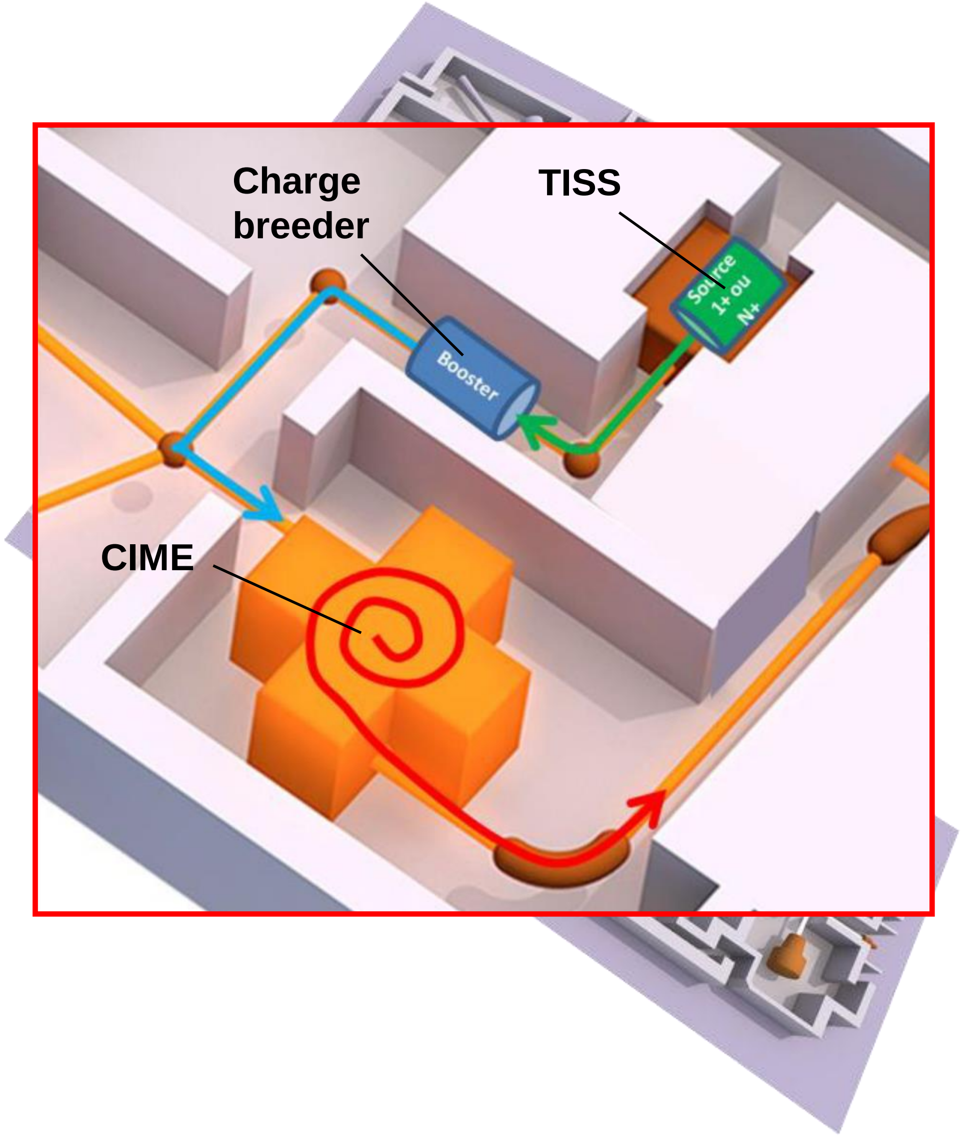
First results of SPIRAL1 Upgrade

(What we can do, what we could do and what we cant do)

Pierre Chauveau

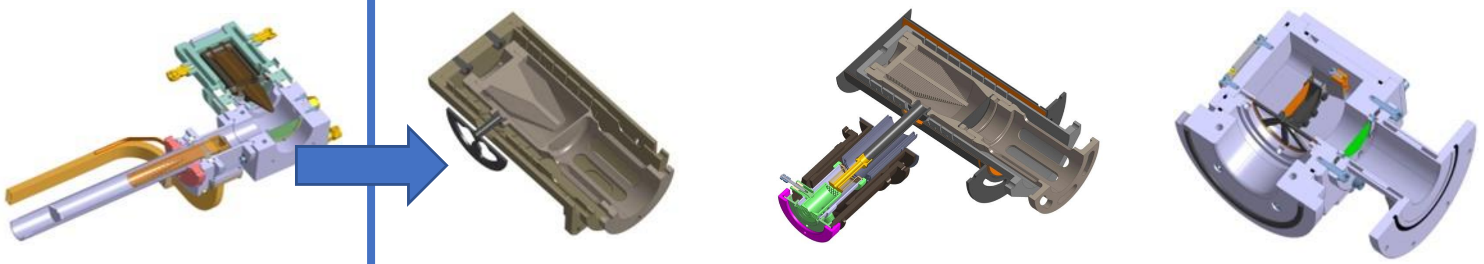
Introduction



What is the upgrade

- New target Ion Source Systems (FEBIAD)

New 1+ sources



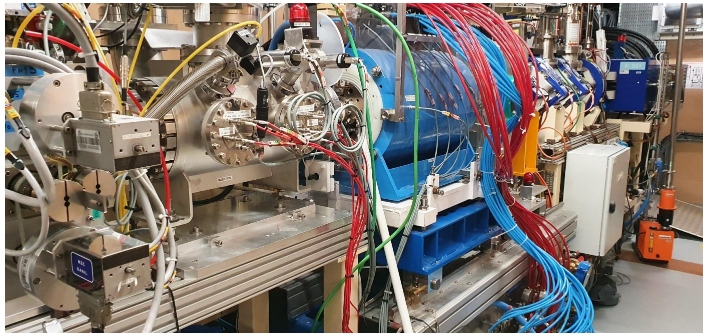
Nanogan
For gaz elements

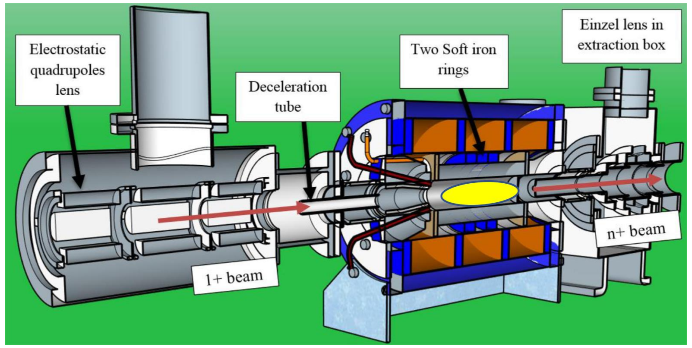
MonoNaKe
For alkaline elements

FEBIAD
For condensable elements

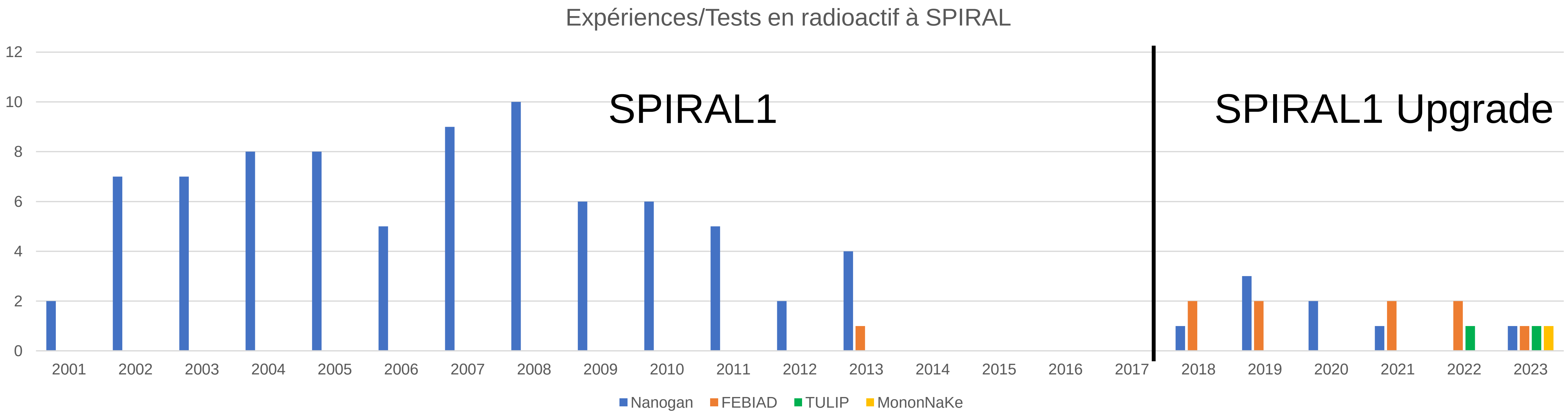
TULIP
For proton rich isotopes

- The charge breeder





SPIRAL1 so far



- Less SPIRAL1 experiments & tests
- But new ECS are on the rise
- FEBIAD is reliable and resilient
- The Booster is operational

Now is the time for users to look at SPIRAL1 beams again

Introduction/outline

I. Recent progress and results

- FEBIAD
- Charge breeder

II. Limitations and ongoing improvements

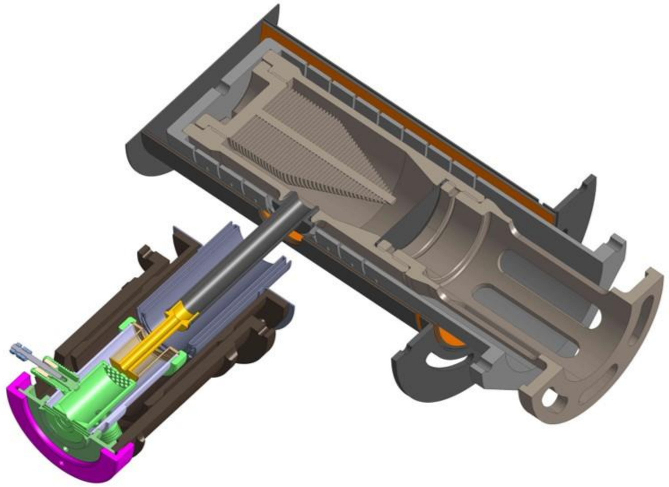
Introduction/outline

I. **Recent progress and results**

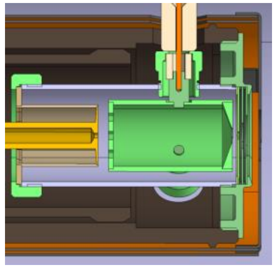
- **FEBIAD**
- Charge breeder

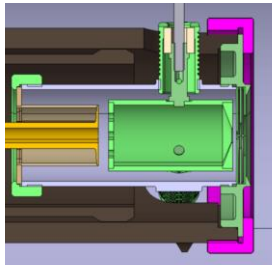
II. Limitations and ongoing improvements

The upgrades on the FEBIAD



Poster ICIS
V. Bosquet

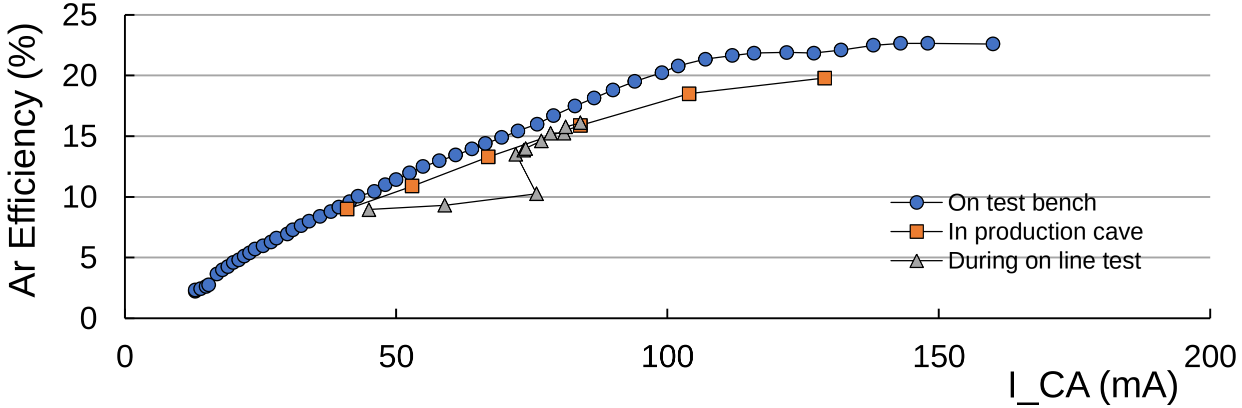




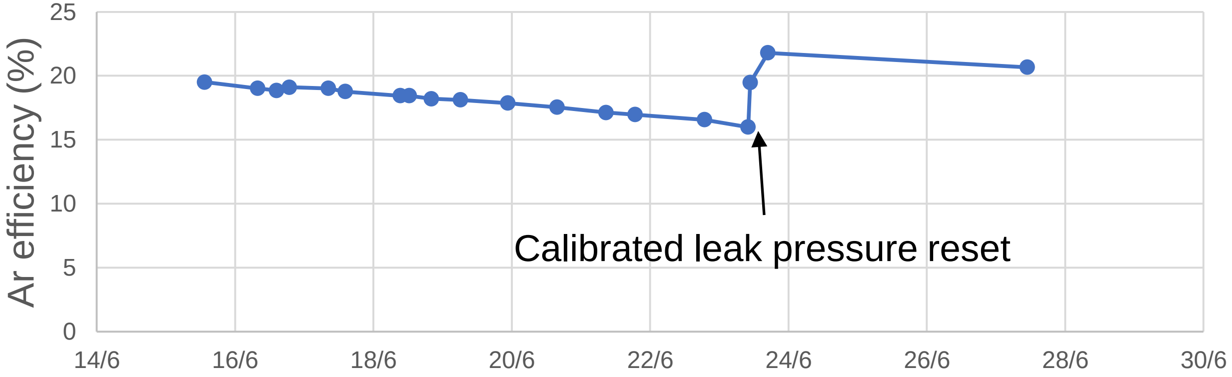
Insulator were the main point of failure.

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

Progress in resilience and reliability

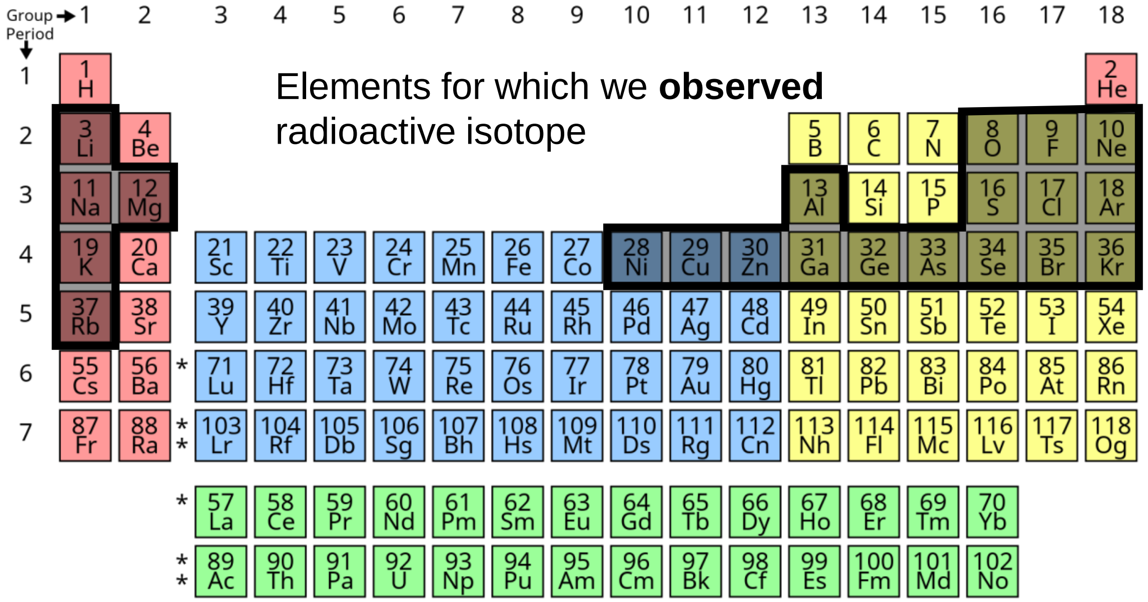


- 3 months in SPIRAL1
- 3 Machine study (2 radioactive + 1 stable)
- 10+ heating cycles
- **Efficient:** ^{40}Ar Efficiency up to 23%
- **Resilient:** 2 days of irradiation, 15 days at 20% ^{40}Ar efficiency and 10+ heating cycles without loss of performance
- **Stable over time :** same results 3 months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



Beams with SPIRAL1 Upgrade so far

- 9 tests/experiments with radioactive beams
- FEBIAD TISSes have received 36Ar (2013,2019,2022), 20Ne (2018), 40Ca (2018,2019), 48Ca (2021), 84Kr (2022)
- 2 post accelerated beams : ^{38m}K (2019), ^{47}K (2021)
- ≈80 radioactive isotopes/isomers **seen**, including 50+ at post-accelerable intensities (>10E5pps).

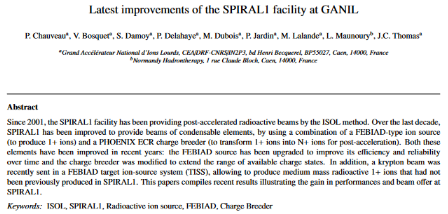


36Ar@74MeV/A 850W beam -> 12C target			
Masse	Isotope(s)	T1/2 (s)	rate@1200W
8	8Li	0.84	1.00E+05
20	20Na	0.4479	1.38E+06
21	21Na	22.49	1.13E+07
	1H20F	11	3.90E+04
23	23Ne	37.25	1.43E+06
	23Mg	11.3046	4.27E+06
24	24Ne	202.8	2.18E+05
	24Na	53989.2	9.29E+07
	24Na_m	0.0202	2.87E+05
	24Al	2.053	9.47E+02
25	25Al	7.183	3.80E+04
	25Na	59.1	8.67E+06
	25Ne	0.602	6.52E+03
	25Na 100V	59.1	8.00E+06
26	26Na	1.07128	2.21E+05
	26Al_m	6.346	9.22E+04
27	27Mg	567.5	2.62E+06
28	28Al	134.7	3.27E+06
29	29Al	394	1.14E+06
	29Mg	1.3	2.27E+03
30	30Al	3.62	1.30E+03
31	31Cl	0.19	8.05E+02
	C19O	26.91	1.92E+03
32	32Ar	0.098	1.16E+03
	32Cl	0.298	8.52E+04
33	33Ar	0.173	9.81E+04
	33Cl	2.511	2.21E+06
34	34Ar	0.8438	7.02E+06
	34Cl	1.5266	2.39E+07
	34mCl	1919.4	7.90E+07
35	35Ar	1.7756	1.54E+08
	H34mCl	1919.4	1.89E+07

84Kr@67MeV/A 10W beam -> 12C target			
Masse	Isotope(s)	T1/2 (s)	rate@500W
80	80Rb	34	7,16E+07
79	79mKr	50	3,04E+07
	79Kr	126144	3,45E+07
	79Rb	1374	1,13E+07
	79mBr	4,85	8,13E+06
78	78mRb	344,4	1,95E+06
	78Rb	1059,6	2,96E+06
	78Br	387	4,69E+07
77	77Rb	226,8	4,01E+05
	77Kr	4275	2,30E+07
	77mBr	256,8	4,24E+07
	77Br	205344	4,49E+07
	77mSe	17,36	1,83E+04
76	76Rb	36,5	1,76E+04
	76Kr	53280	5,40E+06
	76mBr	1,31	1,61E+06
	76Br	58320	4,45E+07
75	75Kr	276	6,28E+05
	75Br	5802	3,20E+07
71	71Se	284,4	2,05E+04
	71As	235080	1,72E+07
	71mZn	14256	1,21E+05
	71Zn	147	1,51E+04
69	69As	912	1,33E+05
	69Ge	140580	1,11E+07
	69mZn	49521,6	2,04E+06
	69Cu	171	3,35E+04
68	68mCu	225	7,92E+04
	68Ga	4062,6	4,68E+07
67	67Ge	1134	1,34E+05
	67Ga	281810,88	3,30E+07
65	65Ga	912	5,54E+06
	65Ni	9061,884	2,96E+04

48Ca@60MeV/A 200W beam -> 12C target			
Masse	Isotope(s)	T1/2 (s)	rate@700W
37	37S	303	9.27E+04
42	H41Cl	38.4	3.50E+05
	42Cl	6.8	3.23E+05
	42K	44496	6.24E+08
43	43Cl	3.3	6.84E+04
	43Ar	322.2	3.92E+07
45	45Ar	21.48	5.68E+06
	45K	1038	4.95E+08
47	47K	17.5	2.67E+08

Results submited for EMIS Proceedings


Latest improvements of the SPIRAL1 facility at GANIL

P. Chauveau[a], V. Bosquet[a], S. Damoy[a], P. Delahaye[a], M. Dubois[a], P. Jardin[a], M. Lalande[a], L. Maunoury[b], J.C. Thomas[a]

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Abstract

Since 2001, the SPIRAL1 facility has been providing post-accelerated radioactive beams by the ISOL method. Over the last decade, SPIRAL1 has been improved to provide beams of condensable elements, by using a combination of a FEBIAD-type ion source (to produce 1+ ions) and a PHOENIX ECR charge breeder (to transform 1+ ions into N+ ions for post-acceleration). Both these elements have been improved in recent years: the FEBIAD source has been upgraded to improve its efficiency and reliability over time and the charge breeder was modified to extend the range of available charge states. In addition, a krypton beam was recently sent in a FEBIAD target ion-source system (TISS), allowing to produce medium mass radioactive 1+ ions that had not been previously produced in SPIRAL1. This papers compiles recent results illustrating the gain in performances and beam offer at SPIRAL1.

Keywords: ISOL, SPIRAL1, Radioactive ion source, FEBIAD, Charge Breeder

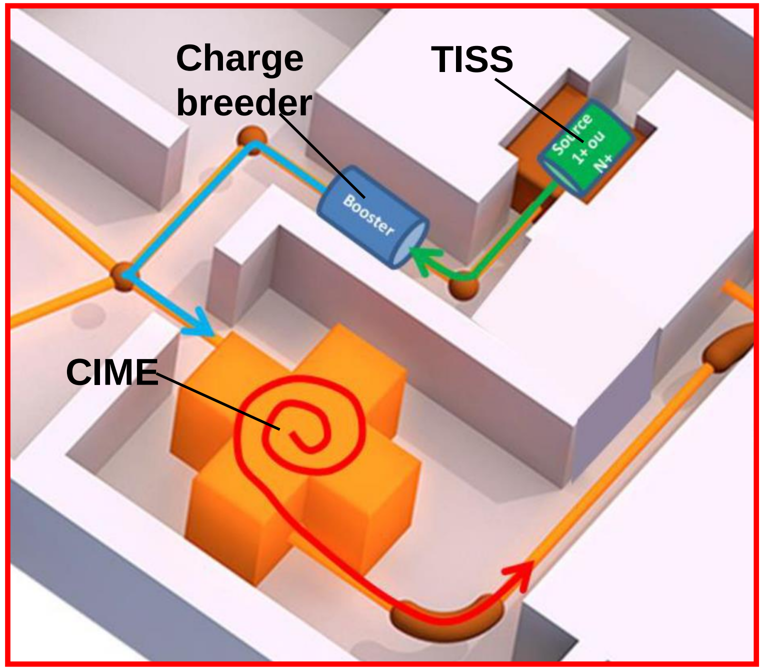
Introduction/outline

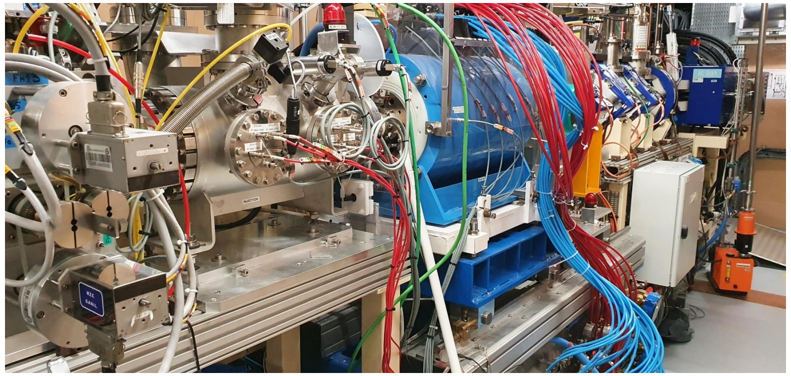
I. **Recent progress and results**

- FEBIAD
- **Charge breeder**

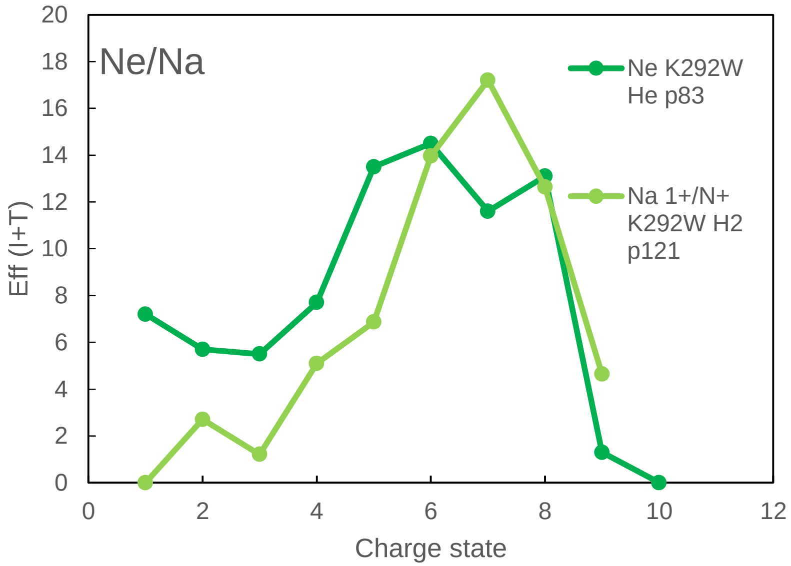
II. Limitations and ongoing improvements

The booster in 1+/N+ mode

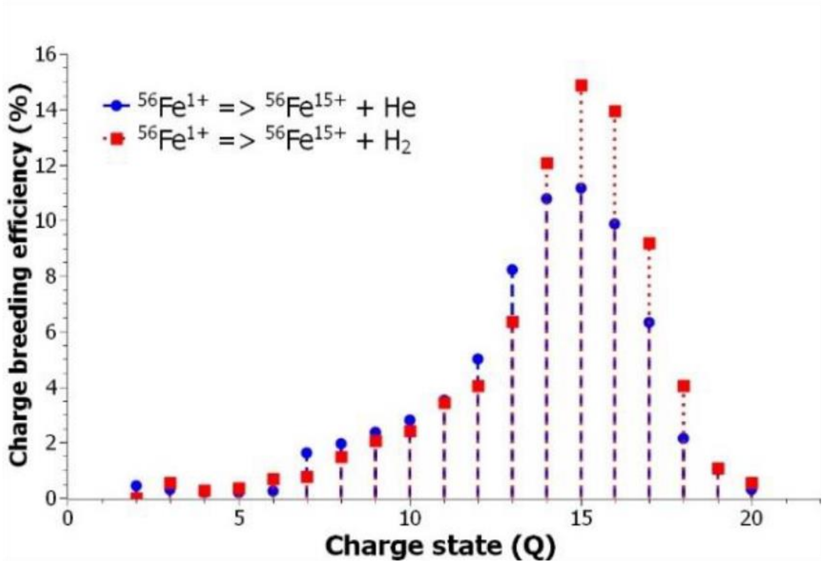




Gaz & Alkali ions



Metalic ions

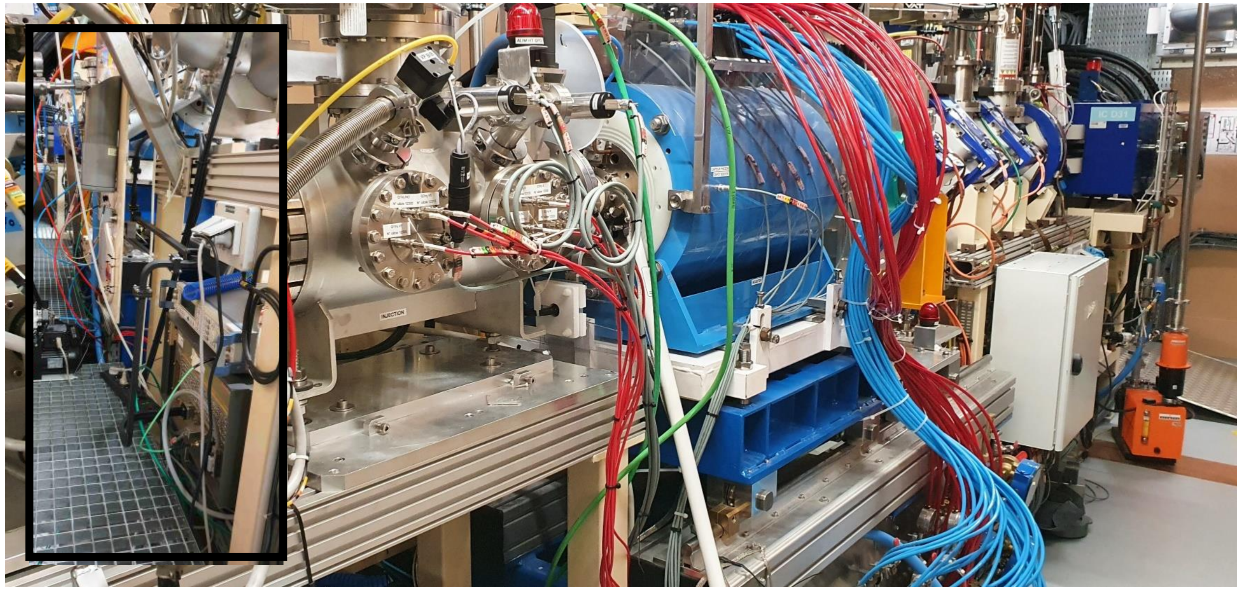


L. Maunoury et al, Charge Breeder at GANIL: metal charge-bred elements, Journal of Physics: Conference Series 2244 (2022) 012066

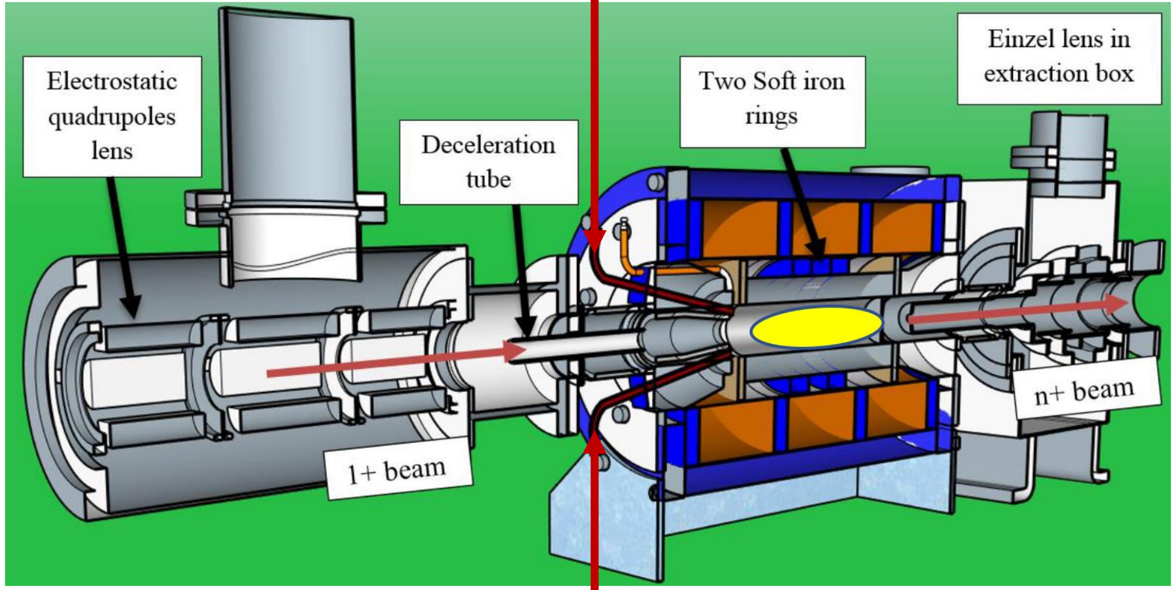
The charge breeder works

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

SPIRAL1 Charge breeder



Klystron 14,5 GHz
0 - 600 W



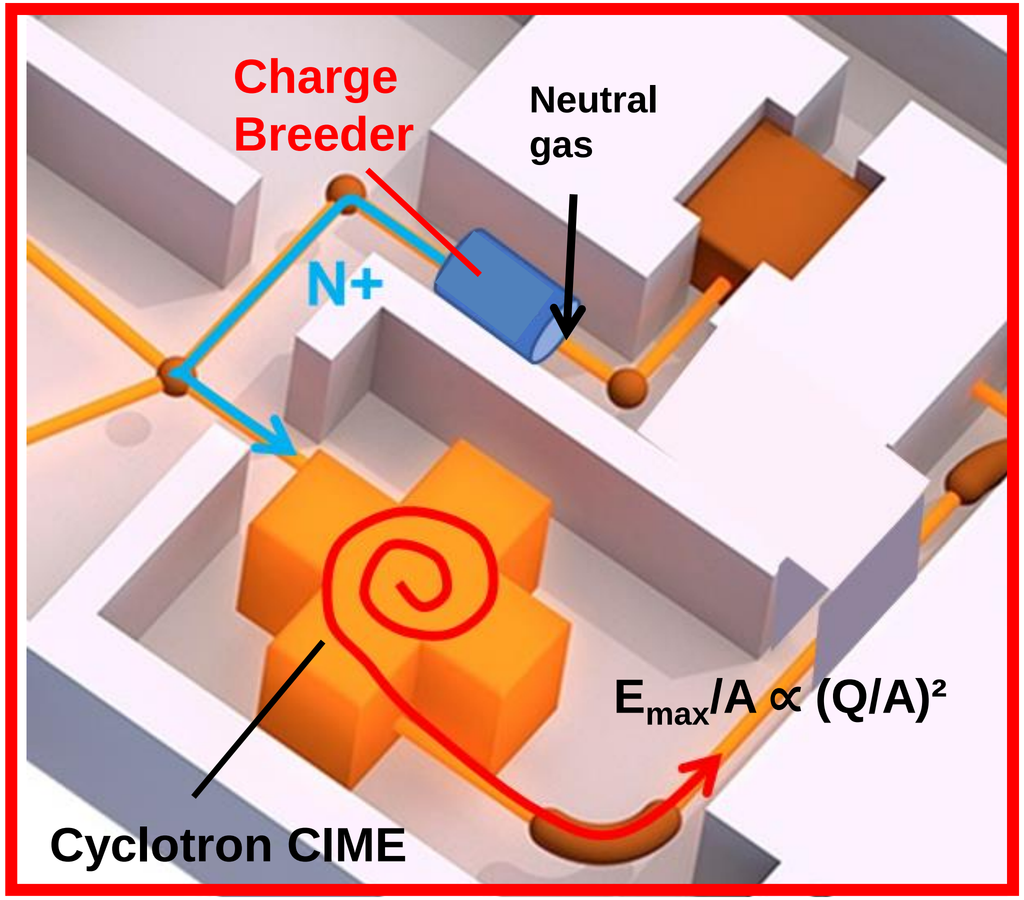
TWTA 8 -18 GHz
0 - 200 W

Plasma in the Charge breeder heated by:

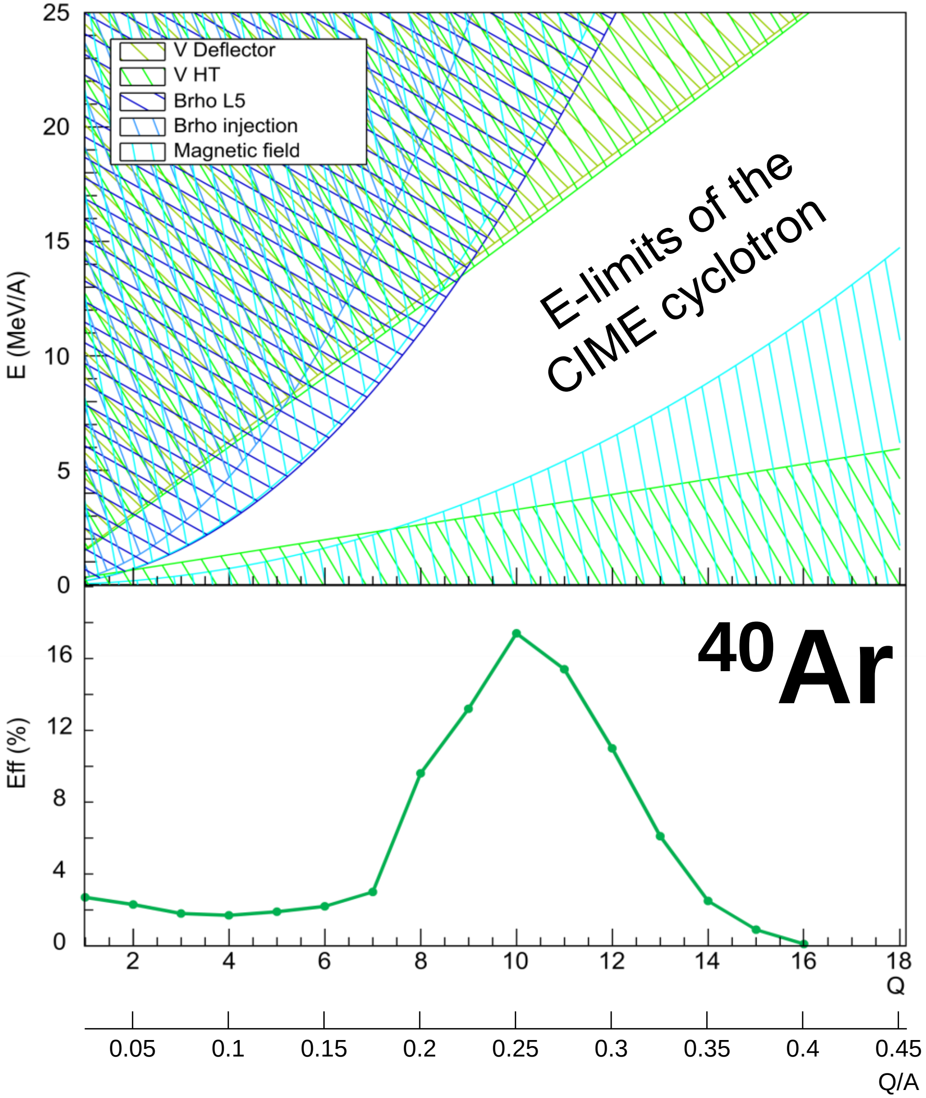
- The historic fixed frequency Klystron
- A variable frequency Travelling-Wave Tube Amplifier, for:
  - Variable Single Frequency heating VSFH (low charge states)
  - Double Frequency Heating DFH (high charge states)

A. Annaluru et al., Beam optics transport and fundamental processes involving a charge breeder in the upgraded SPIRAL1 Facility, PhD thesis (2019)

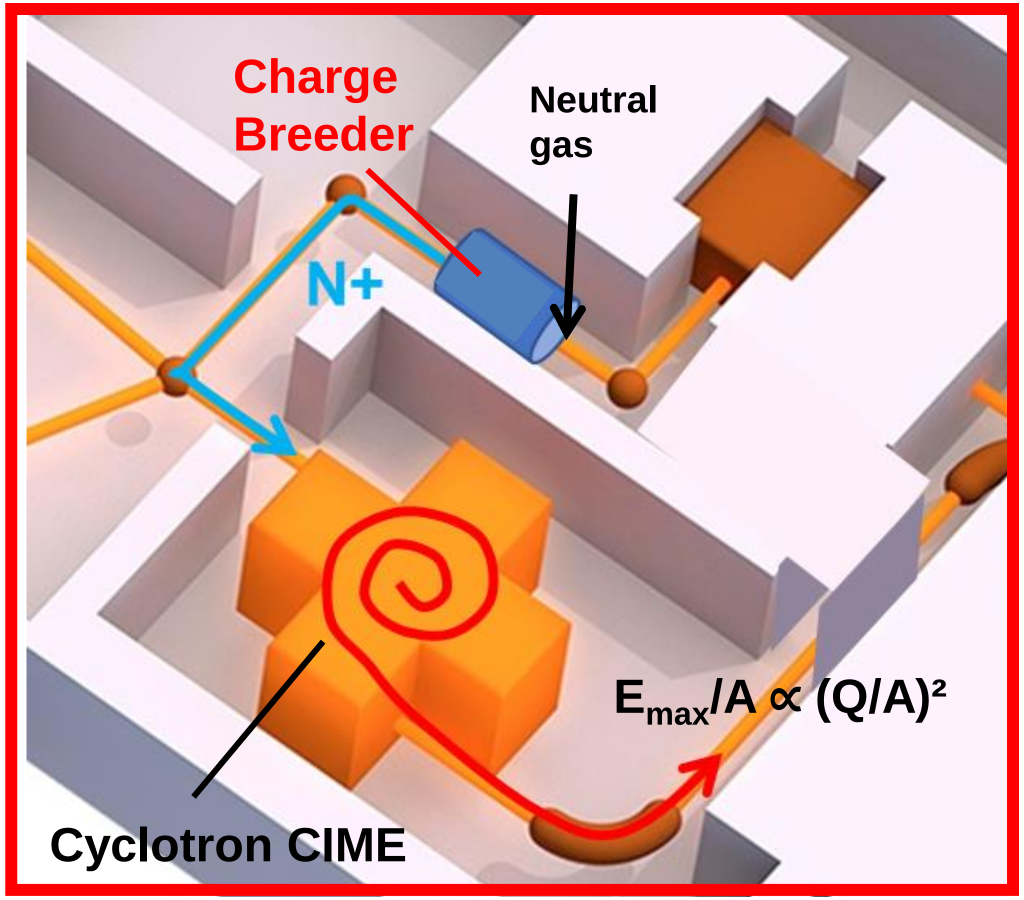
Why controlling the CSD

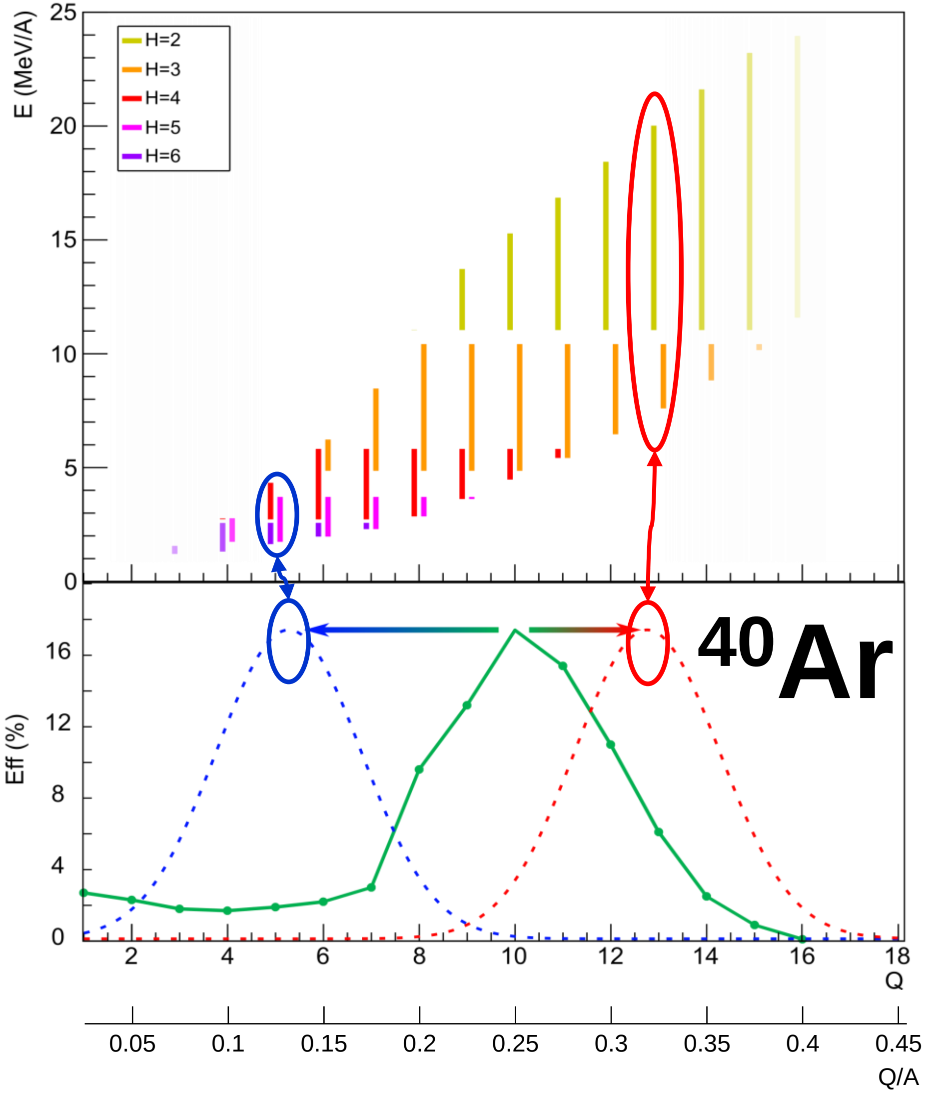


The post-accelerated energy is limited by the installation (B_{CIME}, Bρ, V_{HT})



Why controlling the CSD

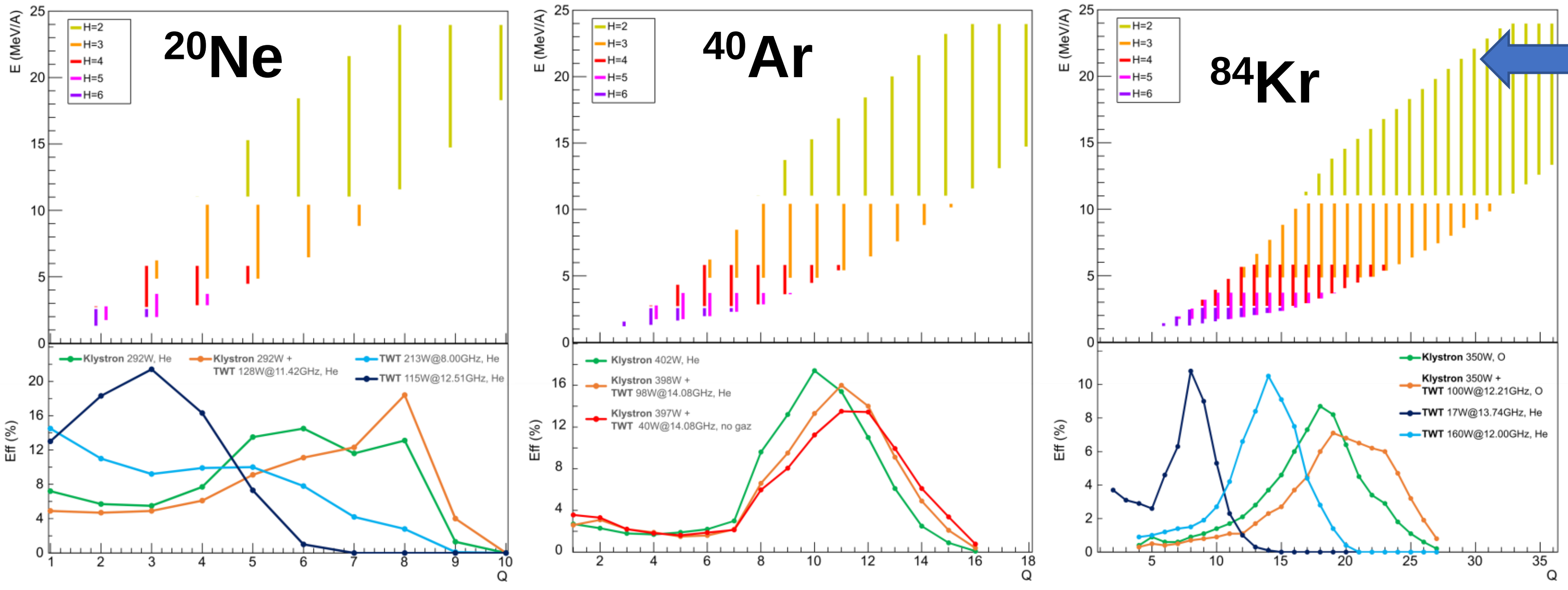




Why controlling the CSD ?

- To optimize efficiency at a given energy
- To reach lower and higher beam energies
- To avoid contamination at Q/A = 1/4, 1/3 …

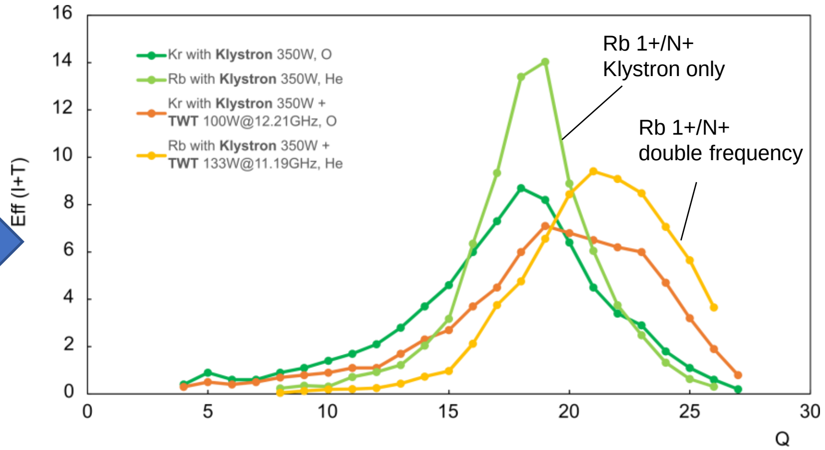
Controlling the CSD: results



Control of the CSD achieved when using the SP1CB as a source

Results submited for ECRIS Proceedings

And ongoing work for 1+/N+



EXPERIMENTAL APPLICATION OF A TWTA TO THE SPIRAL1 CHARGE BREEDER

P. Chauveau[1]*, L. Maunoury[1,2], J. Angot[3], S. Damoy[1] and M. Dubois[1]

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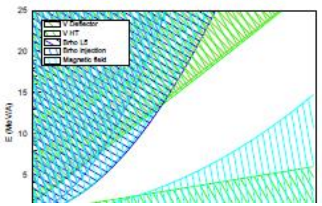
[2]Normandy Hadrontherapy, Caen, France
[3]Laboratoire de Physique Subatomique et Cosmologie (LPSC), Grenoble, France

Abstract

A Travelling Wave Tube amplifier (TWTA) has been connected to the charge breeder of SPIRAL1 (Système de Production d'Ions Radioactifs en Ligne) in addition to the existing Klystron. This second amplifier allows us to better control the charge state distribution (CSD) of the outcoming ions, which widens the variety of post-accelerated ion beams offered by SPIRAL1. In this work, we explored two plasma heating mode enabled by the new amplifier : Variable Single Frequency Heating (VSFH) and Double Frequency Heating (DFH), with promising results.



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- Charge breeder

II. **Limitations and ongoing improvements**

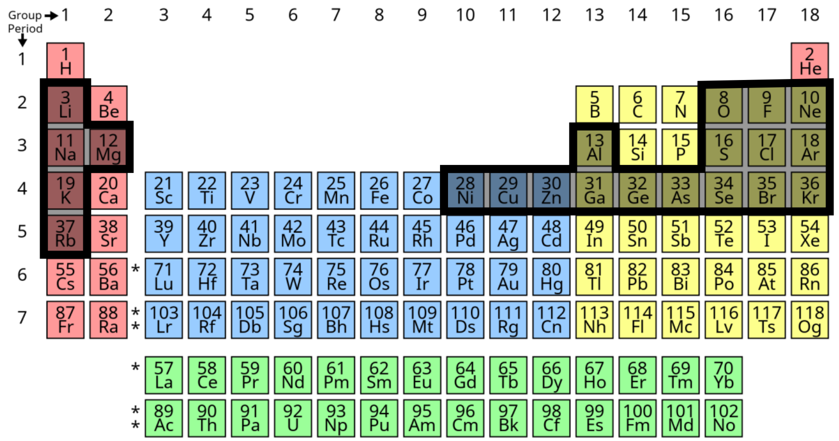
Limitations in SPIRAL 1

Isotopes produced limited by beams and target

- **New primary beams in SPIRAL1** (**Cr**, **Ni**, Xe)

Production rate limited by cross section and beam intensity

- Higher beam intensity
- **New target material** (Nb?)



TISS efficiency limited by isotope half life and by element physical and chemical properties

- **Stronger source heating**
- **Thermal simulations**
- **Custom TISS (see TULIP talk)**
- **Chemical compounds**

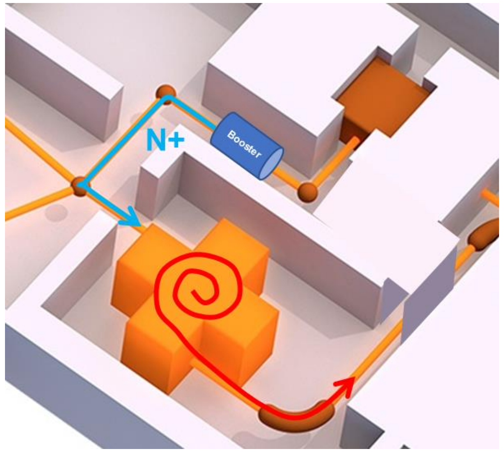
Energy limited by charge state and CIME

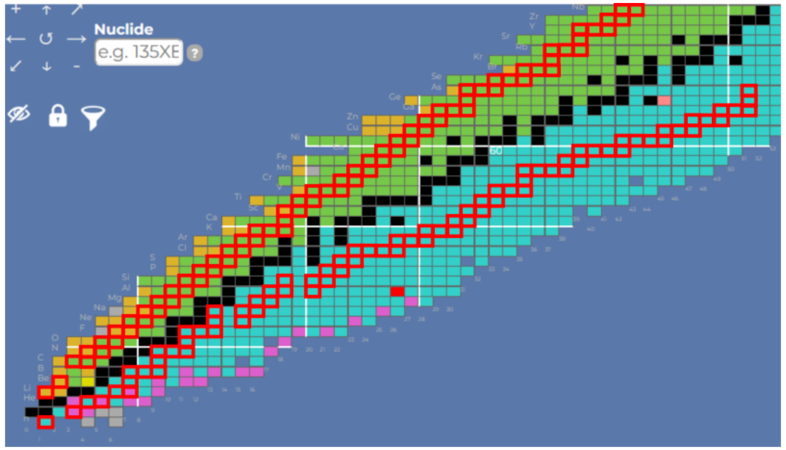
- **Changing the CSD in the charge breeder**

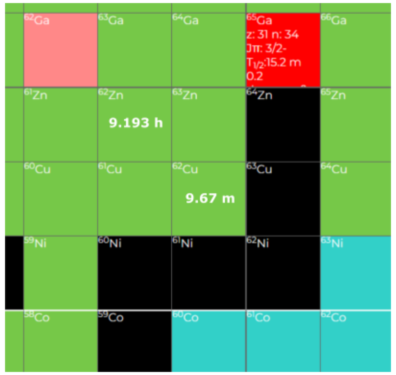
Beam purity

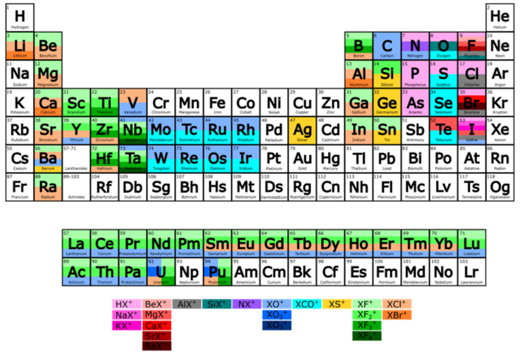
Our tricks for purifying beams

- Mass separation in CIME (best resolution 2E-4)
- « Cold source » for gases (Nanogan)
- Surface ion source for rare-earth (**Mononake**, FEBIAD in surface ionization mode)
- Slow or supress some elements by playing on the target/source temperature
- **Molecular 1+ beams**
- Full stripping (« high energy » neutron-deficient isotopes only)







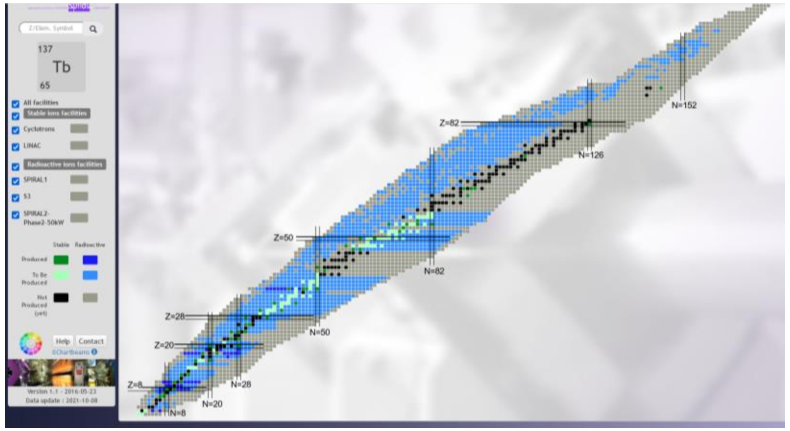


Full stripping efficiency (%)			
Energy	15 MeV/A	10 MeV/A	5 MeV/A
20Ne	95	91	75
40Ar	86	63	11.5
56Ni	20.5	0.9	0.08
84Kr	1.7	0.2	0

Conclusion

- The SPIRAL1 Upgrade project is fulfulling its expectations
  - The FEBIAD and the Charge breeder are fully operational
  - More developments and tests ongoing to extend the range of available beams

- FEBIAD beams are often complex and need to be studied on an isotope-by-isotope basis
  - Need input from physicist



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46K	105	s	8	5,9E+05	1,4E+04	1,2*	8,1**	12C	3,65	95	NiO
46K	105	s	8	3,1E+05	7,3E+03	1,2*	8,1**	12C	3,65	95	Nb
47K	17,5	s	10+	1,00E+06	5,00E+05	7,7	12,2	48Ca $	0,1	60	Carbon
47K	17,5	s	8	1,3E+08	3,1E+06	1,2*	7,7**	48Ca	0,7	60,3	Carbon
47K	17,5	s	8	1,5E+03	3,6E+01	1,2*	7,7**	58Ni	0,7	74,5	Carbon
47K	17,5	s	8	2,1E+03	4,9E+01	1,2*	7,7**	78Kr	1,2	70,4	Carbon
47K	17,5	s	8	1,4E+04	3,3E+02	1,2*	7,7**	86Kr	0,8	57,9	Carbon
47K	17,5	s	8	4,7E+06	1,1E+05	1,2*	7,7**	12C	3,65	95	CaO

Color code :

2,80E+07	:	Extrapolated figures from SIRA experiment from 400 W to 1,4 kW
2,80E+07	:	Measured figures with SPIRAL
2,80E+07	:	Expected figures after acceleration (not measured) with 20% transport efficiency
2,80E+07	:	Intensity estimates for FEBIAD (VADIS) source (January 2016)
---	:	Estimated yields inferior to 5,0E-02

- The main limitation of SPIRAL1 is purity
  - Plenty of tricks but insufficient for many isotopes (metals A>40)

Thank you for your attention