SPIRAL1 beams for DESIR status and development

Pierre Chauveau

Outline

Introduction : SPIRAL1

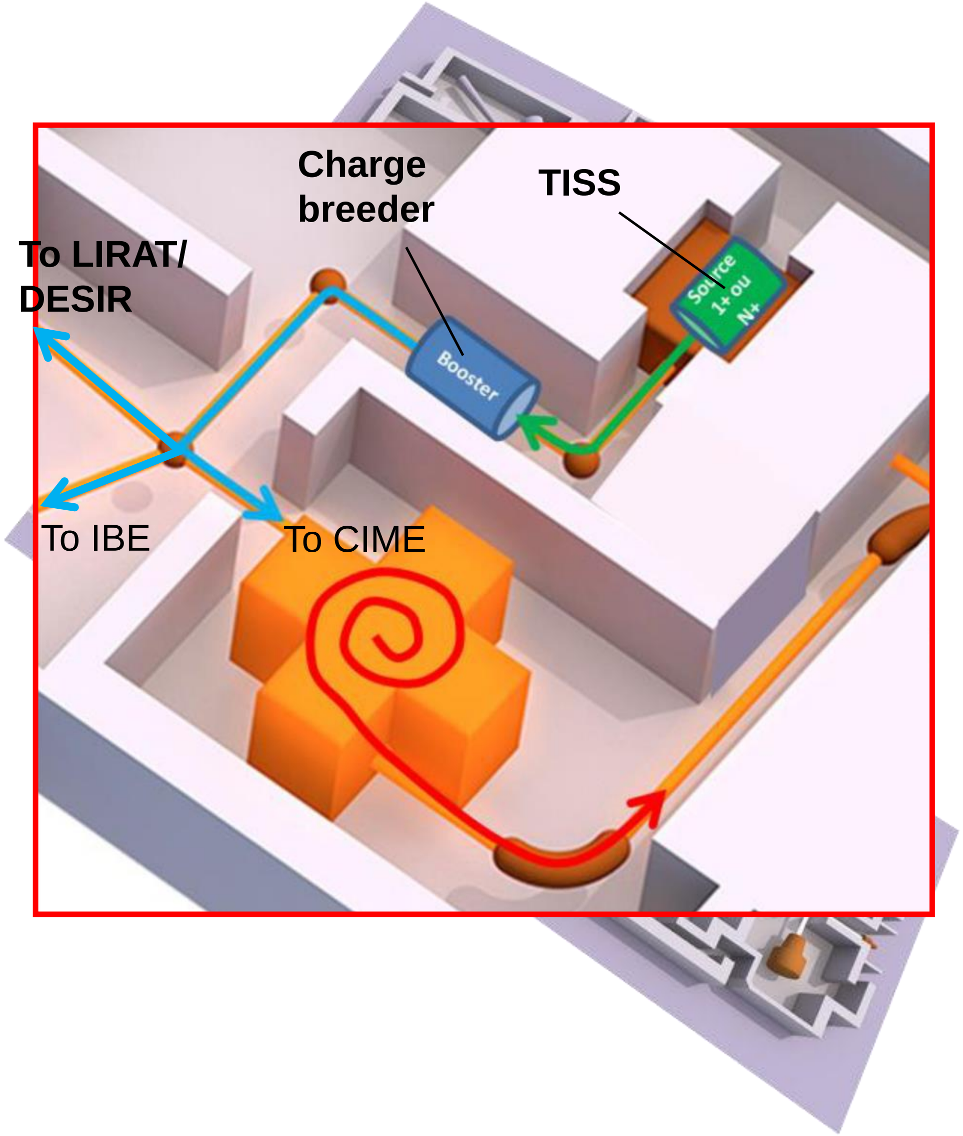
I. Beam production : sources

II. Beam purity

III. Batch mode

Conclusion

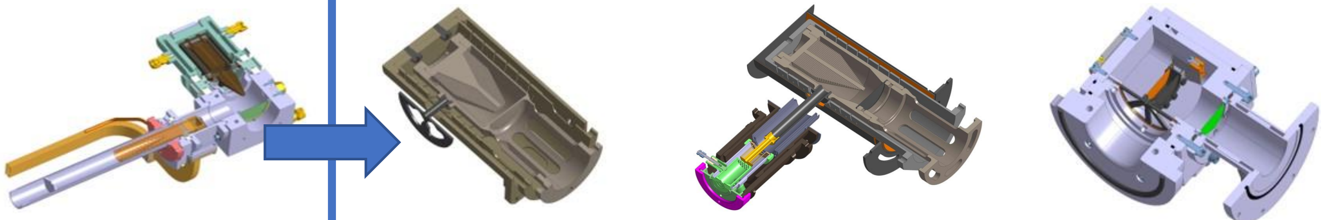
Introduction - SPIRAL



SPIRAL1

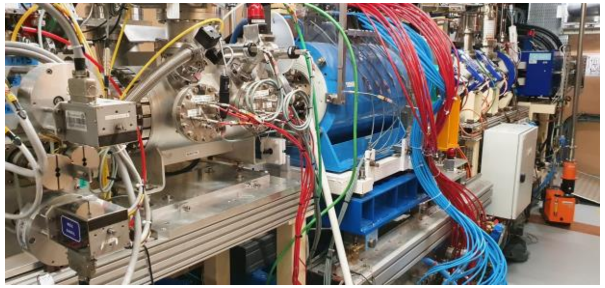
- New target Ion Source Systems (FEBIAD)

New 1+ sources



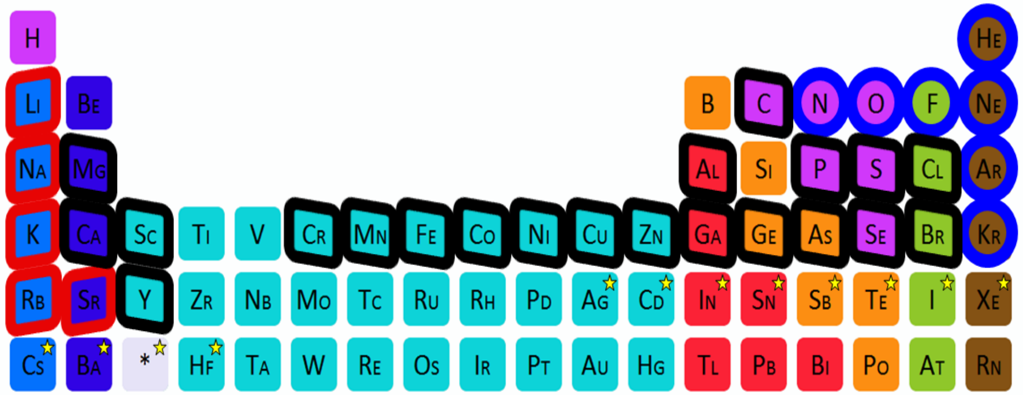
Nanogan	**MonoNaKe**	**FEBIAD**	**TULIP**
For gaz	For alkaline	For condensable	For proton rich isotopes

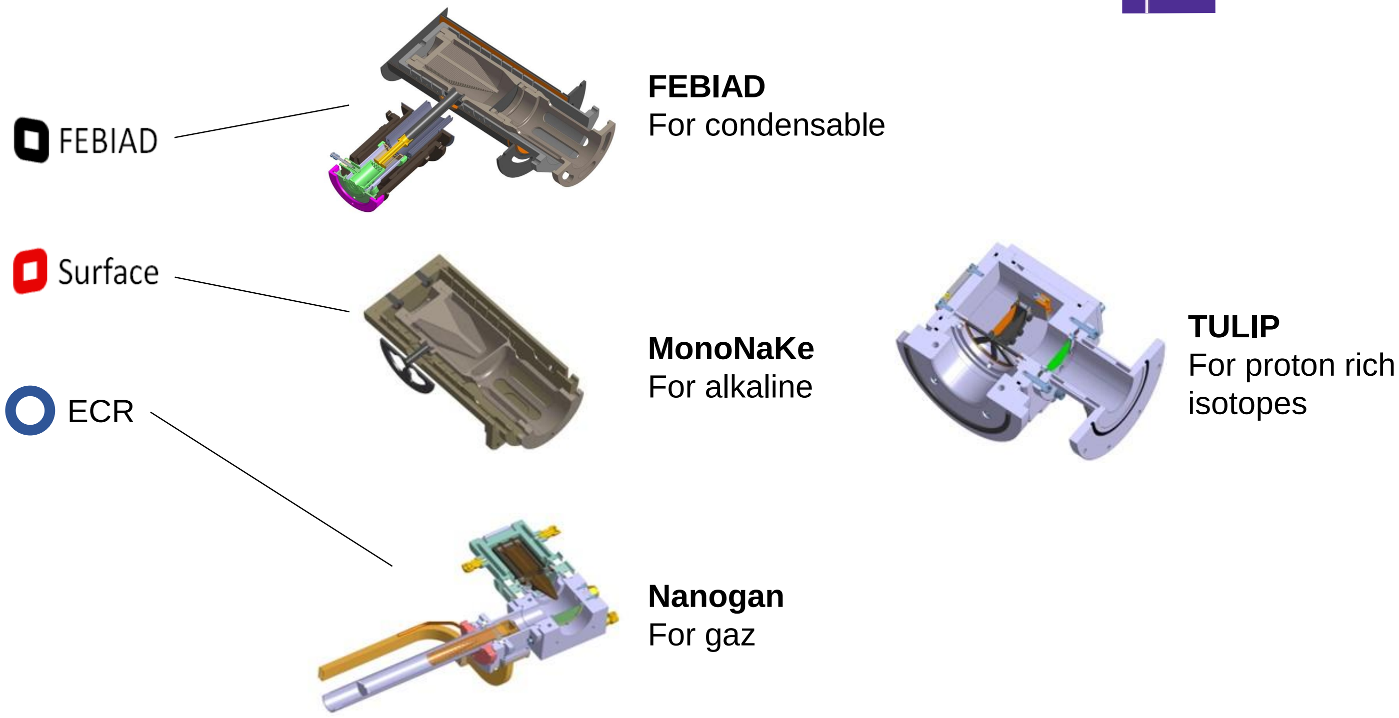
- The charge breeder



- CIME

Beam production



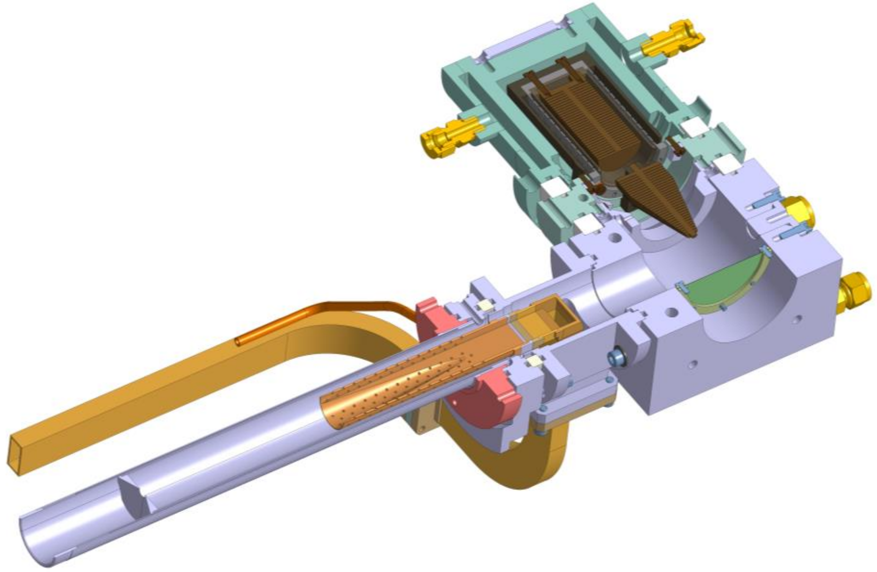


Limitations

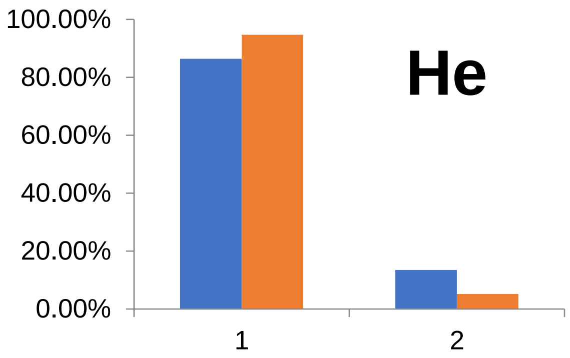
- primary beam power
- fragmentation cross-section
- diffusion/effusion time (refractory materials/short half-lives)
- ionization efficiency
- operational issues (stability, resilience)

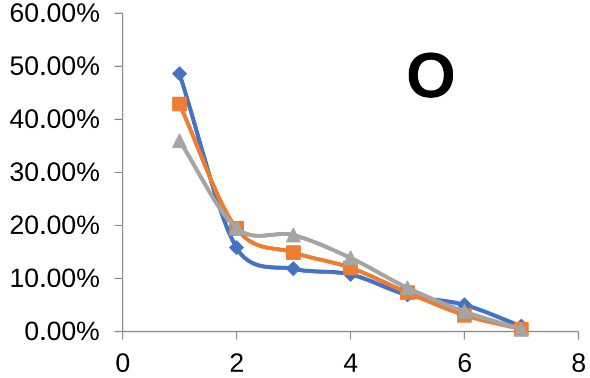
Nanogan III

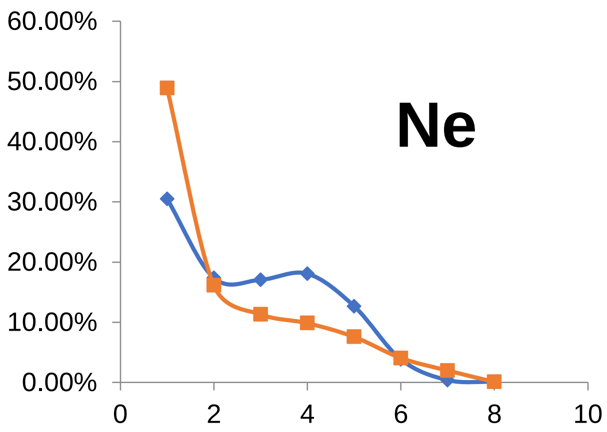
Objective: production of radioactive gaseous ions

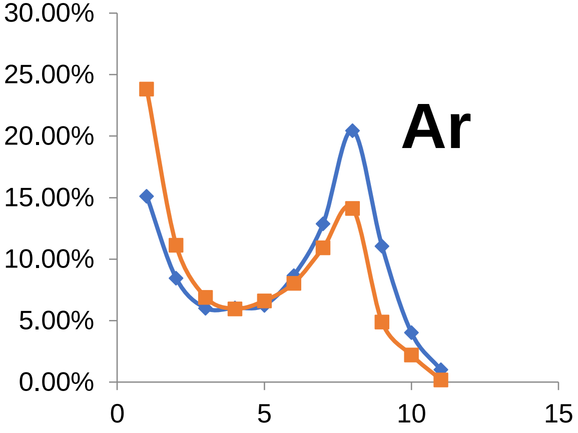


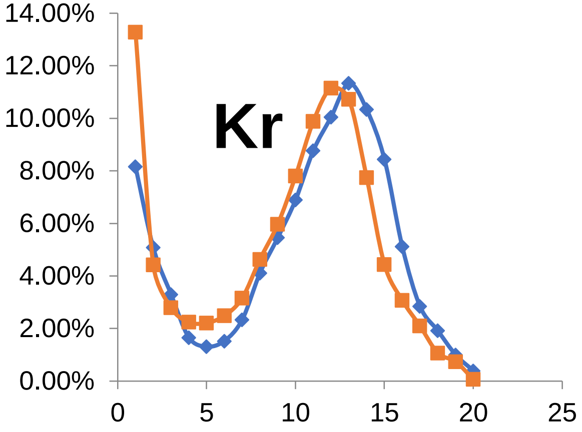
- 87 tests/experiments with radioactive beams since 2001
- Beams of He(6,8), O(14,15,19-21), F(17,18,20,21), Ne(17-19,23-27), Cl(32), Ar(31-35,41,43-46), Kr(71-77,79,81m).

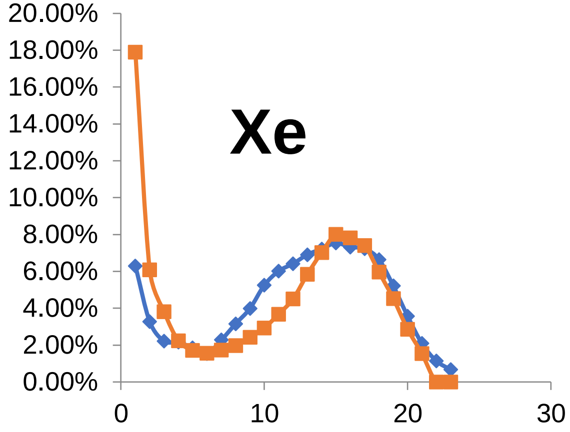






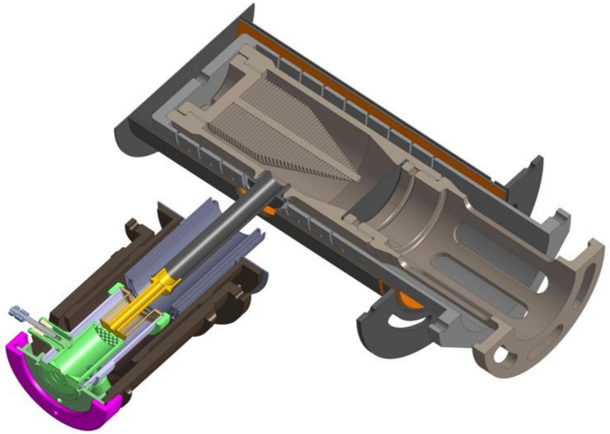






FEBIAD

Objective: production of radioactive metalic ions

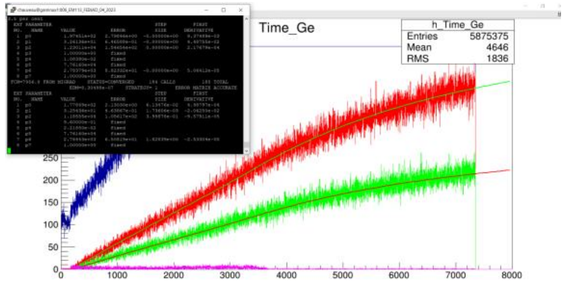


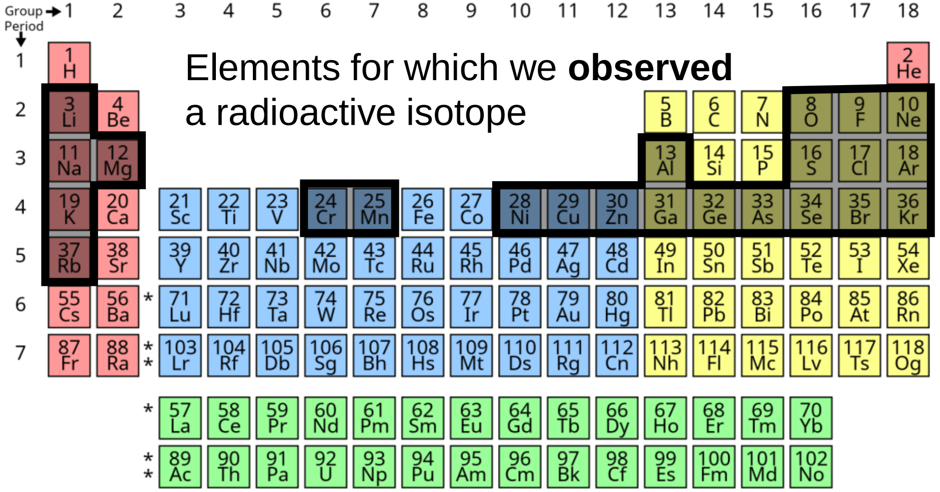
FEBIAD@SPIRAL1

- 90+ radioactive isotopes/isomers **seen**, including around 60 above 1E5pps (1+).
- Efficient: routinely ≈ 20% on Ar
- Resilient: a 15 days endurance test showed no loss in performance

Latest irradiation test (^{50}Cr beam)

- ^{48}Cr (1.2E4pps/W), ^{49}Cr (2.5E4pps/W), ^{50}Mn (3.5E2pps/W)
- very slow Cr release (46min) at low beam power (30W)





Tests for 2024:

- Production of n-deficient isotopes of Fe-Co-Ni (Master student) in July
- Broadband production test at run 3 (Possibly Xe beam) for Cu to Sn isotopes

In the future:

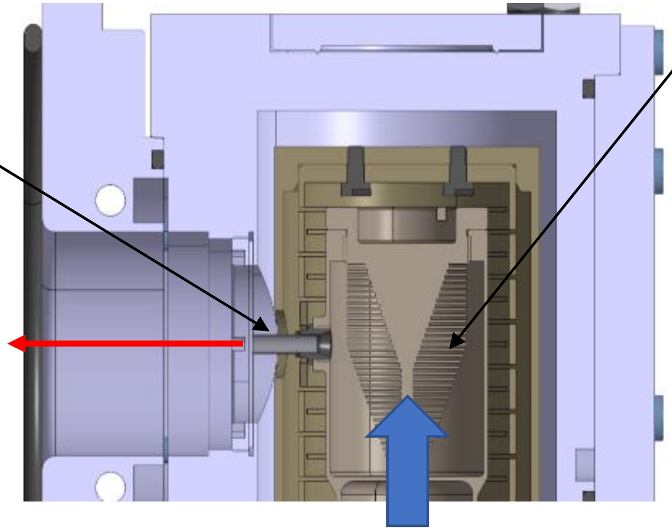
- Fe-Co-Ni beams optimization (PhD student)
- New target (Post-doc + PhD)

MonoNaKe (slide credit P. Jardin)

Objective: production of radioactive alkali ions

Pt ionizer

Graphite ionizer

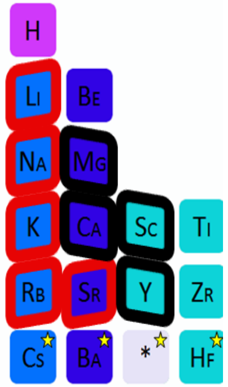


$^{8,9}Li^{+}$

Graphite target

^{13}C 60 MeV/A primary beam

- *In-target production by target and beam fragmentation*
- *Ionization by hot surface*



First on-line test with a Pt ionizer (2023)

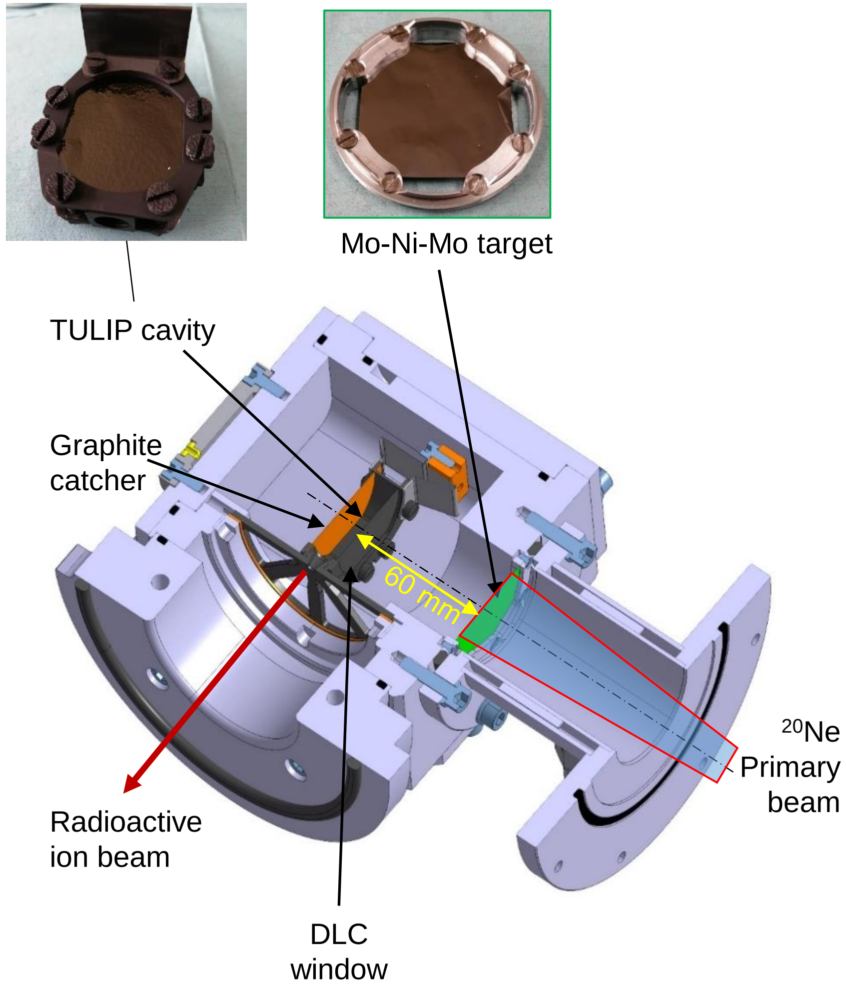
$^{8}Li^{+}$ rate = 2,2.10^{4} pps / 830W : TISS efficiency ~10^{-5} (In 2007, TISS efficiency ~5.10^{-2} with a carbon ionizer)

For 2024:

- Pt and C ionizer will be compared during an off-line test planned in February and March 2024.
- On-line production test in april with the best candidate
- Experiment in june (ACTAR TPC)

TULIP (slide credit P. Jardin)

Objective: production of neutron deficient short-lived isotopes



On-line test 2023: production of $^{74-78}Rb^{+}$ ions

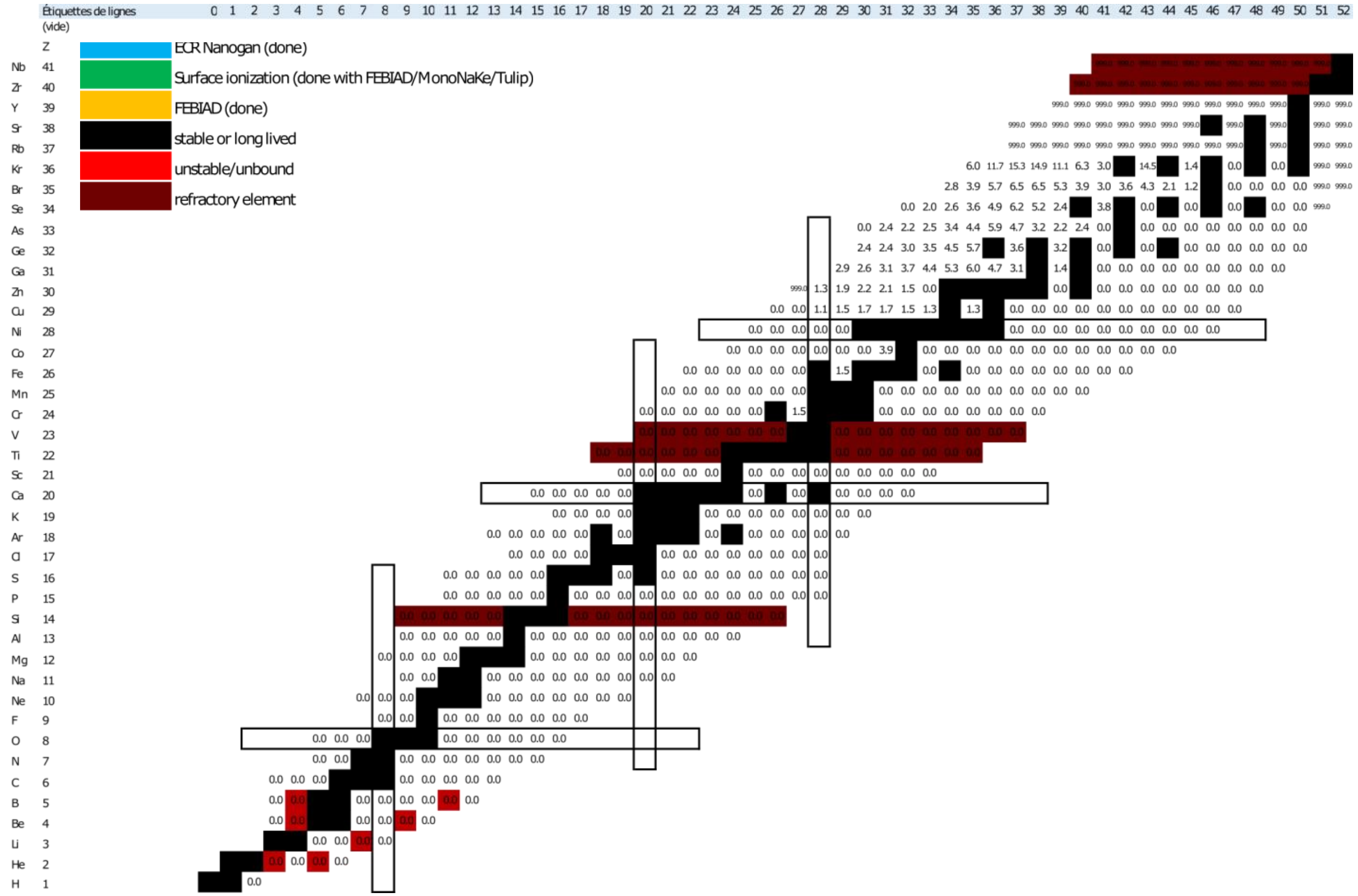
Masse isotope	T1/2	Taux IBE (pps)	
	s	mars-22	juillet 23
74	64,76 ms		1,7E+01
75	19 s		1,5E+04
76	36,8 s	3,80E+03	2,5E+04
77	3,78 m		1,6E+05
78	5,74 m/ 17,66 m	5,80E+04	6,8E+04

In 2024:
Off-line test of the TULIP-FEBIAD coupling

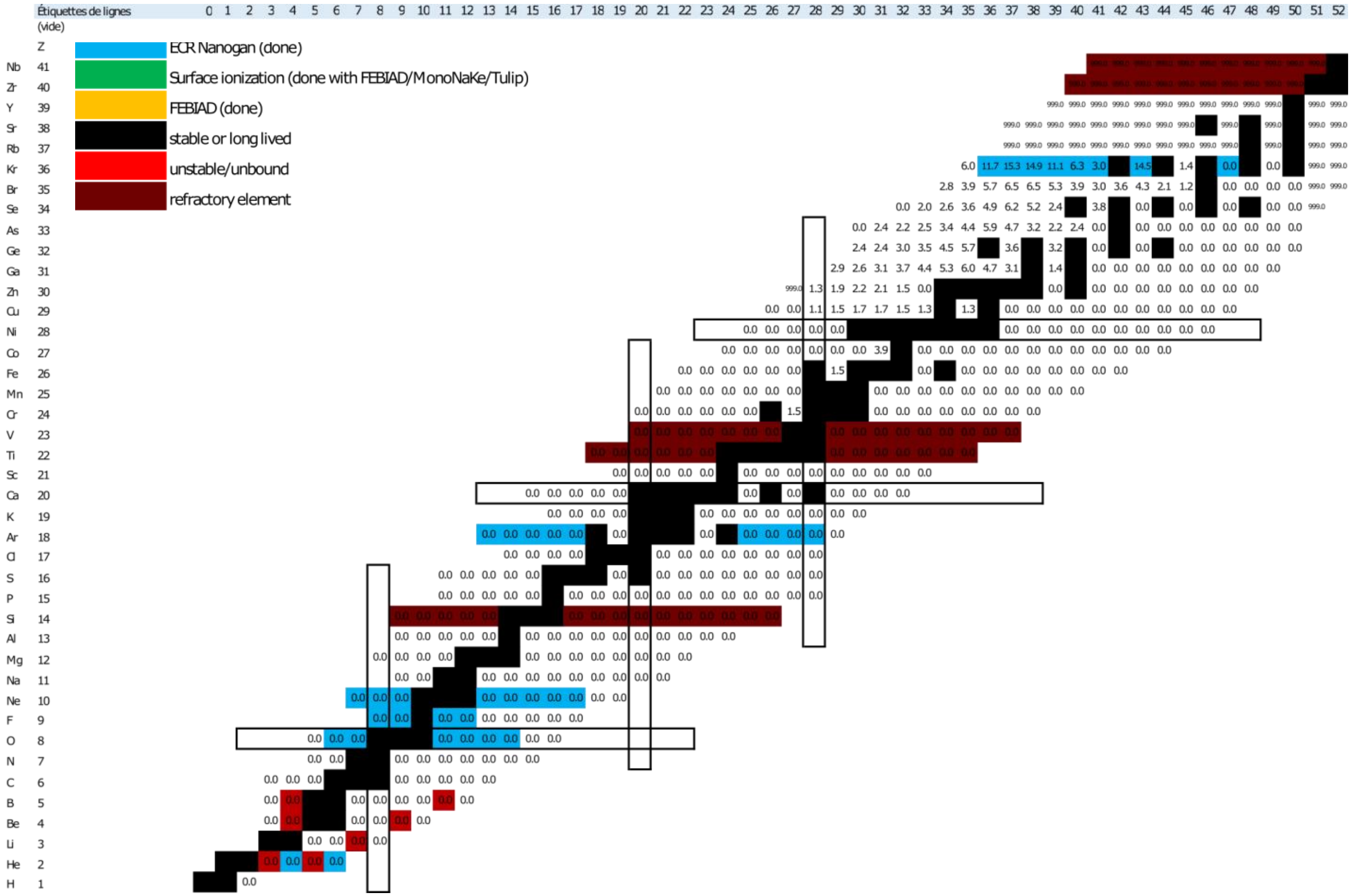
In the future:

- Implementation of a rotating target (production x 7).
- On-line production test of metallic ions close to ^{100}Sn
- Application of the principle to the production of other elements

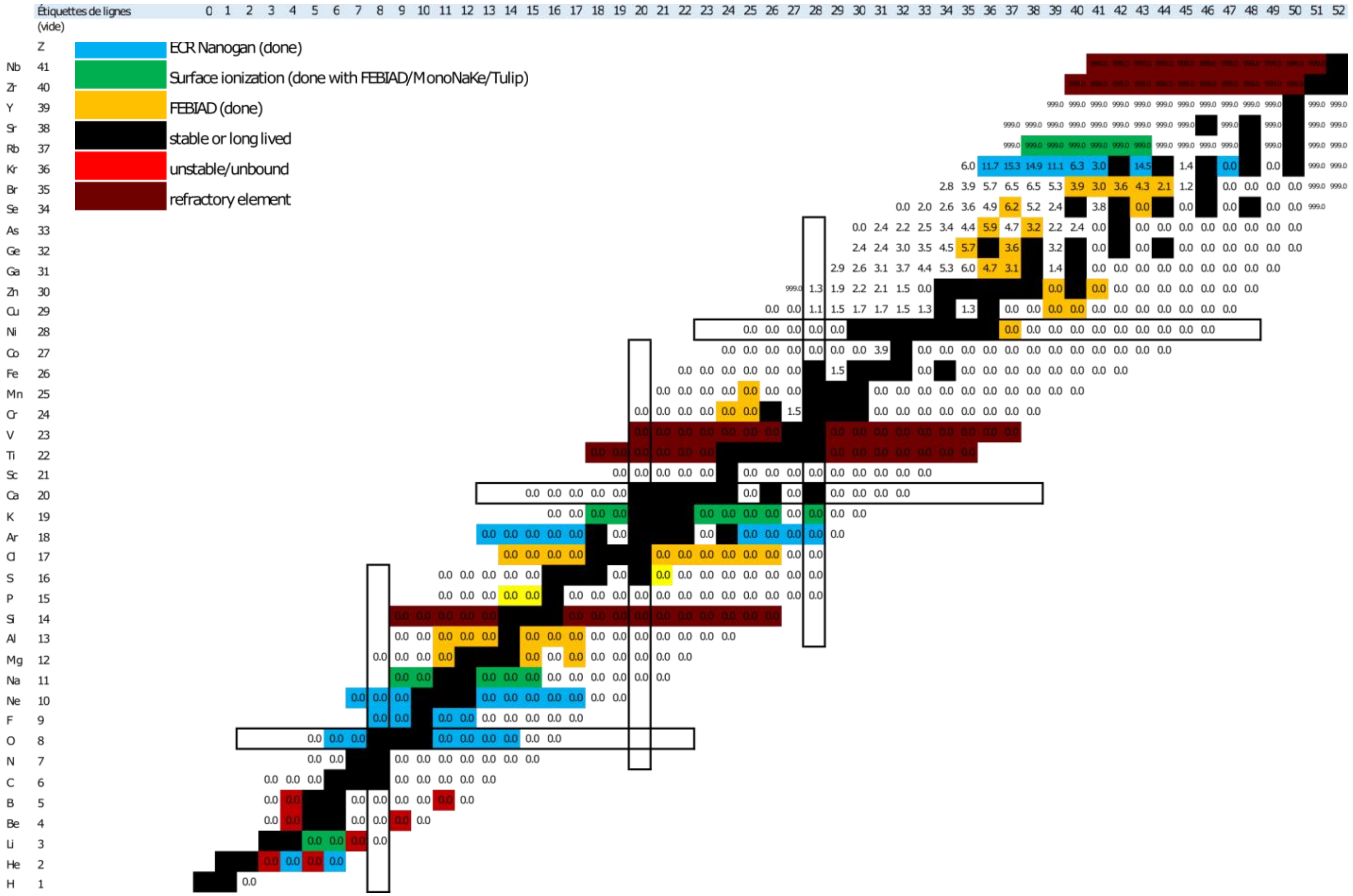
Beam production (status)

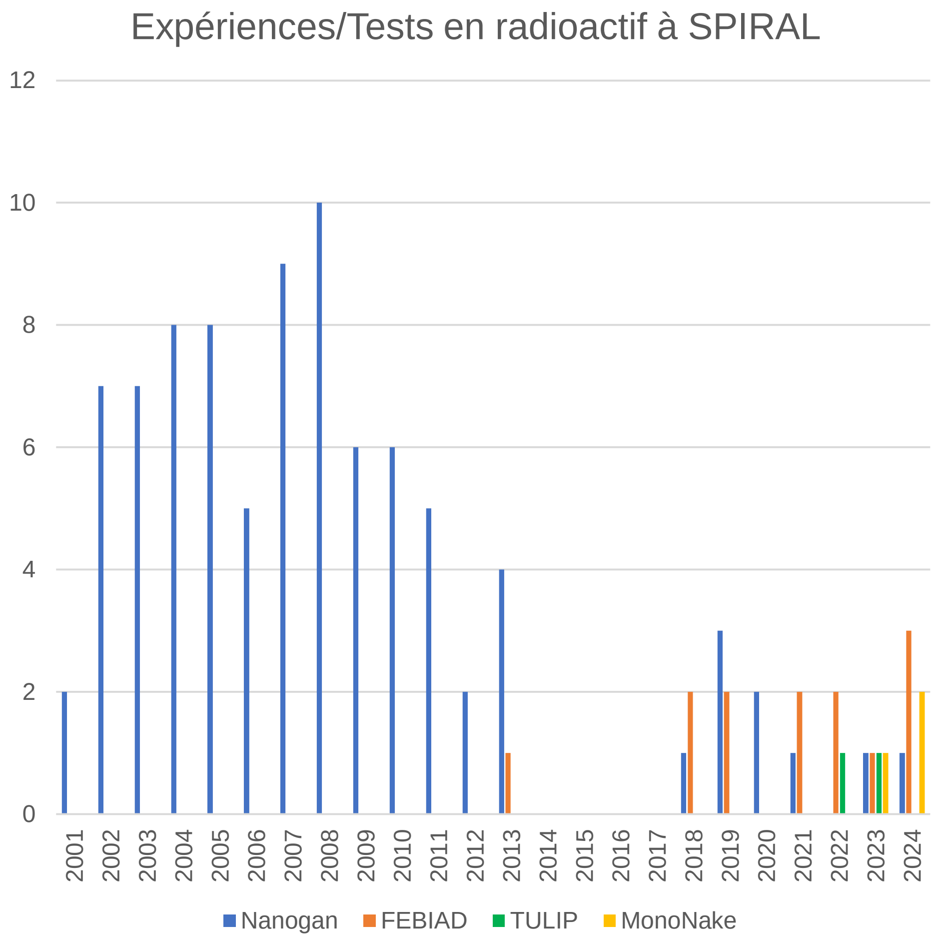


Beam production (status)

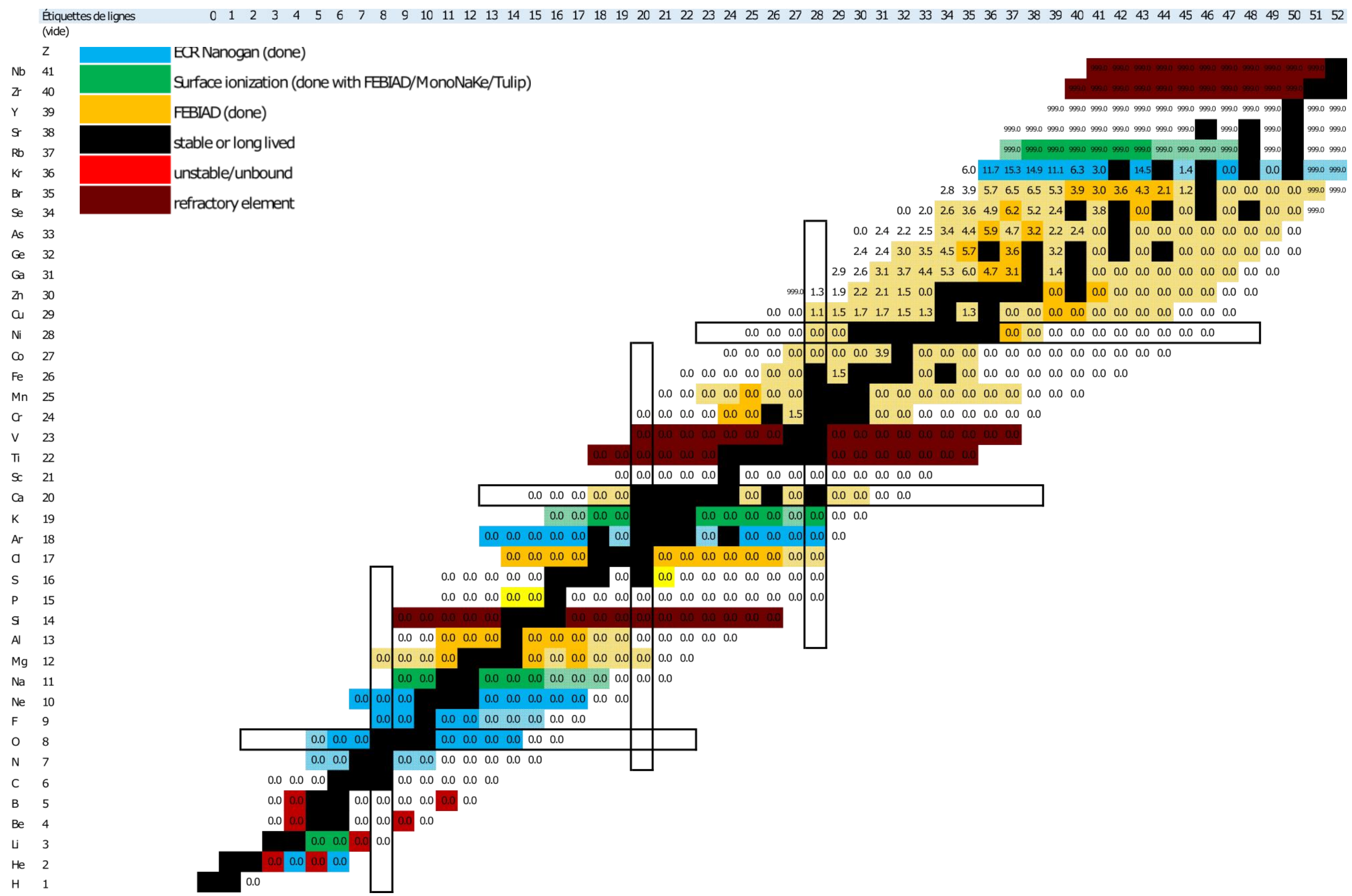


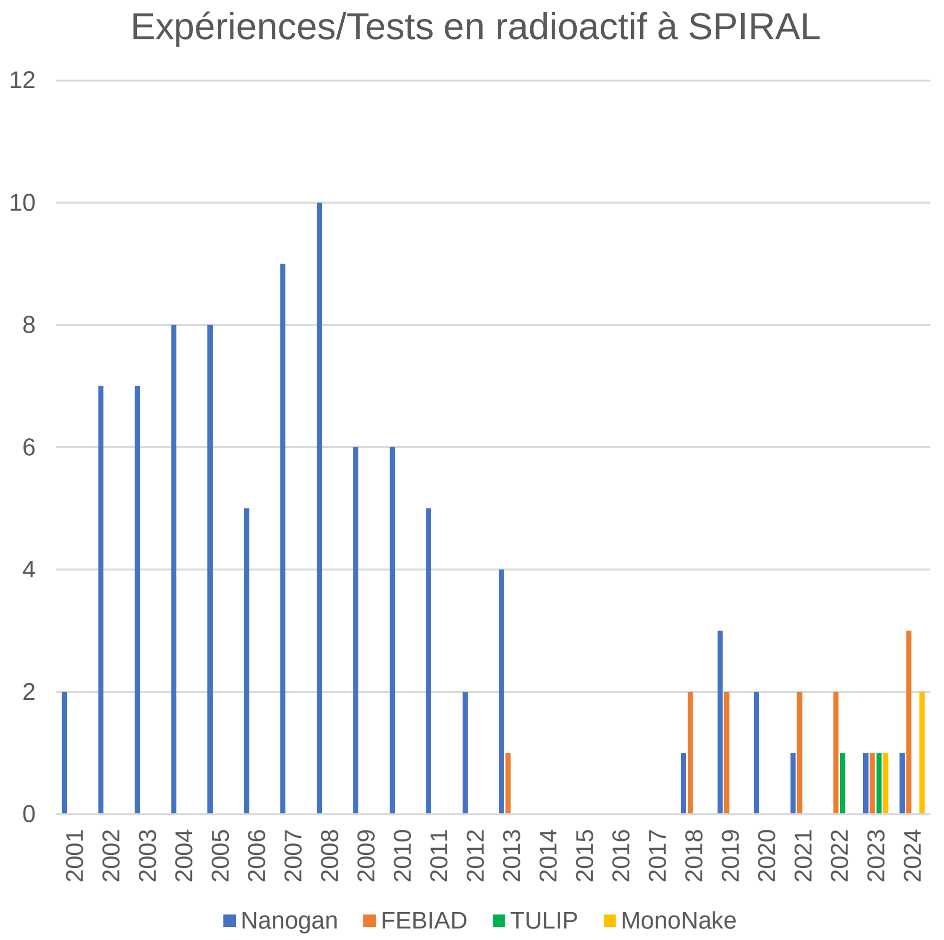
Beam production (status)





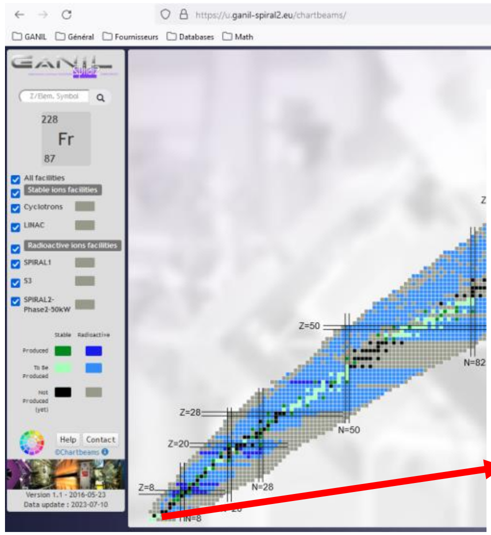
Beam production (status)





New layout for SPIRAL1 beams on the chart

https://u.ganil-spiral2.eu/chartbeams/



Measured Beams & immediate extrapolation

Radioactive Beam	halflife	unit	Charge State	Intensity (pps) Low Energy Beamline	Intensity (pps) Post accelerated (on target)	Min Energy (MeV/nucleon)	Max Energy (MeV/nucleon)	Primary Beam (or reaction mechanism)	Primary Beam Power on ECS Target (kW)	Primary Beam Energy (MeV/nucleon)	RIB production target
8Li	840.3	ms	1+	8.3E+04	--	--	--	36Ar	0.85	74	Carbon
8Li	840.3	ms	1+	2.20E+06	1.10E+04	1,6*	4.3**	13C	0.8	60	Carbon

Color code :
2.80E+07 : Measured rates with SPIRAL
2.80E+07 : Extrapolated rates (not measured) with best primary beam at low energy and after acceleration (0.5% at lowest energy, 10% at 2MeV/A)

Specific codes :
* Indicative value which does not include possible optimizations
** for most abundant charge state. Higher energy is a priori possible, but at a cost of reduced intensity

Estimates requiring beam development (6 months - 2 years)

Radioactive Beam	halflife	unit	Charge State	Intensity (pps) Low Energy Beamline	Intensity (pps) Post accelerated (on target)	Min Energy (MeV/nucleon)	Max Energy (MeV/nucleon)	Primary Beam (or reaction mechanism)	Primary Beam Power on ECS Target (kW)	Primary Beam Energy (MeV/nucleon)	RIB production target
8Li	840.3	ms	2	4.2E+08	1.7E+06	1,6*	16,6**	13C	1.2	75	Carbon
9Li	178.3	ms	2	5.6E+07	2.2E+05	1,6*	13,1**	13C	1.2	75	Carbon
11Li	8.75	ms	2	3.4E+04	8.1E+01	1,6*	8,8**	18O	1.2	75	Carbon

Estimates requiring target development (2-3 years)

Radioactive Beam	halflife	unit	Charge State	Intensity (pps) Low Energy Beamline	Intensity (pps) Post accelerated (on target)	Min Energy (MeV/nucleon)	Max Energy (MeV/nucleon)	Primary Beam (or reaction mechanism)	Primary Beam Power on ECS Target (kW)	Primary Beam Energy (MeV/nucleon)	RIB production target
8Li	840.3	ms	2	8.4E+08	3.3E+06	1,6*	16,6**	12C	3.65	95	SiC
8Li	840.3	ms	2	6.0E+08	2.4E+06	1,6*	16,6**	12C	3.65	95	CaO
8Li	840.3	ms	2	5.1E+08	2.0E+06	1,6*	16,6**	12C	3.65	95	NiO
9Li	178.3	ms	2	9.7E+07	3.7E+05	1,6*	13,1**	12C	3.65	95	SiC
9Li	178.3	ms	2	6.8E+07	2.6E+05	1,6*	13,1**	12C	3.65	95	CaO
9Li	178.3	ms	2	5.8E+07	2.3E+05	1,6*	13,1**	12C	3.65	95	NiO

Color code :
2.80E+07 : Intensity estimates for FEBIAD (VADIS) source (January 2016)
--- : Estimated yields inferior to 5,0E-02

Specific codes :
* Indicative value which does not include possible optimizations
** for cited charge state. Higher energy is a priori possible, but at a cost of reduced intensity

Update : 06/2023

Direct measurement at low energy

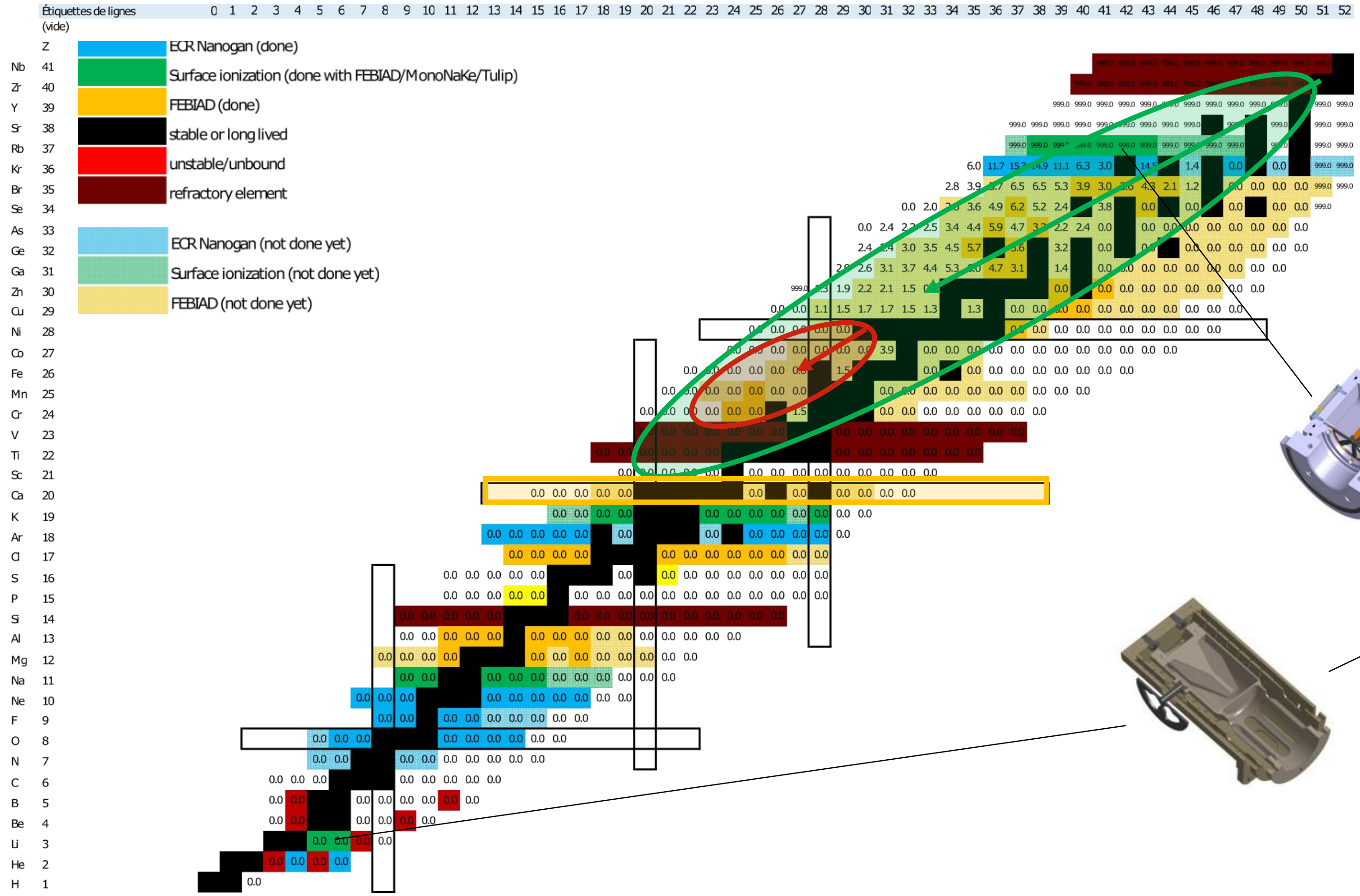
Extrapolation at low energy and after post-acceleration with best beam

Estimates with good beams on 12C target and best source conditions

Estimates with 12C beam on new targets and best source conditions

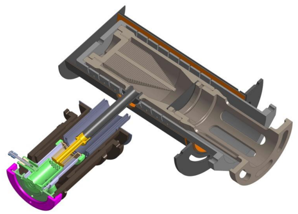
Only displayed if better than best beam extrapolation

Conclusion on beam development

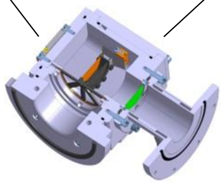


Source development

- New beams (2024)
- New target (2026?)
- Molecular CaF ?



- N-deficient Rb

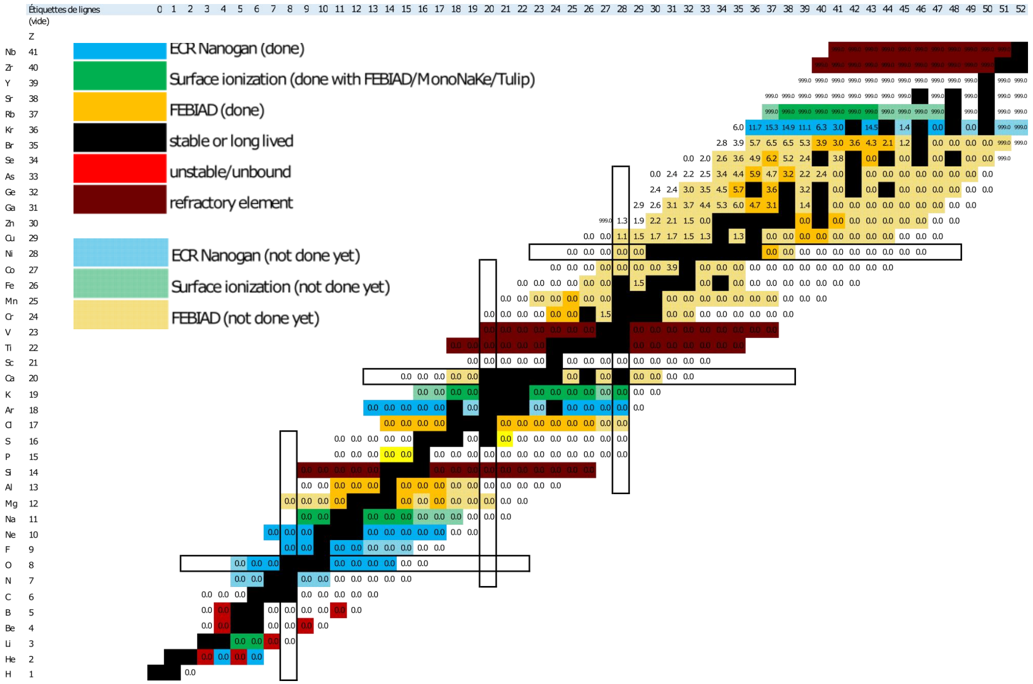


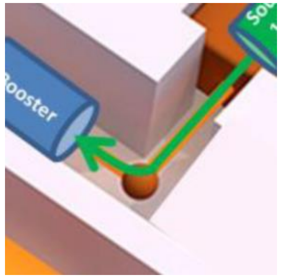
- $^{8\text{-}9}Li$

Main limitations of Spiral1

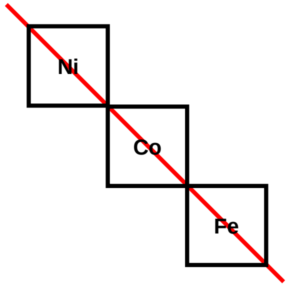
- Diffusion/effusion time
- Purity

Purity

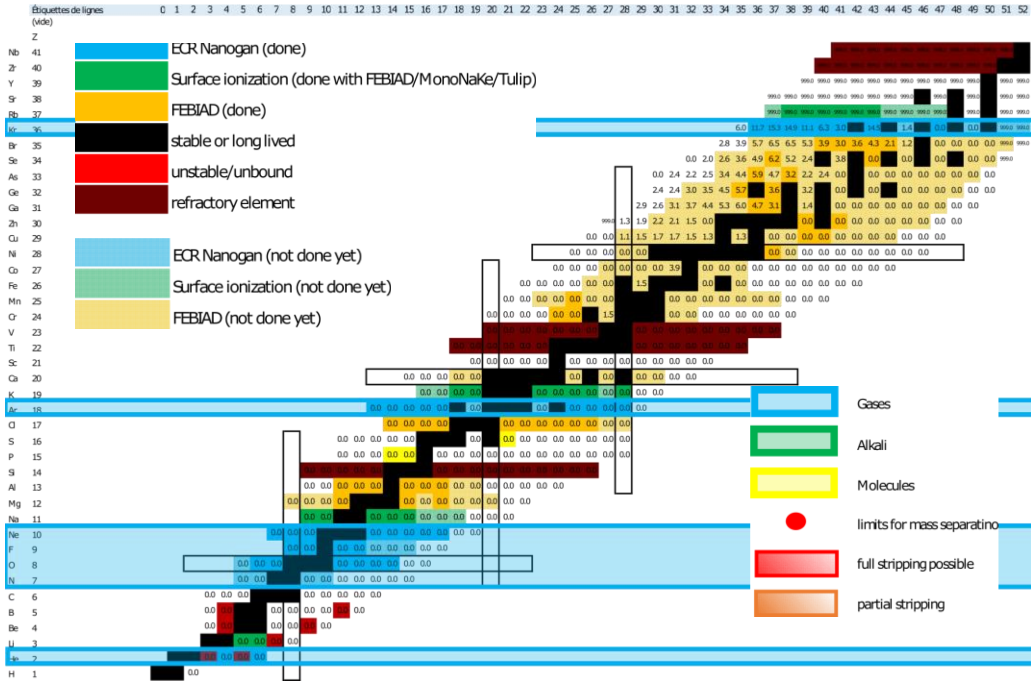


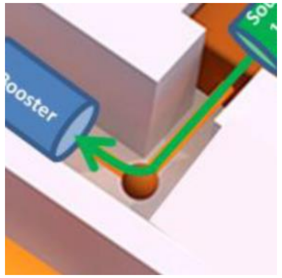


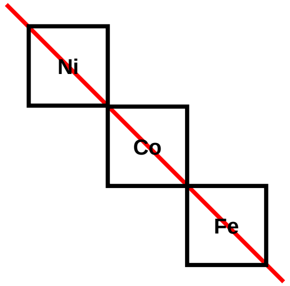
A selection -> Isobaric contaminants (δm/m≈1%)



Purity



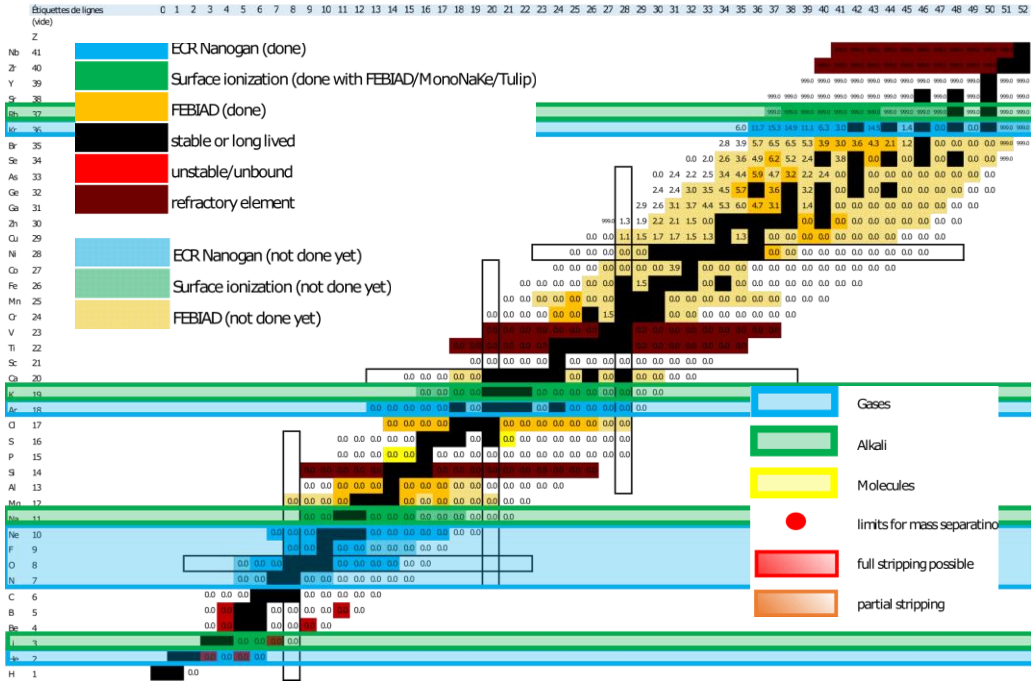


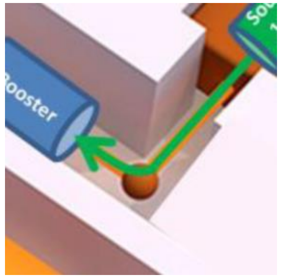


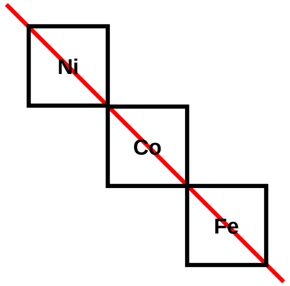
A selection -> Isobaric contaminants (δm/m≈1%)

- Z selection – gaz (Nanogan)

Purity







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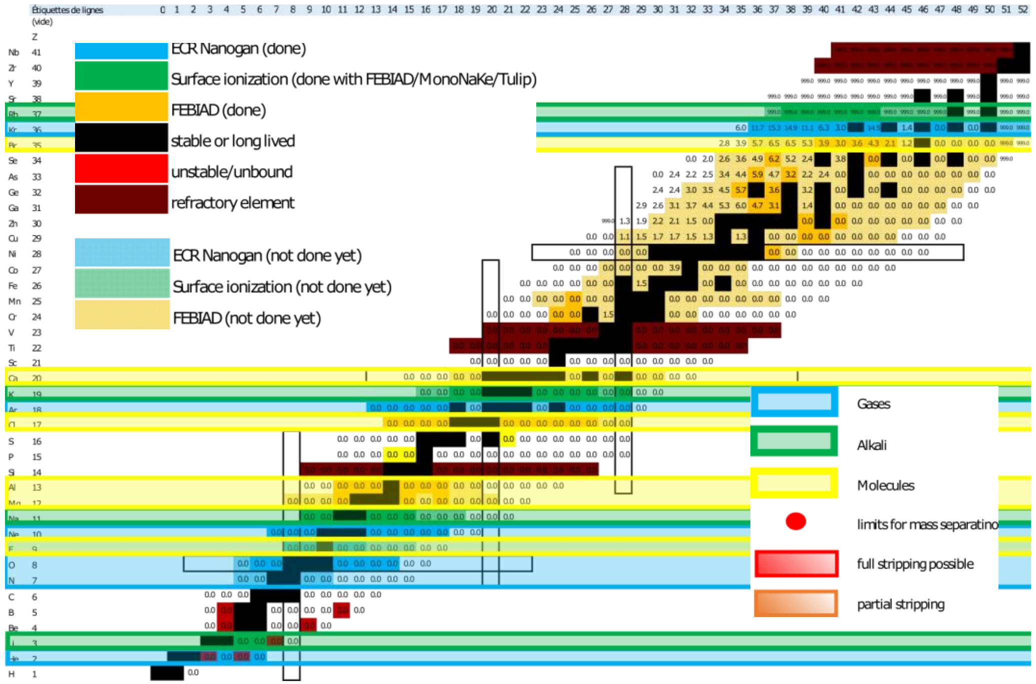
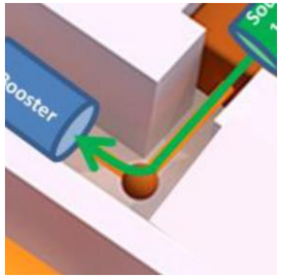
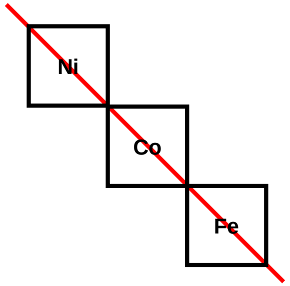
Purity



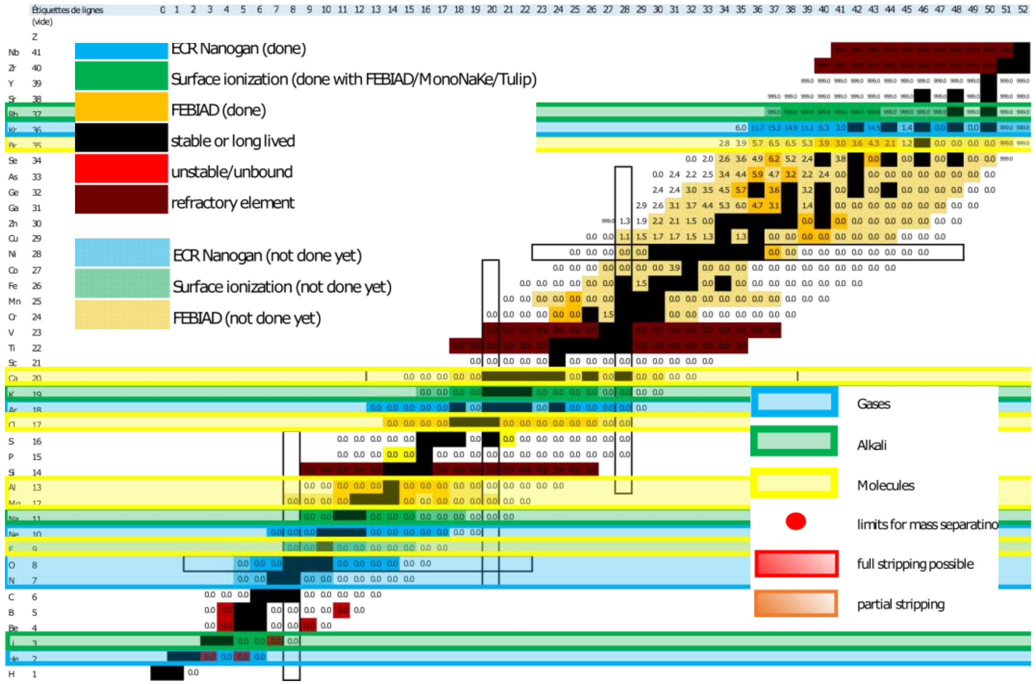


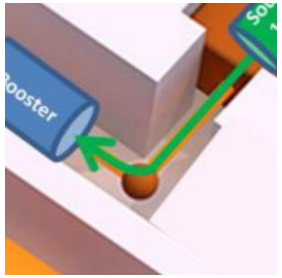


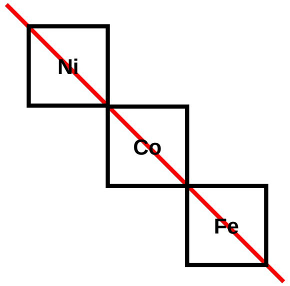
A selection -> Isobaric contaminants (δm/m≈1%)

- Z selection – gaz (Nanogan)
- Z selection – alkali (MonoNaKe/Tulip/FEBIAD)
- Z selection – molecules (reactive gaz injection)

Purity





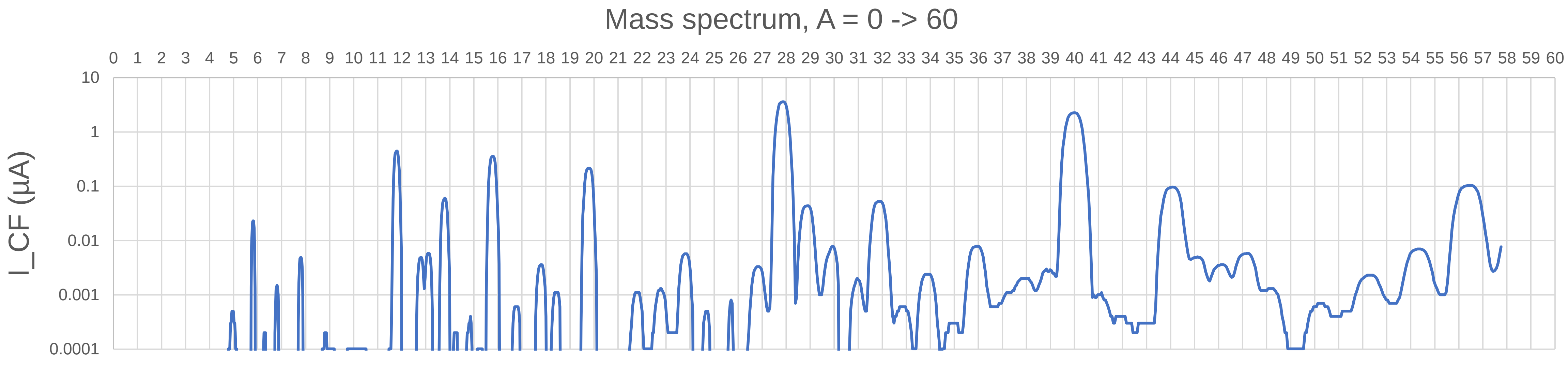


A selection -> Isobaric contaminants (δm/m≈1%)

- Z selection – gaz (Nanogan)
- Z selection – alkali (MonoNaKe/Tulip/FEBIAD)
- Z selection – molecules (reactive gaz injection)
- A selection HRS ? (δm/m≈1/20000)

Purity – Contamination in the FEBIAD

Contamninants



Isotope of interest

DESIR – SPIRAL1 wishlist

- β- decay : ^{45}Cl,^{46}Cl
- β+ decay : ^{22}Al, ^{26}P, ~~^{27}S~~, ^{31}Ar, ~~^{39}Ti~~, ~~^{43}Cr~~
- Mass measurements (nuclear structure) : ^{46}Ar, ^{47}Ar, ^{48}Ar, ^{49}Ar, ^{42}Cl, ^{43}Cl, ^{44}Cl, ^{45}Cl, ^{46}Cl, ^{47}Cl, ^{39}P, ^{40}P, ^{41}P, ^{42}P, ^{43}P
- Mass measurements, T1/2 and BR (0+ -> 0+ and mirror transitions) : ^{21}Na, ^{23}Mg, ^{25}Al, ^{29}P, ~~^{31}S~~, ^{33}Cl, ^{35}Ar, ^{37}K, ^{39}Ca, ^{41}Sc, ~~^{42}Ti~~, ^{46}Cr, ^{50}Fe, ^{54}Ni, ^{58}Zn, ^{62}Ge, ^{66}Ge, ^{70}Br, ^{74}Rb, ~~^{78}Y~~

~~^{27}S~~ : not feasible (1+ rate < 0.1 pps)

1+ rates from FEBIAD estimate or measurements (FEBIAD/Nanogan/TULIP) when available

Purity – RFQ cooler + HRS estimation

Considerations :

- Perfectly gaussian energy distributions
- $R_{HRS,FWHM}$ ranging from
  - 1000 (No SHIRaC, all slits open, FEBIAD ΔE/E)
  - to 24000 (max R in J. Michaud's article with ΔE=1eV -> SHIRaC's best)

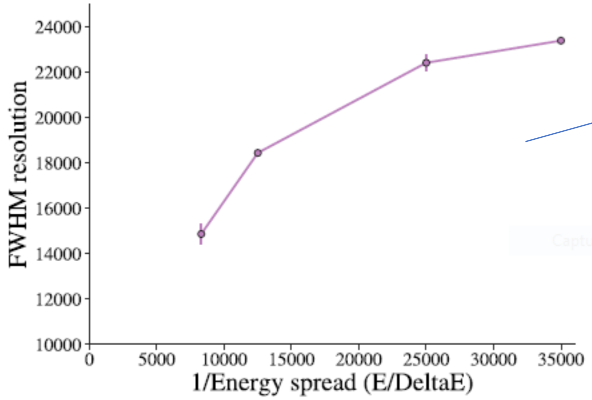
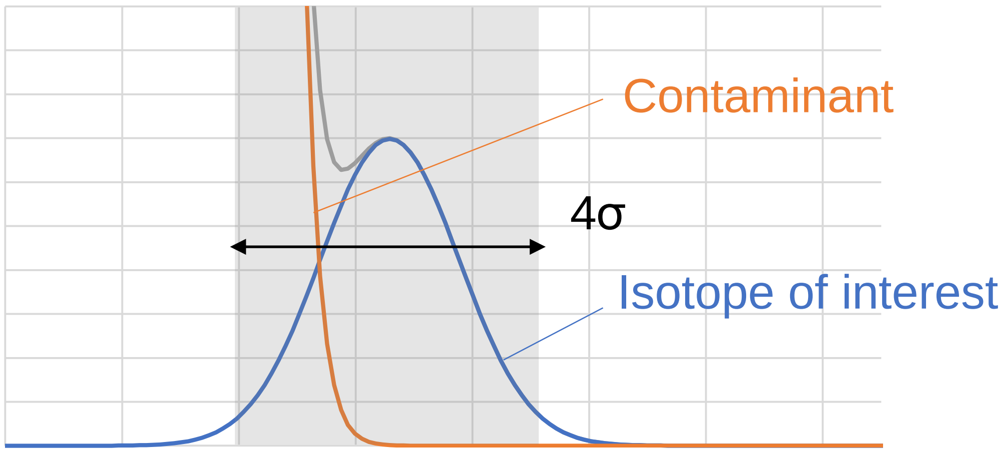


Fig. 6. HRS FWHM resolution as a function of the beam energy spread. The energy spread was introduced by adding a noise on the acceleration voltage by means of an arbitrary waveform generator in the acceleration chain.

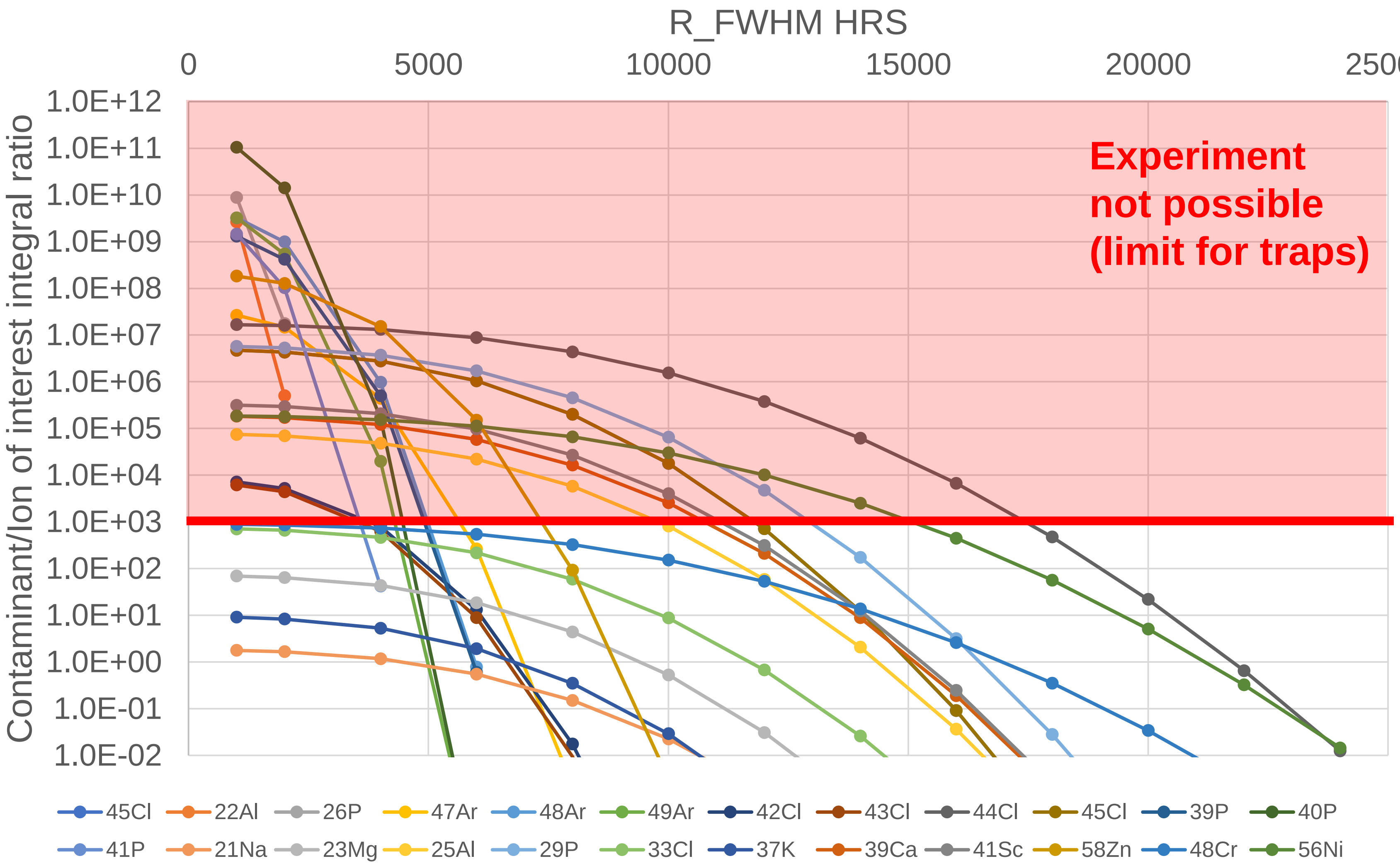
J. Michaud et al, NIMB 541 (2023) 161-164

Slit opening ?

- Cut at +/- 2σ around peak of interest (slit opening ?)



Purity – RFQ cooler + HRS estimation



Conclusions

- SHIRaC is necessary
- High R critical
- Estimation **very** tail-dependant

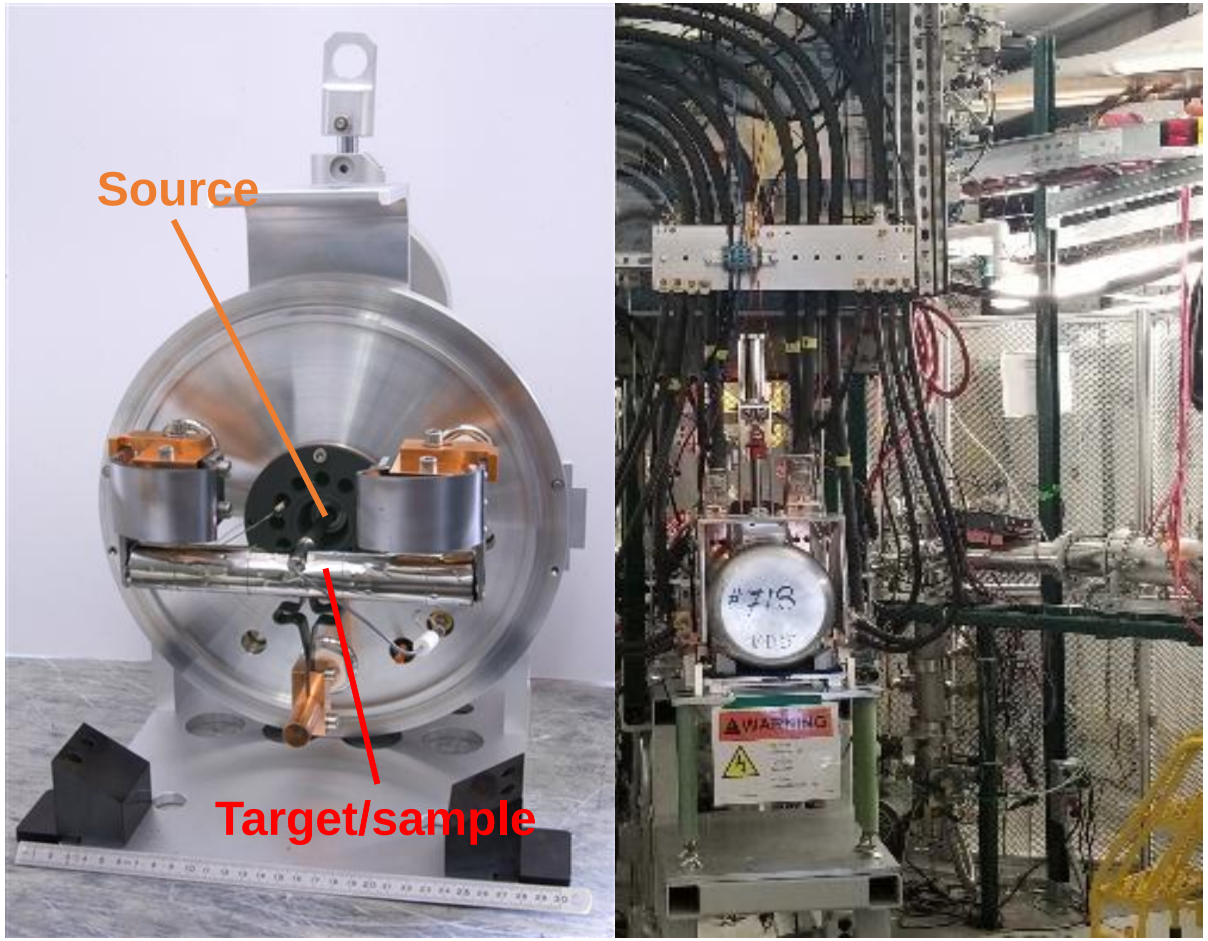
What we need:

- Updated wish list (with intensities)
- Information on the tail on the high energy side at 2-6σ

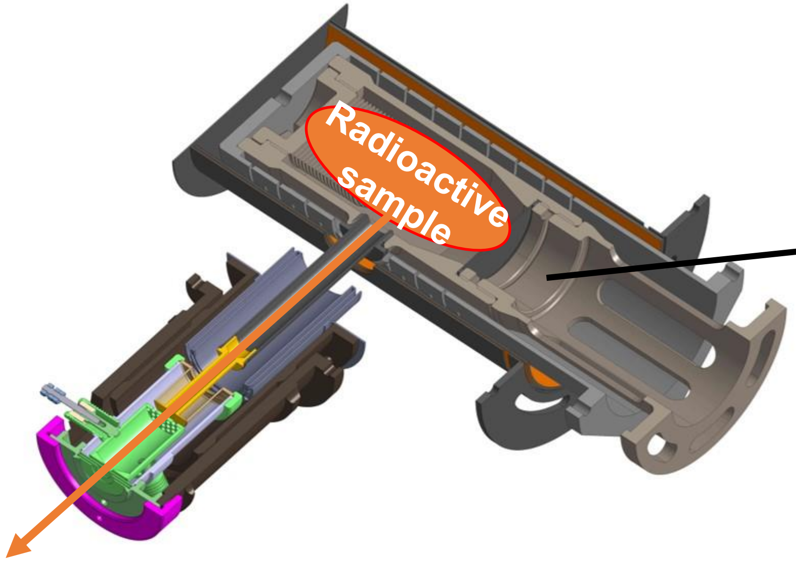
Batch Mode Ion source at FRIB (slide credit A. Villari)

- BMIS built on ISOLDE Target-Ion-Source system to provide RIB in stand-alone operation
  - “Target” replaced by samples of radioactive (relatively long living) isotopes
  - VD5 ion source (FEBIAD type)
  - Surface ion source also possible (not employed yet)
  - Future: laser ionization
- Beams for experiments already delivered:
  - ^{7,10}Be, ^{26}Al, ^{32}Si, ^{73}As – delivered for experiments
  - ^{229}Th, ^{44}Ti and other isotopes under development

Collaboration FRIB-GANIL
Batch mode could also be developped at SPIRAL1

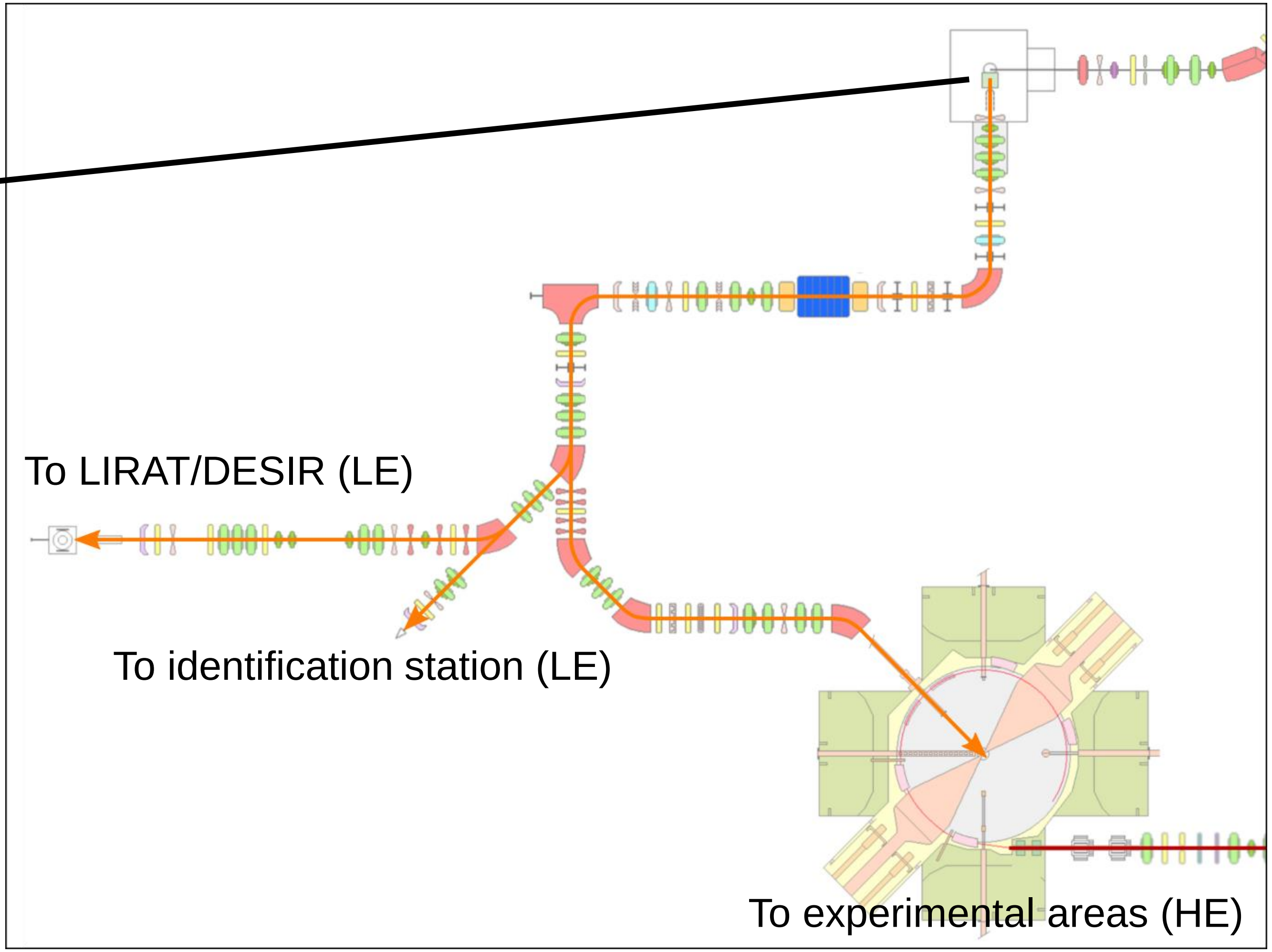


Batch Mode Ion source at GANIL ?



CYREN anticipation:
- No cyclo run3/run4 in 2025-2028
- No cyclo at all in 2029

Opportunities for Batch-mode ions (LE)



Which beams ?

Developed at FRIB

- ^{7}Be ($T_{1/2}$ = 53.22 d)
- ^{10}Be ($T_{1/2}$ = 1.51E6 y)
- ^{26}Al ($T_{1/2}$ = 7.17E5 y)
- ^{32}Si ($T_{1/2}$ = 153 y)
- ^{73}As ($T_{1/2}$ = 53.22 d)

Being developed at FRIB

- ^{44}Ti ($T_{1/2}$ = 60.0 y)
- ^{229}Th ($T_{1/2}$ = 53.22 d)

At FRIB

- Batch mode Intensities are 5e7 pps on average at FRIB
- Some isotopes are produced in Los-Alamos and chemically purified and prepared in-house

At GANIL ?

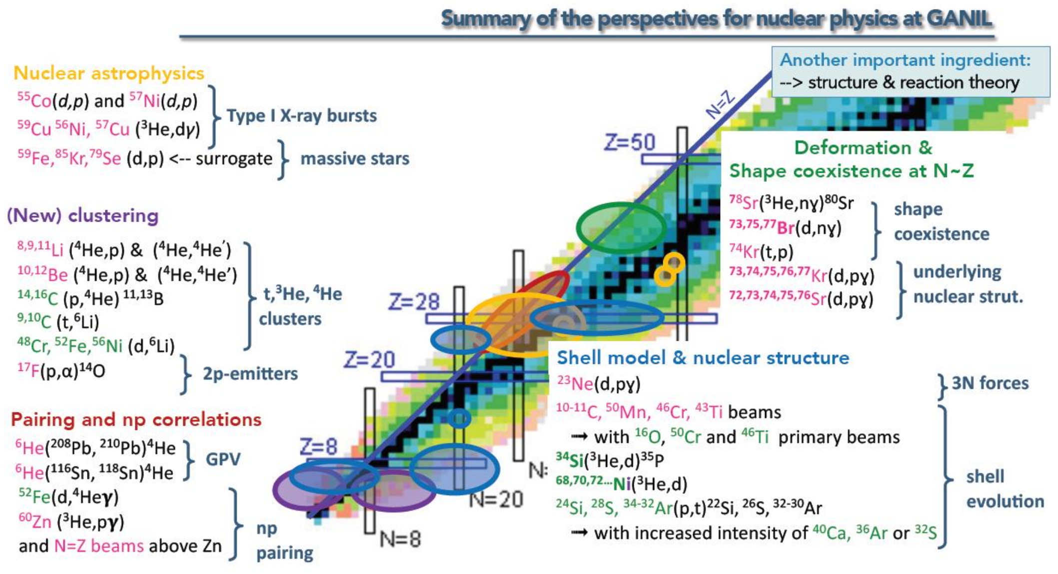
laboratoire commun CEA/DRF CNRS/IN2P3

Thank you for your attention!

Backup – Beam development

Logic of beams development:

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

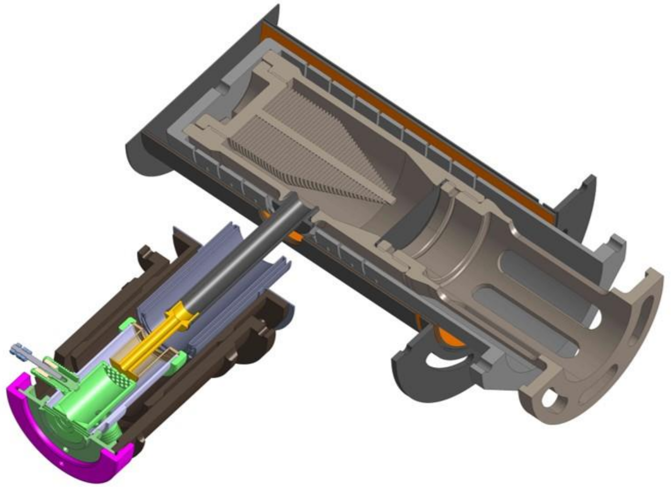


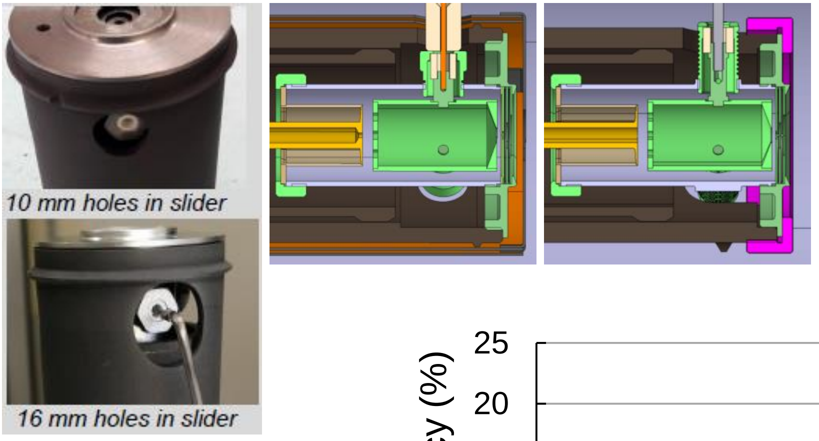
M. Assié, WS Cible-Source, 09/2023

Shopping list SPIRAL1

- ^{6}He
- ^{8,9,11}Li
- ^{10,12}Be
- ^{10,11}C
- ^{17}F
- ^{23}Ne
- ^{43}Ti
- ^{46}Cr
- ^{50}Mn
- ^{59}Fe
- ^{55}Co
- ^{56,57}Ni
- ^{57,59}Cu
- ^{60}Zn
- ^{79}Se
- ^{73,75,77}Br
- ^{73,74,75,76,77}Kr
- ^{72,73,74,75,76}Sr

Backup - The upgrades on the FEBIAD



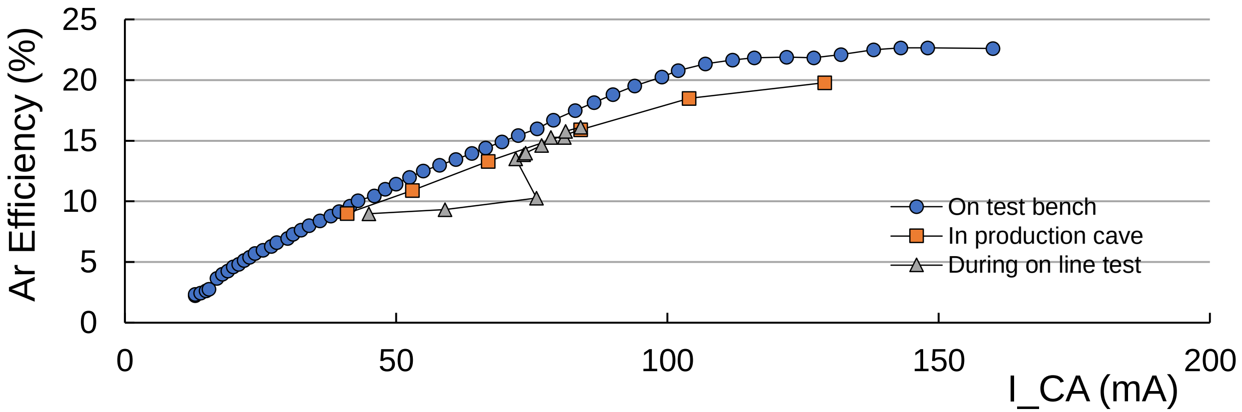


Poster ICIS
V. Bosquet

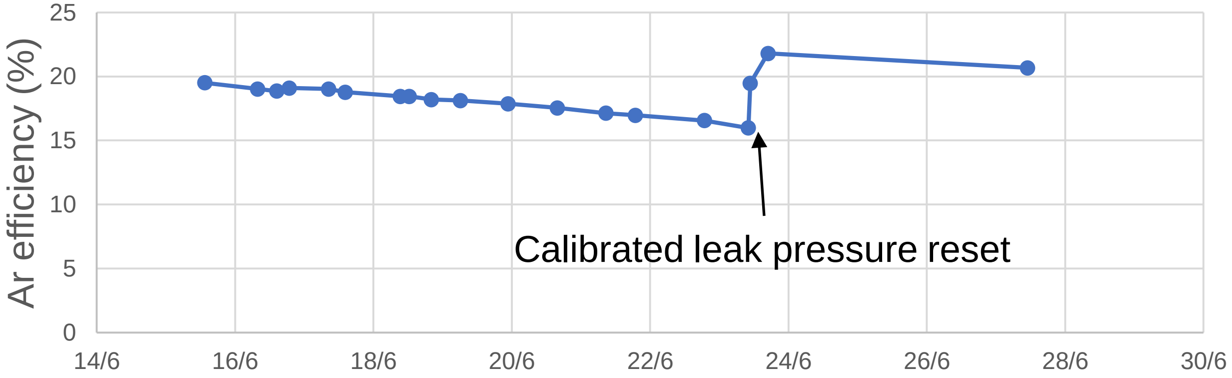
Insulator were the main point of failure.

- Increasing the size of the openings
- Pulling the insulators far from the hot anode

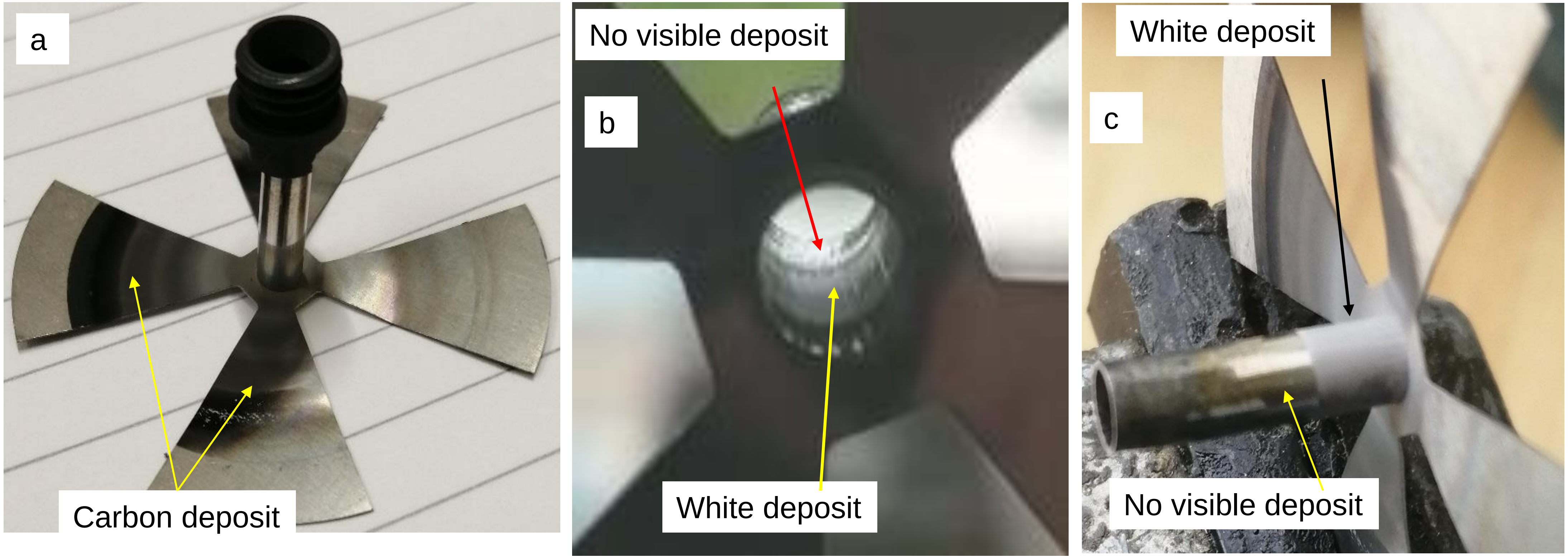
Progress in resilience and reliability



- 3 months in SPIRAL1
- 3 Machine study (2 radioactive + 1 stable)
- 10+ heating cycles
- **Efficient:** ^{40}Ar Efficiency up to 23%
- **Resilient:** 2 days of irradiation, 15 days at 20% ^{40}Ar efficiency and 10+ heating cycles without loss of performance
- **Stable over time :** same results 3 months appart
- Reliable : same results on test bench and SPIRAL and between 2 TISSes



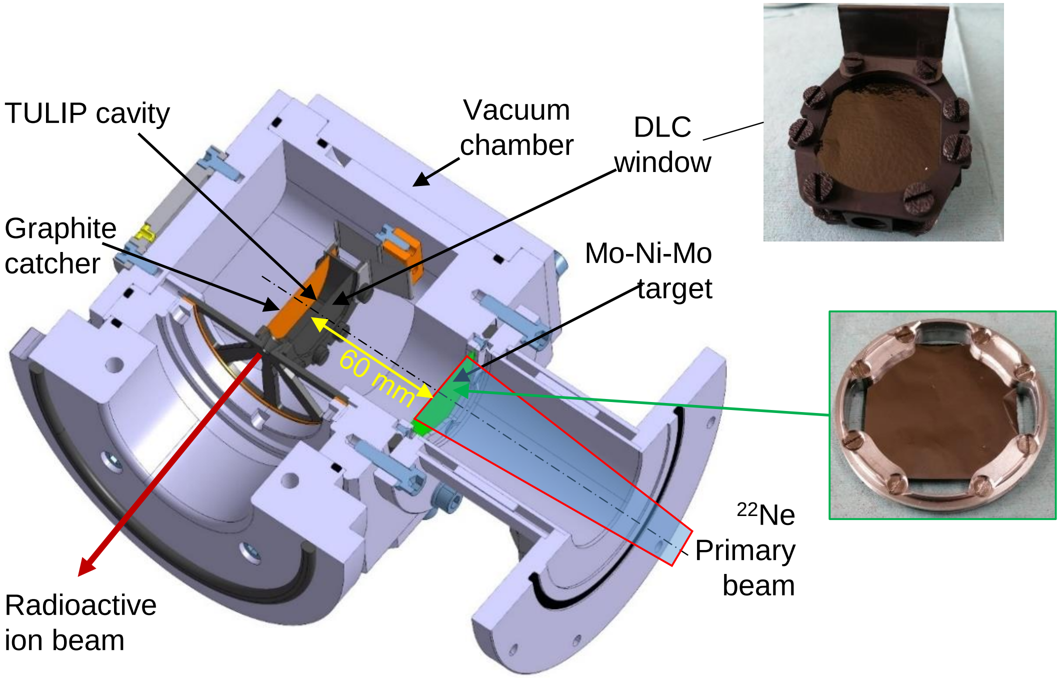
Backup - MonoNaKe
Observations during the off-line test



Backup - TULIP (slide credit P. Jardin)

Objective: production of neutron deficient short-lived isotopes

Proof of principle: production of $^{74\text{-}78}Rb^+$ ions



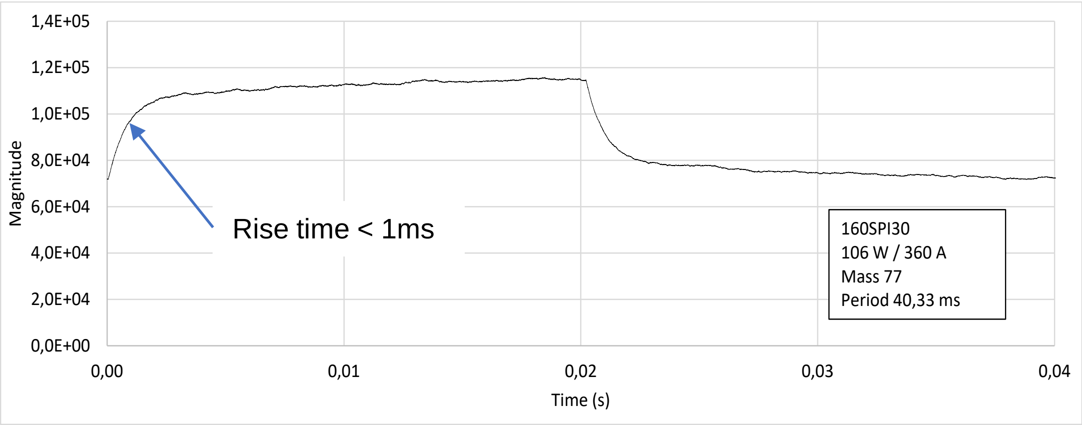
In-target production by fusion-evaporation
Short atom-to-ion transformation time

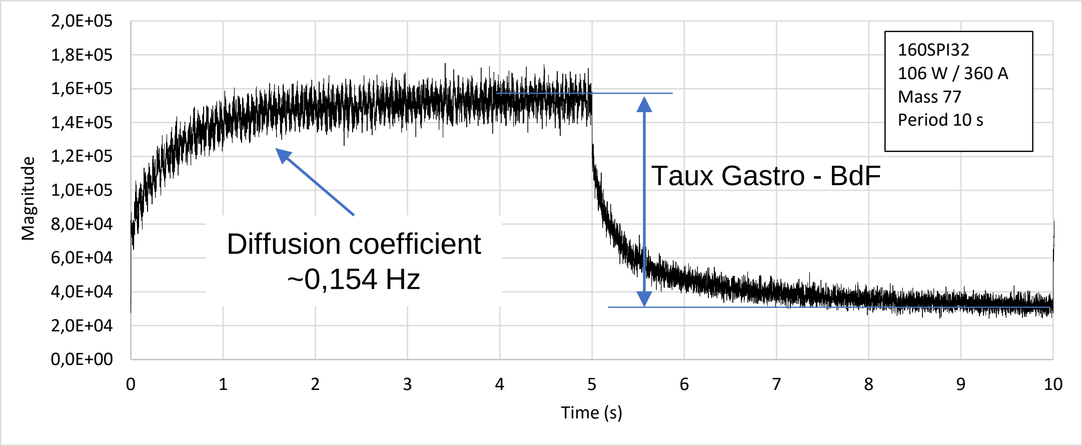
Last On-line test in July 23

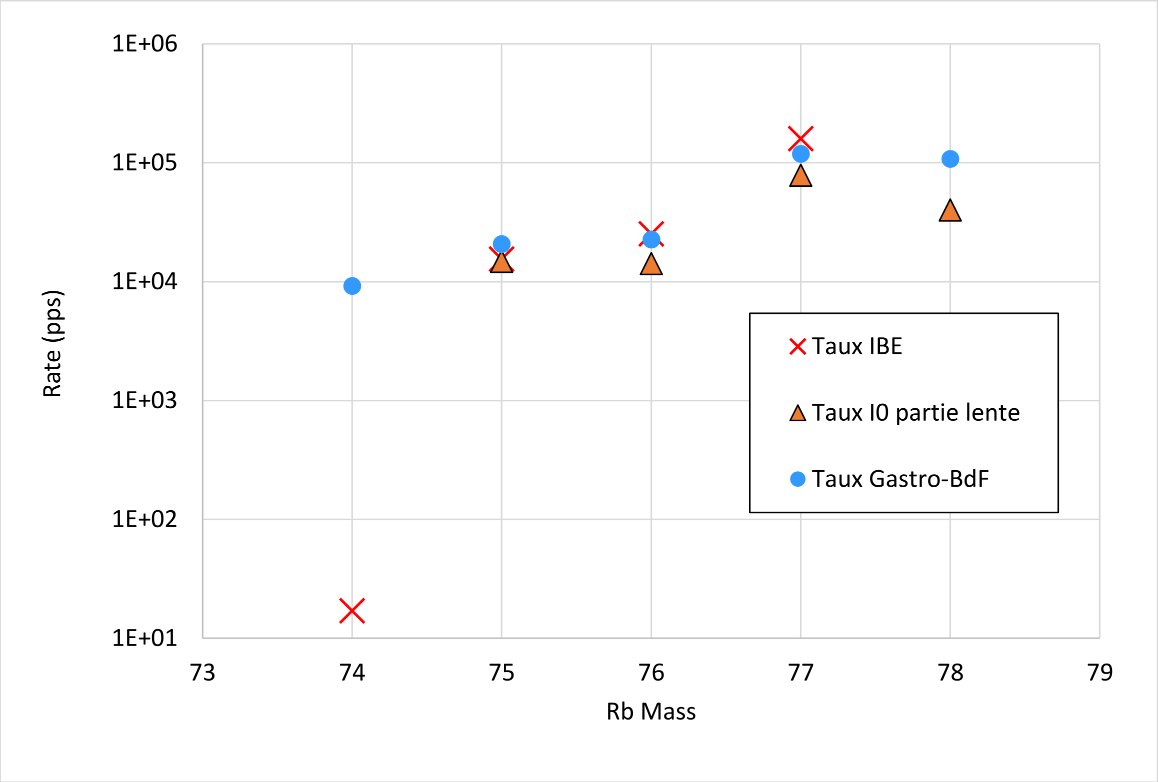
- ^{20}Ne@4,5 MeV/A -> ^{nat}Ni
- $^{74\text{ to }78}Rb^+$ observed
- Rates up to few 10^5 pps
- TISS 3 days under irradiation without damage
- Data under analysis

Backup - TULIP

Objective: production of neutron deficient short-lived isotopes



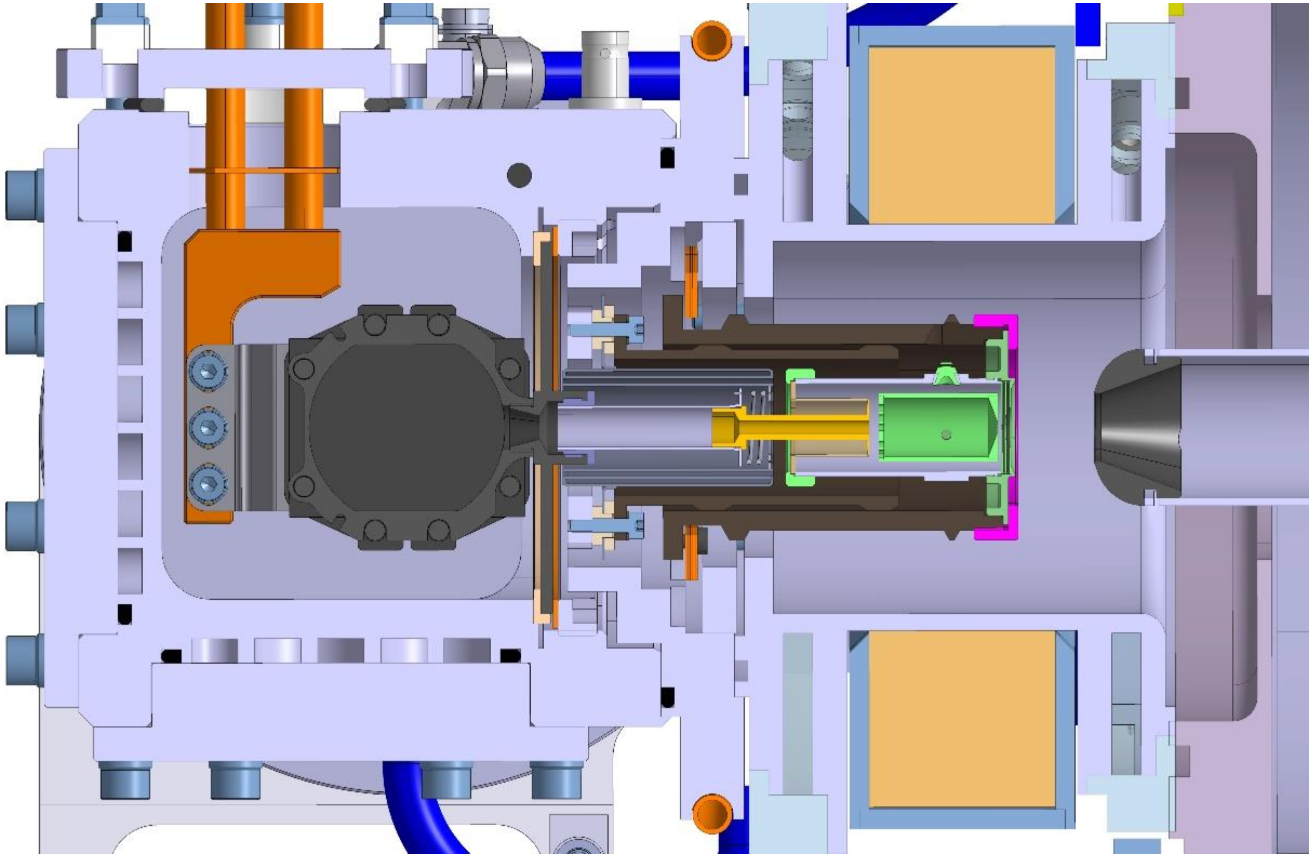




Data currently under analysis

Backup - TULIP

Final objective : production of metallic ions around ^{100}Sn



Next steps:

- coupling the TULIP cavity to a FEBIAD ion source. Test planned by end of 2023
- Implementation of a rotating target (production x 7). Test planned by 2d semester of 2023
- On-line production test of metallic ions around ^{100}Sn. When ^{50}Cr beam available
- Application of the principle to the production of other elements

Purity – SHIRAC + HRS estimation