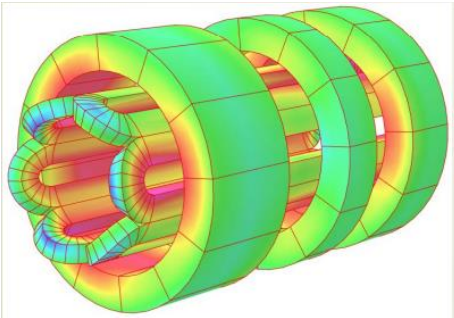
Planning : 2023-2030



Element	A/q	Operational Beam Current (μA)	Particle Current (pμA)	1 σ RMS normalized (π.mm.mrad)
$^{48}Ca^{11+}$	4.36	150	15	0.25
$^{238}U^{34+}$	7	170	5	0.10

Beams of reference for ions source and plateform design

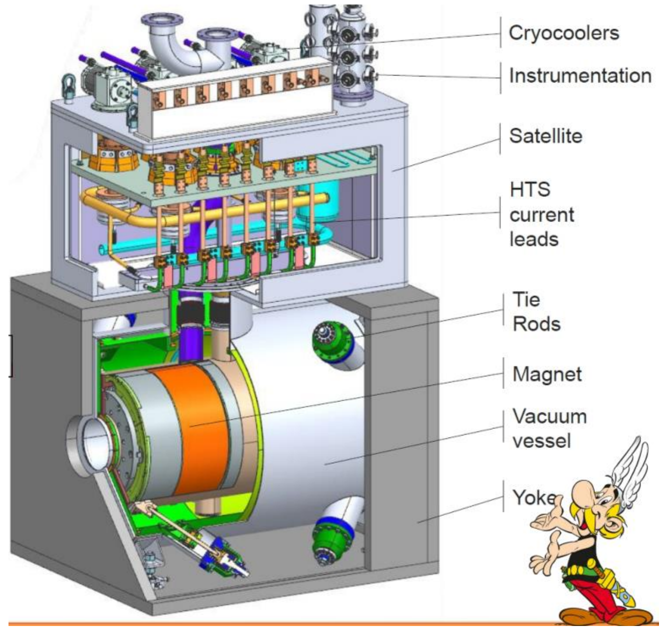
- 28 GHz + 18GHz ion source on a HV platform ~70 kV
  - **Design study under progress**
  - Project team : LPSC, CEA/DACM, GANIL, LPC



SPIRAL2 : NEWGAIN

NEW GANIL INJECTOR

GANIL spiral2 laboratoire commun CEA/DRF CNRS/IN2P3

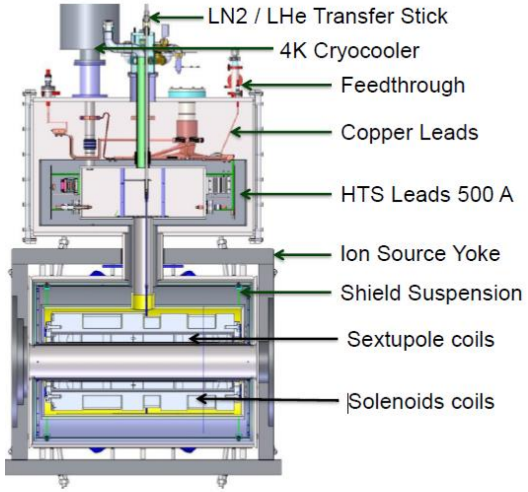


ASTERICS : A new superconducting ECRIS for SPIRAL2
T. Thuillier (LPSC) et al, ICIS23, Vancouver

Development of SC-ECRIS

T. Thuillier, LPSC

- RF Equipments :
  - DC Breakers
  - Mode converter
  - Pressure windows
- Techniques to maintains and align ion source sub-systems
- 28GHz Plasma Chamber designs

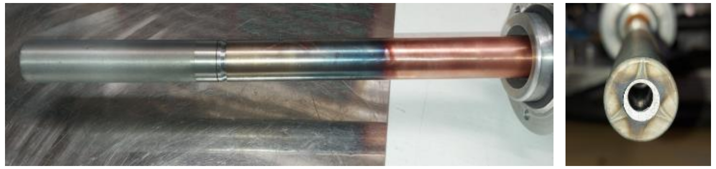


FRIB SC-ECRIS

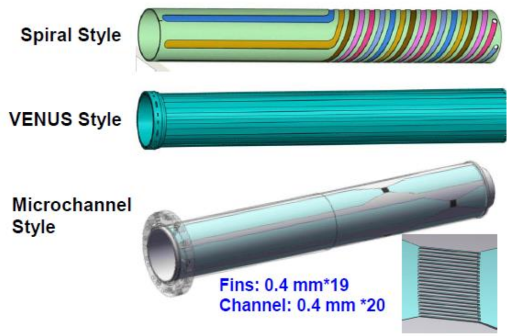
Operation with SC-ECRIS and metallic beams

Share feedback on SC-ECRIS

- Metallic oven designs : resistive, inductive
- Metal sputtering for SC-ECRIS
- Cryogenic operation
- Safety procedure and parameters to control
- Limits in operation : ion source parameters, tuning



High temperature oven GANIL On-line in ECR4M
First beam of ^{238}U



Superconducting Ions Sources @ FRIB
G. Machicoane, Workshop Target Ions Source, 2023, Caen

SUMMARY

GANIL facilities, Ion sources

SPIRAL 1

- Beam production
- Charge Breeding , Acceleration
- R&D on SPIRAL1

Stable Beam production

- Challenge for S3 beams
- R&D for Newgain

Conclusions

Conclusions

Stable beams

Technique around ion beam production with ECR

- High Temperature oven for RT and SC-ECRIS
- Recycling technique for rare isotope
- Stability detectors for operation (OES, X-rays detectors)
- Metallic beams techniques

Share feedback on SC-ECRIS- Joint R&D

- R&D on specific device like plasma chamber, RF,
- Operation with SC-ECRIS and it specificities

ISOL Technique

Share informations about ISOL TISS

- Thin or thick Target/Cavity
- Ion sources (ECR, FEBIAD, IS)
- Purity
- Batch Mode Ion Source ?

Collaboration on Diffusion coefficient data base

- Share data between FRIB and GANIL to construct database
- Participation on construction of specific device to measure diffusion coefficient.

Thank you for your attention !